# OpenVMS AXP Device Support: Developer's Guide

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This manual describes how to write an OpenVMS AXP device driver and, once it is written, how to compile, link, and load it into the OpenVMS AXP operating system.

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# Preface

## Intended Audience

This manual is intended for system programmers who want to write an OpenVMS AXP device driver. A future edition of this book will describe how to write an OpenVMS AXP device driver in a high-level language.

## Associated Documents

The *OpenVMS AXP Device Support: Reference* contains more detailed information about the routines and macros mentioned in this book.

## Conventions

In this manual, every use of OpenVMS AXP means the OpenVMS AXP operating system.

The following conventions are also used in this manual:

| | |
|---|---|
| Ctrl/*x* | A sequence such as Ctrl/*x* indicates that you must hold down the key labeled Ctrl while you press another key or a pointing device button. |
| PF1 *x* | A sequence such as PF1 *x* indicates that you must first press and release the key labeled PF1 and then press and release another key or a pointing device button. |
| Return | In examples, a key name enclosed in a box indicates that you press a key on the keyboard. (In text, a key name is not enclosed in a box.) |
| . . . | Horizontal ellipsis points in examples indicate one of the following possibilities:<br>• Additional optional arguments in a statement have been omitted.<br>• The preceding item or items can be repeated one or more times.<br>• Additional parameters, values, or other information can be entered. |
| .<br>.<br>. | Vertical ellipsis points indicate the omission of items from a code example or command format; the items are omitted because they are not important to the topic being discussed. |
| ( ) | In command format descriptions, parentheses indicate that, if you choose more than one option, you must enclose the choices in parentheses. |

| | |
|---|---|
| [ ] | In command format descriptions, brackets indicate optional elements. You can choose one, none, or all of the options. (Brackets are not optional, however, in the syntax of a directory name in an OpenVMS file specification or in the syntax of a substring specification in an assignment statement.) |
| { } | In command format descriptions, braces surround a required choice of options; you must choose one of the options listed. |
| **boldface text** | Boldface text represents the introduction of a new term or the name of an argument, an attribute, or a reason (user action that triggers a callback).<br>Boldface text is also used to show user input in Bookreader versions of the manual. |
| *italic text* | Italic text emphasizes important information and indicates complete titles of manuals and variables. Variables include information that varies in system messages (Internal error *number*), in command lines (/PRODUCER=*name*), and in command parameters in text (where *device-name* contains up to five alphanumeric characters). |
| UPPERCASE TEXT | Uppercase text indicates a command, the name of a routine, the name of a file, or the abbreviation for a system privilege. |
| `struct` | Monospace type in text identifies the following C programming language elements: keywords, the names of independently compiled external functions and files, syntax summaries, and references to variables or identifiers introduced in an example. |
| - | A hyphen in code examples indicates that additional arguments to the request are provided on the line that follows. |
| numbers | All numbers in text are assumed to be decimal unless otherwise noted. Nondecimal radixes—binary, octal, or hexadecimal—are explicitly indicated. |

# 1 Introduction

An OpenVMS **device driver** is a set of routines and tables that the operating system uses to process an I/O request for a particular device such as disks, tapes, and network controllers.

The operating system's approach to I/O is that the system should perform as much of the processing of an I/O request as possible and that drivers should limit themselves to the device-specific aspects of I/O processing. To accomplish this, the operating system provides drivers with the following services:

- A Queue I/O request ($QIO) system service that preprocesses an I/O request by performing those functions and checks that are common to all devices; for example, validating those arguments of the I/O request that are not device specific
- Many operating system routines that drivers can call to perform I/O preprocessing, allocate and deallocate resources, and synchronize driver execution
- A system I/O postprocessing routine that performs device-independent I/O postprocessing for all I/O requests

Thus, drivers can leave the device-independent I/O processing to the operating system and can concentrate on servicing those aspects of an I/O operation that vary from device type to device type. In addition, drivers can call system routines to perform many functions that are common to several, but not all, devices.

A device driver does not run sequentially from beginning to end. Rather, the operating system uses driver tables and other information maintained by itself and the driver to determine which driver routines to activate and when they should be activated. Because little sequential processing of driver code occurs, the operating system must assume the responsibility for synchronizing the execution of the various driver routines, as well as the execution of all drivers in the system.

This chapter defines the general functions and purposes of a device driver. It then introduces concepts crucial to an understanding of how device drivers work within the operating system and integral to the process of successfully writing one. It concludes with a brief description of the flow of driver activity in servicing an I/O request.

## 1.1 Driver Functions

A system utility loads a device driver into system virtual address space and creates its associated data structures. Once loaded, a device driver controls I/O operations on a peripheral device by performing the following functions:

- Defining the peripheral device for the rest of the operating system

- Preparing a device unit and its controller (or both) for operation at system startup and during recovery from a power failure
- Performing device-dependent I/O preprocessing
- Translating programmed requests for I/O operations into device-specific commands
- Activating a device unit
- Responding to hardware interrupts generated by a device unit
- Responding to device timeout conditions
- Responding to requests to cancel I/O on a device unit
- Reporting device errors to an error-logging program
- Returning status from a device unit to the process that requested the I/O operation

## 1.2 Driver Components

A device driver module can consist of the routines and tables discussed in this section. The order of the routines and tables within the driver module is not important.

### 1.2.1 Driver Tables

The following tables appear in every driver.

The **driver prologue table** (DPT) defines the identity and attributes or characteristics of the driver to the system utility that loads the driver into virtual memory and creates the associated data structures. With the information provided in the DPT, the driver-loading procedure can both load and reload drivers and perform the I/O database initialization that is appropriate to either situation.

Section 4.1 describes the procedure for creating a DPT and further discusses its functions. The DPT contents are shown and described in the *OpenVMS AXP Device Support: Reference*.

The **driver dispatch table** (DDT) lists the addresses of the entry points of standard routines within the driver, and records the size of the diagnostic and error message buffers for drivers that perform error logging. You can find additional information and instructions on how to specify a DDT in Section 4.2. The structure and contents of the DDT are shown and described in the *OpenVMS AXP Device Support: Reference*.

The **function decision table** (FDT) lists all valid function codes for the device, and associates valid codes with the addresses of I/O preprocessing routines, called **FDT routines**. The driver contains device-dependent FDT routines, and the operating system itself provides routines (described in Section 5.2.1) that perform request preprocessing common to many I/O functions.

When a user process calls the $QIO system service, the system service uses the I/O function code specified in the request to select the appropriate **upperlevel FDT routine**. To prepare for the actual I/O operation, FDT routines perform such tasks as allocating buffers in system space, locking pages in memory, and validating the device-dependent arguments (**p1** to **p6**) of the $QIO request. Section 4.3 provides further discussion of the FDT, and Chapter 5 details strategies and rules for writing, specifying, and exiting from an FDT routine.

### 1.2.2 Driver Routines

In addition to any FDT routines it might contain, a device driver generally contains both a start-I/O routine and an interrupt service routine (ISR).

The **start-I/O routine** performs such additional device-dependent tasks as translating the I/O function code into a device-specific command, storing the details of the user request in the device's unit control block (UCB) in the I/O database and, if necessary, obtaining access to controller and adapter resources. Whenever the start-I/O routine must wait for these resources to become available, the operating system suspends the routine, reactivating it when the resources become free.

The start-I/O routine ultimately activates the device by suitably loading the device's registers. At this stage, the start-I/O routine invokes a system macro that causes its execution to be suspended until the device completes the I/O operation and posts an interrupt to the processor. The start-I/O routine remains suspended until the driver's **interrupt service routine** handles the interrupt.

When a device posts an interrupt, its driver's interrupt service routine determines whether the interrupt is expected or unexpected, and takes appropriate action. If the interrupt is expected, the interrupt service routine reactivates the driver's start-I/O routine at the point of suspension. The general course of action of driver mainline code at this time is to perform device-dependent I/O postprocessing and to transfer control to the operating system for device-independent I/O postprocessing.

Details on writing a start-I/O routine appear in Chapter 6. A description of a driver interrupt service routine appears in Chapter 7.

You can also include any of the following routines in a device driver:

The **unit initialization routine** and **controller initialization routine** prepare a device or controller for operation when the driver-loading procedure loads the driver into memory and when the system recovers from a power failure. The amount and type of initialization needed by devices and controllers vary according to the device type and the I/O bus to which the device or controller is attached. additional information about device driver initialization routines.

A **timeout handling routine** retries I/O operations and performs other error handling when a device fails to complete a request in a reasonable period of time. Once every second, the system timer checks all devices in the system for device timeout. When it locates a device that has timed out, because it is off line or some error has occurred, the system timer calls the driver's timeout handling routine.

Depending upon the reason for the timeout, the timeout handling routine may call a system error-logging routine to allocate and fill an error message buffer with information about the error. In turn, the error-logging routine can call a **register-dumping routine** in the driver that also loads into the buffer the contents of device registers at the time of the error.

The operating system calls a driver's **cancel-I/O routine** when a user process issues a Cancel I/O on Channel ($CANCEL) system service for the device. It may also call the routine when the device's reference count goes to zero, which occurs when all users with assigned channels to the device have deassigned them.

## 1.3 I/O Database

Because a driver and the operating system cooperate to process an I/O request, they must have a common and current source of information about the request. This is the function of the I/O database. The I/O database consists of the following three parts:

- Driver tables that allow the system to load drivers, to validate device functions, and to call driver routines at their entry points
- Data structures that describe I/O bus adapters, device types, device units, device controllers, and logical paths from processes to devices
- I/O request packets that define individual requests for I/O activity

Illustrations of I/O database structures and detailed descriptions of their fields appear in the data structure chapter of the *OpenVMS AXP Device Support: Reference*. Figure 1–1 illustrates some of the relationships among system I/O routines, the I/O database, and a device driver.

### 1.3.1 Driver Tables

The three driver tables—driver prologue table, driver dispatch table, and function decision table—are defined in every driver. Section 1.2 lists these tables and the other components of a device driver, and Chapter 4 discusses their contents.

### 1.3.2 Data Structures

I/O database data structures describe peripheral hardware and are used by the operating system to synchronize access to devices. The operating system creates these data structures either at system startup or when a driver is loaded into the system.

The system defines a **unit control block** (UCB) for each device unit attached to the system. A UCB defines the characteristics and current state of an individual device unit.

UCBs are the focal point of the I/O database. When a driver is suspended or interrupted, the UCB keeps the context of the driver in a set of fields collectively known as a **fork block**.[1] In addition, the UCB contains the listhead for the queue of pending I/O request packets (IRPs) for the unit.

A **device data block** (DDB) contains information common to all devices of the same type that are connected to a particular controller. It records the generic device name concatenated with the controller designator (for example, LPA, DKB), and the name and location of the associated device driver. In addition, the DDB contains a pointer to the first UCB for the device units attached to the controller.

The operating system creates a **channel request block** (CRB) for each controller. A CRB defines the current state of the controller and lists the devices waiting for the controller's data channel. It also contains a pointer to the interrupt service routine (ISR).

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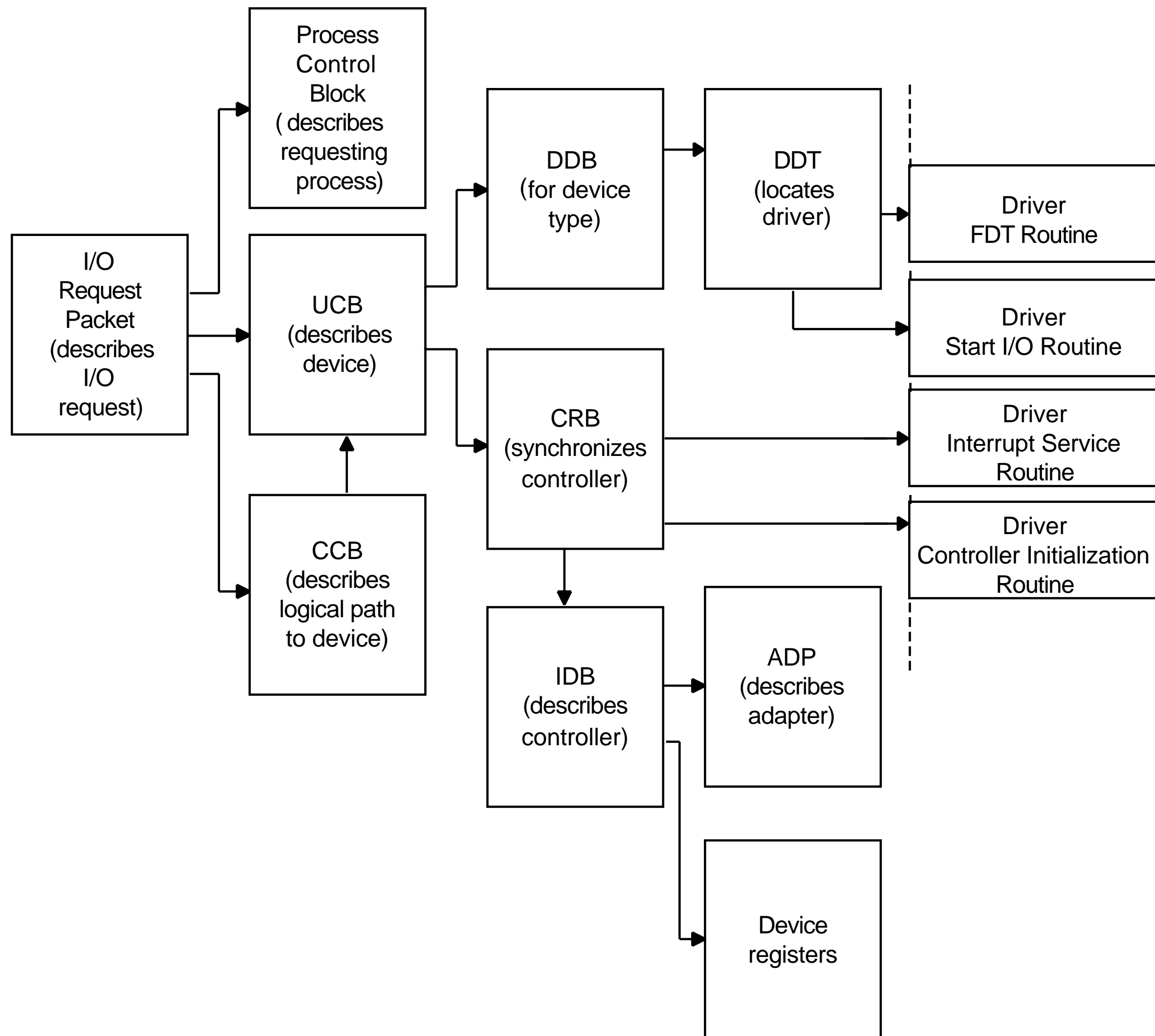
[1] Other structures, such as the CRB, also include a fork block. The discussion of fork blocks and fork processes in Section 1.5 explains the role of fork blocks in driver processing.

**Figure 1–1 I/O Database**




The system also creates for each controller an **interrupt dispatch block** (IDB). An IDB lists the device units associated with a controller and points to the UCB of the device unit that the controller is currently servicing. In addition, an IDB points to device registers and the controller's I/O adapter.

An **adapter control block** (ADP) defines the characteristics and current state of an I/O adapter such as the TURBOchannel interface on a DEC 3000. An ADP contains the information necessary to allocate the adapter's resources. The operating system provides routines that drivers can call to interface with the appropriate adapter.

The **channel control block** (CCB) describes the logical path between a process and the UCB of a specific device unit.[2] Each process owns a number of CCBs.

[2] Channel request blocks (CRBs) and channel control blocks (CCBs) are two separate data structures. To help distinguish the two, it may be helpful to think of the channel request block as the "controller request" block because it describes the hardware controller. In contrast, the channel control block is used by a process and a device unit to manage the

When a process issues the Assign I/O Channel ($ASSIGN) system service, the system writes a description of the assigned device to the CCB.

Unlike the data structures mentioned earlier, a CCB is not located in nonpaged system space, but in the process's control region (P1 space).

### 1.3.3 I/O Request Packets

The third part of the I/O database is a set of I/O request packets. When a process requests I/O activity, the operating system constructs an **I/O request packet** (IRP), that describes the I/O request in a standard form.

The IRP contains fields into which the system and driver I/O preprocessing routines can write information: for instance, the device-dependent arguments specified in the call to the $QIO system service. The packet also includes buffer addresses, a pointer to the target device's UCB, an I/O function code, and pointers to the I/O database. After preprocessing, the IRP can be queued to a list originating in the device's UCB to await processing by the driver.

When the device unit is free and the IRP is next in line to be processed on the unit, the system sends it to the device driver's start-I/O routine. The start-I/O routine uses the IRP as its source of detailed instructions about the operation to be performed.

## 1.4 Synchronization of Driver Activity

Device drivers and other kernel-mode code must maintain synchronization with other priority operating system activities. The term **synchronization** refers to the means by which such code accesses shared data in a consistent, orderly, and predictable fashion. Because there may be more than one processor active in an OpenVMS AXP system, system-level code must synchronize its actions with other code threads it may have preempted on the same (or *local*) processor, as well as with those that are active (or to be activated) on other processors in the system. The operating system uses hardware and software interrupt priority levels (IPLs) to order system events on each local processor in an OpenVMS AXP system.

AXP hardware defines 32 interrupt priority levels (IPLs). The higher numbered IPLs (16 to 31) are reserved for hardware interrupts, such as those posted by devices. The operating system uses the lower numbered IPLs (0 to 15). Code that executes at a higher IPL takes precedence over code that executes at a lower IPL.

A driver, in concert with the operating system, ensures that it maintains system synchronization by performing certain activities and by accessing certain data only at the appropriate IPL. In a multiprocessing system, the driver extends the synchronization it achieves by executing locally at a given IPL by acquiring ownership of the spinlock associated with the operation it is performing.

## 1.5 Driver Context

As indicated in Section 1.2.2, a driver may have several routines to which the operating system may pass control in certain situations. The context in which any one routine receives control from the operating system may differ substantially from that in which another receives control. It is essential that a driver routine not attempt to exceed the limitations of the context in which it executes.

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logical channel (the **channel** argument to the $ASSIGN and $QIO system services) in accomplishing I/O operations.

In general, context is characterized by the following factors:

- Actual parameters that are passed to the routine
- The current IPL of the executing processor
- The range of IPLs that the routine can change and the required IPL on return from the routine.
- The currently owned spinlocks of the executing processor
- The data structures available to the routine
- The ability or inability to access process space

A complete description of the context of each driver routine appears in the entry points chapter of the *OpenVMS AXP Device Support: Reference*. The following are some general observations:

- All device driver routines execute in kernel mode at an elevated IPL.
- Only driver FDT routines execute within process context and can access process space (P0 and P1).
- The majority of driver routines execute in *interrupt* (or *system* context): that is, in the sequence of execution that follows a processor's grant of an interrupt request at a given IPL. Such code can refer only to system (S0) space. Moreover, it cannot incur exceptions, including page faults, without causing a fatal bugcheck.

Most driver processing of an I/O request (before and after the device acknowledges the servicing of the request by requesting an interrupt from the processor) occurs at a *fork IPL*. This portion of driver code, which includes most of the start-I/O routine, is commonly known as the driver's **fork process**.

There are several instances in the processing of an I/O request when a driver fork process must suspend execution to wait for a resource or a device interrupt. To make the matter of saving and restoring fork process context as efficient as possible, the operating system places a restriction on the context of a driver fork process, in addition to those that apply to any process in interrupt context. **Fork context** consists of the following:

- The fork routine parameters (FR3 and FR4)
- The fork routine address (FPC)
- A fork block (usually the unit control block that can contain additional fork process context

The operating system places the fork block of a suspended fork process in either a processor-specific fork queue or a resource wait queue where it waits to be resumed. When it resumes the fork process, the operating system calls the fork routine with the FR3 value, FR4 value, and a pointer to the fork block as parameters.

### 1.5.1 Example of Driver Context-Switching

Because a device driver consists of a number of routines that are activated by the system, the operating system determines the context in which the routines execute.

As an example, consider the following write request that occurs without error:

1. A user process executing in user mode calls the $QIO system service to write data to a device.
2. The $QIO system service gains control in process context but in kernel mode. It performs device-independent preprocessing of the I/O request.
3. The system service uses the driver's function decision table (FDT) to call the appropriate FDT routines to perform device-dependent preprocessing. These FDT routines execute in full process context in kernel mode.
4. When preprocessing is complete, a system routine creates a fork process to execute the driver's start-I/O routine in kernel mode.
5. The start-I/O routine activates the device unit and suspends itself. At this point, the operating system suspends the fork process executing the start-I/O routine and saves sufficient context to reactivate the start-I/O routine at the point of suspension.
6. When the device completes the data transfer, it requests an interrupt. The interrupt causes the system to activate the driver's interrupt service routine.
7. The interrupt service routine executes to handle the device interrupt. It then causes the start-I/O routine to resume in interrupt context.
8. The start-I/O routine regains control in interrupt context but almost immediately issues a request to the operating system to transform its context to that of a fork process. This action dismisses the interrupt.
9. When reactivated in fork process context, the start-I/O routine performs device-specific I/O completion and passes control to the system for additional I/O postprocessing.
10. System I/O postprocessing runs in interrupt context at a lower IPL and issues a special kernel-mode asynchronous system trap (AST) for the user process requesting I/O.
11. When the special kernel-mode AST is delivered, the AST routine executes in full process context in kernel mode to deliver data and status to the process. If the original request specified a user-mode AST, the special kernel-mode AST queues it.
12. When the user process gains control, the user's AST routine executes in full process context in user mode.

## 1.6 Programmed-I/O and Direct-Memory-Access Transfers

Devices are equipped with various registers that initiate, control, and monitor the progress of data transfer, seek operation, or other requests for device activity. When it completes a request, the device posts an interrupt to the processor. The size of the transfer concluded by a device interrupt depends upon the capabilities of the device.

### 1.6.1 Programmed I/O

Drivers for relatively slow devices, such as printers, terminals, and some disk and tape drives, must transfer data to a hardware interface register a byte or a word at a time. These drivers must themselves keep a record of the location of the data buffer in memory, as well as a running count of the amount of data that has been transferred to or from the device. Thus, these devices perform **programmed I/O** (PIO) in that the transfer is largely conducted by the driver program.

The DE422 ISA ethernet interface is an example of a device that uses programmed I/O.

Drivers performing PIO transfers are generally not concerned with the operation of I/O adapters. However, drivers that perform direct-memory-access (DMA) transfers must consider I/O adapter functions, as discussed in Section 1.6.2.

### 1.6.2 Direct-Memory-Access I/O

Devices that perform **direct-memory-access** (DMA) transfers do not require the central processor so frequently. Once the driver activates the device, the device can transfer a large amount of data without requesting an interrupt after each of the smaller amounts. The responsibilities of a driver for a DMA device involve setting a hardware interface register with the starting address of the buffer containing the data to be transferred, a byte offset into the buffer, and the size of the transfer. By setting the appropriate bit or bits in the hardware interface control and status register (CSR), the driver activates the device. The device then automatically transfers the specified amount of data to or from the specified address. Any driver that does DMA must map the DMA buffer. For DMA transfers, drivers must first map the transfer from main memory to I/O bus memory space. The result of this mapping is a set of contiguous addresses in the bus address space that the DMA device can access to successfully perform a DMA transfer. If the bus interface does not have map registers, a bus address is equivalent to a main memory address. If the bus interface has map registers, a bus address undergoes a translation before becomming a system memory address.

## 1.7 Buffered and Direct I/O

A separate issue, but one related to the data transfer capabilities of a device, results from the fact that the original buffer, as specified in the user $QIO request, is in process space and is mapped by process page-table entries. Because the driver cannot rely on process context existing at the time the device is ready to service the I/O request, it must have some means of guaranteeing that it can access both the data involved in the transfer and the page-table entries that map the buffer.

The operating system provides the following two techniques that are employed by device drivers:

- **Direct I/O**, the technique used most commonly by drivers of DMA devices, locks the user buffer in memory as well as the page-table entries that map it. The function decision table (FDT) of such a driver calls a system-supplied FDT routine that prepares the user buffer for direct I/O.
- **Buffered I/O** is the strategy whereby the driver FDT dispatches to an FDT routine in the driver that allocates a buffer from nonpaged pool. It is this intermediate buffer that is involved in the transfer. The driver later refers to the buffer using addresses in system space. Driver preprocessing routines copy the data from the user buffer to the system buffer for a write request; system I/O postprocessing (by means of a special kernel-mode AST) delivers

data from the system buffer to the user buffer for a read request. Drivers most often use buffered I/O for PIO devices such as line printers and card readers.

The trade-off between buffered I/O and direct I/O is the time required to move the data into the user's buffer as against the time required to lock the buffer pages in memory.

# 2 Accessing Device Interface Registers

A **hardware interface register** is the place where software interfaces with a hardware component. Every hardware component on an OpenVMS AXP system, including CPU and memory, has a set of interface registers.

The portion of a processor's physical address space through which it accesses hardware interface registers is known as its **I/O space**.

In the VAX architecture, a hardware implementation usually defines a physical address boundary between memory space and I/O space. I/O space physical addresses are mapped into the processors' virtual address space and are accessed using VAX load and store instructions (for example, MOV, BIS, and others).

For AXP systems, there are no rules governing how hardware implementations allow access to I/O space. Some AXP platforms allow VAX-style I/O space access. Other platforms provide access to I/O space through **hardware I/O mailboxes**. Some platforms implement both styles of I/O register access.

The challenge presented by the AXP architecture is to create software abstractions that hide the hardware mechanisms for I/O space access from the programmer. These software abstractions contribute to driver portability. The AXP architecture also defines no byte or word length load and store instructions. Because some I/O buses and adapters require byte or word register access granularity for correct adapter operation, AXP system hardware designers invented the following mechanisms that provide byte and word access granularity for I/O adapter register access:

- **Sparse space addressing**, which means the device address space is expanded by a factor of two to allow for inclusion of a byte mask in the write data.
- **Swizzle space addressing**, which means where upper order bits in the processor physical address map to an I/O bus address, while lower order bits are used to implement I/O bus byte enable signals. This causes a large amount of processor physical address space to represent the I/O bus address space.
- **Hardware I/O mailboxes**, which are 64-byte, naturally-aligned, physically-contiguous data structures (defined by the AXP architecture) built in system memory and accessed by special I/O subsystem hardware. Drivers can use hardware I/O mailboxes to deliver commands and write data to the interface registers of a device residing on an I/O bus.

A significant part of I/O bus support in the OpenVMS AXP operating system is to provide standard ways to access I/O device registers. OpenVMS AXP provides a set of data structures and routines that can be used for register access on any system, regardless of the underlying I/O hardware. Bus support provides two ways. One way is the CRAM data structure. The other way is the platform independent access routines IOC$READ_IO and IOC$WRITE_IO.

**Note**

In register access discussions, the term **control and status register** (CSR) is sometimes used instead of the generic term **interface register**. In this manual, the terms are equivalent.

## 2.1 Mapping I/O Device Registers

Unlike OpenVMS VAX systems (where the operating system maps device register space into the processors' virtual address space) before you access device registers on OpenVMS AXP systems, you must map the registers into the processor's virtual address space. OpenVMS AXP provides the IOC$MAP_IO routine, which allows a caller to request mapping based on device characteristics without regard to the platform hardware implementation of I/O space access.

**Note**

Register mapping is not required on XMI devices on DEC 7000/10000 systems, and IOC$READ_IO and IOC$WRITE_IO are not supported. If you are porting an OpenVMS VAX XMI device driver to an OpenVMS AXP system, you must use CRAMs.

Once your device is mapped, you can access it using a CRAM data structure and associated routines, or the IOC$READ_IO and IOC$WRITE_IO routines.

## 2.2 Platform Independent I/O Bus Mapping

The platform independent I/O bus mapping routine is called IOC$MAP_IO. This routine maps I/O bus physical address space into an address region accessible by the processor. The caller of this routine can express the mapping request in terms of the bus address space without regard to address swizzling, dense space, sparse space. IOC$MAP_IO is supported on PCI, EISA, TURBochannel, and Futurebus+. It is not supported on XMI.

In additon to IOC$MAP_IO, the following platform independent mapping and access routines exist:

- IOC$READ_IO
- IOC$WRITE_IO
- IOC$UNMAP_IO

The IOC$MAP_IO routine maps I/O bus physical address space into an address region accessible by the processor. The IOC$UNMAP_IO routine is provided to unmap a previously mapped space. IOC$READ_IO and IOC$WRITE_IO are I/O access routines that provide a platform independent way to read and write I/O space without the overhead of CRAM allocation and initialization. These routines require that the I/O space that is to be accessed have been previously mapped by a call to IOC$MAP_IO. For more information about these routines, see *OpenVMS AXP Device Support: Reference*.

### 2.2.1 Using the IOC$MAP_IO Routine

Drivers that need to use the IOC$MAP_IO routine must call that routine under specific spinlock restrictions. The driver cannot be holding any spinlocks that prohibit IOC$MAP_IO from taking out the MMG spinlock.

Most drivers want to call IOC$MAP_IO immediately after they are loaded. Traditionally, the correct place for a driver to call IOC$MAP_IO would be its controller or unit initialization routine. However, because the controller and unit initialization routines are called at IPL$_POWER, IOC$MAP_IO cannot take out the MMG spinlock in this environment.

The new driver support feature for calling IOC$MAP_IO has two elements. First, the driver may request preallocated space for any number of I/O Handles (the output of IOC$MAP_IO). Second, the driver may name a routine that will be called in an environment suitable for calls to IOC$MAP_IO.

Drivers can specify the number of I/O Handles they need to store using the IOHANDLES parameter on the DPTAB macro. The default parameter value is zero. The maximum permitted value is 65,535.

When the IOHANDLES parameter is zero or one, the driver loader does NOT allocate any additional space for I/O Handles. For these two values, the driver is expected to store the I/O Handle it needs directly in the IDB$Q_CSR field.

When the IOHANDLES parameter is greater than one, an MCJ data structure is allocated. The base address of the MCJ is stored in the low-order longword of IDB$Q_CSR and the IDB$V_MCJ flag is set. MCJ$Q_ENTRIES is the base address in the MCJ of an array of quadword I/O Handle slots. The number of slots in the array is exactly the number specified by the drivers dpt$iohandles value.

Drivers specify a CSR Mapping routine using the CSR_MAPPING parameter on the DDTAB macro. The driver loading procedure calls the CSR_MAPPING routine holding the IOLOCK8 spinlock before it calls the controller or unit initialization routines. In this context, the driver can make all its needed calls to IOC$MAP_IO and other bus support routines with similar calling requirements.

**Note**

The CSR mapping routine is not called on power fail recovery.

### 2.2.2 Platform Independent I/O Access Routines

The platform independent I/O access routines are IOC$READ_IO and IOC$WRITE_IO. These provide a platform independent way to read and write I/O space without the overhead of CRAM allocation and initialization. These routines require that the I/O space that is to be accessed has been previously mapped by a call to IOC$MAP_IO.

With the new mapping and access routines, we have the following basic model of I/O bus access:

- Map the device into the processor address space: Do the mapping yourself based on knowledge of a specific platform and bus OR use the new routine IOC$MAP_IO.
- Access the device: Do it yourself based on platform details, use CRAMS, or using the new platform independent access routines.

IOC$READ_IO and IOC$WRITE_IO are supported on PCI, EISA, TURBOchannel, and Futurebus+. These routines are not supported on XMI.

## 2.3 Accessing Registers Directly

Registers that are mapped into the processors' virtual address space and accessed with load and store instructions are said to be accessed directly. This is similar to VAX-style I/O register access. On an AXP system, registers that are implemented on hardware directly connected to the processor-memory interconnect are usually accessed in this manner. Sparse space and swizzle space register access are examples of direct I/O device register access.

## 2.4 Accessing Registers Using CRAMS

Hardware I/O mailboxes exist only on DEC4000 Series and DEC7000/DEC10000 Series computers. The CRAM data structure and associated routines and IOC$READIO and IOC$WRITE_IO hide the underlying hardwarep mechanism (swizzle space, sparse space, or hardware I/O mailbox) from the programmer.

In addition to the CRAM data structure, OpenVMS AXP provides a set of system routines and corresponding macros that, on behalf of a device driver, allocate and initialize CRAMs. Table 2–1 lists these routines and macros. For more information about each system routine and macro, see *OpenVMS AXP Device Support: Reference*. Subsequent sections of this chapter describe driver mailbox operations in more detail.

**Table 2–1 OpenVMS Macros and System Routines That Manage I/O Mailbox Operations**

| Routine | Macro | Description |
|---|---|---|
| IOC$ALLOCATE_CRAM | DPTAB **idb_crams**, **ucb_crams**<br>CRAM_ALLOC | Allocates and initializes a CRAM |
| IOC$CRAM_CMD | CRAM_CMD | Generates values for the command, mask, and remote I/O interconnect address (RBADR) fields of a CRAM |
| IOC$CRAM_IO | CRAM_IO | Issues the I/O space transaction defined by the CRAM |
| IOC$DEALLOCATE_CRAM | CRAM_DEALLOC | Deallocates a CRAM |

## 2.5 Allocating CRAMs

A driver can use the following basic CRAM allocation strategies:

- Allocate a CRAM for every register the driver ever needs to access.
- Allocate a CRAM and reuse it.
- A driver can preallocate CRAMs at driver loading, or in a driver controller or unit initialization routine, linking them to a list connected to a UCB, IDB, or some driver-specific structure. This strategy is optimal for drivers that use CRAMs in performance-sensitive code.
- A driver can reuse and rebuild CRAMs as needed. Although fewer CRAMs suffice for the purposes of such a driver, this strategy is best suited for access to registers that are not in a performance sensitive code path.

Even though a driver can reuse CRAMs, a driver should not reuse a CRAM until it has checked the return status from IOC$CRAM_IO.

### 2.5.1 Preallocating CRAMs to a Device Unit or Device Controller

An OpenVMS AXP device driver can preallocate CRAMs and store them in a linked list associated with some data structure. It accomplishes this by repeatedly calling IOC$ALLOCATE_CRAM and inserting the address of the CRAM returned by this routine in the CRAM list. Or, CRAMS can be automatically preloaded by driver loading as described here.

Drivers often preallocate CRAMs to perform I/O operations on device unit registers or device controller registers. To facilitate the allocation of CRAMs for these purposes, the OpenVMS AXP driver loading procedure examines two fields in the DPT, DPT$W_IDB_CRAMS and DPT$W_UCB_CRAMS, for an indication of how many CRAMs the driver plans on using. Although the default value of both fields is zero, you can insert the number of CRAMs a driver requires to address device unit registers and device controller registers by specifying the **idb_crams** and **ucb_crams** arguments in the driver's DPTAB macro invocation. IDB CRAMs are available for use by a controller or unit initialization routine; UCB CRAMs are available for use by a unit initialization routine.

The driver loading procedure calls IOC$ALLOCATE_CRAM for each requested CRAM and inserts it in either of two singly linked lists: UCB$PS_CRAM as the header of a list of device unit CRAMs, and IDB$PS_CRAM as the header of a list of device controller CRAMs.

### 2.5.2 Calling IOC$ALLOCATE_CRAM to Obtain a CRAM

To allocate a single CRAM, a driver calls IOC$ALLOCATE_CRAM, specifying a location to receive the address of the allocated CRAM and, optionally, the addresses of the IDB, UCB, or ADP.

IOC$ALLOCATE_CRAM allocates the CRAM and initializes it as follows:

| | |
|---|---|
| CRAM$W_SIZE | Size of CRAM structure in bytes |
| CRAM$B_TYPE | Structure type (DYN$C_MISC) |
| CRAM$B_SUBTYPE | Structure type (DYN$C_CRAM) |
| CRAM$Q_RBADR | Address of remote I/O interconnect location (from IDB$Q_CSR) |
| CRAM$B_HOSE | Remote I/O interconnect number (from ADP$B_HOSE_NUM) |
| CRAM$L_IDB | IDB address |
| CRAM$L_UCB | UCB address |

Normally, an OpenVMS AXP device driver can use the DPTAB macro to allocate CRAMs and associate them with a UCB or IDB; drivers that need to associate CRAMs with other structures may elect to allocate them from within a suitable fork thread.

IOC$ALLOCATE_CRAM cannot be called from above IPL$_SYNCH. Therefore, controller and unit initialization routines (which are called by the driver-loading procedure at IPL$_POWER) cannot allocate CRAMs. For CRAMS needed in or managed by controller or unit initialization routines, Digital recommends the DPTAB parameters as the means for CRAM allocation.

## 2.6 Constructing a Mailbox Command Within a CRAM

Once it has allocated CRAMs for its operations on device registers, an OpenVMS AXP device driver initializes each CRAM, so that it can use the CRAM in a transaction to a device interface register.

A driver initializes a CRAM by calls IOC$CRAM_CMD, specifying the **cmd_index**, **byte_offset**, and **adp_ptr**, and **cram_ptr iohandle** arguments. IOC$CRAM_CMD uses the input parameters supplied in the call to generate values for the command, mask, and I/O bus address fields of the CRAM that are specific to the bus that is the target of the mailbox operation.

Use the **cmd_index** argument to indicate the size and type of the register operation the mailbox describes. Although the cramdef.h system header file defines the command indices listed in Table 2–2, the actual commands supported under a given processor–I/O subsystem configuration vary from configuration to configuration. (Your specification of the **adp** argument allows IOC$CRAM_CMD to find the location of the command table that corresponds to a given I/O interconnect.) If you specify a command index that does not correspond to a supported command on the current system, IOC$CRAM_CMD returns the SS$_BADPARAM status.

**Table 2–2 Mailbox Command Indices Defined by cramdef.h**

| Command Index | Description |
|---|---|
| CRAMCMD$K_RDQUAD32 | Quadword read in 32-bit space |
| CRAMCMD$K_RDLONG32 | Longword read in 32-bit space |
| CRAMCMD$K_RDWORD32 | Word read in 32-bit space |
| CRAMCMD$K_RDBYTE32 | Byte read in 32-bit space |
| CRAMCMD$K_WTQUAD32 | Quadword write in 32-bit space |
| CRAMCMD$K_WTLONG32 | Longword write in 32-bit space |
| CRAMCMD$K_WTWORD32 | Word write in 32-bit space |
| CRAMCMD$K_WTBYTE32 | Byte write in 32-bit space |
| CRAMCMD$K_RDQUAD64 | Quadword read in 64 bit space |
| CRAMCMD$K_RDLONG64 | Longword read in 64 bit space |
| CRAMCMD$K_RDWORD64 | Word read in 64 bit space |
| CRAMCMD$K_RDBYTE64 | Byte read in 64 bit space |
| CRAMCMD$K_WTQUAD64 | Quadword write in 64 bit space |
| CRAMCMD$K_WTLONG64 | Longword write in 64 bit space |
| CRAMCMD$K_WTWORD64 | Word write in 64 bit space |
| CRAMCMD$K_WTBYTE64 | Byte write in 64 bit space |

Use the **byte_offset** argument to specify the location of the device register that is the object of the mailbox command. Include the **cram** argument to identify the CRAM that contains the hardware I/O mailbox fields IOC$CRAM_CMD is to initialize.

Before using the hardware I/O mailbox in a write transaction to a device interface register, the driver must insert the data to be written to the register into CRAM$Q_WDATA.

### 2.6.1 Register Data Byte Lane Alignment

The CRAM routines supplied by OpenVMS AXP enforce a **longword oriented** view of I/O adapter register space, which means that adapter register space is viewed as if register bytes occupy a 32 bit data path, as follows:

```
         Adapter Register space

31    24 23  16 15   8 7     0   offset

  byte 3  byte 2 byte 1  byte 0    0
  byte 7  byte 6 byte 5  byte 4    4

            etc
```

Write example: To write a byte to register byte 2, specify IOC$CRAM_CMD parameters as follows:

```
command_index = cramcmd$k_wtbyte32

  byte_offset = 2
  adp_address = adp address
  cram_address = cram address
```

The data to be written must be positioned in bits 23:16 of the write data field (CRAM$Q_WDATA).

Read example: To read a byte from register byte 2, specify IOC$CRAM_CMD parameters as above except use CRAMCMD$K_RDBYTE32 as the command_index.

The data from register byte 2 will be returned in bits 23:16 of the CRAM read data field (CRAM$Q_RDATA).

The programmer must perform the proper byte lane alignment of data for register writes. On register reads, the data is returned in its natural byte lane without any shifting. Note that this way of looking at adapter register space maps directly to the semantics of most I/O buses, but is distinctly diferent from VAX behavior.

## 2.7 Initiating a Mailbox Transaction

An OpenVMS AXP device driver initiates to a device register by issuing a calls to IOC$CRAM_IO.

# 3 Allocating Map Registers and Other Counted Resources

Because AXP systems do not support the UNIBUS, Q22–bus, and MASSBUS adapters, the OpenVMS AXP operating system does not provide the following adapter-specific routines and macros that allocate and manage adapter map registers:

- IOC$ALOALTMAP, IOC$ALOALTMAPN, and IOC$ALOALTMAPSP
- IOC$ALOUBAMAP and IOC$ALOUBAMAPN
- IOC$LOADALTMAP (LOADALT macro)
- IOC$LOADMBAMAP (LOADMBA macro)
- IOC$LOADUBAMAP and IOC$LOADUBAMAPA (LOADUBA macro)
- IOC$RELALTMAP (RELALT macro)
- IOC$RELMAPREG (RELMPR macro)
- IOC$REQALTMAP (REQALT macro)
- IOC$REQMAPREG (REQMPR macro)

Instead, for AXP I/O subsystems that provide map registers, such as the TURBOchannel I/O processor for DEC 3000 AXP Model 500 systems, OpenVMS AXP provides a set of a routines that can manage the allocation of any resource that shares the following attributes of a set of map registers:

- The resource consists of an ordered set of items.
- The allocator can request one or more items. When requesting multiple items, the requester expects to receive a contiguous set of items. Thus, allocated items can be described by a starting number and a count.
- Allocation and deallocation of the resource are common operations and, thus, must be efficient and quick.
- A single deallocation may allow zero or more stalled allocation requests to proceed.

OpenVMS VAX systems record information relating to the availability and use of map registers in a set of arrays and fields within the adapter control block (ADP). OpenVMS AXP employs two new data structures for this purpose:

- A **counted resource allocation block** (CRAB), created by the OpenVMS adapter initialization routine, that describes a specific counted resource. The routine stores the address of the CRAB associated with a given adapter in ADP$L_CRAB.

**Note**

Code that needs to manage items of a private counted resource can use the system routines IOC$ALLOC_CRAB and IOC$DEALLOC_CRAB, described in *OpenVMS AXP Device Support: Reference*, to create a CRAB for that resource.

---

The number of resource items managed by a given CRAB is included in one of its fields. Resource items must be allocated in a numerically ordered, or contiguous series. A CRAB contains an array of quadword descriptors that record the location and length of a set of contiguous resource items that are free. Another CRAB field contains a value that is applied as a rounding factor to requests for resources to compute the actual number of items to be granted. For a detailed description of the CRAB, see *OpenVMS AXP Device Support: Reference*.

- A **counted resource context block** (CRCTX) that describes a specific request for a counted resource. The driver and the counted resource allocation routine exchange information in the CRCTX. A driver allocates a CRCTX before calling the counted resource allocation routine to obtain a certain number of items of the resource. For a detailed description of the CRCTX, see *OpenVMS AXP Device Support: Reference*.

Despite the new structures and new routines, an OpenVMS AXP device driver performs most of the same tasks as an OpenVMS VAX device driver when setting up and completing a direct memory access (DMA) transfer. An OpenVMS AXP device driver:

1. Calls IOC$ALLOC_CRCTX to obtain a CRCTX that describes a request for map registers
2. Loads the request count into the CRCTX$L_ITEM_CNT field
3. Calls IOC$ALLOC_CNT_RES to request the map registers
4. Calls IOC$LOAD_MAP to load the map registers granted in the allocation request
5. Prepares device registers for the transfer and activates the device
6. Calls IOC$DEALLOC_CNT_RES to free the registers for use by other requesters
7. Calls IOC$DEALLOC_CRCTX to deallocate the CRCTX

The following sections describe these steps.

## 3.1 Allocating a Counted Resource Context Block

A driver calls IOC$ALLOC_CRCTX to allocate and initialize a counted resource context block (CRCTX). The CRCTX describes a specific request for a given counted resource, such as a set of map registers. The driver subsequently uses the CRCTX as input to IOC$ALLOC_CNT_RES to allocate a set of the items managed as a counted resource.

IOC$ALLOC_CRCTX requires as input the address of the CRAB that describes the counted resource. For adapters that provide a counted resource, such as a set of map registers, ADP$L_CRAB contains this address.

The following example illustrates a call to IOC$ALLOC_CRCTX that returns the address of the allocated CRCTX to UCB$L_CRCTX, a field in an extended UCB:

```
70$:    PUSHAL  UCB$L_CRCTX(R5)         ; Pass cell to receive CRCTX address
        PUSHL   ADP$L_CRAB(R1)          ; Pass CRAB as argument
        CALLS   #2,IOC$ALLOC_CRCTX      ; Initialize the CRCTX
        BLBC    R0,200$                 ; Branch if failure status returned
```

To avoid the overhead of allocating (and deallocating) a CRCTX for each DMA transfer, drivers often obtain multiple CRCTXs in their controller or unit initialization routines, linking them from a data structure such as the UCB so that they will be available for later use.

See *OpenVMS AXP Device Support: Reference* for a detailed description of IOC$ALLOC_CRCTX.

## 3.2 Allocating Counted Resource Items

A driver calls IOC$ALLOC_CNT_RES to allocate a requested number of items from a counted resource. IOC$ALLOC_CNT_RES requires the addresses of both the CRAB and the CRCTX as input parameters. The resource request is described in the CRCTX structure; the counted resource itself is described in the CRAB.

A driver typically initializes the following fields of the CRCTX before calling IOC$ALLOC_CNT_RES.

| Field | Description |
|---|---|
| CRCTX$L_ITEM_CNT | Number of items to be allocated. When requesting map registers, this value in this field should include two extra map registers to be allocated and loaded as a guard page to prevent runaway transfers. There may be additional bus-specific requirements. See *OpenVMS AXP Device Support: Developer's Guide*. |
| CRCTX$L_CALLBACK | Procedure value of the callback routine to be called when the deallocation of resource items allows a stalled resource request to be granted.<br>A value of 0 in this field indicates that, on an allocation failure, control should return to the caller immediately without queuing the CRCTX to the CRAM's wait queue. |

A caller can also specify the upper and lower bounds of the search for allocatable resource items by supplying values for CRCTX$L_LOW_BOUND and CRCTX$L_UP_BOUND.

IOC$ALLOC_CNT_RES always returns to its caller immediately, whether the allocation request is granted immediately, is stalled, or is unsuccessful. If the request is granted immediately, or when a stalled request is eventually granted, IOC$ALLOC_CNT_RES returns the number of the first item granted to the caller in CRCTX$L_ITEM_NUM and sets CRCTX$V_ITEM_VALID in CRCTX$L_FLAGS.

If there are waiters for the counted resource, or if there are insufficient resource items to satisfy the request, IOC$ALLOC_CNT_RES saves up to 3 quadwords of caller-supplied context in the CRCTX. IOC$ALLOC_CNT_RES writes a –1 to CRCTX$L_ITEM_NUM, and inserts the CRCTX in the resource-wait queue (headed by CRAB$L_WQFL). It then returns SS$_INSFMAPREG status to its caller.

**Note**

If a counted resource request does not specify a callback routine (CRCTX$L_CALLBACK), IOC$ALLOC_CNT_RES does not insert its CRCTX in the resource-wait queue. Rather, it returns SS$_INSFMAPREG status to its caller.

A driver must not deallocate the CRCTX while the resource request it describes is stalled by IOC$ALLOC_CNT_RES. (If the driver must cancel the allocation request, it should call IOC$CANCEL_CNT_RES.)

When a counted resource deallocation occurs, the first CRCTX is removed from the resource-wait queue and the allocation is attempted again. If IOC$ALLOC_CNT_RES is now able to grant the requested number of resource items, it calls the callback routine (CRCTX$L_CALLBACK), passing it the following values:

| Location | Contents |
|---|---|
| R0, R21 | SS$_NORMAL |
| R1, R16 | Address of CRAB |
| R2, R17 | Address of CRCTX |
| R3, R18 | Contents of CONTEXT1 argument at the time of the original allocation request (CRCTX$Q_CONTEXT1) |
| R4, R19 | Contents of CONTEXT2 argument at the time of the original allocation request (CRCTX$Q_CONTEXT2) |
| R5, R20 | Contents of CONTEXT3 at the time of the original allocation request (CRCTX$Q_CONTEXT3) |

The callback routine checks R0 to determine whether it has been called with SS$_NORMAL or SS$_CANCEL status (from IOC$CANCEL_CNT_RES). If the former, the routine typically proceeds to loads the map registers that have been allocated.

The following example illustrates a call to IOC$ALLOC_CNT_RES:

```
40$:    MOVL    SCDRP$L_BOFF(R5),R0     ; Get byte offset
        ADDL    SCDRP$L_BCNT(R5),R0     ; Add in byte count
        ADDL    G^MMG$GL_BWP_MASK,R0    ; Round up to number of pages
        ADDL    G^MMG$GL_PAGE_SIZE,R0   ; Add extra "no access" page
        ASHL    G^MMG$GL_VA_TO_VPN,R0,- ; Get number of pages involved
                   CRCTX$L_ITEM_CNT(R2) ; Pass as number of contiguous
                                        ; registers to allocate
        MOVAB   G^SCS$MAP_RETRY,-       ; SCS$MAP_RETRY is callback routine
                   CRCTX$L_CALLBACK(R2)
        PUSHL   R2                      ; Push CRCTX as argument
        PUSHL   ADP$L_CRAB(R4)          ; Push CRAB as argument
        CALLS   #2,IOC$ALLOC_CNT_RES    ; Allocate the map registers
        BLBC    R0,110$                 ; If allocation is not successful,
                                        ; branch; otherwise proceed
                                        ; to load map registers
        .
        .
        .
```

```
110$:   CMPL    #SS$_INSFMAPREG,R0      ; INSFMAPREG means request queued
        BNEQ    120$                    ; Other status means error; branch
        MOVL    #_C_MAP_ALLOC_WAIT_STATE,-  ; Record wait state in
                   CDRP$L_WAIT_STATE(R5)    ; CDRP
        MOVL    #SS$_INSFMAP,R0         ; Return status to caller of this
                                        ; driver routine
        RSB
120$:   ; Process returned errors (other than SS$_INSFMAPREG)
```

The OpenVMS AXP operating system allows you to indicate that a counted resource request should take precedence over any waiting request by setting the CRCTX$V_HIGH_PRIO bit in CRCTX$L_FLAGS. A driver employs a high-priority counted resource request to preempt normal I/O activity and service some exception condition from the device. (For instance, during a multivolume backup, a tape driver might make a high-priority request, when it encounters the end-of-tape (EOT) marker, to get a subsequent tape loaded before normal I/O activity to the tape can resume. A disk driver might issue a high-priority request to service a disk offline condition.)

IOC$ALLOC_CNT_RES never stalls a high-priority counted resource request or places its CRCTX in a resource-wait queue. Rather, it attempts to allocate the requested number of resource items immediately. If IOC$ALLOC_CNT_RES cannot grant the requested number of items, it returns SS$_INSFMAPREG status to its caller.

See *OpenVMS AXP Device Support: Reference* for a detailed description of IOC$ALLOC_CNT_RES.

## 3.3 Loading Map Registers

A driver calls IOC$LOAD_MAP to load a set of adapter-specific map registers. The driver must have previously allocated the map registers (including an extra two to serve as guard pages) in calls to IOC$ALLOC_CRCTX and IOC$ALLOC_CNT_RES.

IOC$LOAD_MAP requires the following as input:

- the address of the ADP of the adapter that provides the map registers
- the address of the CRCTX that describes the map register allocation
- the system virtual address of the page table entry (PTE) for the first page to be used in the DMA transfer
- the Byte offset into the first page of the transfer

IOC$LOAD_MAP returns to a specified location a port-specific address of a DMA buffer. The following example illustrates a call to IOC$LOAD_MAP:

```
100$:   PUSHAL  UCB$L_ARG(R4)           ; Cell for returned DMA address
        MOVZWL  BD$W_PAGE_OFFSET(R3),-(SP) ; Pass starting buffer offset
        PUSHL   BD$L_SVAPTE(R3)         ; Pass SVAPTE as argument
        PUSHL   R2                      ; Pass CRCTX as argument
        PUSHL   PDT$L_ADP(R4)           ; Pass ADP as argument
        CALLS   #5,IOC$LOAD_MAP         ; Load the allocated map registers
```

See *OpenVMS AXP Device Support: Reference* for a detailed description of IOC$LOAD_MAP.

Having loaded the map registers for a DMA transfer, a driver typically performs some of the following steps to initiate the transfer:

- Loads the port-specific DMA address into a device DMA address register. Some manipulation of the address value might be needed, depending upon the hardware. (For instance, a DEC 3000 AXP Model 500 driver must clear the two low bits before writing to the register.)
- Computes the transfer length and loads a device transfer count register. Typically a driver derives the transfer length from a field such as UCB$L_BCNT.
- Sets to GO byte in the device CSR (possibly indicating the direction of the transfer as well) by writing a mask to the CSR.

## 3.4 Deallocating a Number of Counted Resources

A driver calls IOC$DEALLOC_CNT_RES to deallocate a requested number of items of a counted resource. IOC$DEALLOC_CNT_RES requires the addresses of both the CRAB and CRCTX as input. After deallocating the items, if there are any stalled requests, IOC$DEALLOC_CNT_RES queues a fork thread that will attempt to allocate the resource to the stalled requests.

The following example illustrates a call to IOC$DEALLOC_CNT_RES:

```
PUSHL   R2                      ; Push CRCTX as argument
PUSHL   ADP$L_CRAB(R4)          ; Push CRAB as argument
CALLS   #2,IOC$DEALLOC_CNT_RES  ; Deallocate the map registers
```

See *OpenVMS AXP Device Support: Reference* for a detailed description of IOC$DEALLOC_CNT_RES.

## 3.5 Deallocating a Counted Resource Context Block

A driver calls IOC$DEALLOC_CRCTX to deallocate a CRCTX. IOC$DEALLOC_CRCTX requires only the address of the CRCTX as input.

A driver must not deallocate a CRCTX that describes a request that has been stalled waiting for sufficient resource items to be made available (that is, a CRCTX that is in a given CRAB wait queue). Prior to deallocating such a CRCTX, a driver should call IOC$CANCEL_CNT_RES to cancel the resource request.

The following example illustrates a call to IOC$DEALLOC_CRCTX:

```
PUSHL   R2                      ; Pass CRCTX as argument
CALLS   #1,IOC$DEALLOC_CRCTX    ; Deallocate the CRCTX
```

See *OpenVMS AXP Device Support: Reference* for a detailed description of IOC$DEALLOC_CRCTX.

# 4 Writing Device-Driver Tables

Every device driver declares three static tables that describe the device and driver:

- **Driver prologue table (DPT)**—Describes the device type, driver name, and fields in the I/O database to be initialized during driver loading and reloading.
- **Driver dispatch table (DDT)**—Lists some of the driver's entry points to which the operating system transfers control. The function decision table lists other entry points.
- **Function decision table (FDT)**—Provides the names of action routines for I/O functions the driver supports and indicates which of those functions it supports by using an intermediate system buffer.

The operating system provides macros that drivers can invoke to initialize these tables.

## 4.1 Driver Prologue Table

The driver prologue table (DPT), along with parameters to the System Management utility (SYSMAN) command that request driver loading, describes the driver to the driver-loading procedure. The driver-loading procedure performs the following tasks:

- Further initializes the DPT
- Creates data structures for the new devices in the I/O database
- Calls the OpenVMS executive loader to compute the size of the driver and load it into nonpaged system memory
- Links the new DPT into a list of all DPTs known to the system (IOC$GL_DPTLIST).

Device drivers can pass data-structure initialization information to the driver-loading procedure through values stored in the DPT. In addition, the driver-loading procedure initializes some fields within the I/O database using information from its own tables.

To create a DPT, a driver invokes the DPTAB macro, as described in *OpenVMS AXP Device Support: Reference*. The DPTAB macro generates a driver prologue table (DPT) in a program section called $$$105_PROLOGUE.

The DPTAB macro requires the following information:

- An indication that the driver conforms to the coding practices for a OpenVMS AXP device driver by supplying **step**=**2** in the **step** argument.
- An indication that the driver has been written to run in a symmetric multiprocessing system. All OpenVMS AXP drivers must specify **smp**=**YES**.

- Code identifying the device by its adapter type in the **adapter** argument. You can supply any name that, when appended to the string "AT$_", results in a symbol defined by the $DCDEF macro in SYS$LIBRARY:STARLET.MLB. Of these symbols, the driver-loading procedure takes special action only when the keyword **NULL** is present. The driver-loading procedure creates no ADP for a null adapter (AT$_NULL) and clears the VEC$PS_ADP and IDB$L_ADP fields.
- Size of the unit control block (UCB) in the **ucbsize** argument.

The DPTAB also allows you to specify the following information, if applicable to the device driver:

- Whether the driver needs a permanently allocated system page
- Whether the driver needs controller register access mailboxes (CRAMs) to be preallocated and associated with the unit control block (UCB) or interrupt dispatch block (IDB).
- Maximum number of units supported by the driver (default is 8)
- Number of UCBs to be created when the driver is loaded by means of the System Management (SYSMAN) utility's autoconfiguration facility and the address of a unit delivery routine to be called by that facility

A driver typically follows the DPTAB macro invocation with several instances of the DPT_STORE macro and the DPT_STORE_ISR macro, which allow the driver to communicate its initialization needs to the driver-loading procedure and reloading procedures. A driver uses these macros in the following manner:

- A driver invokes the DPT_STORE macro once, specifying the **INIT** keyword, to automatically generate a driver I/O database initialization routine. This routine, which executes when the driver is first loaded into the system, initializes those fields specified by the series of DPT_STORE macros that intervene between the DPT_STORE **INIT** and DPT_STORE **REINIT** declarations.

  Drivers use the DPT_STORE macro with the **INIT** table marker label to begin a list of DPT_STORE invocations that supply initialization data for the following fields:

  UCB$B_FLCK — Index of the fork lock under which the driver performs fork processing. Fork lock indexes are defined by the $SPLCODDEF definition macro (invoked by DPTAB) as follows:

  | IPL | Fork Lock Index |
  |---|---|
  | 8 | SPL$C_IOLOCK8 |
  | 9 | SPL$C_IOLOCK9 |
  | 10 | SPL$C_IOLOCK10 |
  | 11 | SPL$C_IOLOCK11 |

  UCB$B_DIPL — Device interrupt priority level

  Other commonly initialized fields are as follows:

  UCB$L_DEVCHAR — Device characteristics

| | |
|---|---|
| UCB$B_DEVCLASS | Device class |
| UCB$B_DEVTYPE | Device type |
| UCB$W_DEVBUFSIZ | Default buffer size |
| UCB$Q_DEVDEPEND | Device-dependent parameters |

- A driver invokes the DPT_STORE macro once, specifying the **REINIT** keyword, to automatically generate a driver I/O database reinitialization routine. This routine, which executes when the driver is first loaded into the system, and whenever the driver is reloaded, initializes those fields specified by the series of DPT_STORE and DPT_STORE_ISR macros that intervene between the DPT_STORE **REINIT** and DPT_STORE **END** declarations.

  Drivers use the DPT_STORE macro with the **REINIT** table marker label to begin a list of DPT_STORE and DPT_STORE_ISR invocations that supply initialization and reinitialization data. The following fields are declared with the DPT_STORE_ISR macro:

| | |
|---|---|
| CRB$L_INTD | Interrupt service routine |
| CRB$L_INTD2 | Interrupt service routine for second interrupt vector |

- A driver invokes the DPT_STORE macro once, specifying the **END** keyword, to denote the end of the reinitialization section.

For additional information on how to use the DPTAB, DPT_STORE, and DPT_STORE_ISR macros, plus an example of their usage, see *OpenVMS AXP Device Support: Reference*.

## 4.2 Driver Dispatch Table

The driver dispatch table (DDT) identifies those driver routines that the operating system calls to process I/O requests. Every driver must create a DDT.

The routines listed in the DDT can reside in the driver module or in a system module. Device-dependent routines are normally located in the driver module. For more information about the system device-independent routines that can be specified, see the Systems Routines section of *OpenVMS AXP Device Support: Reference*.

The driver creates a DDT by invoking the macro DDTAB. The DDTAB macro generates a DDT named **devnam**$DDT, according to the value you supply in **devnam** macro argument. It invokes the DRIVER_DATA macro to place the DDT within the the driver's data program section ($$$110_DATA).

When the driver is loaded into memory, OpenVMS writes the address of its DDT into DDB$L_DDT.

You must specify the address of the driver's function decision table (FDT) in the **functb** argument of the DDTAB macro. Several optional arguments allow you to specify the names of the following routines, if applicable:

- Start-I/O routine
- Controller initialization routine
- Cancel-I/O routine
- Register dumping routine
- Unit initialization routine
- Alternate start-I/O routine

- Mount verification routine
- Cloned UCB routine
- Start-I/O routine for a driver employing the kernel process services

In addition, the DPTAB macro allows you to specify the length of any diagnostic buffer or error message buffer.

See the description of the DDTAB macro in *OpenVMS AXP Device Support: Reference*. for additional information.

## 4.3 Function Decision Table

A function decision table (FDT) is a structure within a driver that consists of two substructures:

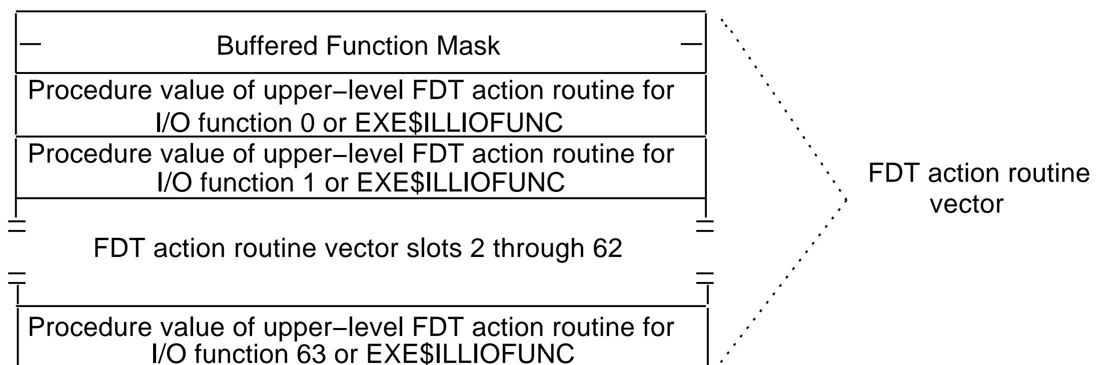
- A quadword bitmap known as the buffered function mask
- A 64-element array of longwords known as the FDT action routine vector

Each bit in the **buffered function mask** represents an I/O function that is serviced by the driver by means of an intermediate system buffer.

Each 32-bit slot of the **FDT action routine vector** corresponds to the symbolic value of an I/O function defined by the $IODEF macro in SYS$LIBRARY:STARLET.MLB. Those vector slots that relate to functions serviced by a driver contain the procedure value of an upper-level FDT action routine that initiates driver-specific preprocessing of the function. Those slots that represent functions the driver does not support contain the procedure value of a system upper-level FDT action routine that processes illegal I/O functions (EXE$ILLIOFUNC). When a $QIO is issued to a device driver, specifying an I/O function code the driver does not support, EXE$ILLIOFUNC executes, calling the FDT completion routine EXE_STD$ABORTIO. EXE_STD$ABORTIO terminates the I/O request and passes SS$_ILLIOFUNC status back to the $QIO caller.

Figure 4–1 depicts the layout of the FDT.

**Figure 4–1 Layout of Function Decision Table (FDT)**




A driver uses the following three macros in sequence to create and initialize its FDT:

- FDT_INI—Creates, labels, and initializes an FDT

- FDT_BUF—Creates the buffered function mask within an FDT
- FDT_ACT—Initializes one or more slots in the FDT action routine vector with the procedure value of an upper-level FDT action routine

The FDT_INI macro creates an FDT, using the DRIVER_DATA macro to place it within the driver's data program section ($$$110_DATA). The macro properly aligns the FDT in memory, assigning it the label specified by the **fdt** argument.

FDT_INI initializes the FDT by clearing the buffered function mask and entering the address of the illegal I/O function processing routine (EXE$ILLIOFUNC) in all FDT action routine vector slots.

If a driver does not explicitly invoke the FDT_INI macro, the FDT_BUF and FDT_ACT macros will automatically invoke it on the driver's behalf, resulting in an FDT named DRIVER$FDT.

The FDT_BUF macro builds the buffered function mask within an FDT from the specified list of I/O functions. The macro takes a single argument: a list of codes (enclosed within angle brackets and separated by commas) for I/O functions supported by the driver that require an intermediate system buffer. The macro expansion prefixes each code with the string IO$_; for example, READVBLK expands to IO$_READVBLK. (See Table 4–1 for a list of symbolic names for I/O functions defined by the $IODEF macro in SYS$LIBRARY:STARLET.MLB.)

If no buffered I/O functions are defined for the device, you can omit the FDT_BUF invocation.

In selecting the functions that are to be buffered, consider the following:

- Direct I/O is intended only for devices whose I/O operations always complete quickly. For example, although terminal I/O appears fast, users can prevent the I/O operation from completing by using Ctrl/S to halt the operation indefinitely; therefore, terminal I/O operations are buffered I/O.
- Use of direct I/O requires that the process pages containing the buffer be locked in memory. Locking pages in memory increases the overhead of swapping the process that contains the pages.
- Use of buffered I/O requires that the data be moved from the system buffer to the user buffer. Moving data requires additional time.
- Routines that manipulate data before delivering it to the user (for example, an interrupt service routine for a terminal) cannot gain access to the data if direct I/O is used. Therefore, transfers that require data manipulation must be buffered I/O.
- The operating system handles the quotas differently for direct I/O and buffered I/O, as described in the *OpenVMS System Manager's Manual*.
- Generally, direct-memory-access (DMA) devices use direct I/O, while programmed I/O devices use buffered I/O.

The FDT_ACT macro identifies the upper-level FDT action routine that processes one or more specified I/O function codes. An upper-level FDT action routine must either be an FDT completion routine or eventually transfer control to an FDT completion routine. An FDT completion routine either queues an I/O request packet (IRP) to a driver, inserts an IRP in the postprocessing queue, or aborts the I/O request. See Chapter 5 for additional information on upper-level FDT action routines, FDT support routines, and FDT completion routines.

An OpenVMS AXP device driver specifies one or more legal I/O functions by supplying the address of an upper-level FDT action routine for that function to the FDT_ACT macro. The FDT_ACT macro initializes the slot in the FDT action routine vector corresponding to each supplied function code with the procedure value of the specified routine.

Multiple invocations of the FDT_ACT macro, in sum, define the full set of I/O functions serviced by the driver. An illegal I/O function is one that the driver does not list in any FDT_ACT macro invocations. Its vector slot contains the procedure value of the illegal I/O function processing routine (EXE$ILLIOFUNC).

Note, however, only one upper-level FDT action routine can service any given I/O function. If you reuse an I/O function code in an FDT_ACT invocation, the compiler generates an error of the form:

```
%MACRO-E-GENERR, Generated ERROR: Multiple actions defined for function IO$_xxxxxx
```

A consequence of this limitation is that, if the preprocessing of a given function requires that several routines be executed, the upper-level FDT action routine must set up the appropriate call chain. Writers of OpenVMS VAX drivers should take special note of this difference between OpenVMS VAX and OpenVMS AXP FDT processing. On OpenVMS VAX systems, the $QIO system service processes entries in the order in which they appear in the FDT. When a function code is associated with more than one FDT routine, the system service sequentially calls every routine specified for the function code until a routine stops the scan by aborting, completing, or queuing an I/O request.

For a description of the FDT_INI, FDT_BUF, and FDT_ACT macros, and an example of their use, see *OpenVMS AXP Device Support: Reference*.

## 4.3.1 OpenVMS AXP I/O Function Codes

Table 4–1 lists the physical, logical, and virtual I/O function codes defined by the operating system. A complete list of function codes and values is contained in the macro iodef.h in SYS$LIBRARY:SYS$LIB_C.TLB.

**Table 4–1 I/O Function Codes**

| Function | Description | Equivalent Symbols |
|---|---|---|
| **Physical I/O** | | |
| IO$_NOP† | No operation | – |
| IO$_UNLOAD | Unload drive (required by all disk drivers) | IO$_LOADMCODE† (load microcode), IO$_START_BUS† (start LAVc bus) |
| IO$_SEEK | Seek cylinder | IO$_SPACEFILE† (space files), IO$_STARTMPROC† (start microprocessor), IO$_STOP_BUS† (stop LAVc bus) |
| IO$_RECAL† | Recalibrate drive | IO$_DUPLEX† (enter duplex mode), IO$_STOP† (stop), IO$_DEF_COMP† (define network component) |
| IO$_DRVCLR† | Drive clear | IO$_INITIALIZE (initialize), IO$_MIMIC† (enter mimic mode), IO$_DEF_COMP_LIST† (define network component list) |

†Unsupported; subject to change without notice

(continued on next page)

**Table 4–1 (Cont.) I/O Function Codes**

| Function | Description | Equivalent Symbols |
|---|---|---|
| **Physical I/O** | | |
| IO$_RELEASE† | Release port | IO$_SETCLOCKP† (set clock—physical), IO$_START_ANALYSIS† (start LAVc failure analysis) |
| IO$_OFFSET† | Offset read heads | IO$_ERASETAPE† (erase tape), IO$_STARTDATAP† (start data transfer—physical), IO$_STOP_ANALYSIS† (stop LAVc failure analysis) |
| IO$_RETCENTER† | Return to center line | IO$_QSTOP† (queue stop request), IO$_START_MONITOR† (start LAVc channel monitor) |
| IO$_PACKACK | Pack acknowledgment (required by all disk drivers) | IO$_STOP_MONITOR† (stop LAVc channel monitor) |
| IO$_SEARCH | Search for sector | IO$_SPACERECORD† (space records), IO$_READRCT† (read replacement and caching table) |
| IO$_WRITECHECK | Write check data | – |
| IO$_WRITEPBLK | Write physical block | – |
| IO$_READPBLK | Read physical block | – |
| IO$_WRITEHEAD† | Write header and data | IO$_RDSTATS† (read statistics), IO$_CRESHAD† (create a shadow set) |
| IO$_READHEAD† | Read header and data | IO$_ADDSHAD† (add member to shadow set) |
| IO$_WRITETRACKD† | Write track data | IO$_COPYSHAD† (perform shadow set copy operations) |
| IO$_READTRACKD† | Read track data | IO$_REMSHAD† (remove member from shadow set) |
| IO$_AVAILABLE | Set device available (required by all disk drivers) | – |
| IO$_SETPRFPATH† | Set preferred path | – |
| IO$_DISPLAY† | Display MSCP/TMSCP volume label | – |
| IO$_DSE | Data security erase (and rewind) | – |
| IO$_REREADN† | Reread next | IO$_DISK_COPY_DATA† (disk copy data) |
| IO$_REREADP† | Reread previous | IO$_WHM† (write history management), IO$_AS_SETCHAR† (Asian set character) |
| IO$_WRITERET† | Write retry | IO$_WRITECHECKH† (write check header and data), IO$_AS_SENSE_CHAR† (Asian sense characteristics) |
| IO$_READPRESET† | Read in preset | IO$_STARTSPNDL† (start spindle) |
| IO$_SETCHAR | Set device characteristics | – |
| IO$_SENSECHAR | Sense device characteristics | – |
| IO$_WRITEMARK† | Write tape mark | IO$_COPYMEM† (copy memory), IO$_PSXSETCHAR† (POSIX set characteristics) |

†Unsupported; subject to change without notice

(continued on next page)

**Table 4–1 (Cont.) I/O Function Codes**

| Function | Description | Equivalent Symbols |
|---|---|---|
| **Physical I/O** | | |
| IO$_WRTTMKR† | Write tape mark retry | IO$_DIAGNOSE† (diagnose), IO$_SHADMV† (perform mount verification on shadow set), IO$_PSXSENSECHAR† (POSIX sense characteristics) |
| IO$_FORMAT | Format | IO$_CLEAN† (clean tape) |
| **Logical I/O** | | |
| IO$_WRITELBLK | Write logical block | – |
| IO$_READLBLK | Read logical block | – |
| IO$_REWINDOFF | Rewind and set offline | IO$_READRCTL† (read RCT sector 0) |
| IO$_SETMODE | Set mode | – |
| IO$_REWIND | Rewind tape | – |
| IO$_SKIPFILE | Skip files | IO$_PSXSETMODE† (POSIX set mode ) |
| IO$_SKIPRECORD | Skip records | IO$_PSXSENSEMODE† (POSIX sense mode) |
| IO$_SENSEMODE | Sense mode | – |
| IO$_WRITEOF | Write end of file | IO$_TTY_PORT_BUFIO† (Terminal port driver FDT routine for buffered I/O) |
| IO$_TTY_PORT† | Terminal port driver FDT routine | IO$_FREECAP† (return free capacity) |
| IO$_FLUSH† | Flush controller cache | IO$_AS_SETMODE† (Asian set mode) |
| IO$_READLCHUNK† | Read large logical block | IO$_AS_SENSEMODE† (Asian sense mode) |
| IO$_WRITELCHUNK† | Write large logical block | – |
| **Virtual I/O** | | |
| IO$_WRITEVBLK | Write virtual block | – |
| IO$_READVBLK | Read virtual block | – |
| IO$_ACCESS | Access file | IO$_PSXWRITEVBLK† (POSIX write virtual block) |
| IO$_CREATE | Create file | – |
| IO$_DEACCESS | Deaccess file | IO$_PSXREADVBLK† (POSIX read virtual block) |
| IO$_DELETE | Delete file | – |
| IO$_MODIFY | Modify file | IO$_NETCONTROL† (X.25 network control function) |
| IO$_READPROMPT | Read terminal with prompt | IO$_SETCLOCK (set clock), IO$_AUDIO (CD–ROM audio) |
| IO$_ACPCONTROL | Miscellaneous ACP control | IO$_STARTDATA (start data) |
| IO$_MOUNT† | Mount volume | – |
| IO$_TTYREADALL† | Terminal read passall | – |

†Unsupported; subject to change without notice

(continued on next page)

**Table 4–1 (Cont.) I/O Function Codes**

| Function | Description | Equivalent Symbols |
|---|---|---|
| **Virtual I/O** | | |
| IO$_TTYREADPALL† | Terminal read with prompt passall | – |
| IO$_CONINTREAD | Connect to interrupt read-only | – |
| IO$_CONINTWRITE | Connect to interrupt with write | – |

†Unsupported; subject to change without notice

#### 4.3.1.1 Defining Device-Specific Function Codes

You can also define device-specific function codes by equating the name of a device-specific function with the name of an existing function that is irrelevant to the device. The selected codes should, however, have a type (logical, physical, or virtual) that is appropriate for the function they represent. Also, user programs that issue $QIO requests specifying a device-specific code must similarly redefine the existing function. For example, the assembly code that follows defines three device-specific physical I/O function codes.

```
IO$_STARTCLOCK=IO$_ERASETAPE      ; Start interval clock
IO$_STOPCLOCK=IO$_OFFSET          ; Stop interval clock
IO$_STARTDATA=IO$_SPACEFILE       ; Start data acquisition
```

## 4.4 Building Driver Tables Using C

The C language does not contain the powerful macro facilities that are available in BLISS and VAX MACRO. For this reason, OpenVMS AXP provides prototype tables in object form and uses run time initialization routines to override the default table values provided by the object module. This approach allows OpenVMS AXP to allocate the tables and assign default values using VAX MACRO or BLISS, while at the same time allowing the user-provided portions of a driver to be written entirely in C.

- The prototype tables are contained in the object module IOC$DRIVER_TABLES.OBJ, which resides in the object library VMS$VOLATILE_PRIVATE_INTERFACES.OLB in SYS$LIBRARY. This object library is included by the driver link procedure.
- To override default values in the prototype tables, the driver writer must code an initialization routine driver$init_tables, which is called by the driver loader with no explicit input parameters and which returns an integer status code. Implicit input parameters are the prototype DDT, DPT, and FDT tables whose global names are driver$ddt, driver$dpt, and driver$fdt respectively.
- Table initialization functions and macros are provided to assist the driver writer in coding driver$init_tables. These are listed below in the sections on each table. The initialization functions are driver$ini_<table><parameter>. $ini_table_parameter where *<table>* may be DDT, DPT or FDT and <parameter> is the parameter name as it exists in the VAX MACRO initialization macros. The function prototypes and macros are available by #include <vms_drivers.h>. This means that the parameter names are the same in MACRO, BLISS and C and can be documented in common.

- Initialization macros may be used as a labor-saving device. Each macro invokes the corresponding function, checks the status it returns and to returns to the driver loader if it encounters an error. The names of the initializtion macros are ini_<table>_<parameter>.
- Table initialization code will be collected in a PSECT using a TBD pragma, so that the space it occupies can be deallocated after initialization. This will not be implemented until DECC provides PSECT control for code.

## 4.4.1 Driver Prologue Table

### 4.4.1.1 DPT Macros

The macros listed in Table 4–2 should be used in the `driver$init_tables` routine to finish the initialization of the prototype Driver Prologue Table. These macros invoke the appropriate initialization function and check the status returned from the function. If an error is returned, the macro will return control back to the driver loader with the error status.

The first parameter for all the DPT initialization macros is a pointer to the driver's DPT structure. Typically, this first parameter will be the address of the prototype DPT.

The values shown in the last column of the table are the initial values that are contained in the prototype DPT structure. These initial values can be changed by using the corresponding macro.

**Table 4–2 DPT Initialization Macros for C**

| Macro name | Data type of second parameter | Prototype value |
|---|---|---|
| ini_dpt_adapt | integer | AT$_UBA |
| ini_dpt_bt_order | integer | 0 |
| ini_dpt_decode | integer | 0 |
| ini_dpt_defunits | integer | 1 |
| ini_dpt_deliver | function pointer | 0 |
| ini_dpt_end[1] | - | - |
| ini_dpt_flags | integer | DPT$M_SMPMOD[2] |
| ini_dpt_idb_crams | integer | 0 |
| ini_dpt_iohandles | integer | 0 |
| ini_dpt_maxunits | integer | 8 |
| ini_dpt_name | string pointer | - |
| ini_dpt_struc_init | function pointer | ioc$return |
| ini_dpt_struc_reinit | function pointer | ioc$return |
| ini_dpt_ucb_crams | integer | 0 |
| ini_dpt_ucbsize | integer | 0 |
| ini_dpt_unload | function pointer | 0 |

[1]The `ini_dpt_end` macro should be used immediately after all the other DPT initialization macros in the `driver$init_tables` routine.

[2]The integer value specified with the `ini_dpt_flags` macro is logically-ORed with the default value and any previously specified values.

(continued on next page)

**Table 4–2 (Cont.) DPT Initialization Macros for C**

| Macro name | Data type of second parameter | Prototype value |
|---|---|---|
| ini_dpt_vector | pointer to vector of pointers | 0 |

The following example shows the usage of the DPT initialization macros.

```
extern DPT driver$dpt;  /* Declare protype DPT */

ini_dpt_name        (&driver$dpt, "XXDRIVER");
ini_dpt_ucbsize     (&driver$dpt, sizeof(XX_UCB));
ini_dpt_adapt       (&driver$dpt, AT$_NULL);
ini_dpt_end         (&driver$dpt);
```

#### 4.4.1.2 DPT Functions

Each of the following functions stores a value in a DPT field and returns SS$_NORMAL, or returns an error status if it detects an error.

```
int      driver$ini_dpt_adapt( DPT *dpt, unsigned long value );
int      driver$ini_dpt_bt_order( DPT *dpt, long value );
int      driver$ini_dpt_decode( DPT *dpt, long value );
int      driver$ini_dpt_defunits( DPT *dpt, unsigned short value );
int      driver$ini_dpt_deliver( DPT *dpt, int ( *func )() );
int      driver$ini_dpt_flags( DPT *dpt, unsigned long value );
int      driver$ini_dpt_idb_crams( DPT *dpt, unsigned short value );
int      driver$ini_dpt_maxunits( DPT *dpt, unsigned short value );
int      driver$ini_dpt_name( DPT *dpt, char *string_ptr );
int      driver$ini_dpt_struc_init( DPT *dpt, void ( *func )() );
int      driver$ini_dpt_struc_reinit( DPT *dpt, void ( *func )() );
int      driver$ini_dpt_ucb_crams( DPT *dpt, unsigned short value );
int      driver$ini_dpt_ucbsize( DPT *dpt, unsigned short value );
int      driver$ini_dpt_unload( DPT *dpt, int ( *func )() );
int      driver$ini_dpt_vector( DPT *dpt, void( **func )() );
```

The following function signals that initialization of the DPT is complete.

```
int      driver$ini_dpt_end( DPT *dpt );
```

### 4.4.2 Driver Dispatch Table

#### 4.4.2.1 DDT Fields

In the following list of DDT field names, the presence of a parameter name indicates that the driver writer may set the field with one of the functions described below. A default value of "None" means that the current VAX MACRO macro definition does not supply a default value for the field.

| Field Name | Parameter Name | Default Value |
| --- | --- | --- |
| ddt$ps_start | start | ioc$return |
| ddt$iw_size | | ddt$k_length |
| ddt$iw_diagbuf | diagbf | 0 |
| ddt$iw_errorbuf | erlgbf | 0 |
| ddt$iw_fdtsize | | fdt$k_length |
| ddt$ps_ctrlinit | ctrlinit | ioc$return |
| ddt$ps_unitinit | unitinit | ioc$return |
| ddt$ps_cloneducb | cloneducb | 0 |
| ddt$ps_fdt2 | | None |
| ddt$ps_fdt | | 0 |
| ddt$ps_cancel | cancel | ioc$return |
| ddt$ps_regdmp | regdmp | ioc$return |
| ddt$ps_altstart | altstart | ioc$return |
| ddt$ps_mntver | mnt_ver | ioc$mntver |
| ddt$ps_mntv_sssc | | ioc$return |
| ddt$ps_mntv_for | mntv_for | ioc$return |
| ddt$ps_mntv_sqd | | ioc$return |
| ddt$ps_aux_storage | aux_storage | ioc$return |
| ddt$ps_aux_routine | aux_routine | ioc$return |
| ddt$ps_channel_assign | channel_assign | ioc$return |
| ddt$ps_cancel_selective | cancel_selective | ioc$return |
| ddt$is_stack_bcnt | stack_size | 0 |
| ddt$is_reg_mask | kp_reg_mask | 0 |
| ddt$ps_kp_startio | kp_startio | ioc$return |

#### 4.4.2.2 DDT Functions

Each of the following functions stores a value in a DDT field and returns SS$_NORMAL, or returns an error status if it detects an error.

```
int       driver$ini_ddt_altstart( DDT *ddt, void (*func)() );
int       driver$ini_ddt_aux_routine( DDT *ddt, int ( *func )()
);
int       driver$ini_ddt_aux_storage( DDT *ddt, void *addr );
int       driver$ini_ddt_cancel( DDT *ddt, void ( *func )() );
int       driver$ini_ddt_cancel_selective( DDT *ddt, int ( *func
)() );
int       driver$ini_ddt_channel_assign( DDT *ddt, void ( *func
)() );
int       driver$ini_ddt_cloneducb( DDT *ddt, int ( *func )() );
int       driver$ini_ddt_ctrlinit( DDT *ddt, int ( *func )() );
int       driver$ini_ddt_diagbf( DDT *ddt, unsigned short value
);
int       driver$ini_ddt_erlgbf( DDT *ddt, unsigned short value
);
int       driver$ini_ddt_kp_reg_mask( DDT *ddt, unsigned long
value );
int       driver$ini_ddt_kp_stack_size( DDT *ddt, unsigned long
value );
int       driver$ini_ddt_kp_startio( DDT *ddt, void ( *func )()
);
int       driver$ini_ddt_mntv_for( DDT *ddt, int ( *func )() );
int       driver$ini_ddt_mntver( DDT *ddt, void ( *func )() );
int       driver$ini_ddt_regdmp( DDT *ddt, void ( *func )() );
int       driver$ini_ddt_start( DDT *ddt, void  ( *func )() );
int       driver$ini_ddt_unitinit( DDT *ddt, int ( *func )() );
```

The following function signals that initialization of the DDT is complete.

```
int       driver$ini_ddt_end( DDT *ddt );
```

#### 4.4.2.3 DDT Macro Calls

The following macros invoke the corresponding function, check the status returned and exit to the driver loader if the status is not a success code.

```
 ini_ddt_altstart( ddt, func )
ini_ddt_aux_routine( ddt, func )
ini_ddt_aux_storage( ddt, addr )
ini_ddt_cancel( ddt, func )
ini_ddt_cancel_selective( ddt, func )
ini_ddt_channel_assign( ddt, func )
ini_ddt_cloneducb( ddt, func )
ini_ddt_ctrlinit( ddt, func )
ini_ddt_diagbf( ddt,  value )
ini_ddt_erlgbf( ddt,  value )
ini_ddt_kp_reg_mask( ddt, value )
ini_ddt_kp_stack_size( ddt, value )
ini_ddt_kp_startio( ddt, func )
ini_ddt_mntv_for( ddt, func )
ini_ddt_mntver( ddt, func )
ini_ddt_regdmp( ddt, func )
ini_ddt_start( ddt, func )
ini_ddt_unitinit( ddt, func )
ini_ddt_end( ddt )
```

### 4.4.3 Function Decision Table

There are two fields in the FDT: a quadword bit mask of functions that are to be processed as buffered I/O by the driver and an array of 64 pointers which is indexed by function code to locate the FDT action routine for the function. The buffered I/O mask is initialized to zero, meaning that no function is treated as buffered by the driver. The pointer array is initialized to EXE$ILLIOFUNC which means that no function is considered valid.

#### 4.4.3.1 FDT Functions

The driver$ini_fdt_act function initializes the action routine and buffered function mask fields in the FDT. The driver$ini_fdt_end function signals that initialization of the FDT is complete. The bufflag parameter has the value BUFFERED if the function is buffered, NOT_BUFFERED or DIRECT otherwise.

```
int       driver$ini_fdt_act( FDT *fdt, unsigned long iofunc,
int ( *action )(),
           unsigned long bufflag );
int       driver$ini_fdt_end( FDT *fdt );
```

#### 4.4.3.2 FDT Macros

The following macros invoke the corresponding function, check the status returned and exit to the driver loader if the status is not a success code.

```
ini_fdt_act( fdt, func, action, bufflag )
ini_fdt_end( fdt )
```

### 4.4.4 Device Database Initialization/Reinitialization

The initialization and reinitialization function addresses are stored in DPT$PS_INIT_PD and DPT$PS_REINIT_PD respectively. The function calls are:

```
func( crb,ddb,idb,orb,ucb );

with the following parameters:

        crb             Channel Request Block address
        ddb             Device Data Block address
        idb             Interrupt Data Block address
        orb             Owner Rights Block address
        ucb             Unit Control Block address
```

#### 4.4.4.1 DPT_STORE_ISR

The dpt_store_isr and dpt_store_isr_vec macros are used to store the procedure descriptor and entry point addresses of an interrupt service routine in a VEC entry in a given Channel Request Block The dpt_store _isr macro fills in the first or only VEC entry in a CRB. The dpt_store_isr_vec macro allows the index of the VEC entry to be supplied.

```
The formats of the macros are:
        dpt_store_isr( crb, isr);

or
        dpt_store_isr_vec( crb, vecno, isr);


with the parameters:

        crb             Channel Request Block address
        vecno           Index (0, 1, 2...) of VEC entry to be
filled in
        isr             Interrupt service routine address
```

# 5 Writing FDT Routines

A driver performs device-specific I/O function preprocessing to validate arguments specified in the original call to the $QIO system service, to complete certain types of function processing such as set mode and sense mode operations, and to prepare to service functions involving a device transaction. Driver I/O function preprocessing on OpenVMS AXP systems often requires the cooperative efforts of upper-level FDT action routines, FDT support routines, and FDT completion routines.

An **upper-level FDT action routine** is a routine listed in a driver's function decision table (FDT) as a result of the driver's invocation of the FDT_ACT macro (see Chapter 4 for more information). FDT dispatching code in the $QIO system service calls an upper-level FDT action routine, passing to it the addresses of the I/O request packet (IRP), process control block (PCB), unit control block (UCB), and channel control block (CCB). An upper-level FDT action routine must return SS$_FDT_COMPL status to the $QIO system service.

The $QIO system service uses the FDT to determine which upper-level FDT action routine to call to initiate driver preprocessing of a specific I/O request. Often a driver can use one of the system-provided upper-level FDT routines, as described in Section 5.2.1. This practice encourages the use of well debugged routines and minimizes driver size. However, if the I/O function requires preprocessing that is unique to the device the driver controls, the driver includes an upper-level FDT routine that services the function in a device-dependent manner.

An upper-level FDT action routine sometimes calls an intermediate FDT routine, known as an **FDT support routine**. An FDT support routine performs some discrete action on behalf of an upper-level action routine, such as determining whether a user buffer is accessible, locking a user buffer in memory, and reformatting data into buffers in the system address space. Often, an FDT support routine calls an FDT completion routine.

There is no uniform interface for calling FDT support routines. These routines are listed and described in the *OpenVMS AXP Device Support: Reference*. The $QIO system service never calls an FDT support routine directly to process a given I/O function.

To conclude the preprocessing of an I/O function, a driver FDT routine (either the upper-level FDT action routine or an FDT support routine) calls a system-provided **FDT completion routine**. An FDT completion routine places the status return to the $QIO system service in the FDT context (FDT_CONTEXT) structure and returns SS$_FDT_COMPL status to its caller. Eventually, the driver's upper-level FDT routine exits FDT processing by returning control to the $QIO system service.

Note that FDT support routines and FDT completion routines return status to their callers. Each FDT routine that participates in the processing of an I/O function should examine the status value returned to it by any routine it calls and should reflect this status to the routine that called it.

## 5.1 Context of Driver FDT Processing

The $QIO system service executes in the context of the process that issues the I/O request, but in kernel mode and at IPL$_ASTDEL. Process context allows the $QIO system service and driver FDT routines to access process address space. Because the $QIO system service expects FDT routines to preserve this context, an FDT routine observes the following conventions:

- An FDT routine must not call system services or OpenVMS RMS routines.
- It must not lower IPL below IPL$_ASTDEL. If an FDT routine raises IPL, it must obtain any appropriate spinlock, and it must lower IPL to IPL$_ASTDEL before exiting, releasing any acquired spin lock.
- It should not access device registers because the device might be active.
- It should exercise caution when modifying the UCB. Routines usually access the UCB while holding the associated fork lock at driver fork IPL to synchronize modifications, and FDT routines do not execute with such synchronization. Drivers containing FDT routines that access device registers or carelessly modify the UCB risk unpredictable operation or a system failure.

## 5.2 Upper-Level FDT Action Routines

An OpenVMS AXP device driver provides a single upper-level FDT routine for each I/O function code it processes. The $QIO system service uses the low-order six bits of the I/O function code as an index into the FDT action routine vector. As described in Chapter 4, any vector slots corresponding to a driver-supported function contain the procedure value of either a system or driver-provided upper-level FDT action routine. Those which correspond to unsupported functions contain the procedure value of the system upper-level FDT action routine EXE$ILLIOFUNC.

The $QIO system service transfers control to an upper-level FDT action routine using the following interface:

```
status = driver_FDT_routine(irp,pcb,ucb,ccb)
```

The parameters include the addresses of:

- the I/O request packet (IRP) for the current I/O request
- the process control block (PCB) of the current process
- the unit control block (UCB) of the device assigned to the process-I/O channel specified as an argument to the $QIO request
- the channel control block (CCB) that describes the process-I/O channel

An upper-level FDT action routine must return SS$_FDT_COMPL status to its caller, the FDT dispatching code in the $QIO system service.

An OpenVMS AXP driver obtains the contents of the function-dependent arguments from IRP$L_QIO_P*n*, where *n* is a parameter number from 1 through 6.

Before exiting, the upper-level FDT action routine takes steps to complete FDT processing. Typically, these steps include:

- Calling an FDT completion routine, which takes steps to complete the processing of an I/O request or to deliver the I/O request to the driver. An FDT completion routine typically provides the final $QIO completion status in the FDT_CONTEXT structure and returns SS$_FDT_COMPL warning status to its caller. SS$_FDT_COMPL status is a warning that FDT processing has been completed and that the IRP is no longer accessible to FDT processing. (For instance, the IRP may have been deallocated or queued to the driver's start-I/O routine, which accesses the IRP at fork IPL.)
- Returning SS$_FDT_COMPL status to its caller, FDT dispatching code in the $QIO system service.

Section 5.2.2 describes the FDT completion routines provided by OpenVMS.

If the preprocessing of a given I/O function requires the execution of multiple upper-level FDT action routines, an OpenVMS AXP driver should provide a *composite* FDT function which sequentially calls each of the required FDT routines as long as the returned status is successful.

### 5.2.1 System-Provided Upper-Level FDT Routines

The system-provided upper-level FDT routines perform I/O request validation that is common to many devices. Whenever possible, drivers should take advantage of these routines. All of the system FDT routines listed in Table 5–1 transfer control to EXE_STD$QIODRVPKT, EXE_STD$FINISHIO, or EXE_STD$ABORTIO to complete the I/O request. These FDT completion routines, as described in Section 5.2.2, place final $QIO completion status in the FDT_CONTEXT structure, and return SS$_FDT_COMPL status to the upper-level FDT action routine. All upper-level FDT action routines return to the FDT dispatching code in the $QIO system service.

For additional information about system-provided FDT routines, see the specific routine descriptions in the *OpenVMS AXP Device Support: Reference*.

**Table 5–1 System-Provided Upper-Level FDT Action Routines**

| FDT Routine | Function | Completion Routine Used |
|---|---|---|
| ACP_STD$ACCESS | Accesses and creates ACP function processing | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| ACP_STD$ACCESSNET | Connects to network function processing | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| ACP_STD$DEACCESS | Deaccesses ACP function processing | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| ACP_STD$MODIFY | Deletes and modifies ACP function processing | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |

(continued on next page)

**Table 5–1 (Cont.) System-Provided Upper-Level FDT Action Routines**

| FDT Routine | Function | Completion Routine Used |
|---|---|---|
| ACP_STD$MOUNT | Initiates ACP mount function processing | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| ACP_STD$READBLK | Processes a read block ACP function | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| ACP_STD$WRITEBLK | Processes a write block ACP function | Calls EXE_STD$ABORTIO, EXE_STD$QIODRVPKT, or EXE_STD$FINISHIO |
| EXE$ILLIOFUNC | Processes I/O functions not supported by the driver | Calls EXE_STD$ABORTIO |
| EXE_STD$LCLDSKVALID | Processes an IO$_PACKACK, IO$_AVAILABLE, or IO$_UNLOAD function on a local disk | EXE_STD$FINISHIO or EXE_STD$QIODRVPKT |
| EXE_STD$MODIFY | Processes a logical-read/write or physical-read/write function for a read and write direct I/O operation to a user-specified buffer | Calls EXE_STD$ABORTIO if an error occurs (for instance, if the user I/O buffers cannot be accessed or cannot be locked in memory); otherwise, calls EXE_STD$QIODRVPKT |
| EXE_STD$ONEPARM | Processes a nontransfer I/O function code that has one parameter associated with it | Calls EXE_STD$QIODRVPKT |
| EXE_STD$READ | Processes a logical-read or physical-read function for a direct I/O operation | Calls EXE_STD$ABORTIO if an error occurs (for instance, if the user I/O buffers cannot be accessed or locked in memory); otherwise, calls EXE_STD$QIODRVPKT |
| EXE_STD$SENSEMODE | Processes the sense-device-mode and sense-device-characteristics functions by reading fields of the UCB | Calls EXE_STD$FINISHIO |
| EXE_STD$SETCHAR[1] | Processes the set-device-mode and set-device-characteristics functions | Calls EXE_STD$FINISHIO |
| EXE_STD$SETMODE[1] | Processes the set-device-mode and set-device-characteristics functions by creating a driver fork process | Calls EXE_STD$ABORTIO if an error occurs; otherwise, calls EXE_STD$QIODRVPKT |
| EXE_STD$WRITE | Processes a logical-write or physical-write function for a direct I/O operation | Calls EXE_STD$ABORTIO if an error occurs (for instance, if the user I/O buffers cannot be accessed or locked in memory); otherwise, calls EXE_STD$QIODRVPKT |
| EXE_STD$ZEROPARM | Processes a nontransfer I/O function code that has no associated parameters | Calls EXE_STD$QIODRVPKT |

[1] If setting device characteristics requires no device activity or requires no synchronization with fork processing, the driver's FDT entry can specify EXE_STD$SETCHAR; otherwise, it must specify EXE_STD$SETMODE.

Driver FDT processing selects an I/O completion path based on the following factors:

- Whether it needs to call another FDT routine to perform additional function-specific processing.

- Whether an error is found in the I/O request.
- Whether the operation is complete.
- Whether the I/O operation requires and is ready for device activity.

Any specific I/O function can be processed by only one upper-level FDT action routine. Although an upper-level routine can call any number of subsequent routines, it must eventually complete I/O processing by returning the SS$_FDT_COMPL status (and final $QIO completion status in the FDT_CONTEXT structure) to its caller, FDT dispatching code in the $QIO system service.

The system-provided upper-level FDT routines, as discussed in Table 5–1, all call an FDT completion routine that queues an IRP, completes an I/O request, or aborts an I/O request. These FDT completion routines insert the final $QIO system service status in the FDT_CONTEXT structure and return SS$_FDT_COMPL warning status to the upper-level FDT action routine. The upper-level FDT action routine returns these status values to its caller, FDT dispatching code in the $QIO system service.

### 5.2.2 FDT Exit Paths

An upper-level FDT action routine completes I/O function invoking one of the completion macros listed in Table 5–2.

**Table 5–2 FDT Completion Macros and Associated Routines**

| Macro | Operation |
|---|---|
| CALL_ABORTIO | Calls EXE_STD$ABORTIO to abort an I/O request.<br>An FDT routine that discovers a device-independent error should always use this method of exiting. Inability to gain access to a data buffer or an error in the specification of the I/O request are examples of device-independent errors. |
| CALL_ALTQUEPKT | Calls EXE_STD$ALTQUEPKT to call an alternate start-I/O routine in the driver (specified in the driver dispatch table at offset DDT$PS_ALTSTART_2) that synchronizes requests for activity on a device unit and initiates the processing of I/O requests.<br>The FDT routine uses this exit method when it has successfully completed all driver preprocessing and the request requires device activity. However, in contrast to EXE_STD$QIODRVPKT, EXE_STD$ALTQUEPKT bypasses the device unit's pending-I/O queue and the device busy flag; thus, the driver is activated regardless of whether the device unit is busy. A driver that can handle two or more I/O requests simultaneously uses this exit method. |

(continued on next page)

**Table 5–2 (Cont.) FDT Completion Macros and Associated Routines**

| Macro | Operation |
|---|---|
| | Be aware that programming a device driver to process simultaneous I/O requests requires detailed knowledge of the internal design of the operating system. A driver that uses the CALL_ALTQUEPKT macro must not only maintain its internal queues but must also synchronize those queues with the unit's pending-I/O queue, which the operating system maintains. In addition, if a driver processes more than one IRP at the same time, it must use separate fork blocks. Such a driver completes the processing of I/O requests by using the CALL_POST macro calling COM_STD$POST. This routine places each IRP in the systemwide I/O postprocessing queue and returns control to the driver. The driver can then fetch another IRP from an internal queue. For more information about COM_STD$POST, see *OpenVMS AXP Device Support: Reference*. |
| | When the alternate start-I/O routine finishes, it returns control to EXE_STD$ALTQUEPKT. EXE_STD$ALTQUEPKT then returns to the FDT routine that called it. The FDT routine performs any necessary postprocessing, returning the SS$_FDT_COMPL status to FDT dispatching code in the $QIO system service |
| CALL_FINISHIO | Moves the contents of R0 and R1 to IRP$L_IOST1 and IRP$L_IOST2, respectively and calls EXE_STD$FINISHIO to insert the IRP in the I/O postprocessing queue. EXE_STD$FINISHIO returns SS$_FDT_COMPL status to the $QIO system service and SS$_NORMAL status (in the FDT_CONTEXT structure) to the caller of $QIO. |
| | An FDT routine that discovers a device-dependent error should always return status using CALL_FINISHIO or CALL_FINISHIOC. |
| CALL_FINISHIOC | Calls EXE_STD$FINISHIO to perform the same operations as CALL_FINISHIO except CALL_FINISHIOC clears the second longword of the final I/O status. |
| CALL_FINISHIO_NOIOST | Calls EXE_STD$FINISHIO to perform the same operations as CALL_FINISHIO except CALL_FINISHIO_NOIOST does not fill in the I/O status fields of the IRP. |
| CALL_IORSNWAIT | Calls EXE_STD$IORSNWAIT. Reserved to Digital. |
| CALL_QIOACPPKT | Calls EXE_STD$QIOACPPKT. Reserved to Digital. |

(continued on next page)

**Table 5–2 (Cont.) FDT Completion Macros and Associated Routines**

| Macro | Operation |
|---|---|
| CALL_ QIODRVPKT | Calls EXE_STD$QIODRVPKT to transfer control to a system routine (EXE_STD$INSIOQ) that either delivers an IRP immediately to a driver's start-I/O routine or places the IRP in a pending-I/O queue waiting for driver servicing. The FDT routine uses this FDT completion routine if all preprocessing is complete, if no errors are found in the specification of an I/O request, and if device activity, synchronized access to the device's UCB, or synchronized access to device registers is required to complete the I/O request. Common examples of such a request are read and write functions.<br><br>EXE_STD$INSIOQ transfers control to the device driver's start-I/O routine only if the device unit is currently idle. If the device unit is busy, EXE_STD$INSIOQ inserts the IRP in a priority-ordered queue of IRPs waiting for the unit.<br><br>Once an FDT routine transfers control to EXE_STD$QIODRVPKT, no driver code that further processes the I/O request can refer to process virtual address space. When a device driver's start-I/O routine gains control, the process that queued the I/O request might no longer be the mapped process. Therefore, the driver must assume that all information regarding the I/O request is in the UCB or the IRP and that all buffer addresses in the UCB are either system addresses or page-frame numbers that can be interpreted in any process context.<br><br>For direct I/O operations, FDT routines also must have locked all user buffer pages in physical memory because paging cannot occur at driver fork level or higher interrupt priority levels. The process virtual address space is not guaranteed to be mapped again until the operating system delivers a special kernel-mode asynchronous system trap (AST) to the requesting process as part of I/O postprocessing. |

## 5.3 FDT Routines for System Direct I/O

The operating system provides two standard FDT routines that are applicable for direct I/O operations: EXE_STD$READ and EXE_STD$WRITE. When called by the driver, these routines completely prepare a direct I/O read or write request. Thus, a driver that uses these routines eliminates the need for its own device-specific FDT routines.

EXE_STD$READ and EXE_STD$WRITE are described in *OpenVMS AXP Device Support: Reference*.

## 5.4 FDT Routines for System Buffered I/O

Device drivers for buffered I/O operations generally contain their own device-specific FDT routines.

An FDT routine for a buffered I/O data transfer operation should confirm either read or write access to the user's buffer and allocate a buffer in system space. Sections 5.4.1 and 5.4.2 describe these tasks.

An FDT routine for a buffered I/O operation that does not involve data transfer accesses the function-dependent parameters of the $QIO request (**p1** to **p6**) from IRP$L_QIO_P*n*, where *n* is a parameter number from one to six. It performs any necessary preprocessing and uses one of the exit methods listed in Section 5.2.2.

### 5.4.1 Checking Accessibility of the User's Buffer

First the FDT routine invokes the CALL_READCHK or CALL_WRITECHK macros (which call EXE_STD$READCHK or EXE_STD$WRITECHK, respectively) to confirm write or read access to the user's buffer. Both of these routines write the transfer byte count into IRP$L_BCNT. EXE_STD$READCHK also sets IRP$V_FUNC in IRP$L_STS to indicate that it is a read function.

### 5.4.2 Allocating the System Buffer

Next, the FDT routine allocates a system buffer in the following manner:

1. It adds 12 bytes to the byte count passed in the **p2** argument of the user's I/O request (obtained from IRP$L_QIO_P2), thus accommodating the standard size of a system buffer header. This is the total system buffer size.
2. It issues a JSB to EXE$DEBIT_BYTCNT_ALO to ensure that the job has sufficient remaining byte count quota to allow its use of the requested buffer. If the job has sufficient quota, EXE$DEBIT_BYTCNT_ALO allocates the requested buffer from nonpaged pool, writes the buffer's size and type into its third longword, and subtracts the system buffer size from JIB$L_BYTCNT.

The operating system also supplies the routines EXE$DEBIT_BYTCNT_BYTLM_ALO, EXE$DEBIT_BYTCNT(_NW), EXE$DEBIT_BYTCNT_BYTLM(_NW), and EXE_STD$ALLOCBUF, which perform the same type of work as EXE$DEBIT_BYTCNT_ALO. These routines are fully described in the *OpenVMS VAX Device Support Reference Manual*.

Once the buffer is allocated, the FDT routine takes the following steps:

1. Loads the address of the system buffer into IRP$L_SVAPTE.
2. Loads the total size of the system buffer into IRP$L_BOFF.
3. Stores the starting address of the system buffer data area in the first longword of the buffer header.
4. Stores the user's buffer address in the second longword of the header.
5. Copies data from the user buffer to the system buffer if the I/O request is a write operation.

At this point, the buffers are ready for the transfer. Figure 5–1 illustrates the format of the system buffer.

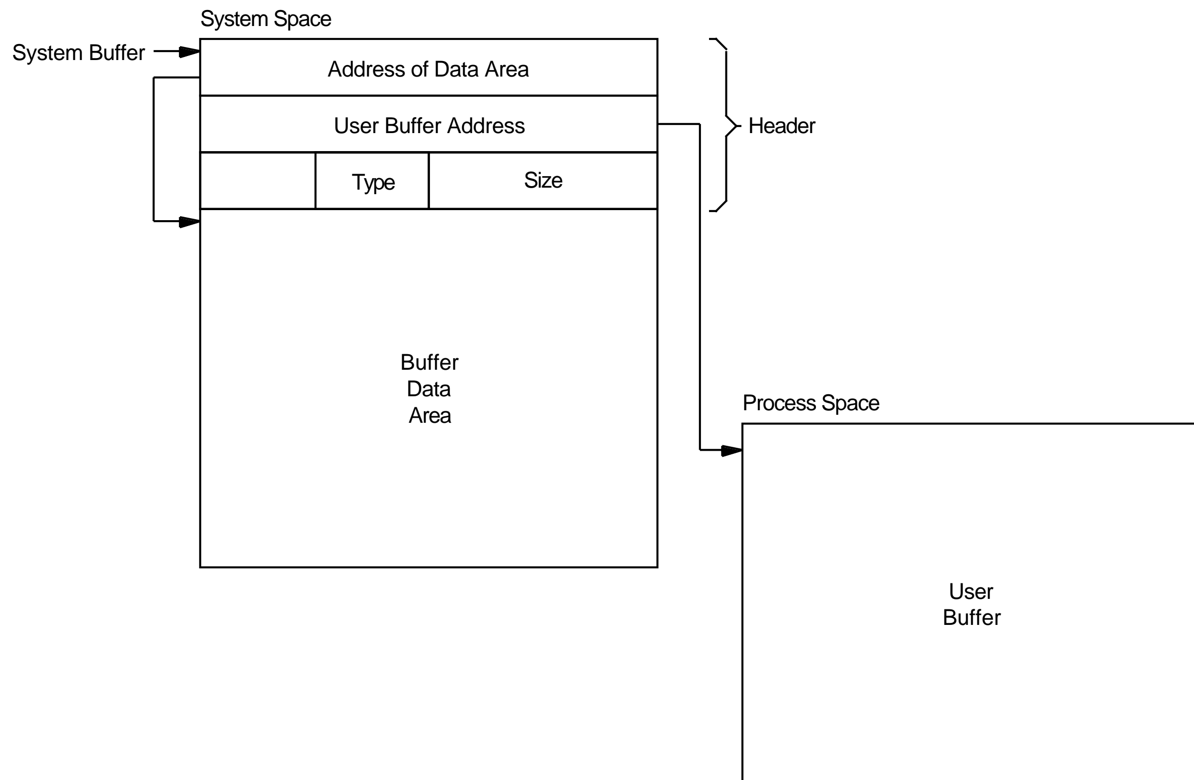
### 5.4.3 Buffered-I/O Postprocessing

When the transfer finishes, the driver returns control to the operating system for completion of the I/O request. The driver writes the final request status in the low-order word of R0. Use of the high-order word of R0 and the longword of R1 is driver specific. Certain drivers use these fields to report a transfer byte count, for example.

The driver must leave the buffer header intact; I/O postprocessing relies on the header's accuracy. When system I/O postprocessing gains control, it performs three steps:

1. Issues a JSB instruction to EXE$CREDIT_BYTCNT to add the value in IRP$L_BOFF to JIB$L_BYTCNT, thus updating the user's byte count quota.

**Figure 5–1 Format of System Buffer for a Buffered-I/O Read Function**




2. If IRP$L_SVAPTE is nonzero, assumes a system buffer was allocated and checks to see whether IRP$V_FUNC is set in IRP$L_STS.
3. If IRP$V_FUNC is clear, deallocates the system buffer used for the write operation; if IRP$V_FUNC is set, the special kernel-mode AST copies the data to the user's buffer and then deallocates the buffer in addition to performing other kernel-mode AST functions.

The special kernel-mode AST performs the following steps to complete a buffered read operation:

1. Obtains the address of the system buffer from IRP$L_SVAPTE.
2. Obtains the number of bytes to write to the user's buffer from IRP$L_BCNT.
3. Obtains the address of the user's buffer from the second longword of the system buffer header.
4. Checks for write accessibility on all pages of the user's buffer.
5. Copies the data from the system buffer to the process buffer.
6. Deallocates the system buffer. Note that the system uses the size listed in the buffer's header to deallocate the buffer.

# 6
# Writing a Start-I/O Routine

A driver start-I/O routine activates a device and then waits for a device interrupt or timeout. This chapter describes the start-I/O routine. Chapter 8 describes the reactivation of the driver routine that performs device-dependent I/O postprocessing. With a few exceptions, the start-I/O routine discussed in the following sections describes a direct-memory-access (DMA) transfer using a single-unit controller.

## 6.1 Transferring Control to the Start-I/O Routine

The start-I/O routine of a device driver gains control from either of two system routines: EXE_STD$QIODRVPKT or IOC_STD$REQCOM.

When FDT processing is complete for an I/O request, the FDT routine transfers control to EXE_STD$QIODRVPKT, which, in turn, calls EXE_STD$INSIOQ. If the designated device is idle, EXE_STD$INSIOQ calls IOC_STD$INITIATE to create a driver fork process. The driver fork process then gains control in the start-I/O routine of the appropriate driver. If the device is busy, EXE_STD$INSIOQ queues the packet to the device unit's pending-I/O queue.

After a device completes an I/O operation, the driver fork process exits by transferring control to IOC_STD$REQCOM. IOC_STD$REQCOM inserts the I/O request packet (IRP) for the finished transfer into the postprocessing queue. It then dequeues the next IRP from the device unit's pending-I/O queue and calls IOC_STD$INITIATE to initiate the processing of this I/O request in the driver's fork process at the entry point of the driver's start-I/O routine.

## 6.2 Context of a Driver Fork Process

A start-I/O routine does not run in the context of a user process. Rather, it has the following context:

| | |
|---|---|
| System context | Driver code can only refer to system virtual addresses. |
| Kernel mode | Execution occurs in the most privileged access mode and can, therefore, change IPL and obtain spinlocks. |
| High IPL | The system routine that creates a driver fork process obtains the driver's fork lock, raising IPL to driver fork level before activating the driver. |
| Kernel stack | Execution occurs on the kernel stack. The driver must not alter the state of the stack without restoring the stack to its previous state before relinquishing control. |

In addition to the context described, the system packet-queuing routines set up R3 and R5 for a driver start-I/O routine, as follows:

- R3 contains the address of the IRP.
- R5 contains the address of the unit control block (UCB) for the device.

The start-I/O routine must preserve all general registers except R0, R1, R2, and R4.

Before the packet-queuing routines call the start-I/O routine, they copy the following IRP fields into their corresponding slots in the device's UCB:

- IRP$L_BCNT → UCB$_BCNT
- IRP$_BOFF → UCB$_BOFF
- IRP$L_SVAPTE → UCB$L_SVAPTE

## 6.3 Functions of a Start-I/O Routine

The processing performed by a start-I/O routine is device specific. A start-I/O routine normally contains elements that perform the following functions to activate:

- Analyzing the I/O function
- Transferring the details of a request from the IRP into the UCB
- Obtaining and initializing the controller
- Modifying device registers to activate the device

A start-I/O routine of a DMA device driver performs additional tasks to prepare the device for a DMA transfer prior to activating the device. These tasks include the following:

- Obtaining I/O adapter resources such as map registers
- Computing the starting address of a data transfer

The following sections describe the general activities of a start-I/O routine for a typical device. The details of DMA processing are specific to the particular device. For more information, see the appropriate bus support chapter in this manual.

### 6.3.1 Obtaining Controller Access

If the device is one of several attached to a controller, the start-I/O routine invokes the system macro REQCHAN to assign the controller's data channel to the device unit. Controllers that control only one device do not require arbitration for the controller's data channel. REQCHAN calls the system routine IOC_STD$PRIMITIVE_REQCHANL that acquires ownership of the controller data channel.

The transfer being controlled by the start-I/O routine discussed here requires no seek preceding the transfer. Disk I/O is an example of a transfer that requires a seek first. To permit seeks to be overlapped with transfers, invoke REQPCHAN with the argument **pri**=HIGH. Specifying **pri**=HIGH inserts a request for a channel at the head of the channel wait queue.

If the channel is not available, IOC_STD$PRIMITIVE_REQCHANL suspends driver processing by saving the driver's context in the UCB fork block and inserting the fork block in the channel wait queue. IOC_STD$PRIMITIVE_REQCHANL then returns control to the caller of the driver, that is, to EXE_STD$INSIOQ.

Note that, because IOC_STD$RELCHAN moves the address of the IDB into R4 before resuming a suspended driver, IOC_STD$PRIMITIVE_REQCHANL does not save R4 in the UCB fork block.

If the channel is available, IOC_STD$PRIMITIVE_REQCHANL locates the interrupt dispatch block (IDB) for the channel with a pointer in the UCB:

UCB → CRB → IDB

The driver for a unit attached to a dedicated controller must contain the code needed to load the IDB address into R4.

IOC_STD$PRIMITIVE_REQCHANL also writes the address of the new channel-owner's UCB in the owner field of the IDB (IDB$L_OWNER). The driver's interrupt service routine later reads this IDB field to determine which device unit owns the controller's data channel. A driver for a single-unit controller must fill the IDB$L_OWNER field in its controller or unit initialization routines.

### 6.3.2 Obtaining and Converting the I/O Function Code and Its Modifiers

The start-I/O routine extracts the I/O function code and function modifiers from the field IRP$_FUNC and translates them into device-specific function codes, which it loads into the device's CSR or other control registers. The start-I/O routine creates and modifies a bit mask that is to be loaded into the CSR when the driver starts the device. To accomplish this, the start-I/O routine converts the function modifiers contained in IRP$_FUNC into device-specific bit settings in the general register.

### 6.3.3 Preparing the Device Activation Bit Mask

For a typical device, the start-I/O routine prepares the device-activation bit mask by setting the interrupt-enable bit and the go bit in the general purpose register that also contains the high-order bits of the bus address and the device-function bits. At this point, the general register contains a complete command for starting the transfer, also known as the **control mask**.

When the start-I/O routine copies the contents of the register into the device's CSR, the device starts the transfer. Before activating the device, however, the start-I/O routine should perform the steps described in Sections 6.3.4 and 6.3.5.

### 6.3.4 Synchronizing Access to the Device Database

The start-I/O routine invokes the system macro DEVICELOCK to synchronize its access to device registers with the interrupt service routine. This macro invocation is doubly important, for it establishes the context wherein the driver can later issue the wait-for-interrupt macro (WFIKPCH or WFIRLCH). The wait-for-interrupt macros expect the driver's fork IPL to be on the stack, as placed there by the DEVICELOCK macro. In addition, the wait-for-interrupt macros issue the DEVICEUNLOCK macro to release ownership of the device lock and restore the previous IPL.

### 6.3.5 Checking for a Local Processor Power Failure

After synchronizing access to device registers, the start-I/O routine invokes the system macro SETIPL to raise IPL to IPL$_POWER to block all interrupts on the local processor.

The start-I/O routine then examines the power failure bit in the UCB's status longword (UCB$V_POWER in UCB$L_STS) to determine whether a local power failure has occurred since the start-I/O routine gained control. If the bit is not set, the transfer can proceed.

If the bit is set, a power failure might have occurred between the time that the start-I/O routine wrote the first device register and the time that the start-I/O routine is ready to activate the device. Such a power failure could modify the already-written device registers and cause unpredictable device behavior if the device were to be started.

If the bit UCB$V_POWER is set, the start-I/O routine branches to an error handler in the driver. The driver error handler must perform the following actions:

- Clear UCB$V_POWER
- Issue the DEVICEUNLOCK macro to release the device lock and restore IPL to fork IPL

After performing these tasks, many drivers transfer control to the beginning of the start-I/O routine, which restarts the processing of the I/O request.

### 6.3.6 Activating the Device

If no power failure has occurred, the start-I/O routine copies the contents of the control mask into the device's CSR. When the device notices the new contents of the device register, it begins to transfer the requested data.

## 6.4 Waiting for an Interrupt or Timeout

Once the start-I/O routine activates the device, the driver fork process cannot proceed until one of these events occurs:

- The device generates a hardware interrupt.
- The device does not generate a hardware interrupt within an expected time limit, which is to say that a device timeout occurs.

Still executing at IPL$_POWER, the driver's start-I/O routine asks the operating system to suspend the driver fork process by invoking one of the following macros:

| | |
|---|---|
| WFIKPCH | Wait for an interrupt or timeout and keep the controller data channel |
| WFIRLCH | Wait for an interrupt or timeout and release the controller data channel |

The WFIKPCH and WFIRLCH macros require the address of a timeout handling routine in the **excpt** argument. Optionally, but almost always, the driver can also indicate the number of seconds the system must wait before signaling a timeout in the **time** argument. For more information, see *OpenVMS AXP Device Support: Reference*.

Both macros invoke routines that release ownership of the device lock, relinquish synchronization, and return IPL to the previous level when exiting. These routines expect to find the return IPL on the stack. This IPL is saved on the stack by the DEVICELOCK macro as described in Section 6.3.4.

Drivers generally keep the controller data channel while waiting for the interrupt or timeout. Drivers of devices with dedicated controllers always keep the channel because only one unit ever needs it. For devices that share a controller, some operations, such as disk seeks, do not require the controller once the operation has begun. In such cases, the driver can release the controller's data channel while waiting for an interrupt or timeout so that other units on the controller can start their operations.

# 7
# Writing an Interrupt Service Routine

When a device generates a hardware interrupt, it requests an interrupt at the appropriate device interrupt priority level (IPL). Either the device or its adapter requests a processor interrupt at that IPL. When the processor executes at an IPL below that device IPL, interrupt dispatching begins.

The mechanism of interrupt dispatching has no direct bearing on the contents of a driver's interrupt service routine. Its implementation varies according to the AXP system and I/O subsystem in use.

For most device drivers, the driver prologue table (DPT) contains, in the reinitialization section established by the DPT_STORE_ISR macro, the address of one or more interrupt service routines. Each interrupt service routine corresponds to an interrupt vector on the I/O bus. You specify the interrupt vector using the SYSMAN command IO_CONNECT.

Most device interrupt service routines perform the following functions:

- Locate the device's unit control block (UCB)
- Determine whether the interrupt was solicited
- Reject or process unsolicited interrupts
- Activate the suspended driver to process solicited interrupts

The remaining sections of this chapter describe the handling of solicited and unsolicited interrupts in further detail.

## 7.1 Servicing a Solicited Interrupt

When a driver's fork process activates a device and expects to service a device interrupt as a result, the fork process suspends its execution and waits for an interrupt to occur. The suspended driver is represented only by the contents of the fork block in the device's UCB and the stack, which contain the following information:

- A description of the I/O request and the state of the device
- The contents of R3 and R4
- The implicit contents of R5 (the address of the UCB fork block)
- The address at which to return control to the driver
- The implicit address of a timeout handling routine

When the interrupt service routine returns control to the main line of driver processing, it has only restored the contents of R3, R4, R5, and the PC.

A driver's interrupt service routine performs the following tasks to process the interrupt and transfer control to the waiting driver:

1. Obtains the address of the device's UCB from the IDB, as follows:

   4(AP) → CRB → IDB → IDB$L_OWNER → UCB

   The interrupt service routine restores the UCB address to R5.

2. Issues the DEVICELOCK macro to obtain synchronized access to device registers.

3. Tests the interrupt-expected bit in the UCB status longword (UCB$V_INT in UCB$L_STS). If the bit is set, the driver is waiting for an interrupt from this device. After performing this test, the interrupt service routine *must* clear UCB$V_INT to indicate that it has received the expected interrupt.

   **Note**

   Because device timeout processing mostly occurs at fork IPL (see Section 8.2), a driver's interrupt service routine, executing at device IPL, could interrupt the processing of a timeout on the same device unit. For this reason, the driver's interrupt service routine should check the interrupt-expected bit (UCB$V_INT) before handling the interrupt. The operating system clears this bit before it calls the driver's timeout handler.

4. Obtains device-status or controller-status information from the device registers, if necessary, and stores the status information in the UCB.

5. Places the contents of UCB$Q_FR3 and UCB$Q_FR4 in R3 and R4, respectively.

6. Issues a JSB instruction to the waiting driver's PC address, which is saved in the UCB fork block at UCB$L_FPC.

The restored driver should execute as briefly as possible in interrupt context. As soon as possible, the driver should invoke the IOFORK macro to request the creation of a fork process at the driver's fork IPL in order to complete the I/O operation. Forking lowers the IPL of driver execution below device IPL, allowing the processor to service additional device interrupts. IOFORK calls the routine EXESTD$PRIMITIVE_FORK. EXESTD$PRIMITIVE_FORK inserts into the appropriate fork queue the UCB fork block that describes the driver process. It then returns control to the driver's interrupt service routine. (See Section 8.1.1 for additional information on driver forking.)

The interrupt service routine then performs the following steps:

1. Removes the IDB pointer from the stack
2. Issues the DEVICEUNLOCK macro to release ownership of the device lock
3. Restores R0 through R5
4. Returns to the interrupt dispatcher via a RET instruction
5. The interrupt dispatcher dismisses the interrupt

## 7.2 Servicing an Unsolicited Interrupt

A device requests an interrupt to indicate to a driver that the device has changed status. If a driver's fork process starts an I/O operation on a device, the driver expects to receive an interrupt from the device when the I/O operation completes or an error occurs.

Other changes in the device's status occur when the device has not been activated by a device driver. The device reports such a change by requesting an unsolicited interrupt. For example, when a user types on a terminal, the terminal requests an interrupt that is handled by the terminal driver. If the terminal is not attached to a process, the terminal driver causes the login procedure to be invoked for the user at the terminal.

As another example, an unsolicited interrupt occurs whenever a disk drive goes off line, as could happen when an operator spins it down or pushes the offline button. The disk driver services the interrupt by altering volume and unit status bits in the disk device's UCB.

Devices request unsolicited interrupts because some external event has changed the status of the device. A device driver can handle these interrupts in two ways:

- Ignore the interrupt as spurious
- Examine the device registers and take action according to their indications of changed status, and then poll for any other changes in device status

As mentioned in Section 7.1, an interrupt service routine first obtains the address of the device's UCB from the IDB. It then issues the DEVICELOCK macro to obtain synchronized access to device registers.

The routine determines whether an interrupt is solicited or not by examining the interrupt-expected bit in the UCB status longword (UCB$V_INT in UCB$L_STS).

If the driver decides to handle the unsolicited interrupt, it must observe certain precautions. Certain methods of servicing unsolicited interrupts—for instance sending a message to the operator or the job controller's mailbox—must be accomplished at an IPL lower than device IPL. Although the interrupt service routine can legitimately fork to accommodate unsolicited interrupts, it should exercise extreme caution in doing so.

If UCB$V_BSY is set in UCB$L_STS, the UCB fork block is currently in use by the driver's start-I/O routine. An attempt by the interrupt service routine to concurrently use the fork block can destroy the fork context already stored in that UCB. Moreover, if UCB$V_BSY is not set, the interrupt service routine cannot safely assume that the fork block is not in use, for it may be currently employed to service a previous unsolicited interrupt.

To avoid confusion, code servicing an unsolicited interrupt must ensure that the fork block it requires is not being used. Perhaps the safest method to guarantee this is for the driver to define a separate fork block in a device-specific UCB extension. The driver should also define a semaphore bit to control access to this fork block and protect against multiple forking. Note that the driver should access the semaphore bit using interlocked instructions (for example, BBSSI or BBCCI).

If, upon servicing an unsolicited interrupt, the driver's interrupt service routine examines the semaphore and discovers that a fork is already in progress (that is, the bit is set), it should not attempt to fork.

The system routine that creates the fork process (once these conditions are satisfied) returns control to the interrupt service routine. The interrupt service routine then releases the device lock, restores the saved registers, and issues an REI instruction to dismiss the interrupt.

# 8

# Completing an I/O Request and Handling Timeouts

Once a driver has activated the device and invoked the wait-for-interrupt macro, the driver remains suspended until the device requests an interrupt or times out.

If the device requests an interrupt, the driver's interrupt service routine handles the interrupt and then reactivates the driver at the instruction following the wait-for-interrupt macro. The reactivated driver performs device-dependent I/O postprocessing.

If the device does not request an interrupt within the designated time interval, the system transfers control to the driver's timeout handling routine. The address of the timeout handling routine is specified as the **excpt** argument to the wait-for-interrupt macro.

## 8.1 I/O Postprocessing

Once the driver interrupt service routine has processed an interrupt, it transfers control to the driver by issuing a CALL instruction. At this point, the driver is executing in interrupt context. If the driver were to continue executing in interrupt context, it would lock out most other processing on the processor including the handling of hardware interrupts.

To restore the driver to the context of a driver fork process, the driver invokes the system macro IOFORK. Once the fork process has been created and dispatched for execution, it executes the driver code that completes the processing of the I/O request.

### 8.1.1 EXE_STD$PRIMITIVE_FORK

IOFORK generates a call to the routine EXE_STD$PRIMITIVE_FORK. EXE_STD$PRIMITIVE_FORK converts the driver context from that of an interrupt service routine to that of a fork process by performing the following steps:

1. It disables software timeouts by clearing the timeout enable bit in the UCB status longword (UCB$V_TIM in UCB$L_STS).
2. It saves R3 and R4 of the current driver context in the UCB fork block (UCB$L_FR3 and UCB$L_FR4).
3. It obtains the fork lock index of the driver from the UCB (UCB$B_FLCK) and uses it to determine in which fork queue it should place the fork block.
4. It inserts the address of the UCB fork block (R5) into the processor-specific fork queue corresponding to the driver's fork IPL.
5. Finally, if the fork block is the first entry in the fork queue, EXE_STD$PRIMITIVE_FORK requests a software interrupt from the local processor at the driver's fork IPL.

The steps listed previously move the fork process context into the UCB's fork block. They save R3 through R5 and the driver's PC address. The driver's fork process resumes processing when the system fork dispatcher dequeues the UCB fork block from the fork queue, and reactivates the driver at the driver's fork IPL.

## 8.1.2 Completing an I/O Request

When the operating system reactivates a driver's fork process by dequeuing the fork block, the driver resumes processing of the I/O operation holding the appropriate fork lock at fork IPL.

1. Releases map registers
2. Releases the controller (applies only to drivers of devices on multiunit controllers)
3. Checks device register images saved in the UCB to determine the status of the I/O operation
4. Saves in the I/O reuest packet (IRP) the status code, transfer count, and device-dependent status that is to be returned to the user process in an I/O status block (IOSB)
5. Returns control to the operating system

### 8.1.2.1 Releasing the Controller

To release the controller channel, the driver code invokes the system macro RELCHAN. RELCHAN calls the system routine IOC_STD$RELCHAN. If another driver is waiting for the controller channel, IOC_STD$RELCHAN grants that driver's fork process the channel, restores its context from the UCB fork block, and transfers control to the saved PC. When no more drivers are awaiting the channel, IOC_STD$RELCHAN returns control to the fork process that released the channel.

Drivers for devices with dedicated controllers need not release the controller's data channel. By means of code in the unit initialization routine, these drivers set up the device's UCB so that the device owns the controller permanently.

Drivers must be executing at driver's fork IPL when they invoke RELCHAN or call IOC_STD$RELCHAN.

### 8.1.2.2 Saving Status, Count, and Device-Dependent Status

To save the status code, transfer count, and device-dependent status, the driver performs the following steps:

1. Loads a success status code (SS$_NORMAL), or whatever is appropriate, into bits 0 through 15 of R0.
2. Loads the number of bytes transferred into the high-order 16 bits of R0 (bits 16 through 31), if the I/O operation performed by the device is a transfer function.
3. Loads device-dependent status information, if any, into R1.[1]

[1] R0 and R1 are the status values that the operating system returns to the user process in the I/O status block specified in the original $QIO system service.

#### 8.1.2.3 Returning Control to the Operating System

Finally, the driver fork process returns control to the system by invoking the REQCOM macro to complete the I/O request. REQCOM calls the system routine IOC_STD$REQCOM. IOC_STD$REQCOM locates the address of the I/O request packet (IRP) corresponding to the I/O operation in the device's UCB (UCB$L_IRP). It then writes the two longwords of completion status contained in R0 and R1 into the media field of the IRP$L_IOST1 and IRP$L_IOST2).

IOC_STD$REQCOM then inserts the IRP in the local processor's I/O-postprocessing queue and requests a software interrupt at IPL$_IOPOST from the current processor so the postprocessing begins when IPL drops below IPL$_IOPOST.

If the error-logging bit is set in the device's UCB (UCB$V_ERLOGIP in UCB$L_STS), IOC_STD$REQCOM obtains the address of the error message buffer from the UCB (UCB$L_EMB). It then writes the following information into the error buffer:

- Final device status (UCB_DEVSTS)
- Final error count (UCB$B_ERTCNT)
- Maximum error retry count for the driver
- Two longwords of completion status (R0 and R1)

To release the error message buffer, IOC_STD$REQCOM calls ERL$RELEASEMB.

If any IRPs are waiting for driver processing, IOC_STD$REQCOM dequeues an IRP from the head of the queue of packets waiting for the device unit (UCB$L_IOQFL), and transfers control to IOC_STD$INITIATE. IOC_STD$INITIATE initiates execution of this I/O request in the driver's fork process, by activating the driver's start-I/O routine.

Otherwise, IOC_STD$REQCOM clears the unit-busy bit in the device's UCB status longword (UCB$V_BSY in UCB$L_STS) and transfers control to IOC_STD$RELCHAN to release the controller channel in case the driver failed to do so. IOC_STD$RELCHAN, in turn, returns control to the caller of the driver fork process (if the fork process issued the REQCOM macro). This is generally the system fork dispatcher. The fork dispatcher releases the fork lock, restores saved registers, and dismisses the fork IPL software interrupt with an REI instruction.

The remaining steps in processing the I/O request are performed by system I/O postprocessing.

## 8.2 Timeout Handling Routines

The operating system transfers control to the driver's timeout handling routine if a device unit does not request an interrupt within the time limit specified in the invocation of the wait-for-interrupt macro. Among its other activities, the system software timer fork routine running at IPL$_SYNCH, scans UCBs once every second to determine whether a device has timed out.

When the software timer interrupt service routine locates a device that has timed out, the routine calls the driver's timeout handling routine by performing the following steps:

1. It obtains both the fork lock and the device lock associated with the device unit to synchronize access to its fork database and device database. It raises IPL to device IPL as a result of obtaining the device lock.
2. It raises IPL on the local processor to IPL$_POWER to block local power failure servicing.
3. It disables expected interrupts and timeouts on the device by clearing bits in the status field of the device's UCB (UCB$V_INT and UCB$V_TIM in UCB$L_STS).
4. It sets the device-timeout bit in the UCB status field (UCB$V_TIMOUT in UCB$L_STS).
5. It lowers IPL to hardware device interrupt IPL (UCB$B_DIPL).
6. It restores the saved R3 and R4 of the driver's fork process from the UCB fork block (UCB$L_FR3 and UCB$L_FR4).
7. It restores R5 (address of the UCB fork block).
8. It transfers control to the driver's timeout handling routine, which is contained in UCB$PS_TOUTROUT.

The driver's timeout handling routine executes in the following context:

- R5 contains the address of the UCB for the device that timed out.
- Only system address space may be accessed.
- The processor is running in kernel mode.
- The processor is running on the kernel stack.
- The processor holds both fork lock and device lock.
- IPL is at hardware device interrupt level.

A timeout handling routine returns control to the software timer interrupt service routine by issuing an RET instruction. The driver's fork process eventually regains control, with R3 and R4 restored from UCB$Q_FR3 and UCB$Q_FR4.

Certain timeout handling routines may find it useful to fork to execute low priority code or to accomplish certain tasks, such as the restarting of an I/O request (see Section 8.2.1). If a driver uses this method, its interrupt service routine should check the interrupt-expected bit (UCB$V_INT) before handling the interrupt. The operating system clears this bit before it calls the driver's timeout handling routine. This allows the routine to determine whether device-timeout processing is in progress at fork IPL.

During recovery from a power failure, the operating system forces a device timeout by altering the timeout field (UCB$L_DUETIM) of a UCB if that device's UCB records that the unit is waiting for an interrupt or timeout (UCB$V_INT and UCB$V_TIM set in UCB$L_STS). The timeout handling routine can perceive that recovery from a power failure is occurring by examining the power bit (UCB$V_POWER in UCB$L_STS) in the UCB.

A timeout handling routine usually performs one of three functions:

- It retries the I/O operation unless a retry count is exhausted.
- It aborts the I/O request, returning status (for instance, SS$_TIMEOUT) in R0.

- It sends a message to an operator mailbox and waits for a subsequent interrupt or timeout.

### 8.2.1 Retrying an I/O Operation

Some devices might retry an I/O operation after a timeout. For example, a disk driver's timeout handling routine might take the following steps after a transfer timeout:

1. Invokes the FORK macro to lower IPL to fork level.
2. Releases any owned map registers, data path, and controller data channel.
3. Determines whether it is possible to retry the I/O operation.
4. Examines the error retry count (UCB$B_ERTCNT) to determine whether it is possible to retry the I/O operation.

   If the retry count is exhausted, the timeout handling routine sets the error code, performs a normal abort I/O cleanup operation, and issues the REQCOM macro to complete the I/O request.

   If the retry count is not exhausted, the routine proceeds to the next step.
5. Examines the power bit (UCB$V_POWER in UCB$L_STS) to determine if it must take special steps before retrying the operation. For instance, the timeout handling routine should load the address of the IRP into R3 and reload the following fields of the IRP into the corresponding UCB fields, if they have been altered by partial processing of the I/O request:

   IRP$L_BCNT
   IRP$L_BOFF
   IRP$L_SVAPTE

   These actions set up an environment in which the transfer can be retried from the beginning.
6. Calls ERL$DEVICTMO to log the device timeout if the driver supports error logging (see Section 4.2).
7. Decreases the error retry count (UCB$B_ERTCNT).
8. Clears the UCB timeout bit (UCB$V_TIMOUT) in UCB$L_STS.
9. Branches to the start-I/O routine to retry the operation.

### 8.2.2 Aborting an I/O Request

A driver's timeout handling routine aborts the I/O request when it exhausts its retry count or when, having read device registers, the driver determines that some fatal error condition has occurred such that there is no point in retrying the request. Similarly, the routine aborts a request if the device's cancel-I/O bit (UCB$V_CANCEL in UCB$L_STS) is set, signifying that a cancel-I/O request was made.

To abort an I/O request, a timeout handling routine performs the following sequence of steps:

1. Clears the device control and status register (CSR), if appropriate to the device and controller
2. Invokes the FORK macro to lower IPL to fork level
3. Releases any owned map registers, data path, and controller data channel
4. Loads the abort status code (SS$_ABORT) into the low word of R0

5. Clears bits 16 through 31 in R0 to indicate that no data was transferred
6. Issues the REQCOM macro to complete the request

### 8.2.3 Sending a Message to the Operator

The following sequence describes a timeout handling routine that sends a message to the operator's mailbox and then goes back into a wait-for-interrupt or timeout state on the presumption that subsequent human intervention will make the device operational:

1. The timeout handling routine invokes the FORK macro to lower IPL to driver fork level.
2. It checks the cancel-I/O bit in the UCB status longword (UCB$V_CANCEL in UCB$L_STS).

   If UCB$V_CANCEL is set, the timeout handling routine can abort the request. However, if UCB$V_CANCEL is clear, the timeout handling routine performs the following actions:

   a. Saves R3 and R4 on the stack.
   b. Loads an operator communication process (OPCOM) message code, such as MSG$_DEVOFFLIN, into R4. Note that the driver must invoke the message definition macro $MSGDEF (located in SYS$LIBRARY:STARLET.MLB) to use these message codes.
   c. Loads the address of the operator's mailbox (a pointer to which is located at SYS$AR_OPRMBX) into R3.
   d. Calls a system routine to place the message in the operator's mailbox, as follows:

      ```
      JSB   G^EXE$SNDEVMSG
      ```

   e. Restores R3 and R4.
   f. Invokes the DEVICELOCK macro to raise IPL to device IPL and obtain the associated device lock.

g. Issues a SETIPL macro to raise IPL$_POWER and prevent power failure interrupts on the local processor.

h. Invokes the WFIKPCH macro to wait for another interrupt or timeout.

When the OPCOM process reads the message in its mailbox, it sends the requested message, in this case “device-offline,” to all operator terminals enabled for that device class.

# 9
# Linking a Device Driver

Use the following LINK command line as the model for the command line to link your OpenVMS AXP device driver. Brief descriptions of each qualifier used in this command follow. See the *OpenVMS Linker Utility Manual* for more detailed information.

```
$ LINK/ALPHA/NATIVE_ONLY/BPAGE=14-
            /SECTION_BINDING/NOTRACEBACK -
            /NODEMAND_ZERO/SHAREABLE=xxDRIVER -
            /SYSEXE=SELECTIVE/NOSYSSHR/DSF=xxDRIVER -
            /MAP=xxDRIVER /FULL /CROSS_REFERENCE -
            xxDRIVER_LNK/OPTION
```

**/ALPHA**
Directs the linker to create an Alpha image. This is the default on Alpha systems.

**/NATIVE_ONLY**
Indicates that there will be no calls to translated shareable images from this image. This is the default qualifier.

**/BPAGE=14**
Specifies the page size the linker should use when it creates the image sections that make up the image. The value **14** is usually specified for executive images and indicates that the linker should lay out image sections on 16KB boundaries.

The driver-loading procedure ignores the image section boundaries defined by the linker if the image is being loaded as a sliced executive image.

**/SECTION_BINDING**
Directs the linker to activate section binding for both code and data image sections in the driver. Upon successful binding of code sections and data sections, the linker sets bits EIHD$V_BIND_CODE and EIHD$V_BIND_DATA in the image's header. If either of these bits is not set, the driver-loading procedure does not load the driver image as a sliced executive image, but rather, performs a normal load of the image.

See the *OpenVMS Linker Utility Manual* for more detailed information.

**/NOTRACEBACK**
Directs the linker to omit traceback information from the image.

**/NODEMAND_ZERO**
Directs the linker to inhibit generation of demand-zero sections in a driver executive image.

**/SHAREABLE=*xx*DRIVER**
Directs the linker to create a shareable image named *xx*DRIVER.EXE.

**/SYSEXE**
Directs the linker to selectively search the system shareable image, SYS$BASE_IMAGE.EXE, to resolve symbols in a link operation. When the linker selectively searches SYS$BASE_IMAGE.EXE, it only includes symbols from its global symbol table that were referenced by input files previously processed in the link operation.

**/DSF**
Directs the linker to create a file called a debug symbol file (DSF) for use by the OpenVMS AXP System-Code Debugger. Specify the character string you want the linker to use as the name of for the debug symbol file. If you do not include a file type in the character string, the linker appends the .DSF file type to the file name.

See the *OpenVMS Linker Utility Manual* for more detailed information.

**/NOSSYSHR**
Directs the linker not to search the system default shareable image library (SYS$LIBRARY:IMAGELIB.OLB) to resolve symbolic references. Drivers cannot resolve symbols from shareable image libraries.

**/MAP=*xx*DRIVER**
Directs the linker to create an image map file. You need a map file for the driver image to assist in debugging.

**/FULL**
Directs the linker to create a full image map when specified with the /MAP qualifier.

**/CROSS_REFERENCE**
Directs the linker to place the Symbols by Name section in the full or default image map with the Symbols Cross-reference section.

***xx*DRIVER_LNK/OPTION**
Identifies the input file specification (here, *xx*DRIVER_LNK) as a linker options file. See Example 9–1 for a representative options file for use in linking an OpenVMS AXP device driver.

## 9.1 Linker Options File for OpenVMS AXP Device Drivers

Example 9–1 shows a standard link options file for linking any OpenVMS AXP driver. A sample link options file is available in the SYS$EXAMPLES directory.

**Example 9–1 Linker Options File (*xx*DRIVER_LNK.OPT) for an OpenVMS AXP Device Driver**

```
!
!   Define symbol table for SDA using all global symbols, not just
!   universal ones
!
SYMBOL_TABLE=GLOBALS
!
!   This cluster is used to control the order of symbol resolution.  All
!   psects must be collected off of this cluster so that it generates
!   no image sections.
!
CLUSTER=VMSDRIVER,,,-
        !
        !   Start with the driver module
        !
        XXDRIVER.OBJ,-
        !
        !   Next process the private interfaces.  (Only include BUGCHECK_CODES if
        !   used by the driver module).  The /LIB qualifier causes the linker to
        !   resolve references in the driver module to DRIVER$INI_xxx routines
        !   (which are defined in the module DRIVER_TABLE_INIT).
        !
        SYS$LIBRARY:VMS$VOLATILE_PRIVATE_INTERFACES/INCLUDE=(BUGCHECK_CODES)/LIB,-
        !
        !   Explicitly include routines for the initialization section - there
        !   will be no outstanding references to cause this to happen when STARLET
        !   is searched automatically.
        !
        SYS$LIBRARY:STARLET/INCLUDE:(SYS$DRIVER_INIT,SYS$DOINIT)
!
!   Use the COLLECT statement to implicitly declare the NONPAGED_EXECUTE_PSECTS
!   cluster.  Mark the cluster with the RESIDENT attribute so that the image
!   section produced is nonpaged.  Collect only the code psect into the cluster.
!   On OpenVMS AXP systems, the execute section cannot contain data.
!   You must collect all data, whether read-only or writeable, into one
!   of the read/write sections.
!
COLLECT=NONPAGED_EXECUTE_PSECTS/ATTRIBUTES=RESIDENT,-
        $CODE$
!
!   Coerce the psect attributes on the different data psects so that they
!   all match.  This will force NONPAGED_READWRITE_PSECTS cluster to yield only
!   one image section.
!
PSECT_ATTR=$LINK$,WRT
PSECT_ATTR=$INITIAL$,WRT
PSECT_ATTR=$LITERAL$,NOPIC,NOSHR,WRT
PSECT_ATTR=$READONLY$,NOPIC,NOSHR,WRT
PSECT_ATTR=$$$105_PROLOGUE,NOPIC
PSECT_ATTR=$$$110_DATA,NOPIC
PSECT_ATTR=$$$115_LINKAGE,WRT
!
!   Use a COLLECT statement to implicitly declare the NONPAGED_DATA_PSECTS
!   cluster.  Mark the cluster with the RESIDENT attribute so that the image
!   section produced is nonpaged.  Collect all the data psects into the cluster.
!
COLLECT=NONPAGED_READWRITE_PSECTS/ATTRIBUTES=RESIDENT,-
        !
        !   Psects generated by BLISS modules
        !
```

(continued on next page)

**Example 9–1 (Cont.) Linker Options File (*xx*DRIVER_LNK.OPT) for an OpenVMS AXP Device Driver**

```
        $PLIT$,-
        $INITIAL$,-
        $GLOBAL$,-
        $OWN$,-
        !
        !   Psects generated by DRIVER_TABLES
        !
        $$$105_PROLOGUE,-
        $$$110_DATA,-
        $$$115_LINKAGE,-
        !
        !   Standard Psects generated by all languages,
        !   including the high level language driver module
        !
        $BSS$,-
        $DATA$,-
        $LINK$,-
        $LITERAL$,-
        $READONLY$
!
!   Coerce the program section attributes for initialization code so
!   that code and data  will be combined into a single image section.
!
PSECT_ATTR=EXEC$INIT_CODE,NOSHR
!
!   Use a COLLECT statement to implicitly declare the INITIALIZATION_PSECTS
!   cluster.  Mark the cluster with the INITIALIZATION_CODE attribute so that the image
!   section produced is identified as INITIALCOD.
!
!   These program sections have special names so that when the linker sorts them
!   alphabetically they will fall in the order: initialization vector table, code,
!   linkage, build table vector.  The order in which they are collected does not affect
!   their order in the image section.
!
!   This is the only place where code and data should reside in the
!   same section.
!
!   NOTE: The linker will attach the fixup vectors to this cluster. This is expected.
!         (The OpenVMS executive loader will deallocate both the fixup section
!         and the initialization section once the driver has been initialized.)
!
!
COLLECT=INITIALIZATION_PSECTS/ATTRIBUTES=INITIALIZATION_CODE,-
        EXEC$INIT_000,-
        EXEC$INIT_001,-
        EXEC$INIT_002,-
        EXEC$INIT_CODE,-
        EXEC$INIT_LINKAGE,-
        EXEC$INIT_SSTBL_000,-
        EXEC$INIT_SSTBL_001,-
        EXEC$INIT_SSTBL_002
```

## 9.2 Resolving CRTL References at Link-Time

When an image containing C code is being linked, the user must choose where to resolve CRTL references. Usually, a C application program resolves such references through IMAGELIB.OLB in DECC$SHR.EXE by linking /SYSSHR.

However, execlets and user-written system services typically link /NOSYSSHR and resolve external symbols without references to other shareable images.

Two options exist for resolving CRTL symbols at link time without references to DECC$SHR.EXE:

- Resolving them out of STARLET.OLB (all the objects that comprise DECC$SHR.EXE exist in STARLET.OLB)
- Link /SYSEXE and resolving the symbols from SYS$BASE_IMAGE.EXE (the kernel CRTL).

There are, however, several ways to resolve symbols from STARLET, and peculiar interactions between various linker qualifiers should be noted.

Most (or all) execlets link /NOSYSSHR/NOSYSLIB/SYSEXE and explicitly extract needed modules from STARLET.OLB and include other objects from various places. Using this method, CRTL references will be resolved from SYS$BASE_IMAGE.EXE. Any references to CRTL routines not supported by the kernel CRTL will generate an undefined symbol error by the linker.

User-written system services have several options. If the code runs in executive or kernel mode exclusively at IPL 0, it may be able to use the full complement of CRTL routines (from STARLET) and not be bound by the subset supported by the kernel CRTL (in SYS$BASE_IMAGE). It may or may not link /SYSEXE for other reasons, depending on whether it requires access to system data cells or routines.

For example, if a user-written system service links /NOSYSSHR/SYSLIB /SYSEXE. All references to kernel CRTL routines will be resolved from SYS$BASE_IMAGE. Any CRTL references not supported by the kernel CRTL will be resolved from STARLET, which may or may not be the desired behavior. If any references are resolved from STARLET, this can possibly lead to multiply-defined symbols as well. It is not recommended.

If the user-written system service does not link /SYSEXE and links /NOSYSSHR /SYSLIB, all CRTL references will be resolved from STARLET. The user can choose instead to resolve these symbols from SYS$BASE_IMAGE by using the /SYSEXE qualifier.

If the user-written system service must link /SYSEXE for other reasons but wants all CRTL references to be resolved from STARLET, the order in which the linker would resolve the CRTL symbol references must be changed as follows:

```
$ link/nosysshr/nosyslib/sysexe=selective user_objects,sys$input/opt
sys$library:starlet.olb/lib
sys$loadable_images:sys$public_vectors.exe/share
```

STARLET.OLB will be searched to resolve the CRTL symbols first, making it unnecessary to resolve them in processing /SYSEXE later. Using /SYSEXE=SELECTIVE avoids multiply-defined symbols.

# 10
# Loading an OpenVMS AXP Device Driver

An OpenVMS AXP device driver, as discussed in Chapter 9, is created as an executive image. It is loaded as an integral part of the executive by the executive loader. You use the System Management utility (SYSMAN) to interface with the system loader.

This chapter describes the procedures you should follow to load an OpenVMS AXP device driver for testing on an AXP system:

- Section 10.1 describes a general method for configuring I/O devices and loading their drivers.
- Section 10.2 describes each command provided by SYSMAN.
- Section 10.3 explains how to enhance system performance by loading as "sliced" images drivers that have been linked with section binding enabled.

## 10.1 Manually Connecting Devices and Loading Drivers

For adapters supported by Digital, there is never any need to manually connect a device. Use the SYSMAN IO AUTOCONFIGURE command with the appropriate /SELECT and /EXCLUDE lists to configure the system. If you omit these qualifiers, the IO AUTOCONFIGURE command configures the entire system.

For non-Digital-supplied adapters and new Digital adapters not yet supported by the IO AUTOCONFIGURE command, you must perform a manual connect, generally issuing an IO CONNECT command in the following format:

```
SYSMAN>
IO CONNECT devname/ADAPTER=x/CSR=y/VECTOR=z/DRIVER=xxdriver-
/node=busspecificinfo
```

In such a command, specifying the device name and driver name is straightforward (and described in Section 10.2). This section describes how to determine the **adapter**, the **csr**, and the **vector** parameters for devices attached to the EISA, XMI, TURBOchannel, and Futurebus+. For more information about specifying node information, see the appropriate bus support chapter in this manual.

### 10.1.1 Obtaining the Adapter's TR Number

The **adapter** parameter tells the SYSMAN interface which adapter the device belongs to. The value you supply in this parameter must match the TR number of some ADP in the I/O database.

To find a value for the **adapter** parameter, use the SYSMAN IO SHOW BUS command to display the adapters present in the system. The TR number of each of the ADPs in the system is part of the IO SHOW BUS display. Find your adapter in the IO SHOW BUS display and use the associated TR number in the IO CONNECT command.

### 10.1.2 Obtaining the Adapter's CSR Address

When connecting a device, the driver loading procedure creates a UCB, CRB, and IDB for it and copies the value of the **csr** parameter of the IO CONNECT command directly to the IDB$Q_CSR field in the IDB.

In general, when manually connecting a device, you should specify the base CSR address of the device register space. As is the case with the adapter TR number used in the **adapter** parameter, the base CSR of each adapter is part of the display provided by the IO SHOW BUS command.

The CSR address format differs from bus to bus. The IO SHOW BUS output shows the CSR address in the proper format for the bus being displayed. Locate your adapter in the IO SHOW BUS display and use the associated CSR address in the IO CONNECT command.

### 10.1.3 Locating the Adapter's Interrupt Vectors

The assignment of vectors to adapters is bus-specific, as follows:

- XMI

  On the XMI, vectors are assigned to adapters during bus probing.

  A future release of SYSMAN will automatically find the vectors for the adapter specified in the **adapter** parameter for manual connections of XMI adapters. As a result, you will not need to specify the **vector** parameter for these adapters.

- Futurebus+

  In general, Futurebus+ adapters require blocks of vectors with an alignment constraint on the base vector. Vectors are not assigned to adapters during bus probing (in contrast to XMI).

  A future release of SYSMAN will automatically allocate the number of vectors specified in the **num_vec** parameter for manual connections of Futurebus+ adapters. For more information, see Chapter 15.

- TURBOchannel

  On the TURBOchannel, vectors are associated with TURBOchannel backplane slots. TURBOchannel adapters do not have programmable vector registers (as do XMI and Futurebus+ adapters). Rather, the slot into which the adapter is plugged determines the vector it uses for interrupts. A side effect of this is that TURBOchannel adapters are restricted to using a single interrupt vector.

  The algorithm for determining slot/vector correspondence is simple:

  ```
  vector = slot_number * 4
  ```

  The node number is part of the IO SHOW BUS display. Node number and slot number are identical concepts for TURBOchannel adapters. Thus, if you locate your adapter in the IO SHOW BUS display, you can use the associated node number to calculate the vector location.

## 10.2 I/O Configuration Support in SYSMAN

On OpenVMS AXP systems, SYSMAN is used to connect devices, load I/O device drivers, and display configuration information useful for debugging device drivers.

Enter the following command to invoke SYSMAN:

```
$ MCR SYSMAN
```

The SYSMAN prompt `SYSMAN>` appears.

All SYSMAN commands that control and display the I/O configuration of an OpenVMS AXP system must be introduced with the prefix IO. For example, to autoconfigure a system, enter the following commands:

```
$ MCR SYSMAN
SYSMAN> IO AUTOCONFIGURE
```

# AUTOCONFIGURE

Automatically identifies and configures all hardware devices attached to a system. The AUTOCONFIGURE command connects devices and loads their drivers.

You must have CMKRNL and SYSLCK privileges to use the AUTOCONFIGURE command.

## Format

**IO AUTOCONFIGURE**

## Parameters

None.

## Description

The AUTOCONFIGURE command identifies and configures all hardware devices attached to a system. It connects devices and loads their drivers. You must have CMKRNL and SYSLCK privileges to use the AUTOCONFIGURE command.

## Qualifiers

***/SELECT=(device_name[,...])***
Specifies the device type to be automatically configured. Use valid device names or mnemonics that indicate the devices to be included in the configuration. Wildcards must be explicitly specified.

The /SELECT and /EXCLUDE qualifiers are not mutually exclusive, as they are on OpenVMS VAX. Both qualifiers can be specified on the command line.

Table 10–1 shows /SELECT qualifier examples.

**Table 10–1 SELECT Qualifier Examples**

| Command | Devices that are configured | Devices that are not configured |
|---|---|---|
| /SELECT=P* | PKA,PKB,PIA | None |
| /SELECT=PK* | PKA,PKB | PIA |
| /SELECT=PKA* | PKA | PKB,PIA |

***/EXCLUDE=(device_name[,...])***
Specifies the device type that should not be automatically configured. Use valid device names or mnemonics that indicate the devices to be excluded from the configuration. Wildcards must be explicitly specified.

The /SELECT and /EXCLUDE qualifiers are not mutually exclusive, as they are on OpenVMS VAX systems. Both qualifiers can be specified on the command line.

***/LOG***
Controls whether the AUTOCONFIGURE command displays information about loaded devices.

# CONNECT

Connects a hardware device and loads its driver, if the driver is not already loaded.

You must have CMKRNL and SYSLCK privileges to use the CONNECT command.

## Format

**IO CONNECT** device-name[:]

## Parameters

**device-name[:]**
Specifies the name of the hardware device to be connected. It should be specified in the format device-type, controller, and unit number (for example, LPA0 where LP is a line printer on controller A at unit number 0). If the /NOADAPTER qualifier is specified, the device is the software device to be loaded.

## Description

The CONNECT command connects a hardware device and loads its driver, if the driver is not already loaded. You must have CMKRNL and SYSLCK privileges to use the CONNECT command.

## Qualifiers

**/ADAPTER=tr_number**
**/NOADAPTER (default)**
Specifies the nexus number of the adapter to which the specified device is connected. It is a nonnegative 32-bit integer. /NOADAPTER indicates that the device is not associated with any particular hardware. The /NOADAPTER qualifier is compatible with the /DRIVER_NAME qualifier only.

**/CSR=csr_address**
The CSR address for the device being configured. This address must be specified in hexadecimal. You must precede the CSR address with %X. The CSR address is a quadword value that is loaded into IDB$Q_CSR without any interpretation by SYSMAN. This address can be physical or virtual depending on the specific device being connected:

- /CSR=%X3A0140120 for a physical address
- /CSR=%XFFFFFFFF807F8000 for a virtual address (the sign extension is required for OpenVMS AXP virtual addresses)

This qualifier is required if /ADAPTER=tr_number is specified.

**/DRIVER_NAME=filespec**
The name of the device driver to be loaded. If this qualifier is not specified, the default is obtained in the same manner as the SYSGEN default name. For example, if you want to load the Digital-supplied SYS$ELDRIVER.EXE, the "SYS$" must be present. Without the "SYS$", SYSMAN looks for ELDRIVER.EXE in SYS$LOADABLE_IMAGES. This implementation separates the user device driver namespace from Digital-supplied device driver namespace.

**/LOG=(ALL,CRB,DDB,DPT,IDB,SB,UCB)**
**/NOLOG (default)**
Controls whether SYSMAN displays the addresses of the specified control blocks. The default value for the /LOG qualifier is /LOG=ALL. If /LOG=UCB is specified, a message similar to the following is displayed:

```
%SYSMAN-I-IOADDRESS, the UCB is located at address 805AB000
```

The default is /NOLOG.

**/MAX_UNITS=maximum-number-of-units**
Specifies the maximum number of units the driver can support. The default is specified in the Driver Prologue Table (DPT) of the driver. If the number is not specified in the DPT, the default is 8. This number must be greater than or equal to the number of units specified by /NUM_UNITS. This qualifier is optional.

**/NUM_UNITS=number-of-units**
Specifies the number of units to be created. The starting device number is the number specified in the device name parameter. For example, the first device in DKA0 is 0. Subsequent devices are numbered sequentially. The default is 1. This qualifier is optional.

**/NUM_VEC=vector-count**
Specifies the number of vectors for this device. The default vector count is 1. The /NUM_VEC qualifier is optional. This qualifier should be used only when using the /VECTOR_SPACING qualifier. When using the /NUM_VEC qualifier, you must also use the /VECTOR qualifier to supply the base vector.

**/SYS_ID=number-of-remote-system**
Indicates the SCS system ID of the remote system to which the device is to be connected. It is a 64-bit integer; you must specify the remote system number in hexadecimal. The default is the local system. This qualifier is optional.

**/VECTOR=(vector-address,...)**
The interrupt vectors for the device or lowest vector. This is a byte offset into the SCB of the interrupt vector for directly vectored interrupts or a byte offset into the ADP vector table for indirectly vectored interrupts. The values must be longword aligned. To specify the vector address(es) in octal or hexadecimal, precede the address(es) with %O or %X, respectively. This qualifier is required when /ADAPTER=tr_number or /NUM_VEC=vector-count is specified. Up to 64 vectors can be listed.

**/VECTOR_SPACING=number-of-bytes-between-vectors**
Specifies the spacing between vectors. Specify the amount as a multiple of 16 bytes. The default is 16. You must specify both the base vector with /VECTOR and the number of vectors with /NUM_VEC. This qualifier is optional.

## Examples

1.
```
SYSMAN> IO CONNECT DKA0:/DRIVER_NAME=SYS$DKDRIVER/CSR=%X80AD00-
/ADAPTER=4/NUM_VEC=3/VECTOR_SPACING=%X10/VECTOR=%XA20/LOG
%SYSMAN-I-IOADDRESS, the CRB is located at address 805AEC40
%SYSMAN-I-IOADDRESS, the DDB is located at address 805AA740
%SYSMAN-I-IOADDRESS, the DPT is located at address 80D2A000
%SYSMAN-I-IOADDRESS, the IDB is located at address 805AEE80
%SYSMAN-I-IOADDRESS, the SB is located at address 80417F80
%SYSMAN-I-IOADDRESS, the UCB is located at address 805B68C0
```

2.
```
SYSMAN> IO CONNECT DKA0:/DRIVER_NAME=SYS$DKDRIVER/CSR=%X80AD00-
/ADAPTER=4/VECTOR=(%XA20,%XA30,%XA40)/LOG=(CRB,DPT,UCB)
%SYSMAN-I-IOADDRESS, the CRB is located at address 805AEC40
%SYSMAN-I-IOADDRESS, the DPT is located at address 80D2A000
%SYSMAN-I-IOADDRESS, the UCB is located at address 805B68C0
```

3.
```
SYSMAN> IO CONNECT
FTA0:/DRIVER=SYS$FTDRIVER/NOADAPTER/LOG=(ALL)
%SYSMAN-I-IOADDRESS, the CRB is located at address 805AEC40
%SYSMAN-I-IOADDRESS, the DDB is located at address 805AA740
%SYSMAN-I-IOADDRESS, the DPT is located at address 80D2A000
%SYSMAN-I-IOADDRESS, the IDB is located at address 805AEE80
%SYSMAN-I-IOADDRESS, the SB is located at address 80417F80
%SYSMAN-I-IOADDRESS, the UCB is located at address 805B68C0
```

4.
```
SYSMAN> IO CONNECT FTA1:/DRIVER=SYS$FTDRIVER/NOADAPTER
SYSMAN>
```

# SET PREFIX

Sets the prefix list which is used to manufacture the IOGEN Configuration Building Module (ICBM) names.

## Format

**IO SET PREFIX=(icbm_prefix[,...])**

## Parameters

**icbm_prefix[,...]**
Specifies ICBM prefixes. These prefixes are used by the AUTOCONFIGURE command to build ICBM image names.

## Description

The SET PREFIX command sets the prefix list which is used to manufacture SYSMAN Configuration Building Module (ICBM) names.

## Qualifiers

None.

## Example

```
SYSMAN> IO SET PREFIX=(SYS$,PSI$,VME_)
```

# SHOW BUS

Lists all the buses, node numbers, bus names, TR numbers and base CSR addresses. You must have CMKRNL privilege to use SHOW BUS.

## Format

**IO SHOW BUS**

## Parameters

None.

## Description

The SHOW BUS command lists all the buses, node numbers, bus names, TR numbers and base CSR addresses. You must have CMKRNL privilege to use SHOW BUS.

## Qualifiers

None.

## Example

```
SYSMAN> IO SHOW BUS

_Bus__________Node_TR#__Name____________Base CSR__________
LSB            0    1    EV3 4MB        FFFFFFFF86FA0000
LSB            6    1    MEM            FFFFFFFF86FC4000
LSB            7    1    MEM            FFFFFFFF86FCA000
LSB            8    1    IOP            FFFFFFFF86FD0000
    XZA XMI-SCSI  0    3    XZA-SCSI        0000008001880000
    XZA XMI-SCSI  1    3    XZA-SCSI        0000008001880000
    XZA XMI-SCSI  0    4    XZA-SCSI        0000008001900000
    XZA XMI-SCSI  1    4    XZA-SCSI        0000008001900000
  XMI           4    2    LAMB            0000008001A00000
    DEMNA         0    5    Generic XMI    0000008001E80000
    DEMNA         0    6    Generic XMI    0000008001F00000
```

# SHOW DEVICE

Displays information on device drivers loaded into the system, the devices connected to them, and their I/O databases. All addresses are in hexadecimal and are virtual.

## Format

**IO SHOW DEVICE**

## Parameters

None.

## Qualifiers

None.

## Description

The SHOW DEVICE command displays information on the device drivers loaded into the system, the devices connected to them, and their I/O databases.

The SHOW DEVICE command specifies that the following information be displayed about the specified device driver:

| | |
|---|---|
| Driver | Name of the driver |
| Dev | Name of each device connected to the driver |
| DDB | Address of the device's device data block |
| CRB | Address of the device's channel request block |
| IDB | Address of the device's interrupt dispatch block |
| Unit | Number of each unit on the device |
| UCB | Address of each unit's unit control block |

All addresses are in hexadecimal and are virtual.

Refer to *A Comparison of System Management on OpenVMS AXP and OpenVMS VAX* and the *OpenVMS System Manager's Manual* for additional information on SYSMAN.

## Example

```
SYSMAN> IO SHOW DEVICE
```

The following is a sample display produced by the SYSMAN IO SHOW DEVICE command:

```
__Driver________Dev_DDB______CRB______IDB______Unit_UCB_____
SYS$FTDRIVER
                FTA 802CE930 802D1250 802D04C0
                                                 0 801C3710
SYS$EUDRIVER
                EUA 802D0D80 802D1330 802D0D10
                                                 0 801E35A0
SYS$DKDRIVER
                DKI 802D0FB0 802D0F40 802D0E60
                                                 0 801E2520
SYS$PKADRIVER
                PKI 802D1100 802D13A0 802D1090
                                                 0 801E1210
SYS$TTDRIVER
OPERATOR
NLDRIVER
```

# SHOW PREFIX

Displays the current prefix list used in the manufacture of ICBM names.

## Format

**IO SHOW PREFIX**

## Parameters

None.

## Description

The SHOW PREFIX command displays the current prefix list on the console. This list is used by the AUTOCONFIGURE command to build ICBM names.

## Qualifiers

None.

## Example

```
SYSMAN> IO SHOW PREFIX
%SYSMAN-I-IOPREFIX, the current prefix list is: SYS$,PSI$,VME_
```

## 10.3 Loading Sliced Executive Images

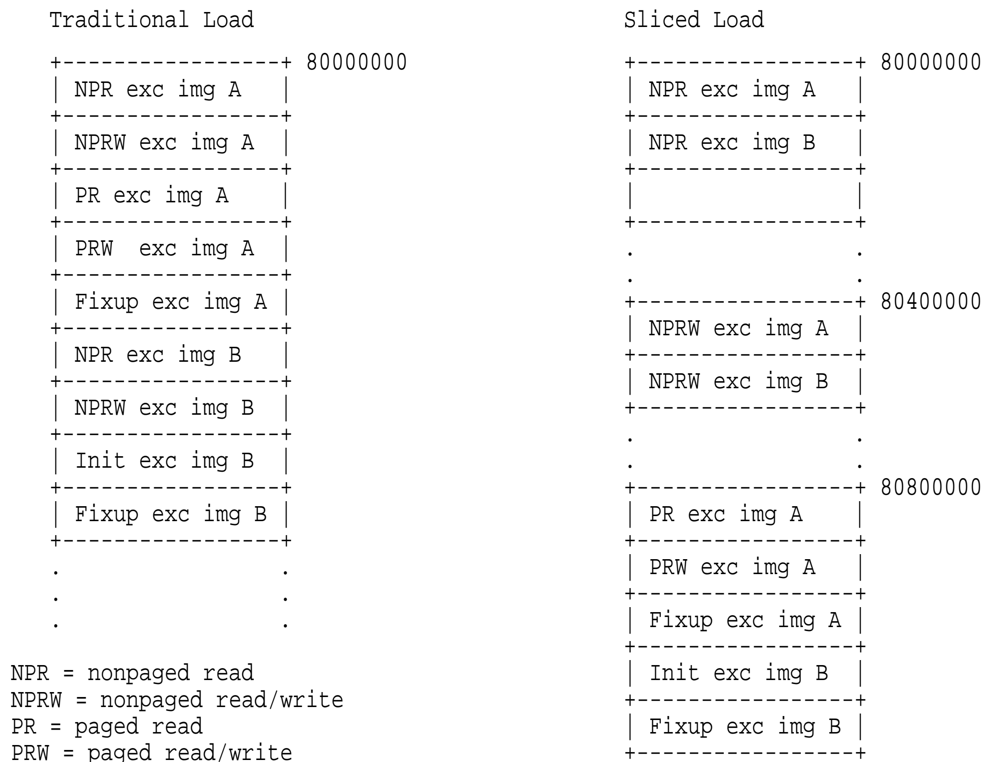
In traditional executive image loading, code and data are sparsely laid out in system address space. The loader allocates the virtual address space for executive images so that the image sections are loaded on the same boundaries as the linker created them. The images are normally linked with the /BPAGE qualifier equal to 14; this puts the image sections on 16 KB boundaries.

AXP hardware can consider a set of pages as a single huge page, which can be mapped by a single page-table entry (PTE) in the translation buffer. To use this mechanism, the loader allocates a PTE for nonpaged code and another for nonpaged data. Pages within this huge page, or **granularity hint region**, must have the same protection. As a result, hence code and data cannot share a huge page. The end result of this is a single translation buffer entry to map the executive nonpaged code, and another to map the nonpaged data.

The loader then loads like nonpaged sections from each executive image into the same region of virtual memory, ignoring the page size according to which the image sections have been created. Paged, fixup and initialization sections are loaded in the same manner as the traditional loader. If the parameter S0_PAGING is set to turn off paging of the executive, all code and data, both paged and nonpaged, is treated as nonpaged and loaded into the granularity hint regions.

This method of loading is called “sliced” loading. Figure 10–1 illustrates a traditional load and a sliced load.

**Figure 10–1 Traditional and Sliced Loads**



### 10.3.1 Controlling Executive Image Slicing

The system parameter LOAD_SYS_IMAGES is a bitmask and has several bits defined:

- SGN$V_LOAD_SYS_IMAGES (bit 0)—Enables loading alternate executive images specified in VMS$SYSTEM_IMAGES.DATA
- SGN$V_EXEC_SLICING (bit 1)—Enables the loading of the executive into granularity hint regions
- SGN$V_RELEASE_PFNS (bit 2)—Enables releasing unused portions of the huge pages

These bits are set by default. Use conversational bootstrap to disable exec slicing.

#### 10.3.1.1 XDELTA Support for Executive Image Slicing

The display of the XDELTA ;L command accommodates both normally loaded and sliced executive images. In Figure 10–2, you can see that EXEC_INIT has only a single base and end address, it has not been sliced. The other executive images all have multiple base and end addresses. These executive images have been sliced. As the boot proceeds, the initialization and fixup sections are deleted; once deleted, they are no longer displayed.

The “Seq#” field uniquely identifies each executive image. This sequence number can be used with ;L to get a partial display.

#### 10.3.1.2 Locating Source Modules with Image Slicing Enabled

The following steps describe how to determine what source module a given program counter (PC) is in:

1. Use XDELTA to get a display of the loaded executive images. Scan the list to find the executive image and image section which contain the PC.
2. Subtract the base address for the image section listed by XDELTA from the PC you are trying to identify.
3. Get a linker map for that executive image and look at the “Image Section Synopsis”. Match the image section the PC is in with an image section from the map.
4. Add the value calculated in step 2 to the base address for the image section listed in the map.
5. Look at the “Program Section Synopsis” in the map and use the offset calculated in step 4 to determine the source module.

The following example demonstrates how to determine the source module that corresponds to address 80026530, using the preceding steps:

1. Use XDELTA to get a display of the loaded executive images. The display shows that address 80026530 is in SYSTEM_SYNCRONIZATION’s nonpaged read only image section.
2. Subtract the base address for the image section listed by XDELTA (80024000) from the PC you are trying to identify (80026530). The difference (2530) is the offset within the image section.

**Figure 10–2 XDELTA Display**

```
Full display:

;L

Seq#  Image Name                             Base      End

0012  EXEC_INIT.EXE                          8080C000  80828000
0010  SYS$CPU_ROUTINES_0101.EXE
          Nonpaged read only                 80038000  8003A200
          Nonpaged read/write                80420200  80420A00
          Initialization                     80808000  80808400
000E  ERRORLOG.EXE
          Nonpaged read only                 8002E000  80036600
          Nonpaged read/write                8041BE00  80420200
          Initialization                     80804000  80804800
000C  SYSTEM_SYNCHRONIZATION.EXE
          Nonpaged read only                 80024000  8002C800
          Nonpaged read/write                8041A000  8041BE00
          Initialization                     80800000  80800800
              .       .     .
              .       .     .
              .       .     .
              .       .     .
              .       .     .
0002  SYS$BASE_IMAGE.EXE
          Nonpaged read only                 80002000  80009400
          Nonpaged read/write                80403000  80414C00
          Fixup                              80620000  80620600
          Symbol Vector                      8040B010  80414560
0000  SYS$PUBLIC_VECTORS.EXE
          Nonpaged read only                 80000000  80001C00
          Nonpaged read/write                80400000  80403000
          Fixup                              8061E000  8061E200
          Symbol Vector                      80401BF0  80402ED0

Partial Display:

C;L

Seq#  Image Name                             Base      End

000C  SYSTEM_SYNCHRONIZATION.EXE
          Nonpaged read only                 80024000  8002C800
          Nonpaged read/write                8041A000  8041BE00
          Initialization                     80800000  80800800
```

3. Look at the “Image Section Synopsis” of a linker map for that executive image. Match the image section that the PC is in and the image section from the map; you find that the offset (2530) is within the nonpaged read-only psect at base address 0.

```
   Cluster      Type Pages   Base Addr  Disk VBN PFC Protection and Paging
   -------      ---- -----   ---------  -------- --- ---------------------

NONPAGED_READONLY_PSECTS
                   4    68    00000000-R       3   0 READ ONLY

NONPAGED_READWRITE_PSECTS
                   4    15    0000C000-R      71   0 READ WRITE   COPY ON REF

INITIALIZATION_PSECTS
                   4     4    00010000-R      86   0 READ WRITE   COPY ON REF
                   2     3    00014000-R      90   0 READ WRITE   FIXUP VECTORS
```

4. Add the value calculated in step 2 (2530) to the base address for the image section (0). The sum (2530) is the offset within the image as written by the linker.
5. Look at the "Program Section Synopsis" section of the linker map. Using the offset (2530) determined in step 4, you find that the address is in module SMPROUT.

```
EXEC$NONPAGED_CODE              00000000 000087BF 000087C0 (      34752.) 2 **
                SMPROUT         00000000 0000391B 0000391C (      14620.) 2 **
                SMPINITIAL      00003920 000051D3 000018B4 (       6324.) 2 **
                SMPINT_COMMON   000051E0 0000684F 00001670 (       5744.) 2 **
                SPINLOCK$MON    00006860 000087BF 00001F60 (       8032.) 2 **

EXEC$HI_USE_PAGEABLE_LINKAGE    0000C000 0000C000 00000000 (          0.) BYTE

EXEC$NONPAGED_DATA              0000C000 0000C4CB 000004CC (       1228.) 2 **
                SMPROUT         0000C000 0000C351 00000352 (        850.) 2 **
                SMPINITIAL      0000C360 0000C4CB 0000016C (        364.) 2 **
```

The ;W command has been added to XDELTA to ease locating addresses within exec loaded images. The command has two forms.

The first form takes a system space address as a parameter and attempts to locate that address within the loaded executive images. This command works for both sliced and unsliced executive images. The output is very similar to ;L, except the offset calculated in steps 1-4 is displayed for you, as in the following example:

```
80026530;W

Seq#  Image Name                               Base      End       Image Offset

000C  SYSTEM_SYNCHRONIZATION.EXE
          Nonpaged read only                   80024000  8002C800  00002530
```

The second form of the command takes an executive image sequence number and an image offset from the map file as parameters. The output, again, is very similar to ;L, except that the system space address which corresponds to the image offset is displayed.

```
C,2530;W

Seq#  Image Name                               Base      End       Address

000C  SYSTEM_SYNCHRONIZATION.EXE
          Nonpaged read only                   80024000  8002C800  80026530
```

# 11 Debugging a Device Driver

The OpenVMS Delta and XDelta Debuggers (DELTA/XDELTA) and the OpenVMS AXP System-Code Debugger (system-code debugger) are tools you can use to debug device drivers. This chapter briefly describes DELTA/XDELTA, and it explains how to use the system-code debugger.

## 11.1 Using the Delta/XDelta Debugger

The OpenVMS Delta/XDelta Debugger (DELTA/XDELTA) is a primitive debugger. It is used to debug code that cannot be debugged with the symbolic debugger, that is, any code that executes at interrupt priority levels (IPLs) above IPL0 or any code that executes in supervisor, executive, or kernel mode. Examples include user-written device drivers and the OpenVMS operating system.

Almost all the commands available on DELTA are also available on XDELTA. Furthermore, both DELTA and XDELTA use the same expressions. However, they are different in two ways: you use them to debug different kinds of code, and you invoke and exit from them in different ways.

You can use DELTA to debug programs that execute at IPL0 in any processor mode (user, supervisor, executive, and kernel). You can also debug user-mode programs with DELTA, but the OpenVMS Debugger is more suitable. To run DELTA in a processor mode other than user mode, your process must have the privilege that allows DELTA to change to that mode—change-mode-to-executive (CMEXEC) or change-mode-to-kernel (CMKRNL) privilege. You cannot use DELTA to debug code that executes at an elevated IPL.

You can use XDELTA to debug programs that execute in any processor mode and at any IPL. To use XDELTA, you must have system privileges, and you must include XDELTA when you boot the system.

You can use DELTA/XDELTA commands to perform the following debugging tasks:

- Open, display, and change the value of a particular location
- Set, clear, and display breakpoints
- Set display modes in byte, word, longword, or ASCII
- Display instructions
- Execute the program in a single step with the option to step over a subroutine
- Set base registers
- List the names and locations of all loaded modules of the executive
- Map an address to an executive module

For more information about using DELTA/XDELTA, see the *OpenVMS Delta /XDelta Debugger Manual*.

## 11.2 Using the OpenVMS AXP System-Code Debugger

The OpenVMS AXP System-Code Debugger (system-code debugger) can be used to debug nonpageable system code and device drivers running at any interupt priority level (IPL). You can use the system-code debugger to perform the following tasks:

- Control the system software's execution—-stop at points of interest, resume execution, intercept fatal exceptions, and so on
- Trace the execution path of the system software
- Monitor exception conditions
- Examine and modify the values of variables
- In some cases, test the effect of modifications without having to edit the source code, recompile, and relink

The system-code debugger is a symbolic debugger. You can specify variable names, routine names, and so on, precisely as they appear in your source code. The system-code debugger can also display the source code where the software is executing, and allow you to step by source line.

You can use the system-code debugger to debug code written in the following languages:

C
BLISS (Note that a BLISS compiler is not available for OpenVMS AXP.)
Macro

The system-code debugger recognizes the syntax, data typing, operators, expressions, scoping rules, and other constructs of a given language. If your code or driver is written in more than one language, you can change the debugging context from one language to another during a debugging session.

To use the system-code debugger, you must do the following:

- Build a system image or device driver to be debugged.
- Set up the target kernel on a standalone system.

  The **target kernel** is the part of the system-code debugger that resides on the system that is being debugged. It is integrated with XDELTA and is part of the SYSTEM_DEBUG execlet.
- Set up the host system, which is integrated with the OpenVMS Debugger.

The following sections cover these tasks in more detail, describe the available user-interface options, summarize applicable OpenVMS Debugger commands, and provide a sample system-code debugger session.

### 11.2.1 User-interface Options

The system-code debugger has the following user-interface options:

- A DECwindows Motif interface for workstations

  When using this interface, you interact with the system-code debugger by using a mouse and pointer to choose items from menus, click on buttons, select names in windows, and so on.

Note that you can also use OpenVMS Debugger commands with the DECwindows Motif interface.

- A character cell interface for terminals and workstations

  When using this interface, you interact with the system-code debugger by entering commands at a prompt. The sections in this chapter describe how to use the system-code debugger with the character cell interface.

For more information about using the OpenVMS DECwindows Motif interface and OpenVMS Debugger commands with the system-code debugger, see the *OpenVMS Debugger Manual*.

### 11.2.2 Building a System Image to Be Debugged

1. Compile the sources you want to debug, and be sure to use the /DEBUG and /NOOPT qualifers.

   **Note**

   Debugging optimized code is much more difficult and is not recommended unless you know the AXP architecture well. The instructions are reordered so much that single-stepping by source line will look like you are randomly jumping all over the code. Also note that you cannot access all variables. The system-code debugger reports that they are optimized away.

2. Link your image using the the /DSF (debug symbol file) qualifier. Do not use the /DEBUG qualifier, which is for debugging user programs. The /DSF qualifier takes an optional filename argument similar to the /EXE qualifier. For more information, see the *OpenVMS Linker Utility Manual*. If you specify a name in the /EXE qualifier you will need one for the /DSF qualifier. For example you would use the following command:

   ```
   $ LINK/EXE=EXE$:MY_EXECLET/DSF=EXE$:MY_EXECLET OPTIONS_FILE/OPT
   ```

   The .DSF and .EXE file names should be the same. Only the extensions will be different, that is .DSF and .EXE.

   The contents of the .EXE file should be exactly the same as if you had linked without the /DSF qualifier. The .DSF file will be a small image containing the image header and all the debug symbol tables for that image. It is not an executable file, so you should not try to run it or load it.

3. Put the .EXE file on your target system.

4. Put the .DSF file on your host system, because when you use the system-code debugger to debug code in your image, it will try to look for a .DSF file first and then look for a .EXE file. The .DSF file is better because it has symbols in it. Section 11.2.4 describes how to tell the system-code debugger where to find your .DSF and .EXE files.

### 11.2.3 Setting Up the Target System for Connections

The target kernel is controlled by flags and devices specified when the system is booted, XDELTA commands, a configuration file, and several sysgen parameters. The following sections contain more information about these items.

### Boot Command

The form of the boot command varies depending on the type of OpenVMS AXP system you are using. However, all boot commands have the concept of boot flag and boot devices as well as a way to save the default boot flags and devices. This section uses syntax from a DEC 3000 Model 400 AXP Workstation in examples.

To use the system-code debugger, you must specify an Ethernet device with the boot command on the target system. This device will be used by the target system to communicate with the host debugger. It is currently a restriction that this device must not be used for anything else (either for booting or network software such as DECnet, TCP/IP products, and LAT products). Thus, you must also specify a different device to boot from. For example, the following command will boot a DEC 3000 Model 400 from the dkb100 disk, and the system-code debugger will use the esa0 ethernet device.

```
>>> boot dkb100,esa0
```

To find out the Ethernet devices available on your system, enter the following command:

```
>>> Show Device
```

In addition to devices, you can also specify flags on the boot command line. Boot flags are specified as a hex number; each bit of the number represents a true or false value for a flag. The following flag values are relevant to the system-code debugger:

- **8000**

  This new boot flag enables operation of the target kernel. If this boot flag is not set, not only will it be impossible to use the system-code debugger to debug the system, but the additional XDELTA commands related to the target kernel will generate an XDELTA error message. If this flag is set, SYSTEM_DEBUG is loaded, and the system-code debugger is enabled.

- **0004**

  This boot flag's function has not changed. It controls whether the system calls INI$BRK at the beginning and end of EXEC_INIT. Notice that if the system-code debugger is the default debugger, the first breakpoint is not as early as it is for XDELTA. It is delayed until immediately after the PFN database is set up.

- **0002**

  This boot flag, which has always controlled whether XDELTA is loaded, behaves slightly differently when the system-code debugger boot flag is also set.

  If the system-code debugger boot flag is clear, this flag works as it always has. If the system-code debugger boot flag is set, this flag determines whether XDELTA or the system-code debugger is the default debugger. If the XDELTA flag is set, XDELTA will be the default debugger. In this state, the initial system breakpoints and any calls to INI$BRK trigger XDELTA, and you must issue an XDELTA command to start using the system-code debugger. If this flag is clear, the initial breakpoints and calls to INI$BRK go to the system-code debugger. You cannot use XDELTA if the XDELTA flag is clear.

**Boot Command Example** The following command boots a DEC 3000 Model 400 from the dka0 disk, enables the system-code debugger, defaults to using XDELTA, and takes the initial system boot breakpoints:

```
>>> boot dka0,esa0 -fl 0,8006
```

You can set these devices and flags to be the default values so that you will not have to specify them each time you boot the system. On a DEC 3000 Model 400, use the following commands:

```
>>> set BOOTDEF_DEV dka0,esa0
>>> set BOOT_OSFLAGS 0,8006
```

### System-Code Debugger Configuration File

The system-code debugger target system reads a configuration file in SYS$SYSTEM named DBGTK$CONFIG.SYS. The first line of this file contains a default password, which must be specified by the host debug system to connect to the target. Other lines in this file are reserved by Digital. Note that you must create this file because Digital does not supply it. If this file does not exist, you cannot run the system-code debugger.

### XDELTA Commands

When the system is booted with the 8000 boot flag, the following two additional XDELTA commands are enabled:

- n,\xxxx;R Control System-Code Debugger connection

  This command can be used to do the following:

  - Change the password which the system-code debugger must present
  - Disconnect the current session from the system-code debugger
  - Give control to the remote debugger by simulating a call to INI$BRK
  - Any combination of these

  Optional string argument xxxx specifies the password that the system-code debugger must present for its connection to be accepted. If this argument is left out, the required password is unchanged. The initial password is taken from the first line of the SYS$SYSTEM::DBGTK$CONFIG.SYS file .

  The optional integer argument *n* controls the behavior of the ;R command as follows:

| Value of N | Action |
|---|---|
| +1 | Gives control to the system-code debugger by simulating a call to INI$BRK |
| +2 | Returns to XDELTA after changing the password. 2;R without a password is a no-op |
| 0 | Performs the default action |
| -1 | Changes the password, breaks any existing connection to the System Debugger and then simulates a call to INI$BRK (which will wait for a new connection to be established and then give control to the system-code debugger) |
| -2 | Returns to XDELTA after changing the password and breaking an existing connection |

  Currently, the default action is the same action as +1.

If the system-code debugger is already connected, the ;R command transfers control to the system-code debugger, and optionally changes the password that must be presented the next time a system-code debugger tries to make a connection. This new password does not last across a boot of the target system.

- n;K Change inibrK behavior

  If optional argument *n* is 1, future calls to INI$BRK will result in a breakpoint being taken by the system-code debugger. If the argument is 0, or no argument is specified, future calls to INI$BRK will result in a breakpoint being taken by XDELTA.

**Sysgen Parameters**

- **DBGTK_SCRATCH**

  This new parameter specifies how many pages of memory are allocated for the system-code debugger. This memory is allocated only if system-code debugging is enabled with the 8000 boot flag (described earlier in this section). Usually, the default value of 1 is adequate; however, if the system-code debugger issues an error message, increase this value.

- **SCSNODE**

  Identifies the target kernel node name for the system-code debugger. See Section 11.2.3.1 for more information.

#### 11.2.3.1 Making Connections Between the Target Kernel and the System-Code Debugger

It is always the system-code debugger that initiates a connection to the target kernel. When the system-code debugger initiates this connection, the target kernel accepts or rejects the connection based on whether the remote debugger presents it with a node name and password that matches the password in the target system (either the default password from the SYS$SYSTEM::DBGTK$CONFIG.SYS file, or a different password specified via XDELTA). The system-code debugger gets the node name from the SCSNODE Sysgen parameter.

The target kernel can accept a connection from the system-code debugger anytime the system is running below IPL 22, or if XDELTA is in control (at IPL 31) However, the target kernel actually waits at IPL 31 for a connection from the system-code debugger in two cases: When it has no existing connection to a system-code debugger and (1) It receives a breakpoint caused by a call to INI$BRK (including either of the initial breakpoints), or (2) when you issue a 1;R or -1;R command from XDELTA.

#### 11.2.3.2 Interactions between XDELTA and the Target Kernel/System-Code Debugger

XDELTA and the target kernel are integrated into the same system. Normally, you choose to use one or the other. However, XDELTA and the target kernel can be used together. This section explains how they interoperate.

The 0002 boot flag controls which debugger (XDELTA or the target kernel) gets control first. If it is not set, the target kernel gets control first, and it is not possible to use XDELTA without rebooting. If it is set, XDELTA gets control first, but you can use XDELTA commands to switch to the system-code debugger and to switch INI$BRK behavior such that the system-code debugger gets control when INI$BRK is called.

Breakpoints always *stick* to the debugger that set them. For example, if you set a breakpoint at location "A" with XDELTA, and then you issue the command 1;K (switch INI$BRK to the system-code debugger) and ;R (start using the system-code debugger). Then, from the system-code debugger, you set a breakpoint at location "B". If the system executes the breakpoint at A, XDELTA will report a breakpoint, and the remote debugger will see nothing (though you could switch the system-code debugger by issuing the XDELTA ;R command). If the system executes the breakpoint at B, the system-code debugger will get control and report a breakpoint (you cannot switch to XDELTA).

Notice that if you examine location A with the system-code debugger, or location B with XDELTA, you will see a BPT instruction, not the instruction that was originally there. This is because neither debugger has any information about the breakpoints set by the other debugger.

One useful way to use both debuggers together is when you have a system that exhibits a failure only after hours or days of heavy use. In this case, you can boot the system with the system-code debugger enabled (8000), but with XDELTA the default (0002) and with initial breakpoints enabled (0004). When you reach the initial breakpoint, set an XDELTA breakpoint at a location that will only be reached when the error occurs. Then proceed. When the error breakpoint is reached, possibly days later, then you can set up a remote system to debug it and issue the ;R command to XDELTA to switch control to the system-code debugger.

Here is another technique for use when you do not know where to put an error breakpoint as previously mentioned. Boot the system with only the 8000 flag. When you see that the error has happened, halt the system and initiate an IPL 14 interrupt, as you would to start XDELTA. The target kernel will get control and wait for a connection for the system-code debugger.

### 11.2.4 Setting Up the Host System

To set up the host system, you need access to all system images and drivers that are loaded (or can be loaded) on the target system. You should have access to a result disk or a copy of the following directories:

SYS$LOADABLE_IMAGES:
SYS$LIBRARY:
SYS$MESSAGE:

You need all the .EXE files in those directories. The .DSF files are available with the OpenVMS AXP source listings kit.

Optionally, you need access to the source files for the images to be debugged. The system-code debugger will look for the source files in the directory where they were compiled. If your build machine and host machine are different, you must use the SET SOURCE command to point the system-code debugger to location of the source code files. For an example of the SET SOURCE command, see Section 11.4.2. For more information about using the SET SOURCE command, see *OpenVMS Debugger Manual*.

To make the connection, you must set up the logical DBGHK$IMAGE_PATH, which must be set up as a search list to the area where the system images are kept. For example, if the copies are in the following directories,

```
DEVICE:[SYS$LDR]
DEVICE:[SYSLIB]
DEVICE:[SYS$MSG]
```

you would define DBGHK$IMAGE_PATH as follows:

```
$ define dbghk$image_path DEVICE:[SYS$LDR],DEVICE:[SYSLIB],DEVICE:[SYS$MSG]
```

This works well for debugging using all the images normally loaded on a given system. However, you might be using the debugger to test new code in an execlet or a new driver and might want to debug that new code. Because that image is most likely in your default directory, you must define the logical as follows:

```
$ define dbghk$image_path [],DEVICE:[SYS$LDR],DEVICE:[SYSLIB],DEVICE:[SYS$MSG]
```

If the system-code debugger cannot find one of the images through this search path, a warning message is displayed. The system-code debugger will continue initialization as long as it finds at least one image. If the system-code debugger cannot find the SYS$BASE_IMAGE file, which is the OpenVMS AXP operating system's main image file, an error message is displayed and the debugger exits.

Check the directory for the image files and compare it to what is loaded on the target system.

### 11.2.5 Starting the System-Code Debugger

To start the system-code debugger on the host side, enter the following command:

```
$ DEBUG/KEEP
```

The system-code debugger displays the DBG> prompt. With the DBGHK$IMAGE_PATH logical defined, you can invoke the CONNECT command and optional qualifiers /PASSWORD and /IMAGE_PATH.

To use the CONNECT command and optional qualifiers (/PASSWORD and /IMAGE_PATH) to connect to the node with name <node-name> enter the following command:

```
DBG> CONNECT %NODE_NAME node-name /PASSWORD="password"
```

If a password has been set up on the target system, you must use the /PASSWORD qualifier. If a password is not specified, a zero length string is passed to the target system as the password.

The /IMAGE_PATH qualifier is also optional. If you do not use this qualifier, the system-code debugger uses the DBGHK$IMAGE_PATH logical as the default. The /IMAGE_PATH qualifier is a quick way to change the logical. However, when you use it, you cannot specify a search list. You can use only a logical or a device and directory, although the new logical could be a search list.

Usually, the system-code debugger gets the file name from the object file. This is put there by the compiler when the source is compiled with the /DEBUG qualifier. The SET SOURCE command can take a list of paths as a parameter. It treats them as a search list.

### 11.2.6 Summary of OpenVMS Debugger Commands

The following OpenVMS Debugger commands can also be used with the system-code debugger:

DISPLAY
EXPAND
EXTRACT
MOVE

SAVE
SCROLL
SEARCH
SELECT
TYPE
SET MARGINS
SET SEARCH
SET WINDOW
CANCEL DISPLAY
CANCEL WINDOW
SHOW DISPLAY
SHOW MARGINS
SHOW SEARCH
SHOW SELECT
SHOW WINDOW

The following commands are useful for writing OpenVMS Debugger command programs and for adding new commands at run time:

DECLARE
DO
EXITLOOP
FOR
IF
REPEAT
WHILE

The following commands are useful for miscellaneous operations:

ATTACH
CTRL_C
CTRL_Y
EDIT
SPAWN
SET ABORT_KEY
SET ATSIGN
SET EDITOR
SET KEY
SET LOG
SET MODE
SET OUTPUT
SET PROMPT
SET RADIX
SET TERMINAL
CANCEL MODE
CANCEL RADIX
SHOW ABORT_KEY
SHOW ATSIGN
SHOW EDITOR
SHOW KEY
SHOW LOG
SHOW MODE
SHOW OUTPUT
SHOW RADIX
SHOW TERMINAL

The following commands manipulate symbols and source code for the debugged code. For example, you can use these commands to define new symbols, change the current scope (to a different image, module or routine), tell the debugger where the source code resides, and set the current language. The SHOW IMAGE command behaves like the XDELTA ;L command. The DEFINE command behaves in a similar way to the XDELTA ;X command.

DEFINE
DELETE
EVALUATE
SYMBOLIZE
SET DEFINE
SET IMAGE
SET LANGUAGE
SET SCOPE
SET MAX_SOURCE_FILES
SET SOURCE
SET TYPE
CANCEL IMAGE
CANCEL MODULE
CANCEL SCOPE
CANCEL SOURCE
CANCEL TYPE
SHOW DEFINE
SHOW IMAGE
SHOW LANGUAGE
SHOW SCOPE
SHOW MAX_SOURCE_FILES
SHOW SOURCE
SHOW SYMBOL
SHOW TYPE

The following commands make the user program (or the system-code debugger) execute code. The GO command is the same as the XDELTA ;P and ;G commands (GO takes an optional PC value). The STEP command is the same as the XDELTA S and O commands for single stepping. These commands are implemented in both the main and kernel sections of the debugger.

GO
RERUN
RUN
STEP
SET STEP
SHOW STEP

The following commands set, cancel, show and temporarily deactivate and activate breakpoints. These commands are the same as the XDELTA ;B command. However, unlike, XDELTA there is no limit on the number of breakpoints.

SET BREAK
CANCEL BREAK
SHOW BREAK
CANCEL ALL
ACTIVATE BREAK
DEACTIVATE BREAK

The following commands access the user programs' (or in this case the system-code debugger) memory and registers. The DEPOSIT and EXAMINE commands implement the following set of XDELTA commands: /, !, [, ", '.

DEPOSIT
EXAMINE
SHOW STACK
SHOW CALLS

### 11.2.7 System-Code Debugger Network Information

The system-code debugger and the target kernel on the target system use a private Ethernet protocol to communicate. For the two systems to see each other, they have to be on the same Ethernet segment.

The network portion of the target system finds the first Ethernet device and communicates through it. The network portion of the host system also finds the first Ethernet device and communicates through it. However, if for some reason, the system-code debugger picks the wrong device, you can override this by defining the logical DBGHK$ADAPTOR to the template device name for the appropriate adaptor.

## 11.3 Troubleshooting Checklist

If you have trouble starting a connection, perform the following tasks to correct the problem:

- Check SCSNODE on the target system.

  It must match the name you are using in the host CONNECT command.
- Make sure that both the Ethernet and boot device are on the boot command.
- Make sure that the host system is using the correct Ethernet device, and that the host and target systems are connected to the same Ethernet segment.
- Check the version of the operating system and make sure that both the host and target systems are running the same version (OpenVMS AXP Version 6.1).

## 11.4 Troubleshooting Network Failures

There are three possible network errors:

- NETRERTRY

  Displayed if the system-code debugger connection is lost.
- SENDRETRY

  Indicates a message send failure.
- NETFAIL

  Caused by the two previous messages.

The netfail error message has a status code that can be one of the following values:

| Value | Status |
|---|---|
| 2, 4, 6 | Internal network error, submit an SPR with the code. |
| 8,10,14,16,18,20,26,28,34,38 | Network protocol error, submit an SPR with the code. |
| 22,24 | Too many errors on the network device most likely due to congestion. Reduce the network traffic or switch to another network backbone. |
| 30 | Target system scratch memory not available. Check DBGTK_SCRATCH. If increasing this value does not help, submit an SPR. |
| 32 | Ran out of target system scratch memory. Increase value of DBGTK_SCRATCH. |
| All others | There should not be any other network error codes printed. If one occurs that does not match the above, submit an SPR. |

### 11.4.1 Access to Symbols in OpenVMS Executive Images

Accessing OpenVMS executive images' symbols is not always straightforward with the system-code debugger. Only a subset of the symbols may be accessible at one time and in some cases, the symbol value the debugger currently has may be stale. To understand these problems and their solutions, you must understand how the debugger maintains its symbol tables and what symbols exist in the OpenVMS executive images. The following sections briefly summarize these topics.

#### 11.4.1.1 Overview of How the OpenVMS Debugger Maintains Symbols

The debugger can access symbols from any image in the OpenVMS loaded system image list by either reading in the .DSF or .EXE file for that particular image. The .EXE file only contains information about symbols that are part of the symbol vector for that image. The current image symbols for any set module are defined. (You can tell if you have the .DSF or .EXE by doing a SHOW MODULE. If there are no modules you have the .EXE.) This includes any symbols in the SYS$BASE_IMAGE.EXE symbol vector for which the code or data resides in the current image. However, a user cannot access a symbol that is part of the SYS$BASE_IMAGE.EXE symbol vector that resides in another image.

In general, at any one point in time, the debugger can only access the symbols from one image. (A later section describes how to get around this limitation). It does this to reduce the time it takes to search for a symbol in a table. To load the symbols for a particular image, use the SET IMAGE command. When you set an image, the debugger loads all the symbols from the new image and makes that image the current image. The symbols from the previous image are in memory but the debugger will not look through it to translate symbols. To remove symbols from memory for an image, use the CANCEL IMAGE command (which does not work on the main image, SYS$BASE_IMAGE).

There is a set of modules for each image the debugger accesses. The symbol tables in the image that are part of these modules are not loaded with the SET IMAGE command. Instead they can be loaded with the SET MODULE module-name or SET MODULE/ALL commands. As they are loaded, a new symbol table is created in memory under the symbol table for the image. The following figure shows what this looks like:

```
Current Image
      ||
      \/
+===============+ +===============+ +===============+
|  | |  | |  |
 Symbol Table | | Symbol Table | | Symbol Table |
  for Image 1 |  .... | for Image N-1 | | for Image N |
|  | |  | |  |
+===============+ +===============+ +===============+
 ||   ||   ||
 /\   /\   /\
    ---------+  +-------------+     ....        ....
     |    |             |
 +--------+  +--------+    +--------+
 | Module |  | Module |    | Module |
 |   1    |  |   2    | .. |   M    |
 +--------+  +--------+    +--------+
```

So, when the debugger needs to translate a value into a symbol or a symbol into a value, it first looks at the current image to find the information. If it does not find it there, then it looks into the appropriate module. It determines which module is appropriate by looking at the module range symbols which are part of the image symbol table.

To see what symbols are currently loaded, use the DEBUG SHOW SYMBOL command. This command has a few options to get more than just the symbol name and value. See the *OpenVMS Debugger Manual* for more details.

#### 11.4.1.2 Overview of OpenVMS Executive Image Symbols

Depending on whether the debugger has access to the .DSF or .EXE file, different kinds of symbols could be loaded. Most users will have the .EXE file for the OpenVMS executive images and a .DSF file for their private images—that is, the images they are debugging.

The OpenVMS executive consists of two base images, SYS$BASE_IMAGE.EXE and SYS$PUBLIC_VECTORS.EXE, and a number of separately loadable executive images.

The two base images contain symbol vectors. For SYS$BASE_IMAGE.EXE the symbol vector is used to define symbols accessible by all the separately loadable images. This allows these images to communicate with each other through cross-image routine calls and memory references. For SYS$PUBLIC_VECTORS.EXE, the symbol vector is used to define the OpenVMS system services. Because these symbol vectors are in the .EXE and the .DSF files, the debugger can load these symbols no matter which one the user has.

All images in the OpenVMS executive also contain global and local symbols. However, none of these symbols ever get into the .EXE file for the image. These symbols are put in the specific modules section of the .DSF file if that module was compiled /DEBUG and the image was linked /DSF.

#### 11.4.1.3 Possible Problems You May Encounter

- **Access to All Executive Image Symbols**

  When the current image is not SYS$BASE_IMAGE, but one of the separately loaded images, the debugger does not have access to any of the symbols in the SYS$BASE_IMAGE symbol vector. This means the user cannot access (set break points, etc.) any of the cross-image routines or data cells. The only symbols the user has access to are the ones defined by the current image.

If the debugger only has access to the .EXE file, this means no symbols at all for images with no symbol vectors. For .DSF files, the current image symbols for any set module are defined. (You can tell if you have the .DSF or .EXE by using the SHOW MODULE command—if there are no modules you have the .EXE). This includes any symbols in the SYS$BASE_IMAGE.EXE symbol vector for which the code or data resides in the current image. However, the user cannot access a symbol that is part of the SYS$BASE_IMAGE.EXE symbol vector that resides in another image. For example, if you are in one image and you want to set a break point in a cross-image routine from another image, you do not have access to the symbol. Of course, if you know which image it is defined in, you can just do a SET IMAGE, SET MODULE /ALL and then a SET BREAK.

There is a debugger workaround for this problem. The debugger and the system-code debugger let you use the SET MODULE command on an image by prefixing the image name with SHARE$ (SHARE$SYS$BASE_IMAGE for example). This treats that image as a module which is part of the current image. In the previous figure, think of it as another module in the module list for an image. Note, however, that only the symbols for the symbol vector are loaded. None of the symbols for the modules of the SHARE$xxx image are loaded. Therefore, this command is only useful for base images.

So in other words, by doing SET MODULE SHARE$SYS$BASE_IMAGE, the debugger gives you access to all cross-image symbols for the VMS Executive.

- **Stale Data From the Symbol Vector**

  When an OpenVMS Executive Based Image is loaded, the values in the symbol vectors are only correct for information that resides in that based image. For all symbols that are defined in the separately loaded images, it contains a pointer to a placeholder location. For routine symbols this is a routine that just returns an image not loaded failure code. A symbol vector entry is fixed to contain the real symbol address when the image in which the data resides is loaded.

  Therefore, if the user does a SET IMAGE to a base image before the all the symbol entries are corrected, it will get the placeholder value for those symbols. Then once the image containing the real data is loaded, the debugger will still have the placeholder value. This means the user is looking at stale data. One solution to this is to make sure to do a CANCEL IMAGE and SET IMAGE on the based image in order to get the most up to date symbol vector loaded into memory.

  The CANCEL IMAGE/SET IMAGE combination does not currently work for SYS$BASE_IMAGE because it is the main image and DEBUG does not allow you to CANCEL the main image. Therefore, if you connect to the target system early in the boot process, you will have stale data as part of the SYS$BASE_IMAGE symbol table. However, the SET MODULE SHARE$xxx command always re-loads the information from the symbol vector. So to get around this problem you could SET IMAGE to an image other than SYS$BASE_IMAGE and then do use CANCEL MODULE SHARE$SYS$BASE_IMAGE and SET MODULE SHARE$SYS$BASE_IMAGE to do the same thing. The only other solution is to always connect to the target system once all images are loaded which define the real data for values in the symbol vectors. You could also enter the following commands, and you would get the latest values from in the symbol vector.

```
SET IMAGE EXEC_INIT
SET MODULE/ALL
SET MODULE SHARE$SYS$BASE_IMAGE
```

- **Problems with SYS$BASE_IMAGE.DSF**

  For those that have access to the SYS$BASE_IMAGE.DSF file, there may be another complication with accessing symbols from the symbol vector. The problem is that the module SYSTEM_ROUTINES contains the placeholder values for each symbol in the symbol vector. So, if SYSTEM_ROUTINES is the currently set module (which is the case if you are sitting at the INI$BRK break point) then the debugger will have the placeholder value of the symbol as well as the value in the symbol vector. You can see what values are loaded with the SHOW SYMBOL/ADDRESS command. The symbol vector version should be marked with (global), the local one is not.

  To set a break point at the correct code address for a routine when in this state, use the SHOW SYMBOL/ADDRESS command on the routine symbol name. If the global and local values for the code address are the same, then the image with the routine has not been loaded yet. If not, set a break point at the code address for the global symbol.

### 11.4.2 Sample System-Code Debugging Session

This section provides a sample session that shows the use of some DEBUG commands as they apply to the system-code debugger. The examples in this session show how to work with C code that has been linked into the SYSTEM_DEBUG execlet. It is called as an initialization routine for SYSTEM_DEBUG.

To reproduce this sample session, you need access to the SYSTEM_DEBUG.DSF matching the SYSTEM_DEBUG.EXE file on your target system and to the source file C_TEST_ROUTINES.C, which is available in SYS$EXAMPLES. The target system is booted with the command bootflags 0, 8004 DKA0, ESA0, so it stops at an initial breakpoint.

The example begins by invoking the system-code debugger's character cell interface.

**Example 11–1 Invoking the System-Code Debugger**

```
$ define dbg$decw$display " " ! Don't use Motif version
$ debug/keep

         OpenVMS Alpha AXP DEBUG Version T2.0-001

DBG>
```

Use the CONNECT command to connect to the target system. In this example, a password is not set up, and the example uses the logical DBGHK$IMAGE_PATH for the image path; those qualifiers are not being used. You may need to use them.

When you have connected to the target system, the DEBUG prompt is displayed. Enter the SHOW IMAGE command to see what has been loaded. Because you are reaching a breakpoint early in the boot process, there are very few images. See Example 11–2. Notice that SYS$BASE_IMAGE has an asterisk next to it. This is the currently set image and all symbols currently loaded in the debugger come from that image.

### Example 11–2 Connecting to the Target System

```
DBG> connect %node_name TSTSYS
%DEBUG-I-EXPMEMPOOL, expanding debugger memory pool
DBG> sho image

 image name                      set    base address    end address

 ERRORLOG                        no     00000000        0000E000
    NPRO0                               8005C000        8005EE00
    NPRW1                               80830200        80830800
 EXEC_INIT                       no     8234C000        82366000
*SYS$BASE_IMAGE                  yes    00000000        00028000
    NPRO0                               80002000        8000CA00
    NPRW1                               80804000        8081EA00
 SYS$CNBTDRIVER                  no     00000000        0000C000
    NPRO0                               8000E000        8000F400
    NPRW1                               8081EA00        8081EE00
 SYS$CPU_ROUTINES_0402           no     00000000        00016000
    NPRO0                               80060000        80068E00
    NPRW1                               80830800        80833200
 SYS$OPDRIVER                    no     00000000        00030000
    NPRO0                               80010000        80013C00
    NPRW1                               8081EE00        8081F800
 SYS$PUBLIC_VECTORS              no     00000000        00008000
    NPRO0                               80000000        80001600
    NPRW1                               80800000        80804000
 SYSTEM_DEBUG                    no     00000000        00034000
    NPRO0                               80014000        80034C00
    NPRW1                               8081F800        80827C00
 SYSTEM_PRIMITIVES               no     00000000        0002A000
    NPRO0                               80036000        80050200
    NPRW1                               80827C00        8082E400
 SYSTEM_SYNCHRONIZATION          no     00000000        00016000
    NPRO0                               80052000        8005BA00
    NPRW1                               8082E400        80830200

 total images: 10                bytes allocated: 517064
```

Example 11–3 shows the console display during the connect sequence. Note that for security reasons, the name of the host system, the user's name, and process ID is displayed.

### Example 11–3 Target System Connection Display

```
DBGTK: Initialization succeeded.  Remote system debugging is now possible.
DBGTK: Waiting at breakpoint for connection from remote host.
DBGTK: Connection attempt from host HSTSYS   user GUEST      process 45800572
DBGTK: Connection attempt succeeded
```

### Example 11–4 Setting a Breakpoint

(continued on next page)

**Example 11–4 (Cont.) Setting a Breakpoint**

```
DBG> set image system_debug
DBG> show module
module name                     symbols    size

C_TEST_ROUTINES                 no         2152
FATAL_EXC                       no         3116
SERVER_NET                      no         2632
TARGET_KERNEL                   no        18296

total C modules: 5.             bytes allocated: 549256.
DBG> set module c_test_routines
DBG> show module
module name                     symbols    size

C_TEST_ROUTINES                 yes        2152
FATAL_EXC                       no         3116
SERVER_NET                      no         2632
TARGET_KERNEL                   no        18296

total C modules: 5.             bytes allocated: 553848.
DBG> set language c
DBG> show symbol test_c_code*
routine C_TEST_ROUTINES\test_c_code3
routine C_TEST_ROUTINES\test_c_code2
routine C_TEST_ROUTINES\test_c_code
DBG> set break test_c_code
DBG> sho break
breakpoint at routine C_TEST_ROUTINES\test_c_code
```

To set a breakpoint at the first routine in the C_TEST_ROUTINES module of the SYSTEM_DEBUG.EXE execlet, do the following:

1. Load the symbols for the SYSTEM_DEBUG image with the DEBUG SET IMAGE command.
2. Use the SET MODULE command to get the symbols for the module.
3. Set the language to be C and set a breakpoint at the routine test_c_code.

   The language must be set because C is case sensitive and test_c_code needs to be specified in lower case. The language is normally set to the language of the main image, in this example SYS$BASE_IMAGE.EXE. Currently that is not C.

Now that the breakpoint is set, you can proceed and activate the breakpoint. When that occurs, the debugger tries to open the source code for that location in the same place as where the module was compiled. Because that is not the same place as on your system, you need to tell the debugger where to find the source code. This is done with the DEBUG SET SOURCE command, which takes a search list as a parameter so you can make it point to many places.

**Example 11–5 Finding the Source Code**

```
DBG> go
break at routine C_TEST_ROUTINES\test_c_code
%DEBUG-W-UNAOPNSRC, unable to open source file DSKD$:[DELTA.SRC]C_TEST_ROUTINES.
C;*
-RMS-F-DEV, error in device name or inappropriate device type for operation
    80: Source line not available
DBG> set source sys$examples:
```

Now that the debugger has access to the source, you can put the debugger into screen mode to see exactly where you are and the code surrounding it.

**Example 11–6 Using the Set Mode Screen Command**

```
DBG> Set Mode Screen; Set Step Nosource

- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
    68:     xdt$fregsav[3] = test;
    69:     return xdt$fregsav[23];
    70: }
    71: void test_c_code(void)
    72: {
    73:     int x,y;
    74:     int64 x64,y64;
    75:
->  76:     x = xdt$fregsav[0];
    77:     y = xdt$fregsav[1];
    78:     x64 = xdt$fregsav[2];
    79:     y64 = xdt$fregsav[3];
    80:     xdt$fregsav[14] = test_c_code2(x64+y64,x+y,x64+x,&y64);
    81:     return;
    82: }
- OUT -output-------------------------------------------------------------------



- PROMPT -error-program-prompt--------------------------------------------------




DBG>
```

Now, you want to set another breakpoint inside the test_c_code3 routine. You use the SCROLL/UP DEBUG command (8 on the keypad) to move to that routine and see that line 56 would be a good place to set the breakpoint. It is at a recursive call. Then you proceed to that breakpoint with the GO command.

**Example 11–7 Using the SCROLL/UP DEBUG Command**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    44: Source line not available
    45: Source line not available
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
    56:         subrtnCount = test_c_code3(subrtnCount);
    57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
- OUT -output-------------------------------------------------------------------









- PROMPT -error-program-prompt--------------------------------------------------


DBG> Scroll/Up
DBG> set break %Line 56
DBG> go
DBG>
```

When you reach that breakpoint, the source code display is updated to show where you currently are, which is indicated by an arrow. A message also appears in the OUT display indicating you reach the breakpoint at that line.

**Example 11–8 Break Point Display**

```
- SRC: module C_TEST_ROUTINES -------------------------------------------------
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
->  56:         subrtnCount = test_c_code3(subrtnCount);
    57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
- OUT -output------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56







- PROMPT -error-program-prompt-------------------------------------------------


DBG> Scroll/Up
DBG> set break %Line 56
DBG> go
DBG>
```

Now you try the DEBUG STEP command. The default behavior for STEP is STEP/OVER unlike XDELTA and DELTA which is STEP/INTO. So normally you would expect to step to line 57 in the code. However, because you have a breakpoint inside test_c_code3 that is called at line 56, you will reach that event first.

**Example 11–9 Using the Debug Step Command**

```
- SRC: module C_TEST_ROUTINES -scroll-source-----------------------------------
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
->  56:         subrtnCount = test_c_code3(subrtnCount);
    57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
- OUT -output------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
break at C_TEST_ROUTINES\test_c_code3\%LINE 56






- PROMPT -error-program-prompt--------------------------------------------------

DBG> Scroll/Up
DBG> set break %Line 56
DBG> go
DBG> step
DBG>
```

Now, you try a couple of other commands, EXAMINE and SHOW CALLS. The EXAMINE command allows you to look at all the C variables. Note that the C_TEST_ROUTINES module is compiled with the /NOOPTIMIZE switch which allows access to all variables. The SHOW CALLS command shows you the call sequence from the beginning of the stack. In this case, you started out in the image EXEC_INIT. (The debugger prefixes all images other than the main image with SHARE$ so it shows up as SHARE$EXEC_INIT.)

**Example 11–10 Using the Examine and Show Calls Commands**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
->  56:         subrtnCount = test_c_code3(subrtnCount);
    57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
- OUT -output-------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
C_TEST_ROUTINES\test_c_code3\subrtnCount:      8
 module name     routine name                     line       rel PC    abs PC
*C_TEST_ROUTINES test_c_code3                       56      0000002C  8002A7CC
*C_TEST_ROUTINES test_c_code3                       56      0000003C  8002A7DC
*C_TEST_ROUTINES test_c_code2                       67      000000AC  8002A8A4
*C_TEST_ROUTINES test_c_code                        80      00000084  8002A960
                                                            00000000  8234A244
                                                            00000000  8234A0C0
 SHARE$EXEC_INIT                                            00000000  82379BC4


- PROMPT -error-program-prompt--------------------------------------------------
DBG> Scroll/Up
DBG> set break %Line 56
DBG> go
DBG> step
DBG> examine subrtnCount
DBG> show calls
DBG>
```

If you want to proceed because you are done debugging this code, first cancel all the breakpoints and then enter the GO command. Notice however, that you do not keep running but get a message that you have stepped to line 57. This happens because the STEP command used earlier never completed. It was interrupted by the breakpoint on line 56.

Note that the debugger remembers all step events and only removes them once they have completed.

**Example 11–11 Canceling the Breakpoints**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
    56:         subrtnCount = test_c_code3(subrtnCount);
->  57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
    68:     xdt$fregsav[3] = test;
- OUT -output-------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
C_TEST_ROUTINES\test_c_code3\subrtnCount:      8
 module name     routine name                     line       rel PC    abs PC
*C_TEST_ROUTINES test_c_code3                       56      0000002C  8002A7CC
*C_TEST_ROUTINES test_c_code3                       56      0000003C  8002A7DC
*C_TEST_ROUTINES test_c_code2                       67      000000AC  8002A8A4
*C_TEST_ROUTINES test_c_code                        80      00000084  8002A960
                                                            00000000  8234A244
                                                            00000000  8234A0C0
 SHARE$EXEC_INIT                                            00000000  82379BC4
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 57

- PROMPT -error-program-prompt--------------------------------------------------
DBG> go
DBG> step
DBG> examine subrtnCount
DBG> show calls
DBG> cancel break/all
DBG> go
DBG>
```

Next, issue a STEP command when sitting at a return statement. Returns are branches on OpenVMS AXP; however the debugger treats them as a special case. So, for branches the default is STEP/OVER; however for return instructions the default is STEP/INTO. You pop back up a level and are now sitting at an event point at line 56.

The reason you we are at line 56 and not line 57 is that you have returned from the subroutine; however you have not stored the result in subrtnCount yet.

**Example 11–12 Using the Step Command**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                use iregsav because the debugger will r
    50:                                be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
->  56:         subrtnCount = test_c_code3(subrtnCount);
    57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
- OUT -output-------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
C_TEST_ROUTINES\test_c_code3\subrtnCount:      8
 module name     routine name                     line       rel PC    abs PC
*C_TEST_ROUTINES test_c_code3                       56      0000002C  8002A7CC
*C_TEST_ROUTINES test_c_code3                       56      0000003C  8002A7DC
*C_TEST_ROUTINES test_c_code2                       67      000000AC  8002A8A4
*C_TEST_ROUTINES test_c_code                        80      00000084  8002A960
                                                            00000000  8234A244
                                                            00000000  8234A0C0
 SHARE$EXEC_INIT                                            00000000  82379BC4
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 57
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 56

- PROMPT -error-program-prompt--------------------------------------------------
DBG> step
DBG> examine subrtnCount
DBG> show calls
DBG> cancel break/all
DBG> go
DBG> step
DBG>
```

The STEP/RETURN command, a different type of step command, single steps assembly code until it finds a return instruction. This command is useful if you want to see the return value for the routine, which is done here by examining the R0 register.

For more information about using other STEP command qualifiers, see the *OpenVMS Debugger Manual*. For other useful STEP qualifiers, see the DEBUG documentation for more details.

**Example 11–13 Using the Step/Return Command**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
    56:         subrtnCount = test_c_code3(subrtnCount);
->  57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
    66:         *pVar = (*pVar + xdt$fregsav[17]);
    67:     xdt$fregsav[7] = test_c_code3(10);
    68:     xdt$fregsav[3] = test;
- OUT -output-------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
C_TEST_ROUTINES\test_c_code3\subrtnCount:       8
 module name     routine name                     line       rel PC    abs PC
*C_TEST_ROUTINES test_c_code3                       56      0000002C  8002A7CC
*C_TEST_ROUTINES test_c_code3                       56      0000003C  8002A7DC
*C_TEST_ROUTINES test_c_code2                       67      000000AC  8002A8A4
*C_TEST_ROUTINES test_c_code                        80      00000084  8002A960
                                                            00000000  8234A244
                                                            00000000  8234A0C0
 SHARE$EXEC_INIT                                            00000000  82379BC4
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 57
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 56
stepped on return from C_TEST_ROUTINES\test_c_code3\%LINE 56+16 to C_TEST_ROUTI
C_TEST_ROUTINES\test_c_code3\%R0:       0
- PROMPT -error-program-prompt--------------------------------------------------
DBG> show calls
DBG> cancel break/all
DBG> go
DBG> step
DBG> step/return
DBG> examine r0
DBG>
```

After you finish the system-code debugging session, enter the GO command to leave this module. You will encounteranother INI$BRK breakpoint at the end of init. An error message indicating there are no source lines for address 80002010 is displayed, because debug information on this image or module is not available. The debugger leaves the source code for C_TEST_ROUTINES on the screen; however, it is not valid.

Also notice that there is no message in the OUT display for this event. That is because INI$BRK's are special breakpoints that are handled as SS$_DEBUG signals. They are a method for the system code to break into the debugger and there is no real breakpoint in the code.

**Example 11–14 Source Lines Error Message**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
%DEBUG-W-SCRNOSRCLIN, no source line for address 80002010 for display in SRC
    45: Source line not available
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
    56:         subrtnCount = test_c_code3(subrtnCount);
->  57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
--------------------------------------------------------------------------------
break at C_TEST_ROUTINES\test_c_code3\%LINE 56
C_TEST_ROUTINES\test_c_code3\subrtnCount:      8
 module name     routine name                     line       rel PC    abs PC
*C_TEST_ROUTINES test_c_code3                       56      0000002C  8002A7CC
*C_TEST_ROUTINES test_c_code3                       56      0000003C  8002A7DC
*C_TEST_ROUTINES test_c_code2                       67      000000AC  8002A8A4
*C_TEST_ROUTINES test_c_code                        80      00000084  8002A960
                                                            00000000  8234A244
                                                            00000000  8234A0C0
 SHARE$EXEC_INIT                                            00000000  82379BC4
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 57
stepped to C_TEST_ROUTINES\test_c_code3\%LINE 56
stepped on return from C_TEST_ROUTINES\test_c_code3\%LINE 56+16 to C_TEST_ROUTI
C_TEST_ROUTINES\test_c_code3\%R0:      0
- PROMPT -error-program-prompt--------------------------------------------------
DBG> cancel break/all
DBG> go
DBG> step
DBG> step/return
DBG> examine r0
DBG> go
DBG>
```

If you enter GO, the target system boots completely, because there are no more breakpoints in the boot path. The debugger will wait for another event to occur.

If you enter the SHOW IMAGE command, more images are displayed.

**Example 11–15 Using the Show Image Command**

```
- SRC: module C_TEST_ROUTINES -scroll-source------------------------------------
%DEBUG-W-SCRNOSRCLIN, no source line for address 80002010 for display in SRC
    45: Source line not available
    46: Source line not available
    47: #pragma noinline(test_c_code,test_c_code2,test_c_code3)
    48: extern volatile int64 xdt$fregsav[34]; /* Lie and say these are integer
    49:                                 use iregsav because the debugger will r
    50:                                 be using those!*/
    51:
    52: int test_c_code3(int subrtnCount)
    53: {
    54:     subrtnCount = subrtnCount - 1;
    55:     if (subrtnCount != 0)
    56:         subrtnCount = test_c_code3(subrtnCount);
->  57:     return subrtnCount;
    58: }
    59: int test_c_code2(int64 in64,int in32, int64 test, int64* pVar)
    60: {
    61:     xdt$fregsav[5] = in64;
    62:     xdt$fregsav[6] = in32;
    63:     if (xdt$fregsav[9] > 0)
    64:         *pVar =  (*pVar + xdt$fregsav[17])%xdt$fregsav[9];
    65:     else
--------------------------------------------------------------------------------
    NPRW0                               80852C00        80853000
    PRO1                                824AA000        824ADE00
    PRW2                                824AE000        824AE600
*SYSTEM_DEBUG                   yes     00000000        00034000
    NPRO0                               80028000        80048C00
    NPRW1                               80823200        8082B600
 SYSTEM_PRIMITIVES              no      00000000        0002A000
    NPRO0                               8004A000        80064200
    NPRW1                               8082B600        80831E00
 SYSTEM_SYNCHRONIZATION         no      00000000        00016000
    NPRO0                               80066000        8006FA00
    NPRW1                               80831E00        80833C00

 total images: 43               bytes allocated: 713656
- PROMPT -error-program-prompt--------------------------------------------------
DBG> go
DBG> step
DBG> step/return
DBG> examine r0
DBG> go
DBG> show image
DBG>
```

# 12 TURBOchannel Bus Support

This chapter discusses TURBOchannel support in the OpenVMS AXP operating system and describes TURBOchannel concepts and implementations on AXP platforms.

## 12.1 TURBOchannel Overview

The TURBOchannel is a synchronous I/O bus with a 32 bit multiplexed address and data path. It can operate at clock frequencies from 12.5 to 25 MHz with a peak DMA bandwidth of 100 Mbytes per second. The TURBOchannel architecture distinguishes between a system module, containing the processor /memory system, and option modules, which are generally I/O controllers. The TURBOchannel is asymmetric, in that the system module can read or write option modules and option modules can read or write the system module, but direct communication between option modules is not allowed.

Option modules occupy TURBOchannel backplane slots. The backplane slot determines the base address of the option module. Each slot has from 4 to 512 Mbytes of address space. The actual address space allocated to each TURBOchannel slot and the base address of each slot is system specific. The TURBOchannel supports the notion of integral options, which are logical TURBOchannel options, physically implemented on the system module, that do not occupy backplane slots. I/O transactions on the TURBOchannel are defined as loads and stores from the system module to option module addresses. I/O transaction addresses on the TURBOchannel are 29 bits, with the two least significant bits implicitly zero. DMA transactions on the TURBOchannel are defined as option module reads and writes to system memory. The TURBOchannel architecture defines a 34 bit byte address, with the two least significant bits implicitly zero, for DMA address space. The actual DMA address space is system specific. All TURBOchannel DMA transfers are in units of 32 bit longwords, and can be of any length up to a system specific limit. Interrupts on the TURBOchannel are associated with the TURBOchannel slots and are level sensitive. The interrupt priority of each slot is system specific. An option must maintain its interrupt signal until software explicitly clears the interrupt condition at the option. All TURBOchannel options must implement an Option ROM, which contains information about the option module.

## 12.2 TURBOchannel on DEC 3000 Model 500

The following sections cover the DEC 3000 Model 500 TURBOchannel address map, DEC 3000 Model 500 TURBOchannel dense and sparse space addressing, register access, DMA and map register support, bus interface hardware registers, I/O space mapping, and loading a driver for a TURBOchannel option.

### 12.2.1 DEC 3000 Model 500 TURBOchannel Address Map

The TURBOchannel bus on a DEC 3000 Model 500 system contains 6 option slots, labelled 0-5 by OpenVMS AXP. The TURBOchannel address map for DEC 3000 Model 500 is shown below:

```
DEC 3000 Model 500 TURBOchannel Address Map

Slot      Base Physical Addresse       Space

  0       1 0000 0000       128 MB     Slot 0 Dense space

          1 0800 0000       128 MB     Reserved
          1 1000 0000       256 MB     Slot 0 Sparse space

  1       1 2000 0000       128 MB     Slot 1 Dense space

          1 2800 0000       128 MB     Reserved
          1 3000 0000       256 MB     Slot 1 Sparse space

  2       1 4000 0000       128 MB     Slot 2 Dense space

          1 4800 0000       128 MB     Reserved
          1 5000 0000       256 MB     Slot 2 Sparse space

  3       1 6000 0000       128 MB     Slot 3 Dense space

          1 6800 0000       128 MB     Reserved
          1 7000 0000       256 MB     Slot 3 Sparse space

  4       1 8000 0000       128 MB     Slot 4 Dense space

          1 8800 0000       128 MB     Reserved
          1 9000 0000       256 MB     Slot 4 Sparse space

  5       1 A000 0000       128 MB     Slot 5 Dense space

          1 A800 0000       128 MB     Reserved
          1 B000 0000       256 MB     Slot 5 Sparse space
```

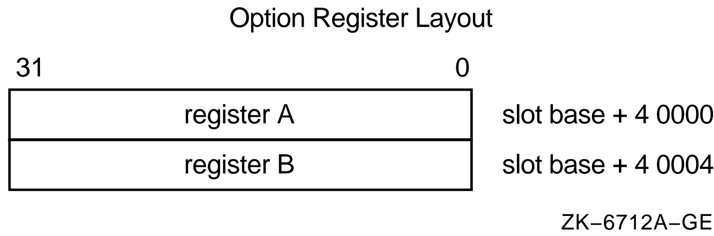
DEC 3000 Model 500 also contains 3 integral options–the integrated SCSI adapter (TURBOchannel slot 6), the Core I/O subsystem (TURBOchannel slot 7), and an integrated graphics controller (TURBOchannel slot 8). Symbols defining the slot base physical addresses for the TURBOchannel on DEC 3000 Model 500 can be found in file [LIB.LIS]IO0402DEF.SDL. These symbols are of the form IO0402$Q_SLOTx_DENSE_BASE or IO0402$Q_SLOTx_SPARSE_BASE.

### 12.2.2 Dense and Sparse Space Addressing

The DEC 3000 Model 500 TURBOchannel bus interface hardware maps every byte of TURBOchannel address space into two distinct address spaces. These address spaces are called dense and sparse address space. Dense space addresses correspond to "normal" addresses, where successive longword addresses are 4 bytes apart. In sparse space, the address space has been expanded by a factor of two, so that successive longword addresses are actually 8 bytes apart. This allows space for a byte mask to be supplied on I/O write transactions. This can be better illustrated by an example.

Suppose an option implements two longword registers as shown in Figure 12–1.

**Figure 12–1 Option Register Layout**




If this option was installed in slot 0 in the DEC 3000 Model 500 TURBOchannel, the option registers would appear at two different physical addresses, as shown in Figure 12–2 and Figure 12–3.

**Figure 12–2 Option Register Layout—Dense Space**

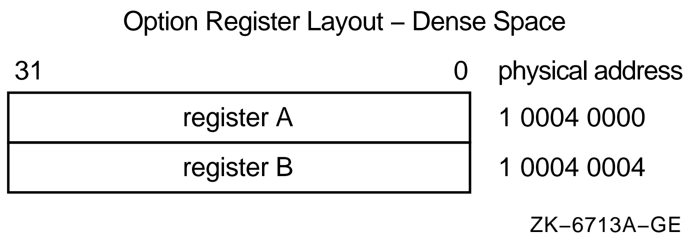
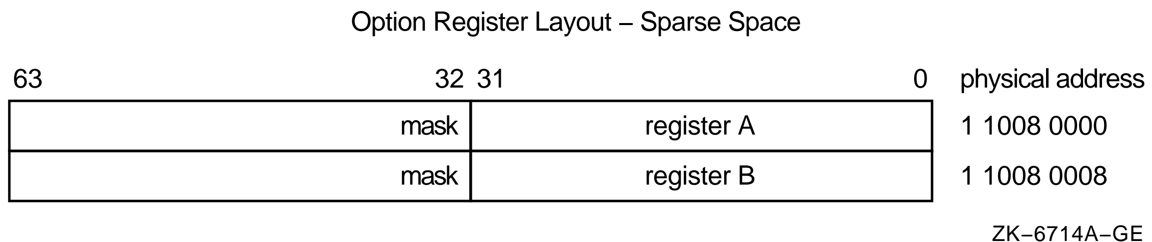



**Figure 12–3 Option Register Layout—Sparse Space**




---

**Note**

Option space addresses are expanded by a factor of two in sparse space. To convert from a dense space address to an equivalent sparse space address, set bit 28 of the physical address and shift 26:0 left by one bit. In sparse space, bits 35:32 of the data longword are used as a byte mask on write transactions. Byte mask bit set to a 1 causes corresponding data byte to be written.

---

The access characteristics of dense space and sparse space are different. In general, LDL/STL/LDQ/STQ are legal in either dense or sparse space. The main reason for having sparse space is that it allows the programmer to specify a byte mask for I/O write transactions, which allows byte write granularity. The following general guidelines apply to sparse and dense space access:

- To read a longword from an option register, use a LDL to the sparse space address.
- To write a longword to an option register, use a STL to either the dense or sparse space address.
- To write 1-3 bytes to an option register, use a STQ to the sparse space address with the appropriate mask bits set in the upper longword of the data quadword (mask bit equal to a 1 causes corresponding data byte to be written).
- LDL or LDQ to a dense space address always results in two TURBOchannel I/O read transactions to consecutive longword addresses Use caution in dense space if the option has registers with read side effects.
- STQ to a dense space address causes two TURBOchannel I/O write transactions to consecutive longword addresses. This may result in writing more data than intended.

### 12.2.3 DEC 3000 Model 500 TURBOchannel Register Access

DEC 3000 Model 500 does not implement hardware mailboxes for I/O register access. To reference a TURBOchannel option module register, the option slot address space must be mapped into the processors' virtual address space. The option registers can then be accessed using load or store instructions. This is an example of direct register access.

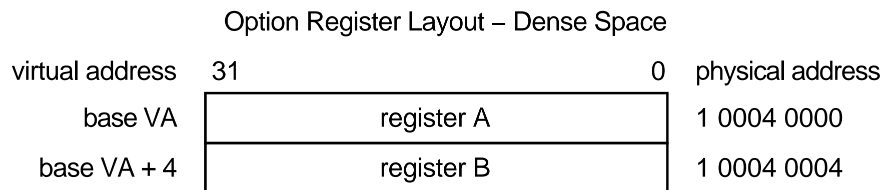
However, the OpenVMS AXP mailbox data structures and routines can still be used for I/O register access. The following sections give examples of how to access registers directly or through CRAMs.

#### 12.2.3.1 Direct Register Access on DEC 3000 Model 500 TURBOchannel

On DEC 3000 Model 500, a programmer can access registers directly, use the OpenVMS AXP CRAM routines, or use IOC$READ_IO and IOC$WRITE_IO. For direct access, the programmer must decide in which space (sparse or dense) to map the registers. Then, registers can be accessed using load and store instructions.

Consider the previous example of the option with two registers. To access these registers in dense space, the programmer should map the option into virtual address space as shown in Figure 12–4.

**Figure 12–4 Option Register Layout—Dense Space**




Register A and B now can be accessed in a number of ways, with somewhat different results. In the following examples, assume the base VA has been loaded into register R0. A.LDL R1, (R0)

Two TURBOchannel I/O read transactions are issued. Register A and register B are both read. The data from register A is sign extended and returned in bits 31:0 of R1. The data from register B is discarded.

```
B.LDQ   R1, (R0)
```

Two TURBOchannel read transactions are issued. Register A and register B are both read. The data from register A is returned in bits 31:0 of R1, and the data from register B is returned in bits 63:32 of R1.

```
C.STL   R1, (R0)
```

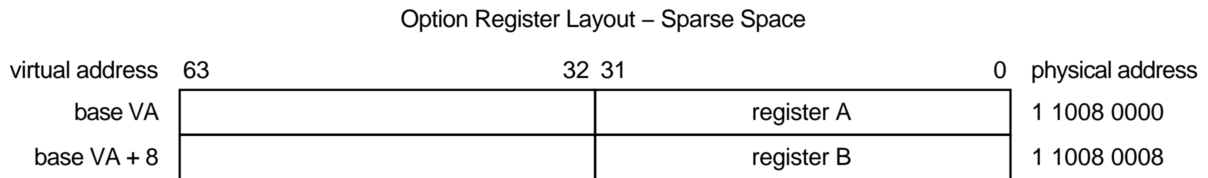
Two TURBOchannel write transactions are issued. Bits 31:0 of R1 are written to both register A and register B.

```
D.STQ   R1, (R0)
```

Two TURBOchannel write transactions are issued. Bits 31:0 of R1 are written to register A, and bits 63:32 of R1 are written to register B.

Now suppose that the registers are mapped in sparse space, as shown in Figure 12–5.

**Figure 12–5 Option Register Layout—Sparse Space**




In sparse space, the register access behaviour is as follows. Assume the base VA is contained in R0.

```
A.LDL   R1, (R0)
```

Register A is read. The data from register A is sign extended and returned in bits 31:0 of R1.

```
B.LDQ   R1, (R0)
```

Register A is read. The data from register A is returned in bits 31:0 and in bits 63:32 of R1.

```
C.STL   R1, (R0)
```

Bits 31:0 of R1 are stored in register A.

```
D.STQ   R1, (R0)
```

1-4 bytes of the data in R1 are stored in register A, depending on the byte mask in bits 35:32 of R1. A "1" in the byte mask causes the corresponding byte to be written.

As can be seen from the above examples, the access characteristics of each space are different. These characteristics must be considered when deciding how to do option register access.

#### 12.2.3.2 Mailbox Register Access on DEC 3000 Model 500 TURBOchannel

DEC 3000 Model 500 does not implement hardware mailboxes as described in the Alpha SRM. However, OpenVMS AXP still provides the CRAM data structures and CRAM routines for I/O register access on DEC 3000 Model 500 TURBOchannel. Basically, IOC$CRAM_CMD is used to specify the transaction type and length, and then the IOC$CRAM_IO routine issues the appropriate load or store instruction based on the command field in the CRAM. There is no MBPR, the mailbox is not actually queued to an I/O bridge, and there is no need to wait for the DONE bit. The actual access is accomplished by a load or a store directed to an address in the processors' virtual address space, exactly as in direct access. On DEC 3000 Model 500, IOC$CRAM_QUEUE simply calls IOC$CRAM_IO, and IOC$CRAM_WAIT simply returns SS$_NORMAL.

For I/O register access, the OpenVMS/AXP CRAM routines expect the option registers to be mapped into sparse space. Sparse space was chosen as the design center for IOC$CRAM_CMD on DEC 3000 Model 500/TURBOchannel because it allows byte write granularity and avoids dense space side effects. Before performing any kind of register access on DEC 3000 Model 500 TURBOchannel, the option registers must be mapped into the processors' virtual address space. Thus the driver must be told the base physical address of the TURBOchannel slot into which its option is installed. When a driver is loaded using the SYSMAN IO CONNECT command, the value specified as the "csr" parameter is copied to the IDB$Q_CSR field in the IDB. For the TURBOchannel, the csr parameter should be specified as the TURBOchannel slot base physical address of the TURBOchannel option. For mailbox register access on DEC 3000 Model 500 TURBOchannel, the csr parameter should be the sparse space base slot physical address (which is displayed in the SYSMAN IO SHOW BUS command). Then in the driver controller init routine, the driver should map its option registers into sparse space and copy the base virtual address of the option registers back into the IDB$Q_CSR field. The IDB$Q_CSR field is used by IOC$CRAM_CMD as the base address of the option registers. A driver can call IOC$MAP_IO to map registers as described previously. For more information about IOC$MAP_IO, see Appendix A.

IOC$CRAM_CMD and IOC$CRAM_IO on DEC 3000 Model 500 have been designed together to accomplish register access in sparse space. IOC$CRAM_CMD initializes the COMMAND, MASK, and RBADR fields based on the command_index and byte_offset input parameters. IOC$CRAM_IO interprets the COMMAND field and generates the proper instruction (LDL, STL, or STQ) to the address in the RBADR field. The RBADR field in the CRAM is initialized using the byte offset parameter and the IDB$Q_CSR field in the IDB. The byte offset is longword aligned, multiplied by 2 to account for sparse space mapping, and added to the IDB$Q_CSR field. The resulting address is stored in the RBADR field of the CRAM.

The COMMAND field in the CRAM is derived from the command index parameter. All quadword length command indices are rejected, as the TURBOchannel does not support quadword I/O transactions. If the caller specifies a read transaction (one of cramcmd$k_rdlong32/64, cramcmd$k_rdword32/64, or cramcmd$k_rdbyte32/64), the command index is converted to cramcmd$k_rdlong32 and stored in the COMMAND field in the CRAM, so that IOC$CRAM_IO will issue a LDL instruction for all TURBOchannel I/O reads. If the caller specifies a byte or word length write (one of cramcmd$k_wtbyte32/64 or cramcmd$k_wtword32/64), IOC$CRAM_CMD must also generate the proper byte mask. The byte mask is generated using the command index to determine the transaction length (byte or word), and the byte offset parameter to determine the

first byte involved in the transaction. IOC$CRAM_CMD forms a 4 bit mask and copies it to the MASK field in the CRAM and also to bits 35:32 of the WDATA field. The byte or word command index is converted to cramcmd$k_wtquad32 and stored in the COMMAND field of the CRAM, so that IOC$CRAM_IO will generate a STQ (with the proper mask bits set in bits 35:32 of the data quadword) for all byte and word length writes. On byte or word length writes, the programmer must be careful not to overwrite the mask in bits 35:32 of the WDATA field when loading write data into the CRAM. If the caller specifies a longword write (cramcmd$k_wtlong32), IOC$CRAM_CMD copies the command index directly to the COMMAND field. IOC$CRAM_IO will generate a STL for all longword writes, which causes all 4 bytes of the register data to be written.

The following section contains examples of register reads and writes using CRAMS. Consider the previous example of the option with two registers, mapped into sparse space as shown in Figure 12–6 and Figure 12–7.

**Figure 12–6 Option Register Layout**

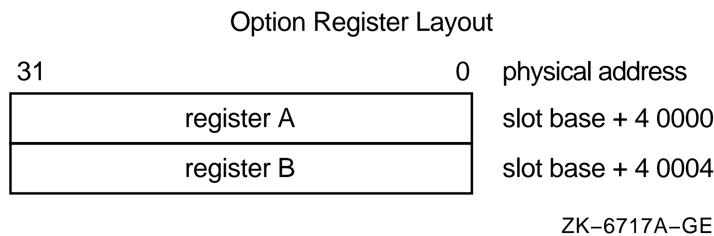
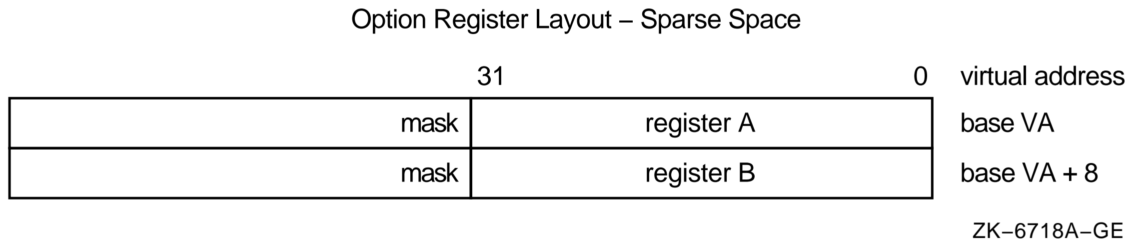



**Figure 12–7 Option Register Layout—Sparse Space**




To initialize the CRAM for a read to register A, call IOC$CRAM_CMD as follows:

```
status = ioc$cram_cmd (cramcmd$k_rdlong32,
                                     0,
                                     adp_address,
                                     cram_address);
```

IOC$CRAM_CMD forms the RBADR field of the CRAM by 1) longword aligning the byte offset input parameter, and 2) multiplying the longword aligned byte offset by 2 (to account for sparse space) and 3) adding the longword aligned byte offset to the value from IDB$Q_CSR. In this example with a byte offset parameter of zero, the resulting address would be "base VA". Then, to perform the actual read to register A, call IOC$CRAM_IO as follows:

```
status = ioc$cram_io (cram_address);
```

IOC$CRAM_IO will issue a LDL to the address in the RBADR field in the CRAM. In this example, this will be a LDL to "base VA". The data from register A will be returned in the RDATA field in the CRAM.

To set up a CRAM for a read to register B, call IOC$CRAM_CMD as follows:

```
status = ioc$cram_cmd (cramcmd$k_rdlong32,
                       4,
                       adp_address,
                       cram_address);
```

IOC$CRAM_CMD longword aligns the byte offset parameter, multiplies the aligned byte offset by 2 (to account for sparse space) and adds the result to the value from IDB$Q_CSR. In this example the resulting address would be "base VA+8". To perform the actual read, issue a call to IOC$CRAM_IO. The data from register B will be returned in the RDATA field of the CRAM. To set up a CRAM for a longword write to register B, call IOC$CRAM_CMD as follows:

```
status = ioc$cram_cmd (cramcmd$k_wtlong32,
                       4,
                       adp_address,
                       cram_address);
/* Load the CRAM WDATA field with the data to be
   written. */
```

IOC$CRAM_CMD longword aligns the byte offset parameter, multiplies the aligned byte offset by 2 (to account for sparse space) and adds the result to the value from IDB$Q_CSR. In this example the resulting address would be "base VA+8". A subsequent call to IOC$CRAM_IO will cause a STL using the WDATA field of the CRAM as the write data, to the address in RBADR (which is "base VA+8").

Now suppose that the programmer wants to write byte 3 of register A without affecting bytes 0, 1, or 2. To set up a CRAM for this operation, call IOC$CRAM_CMD as follows:

```
status = ioc$cram_cmd (cramcmd$k_wtbyte32,
                       3,
                       adp_address,
                       cram_address);
/* Now load the CRAM WDATA field with the data to be
    written. */
```

In the previous example, IOC$CRAM_CMD will form RBADR by longword aligning the byte offset and multiplying it by 2, then adding the result to the value from IDB$Q_CSR. In this example the resulting address will be "base VA". IOC$CRAM_CMD will use the command index (wtbyte32) and the byte offset to form a mask of 1000 (binary). This mask will be copied to bits 35:32 of the WDATA field. To perform the actual write, issue a call IOC$CRAM_IO.

```
status = ioc$cram_io (cram_address);
```

IOC$CRAM_IO will generate a STQ using the WDATA field as the write data, to the address in the RBADR field in the CRAM. Since bits 35:32 of the WDATA field contain a mask of 1000 (binary), only byte 3 of register A will actually be written. You can also use the device register access routines IOC$READ_IO and IOC$WRITE_IO to do this. For more information about these routines, see Appendix A.

#### 12.2.3.3 DEC 3000 Model 500 TURBOchannel DMA

This section summarizes and describes the OpenVMS AXP routines that support DEC 3000 Model 500 map register usage.

The TURBOchannel architecture defines a 34 bit DMA address, however, DEC 3000 Model 500/TURBOchannel implements a 30 bit DMA address. DEC 3000 Model 500 restricts DMA bursts on the TURBOchannel to be 128 longwords or less. A DMA burst must not cross a 2 KB address boundary. DEC 3000 Model 500 implements a set of map registers (also called a **Scatter/Gather map**) that can be used to direct DMA transfers to anywhere in DEC 3000 Model 500 system memory. Use of the Scatter/Gather map for DMA can be enabled on a per-slot basis (described later). DEC 3000 Model 500 refers to “physical DMA” as DMA that does not use the Scatter/Gather map, and “virtual DMA” as DMA that uses mapping information from the Scatter/Gather map.

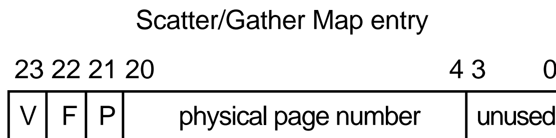
#### 12.2.3.4 Physical DMA

In physical DMA, the TURBOchannel option emits a 30 bit DMA address on the TURBOchannel (it may emit more bits, but DEC 3000 Model 500/TURBOchannel only implements 30 bits). This address is passed directly to system memory. The pages of the system memory buffer to which the DMA is directed must be physically contiguous. As mentioned, an individual DMA burst may not exceed 128 longwords in length, and may not cross a 2 KB address boundary.

#### 12.2.3.5 Virtual DMA

In virtual DMA, part of the DMA address from the TURBOchannel option is used to access the Scatter/Gather map. The Scatter/Gather map entry provides the “physical page number”, which is appended to the byte offset from the option DMA address to form the address that is sent to system memory. The format of a Scatter/Gather map entry and a diagram of the address translation is shown in Figure 12–8.

**Figure 12–8 Scatter/Gather Map Entry**




Bit 23 – Valid bit, indicates entry is valid
Bit 22 – Funny bit, used by diagnostics
Bit 21 – Parity bit, protects entire entry
Bit 20:4 – Physical Page Number

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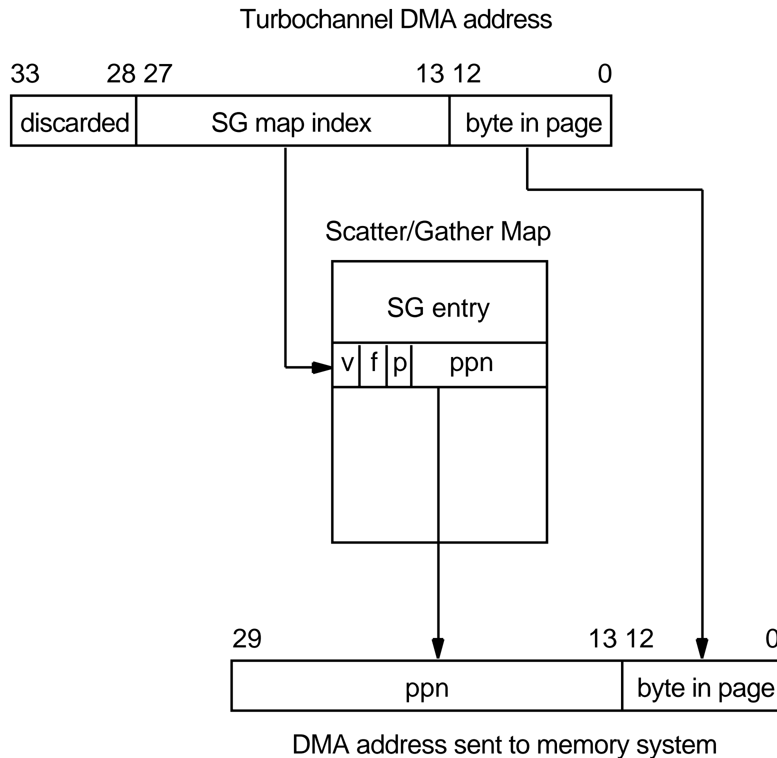
The Scatter/Gather Map is used to translate a TURBOchannel DMA address as shown in Figure 12–9.

**Figure 12–9 TURBOchannel DMA Address**




For virtual DMA, the programmer sets up the Scatter/Gather map to properly map the DMA buffer in system memory. The DMA buffer need not be physically contiguous in system memory. The TURBOchannel DMA addresses emitted by the TURBOchannel option are intercepted by the Scatter/Gather map and translated as shown above.

A "SG Enable" bit must also be set in the IOSLOT register. The following sections explain how to allocate and initialize Scatter/Gather map entries.

#### 12.2.3.6 Scatter/Gather Map Management

The Scatter/Gather map is an example of a **counted resource**. Counted resource management is accomplished using a Counted Resource Context Block (CRAB), which is pointed to by the ADP$L_CRAB field in the TURBOchannel ADP. The CRAB contains a count of the number of Scatter/Gather entries, the allocation granularity, and an allocation array, which keeps track of the allocated entries.

#### 12.2.3.7 Allocating Scatter/Gather Map Entries

Allocating Scatter/Gather entries for a DMA operation involves two routines. The programmer first must allocate a Counted Resource Context Block (CRCTX), which is used to describe the request for a counted resource. A call to IOC$ALLOC_CRCTX is shown below:

```
status = ioc$alloc_crctx (crab_address, !Address of CRAB
                          crctx_ref);   !Address of longword cell to
                                        !receive address
                                        !of CRCTX
```

The programmer then initializes the CRCTX$L_ITEM_CNT field of the CRCTX with the requested number of Scatter/Gather entries. The caller must request two more entries than required to actually map the DMA buffer, since the second to last entry of a request is always initialized to point to the black hole page (from EXE$GL_BLAKHOLE), and the last entry of a request is always initialized to zero to protect against runaway transfers.

To allocate the Scatter/Gather entries, the programmer calls IOC$ALLOC_CNT_RES, as follows:

```
status = ioc$alloc_cnt_res (crab_address,  /* Address of CRAB  */
        crctx_address);                   /* Address of CRCTX */
```

On DEC 3000 Model 500, the requested number of Scatter/Gather map entries (from CRCTX$L_ITEM_CNT) is rounded up to a multiple of 16, so that Scatter/Gather entries are are always allocated in multiples of 16. The reason for this is to lessen the management overhead in the CRAB. IOC$ALLOC_CNT_RES returns the item number of the first allocated resource in CRCTX$L_ITEM_NUM. For a complete description of IOC$ALLOC_CRCTX and IOC$ALLOC_CNT_RES, see *OpenVMS AXP Device Support: Reference*.

#### 12.2.3.8 Loading Scatter/Gather Map Entries

After the Scatter/Gather entries have been allocated, they must be loaded such that they properly map the DMA buffer in system memory. This is accomplished by a call to IOC$LOAD_MAP, as follows:

```
status = ioc$load_map (adp_address,    /* Address of Turbo ADP  */
        crctx_address,                 /* Address of CRCTX      */
        svapte,                        /* System virtual address of PTE */
                                       /* for first page of DMA buffer   */
        boff,                          /* Byte offset into first page of */
                                       /* DMA buffer   */
        dma_addr_ref);                 /* Address of location to receive */
                                       /* TURBOchannel DMA address       */
```

IOC$LOAD_MAP uses the CRCTX$L_ITEM_NUM field to find the first Scatter/Gather entry that has been allocated, and then initializes the Scatter/Gather entries based on the starting system virtual address of the DMA buffer. The DMA address is written to the location specified by dma_addr_ref. Note that the DMA address is a full byte address–the lower two bits must be cleared before the address is written to a TURBOchannel option DMA address register.

### 12.2.4 DEC 3000 Model 500/TURBOchannel Interface Registers

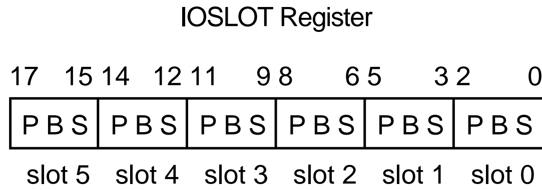
DEC 3000 Model 500 provides two registers that provide control over the characteristics of a TURBOchannel slot. These registers are the IOSLOT register and the IMASK register. The IOSLOT register, on a per-slot basis, enables or disables Scatter/Gather map usage and TURBOchannel parity generation and checking. The IMASK register, on a per-slot basis, enables or disables the delivery of TURBOchannel interrupts to the processor.

OpenVMS AXP provides access to these registers via the IOC$NODE_FUNCTION routine.

#### 12.2.4.1 IOSLOT Register

The IOSLOT register contains 3 bits per TURBOchannel slot, as shown in Figure 12–10.

**Figure 12–10 IOSLOT Register**




P – Parity bit
B – Block Mode bit
S – Scatter/Gather bit

IOSLOT physical address: 1 C200 0000 (dense), 1 D400 0000 (sparse)

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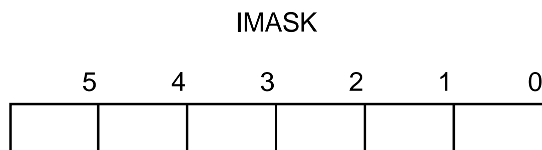
The parity bit, when set, means that the system will check parity on cycles during which the option in that slot is driving the bus (the system always generates parity when the system is driving the bus).

The Block Mode bit enables a specialized DEC 3000 Model 500 TURBOchannel style of I/O write transactions. No option should ever set this bit. The Scatter /Gather bit, when set, means that DMA transfers from that TURBOchannel slot will use the Scatter/Gather map.

#### 12.2.4.2 IMASK Register

The Interrupt Mask (IMASK) register enables or disables TURBOchannel interrupts on a per-slot basis. When the console transfers control to the operating system, the IMASK is set to all ones, meaning that interrupts from all TURBOchannel slots are masked (disabled). It is up to the TURBOchannel option driver to enable interrupts for its slot. The IMASK register is shown in Figure 12–11.

**Figure 12–11 IMASK**




Bits 5:0 enable/disable interrupts from corresponding Turbochannel slot.
When bit is set to a one, interrupts are masked (disabled).
When bit is set to a zero, interrupts are unmasked (enabled).

IMASK physical address: 1 C2400 0000 (dense space only).

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The IMASK register should be set up during the driver's controller or unit init routine by using the IOC$NODE_FUNCTION routine as explained below.

#### 12.2.4.3 IOC$NODE_FUNCTION

IOC$NODE_FUNCTION provides an easy way for drivers to manipulate the IOSLOT register and the IMASK register.

IOC$NODE_FUNCTION accepts the CRB address and a function code as input arguments. The CRB$L_NODE field must contain the TURBOchannel slot number of the TURBOchannel option. On DEC 3000 Model 500 TURBOchannel, when a device is manually configured using the SYSMAN IO CONNECT command, the user must use the /NODE qualifier, specifying the TURBOchannel slot number into which the option is installed. This causes SYS$LOAD_DRIVER to copy the TURBOchannel slot number to the CRB$L_NODE field in the CRB. The function codes are defined in [LIB.LIS]IOCDEF.SDL and are listed below:

```
ioc$k_enable_intr       Causes IMASK bit for TC slot tobe cleared.

ioc$k_disable_intr      Causes IMASK bit for TC slot to be set.

ioc$k_enable_sg Causes S bit in IOSLOT for TC slot to be set.

ioc$k_disable_sg        Causes S bit in IOSLOT for TC slot to be cleared.

ioc$k_enable_par        Causes P bit in IOSLOT for TC slot to be set.

ioc$k_disable_par       Causes P bit in IOSLOT for TC slot to be cleared.

ioc$k_enable_blkm       Causes B bit in IOSLOT for TC slot to be set.

ioc$k_disable_blkm      Causes B bit in IOSLOT for TC slot to be cleared.
```

An example call to IOC$NODE_FUNCTION is shown below:

```
status = ioc$node_function (crb_address,
                            ioc$k_enable_intr);
```

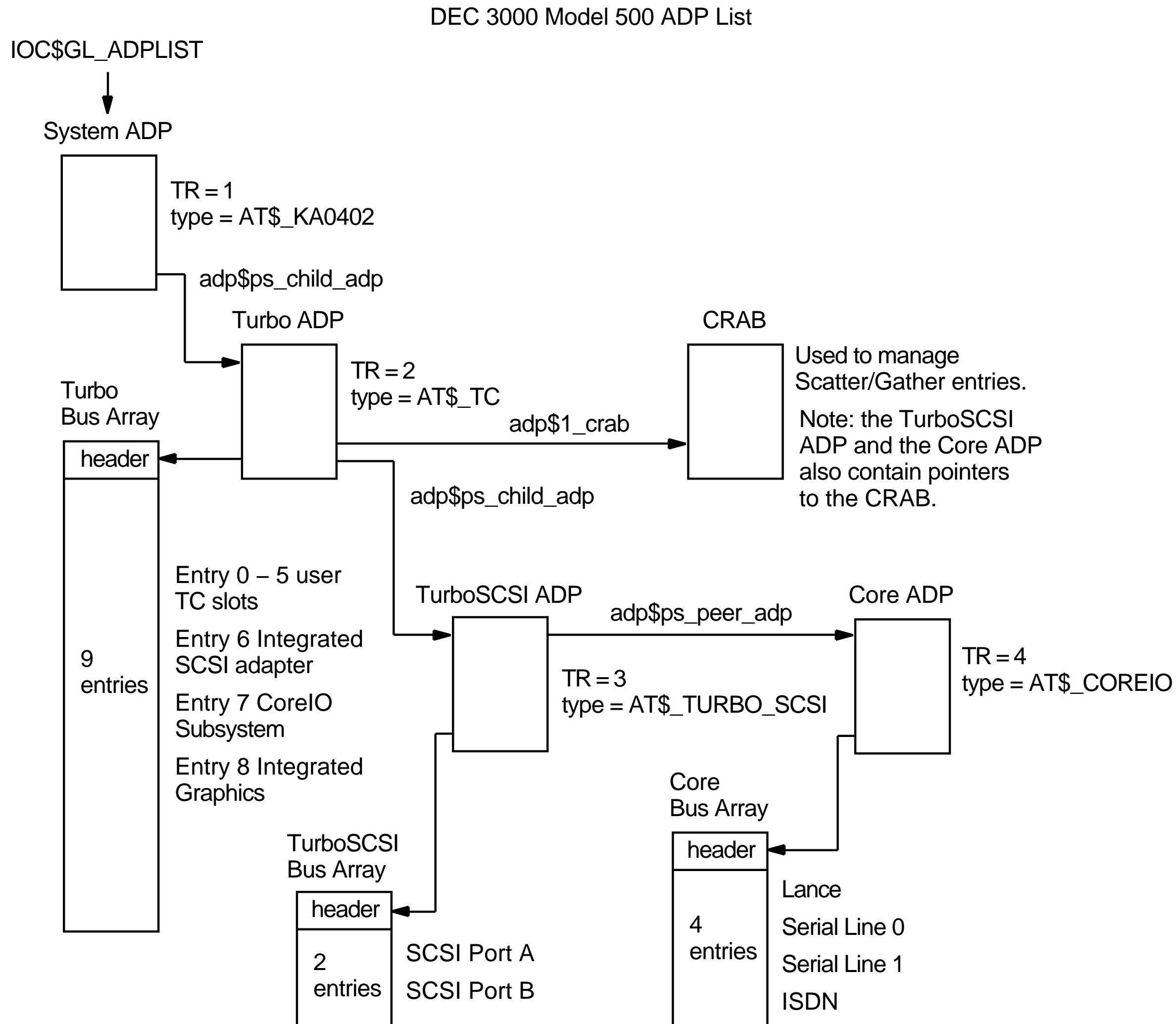
IOC$NODE_FUNCTION finds the TURBOchannel slot number from the CRB$L_NODE field, and sets or clears the appropriate bit in IOSLOT or IMASK, depending on the function code.

Note that IOC$NODE_FUNCTION acquires the MEGA spinlock while performing all of the above functions.

#### 12.2.4.4 DEC 3000 Model 500 TURBOchannel I/O Space Map

During booting, INI$IOMAP creates an ADP list for DEC 3000 Model 500 TURBOchannel. The ADP list is shown in Figure 12–12. .

**Figure 12–12 DEC 3000 Model 500 ADP List**




After setting up the data structures, INI$IOMAP tests each TURBOchannel slot for the presence of an option module. For each slot, INI$IOMAP tests the option ROM base address. If the option responds, INI$IOMAP reads the test pattern locations in the ROM to verify that the ROM is valid. If the ROM is valid, the corresponding bus array entry for the TURBOchannel slot is initialized as follows:

**BUSARRAY$Q_HW_ID**
The Module Name string (8 bytes) is read from the ROM and stored in this field.

**BUSARRAY$Q_CSR**
The slot base address (sparse space) is stored in this field.

**BUSARRAY$L_NODE_NUMBER**
The TURBOchannel slot number of the option is stored in this field.

**BUSARRAY$L_AUTOCONFIG**
The slot interrupt vector is stored in this field.

**BUSARRAY$Q_BUS_SPECIFIC**
The slot base address (dense space) is stored in this field.

### 12.2.5 Configuring a Device on DEC 3000 Model 500/TURBOchannel

The SYSMAN utility is used to manually configure devices. In order to configure a TURBOchannel option on DEC 3000 Model 500, the first step is to issue the SYSMAN IO SHOW BUS command. This command uses the ADP list (pictured above) to display information on all of the I/O options that are present in the system. The information in the SYSMAN IO SHOW BUS display is most of the information that is necessary to configure a device.

The SYSMAN IO CONNECT command is used to actually configure the device. On DEC 3000 Model 500, this command should be issued as follows:

```
SYSMAN>IO CONNECT devname /adapter=x /csr=y /vector=z /node=w
/driver=yourdriver.exe
```

The "devname" parameter should be specified in standard device naming format—a 2 letter device code, controller letter, and unit number (such as XXA0). The "adapter" parameter should be specified as the TR number of the TURBOchannel ADP. This is part of the SYSMAN IO SHOW BUS display.

The "csr" parameter is the base physical address of the TURBOchannel option slot. The SYSMAN IO SHOW BUS display shows the sparse space slot base address. The value specified in the "csr" parameter is copied directly to the IDB$Q_CSR field in the IDB by the SYS$LOAD_DRIVER program. The "vector" parameter specifies the TURBOchannel slot interrupt vector. This value is not part of the SYSMAN IO SHOW BUS display. For DEC 3000 Model 500 TURBOchannel, the vector should be specified as:

```
(TURBOchannel slot number * 4)
```

The "node" parameter specifies the TURBOchannel slot number. The node number is part of the SYSMAN IO SHOW BUS display. The specified value is copied to the CRB$L_NODE field in the CRB by the SYS$LOAD_DRIVER program. This parameter must be specified in order for routines IOC$NODE_FUNCTION and IOC$NODE_DATA to work correctly.

The "drivername" parameter is the file name of the driver.

### 12.2.6 IOC$NODE_DATA

IOC$NODE_DATA is a system specific routine that returns bus-slot specific information to the caller. On DEC 3000 Model 500 TURBOchannel, IOC$NODE_DATA can be used by a driver to obtain the TURBOchannel slot sparse or dense space base physical address.

IOC$NODE_DATA requires a CRB address, a function code, and a pointer to a buffer as input arguments. The CRB$L_NODE field must contain the TURBOchannel slot number of the TURBOchannel option (the driver must be loaded using the /node qualifer). It is up to the caller to supply the address of a buffer large enough for the requested information. On DEC 3000 Model 500/TURBOchannel, a quadword buffer is required to contain a TURBOchannel slot physical address.

The function codes available for DEC 3000 Model 500/TURBOchannel are defined in [LIB.LIS]IOCDEF.SDL and are listed below:

```
        ioc$k_turbo_slot_sparse_pa      returns sparse space
slot base address
        ioc$k_turbo_slot_dense_pa       returns dense space slot
base address
```

An example call to IOC$NODE_DATA is shown below:

```
status = ioc$node_data (crb_address,
                ioc$k_turbo_slot_sparse_pa,
                address_of_buffer);
```

IOC$NODE_DATA reads the TURBOchannel slot number from the CRB$L_NODE field of the CRB and returns the sparse space slot physical address in the caller's buffer.

## 12.3 TURBOchannel on DEC 3000 Model 400

The DEC 3000 Model 400 platform is based on the DEC 3000 Model 500 platform. The only differences are that DEC 3000 Model 400 implements 3 TURBOchannel option slots and does not contain an integrated graphics controller. The only difference in TURBOchannel bus support on DEC 3000 Model 500 and DEC 3000 Model 400 is the TURBOchannel address map. The DEC 3000 Model 400/TURBOchannel address map is shown below.

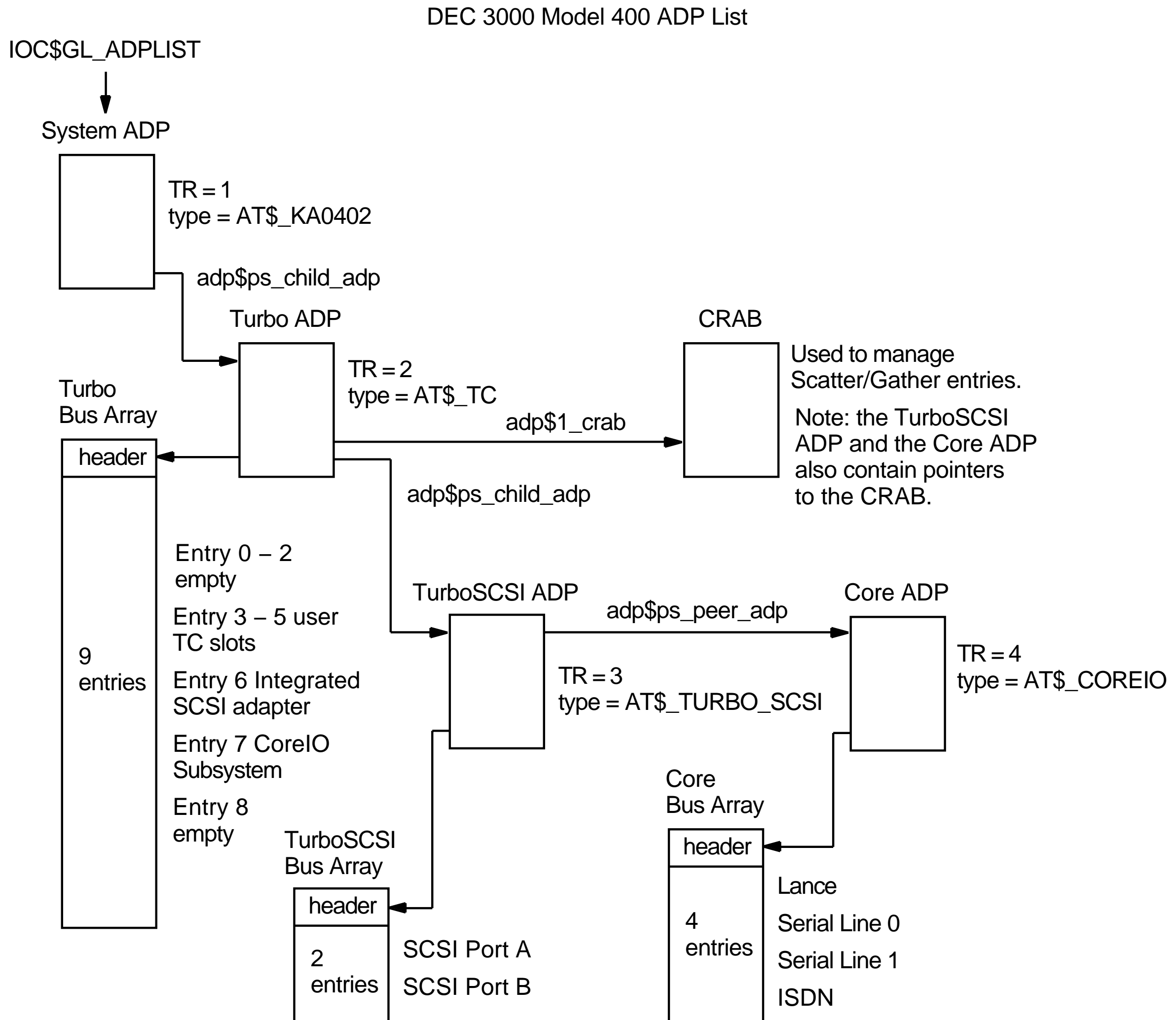
DEC 3000 Model 400 TURBOchannel Address Map

| Slot | Base Physical Address | ze | Space |
|---|---|---|---|
| 3 | 1 6000 0000 | 128 MB | Slot 3 Dense space |
| | 1 6800 0000 | 128 MB | Reserved |
| | 1 7000 0000 | 256 MB | Slot 3 Sparse space |
| 4 | 1 8000 0000 | 128 MB | Slot 4 Dense space |
| | 1 8800 0000 | 128 MB | Reserved |
| | 1 9000 0000 | 256 MB | Slot 4 Sparse space |
| 5 | 1 A000 0000 | 128 MB | Slot 5 Dense space |
| | 1 A800 0000 | 128 MB | Reserved |
| | 1 B000 0000 | 256 MB | Slot 5 Sparse space |

DEC 3000 Model 400 implements the same integral options as DEC 3000 Model 500, except that there is no integrated graphics controller. Thus, the address map also contains an integrated SCSI adapter (TURBOchannel slot 6) and the Core I/O subsystem (TURBOchannel slot 7). OpenVMS AXP uses the same platform specific image to support both DEC 3000 Model 500 and DEC 3000 Model 400. Therefore, the 3 TURBOchannel option slots available on DEC 3000 Model 400 are labeled 3, 4, and 5 by OpenVMS AXP, since their option slot addresses correspond exactly to DEC 3000 Model 500/TURBOchannel slots 3, 4, and 5. [LIB.LIS}IO0402DEF.SDL defines symbols for DEC 3000 Model 500 and DEC 3000 Model 400 physical addresses. Note that the DEC 3000 Model 400 console uses a different slot labeling scheme.

The ADP list looks exactly the same on DEC 3000 Model 400 as on DEC 3000 Model 500, except that entries 0, 1, 2, and 8 will always be empty on DEC 3000 Model 400. The DEC 3000 Model 400 ADP list is shown in Figure 12–13.

**Figure 12–13 DEC 3000 Model 400 ADP List**




Dense and sparse space addressing, register access, DMA and Scatter/Gather map management, bus interface registers, and device configuration are all treated exactly the same on DEC 3000 Model 400 as on DEC 3000 Model 500. IOC$NODE_DATA and IOC$NODE_FUNCTION work identically on DEC 3000 Model 400 as on DEC 3000 Model 500.

## 12.4 TURBOchannel on DEC 3000 Model 300

The TURBOchannel on DEC 3000 Model 300 has some differences from the DEC 3000 Model 500/DEC 3000 Model 400 implementation. There are only two option slots, and the address map is different. The Integrated SCSI adapter offers only a single SCSI port. However, the most significant difference is the lack of a Scatter/Gather map on DEC 3000 Model 300. All TURBOchannel DMA on DEC 3000 Model 300 must be physical DMA. The DMA burst size is limited to 64 longwords (compared to 128 longwords on DEC 3000 Model 500 and DEC 3000 Model 400). Also, DEC 3000 Model 300 does not support TURBOchannel parity. Option modules that support parity checking should disable this feature on DEC

3000 Model 300. The details of register access and driver loading are the same on DEC 3000 Model 300 as on DEC 3000 Model 500 and DEC 3000 Model 400.

DEC 3000 Model 300/TURBOchannel differences are covered in the following sections.

### 12.4.1 DEC 3000 Model 300/Turbochannal Address Map

The DEC 3000 Model 300/TURBOchannel address map is shown below:

```
DEC 3000 Model 300 TURBOchannel Address Map

Slot      Base Physical Addresse       Space

  0       1 0000 0000       32 MB      Slot 0 Dense space

          1 0200 0000       224 MB     Reserved
          1 1000 0000       64 MB      Slot 0 Sparse space

  1       1 2000 0000       32 MB      Slot 1 Dense space

          1 2200 0000       224 MB     Reserved
          1 3000 0000       256 MB     Slot 1 Sparse space
```

On DEC 3000 Model 300, each of the two option slots has 32 MB dense and 64 MB sparse space, as compared to 128 MB dense and 256 MB sparse on DEC 3000 Model 500 and DEC 3000 Model 400. [LIB.LIS]IO0702DEF.SDL defines symbols for DEC 3000 Model 300 physical addresses.

DEC 3000 Model 300 has the same integral options as DEC 3000 Model 500, but in different slots. On DEC 3000 Model 300, the integrated SCSI adapter is in slot 4, the Core I/O subsystem is in slot 5, and the integrated graphics controller is in slot 6.

### 12.4.2 TURBOchannel Interrupts on DEC 3000 Model 300

DEC 3000 Model 300 does not implement the IMASK register for enabling and disabling interrupts from a TURBOchannel option slot. The option slot interrupt enable bits are implemented in the SIR and SIMR registers, which are Core I/O subsystem interface registers.

### 12.4.3 IOC$NODE_FUNCTION on DEC 3000 Model 300

Routine IOC$NODE_FUNCTION should be used to enable option slot interrupts on DEC 3000 Model 300. See the DEC 3000 Model 500 description of IOC$NODE_FUNCTION for an explanation of how to call this routine.

The only IOC$NODE_FUNCTION function codes supported on DEC 3000 Model 300 are ioc$k_enable_intr and ioc$k_disable_intr.

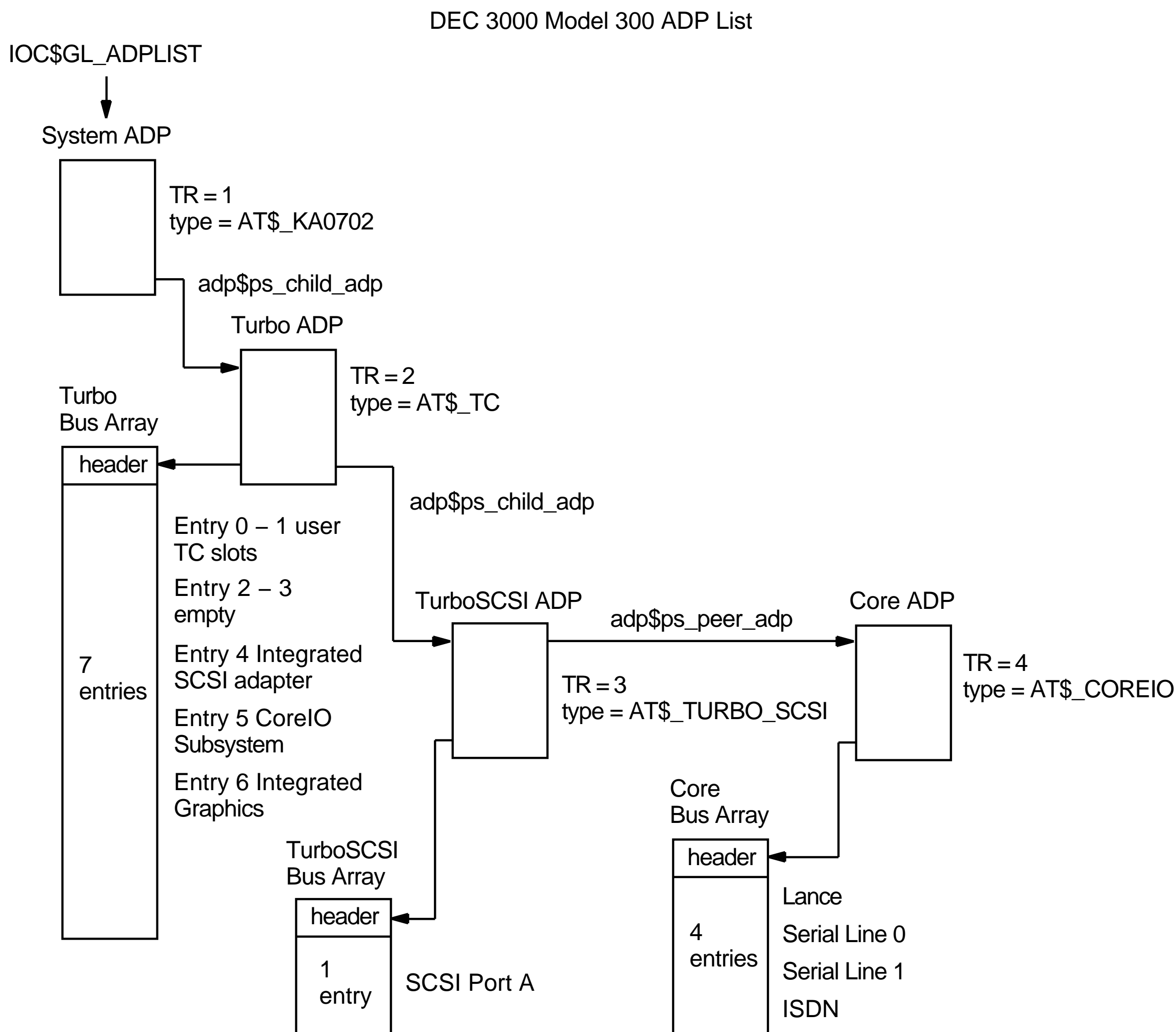
### 12.4.4 IOC$NODE_DATA on DEC 3000 Model 300

IOC$NODE_DATA on DEC 3000 Model 300 works exactly the same as IOC$NODE_DATA on DEC 3000 Model 500. It can be used to obtain the TURBOchannel dense or sparse space base physical addresses for a TURBOchannel slot.

### 12.4.5 DEC 3000 Model 300/TURBOchannel I/O Map

INI$IOMAP creates an ADP list for DEC 3000 Model 300 as shown in Figure 12–14.

**Figure 12–14 DEC 3000 Model 300 ADP List**



# 13 PCI Bus Support

This chapter discusses PCI (Peripheral Component Interconnect) bus concepts and implementations on AXP platforms.

Other PCI bus characteristics include the following:

- 32 bit address.
- 32 bit data.
- Separate memory, I/O, and configuration space.

  Each space (memory, I/O, and configuration) is a separate 32 bit address space. 64 bit addressing is also defined for PCI memory space.
- Bus operation is synchronous at frequencies up to 33 MHZ.

  33 MHz operation yields 132 MB/second peak performance: 33 * 10^6 cycles/second * 4 bytes/cycle = 132 MB/second. Interrupts are not part of the bus specification.

The PCI bus has been designed with the notion of a bus hierarchy. The PCI bus closest to the CPU is accessed through a Host/PCI bridge, and is called the host PCI. Remote PCI buses are accessed through PCI-PCI bridge chips that are connected to PCI buses closer to the processor.

**Note**

OpenVMS AXP V6.1 supports single function PCI devices. There is no support for PCI-PCI bridges or multifunction PCI devices. Support for PCI-PCI bridges and multifunction PCI devices will appear in a future release.

---

## 13.1 PCI Addressing

PCI defines three separate address spaces: memory, I/O, and configuration. PCI Configuration space is intended for use primarily during booting and configuration, although it is required to be accessible at all times. PCI I/O space is similar to EISA I/O space, and is generally used for registers and control functions that require byte and word length access. PCI memory space is intended for devices with memory buffers that require memory address space, such as frame buffers. PCI memory space is also intended for device registers.

On the hardware level, one accesses the different address spaces (memory, I/O, or configuration) by using different PCI transaction types. That is, for a read to memory space, the hardware generates a Mem_Read cycle, while for a read to I/O space, the hardware generates an IO_Read cycle, and for a read to Configuration Space, the hardware generates a Config_Read cycle. Digital platforms use a

combination of address tricks and CSR control bits to permit access all three spaces.

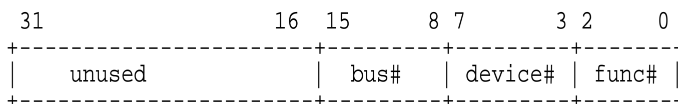
The PCI specification recommends that devices be designed such that they can use memory space for all device registers and device control functions. This is because Intel processors are only capable of accessing 64 KB of I/O space. However, there are PCI devices that require both memory space and I/O space. The example most often cited is a graphics adapter with control registers in I/O space and a frame buffer in memory space.

## 13.2 PCI Configuration Space

Every PCI device has its own section of the Configuration Space address space. Within the device Configuration Space, the device must implement a predefined header, called the Configuraiton Space header, accessible at offset 0 in the device Configuration Space. The Configuration Space header contains such information as Vendor ID, Device ID, Device Class/Type, and Base Address registers. PCI bus probe routines attempt to read the Vendor and Device ID from the Configuration Space header of each potential PCI slot on the host PCI bus, in order to discover which PCI devices are present in the system.

The PCI specification defines a mechanism for accessing the Configuration Space of all possible PCI devices, whether the devices are on the host PCI (closest to the CPU), or on a remote PCI accessed through a PCI-PCI bridge. This mechanism encodes the bus number (0-255, where bus 0 is always the PCI closest to the CPU), a device number (0-31), and a function number (0-7) to form a unique Configuration Space address. The device number is analogous to a backplane slot number, though in reality it is decoded by hardware into a chip select signal for a single PCI device. Therefore, we can treat PCI as a "slot-based" bus, where we can find a device based on the bus number and the device slot number.

To match the PCI specification of a Configuration Space address, OpenVMS/AXP defines a PCI node number as follows:




Because OpenVMS AXP Version 6.1 does not support PCI-PCI bridges or multifunction devices, the bus# and function# portions of the PCI node number are not actually used by any of the PCI bus support routines in OpenVMS AXP Version 6.1. A future release will include support for PCI-PCI bridges and multifunction PCI devices.

Although 5 bits are required for the device number, electrical loading considerations usually limit the number of PCI devices on a bus to less than 32 devices.

The PCI specification defines up to 6 Base Address registers in the Configuration Space header. The Base Address registers are used to locate the device in the proper PCI address space (memory or I/O). Bus mapping software reads a Base Address register to determine how much and what kind of address space a device requires, and then assigns the base address of the device by writing the Base Address register. PCI address space assignment is done by the console on AXP platforms.

A device may implement up to 6 Base Address registers. This allows a device to use up to 6 separate address ranges for device registers or memory buffers. Generally a device will only require one or two Base Address registers.

The predefined Configuration Space header and the Base Address registers enable system independent software to locate all PCI devices in the system address space, and to assign address space to devices in a conflict-free configuration. As mentioned previously, the PCI address space assignment is done by the console on Digital AXP platforms.

## 13.3 PCI as an I/O Bus on AXP Platforms

The Alpha I/O Task Force has defined a standard reference model for I/O bus and device access. The intent of this model is to move away from hardware mailboxes and toward a direct, swizzle space mechanism for device register access. PCI requirements are a driving force behind this model.

The reference model says that platforms will provide access to PCI memory and I/O space through different address regions in the platform physical address space.

Access to PCI I/O space is through a swizzle space address encoding with a 5 bit address shift. Only a small portion of the 4 GB PCI I/O space is addressible by the CPU (due to the 5 bit address swizzle). Some platforms allow access to 128 MB of PCI I/O space, while others may allow access to only the lowest 64 KB of PCI I/O space. Lack of addressibility of the entire PCI I/O address space is not seen as a problem because PCI devices are encouraged to implement device registers in PCI memory space, and INTEL processors can only access 64 KB of PCI I/O space.

PCI memory space is accessible in both dense and swizzle space. There are separate platform physical address regions for swizzle space and dense space. The access characteristics of each space are different. Swizzle space (5 bit address shift) is intended for byte, word, long, and quad access granularity. The size of the transfer and which bytes will be transfered are encoded in bits 6:3 of the CPU address. Software must align the data in the correct byte lanes. To maintain ordering of data transfers, software must issue memory barriers after each device access. Device control registers that are implemented in PCI memory space should be assigned (by the console) to swizzle space.

The minimum access granularity of dense space is longword. In dense space, the Alpha CPU address maps directly to the PCI address–there is no address bit shifting as in swizzle space. Platforms are permitted to implement read prefetching and write merging in dense space. Device control registers should not be placed in dense space. Dense space is intended for frame buffers and other on-chip buffers with memory-like behaviour.

## 13.4 PCI Device Interrupts

The PCI specification does not define an interrupt mechanism for I/O device interrupts. Some systems implement Intel-style interrupts using PC style interrupt controller chips, such as the 8259. Other systems implement custom interrupt handling logic.

In general, a distinction is made between "motherboard" PCI devices, which are built into the system and always present, and option slot devices. A motherboard device generally interrupts through a unique input on the system interrupt controller.

For PCI option slots, the PCI specification defines 4 interrupt signals per slot, called INTA, INTB, INTC, and INTD. There are no rules about how systems are supposed to present option slot interrupts to the system interrupt logic. Some systems combine the INTx signals from each slot and present a single slot interrupt to the system interrupt logic. Other systems present each INTx signal as a unique interrupt to the system interrupt logic. OpenVMS AXP Version 6.1 only supports single function PCI options that interrupt through INTA. Support for multifunction PCI options and PCI-PCI bridges will be available in a future release.

## 13.5 OpenVMS AXP PCI Bus Support Data Structures

A PCI bus is represented by an ADP and an associated bus array. The bus array has an entry for each PCI device attached to the bus. The ADP address and PCI node number allow software to find the bus array entry associated with a PCI device.

## 13.6 Probing the PCI to Find Devices

The PCI bus support module contains a PCI bus probe routine that steps through the device number of each potential PCI device on the host PCI. For each PCI slot on the host PCI, the PCI probe routine attempts to read the Vendor ID and Device ID from the Configuration Space header of the device. If a device responds with a valid Vendor ID, the following information is recorded in the bus array entry for the PCI device:

```
BUSARRAY$Q_HW_ID    Device ID in bits 31:16, Vendor ID in bits
                    15:0.

BUSARRAY$Q_CSR      VA of base of PCI config space for this
                    device.

BUSARRAY$L_NODE_NUMBER  PCI node number.  Device number in bits
                    7:3, function number in bits 2:0.

BUSARRAY$L_BUS_SPECIFIC_L   Interrupt vector offset for this
                    device.
```

A bus array entry for a PCI device found during bus probing looks like the following:

```
 63                32 31                   0
+-------------------+---------------------+
|                   | DeviceID | VendorID |  0x0
+-----------------------------------------+
|  config space base virtual address      |  0x8
+-----------------------------------------+
|                   |  PCI node number    | 0x10
+-----------------------------------------+
|                                         | 0x18
+-----------------------------------------+
|                                         | 0x20
+-----------------------------------------+
|                   | interrupt vector    | 0x28
+-----------------------------------------+
```

## 13.7 Register Access on PCI Buses

To access registers on a PCI device, you must first determine the PCI physical address that is assigned to the device and then map the PCI physical address into the processor's virtual address space. Then you can access the device using the platform independent access routines IOC$READ_IO or IOC$WRITE_IO, or using the CRAM data structure and associated routines IOC$CRAM_CMD and IOC$CRAM_IO.

## 13.8 Finding the PCI Physical Addresses Assigned to a Device

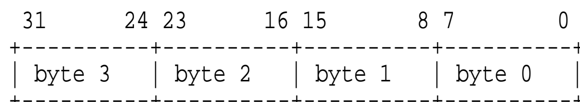
As mentioned previously, a PCI device may implement up to 6 Base Address registers in its Configuration Space header. On Digital AXP platforms, the console assigns PCI address space to each PCI device by writing a PCI physical address into a Base Address register.

OpenVMS AXP provides two routines for PCI Configuration space access. The prototypes for these routines are:

```
int ioc$read_pci_config (ADP    *pci_adp,
                         int    pci_node,
                         int    offset,
                         int    length,
                         int    *data)

and

int ioc$write_pci_config (ADP    *pci_adp,
                          int    pci_node,
                          int    offset,
                          int    length,
                          int    data)

Inputs:

    pci_adp     Address of PCI ADP.  Available to driver from
                IDB$PS_ADP.

    pci_node    PCI node number.  Function number in bits 2:0,
                device number in bits 7:3, bus number in bits
                15:8.  Available to driver from CRB$L_NODE.
                (driver must be loaded with /NODE  qualifier).

    offset      Byte offset in Configuration space of field to
                be read or written.

    length      Length of data field (expressed in bytes) to be
                read or written.  Must be 1 (byte), 2 (word), 3
                (tribyte), or 4 (longword).

    data        For reads, a pointer to a longword cell to be
                written with the data read from Configuration
                space.  For writes, a longword containing the data
                to be written to Configuration space.

Outputs:

    SS$_NORMAL  Success.  For reads, data is returned in the
                caller's buffer.  For writes, data is written
                to PCI Configuration space.

    SS$_BADPARAM Failure.  Could not find Configuration space
                address for the specified PCI node number.
```

These routines acquire the MCHECK spinlock (raising IPL to 31) to assure that they are single threaded. This is necessary because Configuration Space access involves manipulation of hardware registers in the host PCI interface. You must use these routines to access Configuration Space. Do not be tempted to use the Config Space base VA from the bus array. Also note that IOC$WRITE_PCI_CONFIG issues a memory barrier instruction.

These routines do not do any byte lane alignment of the data. For reads, data is returned in its natural byte lane. For writes, data must be positioned in its natural byte lane. In this context, natural byte lane means:




This means, for example, if you read a field of length 2 bytes from offset 2 in the Configuration Space header, the data will be returned in bits 31:16.

You should use IOC$READ_PCI_CONFIG to read the PCI physical address from the Base Address register(s) in your device's Configuration Space. Your device specification should indicate which Base Address registers are actually implemented by your device, and should give you their offsets in the Configuration Space header for the device.

The following example shows a call to IOC$READ_PCI_CONFIG that reads the Vendor ID from PCI configuration space:

```
int    vendor_id;
int    status;

status = ioc$read_pci_config (pci_adp,
                              crb->crb$l_node,
                              0,   /* vendor id offset     */
                              2,   /* vendor id is 2 bytes */
                              &vendor_id);
```

The vendor ID will be returned in bits 15:0 of the vendor_id longword (the Vendor ID is a 2 byte field starting at Configuration Space offset 0).

## 13.9 Mapping a PCI Physical Address

Once you have obtained the PCI physical address, you must map it into the processor's virtual address space.

The correspondence between PCI physical address and platform physical address is different depending on whether you want the address to be mapped in PCI I/O space, PCI swizzled memory space, or PCI dense memory space. The platform physical address regions corresponding to each of the PCI address spaces are different from platform to platform. In order to abstract these differences, OpenVMS AXP provides a platform independent I/O bus mapping routine called IOC$MAP_IO. IOC$MAP_IO allows a programmer to express a mapping request in terms of the device and desired access characteristics, without regard to the underlying platform address map and address tricks. The prototype for the IOC$MAP_IO routine is as follows:

```
int ioc$map_io (ADP     *adp,
                int     node,
                uint64  *physical_offset,
                int     num_bytes,
                int     attributes,
                uint64  *iohandle)
```

```
Inputs

adp    Address of bus ADP.  Available to driver from
       IDB$PS_ADP.

node   Bus node number of device.  Bus specific
       interpretation.  Available to driver from CRB$L_NODE
       (driver must be loaded with /NODE  qualifier).

physical_offset Address of a quadword cell.  For EISA,
       PCI, and Futurebus, the quadword cell should contain
       the starting bus physical address to be mapped.  For
       Turbochannel, the quadword cell should contain the
       physical offset from the Turbochannel slot base
       address.

num_bytes   Number of bytes to be mapped.  Expressed in
       terms of the device without regard to the
       platform hardware addressing tricks.  You should
       figure out this value from your device spec.  You
       should request enough bytes to map all of the address
       space that you need to touch all of your registers.

attributes  Specifies desired attributes of space to be
       mapped.  From [lib]iocdef.  One of the following:

       IOC$K_BUS_IO_BYTE_GRAN

       This attribute means that you want mapping in a
       platform address space which corresponds to bus I/O
       space and provides byte granularity access.  In general,
       if you are mapping device control registers that exist
       in bus I/O space, you should specify this attribute.
       For example, drivers for PCI devices with registers in
       PCI I/O space or EISA devices with EISA I/O port
       addresses should request mapping with this attribute.

       IOC$K_BUS_MEM_BYTE_GRAN

       This attribute means that you want mapping in a
       platform address space which corresponds to bus memory
       space and provides byte granularity access.  In general,
       if you are mapping device registers that exist in bus
       memory space, you should specify this attribute.  For
       example, drivers for PCI devices with registers in PCI
       memory space should request mapping with this attribute.

       IOC$K_BUS_DENSE_SPACE

       This attribute means that you want mapping in a
       platform address space that corresponds to bus memory
       space and provides coarse access granularity.
       IOC$K_BUS_DENSE_SPACE is suitable for mapping device
       memory buffers such as graphics frame buffers.  In
       IOC$K_BUS_DENSE_SPACE, there must be no side effects on
       reads and it may be possible for the processor to merge
       writes.  Thus you should not map device registers in
       dense space.

iohandle    Pointer to a 64 bit cell.  A 64 bit
       number is written to this cell by IOC$MAP_IO when the
       mapping request is successful.  The caller  must save
       the iohandle, as it is an input to the platform
       independent access routines IOC$READ_IO and
       IOC$WRITE_IO, and the CRAM initialization routine
       IOC$CRAM_CMD.

Outputs

SS$_NORMAL  Success.  The address space is mapped.  A 64 bit
       IOHANDLE is written to the caller's buffer.
```

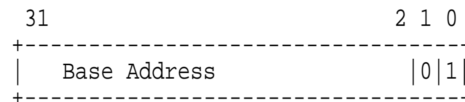
```
SS$_BADPARAM Bad input argument.  For example, the requested
       bus address may not be accessible from the CPU, or the
       attribute may be unrecognized.

SS$_UNSUPPORTED Address space with the requested attributes
       not available on this platform.  For example, the DEC 2000
       Model 150 platform does not support EISA memory dense space.

SS$_INSFSPTS Not enough PTEs to satisfy mapping request.

Routine ioc$unmap_io is provided to unmap a previously mapped
space, returning the iohandle and the PTEs to the system.
The caller's quadword cell containing the IOHANDLE is
cleared.

The routine prototype is shown below:

int ioc$unmap_io (ADP   *adp,
                  uint64 *iohandle)
```

```
IOC$MAP_IO may acquire the MMG spinlock.  Thus it must be called
at IPL 8 or below, and the caller cannot be holding any spinlocks
of higher rank than MMG.

An example call to IOC$MAP_IO is shown below.  This call maps 64
KB of PCI I/O space in a region that offers byte granularity,
starting at PCI I/O address 0.

     int    status;
     uint64 iohandle;
     uint64 pci_physical_address = 0;

     status = ioc$map_io (pci_adp,
                          crb->crb$l_node,
                          &pci_physical_address,
                          16*4096,
                          IOC$K_BUS_IO_BYTE_GRAN,
                          &iohandle);
```

## 13.10 PCI Configuration Space Base Address Register Format

A PCI Configuration space Base Address register can specify a PCI memory space address or a PCI I/O space address. The two forms of a Base Address register are as follows:

```
Memory Format Base Address Register

                         4 3 2 1 0
+------------------------------------+
|   Base Address         | | | |0|
+------------------------------------+

Bit 3  Prefetchable.  Set to 1 if there are no side effects
on reads, the device returns all bytes on reads regardless of
the byte enables, and host bridges can merge processor writes
into this range without causing errors.  Bit must be set to
zero otherwise.

Bits 2:1   Type.

           00  Locate anywhere in 32 bit address space.
           01  Locate below 1 MB.
           10  Locate anywhere in 64 bit address space.
           11  reserved.

Bit 0  Set to zero to indicate memory format Base Address
register.


I/O Format Base Address Register
```




```
Bit 1  Reserved.
Bit 0  Set to one to indicate I/O format Base Adddress
register.
```

Your device specification should state which Base Address registers are implemented and which PCI address space (memory or I/O) they describe.
In general, if your device requires an address region in PCI I/O space, there will be a Base Address register that contains the starting address of the PCI I/O space assigned to your device. You can read this Base Address register using the IOC$READ_PCI_CONFIG routine. However, before you call the IOC$MAP_IO routine to map the PCI physical I/O address, you should clear bit 0 in the data returned from the read of an I/O format Base Address register before passing the address to IOC$MAP_IO. For a PCI I/O address, you should specify the IOC$K_BUS_IO_BYTE_GRAN attribute in the call to IOC$MAP_IO.

Likewise, if your device requires an address region in PCI memory space, there will be a Base Address register that contains the starting address of the PCI memory space assigned to your device. You can read the Base Address register using the IOC$READ_PCI_CONFIG routine. You should clear bits 3:0 of the data returned from the read of a memory format Base Address register before passing the PCI physical address as an argument to the IOC$MAP_IO routine. For a PCI memory address, you can specify either the IOC$K_BUS_MEM_BYTE_GRAN attribute (to map device registers) or the IOC$K_BUS_MEM_DENSE attribute (for on-board device memory buffers). You should check the return status on calls to IOC$MAP_IO, as not all attributes are supported on all platforms. If a call using one of the attributes fails, then try the other one. If they both fail, you are out of luck. File a QAR. Either the console mistakenly assigned an un-mappable address to your device, or there is a bug in the OpenVMS AXP IOC$MAP_IO routine.

If your device requires multiple address regions in PCI memory or I/O space, you should call IOC$READ_PCI_CONFIG and IOC$MAP_IO to map each region.

## 13.11 When to Call IOC$MAP_IO and Where to Keep IOHANDLES

OpenVMS AXP Version 6.1 offers a new driver support feature for drivers that need to call IOC$MAP_IO and need to save IOHANDLEs. There is a new IOHANDLES parameter for the DPTAB macro, which allows a driver to specify the number of IOHANDLEs required by the driver. There is also a new CSR_MAPPING parameter for the DDTAB macro, which allows the driver to name a routine that will be called by the driver loading program. This routine will be called in an environment from which calls to IOC$MAP_IO can be made.

## 13.12 Direct Memory Access (DMA) on the PCI Bus

Direct Memory Access (DMA) refers to PCI devices reading or writing system memory. The PCI bus places no restrictions on DMA. From the point of view of a PCI device, system memory can be viewed as another device on the PCI with an assigned address space. A PCI device does DMA by issuing reads or writes to the address space assigned to system memory.

However, AXP platform implementations may place some restrictions on how a PCI device must perform DMA. There are a number of reasons for these restrictions, mostly related to EISA and ISA compatibility.

Current AXP platforms define two PCI DMA windows, which can be thought of as the PCI memory address space assigned to system memory. A PCI DMA window can be configured to be a direct mapped window or a scatter/gather mapped window. In a direct mapped window, the PCI memory address is passed directly to system memory (perhaps with an address offset from a hardware register). In a scatter/gather mapped window, the PCI memory address undergoes a scatter /gather map translation. A translated address is eventually passed to system memory. The PCI DMA windows are set up during system boot and are never changed.

You must check the platform address map for each platform to see how the DMA windows are set up on that machine. All platforms with a PCI bus will have at least one scatter/gather PCI DMA window. Thus, for maximum driver portability, you should code your driver to use the scatter/gather map for DMA. In OpenVMS AXP, scatter/gather support (also known as map register support) is accomplished through the use of generic counted resource management routines IOC$ALLOC_CRCTX, IOC$ALLOC_CNT_RES, and IOC$LOAD_MAP. For detailed information about these routines, see Appendix A.

## 13.13 Configuring a PCI Device and Loading A Driver

To configure a PCI device and load its driver, you can write an IOGEN Configuration Building Module (ICBM), and set up the SYSMAN utility to call your autoconfiguration routine. Or, you can use the SYSMAN IO CONNECT command to manually configure your device and load its driver.

For PCI, manual configuration of a device using the SYSMAN IO CONNECT command is similar to configuration of devices on other I/O buses. The differences are in the specification of the /CSR qualifier and the /VECTOR qualifier.

To configure your device, use the followng command to invoke SYSMAN utility:

```
$ mc sysman
SYSMAN>
```

Use the IO SHOW BUS command to see what is installed on the PCI. If your device is not recognized by OpenVMS AXP, it will display as “Unknown”. You will need the TR# and the Node from the IO SHOW BUS display.

```
SYSMAN> IO SHOW BUS
```

Enter the IO CONNECT command as follows. (The CONNECT command qualifiers are explained later.)

```
SYSMAN> IO CONNECT xxa0 /ADAPTER=a /CSR=0 /VECTOR=v /NODE=n -
/driver=filename
```

xxa0 is the device name. Specify the device name in the standard OpenVMS format— a 2 letter device code, a controller letter, and a unit number.

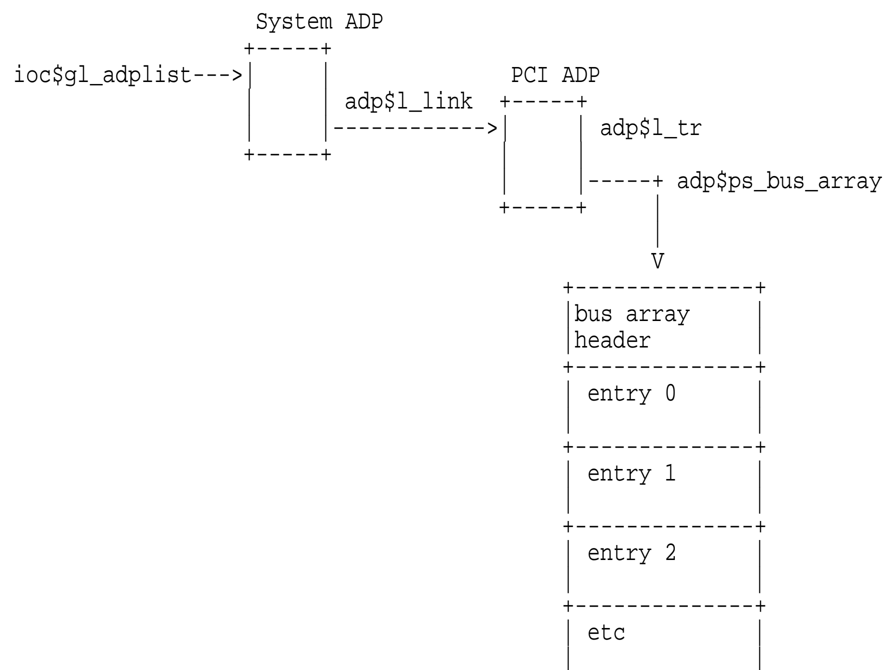
- /ADAPTER specifies the ADP that represents the bus to which your device is connected. Use the TR# from the IO SHOW BUS display that is associated with your device.
- /CSR The /CSR qualifier is required by the driver loading program. The value specified in the /CSR qualifier is copied to IDB$Q_CSR by the driver loading program. On some buses, this qualifier is used to tell the driver the physical address at which the device is located. However, for PCI, the physical address information is stored in the Configuration Space header of the device, as

explained earlier. Therefore, this qualifier is not useful for PCI and should be specified as /CSR=0.

- /NODE The /NODE qualifier identifies the PCI device to the PCI bus support routines. The value specified in the /NODE qualifier is copied to CRB$L_NODE by the driver loading program. Use the Node value from the IO SHOW BUS display that is associated with your device.
- /VECTOR The /VECTOR qualifier is used by the driver loading program to hook up your driver interrupt service routine to a hardware interrupt vector.

  There is no vector information in the IO SHOW BUS display. And because of the wide latitude in system interrupt logic design for PCI, there is no convenient rule you can use for figuring out the interrupt vector associated with your device. You must run SDA on a running system to find the interrupt vector for your device. The ADP list and bus arrays are set up as shown in the following diagram. You must find the bus array entry for your PCI device. The bus array entry contains the interrupt vector offset that should be used as the value for the /VECTOR qualifier.

The ADP list on a platform with a PCI bus is as follows: (Note that there may be intervening ADPs between the System ADP and the PCI ADP)




System global cell ioc$gl_adplist points to a list of ADPs. An ADP is an OpenVMS AXP data structure that represents an adapter. The PCI interface is an example of an adapter. The System ADP is always the first ADP in the list. Each ADP has a Bus Array, pointed to by ADP cell adp$ps_bus_array. A Bus Array consists of a header and a number of entries. There is an entry in the Bus Array for each device connected to the bus.

The structure definition of the ADP is available in [syslib]sys$lib_c.tlb, lib.r64, and lib.mlb. You can use the Librarian utility to extract its definition if you want to see it. For example:

```
libr /alpha /extract=adpdef /out=adpdef.h sys$lib_c.tlb
```

or

```
libr /alpha /extract=$adpdef /out=adpdef.mar sys$lib_c.tlb
```

The structure definition of the Bus Array is also available in [syslib]sys$lib_c.tlb. For example:

```
libr /alpha /extract=busarraydef /out=busarraydef.h sys$lib_c.tlb
```

or

```
libr /alpha /extract=$busarraydef /out=busarraydef.mar sys$lib_c.tlb
```

You might find the .mar file easier to understand than the .h file.

Here is an example of how to traverse the ADP list to find the interrupt vector offset for your PCI device. Note that you should first go into SYSMAN and say IO SHOW BUS. Write down the TR number associated with the display information of your device. Then enter the following:

```
$ analyze/sys
SDA> read sys$loadable_images:sysdef
SDA> format @ioc$gl_adplist
```

This will display all of the fields of the System ADP. Find the address in field ADP$L_LINK. Then format that address as follows:

```
SDA> format addr_from_adp$l_link
```

This will display all of the fields of the next ADP in the ADP list. Keep following the adp$l_link pointers until you find the ADP with a TR number that matches the TR number you found from SYSMAN IO SHOW BUS. The TR number is found in field ADP$L_TR. When you find the matching TR number, you have found the PCI ADP. Note that the PCI ADP will usually be the second ADP in the list. Once you have found the PCI ADP, get the address from ADP field ADP$PS_BUS_ARRAY.

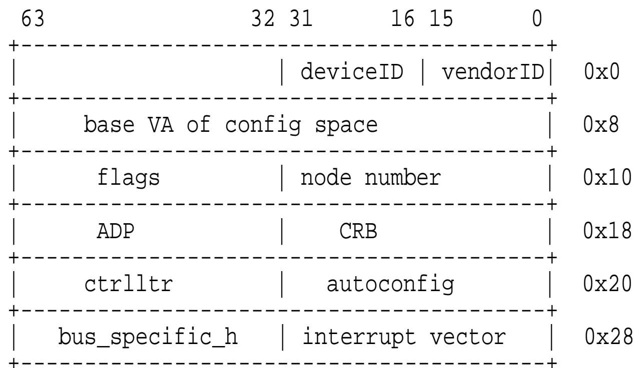
Note that this format does not work on the Bus Array structure. The key points to remember about the bus array is that the header is three quadwords and each entry is 6 quadwords. The bus array header is shown as follows:

```
 63                 32 31                  0
+------------------------------------------+
|                     | parent ADP         |  0x0
+------------------------------------------+
|    bus type         |subty|type|  size   |  0x8
+------------------------------------------+
|                     | node count         |  0x10
+------------------------------------------+
```

The Bus Array entries start after the bus array header. A generic Bus Array entry is shown as follows:

```
 63                 32 31                  0
+------------------------------------------+
|           hardware id                    |  0x0
+------------------------------------------+
|           CSR                            |  0x8
+------------------------------------------+
|      flags          | node number        |  0x10
+------------------------------------------+
|      ADP            |    CRB             |  0x18
+------------------------------------------+
|     ctrlltr         |   autoconfig       |  0x20
+------------------------------------------+
|   bus_specific_h    | bus_specific_l     |  0x28
+------------------------------------------+
```

A PCI bus array entry is shown in the following diagram:




In SDA, once you have found the PCI ADP and Bus Array, you should examine the Bus Array until you find the DeviceID and VendorID of your device.

Note that the interrupt vector offset is in the bus_specific_l field of the Bus Array entry for your device. This is the value that you should use for the /VECTOR qualifier in the SYSMAN IO CONNECT command. Once you have done this and found the interrupt vector, the interrupt vector will not change from boot to boot. If you move your device to a different slot, you will have to find the new interrupt vector. If you move your device to a different machine, you will have to find the new interrupt vector.

Alternatively you can write an ICBM to configure your device. If you do this, your ICBM will be called when the upper level autoconfiguration routines find a PCI ADP. Your ICBM will do basically the same steps that I outlined by hand, and will make an explicit call to SYS$LOAD_DRIVER to configure your device.

# 14
# EISA and ISA Bus Support

This chapter describes the evolution of the Extended Industry Standard Architecture (EISA) bus, provides backround information on the Industry Standard Architecture (ISA) bus, and discusses the EISA bus on the DEC 2000 system.

## 14.1 Evolution of the EISA Bus

The EISA bus is an extension of the ISA bus. ISA started as the 8 bit bus in early IBM personal computers and was based on the INTEL 8088 chip. The I/O cards used an 8 bit data bus, and a 16 bit address bus. To save decode logic on the cards, they only decoded the lower 10 address bits for I/O space. Most cards had their resources (IRQ, DMA, IO Ports, Memory Range) hardwired into them. There were 8 interrupt levels (provided by an INTEL 8259 chip), and 4 DMA Channels (provided by an INTEL 8237 chip) available. The configuration of the machine was limited by these resources. As the CPU chips got faster, and system size increased, the ISA bus functionality was increased to offer 15 interrupt lines, 7 DMA channels, and a 16 bit data bus to/from I/O. This is known as 16 bit ISA. The cards still decoded only 10 bits in I/O space. To differentiate between memory and I/O space addresses the cards used the AEN signal distributed by the CPU. If AEN was asserted, the cards were enabled to look at the address on the bus. If it matched their IO Port address range, they responded. While DMA was happening AEN was deasserted so that no card would accidentally decode a DMA address as an IO space access. At this point, IBM archictected a new I/O bus, Microchannel Architecture (MCA), which was totally incompatable with the ISA bus. This led the industry to design the EISA bus. Designed to accept both 8 and 16 bit ISA cards as well as EISA cards, the EISA bus allowed customers to protect their current investment in PC hardware. EISA extended the data path to addr[9:8]32 bits, added software readable product ID's (essential to automatic configuration), slot specific I/O addressing, and active-low level sensitive interrupts (allowing true sharing of IRQ levels).

To allow ISA cards to work in the new EISA systems, slot specific AEN signals were added. In I/O space addr[9:8]32 were not equal to 00, it was assumed that the access was intended for an old style ISA card, and AENx was asserted at all slots to allow the proper card to decode it. If I/O address bits addr[9:8]32 = 00, then the reference is assumed to be to a new EISA card, and addr[9:8]32 are used to select which slot answers the access (via AENx).

Note that the ISA bus is the prevalent bus seen in PCs today. There are still both 8 and 16 bit ISA cards in many machines. EISA offers higher bandwidth, due to the increased data path size, thus is more suited to the faster microprocessors available today. Also note that the EISA bus functionality is a superset of the ISA bus. Anything that works on the ISA bus will also work on the EISA bus, however, the reverse is not true. EISA cards will not work on an ISA bus.

## 14.2 Intel 82350DT EISA Chipset

INTEL offers a chip set which is designed to provide an interface between a CPU and the EISA Bus. This chipset provides a 15 level Interrupt Controller(2 logical 8259 chips cascaded), a 7 channel DMA controller(2 logical 8237 chips cascaded), timers, buffers, and logic to convert the 8 and 16 bit ISA protocols to the 32 bit EISA protocol. There is also a chip designed for use by adapter boards to interface to the EISA bus. The INTEL 82355 Bus Master Interface chip is intended for use by adapters wishing to talk EISA protocol, and works in conjunction with the 82350 chip set. Documentation that describes this chip set is available from INTEL.

## 14.3 EISA Bus Resources

The EISA bus has a limited set of system resources. Each adapter is designed to use some subset of the available EISA resources:

- Interrupt Request Levels (IRQ's)
- DMA Channel
- I/O Port Addresses
- EISA Memory space addresses

Due to the limited number of these resources, the large supply of E/ISA adapter vendors, and the need to plug up to 15 adapters into the EISA bus, the configuration of EISA based machines is a very complicated task. Configuration of the system refers to the assignment of resources in a conflict free manner, allowing all adapters to work properly. Adapters are typically designed to use a subset of each of the resource types. The assignment of these resources to adapters is done by an EISA Configuration Utility (ECU) which is run before booting the machine.

The following sections quickly describe each of these resources and provide a description of the ECU.

### 14.3.1 IRQs

Each EISA slot connector has 15 pins dedicated to the IRQ levels, assuring each card that it can use any of the available IRQ levels. These wires are routed to the Interrupt Controller chip which performs priority resolution, and notification of the CPU. See below for a more detailed description of the interrupt flow. EISA cards typically have a software programmable register that the driver must set up to inform the hardware which IRQ line to drive. ISA cards typically have jumpers on the board which must be set up to tell the hardware which IRQ line to use. The assignment of an IRQ level to a board is done by the Configuration Utility, discussed below.

### 14.3.2 DMA Channel

For boards that do not have the Bus Master capability (ie, are not complex enough to take control of the EISA bus) the 82350 chip set provides seven DMA channels. The driver must set up the registers in the 82357 chip (base address, count, etc.) corresponding to the assigned DMA channel. See the section below on DMA for a more detailed description. The ECU is responsible for assigning the DMA channels to the boards that require them.

### 14.3.3 I/O Port Addresses

This resource applies to ISA cards. As mentioned earlier, when the ISA bus was developed, cards were designed to respond to specific 10 bit addresses. As ISA became more popular, and vendors increased, the I/O addresses each board recognized started to overlap. In order to avoid 2 cards answering to the same I/O address, boards began to provide a jumper to select a range of I/O addresses they would answer to, increasing flexibility of configuration. Thus the ECU is responsible for assigning ISA boards an I/O Port starting address. See the System Address Map in a later section for a description of the available ISA I/O ports. EISA cards generally do not need to have I/O ports assigned to them as they can do geographical slot-based addressing using the AENx signal in the EISA protocol.

### 14.3.4 EISA Memory Addresses

On some PC machines, system memory is accessed directly over the EISA bus. On Digital machines, the EISA bus is used as an I/O bus. Digital machines provide access to EISA memory space to access 00 on-board memory, such as frame buffers, on some EISA option cards. See the System Address Map in a following section for a description of these address ranges.

### 14.3.5 EISA Configuration Utility

The ECU is a standalone program that is run prior to booting the machine. The purpose of the ECU is to assign resources to all the cards plugged into the EISA bus in a conflict free manner. The ECU uses configuration files (.CFG files) to get resource requirements for the EISA devices in the system, and prompts for user input to get resource requirements for the ISA devices in the system. The EISA protocol added a software readable ID at a predefined offset on the board ( C80-C83). The board manufacturer is free to choose any ID they want for the offset, but, typically, companies are assigned a 3 letter code which uniquely identifies their boards. It is then up to the manufacturer to keep track of its own IDs so that each board is uniquely identifiable. For details on the contents of the configuration files, see the EISA spec. The .cfg file contains initialization information and resource requirements. The ECU writes all the configuration data, including initialization urp information to NVRAM. It is up to the firmware operating system to use this configuration initialization information. It then determines the requirements of all the options and find a conflict free assignment of the resources if possible. If the ECU cannot find a conflict free assignment of resources, it indicates that a different configuration must be used. The ECU also has the capability of prompting the user to enter configuration information about ISA cards, which typically have no configuration information files. The ECU then writes the configuration information into NVRAM on the system board, using console (or BIOS) callback routines. This information in NVRAM is made available to the drivers via the operating system. (IOC$NODE_FUNCTION, IOC$NODE_DATA are the routines provided by OpenVMS AXP). After writing the configuration information to NVRAM, the ECU instructs the user to power off the system, set any jumpers/switches on the ISA boards, remove the ECU diskette, and power on. At this point the drivers must call the available routines to determine which resources they have been assigned. Note that the ECU need only be run when the system configuration is changed, that is, when boards are added, deleted, or moved around in the EISA slots. It is not necessary to run the ECU before each boot, as the configuration is stored in NVRAM.

## 14.4 EISA Interrupts

The interrupt mechanism on EISA is designed around the requirements of the INTEL 8259 interrupt controller chip. An EISA I/O adapter is designed to work using a small subset of the available interrupt levels on EISA. The cards are designed this way to allow many different configurations to be supported. What this means to the driver writer is you need a method of finding out which IRQ has been assigned to the board so that you can program the board to work with the IRQ (or set a jumper if the board is an ISA board). The IOC$NODE_DATA routine provides this functionality and is described in a later section.

The following is an overview of the sequence of events surrounding an EISA device interrupt.

- The EISA Device requires an interrupt, and asserts the programmed EISA irq line. These lines can be programmed for either edge-triggered (active high) or level-sensitive (active low for sharing irqs) mode.
- The 82357 sees at least one bit in the Interrupt Request Register go high and sets an interrupt pin on the CPU.
- PALcode is invoked and determines that the interrupt is an EISA I/O interrupt
- An INTA (Interrupt Acknowledge) command is sent out over the EISA bus to the 82357.
- This INTA causes the 82357 to lock the Interrupt Request Register for prioritization of the requesting interrupts, and sets a bit in the In Service Register denoting the interrupt selected for service.
- The CPU sends another INTA command over the bus to the 82357, and this command causes a vector identifying the highest priority IRQ requesting service to be sent back over the EISA bus to the CPU.
- PALcode recieves the vector and vectors through the appropriate SCB vector.
- The Driver Interrupt Service Routine services the interrupt and returns to the Operating System Support EISA support code.
- The EISA support code then issues an End Of Interrupt (EOI) command to the 82357 which clears the In Service Register, allowing interrupts of equal and lower priority to occur again. This EOI command is done automatically by Bus Support code in OpenVMS AXP. Operating system code then REIs back to the interrupted thread. Note that if software does not perform the EOI, all future interrupts of equal or lower priority will be disabled.

## 14.5 EISA DMA Support

The 82357 Chip provides 7 independently programmable DMA channels for use by EISA/ISA cards that do not have Bus Master capability, and cannot drive the necessary signals to perform DMA on their own. These seven channels are implemented using the logic of 2 INTEL 8237 chips, with one cascading into the other (Channel 4 is used to cascade the two controllers together). Any channel can be programmed for 8, 16, or 32 bit DMA device size, and ISA compatible "type a", "type b", or burst dma "type c" modes. The EISA Bus Controller chip handles the data size translation. The DMA addressing circuitry supports full 32 bit addresses for DMA devices. Each channel includes a 16 bit Current register, a low Page register and a high page register. Both page registers are 8 bits, and between the 3 cover the 32 bits. The channels can be programmed for one

of four different transfer modes: single, block, demand, and cascade. The DMA controller also offers buffer chaining, auto-initialization, and support for a Ring buffer Data Structure in memory. Buffer Chaining is not supported in OpenVMS AXP.

Documentation that describes the DMA channel is available from INTEL.

## 14.6 EISA I/O Address Map

For a detailed description of the register addresses on the INTEL 82350DT Chip Set, refer to the INTEL documentation.These registers include all the Interrupt Controller CSRs, the DMA controller CSRs, and the Interval timer CSRs. Note all addresses and offsets are hexadecimal unless otherwise specified. EISA I/O space is slot specific for EISA boards, with address bits <15:12> signifying the slot number the board is in. Thus each slot has available 12 bits, or 4K, of I/O space (1000h ). As a side effect of keeping the EISA bus backwards compatible with the ISA bus, certain ranges of this 4K of I/O space are used only for ISA boards. These ranges are called "alias" addresses in the documentation. Since the ISA boards react to any 10 bit address which matches their assigned address, EISA boards are designed to use only addresses with 0s in bits 8 and 9. ISA boards react only to addresses with bits <9:8> not equal to 00. Thus, if this restriction is followed, there will be no conflicts between boards. Address aliases mean that the two address ranges address the same physical board: 0100 is the same as 0900 if you use only the first 10 bits. In the following list “z” (the EISA slot number) can range from 0-F.

- 0000 - 00FF are system board (slot 0) addresses
- 0100 - 03FF are ISA board addresses
- 0400 - 04FF are system board (slot 0) addresses
- 0500 - 07FF are "alias" ISA board addresses
- 0800 - 08FF are system board addresses
- 0900 - 0BFF are ISA alias addresses
- 0C00 - 0CFF are system board addresses
- 0D00 - 0FFF are ISA alias addresses
- z000 - z4FF are slot z EISA board addresses
- z500 - z7FF are slot z ISA board addresses
- z800 - z8FF are slot z EISA board addresses
- z900 - zBFF are ISA alias addresses
- zC00 - zCFF are slot z EISA board addresses
- zD00 - zFFF are ISA alias addresses

The following example using the DEC 2000—Model 300 system clarifies the "alias" addressing. Lets say that we have a DEC 2000 with an EISA board plugged into slot 1, and an ISA board in slot 4. Assume the ISA board has been configured using jumpers to respond to starting I/O port address 03F0 (as is the floppy on DEC 2000). Referencing addresses z3F0, z7F0, zFF0, where z is 0-6 on DEC 2000, will access the same register on the floppy. If the EISA board plugged into slot 1 was designed improperly, and included a register at address z3F0, both boards would try to respond to a reference to address 13F0.

## 14.7 EISA Bus Support on DEC 2000

The following sections describe the EISA Bus Support offered on DEC 2000. Specifically, they describe the following:

- The DEC 2000 System Address map
- The addressing scheme used for byte access to EISA registers
- Interrupt processing
- DMA channels
- OpenVMS AXP provided bus support routines

### 14.7.1 DEC 2000 System Address Map

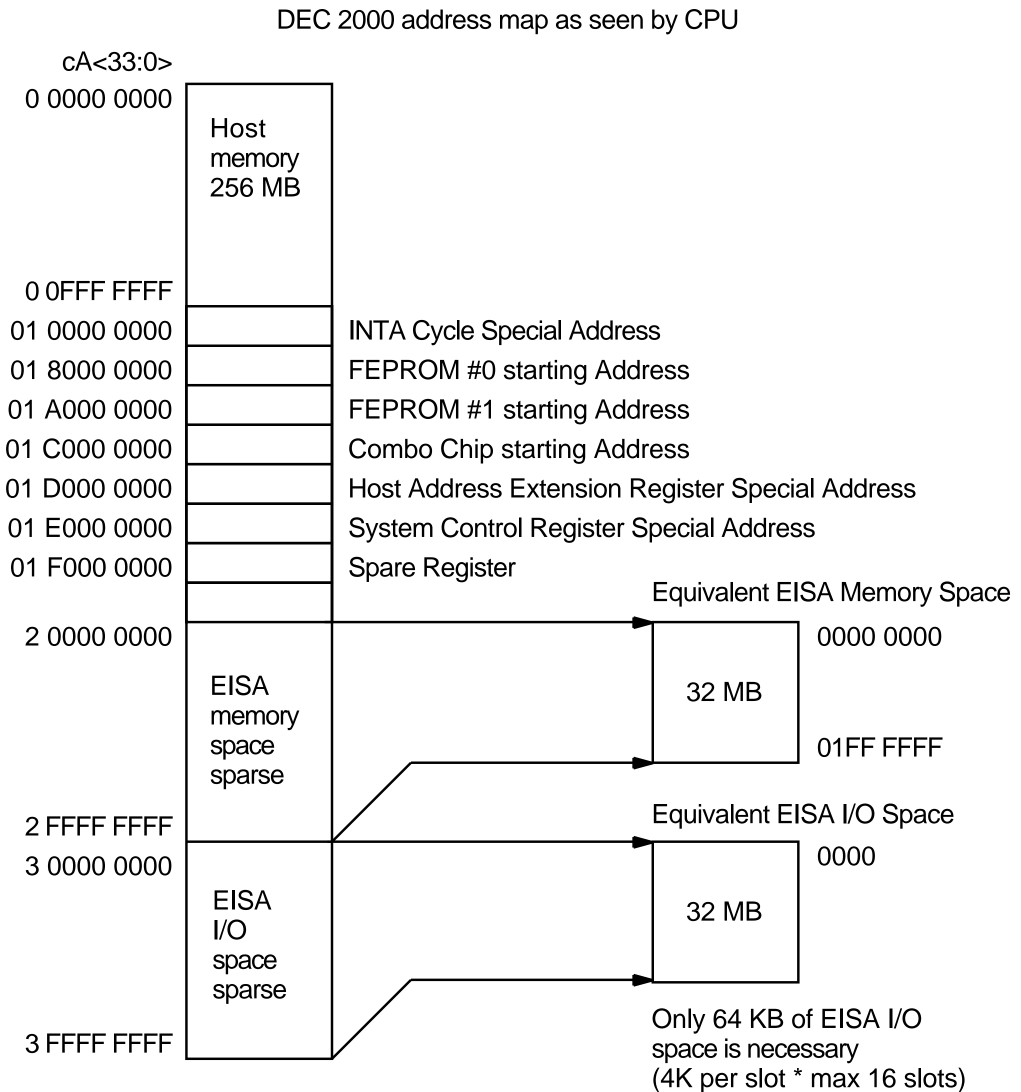
The addressing scheme on DEC 2000 is shown in the following table.

| cpu Addr33:32 | cpu Addr 31 | cpu Addr 30 | cpu Addr29:28 | Effect |
|---|---|---|---|---|
| 00 | MBZ | MBZ | MBZ | Local Memory<br>cAddr 31:28 MBZ |
| 01 | 1 | MBZ | MBZ | EISA INTA cycle<br>(I/O space)<br>cA 31:5 MBZ<br>cA 4:0 SBZ |
| 01 | 1 | 0 | 0x | FEPROM #0 cA 28:9w<br>= addr for up to<br>1MB of ROM,<br>cA 8:0 SBZ<br>Data in low byte |
| 01 | 1 | 0 | 1x | FEPROM #1 cA 28:9<br>= addr for up to<br>1MB of ROM<br>cA 8:0 SBZ |
| 01 | 1 | 1 | 00 | Combo Chip byte<br>ComboAddr ..9 from<br>cA ..9 cA 8:0 SBZ<br>Data in low byte |
| 01 | 1 | 1 | 01 | Host Address<br>Extension Reg<br>cA 27:0 SBZ |
| 01 | 1 | 1 | 10 | System Control Reg<br>cA 27:0  SBZ |
| 01 | 1 | 1 | 11 | Spare Register |
| 10 | x | x | xx | EISA Memory<br>A 31:25 - HAE 6:0<br>A 24:2  -cA 31:9<br>Length/Offset from |
| 11 | x | x | xx | EISA IO<br><br>A 31:25 - HAE 6:0<br>A 24:2  -cA 31:9<br>Length/Offset from<br>cA 8:5 |

#### 14.7.1.1 DEC 2000 Address Space

Figure 14–1 shows the DEC 2000 address map as seen by the CPU.

**Figure 14–1 DEC 2000 Address Map**




#### 14.7.1.2 DEC 2000 System Memory (0-FFF.FFFF)

The DEC 2000 system will support up to 256MB of main memory, addressable using cpu address bits <27:0>. Note that the memory will not respond to access by any device other than the CPU in the upper half-megabyte of the first megabyte of memory (0.5-1MB). This mean that no DMA is allowed into that address range. This restriction is to allow E/ISA devices with on board memory buffers to address those buffers in the first megabyte of EISA memory space.

#### 14.7.1.3 INTA Cycle Access (1.0000.0000)

The interrupt scheme defined for this machine includes an access to the 82357 chip in order to find out which IRQ level is requesting an interrupt. The mechanism by which this is accomplished on the DEC 2000 is via the special address, 1.0000.0000 . Reading this address will cause hardware to issue an INTA cycle over the EISA bus, which is responded to by the 82357 Interrupt Controller. The first INTA cycle causes the controller to lock the request register for priority resolution, and the second read to this address causes the controller to return a vector in the low byte. This vector indicates the EISA irq currently being serviced (irq + 8 is returned). Device drivers should never need to access this register. The INTA cycle is performed by PALcode.

#### 14.7.1.4 NVRAM Access (1.8000.0000, 1.A000.0000)

The Flash Rom on DEC 2000 stores console code and configuration information. It is divided up into logical blocks of size 64K. The SRM console is contained in the first 6 logical blocks, with the SRM EISA configuration information contained in the 7th logical block. The Windows/NT console is contained in blocks 8 through 12, with the NT EISA configuration data contained in block 13. The remaining blocks contain the Failsafe Loader. Device drivers should never access NVRAM directly. Bus Support routines are provided as an interface to the configuration data blocks (IOC$NODE_DATA, IOC$NODE_FUNCTION).

#### 14.7.1.5 VTI VL82C106 Combination Chip (1.C000.0000)

The Combo chip is addressed starting at physical address 1.C000.0000. All the port addresses given in the VTI Combo Chip spec are offset from that base address. Refer to the Combo Chip spec for more details on register offsets. The data returned from reads to this space is returned in the low byte, regardless of the byte offset. This space is mapped into the processor’s virtual address space by the Bus support code, and the VA can be found in the ADP$Q_CSR offset of the COMBO ADP (TR # = 3), or in the IDB$Q_CSR field if your driver is loaded via autoconfigure. It is important to note that the Combo Chip addresses need to be swizzled before being put out on the bus. The combo chip offsets should be shifted up by 9 bits before being put out over the bus by the driver. The hardware then shifts them down when presenting them to the Combo chip. For example, byte offset 3BC in combo chip space is used to address a parallel port register. In order to get the proper physical address to map the following translation must take place:

```
PA =  1.C000.0000 +  3BC ^ 9 =  1.C007.7800
```

Or, using the base VA from the Combo ADP, ADP$Q_CSR + 77800 would access the register. The CRAM routines perform this address shifting for you when used for register access.

#### 14.7.1.6 Host Address Extension Register (1.D000.0000)

This register is used to extend the addressable space on DEC 2000. This 8 bit register is used to form address bits <31:25> on the EISA bus. For the DEC 2000 implementation, this register is set to 0 by console, and is not used afterwards. If this register will be changed or used in the future, synchronization issues will have to be resolved. Device drivers should never access this register. OpenVMS AXP assumes that this register is always zero.

#### 14.7.1.7 System Control Register Access ( 1.E000.0000)

The System Control Register contains Memory configuration information in bits <7:4>, and a code for the LED's in bits <3:0>.

#### 14.7.1.8 EISA Memory Space Access (2.0000.0000 - 2.FFFF.FFFF)

On the DEC 2000, this address space is used to access the RAM buffers which are built into some EISA adapter boards. For instance, the DE422 card contains a 64KB buffer on board which is accessed via EISA Memory Space. The memory addresses are assigned to the boards that need them by the EISA Configuration Utility. These starting addresses are no larger than F8000. From the EISA adapter point of view, that address appears to be in system memory space. That is the primary reason that the system board does not recognize EISA addresses in the range 0.5 - 1 MB as DMA addresses. The following figures are intended to show the mapping of EISA Memory space, and then give several examples describing how a particular board uses this mapping.

**Note**

Devices cannot use this memory region at will. They must be assigned a particular address range by the ECU to avoid overlap.

---

An example of how an EISA memory address would be formed illustrates the bit shifting. Assume that the DE422 board is assigned a 64K buffer in EISA memory space, starting at address C0000. To access a longword at address C0008 the CPU would have to map the following PA:

```
PA = base_addr         + offset_shifted_by_7 + length_constant_for_longword
2.0000.0000 +  C0008 ^ 7           +  060 = 2.0600.0460
```

The base address is 2.0000.0000, the offset is shifted by 7 bits, putting the byte offset into bits <8:7>, and the length constant for longword is put into bits<6:5> by adding 060. Mapping this PA would yield a VA which would access the longword on the DE422 on-board RAM starting at offset 8.

**Note**

This means you can not access E/ISA card buffer space as you did in the INTEL architecture machines. In fact, unless your card is addressable at an EISA address between 0x80000 and 0x100000, you risk corruption of system memory if you attempt to access the E/ISA board buffer. The next diagram shows this overlap of memory addresses.

Note also that EISA memory space is subject to the same sparse space addressing as the EISA IO space. There are solutions available for cards that cannot meet the previously described addressing requirements, but they involve losing part of the available system physical memory.

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Figure 14–2 shows EISA memory address space as seen by an EISA adapter on a DEC 2000.

**Figure 14–2 EISA Memory Address Space**

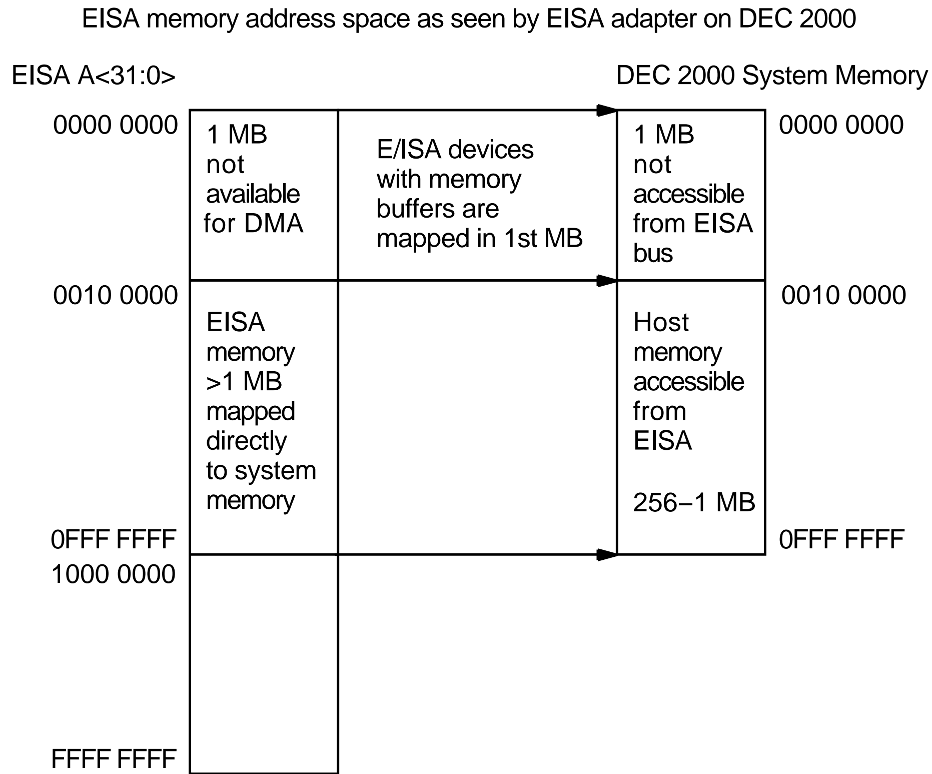
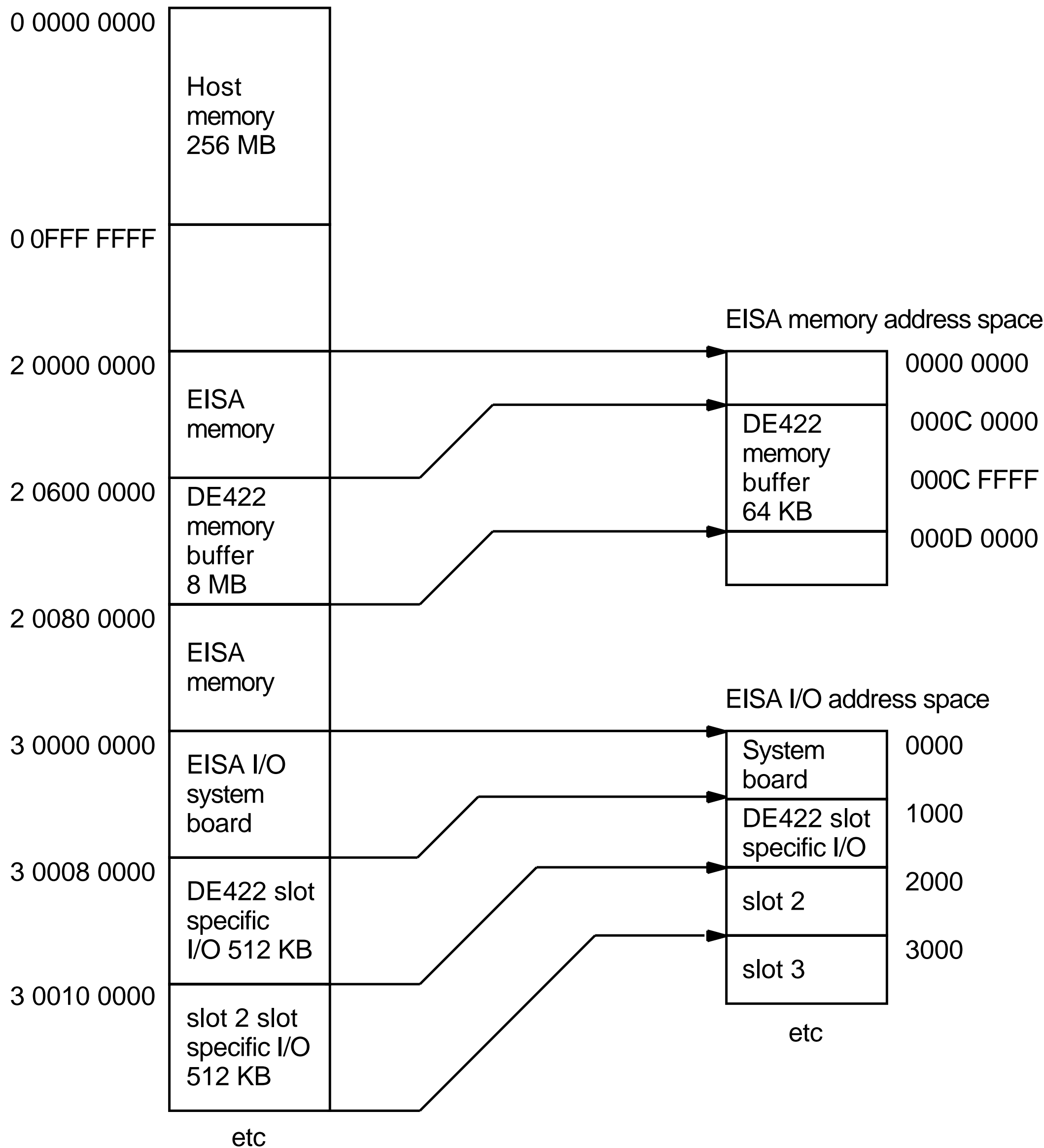



Figure 14–3 shows an example of installing a DE422 EISA Ethernet card in a DEC 2000/EISA slot 1. The DE422 uses slot specific I/O space for control register access and requires a 64KB EISA memory buffer. For this example, assume the DE422 is in slot 1, and the ECU has assigned it a buffer address of C0000. Install a DE422 EISA Ethernet card in a DEC 2000/EISA slot. Figure 14–3 shows a DEC 2000 address map as seen by the CPU.

Figure 14–3 DEC 2000 Address Map




#### 14.7.1.9 EISA I/O Space Access (3.0000.0000 - 3.FFFF.FFFF)

EISA I/O space is mapped into the address space accessed by CPU addresses 3.0000.0000 thru 3.FFFF.FFFF. As mentioned in the historical discussion of the EISA/ISA busses, the cards in the system decode only 10 I/O address bits, with the EISA cards using bits <15:12> to provide geographical addressing (they choose the slot the reference is directed to). Because each slot can take up a maximum of 4 Kbytes, the maximum I/O space needed on this system is 64 Kbytes. Unfortunately, this requirement gets shifted up by 7 bits and turns into 8 Mbytes of EISA I/O address space. Because the Compaq VGA card will address registers on all of the 16 slots of EISA I/O space, all 64 Kbytes must be mapped. An expanded view of the mapping of EISA I/O space to the DEC 2000 Address Map is shown on the following page. As an example of how the address for an EISA I/O space access is formed, assume that the Adaptech 1742a board is in

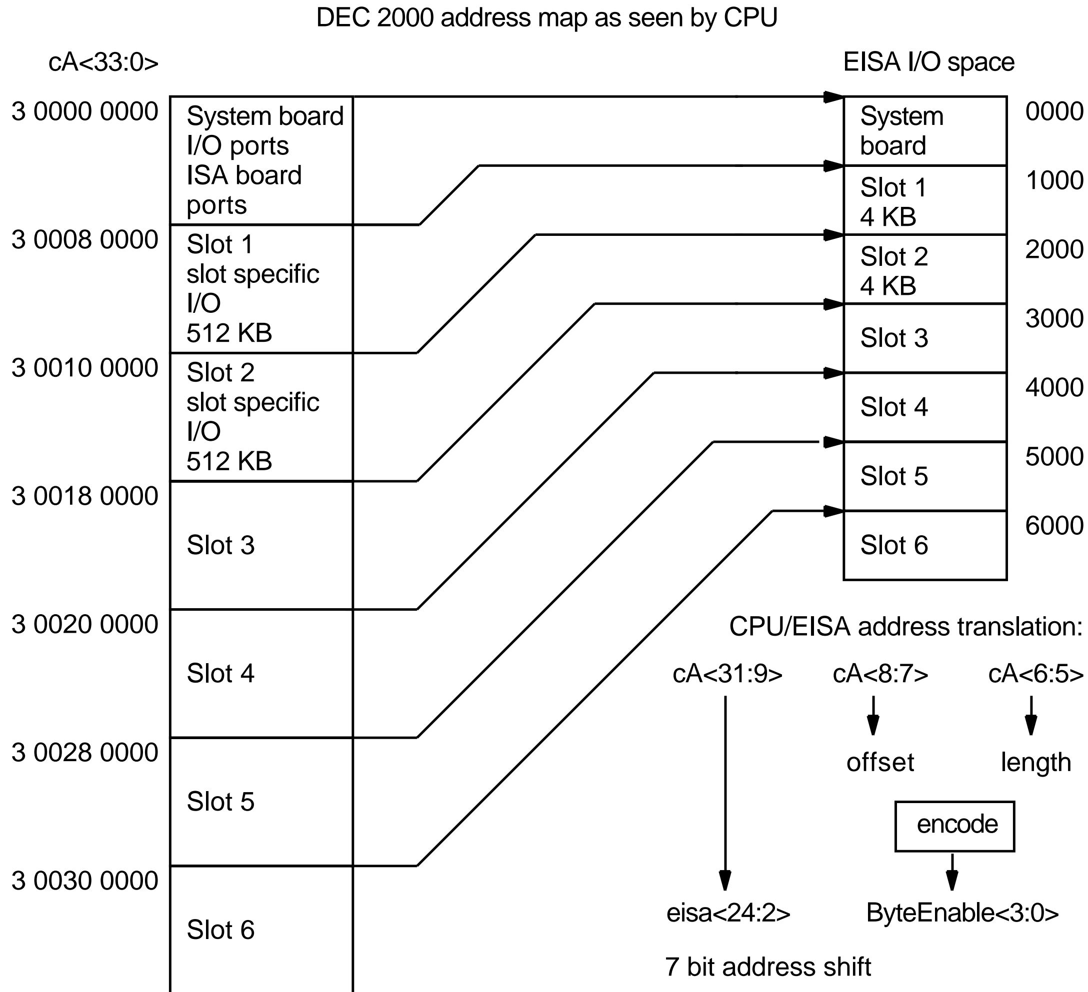
EISA bus slot 4, and you want to read the product ID longword. The PID is stored starting at offset C80. The address would be formed as follows:

```
PA = base_addr+( slot *  1000 + slot_offset) ^7 +
   length_constant_for_longword
       3.0000.0000 +(  4C80 ^ 7) +  060
             3.0000.0000 +  264000 +  060 = 3.0026.4060
```

Mapping this PA would give access to the longword containing the PID for any board in slot 4. Note also that the CRAM routines provided by the Bus Support Code insulate the user from all this bit manipulation. The interface to these handy routines is described in an earlier chapter. Note that the CRAM routines expect the user to use the proper byte lane when reading or writing data from the CRAM$Q_RDATA/CRAM$Q_WDATA fields of the CRAM. Specifically, if it is intended to write a byte at byte offset 1 of a quadword, that data byte must be placed in byte lane 1 of the CRAM$Q_WDATA quadword.

Note that for all ISA devices the slot number is considered to be 0. All ISA devices respond to slot 0 addresses regardless of what is put into address bits <15:12> on the EISA bus. If the slot offset has bits <9:8> = 00, then the ISA devices don't respond at all, if bits <9:8> != 00 then the ISA devices respond, no matter what the "slot" bits (<15:12> ) are set to. Figure 14–4 shows an expanded view of DEC 2000/EISA I/O space.

**Figure 14–4 Expanded view of DEC 2000/EISA I/O Space**




## 14.7.2 Sparse Space

All I/O access on DEC 2000 is done in "sparse" space. There is no dense space. Address bits <8:5> are used to select the length of the transaction and the starting longword offsets as shown in the following table.

| Addr bits 8:7 | Addr bits 6:5 | Access type | Byte Enables | length constant |
|---|---|---|---|---|
| 00 | 00 | byte access to | f f f T | 000 |
| 00 | 01 | word access to word 0 | f f T T | 020 |
| 00 | 10 | tribyte access to | f T T T | 040 |
| 00 | 11 | longword access to LW 0 | T T T T | 060 |
| 01 | 00 | byte access to byte 1 | f f T f | 080 |
| 01 | 01 | word access to | f T T f | 0A0 |
| 01 | 10 | tribyte access to tribyte 1 | T T T f | 0C0 |
| 01 | 11 | reserved | | |
| 10 | 00 | byte access to byte 2 | f T f f | 100 |
| 10 | 01 | word access to | T T f f | 120 |
| 10 | 10 | reserved | | |
| 10 | 11 | reserved | | |
| 11 | 00 | byte access to byte 3 | T f f f | 180 |
| 11 | 01 | reserved | | |
| 11 | 10 | reserved | | |
| 11 | 11 | reserved | | |

## 14.7.3 Register Access

Register access on the DEC 2000 is done with the direct access method or using the device register access routines described in Appendix A. There is no mailbox hardware on DEC 2000 systems. However, to make the interface easier for the driver writer, the CRAM routines are provided, and simply perform direct access of registers, as opposed to a mailbox access. Usage of these routines is highly recommended, as the EISA bus will be found on newer platforms, and uses different shift amounts than DEC 2000. If the driver uses the CRAM routines for register access, there is one less thing that may need to change to move the driver between EISA platforms.

### 14.7.3.1 Direct Register Access

Daring authors are certainly able to do the direct access of registers without using CRAMs. Be sure to pay strict attention to the setting of the length/offset bits <8:5>, and be sure to understand the address bit shifting that is occuring over the various buses in the DEC 2000. In the case of an EISA bus access, the cycle time of the EISA bus is so slow relative to the EV4, that the overhead of a routine call for the CRAM routines is negligible.

### 14.7.3.2 CRAM Register Access

CRAM register access on the DEC 2000 works similarly to the other AXP machines. The same CRAM routine interface (IOC$CRAM_INIT, IOC$CRAM_CMD, IOC$CRAM_IO, and others) is provided, and it works in the same fashion. Obviously there is quite a lot of bit shifting going on behind the scenes of the routine calls. Be sure to byte lane the data in the CRAM RDATA and WDATA quadwords before using. Note that this is not true Hardware Mailbox access, as defined in the SRM. The DEC 2000 has no mailbox hardware, the CRAM routines use direct access methods. That is, the actual access is performed using a load or store instruction to a virtual address.

## 14.7.4 DMA on DEC 2000

There is no Scatter/Gather Map on DEC 2000. A DMA engine is provided for those devices that don't have Bus Master capability. 7 DMA channels exist in the 82357 chip. The channels are assigned as resources by the ECU. It is up to the driver to set up the channel for operation via writes to the 82357 DMA registers. IOC$NODE_DATA can be used to get the DMA channel assigned to a board. The IOC$NODE_DATA interface is described below. A brief example is given, showing one usage of a DMA channel. For complete details, please refer to the INTEL 82357 specification.

### 14.7.4.1 DMA Example

This example shows how the floppy driver on DEC 2000 made use of one of the provided DMA channels. The floppy chip (82077) is resident on the Adaptech SCSI board, but is considered to be a seperate device, using the ISA protocol. It is hardcoded to use IRQ6, I/O ports 3F2h-3F7h, and DMA channel #2.

The driver allocates and maps a contiguous buffer to store the DMA data in between the floppy device and the requestor. Then for each access it must set up a number of DMA registers in the 82357 chip to program the channel for the access. One sequence used to set up a channel looks as follows:

- Setup the channel in the desired mode, enable it as follows:
  - Command register, offset 8D0, enable the channel. Note channel 4 must be enabled if device is using channels 0-3, as they are cascaded through channel 4.
  - Mode Register, offsets B,D6, set the desired mode: chan 4 = cascade, and set the assigned channel to be either read or write, depending on the command to be issued.
- Set up the target address as follows:
  - Clear the byte pointer, offset C. This clears a byte pointer flip-flop which indicates whether the high or low byte was accessed last. This must be done prior to R/W of the address or word count registers.
  - Load the base addr register, offset 4. This byte register is written twice to load the 16 bits of the base address register.
  - Load the low page register, offset 81. This byte register contains bits <16:23> of the 32 bit target address
  - Load the high page register, offset 481. This is the high byte of the target address.
- Load the transfer count registers as follows:
  - Clear the byte pointer once again
  - Load base count register, offset 5. Note it is necessary to load #_of_bytes_ to_transfer - 1 in the count register due to the HW of the 82357 chip.
  - Load the count register, offset 405. Load the 2nd byte of the count register.
- Enable the channel, fill the command silo of the 82077 chip, and let it rip!
  - Set Mask Write register, offset A. Set the bits enabling channel 2 to do DMA.
  - Perform the DMA action.

Note that some of this setup is required for each transfer.

### 14.7.5 I/O Interrupts on DEC 2000

An earlier section described the general flow of an E/ISA device interrupt. This section describes the OpenVMS AXP view in more detail. It is assumed that the reader has read the previous section on EISA interrupts.

#### 14.7.5.1 EISA IRQs

There are 15 IRQ levels available on DEC 2000. Each E/ISA device reports its interrupts through one of these IRQ levels. The default set-up for the IRQ's is to be edge-triggered. The ECU/console is responsible for assignment of the IRQ level to a board. The assignment of the IRQ levels depends on the order boards are plugged into the EISA slots. One IRQ level can be given to one of a subset of boards; that is, many boards are designed to use each particular IRQ. The first board encountered during resource assignment (board in the earliest EISA slot) will be given the IRQ. The others boards that may use that IRQ are assigned another available IRQ.

Currently, the console assigns the IRQ's as follows:

- IRQ0—82357 Timer Interrupt
- IRQ1—Combo chip Parallel Port Interrupt
- IRQ2—Not a valid interrupt, used to cascade the slave 8259 IRQ's into the master 8259
- IRQ3—Not assigned to any device
- IRQ4—Not assigned to any device
- IRQ5—Assigned to the first DE422 board encountered in system
- IRQ6—Not assigned by console, given to the Floppy by Bus Support Code
- IRQ7—Not assigned, this is the spurious interrupt IRQ level, see 82357 spec for details
- IRQ8—Not a valid interrupt, it is asserted low, and not used on DEC 2000
- IRQ9—Compaq VGA card uses IRQ9, DEFEA card can also use IRQ9
- IRQ10—Second DE422 is assigned this IRQ
- IRQ11—First DEFEA card found is assigned this IRQ
- IRQ12—First Adaptech SCSI board found is assigned this IRQ
- IRQ13—Not assigned to any device, used for Buffer Chaining by DMA engine
- IRQ14—Assigned to the second Adaptech SCSI board found
- IRQ15—Assigned to the second DEFEA card found in the system

Note that the COM ports on the COMBO chip do not report via an EISA IRQ. They are wired directly to an Interrupt Request Level on the EV4 chip.

#### 14.7.5.2 SCB Vectors

On OpenVMS AXP EISA device I/O interrupts are dispatched through SCB vectors 800h-8F0h. Each IRQ level is assigned a vector using the following formula:

```
SCB = 800h + (IRQ * 10h)
```

So IRQ 0 reports through SCB vector 800, IRQ1 through 810, etc. In the special DEC 2000 release version, interrupt dispatching is indirectly vectored, and all SCB vectors 800-8F0 point to the indirect dispatcher, which will then call the appropriate driver's Interrupt Service Routine.

#### 14.7.5.3 EOI

The End Of Interrupt command is used to release an interrupt on DEC 2000. The release of an interrupt enables future interrupts of equal or lower priority, thus is critical to the interrupt flow. The EOI command is sent out over the EISA bus to the 82357 chip, which sends it to the associated logical 8259 chip to release the interrupt. OpenVMS AXP uses indirect dispatching to control the dispatch of interrupts. The indirect dispatcher is responsible for issuing the EOI command for all EISA interrupts.

### 14.7.6 EISA Bus Interface Registers

#### 14.7.6.1 Interrupt Enable Register

EISA I/O interrupts are enabled or disabled via the Interrupt Enable Register. This 82357 register is accessed via the IOC$NODE_FUNCTION routine using the IOC$K_ENABLE_INTR and IOC$K_DISABLE_INTR function codes.. When a driver is ready to handle device interrupts, it should call the IOC$NODE_ FUNCTION routine with the IOC$K_ENABLE_INTR function code. This will cause a bit in the Interrupt Enable register to be asserted, enabling EISA interrupts from the IRQ assigned to the device driver calling the routine. The interrupts can also be disabled by using the IOC$K_DISABLE_INTR command index. This will clear the enable bit in the Interrupt Enable Register, prohibiting further interrupts from the IRQ associated with the device. As an example call of this routine is shown below:

```
status = IOC$NODE_FUNCTION (crb_address,
                            ioc$k_enable_intr);
```

#### 14.7.6.2 End of Interrupt Command

As mentioned above the EOI command is critical to the success of the EISA interrupts. This 82357 register is accessed via the IOC$NODE_FUNCTION routine with the command index IOC$K_ISSUE_EOI. This routine call will write the EOI register with the IRQ level assigned to the calling device, releasing the interrupt. Early test versions of OpenVMS AXP required drivers to use this call in the driver interrupt service routine to release the interrupt, however, the EOI is now done by the indirect interrupt dispatcher. It is not necessary for drivers to isse the call to IOC$NODE_FUNCTION to cause an EOI.

#### 14.7.6.3 IOC$NODE_FUNCTION and IOC$NODE_DATA

**14.7.6.3.1 IOC$NODE_FUNCTION** On DEC 2000 this routine is used to enable /disable EISA interrupts. The parameters are CRB address and function code. The available functions are ioc$k_enable_intr and ioc$k_disable_intr. Both ioc$k_enable_intr and ioc$k_disable_intr work on the Interrupt Mask Register in the Interrupt Controller Chip (82357) for the EISA bus. In the driver unit or controller init routine, after the device is set up to handle interrupts, the driver should call IOC$NODE_FUNCTION with the ioc$k_enable_intr code. Note

that many EISA devices also have interrupt enable bits resident on the boards themselves which the driver must explicitly enable also.

The IOC$NODE_FUNCTION function codes are defined in [LIB.LIS]IOCDEF.SDL.

**14.7.6.3.2 IOC$NODE_DATA** This routine is used by a driver to get the resources assigned to its device using an EISA Configuration Utility (ECU) from MCS Corporation. The resources which are assigned to EISA boards are Interrupt Request Level (IRQ), DMA Channel #, EISA IO Port address, and EISA Memory address.

**Important Note**

ECU may assign multiple resources for a board, depending on what is in the manufacturers configuration file. It is suggested that the callers of this routine allocate a buffer large enough to hold the information for all the resources. That is to say, if the board can be assigned more than 1 Memory Buffer, say 4 (as is the case for the COMPAQ VGA card), the caller ought to be sure to allocate 4 times the suggested buffer size given below. All buffer sizes given below are for a single resource.

---

The parameters to IOC$NODE_DATA are:

- crb—Address of the CRB which contains the EISA slot number
- fnc_code—Function code to be performed.

  This routine supports only 4 of the available function codes: ioc$k_eisa_irq, ioc$k_eisa_dma_chan, ioc$k_eisa_io_port, and ioc$k_eisa_mem. Any of the other function codes will return bad status.
- user_buffer—Address of a user supplied buffer to contain the data. It is assumed that the user has allocated enough space for the return data.

  Function code ioc$k_eisa_irq requires a longword buffer, and returns the IRQ assigned to the board in that buffer. Valid EISA IRQ's for DEC 2000 are 0,1,3-7,9-12,14,15. Boards are typically designed to work with a subset of these IRQ's, and need to be told which IRQ they will be using in the current system configuration. Drivers typically need to program the board to use the IRQ it has been assigned, and can use this routine to find that out.

Function code IOC$K_EISA_DMA_CHAN requires a longword buffer and returns the EISA DMA Channel assigned to the board. There are 7 DMA Channels available on DEC 2000, 0-3 and 5-7. Not all boards do DMA, nor do all DMA boards use the DMA engine provided by the Intel 82350DT Chip set.

Function code ioc$k_eisa_io_port requires a longword length buffer. It returns to the user the starting address of the assigned IO port as well as the number of consecutive bytes assigned. Many ISA boards, and some EISA boards are designed to use some number of different address ports for CSR access. This routine will return the starting IO port address assigned to this board with the lower word and the number of bytes in the upper word.

Function code ioc$k_eisa_mem require at least a quadword buffer. It will return the assigned starting address of EISA memory in the first longword, and the size of the allocated buffer in the second longword. These addresses are used to access on board RAM on DEC 2000 adapters. Available EISA memory addresses on DEC 2000 are A0000 - EFFFF, and are given out in chunks of 32 or 64K.

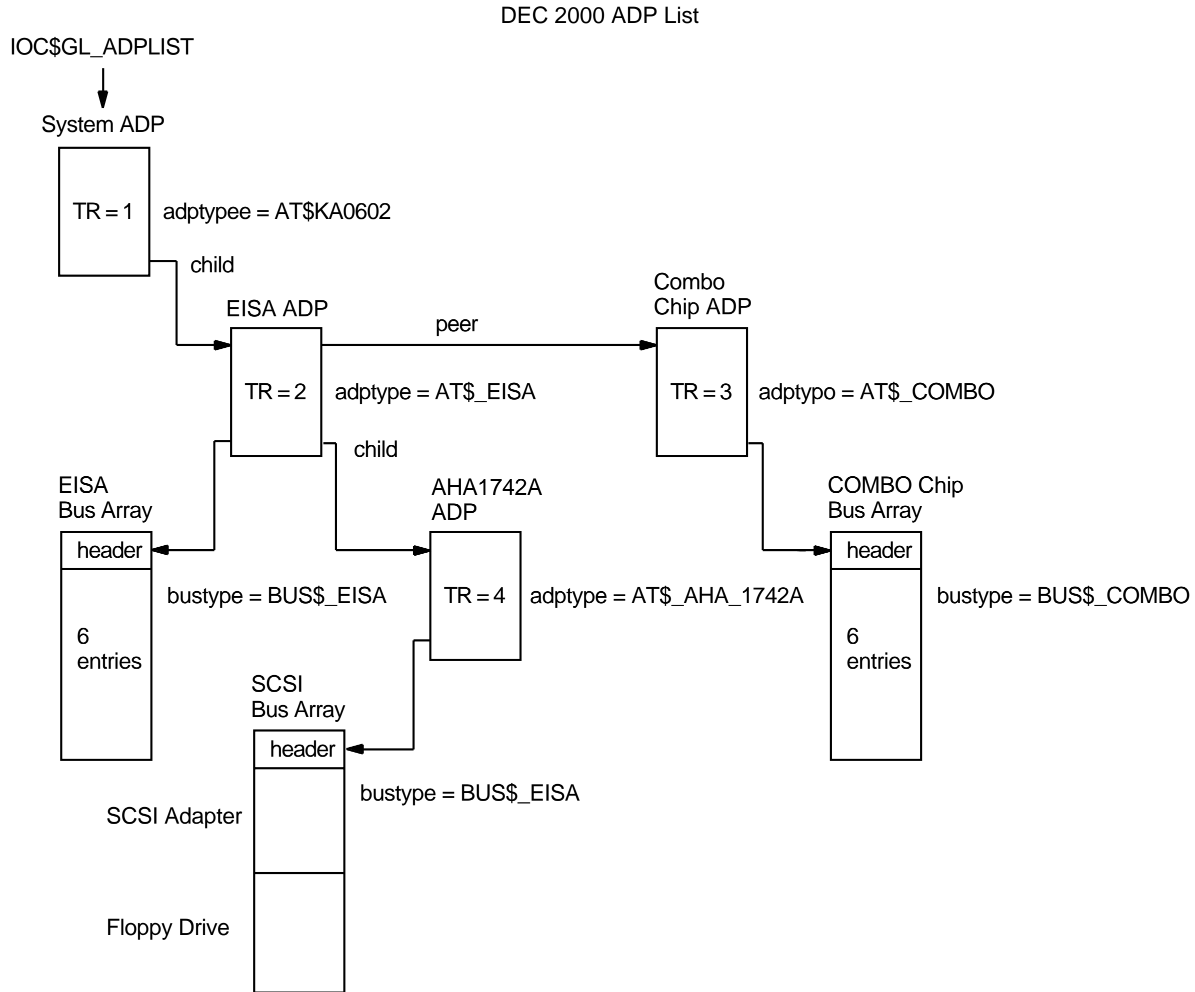
Note the driver is responsible for mapping the PA of the EISA board mem buffer (=2.0000.0000 + (start_addr ^ 7)). Currently there are only 3 boards supported which request memory buffers: DE422, DEFEA, and VGA card. However, depending on how many of each of these cards are in the system, the available memory resources can be exhausted. The VGA card is assigned addresses A0000-C7FFF(3 chunks). The NI and FDDI cards compete for the same memory buffer addresses, E0000/D0000. The NI card requires a 64K buffer, and asks for a starting address of either E0000, or D0000. The FDDI card requires either a 32K or 64K buffer, and asks for a starting address of either C8000, or E0000 then D0000. So, we can not have 2 NI and 2 FDDI cards in the system at one time. The resources limit the configuration to 1 NI & 2 FDDI or 1 FDDI & 2 NI. See the later section on resource assignment for all the details of available resources.

**14.7.6.3.3 CRB$L_NODE** The CRB$L_NODE field contains information critical to the success of these routines. If the driver is manually connected, the command must include the "/NODE=%xyyyyzzzz" qualifier, where yyyy is the IRQ assigned, and zzzz is the slot number the board is plugged into. For instance, if the console assigns the board IRQ 5, and it is plugged into slot 6, the CONNECT command would include /NODE=%x00050006. If the driver is autoconfigured, then this field is filled in by the driver loading code.

### 14.7.7 DEC 2000 I/O Space Map

The Bus Support Code is responsible for creating a map of the I/O space. This is done during bus probe time, as mentioned earlier. The ADP map created for DEC 2000 is shown in Figure 14–5.

**Figure 14–5 DEC 2000 ADP List**




## 14.7.8 Configuring a Device on DEC 2000

If your device is not supported by the Bus Support code on DEC 2000, it will need to be manually configured. The method to do this is similar to all other AXP platforms, with the exception of the CRB$L_NODE field. Below is given the command to issue in order to configure a device and load the driver for an EISA adapter. Each of the command parameters is discussed in detail.

```
$ MCR SYSMAN IO CONNECT xxA0 /driver=sys$xxdriver
/vector=(irq*4)
/node=%x000z000a
/adap=2
/csr=b
```

Specify the device name and driver name as you would for any system.

#### 14.7.8.1 Vector parameter

/vector=(irq*4):

The vector is slightly tricky. Because DEC 2000 uses indirect dispatching, the vector is computed, similar to the other indirectly dispatched platforms, using the IRQ as follows: vector=(irq*4). For example, if your device is going to use IRQ 4, the vector parameter would be 16. Choosing an available IRQ is the tricky part. You must choose an IRQ that your board can work with that has not already been assigned by the console.

Note that the DMA channel and the EISA Memory resource are not specified in the CONNECT command anywhere. There is no system software checking for conflicts in usage of the resources. It is assumed that the user runs the ECU that will check for conflicts before boot time, and the driver is assured of a conflict free assignment by using the IOC$NODE_DATA function to get ECU assigned resources.

#### 14.7.8.2 Node parameter

```
/node=%x000z000a:
```

Here "z" is the IRQ level that is chosen, and "a" is the slot number the board is plugged into. The slots are numbered from 1 to 6. Note that without this qualifier, the IOC$NODE_DATA and IOC$NODE_FUNCTION routines will NOT work.

#### 14.7.8.3 CSR parameter

```
/csr = b:
```

The CSR address can be found using the MCR SYSMAN IO SHOW BUS command. For each adapter plugged into the system, the EISA Bus Support code maps that adapters IO Space. This is the base VA which is used by the CRAM routines to access CSR's on the board. It is strongly encouraged that you use CRAM routines (IOC$CRAM_CMD and IOC$CRAM_IO) to access CSR's, as then the bus support code performs all the funny address bit shuffling for you. The CSR parameter is copied into the IDB$Q_CSR field.

#### 14.7.8.4 Resource Assignment on DEC 2000

Resource Assignment on DEC 2000 systems use the ECU to configure the system.

**14.7.8.4.1 IRQ's** In a typical system, where there is only 1 SCSI board, 1 NI board, and a VGA card the user is free to choose any IRQ for the board except for:

```
IRQ0 - assigned to the 82357 Timer
IRQ1 - assigned to the Parallel Port on the Combo chip
IRQ2 - used to cascade IRQs 8-15 into IRQs 0-7
IRQ5 - assigned to the Ethernet card
IRQ6 - assigned to the Floppy Chip, resident on the Adaptech
      1742a card
IRQ8 - this is active low and not used on DEC 2000
IRQ9 - assigned to the Compaq VGA card
IRQ12 - assigned to the Adaptech 1742a SCSI controller
IRQ13 - used by the DMA controller, not available on DEC 2000
         Explicitly, that would be IRQs: 3,4,7,10,11,14,15.
```

**14.7.8.4.2 EISA Memory Addresses** If your board needs EISA MEM space, you are restricted to choosing something in the range 80000h - 100000h. Depending on the configuration, choose something other than:

```
A0000-C7FFF - assigned to the Compaq VGA card
D0000-DFFFF - assigned to the DE422 card, or a second DEFEA
            card
E0000- EFFFF - assigned to the DEFEA FDDI card if present,
            or a second DE422 card
```

Note that these memory requirements prohibit an EISA bus configuration consisting of 2 DE422 cards and 2 DEFEA cards. There is not enough memory space to go around.

**14.7.8.4.3 ISA I/O Port Addresses** The only port addresses being used on the DEC 2000 system are that of the floppy port. The floppy is using ports 3F2-3F7h. If more ISA devices are plugged into the EISA bus, they will also be assigned port addresses by the ECU.

To connect new devices, which will not show up in the SYSMAN IO SHOW BUS display, you must specify the virtual address of the base of the EISA I/O space. This virtual address can be obtained from the IO SHOW BUS display in the line associated with the floppy. All ISA devices share the same base virtual address and the floppy CSR shown is the base of EISA I/O space. Alternatively, use the ANALYZE/SYS facilty to look at the ADP$Q_CSR Field of the EISA ADP to get the CSR parameter value for new ISA cards.

# 15
# Futurebus+ Bus Support

This chapter discusses base Futurebus+ support in the OpenVMS AXP operating system. First a general description of Futurebus+ concepts is given, followed by a description of Futurebus+ support in the operating system and a description of Futurebus+ support on the DEC 4000 and DEC 10000/7000 platforms.

## 15.1 Futurebus+ Overview

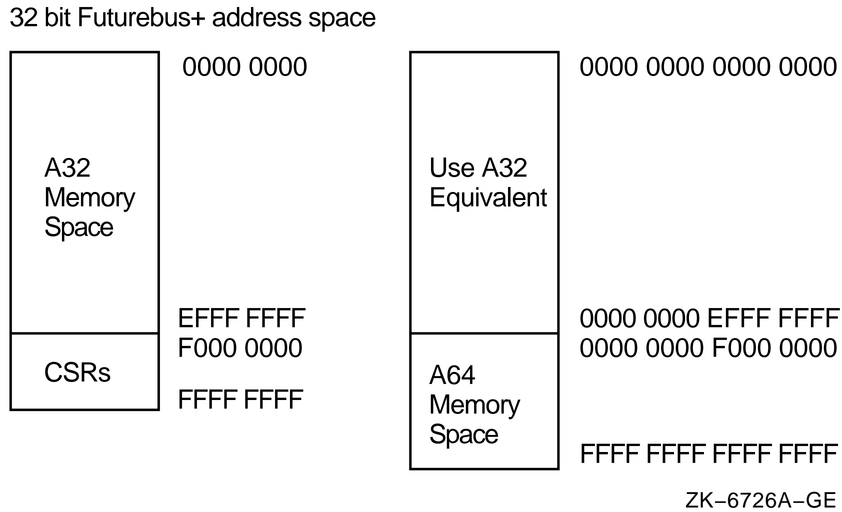
Futurebus+ is an industry standard bus defined by IEEE standards 896.1 (Logical Layer), 896.2 (Physical Layer and Profiles), 896.3 (Recommended Practices), and 1212 (CSR architecture). Digital AXP platforms implement Profile B, which is intended as a general purpose I/O bus. Futurebus+ Profile B is required to support 32 bit addressing (A32) and optionally supports 64 bit addressing (A64). Data widths from 32 to 256 bits are supported, though only 32 bit support (D32) is required. The bus uses an asynchronous protocol, so that the achievable bandwidth depends on the components used to build the modules. Current implementations (DEC 4000 and DEC 10000/7000) have demonstrated bandwidths on the order of 150 MB/second.

The Futurebus+ specifications describe a module as occupying a physical backplane slot. A module can implement one or two nodes. A maximum of 62 nodes per bus is supported. The physical backplane slot number of a module determines the base address of Futurebus+ node space for the nodes on the module. Futurebus+ is currently available on the DEC 10000/7000 and DEC 4000 platforms.

## 15.2 Futurebus+ Address Space

The Futurebus+ supports 2 distinct address spaces, 32 bit address space (A32) and 64 bit address space (A64). Since all nodes are required to support A32, all A64 transactions to addresses with 32 bit equivalents should use A32 to insure interoperability . 32 bit and 64 bit Futurebus+ address space is shown in Figure 15–1.

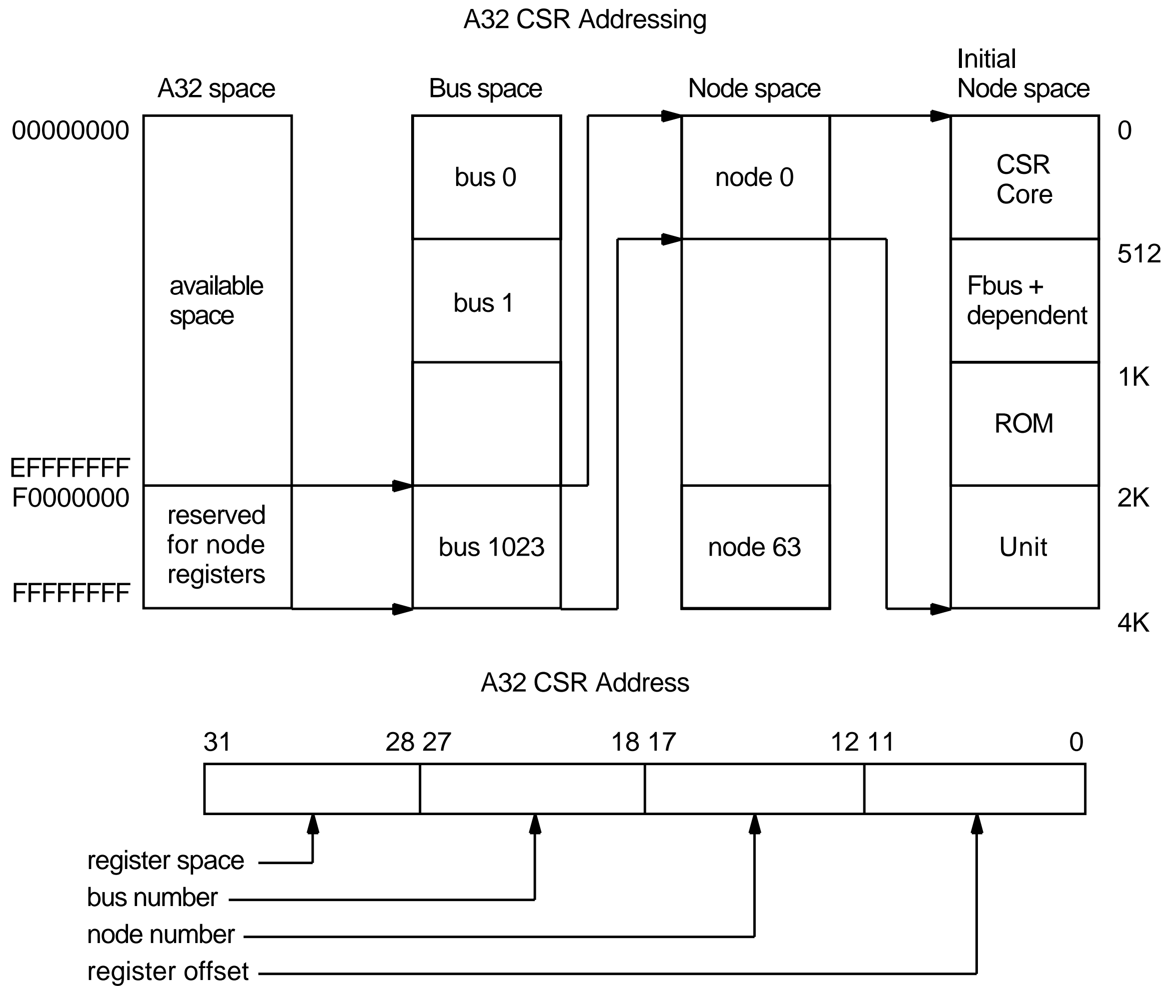
**Figure 15–1 32 Bit Futurebus+ Address Space**




## 15.3 Futurebus+ CSR Addressing

Futurebus+ requires that all nodes support A32 addressing. While referencing CSRs only 32 bit addressing should be used. Futurebus+ A32 space and the format of an A32 CSR address are shown in Figure 15–2.

**Figure 15–2 Format of an A32 CSR Address**




Futurebus+ A32 register space is accessed when bits 31:28 of the address are 1111 (binary). This uses up 1/16 of the available 32 bit address space for register space. Futurebus+ A32 addressing allows for bus numbers, such that 1023 separate buses, each with 63 nodes, can exist in the same address space. Futurebus+ reserves node 63 as a "broadcast space" address, so Futurebus+ systems are limited to 62 nodes on a bus.

Configuration software is expected to number all of the buses that may be present in a system. Nodes on the same Futurebus+ can access each other's register space using the actual bus number (from the NODE_IDS register) or bus number 1023, which is always interpreted as the local bus. OpenVMS AXP uses bus number 1023 for all accesses to Futurebus+ address space. Modules get the 5 most significant bits of their 6 bit node address from the Geographical Address lines GA<4:0>, which are hardwired in each backplane slot. The least significant bit of the node address determines which node on a module is addressed (0 or 1). Modules which only implement a single node are supposed to use node 0 addresses. As shown in the above diagram, each node is assigned a 4KB block of initial node space for CSRs. The 4KB space is broken up into 4 regions–CSR

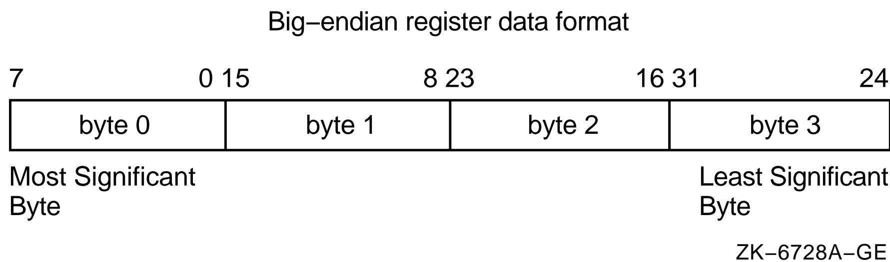
Core, Futurebus+ Dependent, ROM, and Initial Units Space. The CSR Core space is defined by IEEE 1212 (CSR Architecture). Futurebus+ Dependent space is defined by IEEE 896.2 (Physical Layer and Profile). ROM space is defined by both IEEE 1212 and 896.2. Initial Units Space is vendor defined.

[LIB.LIS]FBUSDEF.SDL defines symbolic register offsets for the 4KB initial node space.

## 15.4 CSR Data Format

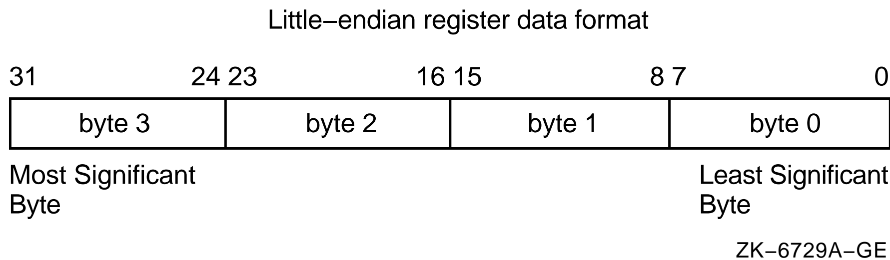
CSR register definitions for the CSR Core, Futurebus+ Dependent, and ROM area are given in IEEE 1212 and 896.2 in "big-endian" data format. Big-endian register data format is specified as shown in Figure 15–3.

**Figure 15–3 Big-Endian Register Data Format**




Little-endian register format is defined as shown in Figure 15–4.

**Figure 15–4 Little Endian Register Data Format**




When a big-endian register is driven onto the Futurebus+, byte 0 is driven on Futurebus+ AD<7:0>, byte 1 is driven on AD<15:8>, byte 2 is driven on AD<23:16>, and byte 3 is driven on AD<31:24>. FBUSDEF.SDL defines CSR Core, Futurebus+ Dependent, and ROM registers in little-endian format, thus, byte lane swapping must be performed after reading and before writing registers in the CSR Core, Futurebus+ Dependent, and ROM areas in order to make the register data match the FBUSDEF.SDL definitions. In general a driver has no need to access registers in the CSR Core, Futurebus+ Dependent, or ROM areas. These areas are primarily used for initial node setup and are only accessed during booting and system configuration. Initial Unit Space is vendor-defined, so registers in Initial Unit Space may be either big or little endian. Digital adapters generally use little-endian register definitions for Initial Unit Space registers.

## 15.5 Futurebus+ Register Access

On both the DEC 10000/7000 and DEC 4000 platforms, access to Futurebus+ CSR space is accomplished through hardware I/O mailboxes or the device register access routines described in Appendix A. A driver uses the standard register access routines provided by OpenVMS/AXP to accomplish a register access.

### 15.5.1 Allocating CRAMs for Futurebus+ Register Access

There is nothing that is specific to Futurebus+ in the area of CRAM allocation. As mentioned previously, CRAM allocation can be done automatically by the driver loading program by specifying the desired number of CRAMs in DPT$W_IDB_CRAMS or DPT$W_UCB_CRAMS, or the driver can directly call IOC$ALLOCATE_CRAM.

### 15.5.2 Initializing CRAMS

As with all mailbox register accesses, IOC$CRAM_CMD is used to initialize the COMMAND, MASK, and RBADR fields of the CRAM. The initialization of these fields is done in a bus-specific manner. For the Futurebus+, the COMMAND field is initialized (based on the command index) with bit patterns that are directly driven onto the Futurebus+ CM<7:0> wires during a Futurebus+ command cycle. The MASK bits become Futurebus+ byte enable signals at the appropriate time during a Futurebus+ cycle. The RBADR field is initialized with the target address of the Futurebus+ CSR. The following table shows which command indices are supported on Futurebus+, and the COMMAND field bit patterns that are generated for each command index.

```
 Command Index   Mailbox Command      Description
                 Field Contents
                   (bits 7:0)


cramcmd$k_rdquad3    0 0 1 0 0 0 read, unlocked, aw=32,
                 0 0             dw=64
cramcmd$k_rdlong3    0 0 0 0 0 0 read, unlocked, aw=32,
cramcmd$k_rdword3    0 0 0 0 0 0 read, partial, aw=32,
                 1 0             dw=32
cramcmd$k_rdbyte3    0 0 0 0 0 0 read, partial, aw=32,
cramcmd$k_wtquad3    0 0 1 1 0 0 write, unlocked,
                 0 0             aw=32, dw=64
cramcmd$k_wtlong3    0 0 0 1 0 0 write, unlocked,
cramcmd$k_wtword3    0 0 0 1 0 0 write, partial, aw=32,
                 1 0             dw=32
cramcmd$k_wtbyte3    0 0 0 1 0 0 write, partial, aw=32,
cramcmd$k_rdquad6    1 0 1 0 0 0 read, unlocked, aw=64,
                 0 0             dw=64
cramcmd$k_rdlong6    1 0 0 0 0 0 read, unlocked, aw=64,
cramcmd$k_rdword6    1 0 0 0 0 0 read, partial, aw=64,
                 1 0             dw=32
cramcmd$k_rdbyte6    1 0 0 0 0 0 read, partial, aw=64,
cramcmd$k_wtquad6    1 0 1 1 0 0 write, unlocked,
                 0 0             aw=64, dw=64
cramcmd$k_wtlong6    1 0 0 1 0 0 write, unlocked,
                 0 0             aw=64, dw=32
cramcmd$k_wtword6    1 0 0 1 0 0 write, partial, aw=64,
cramcmd$k_wtbyte6    1 0 0 1 0 0 write, partial, aw=64,
                 1 0             dw=32
```

An example call to IOC$CRAM_CMD is as follows:

```
                status = ioc$cram_cmd(cramcmd$k_rdlong32,           /*
        command index   */
                                4,              /* byte offset  */
                                adp_address,
                                cram_address);
```

The COMMAND field bit patterns are stored in a table pointed to by field ADP$PS_COMMAND_TBL in the Futurebus+ ADP. IOC$CRAM_CMD uses the command index to find the proper COMMAND field bit pattern, and copies the command field bits to CRAM$L_COMMAND. RBADR is calculated from the byte offset input parameter and the IDB$Q_CSR field in the IDB. The byte offset is added to the value in IDB$Q_CSR, and the result is copied to CRAM$Q_RBADR.

No further alignment is applied to RBADR. The MASK field is calculated based on the command index and the byte offset. If the caller specifies a byte or word length read or write, the MASK bits are set based on the transfer size (byte or word) and the first byte involved in the transfer.

### 15.5.3 Issuing the Futurebus+ Register Access

There is nothing specific to the Futurebus+ in issuing the CRAM. A driver calls IOC$CRAM_IO, as follows:

```
status = ioc$cram_io (cram_address);
```

On Futurebus+ platforms, IOC$CRAM_IO performs the entire Alpha I/O mailbox operation, including queueing the mailbox and waiting for the DONE bit. A driver may also call IOC$CRAM_QUEUE, which queues the hardware mailbox and returns to the caller without waiting for the DONE bit to be set. If a driver uses IOC$CRAM_QUEUE, the driver should call IOC$CRAM_WAIT to check that the DONE bit is set (indicating the previous operation has completed) before re-using the CRAM for another register access.

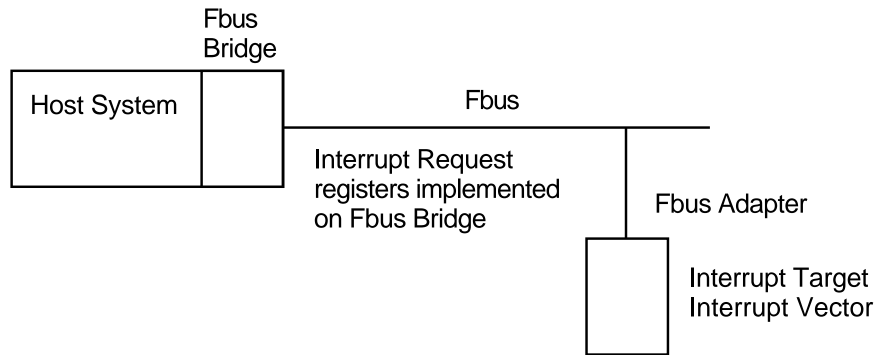
## 15.6 DMA

On the DEC 4000 and DEC 10000/7000 platforms, Futurebus+ adapters access system memory through the Futurebus bridge. The bridge accepts all non-register space Futurebus+ addresses, and passes them directly to the system memory. There are no map registers in either DEC 4000 or DEC 10000/7000, hence all DMA is "physical" DMA.

## 15.7 Futurebus+ Interrupts

A Futurebus+ adapter interrupts the host by writing a 32 bit quantity (an interrupt vector) to an Interrupt Request register address. The Interrupt Request register address is not specified by the Futurebus+ specifications–it is left up to system implementors to define the interrupt mechanisms for a particular system. Digital Futurebus+ bridges implement 4 Interrupt Request register addresses at offsets 800, 804, 808, and 80C (hex) in the bridge's Initial Unit Space. Futurebus+ adapters generally implement an Interrupt Target and an Interrupt Vector register in the adapter Initial Unit Space. During driver initialization, the driver writes the adapter Interrupt Target register with the address of one of the bridge's Interrupt Request registers, and writes the adapter Interrupt Vector register with the assigned interrupt vector (the adapter interrupt vector is assigned when the driver is loaded). The Futurebus+ adapter interrupts the host by writing the value in its Interrupt Vector register to the address stored in its Interrupt Target register. This is shown in Figure 15–5.

**Figure 15–5 Futurebus+ Target Register**




Interrupt Target programmed with Interrupt Request register address during driver initialization.
Interrupt Vector programmed with vector during driver initialization.
Fbus Adapter interrupts host by writing Interrupt Vector contents to Interrupt Request register on bridge.

ZK–6730A–GE

The Futurebus+ Bridge supplies different Interrupt Request register addresses to allow Futurebus+ adapters to interrupt the host at different Interrupt Priority Levels. On the DEC 10000/7000 and DEC 4000 platforms, the Interrupt Request register addresses are used as follows:

```
Interrupt Register oDEC 10000/7000    DEC 4000

   800             IPL 14 (hex) interIPL 14 (hex) interrupt

   804             IPL 15 (hex) interIPL 14 (hex) interrupt
   808             IPL 16 (hex) interIPL 14 (hex) interrupt

   80C             IPL 17 (hex) interIPL 14 (hex) interrupt
```

The actual address of the bridge Interrupt Register depends on the Futurebus+ node number of the bridge. The bridge may reside in different Futurebus+ slots on different platforms, so OpenVMS AXP uses system routine IOC$NODE_DATA to return the base Interrupt Register address to a driver. An example call to IOC$NODE_DATA to get the base Interrupt Register address is shown below:

```
status = ioc$node_data (crb_address,
                        ioc$k_fbus_int_loc,
                        addr_of_longword);
```

IOC$NODE_DATA finds the bridge Futurebus+ slot number and returns

```
bridge_nodespace_base + 800
```

in the caller's buffer. If the bridge is installed in Futurebus+ slot 0, for example, IOC$NODE_DATA would return FFFC0800 to the caller. The driver should program this value (if interrupt priority level 14H is desired) to the Interrupt Target register on the driver's Futurebus+ adapter.

## 15.8 Futurebus+ System Routines

The Initial Node Space base address of a Futurebus+ adapter is determined by the backplane slot into which the adapter is installed. For most adapters, device control functions can be accomplished through registers located in the adapter Initial Unit Space. However, some adapters require additional Futurebus+ address space for their operation. An example of such an adapter may be a bus bridge, which may require a large chunk of Futurebus+ address space to serve as a window to a remote bus. OpenVMS/AXP provides two routines to manage the allocation of Futurebus+ address space. These routines are IOC$RESERVE_FBUS_A32, which manages Futurebus+ A32 space, and IOC$RESERVE_FBUS_A64, which manages Futurebus+ A64 space. A driver which requires Futurebus+ address space in addition to its Initial Node Space may call one of these routines to reserve a region of Futurebus+ address space. The operation of these routines is explained below.

### 15.8.1 IOC$RESERVE_FBUS_A32

IOC$RESERVE_FBUS_A32 may be called by a driver that requires a region of Futurebus+ A32 space. A bus bridge, which requires address space for a window to a remote bus, is an example of an adapter that may require Futurebus+ address space in addition to its registers. The minimum granularity of A32 space address allocation is 16 MB (that is, the smallest possible request for A32 address space is for a 16 MB region). The reason for this granularity is to reduce the management overhead in keeping track of the allocated space. An example call is given below:

```
status = ioc$reserve_fbus_a32 (fbus_adp,
                               request_amt,
                               buffer_addr);

Inputs

    fbus_adp    : address of Futurebus+ ADP
    request_amt : Amount of requested A32 space in 16 MB
    chunks.
```

### 15.8.2 IOC$RESERVE_FBUS_A64

IOC$RESERVE_FBUS_A64 is similar in operation to IOC$RESERVE_FBUS_A32. The minimum granularity of A64 space address allocation is 4 GB (that is, the smallest possible request for A64 address space is for a 4 GB region). The reason for this granularity is to reduce the management overhead in keeping track of the allocated space. An example call is given below:

```
status = ioc$reserve_fbus_a64 (fbus_adp,
                                request_amt,
                                buffer_addr);

Inputs

    fbus_adp    : address of Futurebus+ ADP
    request_amt : Amount of requested A64 space in 4 GB chunks.
```

## 15.9 Configuring a Futurebus+ Adapter

Manual configuration of adapters is very similar across platforms and buses. There are some bus-specific differences, usually in the format of the base CSR address and in the specification of the interrupt vector(s). The SYSMAN utility is used to manually configure adapters. In order to manually configure a Futurebus+ adapter, the first step is to issue the SYSMAN IO SHOW BUS command. This command uses the ADP list (pictured in the DEC 4000 and DEC 10000/7000 chapter) to display information on all of the I/O options that are present in the system.

The SYSMAN IO CONNECT command is used to actually configure an adapter. For a Futurebus+ adapter, this command should be issued as follows:

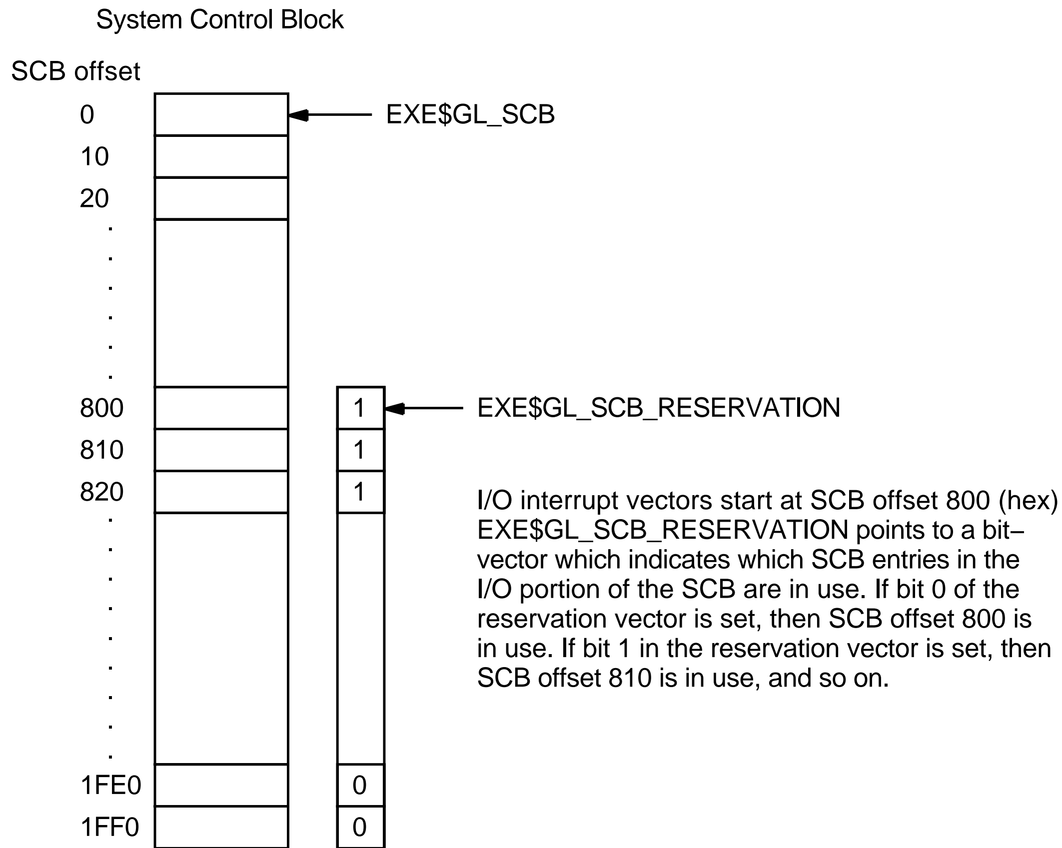
```
SYSMAN> IO CONNECT devname /adapter=x  /csr=y /node=w /vec=z
/driver=yourdriver.exe
```

The devname parameter should be specified in the standard device naming format–a 2 letter device code, controller letter, and unit number (such as XXA0). The ADAPTER parameter should be specified as the TR number of the Futurebus+ ADP. This is part of the SYSMAN IO SHOW BUS display. The csr parameter is the base of Futurebus+ Initial Node Space for the adapter. This is an A32 Futurebus+ address in Futurebus+ CSR space. The value specified in the "csr" parameter is copied directly to the IDB$Q_CSR field in the IDB by the SYS$LOAD_DRIVER program. The /node parameter specifies the Futurebus+ node number of the adapter. The node number is part of the SYSMAN IO SHOW BUS display. The /node parameter is copied to the CRB$L_NODE field in the CRB by the SYS$LOAD_DRIVER program. The /driver parameter is the file name of the driver. The vec parameter specifies the interrupt vector to be used by this Futurebus+ adapter. If the adapter and driver use multiple interrupt vectors, they must be explicitly listed as follows:

```
/vec = (vec1, vec2, vec3, ...)
```

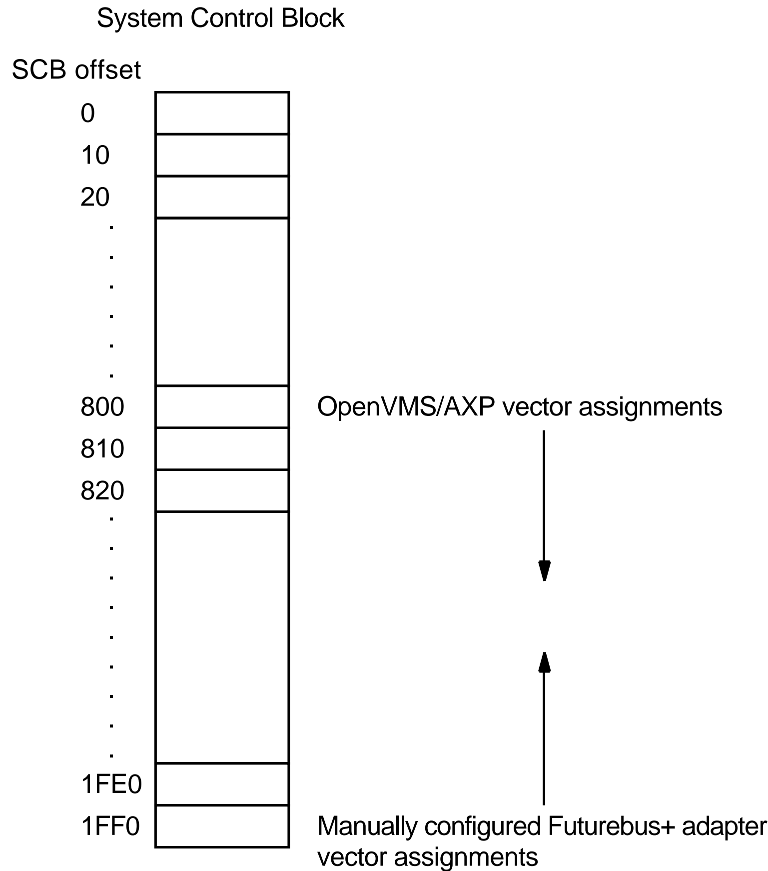
You must be careful when specifying interrupt vectors not to use one that is already in use by another driver/adapter. OpenVMS/AXP maintains a data structure which keeps track of which SCB vectors are in use. This is shown in Figure 15–6.

**Figure 15–6 System Control Block**




Using SDA, you can look at the SCB Reservation bit vector to determine which interrupt vectors are already in use. Since OpenVMS/AXP starts vector assignment at SCB offset 800 (hex) and proceeds to higher vector numbers, it is suggested that for manually configured Futurebus+ adapters, you start at the opposite end of the SCB at offset 1FF0 and work your way towards lower vector numbers, as shown in Figure 15–7. This reduces any chance of a conflict with a previously assigned vector.

**Figure 15–7 System Control Block**




Note that interrupt vectors assigned using SYSMAN IO CONNECT commands will not be reflected in the SCB Reservation bitmap.

## 15.10 Futurebus+ Bus Probing During Booting

During booting, INI$IOMAP constructs an ADP list that represents the I/O adapters present in the system. For the Futurebus+, an ADP (representing the Futurebus+ bridge) and associated Bus Array are allocated. The size of the Futurebus+ Bus Array is based on the number of physical Futurebus+ backplane slots. The bus array is made large enough to contain an entry for the maximum number of Futurebus+ nodes that could be present in the system, which is twice the number of physical backplane slots.

After setting up the Futurebus+ bridge ADP and Bus Array, INI$IOMAP tests each potential Futurebus+ node to determine if an adapter is present. For each Futurebus+ node, INI$IOMAP reads the TEST_STATUS register in Core CSR space. If the node responds, INI$IOMAP then reads locations in the node ROM space to identify the node. Specifically, INI$IOMAP searches node ROM space for a ROM location that identifies the module manufacturer. Normally this will be one of MODULE_VENDOR_ID or NODE_VENDOR_ID (the Futurebus+ specifications say that only one of these locations should be present in the ROM). The Futurebus+ specifications also define MODULE_SPEC_ID, NODE_SPEC_ID, and UNIT_SPEC_ID for the case when a board from manufacturer X requires

a driver from vendor Y–the spec_id identifies the manufacturer that supplies the driver (vendor Y, in this example). If a spec_id is found, INI$IOMAP uses it rather than the vendor_id to identify the board manufacturer. INI$IOMAP also searches the node ROM space for one of MODULE_SW_VERSION, NODE_SW_VERSION, or UNIT_SW_VERSION (again, the Futurebus+ specifications claim that only one of these locations should be present in the ROM). The sw_version identifies the driver required to support the Futurebus+ adapter.

INI$IOMAP concatenates the vendor_id and sw_version to form a 64 bit identifier, and stores it in the BUSARRAY$Q_HW_ID field in the corresponding bus array entry. This 64 bit identifier uniquely identifies a Futurebus+ adapter. It is used by Digital bus configuration routines to associate an adapter and driver. The bus specific fields of a Futurebus+ node bus array entry are initialized as follows:

- BUSARRAY$Q_HW_ID—the concatenation of the vendor_id and sw_version is stored in this field.
- BUSARRAY$Q_CSR—the base of Futurebus+ Initial Node Space is stored in this field.
- BUSARRAY$L_NODE_NUMBER—the Futurebus+ node number is stored in this field.

The information in the Futurebus+ bus array is displayed by the SYSMAN IO SHOW BUS command, and is useful for manual CONNECTion of devices.

## 15.11 Futurebus+ on DEC 4000

This section explains some of the details of the DEC 4000 Futurebus+ implementation. More information can be found in the DEC 4000 System Specifications.

### 15.11.1 The DEC 4000 Futurebus+ Bridge

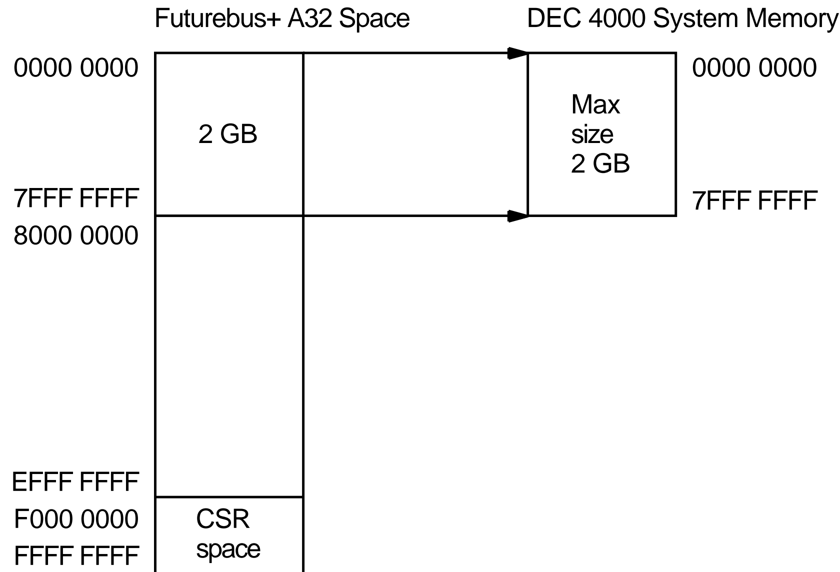
The DEC 4000 I/O Module implements a Local I/O subsystem and a Futurebus+ bridge. The Futurebus+ bridge portion of the I/O module occupies Futurebus backplane slot 0. Backplane slots 1-6 are available for user Futurebus+ options. As a Futurebus+ master, the I/O module is capable of generating transactions using A32 or A64 address width and D32 or D64 data width.

As a Futurebus+ slave, the I/O module only responds to A32 address width transactions. It does not support A64 addressing as a Futurebus+ slave.

### 15.11.2 DEC 4000 Futurebus+ Address Space

The DEC 4000 Futurebus+ bridge maps Futurebus+ A32 address space to DEC 4000 system memory space as shown in Figure 15–8.

**Figure 15–8 DEC 4000 Futurebus+ Address Space**




The DEC 4000 I/O module responds as a Futurebus+ slave to A32 addresses in the range 0000 0000 to 7FFF FFFF. A32 transfers in this address range will be passed to system memory by the I/O module. Since the maximum size of DEC 4000 system memory is 2 GB (31 address bits), a Futurebus+ A32 address has enough bits to access the entire DEC 4000 system memory.

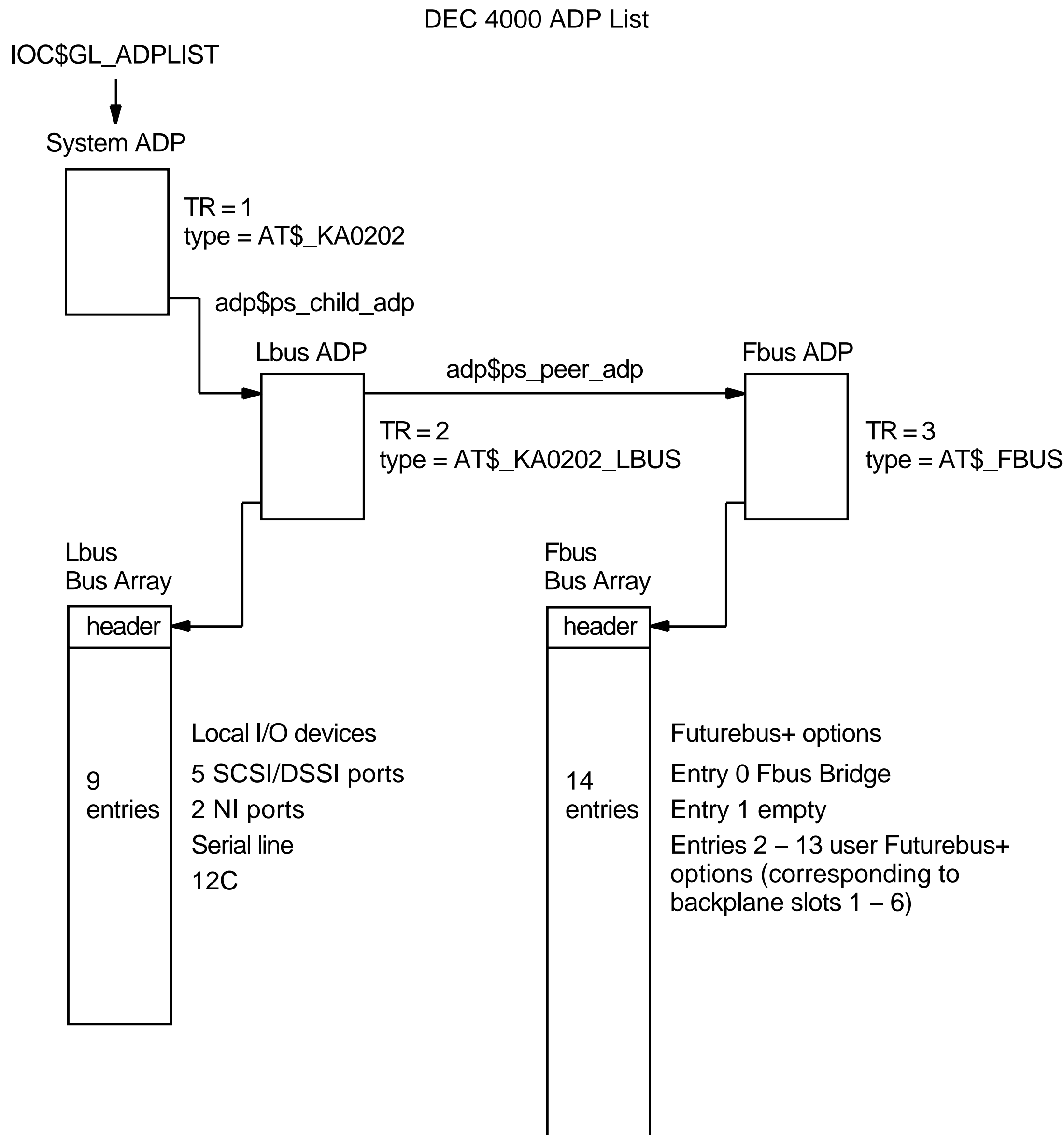
If a Futurebus+ adapter requires Futurebus+ A32 space (in addition to its Initial Node Space), the driver must call IOC$RESERVE_FBUS_A32 to reserve a region of A32 space. On DEC 4000, IOC$RESERVE_FBUS_A32 will allocate 16 MB pieces of address space in the region from A32 address 8000 0000 through EFFF FFFF.

If the adapter requires Futurebus+ A64 space, the driver must call IOC$RESERVE_FBUS_A64 to reserve a region of A64 space. Since the DEC 4000 I/O module does not respond to A64 addresses, the entire A64 address space is available to adapters.

### 15.11.3 DEC 4000 ADP List

During booting, INI$IOMAP creates an ADP list that describes the DEC 4000 I/O subsystem. The DEC 4000 ADP list appears as shown in Figure 15–9.

**Figure 15–9 DEC 4000 ADP list**




## 15.12 Futurebus+ on DEC 10000/7000

This section describes some of the details of DEC 10000/7000 Futurebus+ implementation.

### 15.12.1 The DEC 10000/7000 Futurebus+ Bridge

The DEC 10000/7000 platform contains an IOP module which interfaces to the DEC 10000/7000 I/O subsystem. The IOP supports up to 4 bridges to remote I/O buses. Currently the supported I/O buses on DEC 10000/7000 are XMI and Futurebus+. The Futurebus+ bridge on DEC 10000/7000 is implemented in a distinct Futurebus+ module called the Flag. The DEC 10000/7000 Futurebus+ backplanes are 10 slots. The Flag must be installed in slot 5. Slots 0-4 and 6-9 are available for user Futurebus+ options.

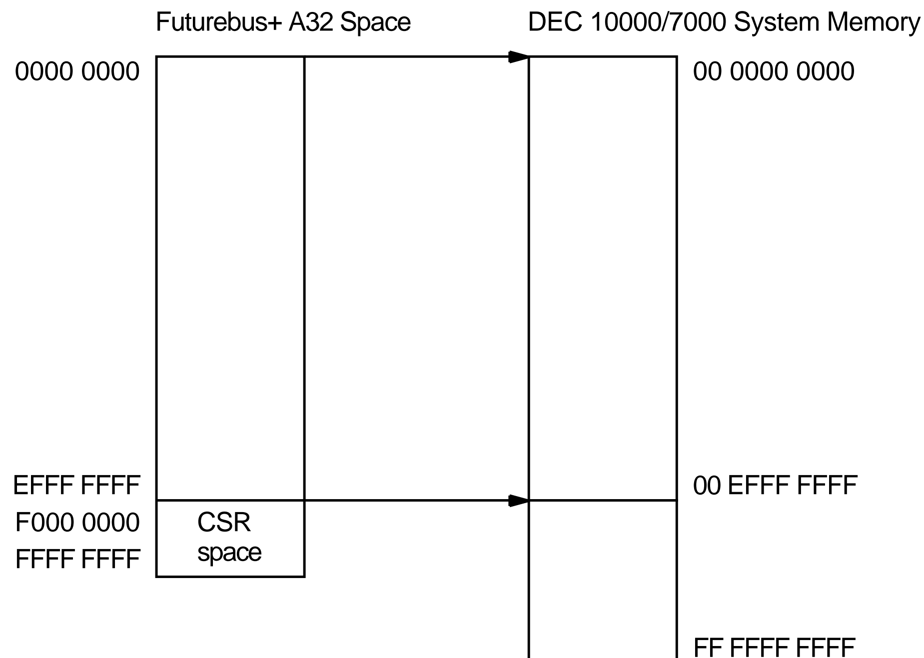
As a Futurebus+ master, the Flag can generate A32 and A64 address width transactions, and D32 and D64 data width transactions.

As a Futurebus+ slave, the Flag accepts both A32 and A64 address width transactions, and D32 and D64 data width transactions.

### 15.12.2 DEC 10000/7000 Futurebus+ Address Space

The DEC 10000/7000 system supports a 40 bit (1 TB) memory address space. The Flag module maps Futurebus A32 space to DEC 10000/7000 memory space as shown in Figure 15–10

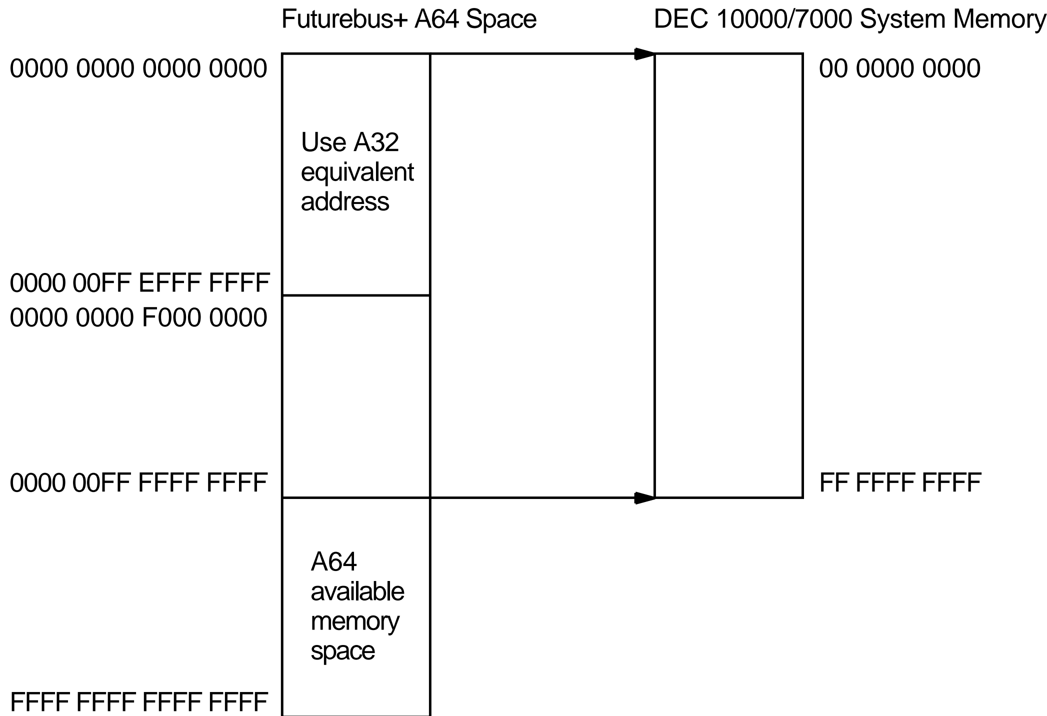
**Figure 15–10 Futurebus+ A32 Space**




The Flag responds as a Futurebus+ slave to A32 transfers from 00000000 to EFFFFFFF in Futurebus+ 32 bit address space and passes the transfer to DEC 10000/7000 system memory. DEC 10000/7000 system memory above 00EFFFFFFF is not accessible from the Futurebus+ using 32 bit addressing. Since the Flag module consumes the entire A32 address region (except for CSR space), Futurebus+ adapters which require A32 space (that is, which require A32 address space in addition to their CSR space) will not work on DEC 10000/7000.

The Flag module maps Futurebus+ 64 bit address space as shown in Figure 15–11.

**Figure 15–11 Futurebus+ A64 Space**

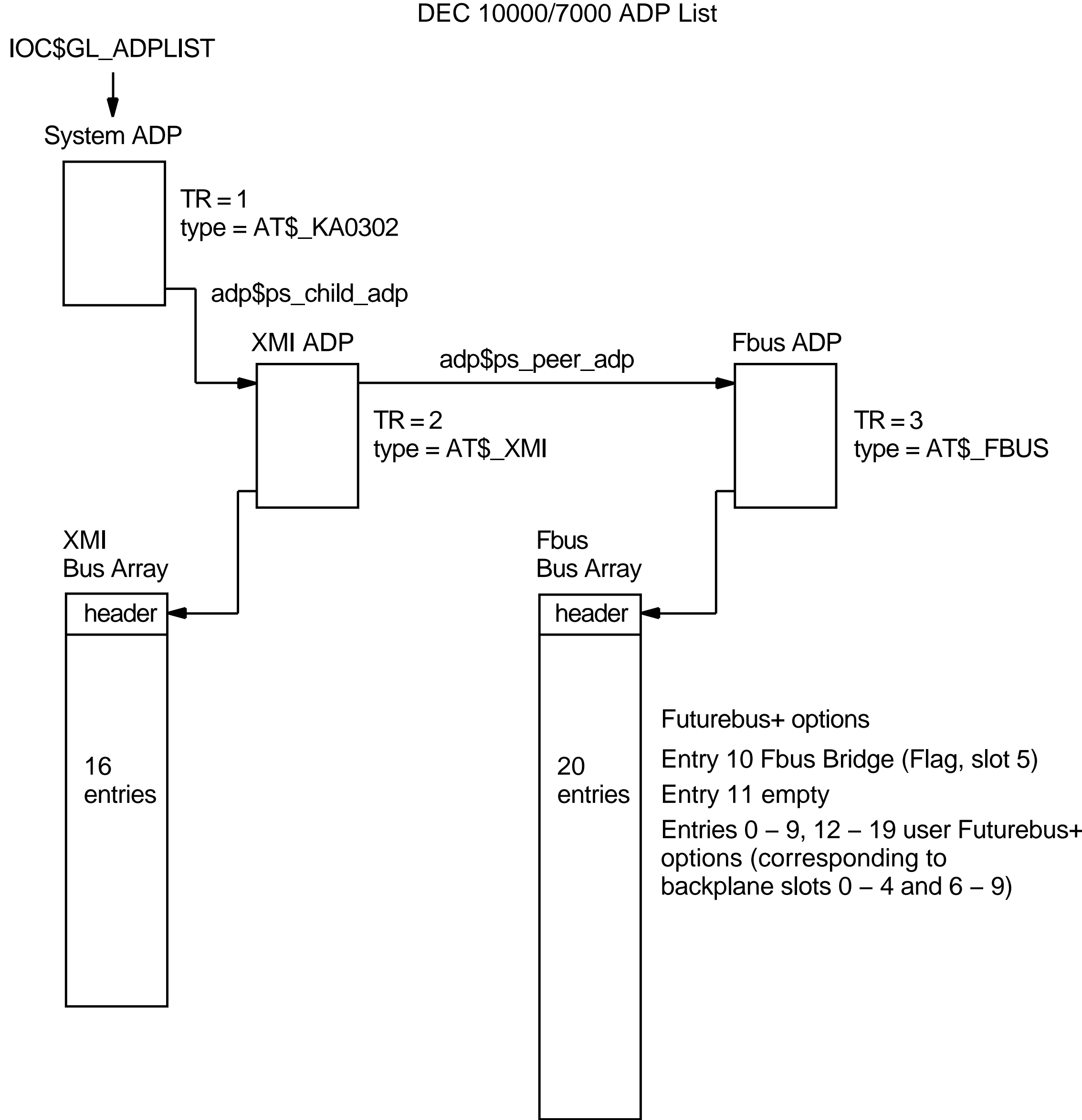



The Flag responds as a Futurebus slave to A64 transactions from 0000 0000 F000 0000 to 0000 00FF FFFF FFFF and passes the transfer to DEC 10000/7000 system memory. The Flag does not respond to A64 transactions directed to 64 bit address space from 0 to 0000 0000 EFFF FFFF. Adapters should not generate A64 accesses in this region anyway, as this region overlaps A32 address space. The equivalent A32 address should be used in the address range below EFFF FFFF. See the Flag specification and the IEEE Futurebus+ specifications for more information. If a Futurebus+ adapter requires A64 space, the driver must call IOC$RESERVE_FBUS_A64 to reserve a region of A64 space. The A64 address region at 100 0000 0000 through FFFF FFFF FFFF FFFF (which is the address range beyond the space consumed by the Flag module) is available to adapters.

### 15.12.3 DEC 10000/7000 ADP List

During booting, INI$IOMAP creates an ADP list describing the DEC 10000/7000 I/O subsystem. The exact format of the DEC 10000/7000 ADP list depends on which I/O bridges and backplanes are installed in the system. An example of a DEC 10000/7000 ADP list with an XMI and a Futurebus+ backplane is shown in Figure 15–12.

**Figure 15–12 DEC 10000/7000 ADP List**



# A

# Device Support Bus Routines

This appendix provides more information about some of the device support bus routines described in this manual.

## IOC$ALLOC_CNT_RES

Allocates the requested number of items of a counted resource.

### Module

ALLOC_CNT_RES

### Format

IOC$ALLOC_CNT_RES crab ,crctx

### Context

IOC$ALLOC_CNT_RES conforms to the OpenVMS AXP calling standard. Its caller must be executing at fork IPL, holding the corresponding fork lock.

### Arguments

**crab**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (signed) |
| access: | read only |
| mechanism: | by reference |

Address of CRAB that describes the counted resource. For adapters that supply a counted resource, such as map registers, ADP$L_CRAB often contains this address.

**crctx**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (signed) |
| access: | read only |
| mechanism: | by reference |

Address of CRCTX structure that describes the request for the counted resource.

### Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

### Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |

| | |
|---|---|
| SS$_BADPARAM | Request count was greater than the total number of items managed by the CRAB or the total number of items defined by a bounded request. This status is also returned if the lower bound of the request (CRCTX$L_LOW_BOUND) is greater than the upper bound (CRCTX$L_UP_BOUND). |
| SS$_INSFMAPREG | Insufficient resources to satisfy request. |

## Description

IOC$ALLOC_CNT_RES allocates a requested number of items from a counted resource. The resource request is described in the CRCTX structure; the counted resource itself is described in the CRAB.

A driver typically initializes the following fields of the CRCTX before submitting it in a call to IOC$ALLOC_CNT_RES.

| Field | Description |
|---|---|
| CRCTX$L_ITEM_CNT | Number of items to be allocated. When requesting map registers, this value in this field should include two extra map registers to be allocated and loaded as guard pages to prevent runaway transfers. |
| CRCTX$L_CALLBACK | Procedure value of the callback routine to be called when the deallocation of resource items allows a stalled resource request to be granted.<br>A value of 0 in this field indicates that, on an allocation failure, control should return to the caller immediately without queueing the CRCTX to the CRAM's wait queue. |

A caller can also specify the upper and lower bounds of the search for allocatable resource items by supplying values for CRCTX$L_LOW_BOUND and CRCTX$L_UP_BOUND.

IOC$ALLOC_CNT_RES performs the following tasks:

- It acquires the spin lock indicated by CRAB$L_SPINLOCK, raising IPL to IPL$_IOLOCK11 in the process.
- If there are no waiters for the counted resource (that is, the resource wait queue headed by CRAB$L_WQFL is empty) or if the CRCTX describes a high-priority allocation request (CRCTX$V_HIGH_PRIO in CRCTX$L_FLAGS is set), IOC$ALLOC_CNT_RES attempts the allocation immediately. It scans the CRAB allocation array for a descriptor that contains as many free items as requested by the caller (in CRCTX$L_ITEM_CNT).

  In performing the scan, IOC$ALLOC_CNT_RES considers any indicated range of counted resource items that are to be involved in the scan, and limits its search to those item descriptors in the allocation array that describe items within these bounds. A bounded search is indicated by nonzero values in CRCTX$L_UP_BOUND and CRCTX$L_LOW_BOUND. IOC$ALLOC_CNT_RES rounds up the allocation request to the minimal allocation granularity, as indicated by CRAB$L_ALLOC_GRAN_MASK.

The number of the first resource item granted to the caller is placed in CRCTX$L_ITEM_NUM and CRCTX$V_ITEM_VALID is set in CRCTX$L_FLAGS.

- If this allocation attempt fails, saves the current values of R3, R4, and R5 in the CRCTX fork block. IOC$ALLOC_CNT_RES writes a –1 to CRCTX$L_ITEM_NUM, and inserts the CRCTX in the resource-wait queue (headed by CRAB$L_WQFL). It then returns SS$_INSFMAPREG status to its caller.

**Note**

If a counted resource request does not specify a callback routine (CRCTX$L_CALLBACK), IOC$ALLOC_CNT_RES does not insert its CRCTX in the resource-wait queue. Rather, it returns SS$_INSFMAPREG status to its caller.

When a counted resource deallocation occurs, the CRCTX is removed from the wait queue and the allocation is attempted again.

When the allocation succeeds, IOC$ALLOC_CNT_RES issues a JSB instruction to the callback routine (CRCTX$L_CALLBACK), passing it the following values:

| Location | Contents |
|---|---|
| R0 | SS$_NORMAL |
| R1 | Address of CRAB |
| R2 | Address of CRCTX |
| R3 | Contents of R3 at the time of the original allocation request (CRCTX$Q_FR3) |
| R4 | Contents of R4 at the time of the original allocation request (CTCTX$Q_FR4) |
| R5 | Contents of R5 at the time of the original allocation request (CRCTX$Q_FR5) |
| Other registers | Destroyed |

The callback routine checks R0 to determine whether it has been called with SS$_NORMAL or SS$_CANCEL status (from IOC$CANCEL_CNT_RES). If the former, it typically proceeds to loads the map registers that have been allocated.

- It releases the spin lock indicated by CRAB$L_SPINLOCK.

OpenVMS AXP allows you to indicate that a counted resource request should take precedence over any waiting request by setting the CRCTX$V_HIGH_PRIO bit in CRCTX$L_FLAGS. A driver uses a high-priority counted resource request to preempt normal I/O activity and service some exception condition from the device. (For instance, during a multivolume backup, a tape driver might make a high-priority request, when it encounters the end-of-tape marker, to get a subsequent tape loaded before normal I/O activity to the tape can resume. A disk driver might issue a high-priority request to service a disk offline condition.)

IOC$ALLOC_CNT_RES never stalls a high-priority counted resource request or places its CRCTX in a resource-wait queue. Rather, it attempts to allocate the requested number of resource items immediately. If IOC$ALLOC_CNT_RES cannot grant the requested number of items, it returns SS$_INSFMAPREG status to its caller.

# IOC$ALLOC_CRAB

Allocates and initializes a counted resource allocation block (CRAB).

## Module

ALLOC_CNT_RES

## Format

IOC$ALLOC_CRAB item_cnt ,req_alloc_gran ,crab_ref

## Context

IOC$ALLOC_CRAB conforms to the OpenVMS AXP calling standard. Because IOC$ALLOC_CRAB calls EXE$ALONONPAGED to allocate sufficient memory for a CRAB, its caller cannot be executing above IPL$_POOL.

## Arguments

**item_cnt**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by value

Number of items associated with the resource.

**req_alloc_gran**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by value

Requested allocation granularity associated with the resource.

**crab_ref**
VMS Usage: address
type: longword (unsigned)
access: write only
mechanism: by reference

Address of a cell to which IOC$ALLOC_CRAB returns the address of the allocated CRAB.

## Returns

VMS Usage: cond_value
type: longword_unsigned
access: longword (unsigned)
mechanism: write only—by value

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_BADPARAM | Specified allocation granularity is larger than the specified item count. |
| SS$_NORMAL | The routine completed successfully. |
| SS$_INSFMEM | Memory allocation request failed. |

## Description

A driver calls IOC$ALLOC_CRAB to allocate a counted resource allocation block (CRAB) that describes a counted resource. A counted resources, such as a set of map registers, has the following attributes:

- The resource consists of an ordered set of items.
- The allocator can request one or more items. When requesting multiple items, the requester expects to receive a contiguous set of items. Thus, allocated items can be described by a starting number and a count.
- Allocation and deallocation of the resource are common operations and, thus, must be efficient and quick.
- A single deallocation may allow zero or more stalled allocation requests to proceed.

IOC$ALLOC_CRAB computes the size of the CRAB as the sum of the fixed portion of the CRAB, plus the maximum number of descriptors required in the allocation array. It then calls EXE$ALONONPAGED to allocate the CRAB. If the allocation request succeeds, IOC$ALLOC_CRAB initializes the CRAB as follows and returns SS$_NORMAL to its caller:

| Field | Description |
|---|---|
| CRAB$W_SIZE | Size of the CRAB in bytes |
| CRAB$B_TYPE | DYN$C_MISC |
| CRAB$B_SUBTYPE | DYN$C_CRAB |
| CRAB$L_WQFL | CRAB$L_WQFL |
| CRAB$L_WQBL | CRAB$L_WQFL |
| CRAB$L_TOTAL_ITEMS | Contents of the **item_cnt** argument |
| CRAB$L_ALLOC_GRAN_MASK | One less than the contents of the **req_alloc_gran** argument (rounded up to the next highest power of two if the value specified is not a power of two) |
| CRAB$L_VALID_DESC_CNT | 1 |
| CRAB$L_SPINLOCK | Address of dynamic spin lock used to synchronize access to this CRAB. Currently, CRAB spin locks are obtained at IPL$_IOLOCK11. |

IOC$ALLOC_CRAB initializes the first descriptor in the allocation array to indicate a set of **item_cnt** items of the resource, starting at item 0.

# IOC$ALLOC_CRCTX

Allocates and initializes a counted resource context block (CRCTX).

## Module

ALLOC_CNT_RES

## Format

IOC$ALLOC_CRCTX crab ,crctx_ref ,[fleck_index]

## Context

IOC$ALLOC_CRCTX conforms to the OpenVMS AXP calling standard. Because IOC$ALLOC_CRCTX calls EXE$ALONONPAGED to allocate sufficient memory for a CRCTX, its caller cannot be executing above IPL$_POOL.

## Arguments

**crab**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRAB that describes the counted resource. For adapters that supply a counted resource, such as map registers, ADP$L_CRAB often contains this address.

**crctx_ref**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | write only |
| mechanism: | by reference |

Address of a location in which IOC$ALLOC_CRCTX places the address of the allocated CRCTX.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |
| SS$_INSFMEM | Memory allocation request failed. |

## Description

A driver calls IOC$ALLOC_CRCTX to allocate a CRCTX to describe a specific request for a given counted resource, such as a set of map registers. The driver subsequently uses the CRCTX as input to IOC$ALLOC_CNT_RES to allocate a given set of the objects managed as a counted resource.

IOC$ALLOC_CRCTX calls EXE$ALONONPAGED to allocate the CRCTX. If the allocation request succeeds, IOC$ALLOC_CRCTX initializes the CRCTX as follows and returns SS$_NORMAL to its caller:

| Field | Description |
|---|---|
| CRCTX$W_SIZE | Size of the CRCTX in bytes |
| CRCTX$B_TYPE | DYN$C_MISC |
| CRCTX$B_SUBTYPE | DYN$C_CRCTX |
| CRCTX$L_CRAB | Address of CRAB as specified in the **crab** argument |
| CRCTX$B_FLCK | Contents of flck_index argument is supplied, else defaults to IPL$C_IOLOCK8 |

# IOC$ALLOCATE_CRAM

Allocates a controller register access mailbox.

## Module

CRAM-ALLOC

## Macro

DPTAB (**ucb_crams** and **idb_crams** arguments) CRAM_ALLOC

## Format

IOC$ALLOCATE_CRAM cram [,idb] [,ucb] [,adp]

## Context

IOC$ALLOCATE_CRAM conforms to the OpenVMS AXP calling standard. Because IOC$ALLOCATE_CRAM may need to allocate pages from the free page list, its caller must be executing at or below IPL$_SYNCH and must not hold spin locks ranked higher than IO_MISC.

IOC$ALLOCATE_CRAM acquires and releases the IO_MISC spin lock and returns to its caller at its caller's IPL.

## Arguments

### cram

VMS Usage: address
type: longword (unsigned)
access: write only
mechanism: by reference

Address of CRAM allocated by IOC$ALLOCATE_CRAM

### idb

VMS Usage: address
type: longword (unsigned)
access: read only
mechanism: by reference

Address of IDB for device.

### ucb

VMS Usage: address
type: longword (unsigned)
access: read only
mechanism: by reference

Address of UCB for device.

### adp

VMS Usage: address
type: longword (unsigned)
access: read only
mechanism: by reference

Address of ADP for device.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | CRAM has been successfully allocated. |
| SS$_INSFARG | Insufficient arguments supplied in call |

## Description

IOC$ALLOCATE_CRAM allocates a single controller register access mailbox (CRAM) and fills in the following fields:

| | |
|---|---|
| CRAM$W_SIZE | Size of CRAM |
| CRAM$B_TYPE | Structure type (DYN$C_MISC) |
| CRAM$B_SUBTYPE | Structure type (DYN$C_CRAM) |
| CRAM$Q_RBADR | Address of remote tightly-coupled I/O interconnect (from IDB$Q_CSR) |
| CRAM$Q_HW_MBX | Physical address of hardware I/O mailbox |
| CRAM$L_MBPR | Mailbox pointer register (from ADP$PS_MBPR) |
| CRAM$Q_QUEUE_TIME | Default mailbox queue timeout value (from ADP$Q_QUEUE_TIME) |
| CRAM$Q_WAIT_TIME | Default mailbox wait-for-completion timeout value (from ADP$Q_WAIT_TIME) |
| CRAM$B_HOSE | Number of remote tightly-coupled I/O interconnect (from ADP$B_HOSE_NUM) |
| CRAM$L_IDB | IDB address |
| CRAM$L_UCB | UCB address |

A driver may choose to allocate a CRAM on a per-controller or a per-unit basis. Typically a driver specifies values in the **idb_crams** and **ucb_crams** arguments of the DPTAB macro that indicate how many CRAMs should be allocated to a controller (IDB) or a unit (UCB). If these values (DPT$W_IDB_CRAMS and DPT$W_UCB_CRAMS) are nonzero in the DPT, the driver loading procedure automatically invokes IOC$ALLOCATE_CRAM to allocate the specified number of CRAMs. The driver-loading procedure thereafter sets up IDB$PS_CRAM to point to a linked list of CRAMs associated with a controller, UCB$PS_CRAM to a linked list of CRAMs associated with a device unit.

# IOC$CANCEL_CNT_RES

Cancels a thread that has been stalled waiting for a counted resource.

## Module

ALLOC_CNT_RES

## Format

IOC$CANCEL_CNT_RES crab ,crctx [,resume_flag]

## Context

IOC$CANCEL_CNT_RES conforms to the OpenVMS AXP calling standard. Its caller must be executing at fork IPL, holding the corresponding fork lock.

## Arguments

**crab**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRAB that describes the counted resource. For adapters that supply a counted resource, such as map registers, ADP$L_CRAB often contains this address.

**crctx**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRCTX structure that describes the request for the counted resource.

**[resume_flag]**

| | |
|---|---|
| VMS Usage: | boolean |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by value |

Indication of whether the cancelled thread should be resumed. If true, IOC$CANCEL_CNT_RES calls the driver callback routine with SS$_CANCEL status. If not specified or false, IOC$CANCEL_CNT_RES does not resume the cancelled thread.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |
| SS$_BADPARAM | The specified CRCTX was not found in the CRAB wait queue. |

## Description

IOC$CANCEL_CNT_RES cancels a thread that has been stalled waiting for a counted resource. The resource request is described in the CRCTX structure; the counted resource itself is described in the CRAB.

IOC$CANCEL_CNT_RES scans the CRAB wait queue (CRAB$L_WFQL) to locate the specified CRCTX. If it cannot locate the CRCTX, it returns SS$_BADPARAM status to its caller.

If it locates the CRCTX in the CRAB wait queue and the **resume_flag** argument is not specified or is false, it removes the CRCTX from the queue and returns SS$_NORMAL status to its caller. Otherwise, after removing the CRCTX, calls the driver's callback routine (CRCTX$L_CALLBACK), passing it the following values:

| Location | Contents |
|---|---|
| R0, R21 | SS$_CANCEL |
| R1, R16 | Address of CRAB |
| R2, R17 | Address of CRCTX |
| R3, R18 | CRCTX$Q_FR3 |
| R4, R19 | CRCTX$Q_FR4 |
| R5, R20 | CRCTX$Q_FR5 |

The callback routine checks R0 to determine whether it has been called with SS$_NORMAL (from IOC$ALLOC_CNT_RES) or SS$_CANCEL status. If the latter, it takes appropriate steps to respond to the request cancellation.

When it regains control from the driver callback routine, IOC$CANCEL_CNT_RES returns SS$_NORMAL status to its caller.

# IOC$CRAM_CMD

Generates values for the command, mask, and remote I/O interconnect address fields of the hardware I/O mailbox that are specific to the interconnect that is the target of the mailbox operation, inserting these values into the indicated mailbox, buffer, or both.

## Module

[CPU*xxxx*]IO_SUPPORT_*xxxx*†

## Macro

CRAM_CMD

## Format

IOC$CRAM_CMD cmd_index ,byte_offset ,adp_ptr [,cram_ptr] [,buffer_ptr]

## Context

IOC$CRAM_CMD conforms to the OpenVMS AXP calling standard. It acquires no spin locks and leaves IPL unchanged. After inserting the hardware I/O mailbox values into the CRAM or specified buffer, IOC$CRAM_CMD returns to its caller.

## Arguments

**cmd_index**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by value

Command index. IOC$CRAM_CMD uses this index to generate a mailbox command that is specific to the tightly-coupled interconnect that is to be the target of a request using this CRAM.

You can specify any of the following values (defined by the $CRAMDEF macro), although which of these I/O operations is supported depends on the I/O interconnect that is to be the object of the mailbox operation.

| Command Index | Description |
|---|---|
| CRAMCMD$K_RDQUAD32 | Quadword read in 32-bit space |
| CRAMCMD$K_RDLONG32 | Longword read in 32-bit space |
| CRAMCMD$K_RDWORD32 | Word read in 32-bit space |
| CRAMCMD$K_RDBYTE32 | Byte read in 32-bit space |
| CRAMCMD$K_WTQUAD32 | Quadword write in 32-bit space |
| CRAMCMD$K_WTLONG32 | Longword write in 32-bit space |
| CRAMCMD$K_WTWORD32 | Word write in 32-bit space |

† where *xxxx* represents the internal OpenVMS code number for an AXP CPU

| Command Index | Description |
|---|---|
| CRAMCMD$K_WTBYTE32 | Byte write in 32-bit space |
| CRAMCMD$K_RDQUAD64 | Quadword read in 64 bit space |
| CRAMCMD$K_RDLONG64 | Longword read in 64 bit space |
| CRAMCMD$K_RDWORD64 | Word read in 64 bit space |
| CRAMCMD$K_RDBYTE64 | Byte read in 64 bit space |
| CRAMCMD$K_WTQUAD64 | Quadword write in 64 bit space |
| CRAMCMD$K_WTLONG64 | Longword write in 64 bit space |
| CRAMCMD$K_WTWORD64 | Word write in 64 bit space |
| CRAMCMD$K_WTBYTE64 | Byte write in 64 bit space |

**byte_offset**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by value

Byte offset of the field to be written or read from the base of device interface register (CSR) space. Calculation of the RBADR and MASK fields of the hardware mailbox depends on the addressing and masking mechanisms provided by the remote bus. The **byte_offset** argument is used by IOC$CRAM_CMD to calculate the RBADR.

**adp_ptr**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by reference

Address of ADP associated with this command. IOC$CRAM_CMD uses this parameter to determine which tightly-coupled I/O interconnect is the object of the mailbox transaction and to construct the mailbox command accordingly.

**cram_ptr**
VMS Usage: longword_unsigned
type: longword (unsigned)
access: read only
mechanism: by reference

Address of CRAM. IOC$CRAM_CMD returns the command, mask, and remote bus address values in the corresponding fields of the hardware I/O mailbox.

## Returns

VMS Usage: cond_value
type: longword_unsigned
access: longword (unsigned)
mechanism: write only—by value

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | The calculated command, mask, and remote bus address values have been written to the CRAM and/or the specified buffer. |
| SS$_BADPARAM | Illegal command supplied as input or illegal argument supplied in call |
| SS$_INSFARG | Insufficient arguments supplied in call |

## Description

IOC$CRAM_CMD calculates the COMMAND, MASK, and RBADR fields for a hardware I/O mailbox according to the requirements of a specific I/O interconnect. It performs the following tasks:

- Obtains the address of the command table specific to the given I/O interconnect from ADP$PS_COMMAND_TBL.
- Uses the value specified in the **command** argument as an index into the command table to determine the corresponding command supported by the I/O interconnect.
- If the command is valid for the I/O interconnect, IOC$CRAM_CMD writes it to CRAM$L_COMMAND, to the specified buffer, or to both. If the command is invalid for the I/O interconnect, IOC$CRAM_CMD returns SS$_BADPARAM status to its caller.
- Calculates the RBADR and MASK fields based of the hardware I/O mailbox, basing their values on the command, the address of device register interface space (ADP$Q_CSR or IDB$Q_CSR, if the **cram** argument is specified), the **byte_offset** argument, and interconnect-specific requirements. It writes these values to CRAM$B_BYTE_MASK and CRAM$Q_RBADR, to the specified buffer, or to both.
- Returns SS$_NORMAL status to its caller.

## IOC$CRAM_IO

Queues the hardware I/O mailbox defined within a controller register access mailbox (CRAM) to the mailbox pointer register (MBPR) and awaits the completion of the mailbox transaction.

### Module

[SYSLOA]CRAM-IO

### Macro

CRAM_IO

### Format

IOC$CRAM_IO cram

### Context

IOC$CRAM_IO conforms to the OpenVMS AXP calling standard. It acquires no spin locks and leaves IPL unchanged. After queuing the request and waiting for its completion, IOC$CRAM_IO returns to its caller.

### Arguments

**cram**

VMS Usage: address
type: longword (unsigned)
access: write only
mechanism: by reference

Address of CRAM associated with the hardware I/O mailbox transaction.

### Returns

VMS Usage: cond_value
type: longword_unsigned
access: longword (unsigned)
mechanism: write only—by value

Status indicating the success or failure of the operation.

### Return Values

| | |
|---|---|
| SS$_NORMAL | CRAM has been successfully queued to the MBPR. |
| SS$_BADPARAM | Supplied argument is not a CRAM. |
| SS$_CTRLERR | Error bit set in mailbox transaction. |
| SS$_INSFARG | No argument supplied in call. |
| SS$_INTERLOCK | Failed to queue hardware I/O mailbox to MBPR in queue time. |

| | |
|---|---|
| SS$_TIMEOUT | Mailbox operation did not complete in mailbox transaction timeout interval. |

## Description

IOC$CRAM_IO performs an entire hardware I/O mailbox transaction from the queuing of the hardware I/O mailbox to the MBPR to the transaction's completion. A call to IOC$CRAM_IO is the equivalent of independent calls to IOC$CRAM_QUEUE and IOC$CRAM_WAIT. Prior to calling IOC$CRAM_IO, a driver typically calls IOC$CRAM_CMD to insert a command, mask, and remote interconnect address into the hardware I/O mailbox portion of the CRAM. For CRAMs involved in writes to device interface registers, the driver must also insert the data to be written into CRAM$Q_WDATA,

IOC$CRAM_IO initiates an I/O operation to a device in remote I/O space by writing the physical address of the hardware I/O mailbox portion of a CRAM to the MBPR. If it is not able to post the mailbox to the MBPR in the MBPR queue timeout interval (CRAM$Q_QUEUE_TIME), it returns SS$_INTERLOCK status to its caller.

If it does successfully queue the mailbox, it sets the CRAM$V_IN_USE bit in CRAM$B_CRAM_FLAGS and repeatedly checks the done bit in the hardware I/O mailbox (CRAM$V_MBX_DONE in CRAM$W_MBX_FLAGS):

- If the done bit is not set in the mailbox transaction timeout interval (CRAM$Q_WAIT_TIME), IOC$CRAM_IO leaves the CRAM$V_IN_USE bit in CRAM$B_CRAM_FLAGS set and returns SS$_TIMEOUT status to its caller.
- If the done bit is set, but the error bit in the mailbox (CRAM$V_MBX_ERROR in CRAM$W_MBX_FLAGS) is also set, IOC$CRAM_IO clears CRAM$V_IN_USE and returns SS$_CTRLERR status to its caller. Note that, if the disable-error bit (CRAM$V_DER) is set, IOC$CRAM_IO never returns an error (although it may request an IOMBXERR fatal bugcheck in the event of an error).
- If the done bit is set and the error bit is clear, IOC$CRAM_IO clears CRAM$V_IN_USE and returns SS$_NORMAL status to its caller. If IOC$CRAM_IO returns SS$_NORMAL status for read mailbox operations, the requested data has been returned to CRAM$Q_RDATA. A return of SS$_NORMAL status for mailbox write operations does not necessarily guarantee that the data placed in CRAM$Q_WDATA has been successfully written to the device register.

# IOC$CRAM_QUEUE

Queues the hardware I/O mailbox defined within a controller register access mailbox (CRAM) to the mailbox pointer register (MBPR).

## Module

[SYSLOA]CRAM-IO

## Macro

CRAM_QUEUE

## Format

IOC$CRAM_QUEUE cram

## Context

IOC$CRAM_QUEUE conforms to the OpenVMS AXP calling standard. It acquires no spin locks and leaves IPL unchanged. After queuing the request, IOC$CRAM_QUEUE returns to its caller. It is expected that the caller will eventually call IOC$CRAM_WAIT to await completion of the request.

## Arguments

**cram**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | write only |
| mechanism: | by reference |

Address of CRAM to be queued.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | CRAM has been successfully queued to the MBPR. |
| SS$_BADPARAM | Supplied argument is not a CRAM. |
| SS$_INSFARG | No argument supplied in call |
| SS$_INTERLOCK | Failed to queue hardware I/O mailbox to MBPR in queue time. |

## Description

IOC$CRAM_QUEUE initiates an I/O operation to a device in remote I/O space by writing the physical address of the hardware I/O mailbox portion of a CRAM to the MBPR. Prior to calling IOC$CRAM_QUEUE, a driver typically calls IOC$CRAM_CMD to insert a command, mask, and remote interconnect address into the hardware I/O mailbox portion of the CRAM. For CRAMs involved in writes to device interface registers, the driver must also insert the data to be written into CRAM$Q_WDATA,

If it is not able to post the mailbox to the MBPR in the MBPR queue timeout interval (CRAM$Q_QUEUE_TIME), IOC$CRAM_QUEUE returns SS$_INTERLOCK status to its caller. If the disable-error bit (CRAM$V_DER) is set, IOC$CRAM_QUEUE does not return an error (although it may request an IOMBXERR fatal bugcheck in the event of an error).

If IOC$CRAM_QUEUE does successfully queue the mailbox, it sets the CRAM$V_IN_USE bit in CRAM$B_CRAM_FLAGS and returns SS$_NORMAL.

# IOC$CRAM_WAIT

Awaits the completion of a hardware I/O mailbox transaction to a tightly-coupled I/O interconnect.

## Module

[SYSLOA]CRAM-IO

## Macro

CRAM_WAIT

## Format

IOC$CRAM_WAIT cram

## Context

IOC$CRAM_WAIT conforms to the OpenVMS AXP calling standard. It acquires no spin locks and leaves IPL unchanged. After queuing the request, IOC$CRAM_WAIT returns to its caller.

IOC$CRAM_WAIT assumes that its caller has previously called IOC$CRAM_QUEUE to post to the MBPR the hardware I/O mailbox defined within the specified CRAM for an I/O operation.

## Arguments

**cram**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | write only |
| mechanism: | by reference |

Address of CRAM associated with a previously-queued hardware I/O mailbox transaction.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | CRAM has been successfully queued to the MBPR. |
| SS$_BADPARAM | Supplied argument is not a CRAM. |
| SS$_CTRLERR | Error bit set in mailbox transaction. |

| | |
|---|---|
| SS$_INSFARG | No argument supplied in call. |
| SS$_TIMEOUT | Mailbox operation did not complete in mailbox transaction timeout interval. |

## Description

IOC$CRAM_WAIT checks the done bit in the hardware I/O mailbox (CRAM$V_MBX_DONE in CRAM$W_MBX_FLAGS):

- If CRAM$V_MBX_DONE is not set in the mailbox transaction timeout interval (CRAM$Q_WAIT_TIME), IOC$CRAM_WAIT leaves the CRAM$V_IN_USE bit in CRAM$B_CRAM_FLAGS set and returns SS$_TIMEOUT status to its caller.
- If CRAM$V_MBX_DONE is set, but the error bit in the mailbox (CRAM$V_MBX_ERROR in CRAM$W_MBX_FLAGS) is also set, IOC$CRAM_WAIT clears CRAM$V_IN_USE and returns SS$_CTRLERR status to its caller. In this case, CRAM$W_ERROR_BITS contains a device-specific encoding of additional status information.
- If the done bit is set and the error bit is clear, IOC$CRAM_WAIT clears CRAM$V_IN_USE and returns SS$_NORMAL status to its caller. If IOC$CRAM_WAIT returns SS$_NORMAL status for read mailbox operations, the requested data has been returned to CRAM$Q_RDATA. A return of SS$_NORMAL status for mailbox write operations does not necessarily guarantee that the data placed in CRAM$Q_WDATA has been successfully written to the device register.

**Note**

If the disable-error bit (CRAM$V_DER) is set, IOC$CRAM_WAIT does not return an error (although it may request an IOMBXERR fatal bugcheck in the event of an error).

## IOC$DEALLOC_CNT_RES

Deallocates the requested number of items of a counted resource.

### Module

DEALLOC_CNT_RES

### Format

IOC$DEALLOC_CNT_RES crab ,crctx

### Context

IOC$DEALLOC_CNT_RES conforms to the OpenVMS AXP calling standard. Its caller must be executing at fork IPL, holding the corresponding fork lock.

### Arguments

**crab**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRAB.

**crctx**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRCTX structure.

### Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

### Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |
| SS$_BADPARAM | CRCTX$L_ITEM_CNT and CRCTX$L_ITEM_NUM fields are invalid. |

## Description

IOC$DEALLOC_CNT_RES deallocates a requested number of items of a counted resource. The resource request is described in the CRCTX structure; the counted resource itself is described in the CRAB. After deallocating the items, IOC$DEALLOC_CNT_RES attempts to restart any waiters for the resource.

IOC$DEALLOC_CNT_RES performs the following tasks:

1. It examines CRCTX$V_ITEM_VALID in CRCTX$L_FLAGS. If it is clear, IOC$DEALLOC_CNT_RES returns SS$_BADPARAM status to its caller.
2. It acquires the spin lock indicated by CRAB$L_SPINLOCK, raising IPL to IPL$_IOLOCK in the process.
3. It scans the CRAB allocation array for a descriptor into which the items being deallocated (indicated by CRCTX$L_ITEM_CNT) can be merged.
4. It adjusts the CRAB allocation array and CRAB$L_VALID_DESC_CNT to reflect the deallocation.
5. If there are waiters for the counted resource, IOC$DEALLOC_CNT_RES removes the CRCTX of the first waiter from the CRAB wait queue (CRAB$L_WQFL) and calls IOC$ALLOC_CNT_RES to grant the requested number of resources.

   If this attempt succeeds, IOC$DEALLOC_CNT_RES restores the context of the stalled waiter (R3 through R5), releases the spin lock indicated by CRAB$L_SPINLOCK (upon the condition that the caller of IOC$DEALLOC_CNT_RES did not already own this spin lock at the time of the call), and issues a standard call to the callback routine indicated by CRCTX$L_CALLBACK, passing it the address of the CRAB; the address of the CRCTX; the values stored in CRCTX$Q_FR3, CRCTX$Q_FR4, and CRCTX$Q_FR5; and SS$_NORMAL status.

   IOC$DEALLOC_CNT_RES continues to attempt to restart waiters in this manner until an allocation request fails. When this occurs, IOC$DEALLOC_CNT_RES replaces its CRCTX in the CRAB wait queue, conditionally releases the spin lock indicated by CRAB$L_SPINLOCK, and returns SS$_NORMAL status to its caller.
6. If there are no waiters for the counted resource, IOC$DEALLOC_CNT_RES conditionally releases the spin lock indicated by CRAB$L_SPINLOCK, and returns SS$_NORMAL status to its caller.

# IOC$DEALLOC_CRAB

Deallocates a counted resource allocation block (CRAB).

## Module

ALLOC_CNT_RES

## Format

IOC$DEALLOC_CRAB crab

## Context

IOC$DEALLOC_CRAB conforms to the OpenVMS AXP calling standard. Because IOC$DEALLOC_CRAB calls EXE$DEANONPAGED, its caller cannot be executing above IPL$_SYNCH.

## Arguments

**crab**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRAB to be deallocated.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |

## Description

A driver calls IOC$DEALLOC_CRAB to deallocate a CRAB. IOC$DEALLOC_CRAB passes the address of the CRAB to EXE$DEANONPAGED and returns SS$_NORMAL status to its caller.

# IOC$DEALLOC_CRCTX

Deallocates a counted resource context block (CRCTX).

## Module

ALLOC_CNT_RES

## Format

IOC$DEALLOC_CRCTX crctx

## Context

IOC$DEALLOC_CRCTX conforms to the OpenVMS AXP calling standard. Because IOC$DEALLOC_CRCTX calls EXE$DEANONPAGED, its caller cannot be executing above IPL$_SYNCH.

## Arguments

**crctx**

| | |
|---|---|
| VMS Usage: | address |
| type: | longword (unsigned) |
| access: | read only |
| mechanism: | by reference |

Address of CRCTX to be deallocated.

## Returns

| | |
|---|---|
| VMS Usage: | cond_value |
| type: | longword_unsigned |
| access: | longword (unsigned) |
| mechanism: | write only—by value |

Status indicating the success or failure of the operation.

## Return Values

| | |
|---|---|
| SS$_NORMAL | The routine completed successfully. |

## Description

A driver calls IOC$DEALLOC_CRCTX to deallocate a CRCTX. IOC$DEALLOC_CRCTX passes the address of the CRCTX to EXE$DEANONPAGED and returns SS$_NORMAL status to its caller.

## IOC$DEALLOCATE_CRAM

Deallocates a controller register access mailbox.

### Module

CRAM-ALLOC

### Macro

CRAM_DEALLOC

### Format

IOC$DEALLOCATE_CRAM cram

### Context

IOC$DEALLOCATE_CRAM conforms to the OpenVMS AXP calling standard. Its caller must be executing at or below IPL 8 and must not hold spin locks ranked higher than IO_MISC.

IOC$DEALLOCATE_CRAM acquires and releases the IO_MISC spin lock and returns to its caller at its caller's IPL.

### Arguments

**cram**

VMS Usage: address
type: longword (unsigned)
access: write only
mechanism: by reference

Address of CRAM to be deallocated by IOC$DEALLOCATE_CRAM

### Returns

VMS Usage: cond_value
type: longword_unsigned
access: longword (unsigned)
mechanism: write only—by value

Status indicating the success or failure of the operation.

### Return Values

| | |
|---|---|
| SS$_NORMAL | CRAM has been successfully deallocated. |
| SS$_BADPARAM | Supplied argument is not a CRAM. |
| SS$_INSFARG | Insufficient arguments supplied in call |

### Description

IOC$DEALLOCATE_CRAM deallocates a single controller register access mailbox (CRAM).

# IOC$MAP_IO

IOC$MAP_IO maps I/O bus physical address space into an address region accessible by the processor. The caller of this routine can express the mapping request in terms of the bus address space without regard to address swizzle space, dense space, or sparse space.

IOC$MAP_IO is supported on PCI, EISA, TURBOchannel, and Futurebus+ systems. It is not supported on XMI systems.

## Description

The routine prototype is as follows:

```
int ioc$map_io (ADP     *adp,
                int     node,
                uint64  *physical_offset,
                int     num_bytes,
                int     attributes,
                uint64  *iohandle)

Inputs

    adp     Address of bus ADP.  Driver can get this from
            IDB$PS_ADP.

    node    Bus node number of device.  Bus specific
            interpretation.  Available to driver in
            CRB$L_NODE (driver must be loaded with /NODE
            qualifier).

    physical_offset Address of a quadword cell.  For EISA, PCI,
            and Futurebus, the quadword cell should contain
            the starting bus physical address to be mapped.  For
            Turbochannel, the quadword cell should contain the
            physical offset from the Turbochannel slot base
            address.

    num_bytes   Number of bytes to be mapped.  Expressed in terms
            of the bus/device without regard to the platform
            hardware addressing tricks.

    attributes  Specifies desired attributes of space to be
            mapped.  From [lib]iocdef.  One of the following:

            IOC$K_BUS_IO_BYTE_GRAN

                Request mapping in a platform address space which
                corresponds to bus I/O space and provides byte
                granularity access.  In general, if you are mapping
                device control registers that exist in bus I/O space,
                you should specify this attribute.  For example,
                drivers for PCI devices with registers in PCI I/O
                space or EISA devices with EISA I/O port addresses
                should request mapping with this attribute.

            IOC$K_BUS_MEM_BYTE_GRAN

                Request mapping in a platform address space which
                corresponds to bus memory space and provides byte
                granularity access.  In general, if you are mapping
                device registers that exist in bus memory space, you
                should specify this attribute.  For example, drivers
                for PCI devices with registers in PCI memory space
                should request mapping with this attribute.

            IOC$K_BUS_DENSE_SPACE
```

Request mapping in a platform address space that corresponds to bus memory space and provides coarse access granularity. IOC$K_BUS_DENSE_SPACE is suitable for mapping device memory buffers such as graphics frame buffers. In IOC$K_BUS_DENSE_SPACE, there must be no side effects on reads and it may be possible for the processor to merge writes. Thus you should not map device registers in dense space.

iohandle — Pointer to a 64 bit cell. A 64 bit magic number is written to this cell by IOC$MAP_IO when the mapping request is successful. The caller must save the iohandle, as it is an input to IOC$CRAM_CMD and to the new platform independent access routines IOC$READ_IO and IOC$WRITE_IO.

Outputs

SS$_NORMAL — Success. The address space is mapped. A 64 bit IOHANDLE is written to the caller's buffer.

SS$_BADPARAM — Bad input argument. For example, the requested bus address may not be accessible from the CPU, or the attribute may be unrecognized.

SS$_UNSUPPORTED — Address space with the requested attributes not available on this platform. For example, the DEC 2000 Model 300 platform does not support EISA memory dense space.

SS$_INSFSPTS — Not enough PTEs to satisfy mapping request.

# IOC$READ_IO

Reads a value from a previously mapped location in I/O address space. This routine requires that the I/O space to be accessed has been previously mapped by a call to IOC$MAP_IO.

IOC$READ_IO is supported on PCI, EISA, TURBOchannel, and Futurebis+ systems. It is not supported on XMI systems.

## Description

The routine prototype for IOC$READ_IO is as follows:

```
int ioc$read_io (ADP    *adp,
                 uint64 *iohandle,
                 int    offset,
                 int    length,
                 void   *read_data)

Inputs

    adp     Address of bus ADP.  Driver can get this from
            IDB$PS_ADP.

    iohandle Pointer to a 64 bit IOHANDLE.  The 64 bit IOHANDLE
            is obtained by calling the platform independent
            mapping routine IOC$MAP_IO.

    offset  Offset in device space of field to be read or written.
            This should be specified as an offset from the base of
            the space that was previously mapped by the call to
            IOC$MAP_IO.  The offset is specified in terms of the
            device or bus without regard to any hardware address
            trickery.

    length  Length of field to be read or written.  Should be 1
            (byte), 2 (word), 3 (tribyte), 4 (longword) or 8
            (quadword).  Note that not all of these lengths are
            supported on all buses.

    read_data Pointer to a data cell.  For ioc$read_io, the
            data read from the device will be returned in this cell.
            If the requested data length was 1, 2, 3, or 4, a
            longword is written to the data cell with valid data
            in the byte lane(s) corresponding to the requested
            length and offset.  If the requested data length was 8,
            a quadword is written to the data cell.

    write_data Pointer to a data cell.  The data cell should
            contain the data to be written to the device.  For
            lengths of 1, 2, 3 or 4, the ioc$write_io routine
            reads a longword from the data cell and writes this
            longword to the bus with the proper byte enables set
            according to the length and offset.  The actual
            data to be written must be positioned in the proper
            byte lane(s) according to the requested length and
            offset.  For a length 8 transfer, the ioc$write_io
            routine reads a quadword from the data cell.

Outputs

    SS$_NORMAL Success.  If IOC$READ_IO, data is returned in the
            caller's buffer.  If IOC$WRITE_IO, data is written to
            device.

    SS$_BADPARAM Bad input argument, such as an illegal length.
```

```
SS$_UNSUPPORTED A transaction length not supported by this bus
        or platform.
```

# IOC$UNMAP_IO

Unmaps a previously mapped I/O address space, returning the IOHANDLE and the PTEs to the system. The caller's quadword cell containing the IOHANDLE is cleared.

## Description

The routine prototype is as follows:

```
int ioc$unmap_io (ADP   *adp,
                  uint64 *iohandle)
```

# IOC$WRITE_IO

Writes a value to a previously mapped location in I/O address space. IOC$WRITE_IO requires that the I/O space to be accessed has been previously mapped by a call to IOC$MAP_IO.

## Description

The routine prototype is as follows:

```
int ioc$write_io (ADP    *adp,
                  uint64 *iohandle,
                  int    offset,
                  int    length,
                  void   *write_data)

Inputs

    adp     Address of bus ADP.  Driver can get this from
            IDB$PS_ADP.

    iohandle Pointer to a 64 bit IOHANDLE.  The 64 bit IOHANDLE
            is obtained by calling the platform independent
            mapping routine IOC$MAP_IO.

    offset  Offset in device space of field to be read or written.
            This should be specified as an offset from the base of
            the space that was previously mapped by the call to
            IOC$MAP_IO.  The offset is specified in terms of the
            device or bus without regard to any hardware address
            trickery.

    length  Length of field to be read or written.  Should be 1
            (byte), 2 (word), 3 (tribyte), 4 (longword) or 8
            (quadword).  Note that not all of these lengths are
            supported on all buses.

    read_data Pointer to a data cell.  For ioc$read_io, the
            data read from the device will be returned in this cell.
            If the requested data length was 1, 2, 3, or 4, a
            longword is written to the data cell with valid data
            in the byte lane(s) corresponding to the requested
            length and offset.  If the requested data length was 8,
            a quadword is written to the data cell.

    write_data Pointer to a data cell.  The data cell should
            contain the data to be written to the device.  For
            lengths of 1, 2, 3 or 4, the ioc$write_io routine
            reads a longword from the data cell and writes this
            longword to the bus with the proper byte enables set
            according to the length and offset.  The actual
            data to be written must be positioned in the proper
            byte lane(s) according to the requested length and
            offset.  For a length 8 transfer, the ioc$write_io
            routine reads a quadword from the data cell.

Outputs

    SS$_NORMAL Success.  If ioc$read_io, data is returned in the
            caller's buffer.  If ioc$write_io, data is written to
            device.

    SS$_BADPARAM Bad input argument, such as an illegal length.

    SS$_UNSUPPORTED A transaction length not supported by this bus
            or platform.
```

# B
# Sample Driver Written in C

This appendix contains a sample driver written in C and a command procedure for compiling and linking the driver.

## B.1 LRDRIVER Example

The LRDRIVER is for the parallel output port of the VL82C106 Combo chip on an ISA option card for the DEC 2000 Model 300 AXP system. You can obtain the most current version of this driver from the SYS$EXAMPLES directory.

```
#pragma module LRDRIVER X1

/*
 ******************************************************************************
 *
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 *
 ******************************************************************************
 *
 *
 * FACILITY:
 *
 *      Example Device Driver for OpenVMS AXP
 *
 * ABSTRACT:
 *
 *      This is an example device driver for OpenVMS AXP Version 6.1 for the
 *      parallel printer port of the VL82C106 Combo chip.  This driver supports
 *      the VL82C106 either on the system bus or on an ISA option card on the
 *      DEC 2000 Model 300 AXP system.
 *
 *      The parallel printer port is a simple programmed I/O device.  There
 *      is a single control register (LPC), a status register (LPS), and a
 *      write data register (LWD).
 *
 * AUTHOR:
 *
 *      OpenVMS AXP Development Group
 *
 * REVISION HISTORY:
 *
 *      X-1     VMS000          OpenVMS AXP Drivers             5-Nov-1993
 *              Initial version.
 */
```

```
/* Define system data structure types and constants */

#include <ccbdef.h>             /* Channel control block */
#include <crbdef.h>             /* Controller request block */
#include <cramdef.h>            /* Controller register access method */
#include <dcdef.h>              /* Device codes */
#include <ddbdef.h>             /* Device data block */
#include <ddtdef.h>             /* Driver dispatch table */
#include <devdef.h>             /* Device characteristics */
#include <dptdef.h>             /* Driver prologue table */
#include <fdtdef.h>             /* Function decision table */
#include <fkbdef.h>             /* Fork block */
#include <idbdef.h>             /* Interrupt data block */
#include <iocdef.h>             /* IOC constants */
#include <iodef.h>              /* I/O function codes */
#include <irpdef.h>             /* I/O request packet */
#include <ka0602def.h>          /* DEC 2000 Model 300 AXP specific defs  */
#include <lpdef.h>              /* Line printer definitions */
#include <orbdef.h>             /* Object rights block */
#include <pcbdef.h>             /* Process control block */
#include <msgdef.h>             /* System-wide mailbox message codes */
#include <mtxdef.h>             /* Longword mutex */
#include <ssdef.h>              /* System service status codes */
#include <stsdef.h>             /* Status value fields */
#include <ucbdef.h>             /* Unit control block */
#include <vecdef.h>             /* IDB interrupt transfer vector */

/* Define function prototypes for system routines */

#include <exe_routines.h>       /* Prototypes for exe$ and exe_std$ routines */
#include <ioc_routines.h>       /* Prototypes for ioc$ and ioc_std$ routines */
#include <sch_routines.h>       /* Prototypes for sch$ and sch_std$ routines */

/* Define various device driver macros */

#include <vms_drivers.h>        /* Device driver support macros, including */
                                /* table initialization macros and prototypes*/

/* Define the DEC C functions used by this driver */

#include <builtins.h>           /* OpenVMS AXP specific C builtin functions */
#include <string.h>             /* String routines provided by "kernel CRTL" */

/* Define constants specific to this driver */

enum {                          /* Miscellaneous constants */
    DEVICE_IPL         =  21,   /*   Interrupt priority level of device */
    NUMBER_CRAMS       =   3,   /*   Number of CRAMs needed */
    LINES_PER_PAGE     =  66,   /*   Default paper size */
    DATA_EXPND_CUSHION =  32    /*   Extra room in system buffer for expansion */
};

enum {                          /* Define various timeout constants */
    LR_WFI_TMO     =      15,   /*   Interrupt timeout value in seconds */
    LR_OFFLINE_TMO =      60,   /*   Initial interval between offline messages */
    ONE_HOUR       = (60*60)    /*   One hour in seconds */
};

enum {                          /* Define names for some ASCII characters */
    CR  =             '\x0d',   /*   Carriage return character */
    LF  =             '\x0a'    /*   Line feed character */
};
```

```
/* Define the line printer port CSR offsets.
 * Note that the unit initialization routine determines if this unit is
 * associated with a VL82C106 on system bus or on an ISA option card.
 * Note also that due to the byte-laned I/O space, data read from the ISA
 * LPS register (byte offset 1) must be shifted right 1 byte, and data read
 * from the LPC register (byte offset 2) must be shifted right 2 bytes.
 */

                                /* Offsets for VL82C106 on system bus */
#define LR_COMBO_LWD   0x3bc    /*   line printer port data write */
#define LR_COMBO_LPS   0x3bd    /*   line printer port status */
#define LR_COMBO_LCW   0x3be    /*   line printer port control write */

                                /* Offsets for VL82C106 on an ISA option card */
#define LR_LPT2_PORT   0x378    /*   ISA I/O address for LPT2 */
#define LR_LPT3_PORT   0x278    /*   ISA I/O address for LPT3 */
                                /*   Actual register offset is LR_LPT2_PORT or */
                                /*   LR_LPT2_PORT plus one of the following: */
#define LR_ISA_LWD       0x0    /*     line printer port data write */
#define LR_ISA_LPS       0x1    /*     line printer port status */
#define LR_ISA_LCW       0x2    /*     line printer port control write */

#define LR_LPT2_IRQ        7    /* Expected ISA IRQ for LPT2 */
#define LR_LPT3_IRQ        5    /* Expected ISA IRQ for LPT3 */


/* Line Printer Control Register
 * Mask values are defined for each of the control bits in the LPC.  This
 * driver always writes a new value to the LPC when a bit needs to be set.
 * A convenient way of doing this is to logically or together a subset of the
 * following masks to form the new LPC value.
 */
enum lpc_masks {
    LPC_M_STROBE    =  0x01,    /* Strobe data to printer */
    LPC_M_AUTO_FEED =  0x02,    /* Auto line feed enabled  */
    LPC_M_INIT_OFF  =  0x04,    /* Disable INIT signal */
    LPC_M_SELECT    =  0x08,    /* Select printer "on line" */
    LPC_M_IRQ_EN    =  0x10,    /* Interrupt enable */
    LPC_M_DIR_READ  =  0x20     /* Direction is read if set, else write */
};

/* Line Printer Status Register
 * Define a structure type with bit fields that corresponds to the status
 * bits.  This structure type facilitates the testing of these conditions.
 */
typedef struct _lps {
    unsigned int             : 2;      /* Reserved */
    unsigned int lps_irqp     : 1;      /* Interrupt pending */
    unsigned int lps_ok       : 1;      /* Ok status, i.e. no error */
    unsigned int lps_online   : 1;      /* Select on line */
    unsigned int lps_paperout : 1;      /* Paper empty */
    unsigned int lps_nak      : 1;      /* Not acknowledge */
    unsigned int lps_ready    : 1;      /* Ready, i.e. not busy */
} LPS;


/* Define Device-Dependent Unit Control Block with extensions for LR device */
```

```
typedef struct {
    UCB    ucb$r_ucb;                    /* Generic UCB */
    MTX    ucb$l_lr_mutex;               /* Line printer UCB mutex */
    int    ucb$l_lr_msg_tmo;             /* Time out value for device offline msg */
    int    ucb$l_lr_oflcnt;              /* Offline time, print msg when reaches lr_msg_tmo */
    int    ucb$l_lr_cursor;              /* Current horizontal position */
    int    ucb$l_lr_lincnt;              /* Current line count on page */
    int    ucb$l_lr_combo;               /* Unit is on system bus, not ISA option */
    int    ucb$l_lr_isa_io_address[2];   /* ISA I/O address range */
    int    ucb$l_lr_isa_irq[2];          /* IRQ returned from ioc$node_data */
    CRAM   *ucb$ps_cram_lwd;             /* Line printer write data register */
    CRAM   *ucb$ps_cram_lps;             /* Line printer status register */
    CRAM   *ucb$ps_cram_lcw;             /* Line printer control register write */
    } LR_UCB;

/* Define the packet header for a system buffer for buffered I/O data */

typedef struct _sysbuf_hdr {
    char *pkt_datap;                     /* Pointer to start of data in packet */
    char *usr_bufp;                      /* User VA of user buffer */
    short pkt_size;                      /* Size of the system buffer packet */
    short :16;
} SYSBUF_HDR;


/* Prototypes for driver routines defined in this module */

/* Driver table initialization routine */

    int  driver$init_tables ();

/* Device I/O database structure initialization routine */

    void lr$struc_init (CRB *crb, DDB *ddb, IDB *idb, ORB *orb, LR_UCB *ucb);

/* Device I/O database structure re-initialization routine */

    void lr$struc_reinit (CRB *crb, DDB *ddb, IDB *idb, ORB *orb, LR_UCB *ucb);

/* Unit initialization routine */

    int  lr$unit_init (IDB *idb, LR_UCB *ucb);

/* FDT routine for write functions */

    int  lr$write (IRP *irp, PCB *pcb, LR_UCB *ucb, CCB *ccb);

/* FDT routine for set mode and set characteristics functions */

    int  lr$setmode (IRP *irp, PCB *pcb, LR_UCB *ucb, CCB *ccb);

/* Start I/O routine */

    void lr$startio (IRP *irp, LR_UCB *ucb);

/* Local routine that sends the next character to the device */

    static int lr$send_char_dev (LR_UCB *ucb);

/* Interrupt service routine */

    void lr$interrupt (IDB *idb);

/* Driver fork routine entered when all I/O completed by interrupt service */

    void lr$iodone_fork (IRP *irp, void *not_used, LR_UCB *ucb);

/* Wait-for-interrupt timeout routine */

    void lr$wfi_timeout (IRP *irp, void *not_used, LR_UCB *ucb);

/* Periodic Check for Device Ready via Fork-wait mechanism */

    void lr$check_ready_fork (IRP *irp, void *not_used, LR_UCB *ucb);
```

```
/*
 * DRIVER$INIT_TABLES - Initialize Driver Tables
 *
 * Functional description:
 *
 *   This routine completes the initialization of the DPT, DDT, and FDT
 *   structures.  If a driver image contains a routine named DRIVER$INIT_TABLES
 *   then this routine is called once by the $LOAD_DRIVER service immediately
 *   after the driver image is loaded or reloaded and before any validity checks
 *   are performed on the DPT, DDT, and FDT.  A prototype version of these
 *   structures is built into this image at link time from the
 *   VMS$VOLATILE_PRIVATE_INTERFACES.OLB library.  Note that the device related
 *   data structures (e.g. DDB, UCB, etc.) have not yet been created when this
 *   routine is called.  Thus the actions of this routine must be confined to
 *   the initialization of the DPT, DDT, and FDT structures which are contained
 *   in the driver image.
 *
 * Calling convention:
 *
 *   status = driver$init_tables ();
 *
 * Input parameters:
 *
 *   None.
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   status     If the status is not successful, then the driver image will
 *              be unloaded.  Note that the ini_* macros used below will
 *              result in a return from this routine with an error status if
 *              an initialization error is detected.
 *
 * Implicit inputs:
 *
 *  driver$dpt, driver$ddt, driver$fdt
 *              These are the externally defined names for the prototype
 *              DPT, DDT, and FDT structures that are linked into this driver.
 *
 * Environment:
 *
 *   Kernel mode, system context.
 */

int driver$init_tables ()  {

    /* Prototype driver DPT, DDT, and FDT will be pulled in from the
     * VMS$VOLATILE_PRIVATE_INTERFACES.OLB library at link time.
     */
    extern DPT driver$dpt;
    extern DDT driver$ddt;
    extern FDT driver$fdt;

    /* Finish initialization of the Driver Prologue Table (DPT) */

    ini_dpt_name        (&driver$dpt, "LRDRIVER");
    ini_dpt_adapt       (&driver$dpt, AT$_KA0602);
    ini_dpt_defunits    (&driver$dpt, 1);
    ini_dpt_ucbsize     (&driver$dpt, sizeof(LR_UCB));
    ini_dpt_struc_init  (&driver$dpt, lr$struc_init );
    ini_dpt_struc_reinit(&driver$dpt, lr$struc_reinit );
    ini_dpt_ucb_crams   (&driver$dpt, NUMBER_CRAMS);
    ini_dpt_end         (&driver$dpt);
```

```
    /* Finish initialization of the Driver Dispatch Table (DDT) */

    ini_ddt_unitinit    (&driver$ddt, lr$unit_init);
    ini_ddt_start       (&driver$ddt, lr$startio);
    ini_ddt_cancel      (&driver$ddt, ioc_std$cancelio);
    ini_ddt_end         (&driver$ddt);

    /* Finish initialization of the Function Decision Table (FDT) */

    ini_fdt_act (&driver$fdt, IO$_WRITELBLK, lr$write, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_WRITEPBLK, lr$write, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_WRITEVBLK, lr$write, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_SETMODE, lr$setmode, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_SETCHAR, lr$setmode, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_SENSEMODE, exe_std$sensemode, BUFFERED);
    ini_fdt_act (&driver$fdt, IO$_SENSECHAR, exe_std$sensemode, BUFFERED);
    ini_fdt_end (&driver$fdt);

    /* If we got this far then everything worked, so return success. */

    return SS$_NORMAL;
}


/*
 * LR$STRUC_INIT - Device Data Structure Initialization Routine
 *
 * Functional description:
 *
 *   This routine is called once for each unit by the $LOAD_DRIVER service
 *   after that UCB is created.  At the point of this call the UCB has not
 *   yet been fully linked into the I/O database.  This routine is responsible
 *   for filling in driver specific fields that in the I/O database structures
 *   that are passed as parameters to this routine.
 *
 *   This routine is responsible for filling in the fields that are not
 *   affected by a RELOAD of the driver image.  In contrast, the structure
 *   reinitialization routine is responsible for filling in the fields that
 *   need to be corrected when (and if) this driver image is reloaded.
 *
 *   After this routine is called for a new unit, then the reinitialization
 *   routine is called as well.  Then the $LOAD_DRIVER service completes the
 *   integration of these device specific structures into the I/O database.
 *
 *   Note that this routine must confine its actions to filling in these I/O
 *   database structures and may not attempt to initialize the hardware device.
 *   Initialization of the hardware device is the responsibility of the
 *   controller and unit initialization routines which are called some time
 *   later.
 *
 * Calling convention:
 *
 *   lr$struc_init (crb, ddb, idb, orb, ucb)
 *
 * Input parameters:
 *
 *   crb        Pointer to associated controller request block.
 *   ddb        Pointer to associated device data block.
 *   idb        Pointer to associated interrupt dispatch block.
 *   orb        Pointer to associated object rights block.
 *   ucb        Pointer to the unit control block that is to be initialized.
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
```

```
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, IPL may be as high as 31 and may not be
 *   altered.
 *
 */

void lr$struc_init (CRB *crb, DDB *ddb, IDB *idb, ORB *orb, LR_UCB *ucb) {

    /* Initialize the fork lock and device IPL fields */

    ucb->ucb$r_ucb.ucb$b_flck = SPL$C_IOLOCK8;
    ucb->ucb$r_ucb.ucb$b_dipl = DEVICE_IPL;

    /* Device Characteristics are :  Record oriented (REC), Available (AVL),
     * Carriage control device (CCL), Output device (ODV)
     */
    ucb->ucb$r_ucb.ucb$l_devchar = DEV$M_REC | DEV$M_AVL | DEV$M_CCL | DEV$M_ODV;

    /* Set to prefix device name with "node$", set device class, device type,
     *  and default buffer size.
     */
    ucb->ucb$r_ucb.ucb$l_devchar2 = DEV$M_NNM;
    ucb->ucb$r_ucb.ucb$b_devclass = DC$_LP;
    ucb->ucb$r_ucb.ucb$b_devtype = LP$_LP11;
    ucb->ucb$r_ucb.ucb$w_devbufsiz = 132;

    /* Lines per page in highest byte of ucb$l_devdepend and LP attributes
     * in lower three bytes.
     */
    ucb->ucb$r_ucb.ucb$l_devdepend = (LINES_PER_PAGE << 24) |
                                     LP$M_MECHFORM | LP$M_TRUNCATE;

    /* Initialize LR device mutex as unowned */

    ucb->ucb$l_lr_mutex.mtx$w_owncnt = -1;

    return;
}


/*
 * LR$STRUC_REINIT - Device Data Structure Re-Initialization Routine
 *
 * Functional description:
 *
 *   This routine is called once for each unit by the $LOAD_DRIVER service
 *   immediately after the structure initialization routine is called.
 *
 *   Additionally, this routine is called once for each unit by the $LOAD_DRIVER
 *   service when a driver image is RELOADED.  Thus, this routine is
 *   responsible for filling in the fields in the I/O database structures
 *   that point into this driver image.
 *
 *   Note that this routine must confine its actions to filling in these I/O
 *   database structures.
 *
 * Calling convention:
 *
 *   lr$struc_reinit (crb, ddb, idb, orb, ucb)
 *
 * Input parameters:
 *
 *   crb        Pointer to associated controller request block.
 *   ddb        Pointer to associated device data block.
 *   idb        Pointer to associated interrupt dispatch block.
 *   orb        Pointer to associated object rights block.
```

```
 *   ucb        Pointer to the unit control block that is to be initialized.
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, IPL may be as high as 31 and may not be
 *   altered.
 *
 */
void lr$struc_reinit (CRB *crb, DDB *ddb, IDB *idb, ORB *orb, LR_UCB *ucb) {

    extern DDT driver$ddt;

    /* Setup the pointer from our DDB in the I/O database to the driver
     * dispatch table that's within this driver image.
     */
    ddb->ddb$ps_ddt = &driver$ddt;

    /* Setup the procedure descriptor and code entry addresses in the VEC
     * portion of the CRB in the I/O database to point to the interrupt
     * service routine that's within this driver image.
     */
    dpt_store_isr (crb, lr$interrupt);

    return;
}


/*
 * LR$UNIT_INIT - Unit Initialization Routine
 *
 * Functional description:
 *
 *   This routine is called once for each unit by the $LOAD_DRIVER service
 *   after a new unit control block has been created, initialized, and
 *   fully integrated into the I/O database.
 *
 *   This routine is also called for each unit during power fail recovery.
 *
 *   It is the responsibility of this routine to bring unit "on line" and
 *   to make it ready to accept I/O requests.
 *
 * Calling convention:
 *
 *   status = lr$unit_init (idb, ucb)
 *
 * Input parameters:
 *
 *   idb        Pointer to associated interrupt dispatch block.
 *   ucb        Pointer to the unit control block that is to be initialized.
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   status     SS$_NORMAL indicates that the unit was initialized successfully.
 *              SS$_IVADDR indicates that an unexpected ISA I/O address or IRQ
 *                         level was detected.
```

```
 *
 * Environment:
 *
 *   Kernel mode, system context, IPL 31.
 */
int lr$unit_init (IDB *idb, LR_UCB *ucb)  {

    static int combo_initialized = 0;           /* First unit is on system bus */

    CRAM *cram;
    ADP *adp;
    int isa_io_addr;            /* Slot I/O address if ISA option */
    int device_data;            /* Data from or for CRAM */
    int status;

#if defined DEBUG

    /* If a debug version of this driver is being built then invoke the loaded
     * system debugger.  This could either be the High Level Language System
     * Debugger, XDELTA, or nothing.
     */
    {
        extern void ini$brk (void);
        ini$brk ();
    }
#endif

    /* Set device initially offline (for error exits) and initialize other
     * UCB cells.
     */
    ucb->ucb$r_ucb.ucb$v_online = 0;

    ucb->ucb$l_lr_msg_tmo = LR_OFFLINE_TMO;

    /* This driver can service only a single unit per DDB and IDB.  Thus,
     * make the single unit the permanent owner of the IDB.  This facilitates
     * getting the UCB address in our interrupt service routine.
     */
    idb->idb$ps_owner = &(ucb->ucb$r_ucb);

    /* Initialize the three CRAMs that were requested in our DPT and allocated
     * before this unit initialization routine was called.
     */
    adp = ucb->ucb$r_ucb.ucb$ps_adp;            /* Pointer to our ADP */
    cram = ucb->ucb$r_ucb.ucb$ps_cram;          /* Pointer to first CRAM */

    /* Note that this driver assumes that the first unit that it initializes
     * is the VL82C106 on the system bus.  All subsequent units are for ISA
     * option cards.
     */
    if ( ! combo_initialized ) {

        combo_initialized = 1;          /* Unit on system bus initialized */
        ucb->ucb$l_lr_combo = 1;        /* This unit is for VL82C106 on system bus */

        /* Initialize CRAM used to write the data register */

        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lwd = cram;
        ioc$cram_cmd (CRAMCMD$K_WTLONG32, LR_COMBO_LWD, adp, cram, 0);

        /* Initialize CRAM used to read the status register */

        cram = cram->cram$l_flink;
        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lps = cram;
        ioc$cram_cmd (CRAMCMD$K_RDLONG32, LR_COMBO_LPS, adp, cram, 0);

        /* Initialize CRAM used to write the control register */
```

```
        cram = cram->cram$l_flink;
        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lcw = cram;
        ioc$cram_cmd (CRAMCMD$K_WTLONG32, LR_COMBO_LCW, adp, cram, 0);

    } else {                            /* This unit is for VL82C106 on ISA bus */

        /* Get and validate the ISA IRQ */

        status = ioc$node_data (ucb->ucb$r_ucb.ucb$l_crb, IOC$K_EISA_IRQ,
                                &ucb->ucb$l_lr_isa_irq[0] );
        if ( ! $VMS_STATUS_SUCCESS(status) ) return status;

        if ( ucb->ucb$l_lr_isa_irq[0] != LR_LPT2_IRQ &&
             ucb->ucb$l_lr_isa_irq[0] != LR_LPT3_IRQ &&
             ucb->ucb$l_lr_isa_irq[1] != LR_LPT2_IRQ &&
             ucb->ucb$l_lr_isa_irq[1] != LR_LPT3_IRQ ) {
            return SS$_IVADDR;
        }

        /* Get and validate the ISA I/O address */

        status = ioc$node_data (ucb->ucb$r_ucb.ucb$l_crb, IOC$K_EISA_IO_PORT,
                                &ucb->ucb$l_lr_isa_io_address[0] );
        if ( ! $VMS_STATUS_SUCCESS(status) ) return status;

        isa_io_addr = ucb->ucb$l_lr_isa_io_address[0];
        if (isa_io_addr != LR_LPT2_PORT  &&  isa_io_addr != LR_LPT3_PORT) {
            isa_io_addr = ucb->ucb$l_lr_isa_io_address[1];
            if (isa_io_addr != LR_LPT2_PORT  &&  isa_io_addr != LR_LPT3_PORT) {
                return SS$_IVADDR;
            }
        }

        /* Initialize CRAM used to write the data register */

        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lwd = cram;
        ioc$cram_cmd (CRAMCMD$K_WTBYTE32, isa_io_addr+LR_ISA_LWD, adp, cram, 0);

        /* Initialize CRAM used to read the status register */

        cram = cram->cram$l_flink;
        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lps = cram;
        ioc$cram_cmd (CRAMCMD$K_RDBYTE32, isa_io_addr+LR_ISA_LPS, adp, cram, 0);

        /* Initialize CRAM used to write the control register */

        cram = cram->cram$l_flink;
        cram->cram$v_der = 1;
        ucb->ucb$ps_cram_lcw = cram;
        ioc$cram_cmd (CRAMCMD$K_WTBYTE32, isa_io_addr+LR_ISA_LCW, adp, cram, 0);

    }

    /* Enable interrupts */

    status = ioc$node_function (ucb->ucb$r_ucb.ucb$l_crb, IOC$K_ENABLE_INTR);
    if ( ! $VMS_STATUS_SUCCESS(status) ) return status;

    /* Set the INIT_OFF bit in the port control register.  The INIT signal is
     * asserted as long as INIT_OFF is clear.  Note byte-lane shift if ISA
     * option.
     */
    if (ucb->ucb$l_lr_combo)
        device_data = LPC_M_INIT_OFF;
    else
        device_data = LPC_M_INIT_OFF << 16;

    ucb->ucb$ps_cram_lcw->cram$q_wdata = device_data;
    ioc$cram_io (ucb->ucb$ps_cram_lcw);
```

```
    /* Mark the device as "on line" and ready to accept I/O requests */

    ucb->ucb$r_ucb.ucb$v_online = 1;

    return SS$_NORMAL;
}


/*
 * LR$SETMODE - FDT Routine for Set Mode and Set Characteristics
 *
 * Functional description:
 *
 *   This routine is called by the FDT dispatcher in the $QIO system service
 *   to process set mode and set characteristics functions.  This FDT routine
 *   completes the I/O request without sending it to the driver start I/O
 *   routine.  The modification of the UCB by this routine is synchronized
 *   with respect to other processes through the use of a mutex.
 *
 *   Since this is an upper-level FDT routine, this routine always returns
 *   the SS$_FDT_COMPL status.  The $QIO status that is to be returned to
 *   the caller of the $QIO system service is returned indirectly by the
 *   FDT completion routines (e. g. exe_std$abortio, exe_std$finishio) via
 *   the FDT context structure.
 *
 * Calling convention:
 *
 *   status = lr$setmode (irp, pcb, ucb, ccb)
 *
 * Input parameters:
 *
 *   irp        Pointer to I/O request packet
 *   pcb        Pointer process control block
 *   ucb        Pointer to unit control block
 *   ccb        Pointer to channel control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   status     SS$_FDT_COMPL
 *
 * Environment:
 *
 *   Kernel mode, user process context, IPL 2.
 */

int  lr$setmode (IRP *irp, PCB *pcb, LR_UCB *ucb, CCB *ccb) {

    /* Define a structure that corresponds to the layout of the caller's
     * set mode or set characteristics buffer and declare a local pointer
     * to a structure of this type.
     */
    typedef struct {
        unsigned char  devclass;
        unsigned char  devtype;
        unsigned short devbufsiz;
        unsigned int   devdepend;
    } SETMODE_BUF;

    SETMODE_BUF *setmode_bufp;
```

```
    /* The caller passes the address of their setmode buffer in the $QIO P1
     * parameter.
     */
    setmode_bufp = (SETMODE_BUF *) irp->irp$l_qio_p1;

    /* Assure that the caller's setmode buffer is readable by the caller.
     * If not, abort the I/O request now with an ACCVIO status and return
     * back to the FDT dispatcher in the $QIO system service.
     */
    if (! ( __PAL_PROBER (setmode_bufp, sizeof(SETMODE_BUF)-1, irp->irp$b_rmod) ))
        return ( call_abortio (irp, pcb, (UCB *)ucb, SS$_ACCVIO) );

    /* Lock the UCB longword mutex for write access */

    sch_std$lockw (&ucb->ucb$l_lr_mutex, pcb);

    /* If function is SETCHAR then set dev class and type */

    if (irp->irp$v_fcode == IO$_SETCHAR) {
        ucb->ucb$r_ucb.ucb$b_devclass = setmode_bufp->devclass;
        ucb->ucb$r_ucb.ucb$b_devtype = setmode_bufp->devtype;
    }

    /* Set the default buffer and device dependent characteristics */

    ucb->ucb$r_ucb.ucb$w_devbufsiz = setmode_bufp->devbufsiz;
    ucb->ucb$r_ucb.ucb$l_devdepend = setmode_bufp->devdepend;

    /* Unlock the UCB mutex */

    sch_std$unlock (&ucb->ucb$l_lr_mutex, pcb);

    /* Finish the IO; return SS$_FDT_COMPL to the FDT dispatcher in the $QIO
     * system service.
     */
    return ( call_finishio (irp, (UCB *)ucb, SS$_NORMAL, 0) );
}


/*
 * LR$WRITE - FDT Routine for Write Function Codes
 *
 * Functional description:
 *
 *   This routine is called by the FDT dispatcher in the $QIO system service
 *   to process write functions.  This FDT routine validates the request,
 *   allocates a buffered I/O packet, formats and copies the contents of the
 *   user buffer into the buffered I/O packet, and queues the IRP to this
 *   driver's start I/O routine.
 *
 *   When the IRP is successfully queued to the driver's start I/O routine,
 *   irp$l_svapte points to the buffered I/O packet, irp$l_boff is the
 *   number of bytes that have been charged against the process, and irp$l_bcnt
 *   is the actual count of data bytes in the buffered I/O packet that are
 *   to be sent to the printer.  Note that the contents of the irp$l_svapte
 *   and irp$l_boff cells must not be changed since I/O post processing will
 *   use these to deallocate the buffer packet and to credit the process.
 *
 *   Since this is an upper-level FDT routine, this routine always returns
 *   the SS$_FDT_COMPL status.  The $QIO status that is to be returned to
 *   the caller of the $QIO system service is returned indirectly by the
 *   FDT completion routines (e. g. exe_std$abortio, exe_std$qiodrvpkt) via
 *   the FDT context structure.
 *
 * Calling convention:
 *
 *   status = lr$write (irp, pcb, ucb, ccb)
 *
 * Input parameters:
 *
```

```
 *   irp        Pointer to I/O request packet
 *   pcb        Pointer process control block
 *   ucb        Pointer to unit control block
 *   ccb        Pointer to channel control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   status     SS$_FDT_COMPL
 *
 * Environment:
 *
 *   Kernel mode, user process context, IPL 2.
 */

int lr$write (IRP *irp, PCB *pcb, LR_UCB *ucb, CCB *ccb) {

    /* Define a structure type for the carraige control information that
     * is returned from exe_std$carriage.  This information is returned in
     * the IRP at the longword that begins with irp->irp$b_carcon.
     */
    typedef struct {
        uint8 prefix_count;     /* Number of prefix chars */
        char  prefix_char;      /* The prefix char, 0 if newline */
        uint8 suffix_count;     /* Number of suffix chars */
        char  suffix_char;      /* The suffix char, 0 if newline */
    } CARCON;

    char *qio_bufp;             /* Pointer to caller's buffer */
    int qio_buflen;             /* Number of bytes in caller's buffer */
    SYSBUF_HDR *sys_bufp;       /* Pointer to a system buffer packet */
    int32 sys_buflen;           /* Computed required system packet size */
    char *sys_datap;            /* Working pointer to next byte in sysbuf */
    int pass_all;               /* True if this is a "pass all" write */
    int status;

    /* Get the pointer to the caller's buffer and the size of the caller's
     * buffer from the $QIO P1 and P2 parameters.
     */
    qio_bufp = (char *) irp->irp$l_qio_p1;
    qio_buflen = irp->irp$l_qio_p2;

    /* Assure that the caller has read access to this buffer to do a write
     * operation.  If not, exe_std$writechk will abort the I/O request and
     * return the SS$_FDT_COMPL warning status.  If this is the case, we must
     * return back to the FDT dispatcher in the $QIO system service.  Note we
     * continue on even if the user buffer is zero length since there may be
     * carriage control to output.
     */
    if (qio_buflen != 0) {
        status = exe_std$writechk (irp, pcb, &(ucb->ucb$r_ucb),
                                   qio_bufp, qio_buflen);
        if ( ! $VMS_STATUS_SUCCESS(status) ) return status;
    }

    /* Start out assuming that the required system buffer packet size is
     * the size of the $QIO buffer plus the size of the buffer packet header.
     */
    sys_buflen = qio_buflen + sizeof(SYSBUF_HDR);

    /* This is a "pass all" request either if the write physical function
     * was specified or if the device is set to "write pass all" mode.
     */
    pass_all = irp->irp$v_func == IO$_WRITEPBLK  ||
               (ucb->ucb$r_ucb.ucb$l_devdepend & LP$M_PASSALL);
```

```
/* If this is not a "pass all" request, then interpret the $QIO P4
 * carriage control parameter.  Adjust the required system buffer packet
 * size by the prefix and suffix counts plus room of data expansion.
 * Currently, the only expansion possible is an extra CR in the prefix
 * and suffix characters if "new line" was specified.
 */
if ( ! pass_all ) {
    irp->irp$l_iost2 = irp->irp$l_qio_p4;
    exe_std$carriage (irp);
    sys_buflen += ((CARCON *) &irp->irp$b_carcon)->prefix_count +
                  ((CARCON *) &irp->irp$b_carcon)->suffix_count +
                  DATA_EXPND_CUSHION;
}

/* Allocate a system buffer for the data in the user buffer.  If this
 * fails then abort the I/O request and return back to the FDT dispatcher
 * in the $QIO system service.  Otherwise, set irp$l_svapte to point to
 * the packet, irp$l_boff to contain the number of bytes charged, and
 * sys_datap to point to the first free data byte in the buffer packet.
 */
status = exe_std$debit_bytcnt_alo (sys_buflen, pcb,
                                   &sys_buflen, (void **) &sys_bufp);
if ( ! $VMS_STATUS_SUCCESS(status) ) {
    return ( call_abortio (irp, pcb, (UCB *)ucb, status) );
}
irp->irp$l_svapte = (void *) sys_bufp;
irp->irp$l_boff = sys_buflen;
sys_datap = (char *) sys_bufp + sizeof(SYSBUF_HDR);

/* If this is a "pass all" request, then simply copy the user supplied
 * data into the system buffer.  Otherwise, process prefix and postfix
 * carriage control in addition to the user buffer data.
 */
if ( pass_all ) {
    memcpy (sys_datap, qio_bufp, qio_buflen);
    irp->irp$l_bcnt = qio_buflen;
} else {
    char carcon_char;
    int  carcon_count;

    irp->irp$l_bcnt = 0;

    /* Expand the prefix carriage control into the allocated system
     * buffer.  If the carriage control count is non-zero and the
     * carriage control character is 0, this means "new line."  Output
     * an initial CR, then the counted number of LFs.
     */
    carcon_count = ((CARCON *) &irp->irp$b_carcon)->prefix_count;
    if (carcon_count != 0) {
        carcon_char = ((CARCON *) &irp->irp$b_carcon)->prefix_char;
        if (carcon_char == 0) {
            *sys_datap++ = CR;
            irp->irp$l_bcnt++;
            carcon_char = LF;
        }
        irp->irp$l_bcnt += carcon_count;
        for ( ; carcon_count > 0 ; carcon_count--) {
            *sys_datap++ = carcon_char;
        }
    }

    /* Copy the user data into the system buffer */

    memcpy (sys_datap, qio_bufp, qio_buflen);
    irp->irp$l_bcnt += qio_buflen;
    sys_datap += qio_buflen;
```

```
        /* Expand the suffix carriage control into the allocated system
         * buffer.  If the carriage control count is non-zero and the
         * carriage control character is 0, this means "new line."  Output
         * an initial CR, then the counted number of LFs.
         */
        carcon_count = ((CARCON *) &irp->irp$b_carcon)->suffix_count;
        if (carcon_count != 0) {
            carcon_char = ((CARCON *) &irp->irp$b_carcon)->suffix_char;
            if (carcon_char == 0) {
                *sys_datap++ = CR;
                irp->irp$l_bcnt++;
                carcon_char = LF;
            }
            irp->irp$l_bcnt += carcon_count;
            for ( ; carcon_count > 0 ; carcon_count--) {
                *sys_datap++ = carcon_char;
            }
        }

    }

    /* Queue this I/O request to the start I/O routine and return SS$_FDT_COMPL
     * back to the FDT dispatcher in the $QIO system service.
     */
    return ( call_qiodrvpkt (irp, (UCB *)ucb) );
}


/*
 * LR$STARTIO - Start I/O Routine
 *
 * Functional description:
 *
 *   This routine is the driver start I/O routine.  This routine is called
 *   by ioc_std$initiate to process the next I/O request that has been
 *   queued to this device.  For this driver, the only function that is
 *   passed to the start I/O routine is a write operation.
 *
 *   Before this routine is called, ucb$v_cancel, ucb$v_int, ucb$v_tim, and
 *   ucb$v_timout are cleared.  The ucb$l_svapte, ucb$l_boff, and ucb$l_bcnt
 *   cells are set from their corresponding IRP cells.  However, unlike their
 *   IRP counterparts, these UCB cells are working storage and can be changed
 *   by a driver.  This driver uses ucb$l_svapte to point to the next byte
 *   to output in the system buffer packet, and irp$l_bcnt to keep the count
 *   of the remaining bytes to output.
 *
 *   This routine acquires the device lock and raises IPL to device IPL.
 *   The device lock is restored and the original IPL is restored via wfikpch
 *   before this routine returns to its caller.
 *
 * Calling convention:
 *
 *   lr$startio (irp, ucb)
 *
 * Input parameters:
 *
 *   irp        Pointer to I/O request packet
 *   ucb        Pointer to unit control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
```

```
 *
 * Environment:
 *
 *   Kernel mode, system context, fork IPL, fork lock held.
 */

void lr$startio (IRP *irp, LR_UCB *ucb) {

    int orig_ipl;

    /* Adjust ucb$l_svapte such that it points to the start of the data in
     * the system buffer packet.
     */
    ucb->ucb$r_ucb.ucb$l_svapte = (char *) ucb->ucb$r_ucb.ucb$l_svapte +
                                  sizeof(SYSBUF_HDR);

    /* Acquire the device lock, raise IPL, saving original IPL */

    device_lock (ucb->ucb$r_ucb.ucb$l_dlck, RAISE_IPL, &orig_ipl);

    /* Send the first character to the device.  We can ignore the status,
     * since we will timeout if the device is not ready.
     */
    lr$send_char_dev (ucb);

    /* Set up a wait for the completion of the I/O by using the wfikpch macro.
     * Wfikpch will restore the device lock and restore IPL.  When output of
     * the entire buffer has been completed, the lr$interrupt routine will
     * queue the lr$iodone_fork routine.  If the I/O does not complete within
     * LR_WFI_TMO seconds, then exe$timeout will call lr$wfi_timeout.
     */
    wfikpch (lr$iodone_fork, lr$wfi_timeout, irp, 0, ucb, LR_WFI_TMO, orig_ipl);

    return;
}


/*
 * LR$SEND_CHAR_DEV - Send Character to the Device
 *
 * Functional description:
 *
 *   This routine sends the next character from the system buffer to the
 *   device via the printer write data register.  This routine decrements the
 *   count of remaining bytes (ucb$l_bcnt) and advances the pointer to the
 *   next character (ucb$l_svapte).
 *
 *   This is an internal routine that is used by the start I/O, interrupt
 *   service, and periodic check device ready routines.
 *
 * Calling convention:
 *
 *   status = lr$send_char_dev (ucb)
 *
 * Input parameters:
 *
 *   ucb        Pointer to unit control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   status     SS$_NORMAL      if the next data byte was sent to the printer
 *                              device.
 *              SS$_DEVOFFLINE  if the next data byte was not sent to the
 *                              printer device since it is not ready to accept
 *                              data.
```

```
 *
 * Environment:
 *
 *   Kernel mode, system context, device IPL, device lock held.
 */

static int lr$send_char_dev (LR_UCB *ucb) {

    int device_data;            /* Data from or for CRAM */
    char *sys_datap;            /* Pointer to next byte in buffer packet */

    /* Set the Port Control Register.
     * Set the INIT_OFF bit to disable the "INIT" signal.  Set the IRQ_EN bit
     * to enable interrupts.  Assure that the STROBE bit is clear so that we
     * can cause a 0-to-1 transition after loading the data register.  Assure
     * that the DIR_READ bit is clear since we are doing writes to the data
     * register.  Note byte-lane shift if ISA option.
     */
    if (ucb->ucb$l_lr_combo)
        device_data = LPC_M_INIT_OFF | LPC_M_IRQ_EN;
    else
        device_data = (LPC_M_INIT_OFF | LPC_M_IRQ_EN) << 16;

    ucb->ucb$ps_cram_lcw->cram$q_wdata = device_data;
    ioc$cram_io (ucb->ucb$ps_cram_lcw);

    /* Read the port status register.  Note byte-lane shift if ISA option. */

    ioc$cram_io (ucb->ucb$ps_cram_lps);
    device_data = ucb->ucb$ps_cram_lps->cram$q_rdata;
    if ( ! ucb->ucb$l_lr_combo) device_data >>= 8;

    /* If the device is not ready to accept a character, then do not attempt
     * to send it.  Return an error status.
     */
    if (   ((LPS *) &device_data)->lps_paperout ||    /* paper out */
         ! ((LPS *) &device_data)->lps_ok       ||    /* not ok, i.e. error */
         ! ((LPS *) &device_data)->lps_online   ||    /* not online */
         ! ((LPS *) &device_data)->lps_ready    )     /* not ready */
        return SS$_DEVOFFLINE;

    /* The device is ready.  Load the data byte.  Update ucb$l_svapte to
     * point to the next byte and decrement the count of bytes lef in
     * ucb$l_bcnt.  Note that no byte-lane shift is necessary for this register.
     */
    sys_datap = (char *) ucb->ucb$r_ucb.ucb$l_svapte;
    device_data = *sys_datap++;
    ucb->ucb$r_ucb.ucb$l_svapte = (void *) sys_datap;
    ucb->ucb$r_ucb.ucb$l_bcnt--;
    ucb->ucb$ps_cram_lwd->cram$q_wdata = device_data;
    ioc$cram_io (ucb->ucb$ps_cram_lwd);

    /* Latch the data byte to the printer.
     * Set the STROBE bit in the port control register to latch the data to
     * the printer.  INIT_OFF and IRQ_EN were set earlier and are kept set.
     * DIR_READ is kept clear.  Note byte-lane shift if ISA option.
     */
    if (ucb->ucb$l_lr_combo)
        device_data = LPC_M_INIT_OFF | LPC_M_IRQ_EN | LPC_M_STROBE;
    else
        device_data = (LPC_M_INIT_OFF | LPC_M_IRQ_EN | LPC_M_STROBE) << 16;

    ucb->ucb$ps_cram_lcw->cram$q_wdata = device_data;
    ioc$cram_io (ucb->ucb$ps_cram_lcw);

    /* Data byte sent.  Return success. */

    return SS$_NORMAL;
}
```

```
/*
 * LR$INTERRUPT - Interrupt Service Routine
 *
 * Functional description:
 *
 *   This is the interrupt service routine for the parallel line printer
 *   port.  This routine is called by the system interrupt dispatcher.
 *
 *   This routine will attempt to send the next character to the device
 *   until either there are no more characters left or the I/O is canceled.
 *   At which point, this routine will queue the lr$iodone_fork routine
 *   which was set up either in lr$startio or lr$check_ready_fork.
 *
 *   If the interrupt is not expected by an active I/O on this device then
 *   it is simply dismissed.
 *
 *
 * Calling convention:
 *
 *   lr$interrupt (idb)
 *
 * Input parameters:
 *
 *   idb        Pointer to interrupt dispatch block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, device IPL.
 *
 */
void lr$interrupt (IDB *idb)  {

    LR_UCB *ucb;
    int device_data;            /* Data from or for CRAM */
    int status;

    /* Get the UCB from the IDB owner field which was set up by the lr$unit_init
     * routine.
     */
    ucb = (LR_UCB *) idb->idb$ps_owner;

    /* Acquire the device lock.  We are already at device IPL */

    device_lock (ucb->ucb$r_ucb.ucb$l_dlck, NORAISE_IPL, NOSAVE_IPL);

    /* If interrupt is expected, then process it, otherwise ignore it */

    if (ucb->ucb$r_ucb.ucb$v_int) {
```

```
        /* If there are characters left and the I/O has not been cancelled
         * then attempt to send the next character.  There is no need to check
         * the status since the interrupt timeout will expire if the device is
         * not ready.  Otherwise, queue the I/O done fork routine that was
         * setup via wfikpch.
         */
        if (ucb->ucb$r_ucb.ucb$l_bcnt > 0  &&  ! ucb->ucb$r_ucb.ucb$v_cancel) {
            lr$send_char_dev (ucb);
        } else {
            ucb->ucb$r_ucb.ucb$v_int = 0;
            ucb->ucb$r_ucb.ucb$v_tim = 0;
            exe_std$queue_fork( (FKB *)ucb );
        }
    }

    /* Restore the device lock, stay at device IPL */

    device_unlock (ucb->ucb$r_ucb.ucb$l_dlck, NOLOWER_IPL, SMP_RESTORE);

    /* return back to interrupt dispatcher */

    return;
}


/*
 * LR$IODONE_FORK - I/O Completion Fork Routine
 *
 * Functional description:
 *
 *   This is the fork routine which passes the current I/O request on to
 *   I/O postprocessing.  This routine is queued by the interrupt service
 *   routine when the I/O request has been completed.  This routine can also
 *   be called directly from lr$check_ready_fork if the I/O request is
 *   cancelled while it is stalled due to an offline condition.
 *
 * Calling convention:
 *
 *   lr$iodone_fork (irp, not_used, ucb)
 *
 * Input parameters:
 *
 *   irp        Pointer to I/O request packet
 *   not_used   Unused fork routine parameter fr4
 *   ucb        Pointer to unit control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, fork IPL, fork lock held.
 */

void lr$iodone_fork (IRP *irp, void *not_used, LR_UCB *ucb) {

    int status = SS$_NORMAL;            /* Assume everything went ok */
```

```
    /* If the request was cancelled or timed out of its own accord then
     * set the status accordingly.
     */
    if (ucb->ucb$r_ucb.ucb$v_cancel) {
        status = SS$_ABORT;
    } else if (ucb->ucb$r_ucb.ucb$v_timout) {
        status = SS$_TIMEOUT;
    }

    /* Send this I/O request to I/O post processing */

    ioc_std$reqcom (status, 0, &(ucb->ucb$r_ucb));
    return;
}


/*
 * LR$WFI_TIMEOUT - Wait-for-interrupt timeout routine
 *
 * Functional description:
 *
 *   This routine is the wait-for-interrupt timeout routine.  It is called
 *   by exe$timeout when an operation set up by wfikpch takes more that the
 *   specified number of seconds.
 *
 *   This routine queues a fork routine, lr$check_ready_fork, to handle
 *   periodic checking of the readiness of the device to resume output and
 *   to issue periodic "device offline" messages via OPCOM.
 *
 * Calling convention:
 *
 *   lr$wfi_timeout (irp, not_used, ucb)
 *
 * Input parameters:
 *
 *   irp        Pointer to I/O request packet
 *   not_used   Unused fork routine parameter fr4
 *   ucb        Pointer to unit control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, device IPL, fork lock held, device lock held.
 *
 */

void lr$wfi_timeout (IRP *irp, void *not_used, LR_UCB *ucb) {

    /* A wait-for-interrupt has timed out.  Count the device as having been
     * offline for the duration of the wait-for-interrupt interval.
     */
    ucb->ucb$l_lr_oflcnt = LR_WFI_TMO;

    /* Queue a fork-wait thread that checks once a second for the device being
     * ready to accept data.  One reason for deferring this work to fork level
     * is that exe_std$sndevmsg cannot be called at device IPL.
     */
    fork_wait (lr$check_ready_fork, irp, 0, ucb);

    return;
}
```

```
/*
 * LR$CHECK_READY_FORK - Periodic Check for Device Ready
 *
 * Functional description:
 *
 *   This routine performs a once-a-second check of the readiness of the
 *   device to resume output.  While the device remains offline this fork
 *   routine reschedules itself via the fork wait queue.  When the device
 *   is ready to resume, the next character is sent and the remainder of
 *   the output is done by the interrupt service routine.
 *
 *   If the device remains offline for ucb$l_lr_msg_tmo seconds (initially
 *   set to LR_OFFLINE_TMO) then a "device offline" message is sent to
 *   OPCOM.  The device offline message interval is doubled each time while
 *   it is less than an hour.  When the device becomes ready again, the offline
 *   message interval is reset to its initial LR_OFFLINE_TMO value.
 *
 * Calling convention:
 *
 *   lr$check_ready_fork  (irp, not_used, ucb)
 *
 * Input parameters:
 *
 *   irp        Pointer to I/O request packet
 *   not_used   Unused fork routine parameter fr4
 *   ucb        Pointer to unit control block
 *
 * Output parameters:
 *
 *   None.
 *
 * Return value:
 *
 *   None.
 *
 * Environment:
 *
 *   Kernel mode, system context, fork IPL, fork lock held.
 */

void lr$check_ready_fork (IRP *irp, void *not_used, LR_UCB *ucb) {

    int orig_ipl;
    int status;

    /* If the I/O request has been canceled while we've been waiting or there
     * are no more characters to send to the device then call our I/O done fork
     * routine directly to complete the I/O request and then return from this
     * routine.
     */
    if (ucb->ucb$r_ucb.ucb$v_cancel || ucb->ucb$r_ucb.ucb$l_bcnt == 0) {
        lr$iodone_fork (irp, 0, ucb);
        return;
    }

    /* Acquire the device lock, raise IPL, saving original IPL */

    device_lock (ucb->ucb$r_ucb.ucb$l_dlck, RAISE_IPL, &orig_ipl);

    /* Attempt to send the next character to the device.  If the device is
     * still not ready, then the character will not be sent and an error status
     * will be returned.
     */
    status = lr$send_char_dev (ucb);
```

```
    /* If we successfully sent a character to the device then we're back in
     * business.  Set up a wait for the completion of the I/O via wfikpch
     * just like our start I/O routine.  Wfikpch will restore the device lock
     * and restore IPL.  But first, clear the offline count and set the offline
     * message interval to its initial value.  And, return from this routine.
     */
    if ( $VMS_STATUS_SUCCESS(status) ) {
        ucb->ucb$l_lr_msg_tmo = LR_OFFLINE_TMO;
        ucb->ucb$l_lr_oflcnt = 0;
        wfikpch (lr$iodone_fork, lr$wfi_timeout, irp, 0, ucb,
                 LR_WFI_TMO, orig_ipl);
        return;
    }

    /* Otherwise, the device is still offline.  Increment the offline time. */

    ucb->ucb$l_lr_oflcnt++;

    /* Restore the device lock, return to the original entry IPL */

    device_unlock (ucb->ucb$r_ucb.ucb$l_dlck, orig_ipl, SMP_RESTORE);

    /* If the offline count has reached the "device offline" message interval
     * then it's time to send it to OPCOM and start a new offline interval.
     * If this message interval was less than an hour, double the next one.
     */
    if (ucb->ucb$l_lr_oflcnt >= ucb->ucb$l_lr_msg_tmo) {

        extern MB_UCB *sys$ar_oprmbx;           /* Pointer to OPCOM mbx ucb */

        exe_std$sndevmsg (sys$ar_oprmbx, MSG$_DEVOFFLIN, &(ucb->ucb$r_ucb));

        ucb->ucb$l_lr_oflcnt = 0;
        if (ucb->ucb$l_lr_msg_tmo < ONE_HOUR)
            ucb->ucb$l_lr_msg_tmo *= 2;
    }

    /* Setup to check the device again in one second via the fork-wait queue */

    fork_wait (lr$check_ready_fork, irp, 0, ucb);

    return;

}
```

## B.2 LRDRIVER.COM

The LRDRIVER.COM command procedure compiles and links the LRDRIVER.C device driver.

```
$ SET NOON
$ SAVED_VFY = F$VERIFY("NO","NO")
$ ON CONTROL_Y THEN GOTO QUIT
$ SET VERIFY=(PROCEDURE,NOIMAGE)
$!
$! LRDRIVER.COM
$! This is the compile and link procedure for the example device driver
$! LRDRIVER.C.
$!
$! Usage:
$!
$!   @LRDRIVER [DEBUG]
$!
$!   P1         If specified as DEBUG then a version of the driver is built
$!              that facilitates debugging with the High Level Language System
$!              Debugger.
$!              The default is to build a normal version of the driver.
$!
$!'F$VERIFY("NO")'
$!
$ DEBUG_CC_OPT = ""
$ IF P1 .NES. ""
$ THEN
$    IF P1 .NES. "DEBUG" THEN EXIT %X14         ! SS$_BADPARAM
$    DEBUG_CC_OPT = "/DEBUG/NOOPTIMIZE/DEFINE=DEBUG"
$ ENDIF
$!
$ IF F$TRNLNM("SRC$") .EQS. "" THEN DEFINE/NOLOG SRC$ 'F$ENVIRONMENT("DEFAULT")'
$ IF F$TRNLNM("LIS$") .EQS. "" THEN DEFINE/NOLOG LIS$ 'F$ENVIRONMENT("DEFAULT")'
$ IF F$TRNLNM("OBJ$") .EQS. "" THEN DEFINE/NOLOG OBJ$ 'F$ENVIRONMENT("DEFAULT")'
$ IF F$TRNLNM("EXE$") .EQS. "" THEN DEFINE/NOLOG EXE$ 'F$ENVIRONMENT("DEFAULT")'
$ IF F$TRNLNM("MAP$") .EQS. "" THEN DEFINE/NOLOG MAP$ 'F$ENVIRONMENT("DEFAULT")'
$!
$ SET VERIFY=(PROCEDURE,NOIMAGE)
$!
$! Compile the driver
$!
$ CC/STANDARD=RELAXED_ANSI89/INSTRUCTION=NOFLOATING_POINT/EXTERN=STRICT-
        'DEBUG_CC_OPT'-
        /LIS=LIS$:LRDRIVER/MACHINE_CODE-
        /OBJ=OBJ$:LRDRIVER-
                SRC$:LRDRIVER -
                +SYS$LIBRARY:SYS$LIB_C.TLB/LIBRARY
$!
$! Link the driver
$!
$ LINK/ALPHA/USERLIB=PROC/NATIVE_ONLY/BPAGE=14/SECTION/REPLACE-
        /NODEMAND_ZERO/NOTRACEBACK/SYSEXE/NOSYSSHR-
        /SHARE=EXE$:SYS$LRDRIVER-               ! Driver image
        /DSF=EXE$:SYS$LRDRIVER-                 ! Debug symbol file
        /SYMBOL=EXE$:SYS$LRDRIVER-              ! Symbol table
        /MAP=MAP$:SYS$LRDRIVER/FULL/CROSS -     ! Map listing
                SYS$INPUT:/OPTIONS
!
!   Define symbol table for SDA using all global symbols, not just
!   universal ones
!
SYMBOL_TABLE=GLOBALS
!
```

```
!   This cluster is used to control the order of symbol resolution.  All
!   psects must be collected off of this cluster so that it generates
!   no image sections.
!
CLUSTER=VMSDRIVER,,,-
        !
        !   Start with the driver module
        !
        OBJ$:LRDRIVER.OBJ,-
        !
        !   Next process the private interfaces.  (Only include BUGCHECK_CODES if
        !   used by the driver module).  The /LIB qualifier causes the linker to
        !   resolve references in the driver module to DRIVER$INI_xxx routines
        !   (which are defined in the module DRIVER_TABLE_INIT).
        !
        SYS$LIBRARY:VMS$VOLATILE_PRIVATE_INTERFACES/INCLUDE=(BUGCHECK_CODES)/LIB,-
        !
        !   Explicitly include routines for the initialization section - there
        !   will be no outstanding references to cause this to happen when STARLET
        !   is searched automatically.
        !
        SYS$LIBRARY:STARLET/INCLUDE:(SYS$DRIVER_INIT,SYS$DOINIT)

!
!   Use the COLLECT statement to implicitly declare the NONPAGED_EXECUTE_PSECTS
!   cluster.  Mark the cluster with the RESIDENT attribute so that the image
!   section produced is nonpaged.  Collect only the code psect into the cluster.
!
COLLECT=NONPAGED_EXECUTE_PSECTS/ATTRIBUTES=RESIDENT,-
        $CODE$

!
!   Coerce the psect attributes on the different data psects to that they
!   all match.  This will force NONPAGED_READWRITE_PSECTS cluster to yield only
!   one image section.
!
PSECT_ATTR=$LINK$,WRT
PSECT_ATTR=$INITIAL$,WRT
PSECT_ATTR=$LITERAL$,NOPIC,NOSHR,WRT
PSECT_ATTR=$READONLY$,NOPIC,NOSHR,WRT
PSECT_ATTR=$$$105_PROLOGUE,NOPIC
PSECT_ATTR=$$$110_DATA,NOPIC
PSECT_ATTR=$$$115_LINKAGE,WRT
```

```
!
!   Use a COLLECT statement to implicitly declare the NONPAGED_DATA_PSECTS
!   cluster.  Mark the cluster with the RESIDENT attribute so that the image
!   section produced is nonpaged.  Collect all the data psects into the cluster.
!
COLLECT=NONPAGED_READWRITE_PSECTS/ATTRIBUTES=RESIDENT,-
        !
        !   Psect generated by BLISS modules
        !
        $PLIT$,-
        $INITIAL$,-
        $GLOBAL$,-
        $OWN$,-
        !
        !   Psects generated by DRIVER_TABLES
        !
        $$$105_PROLOGUE,-
        $$$110_DATA,-
        $$$115_LINKAGE,-
        !
        !   Standard Psects generated by all languages,
        !   including the high level language driver module
        !
        $BSS$,-
        $DATA$,-
        $LINK$,-
        $LITERAL$,-
        $READONLY$

!
!   Coerce the program section attributes for initialization code so
!   that code and data  will be combined into a single image section.
!
PSECT_ATTR=EXEC$INIT_CODE,NOSHR

!
!   Use a COLLECT statement to implicitly declare the INITIALIZATION_PSECTS
!   cluster.  Mark the cluster with the INITIALIZATION_CODE attribute so that the image
!   section produced is identified as INITIALCOD.
!
!   These program sections have special names so that when the linker sorts them
!   alphabetically they will fall in the order: initialization vector table, code,
!   linkage, build table vector.  The order in which they are collected does not affect
!   their order in the image section.
!
!   This is the only place where code and data should reside in the
!   same section.
!
!   NOTE: The linker will attach the fixup vectors to this cluster.  This is expected.
!
COLLECT=INITIALIZATION_PSECTS/ATTRIBUTES=INITIALIZATION_CODE,-
        EXEC$INIT_000,-
        EXEC$INIT_001,-
        EXEC$INIT_002,-
        EXEC$INIT_CODE,-
        EXEC$INIT_LINKAGE,-
        EXEC$INIT_SSTBL_000,-
        EXEC$INIT_SSTBL_001,-
        EXEC$INIT_SSTBL_002
$!
$QUIT: ! 'F$VERIFY(SAVED_VFY)'
$ EXIT $STATUS
```

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