Freescale MQX™ Real-Time Operating System

User's Guide

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Revision History

To provide the most up-to-date information, the revision of our documents on the World Wide Web will be the most current. Your printed copy may be an earlier revision. To verify you have the latest information available, refer to http://www.freescale.com/mqx.

The following revision history table summarizes changes contained in this document.

Revision Number	Revision Date	Description of Changes
Rev. 0	01/2009	Initial Release coming with MQX 3.0
Rev. 0B	04/2009	Text edited and formatting changed for MQX 3.1 release.
Rev. 1	01/2010	New MQX compile-time configuration options described in Section 3.14. BSP porting instructions updated in Chapters 4 and 5.
Rev. 1.1	03/2010	Section 3.6.5 updated. Section 3.10.3.3 added.
Rev. 2	09/2010	Interrupt-level taks priorities described in section 3.2.2.1 NMI handling text edited in section 3.10.3.3 Section 3.14 updated.
Rev. 3	04/2011	"lightweight semaphores" were removed from the list of freed resources in section 3.4.6 Description of the MQX_HARDWARE_INTERRUPT_LEVEL_MAX Configuration Parameter added.

Chapter 1 Before You Begin

1.1 About MQX

The MQX™ Real-Time Operating System from MQX Embedded has been designed for uni-processor, multi-processor, and distributed-processor embedded real-time systems.

To leverage the success of the MQX operating system, Freescale Semiconductor adopted this software platform for its ColdFire® and PowerPC™ familes of microprocessors. Comapring to the original MQX distributions, the Freescale MQX distribution was made simpler to configure and use. One single release now contains the MQX operating system plus all the other software components supported for a given microprocessor part. In this document, the sections specific to Freescale MQX release are marked as below.

FREESCALE MQX	This is how notes specific to Freescale MQX release are marked in this document.

MQX is a run-time library of functions that programs use to become real-time multi-tasking applications. The main features are its scalable size, component-oriented architecture, and ease of use.

MQX supports multi-processor applications and can be used with flexible embedded I/O products for networking, data communications, and file management.

Throughout this book, we use MQX as the abbreviation for MQX.

1.2 About This Book

Use this book in conjunction with:

- MQX Reference — contains MQX simple and complex data types and alphabetically-ordered listings of MQX function prototypes.

FREESCALE MQX	Freescale MQX release includes also other software products, based on MQX operating system. See also user guides and reference manuals for RTCS TCP/IP stack, USB Host Development Kit, USB Device Development Kit, MFS File System and others.

1.3 What's New in Versions 3.0 and 2.50

FREESCALE MQX	To continue version numbering of the original MQX releases, the first Freescale MQX version is released as 3.0. Despite of the major version number change, there are no major features added to MQX, so it is compatible with the version 2.50. See also the Release Notes document for the most up-to-date information about new features available in the Freescale MQX RTOS.

MQX version 3.0, released as Freescale MQX RTOS, brings the following enahancements over version 2.50:

- Other key MQX components like MFS, RTCS, or USB are released together with the Freescale MQX RTOS.
- At the moment of writing this document, the default development environment for Freescale MQX RTOS and other MQX components is CodeWarrior Development Studio. New releases may bring support for other development environments.
- Compile-time configuration of all key Freescale MQX RTOS components (PSP, BSP, RTCS, MFS, USB, ...) is now accomplished by editing the *user_config.h* file, located in board-specific directory in the top-level *config* folder. In the previous versions, the user configuration macros were passed to the build process on a command line by the makefile, or using the CodeWarrior prefix file.
- The PSP component is configured and built for specific board. Originally, the PSP component was built once for the particular device. While the PSP code still remains board-independent, this feature enables finer kernel tuning for a specific board.
- MQX now supports typed memory, which allows additional information to be displayed in the task-aware debugger plugin.

MQX version 2.50 is backward compatible with version 2.40, and offers these enhancements over version 2.40:

- Reduced dependency on 32-bit types — types are determined by the natural size of the processor. For instance, on a 16-bit processor, generic types are 16 bits in size. Code- and data-size requirements are reduced for the smaller-architecture processors.
- Time is measured in ticks — to allow for higher-resolution delays, timeouts, and measurements, MQX measures time in ticks, instead of in seconds and milliseconds. Delays for a specified time, or until a specified time are possible. The change applies to all components that use a timeout. The internal changes are transparent. In addition, MQX adds an extended date structure that represents a calendar date well beyond the 24^{th} century and to an accuracy of a picosecond.
- MMU support is included in PSPs — MMU support allows memory protection between tasks. Each task can establish its own protected data areas.
- Multiple memory pools — applications can allocate memory blocks from an application-defined global memory space as well as they could before, from the default memory pool. The pools are similar to MQX version 2.40 partitions, but let the user allocate variable-sized blocks.

- Lightweight memory — similar to the memory component, except that MQX does fewer checks, when it allocates blocks, and the code and data sizes are smaller. Lightweight memory is faster to allocate and free memory, but slower to release memory, when a task is destroyed.
- Blocked tasks can be created — applications can create tasks that are in the blocked state. MQX creates the task as in MQX version 2.40, but does not add it to the ready queue.
- Lightweight event groups — similar to event groups, except that they are simpler.
- Autoclearing event bits — if an application creates an event group with the autoclearing attribute, MQX automatically clears an event bit immediately after the event bit is set. This behavior makes ready any tasks that are waiting for event bits, but the tasks need not clear the bits.
- Lightweight semaphores can be waited for with a timeout and polled.
- Task can be restarted — an application can restart a task from the beginning of the task's function while keeping the same task descriptor, task ID, and task stack.
- Partitions are enhanced — partitions are a fully registered MQX component. An application can create and destroy them in the same manner as it can do it with other MQX components.
- EDS Server (for embedded debugging) is enhanced and included in MQX — as well, IPC supports EDS Server, so that you can debug across a multi-processor MQX network.
- Multiprocessor events — an application can set events bits from another processor in a multi-processor MQX network.
- 32-bit queue IDs — an application can represent queue IDs as 32-bit quantities in addition to 16-bit quantities. As a result, applications can now use queue numbers and processor numbers higher than 255. You enable the option when you compile the PSP.
- Faster and more compact MQX — an application can use additional compile-time configuration options to build a smaller MQX and use new types of components (lightweight components) to address memory applications and applications that need high speed. Lightweight components typically use memory-mapped data structures (without multi-processor capability). They are faster than their regular counterparts; however, they have fewer features and protection mechanisms. Lightweight components include:
  - Lightweight events (new) — use a memory-mapped data structure to define an event group.
  - Lightweight logs (new) — consist of fixed-sized entries. Kernel log is now a lightweight log.
  - Lightweight memory component (new) — uses less overhead to maintain heaps of variable-sized memory blocks. MQX can be configured to use the lightweight memory component as the default memory component.
  - lightweight semaphores — use a memory-mapped data structure to define a semaphore.
  - lightweight timers (new) — use memory-mapped data structures to provide repetitive time-driven services.

1.4 Conventions

1.4.1 Tips

Tips point out useful information.

TIP	The most efficient way to allocate a message from an ISR is to use **_msg_alloc()**.

1.4.2 Notes

Notes point out important information.

NOTE	Non-strict semaphores do not have priority inheritance.

1.4.3 Cautions

Cautions tell you about commands or procedures that could have unexpected or undesirable side effects or could be dangerous to your files or your hardware.

CAUTION	If you modify MQX data types, some MQX™ Host Tools from MQX Embedded might not operate properly.

Chapter 2 MQX at a Glance

2.1 Organization of MQX

MQX consists of core (non-optional) components and optional components. In the case of core components, only those functions that MQX or the application calls are included in the image. To match its requirements, an application extends and configures core components by adding optional components.

The following diagram shows core components in the center with optional components around the outside.

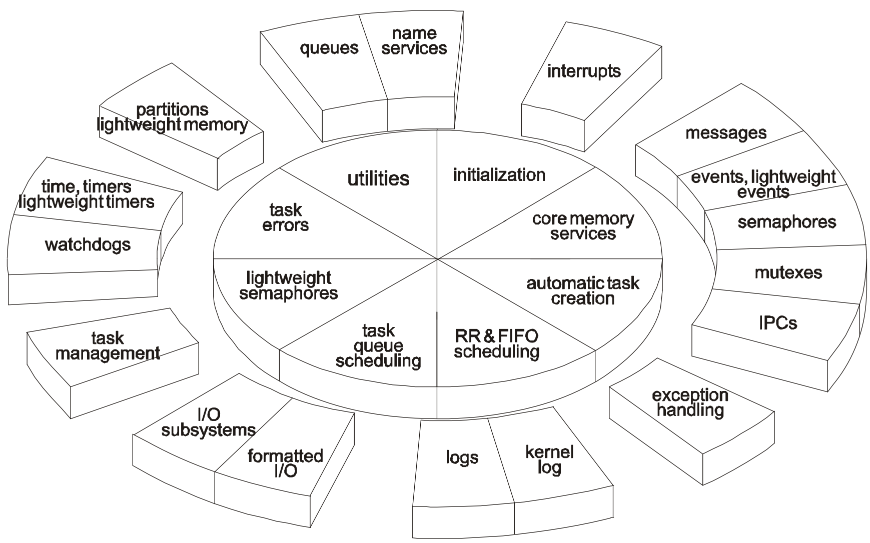


Figure 2-1.

The following table summarizes core and optional components, each of which is briefly described in subsequent sections of the chapter.

Table 2-1. Core and Optional Components

Component	Includes	Type
Initialization	Initialization and automatic task creation	Core
Task management	Dynamic task management	Core
Scheduling	Round robin and FIFO	Core
	Explicit using task queues	Optional
Task synchronization and communication	Lightweight semaphores	Core
	Semaphores	Optional
	Lightweight events	Optional

Table 2-1. Core and Optional Components (continued)

	Events	Optional
	Mutexes	Optional
	Messages	Optional
	Task queues	Optional
Interprocessor communication		Optional
Timing	Time component	Optional (BSP)
	Lightweight timers	Optional
	Timers	Optional
	Watchdogs	Optional
Memory management	Memory with variable-size blocks	Core
	Memory with fixed-size blocks (partitions)	Optional
	MMU, cache, and virtual memory	Optional
	Lightweight memory	Optional
Interrupt handling		Optional (BSP)
I/O drivers	I/O subsystem	Optional (BSP)
	Formatted I/O	Optional (BSP)
Instrumentation	Stack usage	Core
	Kernel log	Optional
	Logs	Optional
	Lightweight logs	Optional
Error handling	Task error codes, exception handling, runtime testing	Core
Queue manipulation		Core
Name component		Optional
Embedded debugging	EDS Server	Optional

2.2 Initialization

Initialization is a core component. The application starts when **_mqx()** runs. The function initializes the hardware and starts MQX. When MQX starts, it creates tasks that the application defines as autostart tasks.

2.3 Task Management

Task management is a core component.

As well as it automatically creates tasks when MQX starts, an application can also create, manage, and terminate tasks as the application runs. It can create multiple instances of the same task, and there is no limit to the total number of tasks in an application. The application can dynamically change the attributes of any task. MQX frees task resources, when it terminates a task.

As well, for each task you can specify:

- An exit function, which MQX calls when it terminates the task.
- An exception handler, which MQX calls if an exception occurs while the task is active.

2.4 Scheduling

Scheduling complies with POSIX.4 (real-time extensions) and supports these policies:

- FIFO (also called priority-based preemptive) scheduling is a core component — the active task is the highest-priority task that has been ready the longest.
- Round robin (also called time slice) scheduling is a core component — the active task is the highest-priority task that has been ready the longest without consuming its time slice.
- Explicit scheduling (using task queues) is an optional component — you can use task queues to explicitly schedule tasks or to create more complex synchronization mechanisms. Because task queues provide minimal functionality, they are fast. An application can specify a FIFO or round robin scheduling policy when it creates the task queue.

2.5 Memory Management

2.5.1 Managing Memory with Variable-Size Blocks

To allocate and free variable-size pieces (called memory blocks) of memory, MQX provides core services that are similar to **malloc()** and **free()**, which most C run-time libraries provide. You can allocate memory blocks from memory pools that are inside and outside the default memory pool. You can allocate memory blocks to a task or to the system. Memory allocated to a task is a resource of the task, and MQX frees the memory if the allocating task terminates.

2.5.2 Managing Memory with Fixed-Size Blocks (Partitions)

Partitions are an optional component. You can allocate and manage fixed-size pieces (called partition blocks) of memory. The partition component supports fast, deterministic memory allocation, which reduces memory fragmentation and conserves memory resources. Partitions can be in the default memory pool (dynamic partitions) and outside it (static partitions). You can allocate partition blocks to a task or to the system. Partition blocks allocated to a task are a resource of the task, and MQX frees them if the allocating task terminates.

2.5.3 Controlling Caches

MQX functions let you control the instruction cache and data cache that some CPUs have.

2.5.4 Controlling an MMU

For some CPUs, you must initialize the memory management unit (MMU) before you enable caches. MQX functions let you initialize, enable, and disable an MMU, and add a memory region to it. You can control an MMU by using MMU page tables.

2.5.5 Lightweight Memory Management

If an application is constrained by data- and code-size requirements, lightweight memory can be used. It has fewer interface functions and smaller code and data sizes. As a result, some areas have less robustness (removal of header checksums) and are slower (task-destruction times).

If you change a compile-time configuration option, MQX uses the lightweight-memory component when it allocates memory. For more information, see Section 3.14, "Configuring MQX at Compile Time."

2.6 Task Synchronization

2.6.1 Lightweight Events

Lightweight events (LWEvents) are an optional component. They are a low-overhead way for tasks to synchronize using bit state changes. Lightweight events require a minimal amount of memory and run quickly.

2.6.2 Events

Events are an optional component. They support the dynamic management of objects that are formatted as bit fields. Tasks and interrupt service routines can use events to synchronize and convey simple information in the form of bit-state changes. There are named and fast-event groups. Event groups can have autoclearing event bits, whereby MQX clears the bits immediately after they are set. An application can set event bits in an event group that is on a remote processor.

2.6.3 Lightweight Semaphores

Lightweight semaphores (LWSems) are a core component. They are a low-overhead way for tasks to synchronize their access to shared resources. LWSems require a minimal amount of memory and run quickly. LWSems are counting FIFO semaphores without priority inheritance.

2.6.4 Semaphores

Semaphores are an optional component. They are counting semaphores. You can use semaphores to synchronize tasks. You can use a semaphore to guard access to a shared resource, or to implement a producer/consumer-signalling mechanism. Semaphores provide FIFO queuing, priority queuing, and priority inheritance. Semaphores can be strict or non-strict. There are named and fast semaphores.

2.6.5 Mutexes

Mutexes are an optional component. They comply with POSIX.4a (threads extensions). A mutex provides mutual exclusion among tasks, when they access a shared resource. Mutexes provide polling, FIFO queuing, priority queuing, spin-only and limited-spin queuing, priority inheritance, and priority protection. Mutexes are strict; that is, a task cannot unlock a mutex, unless it had first locked the mutex.

2.6.6 Messages

Messages are an optional component. Tasks can communicate with each other by sending messages to message queues that are opened by other tasks. Each task opens its own input-message queues. A message queue is uniquely identified by its queue ID, which MQX assigns when the queue is created. Only the task that opens a message queue can receive messages from the queue. Any task can send to any previously opened message queue, if it knows the queue ID of the opened queue.

Tasks allocate messages from message pools. There are system-message pools and private-message pools. Any task can allocate a message (system message) from system-message pools. Any task with the pool ID can allocate a message (private message) from a private-message pool.

2.6.7 Task Queues

In addition to providing a scheduling mechanism, task queues provide a simple and efficient way to synchronize tasks. You can suspend tasks in the task queue and remove them from the task queue.

2.7 Inter-Processor Communication

Inter-processor communication (IPC) is an optional component.

An application can run concurrently on multiple processors with one executable image of MQX on each processor. The images communicate and cooperate using messages that are transferred by memory or over communication links using inter-processor communication. The application tasks in each image need not be the same and, indeed, are usually different.

2.8 Timing

2.8.1 Time Component

Time is an optional component that you can enable and disable at the BSP level. There is elapsed time and absolute time. You can change absolute time. The time resolution depends on the application-defined resolution that is set for the target hardware when MQX starts.

2.8.2 Lightweight Timers

Lightweight timers are an optional component and provide a low-overhead mechanism for calling application functions at periodic intervals. Lightweight timers are installed by creating a periodic queue, then adding a timer to expire at some offset from the start of the period.

When you add a lightweight timer to the queue, you specify a notification function that will be called by the MQX tick ISR when the timer expires. Since the timer runs from an ISR, not all MQX functions can be called from the timer.

2.8.3 Timers

Timers are an optional component. They provide periodic execution of an application function. MQX supports one-shot timers (they expire once) and periodic timers (they expire repeatedly at a given interval). You can set timers to start at a specified time or after a specified duration.

When you set a timer, you specify the notification function that timer task calls when the timer expires. The notification function can be used to synchronize tasks by sending messages, setting events, or using one of the other MQX synchronization mechanisms.

2.8.4 Watchdogs

Watchdogs are option components that let the user detect task starvation and deadlock conditions at the task level.

2.9 Interrupt and Exception Handling

Interrupt and exception handling is optional at the PSP level. MQX services all hardware interrupts within a range that the BSP defines, and saves a minimum context for the active task. MQX supports fully nested interrupts, if the CPU supports nested interrupts. Once inside an interrupt service routine (ISR), an application can re-enable any interrupt level. To further reduce interrupt latencies, MQX defers task rescheduling until after all ISRs have run. In addition, MQX reschedules only if a new task has been made ready by an ISR. To reduce stack size, MQX supports a separate interrupt stack.

An ISR is not a task; it is a small, high-speed routine that reacts quickly to hardware interrupts. An ISR is usually written in C language. Its duties include resetting the device, getting its data, and signaling the appropriate task. An ISR can be used to signal a task with any of the non-blocking MQX functions.

2.10 I/O Drivers

I/O drivers are an optional component at the BSP level. They consist of formatted I/O and the I/O subsystem. I/O drivers are not described in this book.

2.10.1 Formatted I/O

MQX provides a library of formatted I/O functions that is the API to the I/O subsystem.

2.10.2 I/O Subsystem

You can dynamically install I/O device drivers, after which any task can open them.

2.11 Instrumentation

2.11.1 Logs

Logs are an optional component that lets you store and retrieve application-specific information. Each log entry has a timestamp and sequence number. You can use the information to test, debug, verify, and analyze performance.

2.11.2 Lightweight Logs

Lightweight logs are similar to logs, but use only fixed-sized entries. They are faster than the conventional application logs and are used by kernel log.

2.11.3 Kernel Log

Kernel log is an optional component that lets you record MQX activity. You can create kernel log at a specific location or let MQX choose the location. You can configure kernel log to record all MQX function calls, context switches, and interrupt servicing. Performance tool uses kernel log.

2.11.4 Stack Usage

MQX has core functions that let you dynamically examine the interrupt stack and the stack usage by all tasks, so that you can determine whether you have allocated enough stack space.

2.12 Error Handling

2.12.1 Task Error Codes

Each task has a task error code, which is associated with the task's context. Specific MQX functions read and update the task error code.

2.12.2 Exception Handling

You can specify a default ISR that runs for all unhandled interrupts, and an ISR-specific exception handler that runs if the ISR generates an exception.

2.12.3 Run-Time Testing

MQX provides core run-time test functions that an application can call during its normal operation. There are test functions for the following components:

- events and lightweight events
- kernel log and lightweight logs
- memory with fixed-size blocks (partitions)
- memory with variable-size memory blocks and lightweight memory
- message pools and message queues
- mutexes
- name component
- queues (application-defined)
- semaphores and lightweight semaphores
- task queues
- timers and lightweight timers
- watchdogs

2.13 Queue Manipulation

There is a core component that implements a double-linked list of queue elements. You can initialize a queue, add elements, remove elements, and peek at elements.

2.14 Name Component

The name component is optional. It provides a names database that maps a string to a dynamically defined scalar, such as a queue ID.

2.15 Embedded Debugging

EDS Server is optional. It communicates with a host that is running EDS Client, reading and writing MQX messages, and getting various configuration information from the host.

Chapter 3 Using MQX

3.1 Before You Begin

This chapter describes how to use MQX. It includes examples that you can compile and run.

For this information	See
Prototype for each function that is mentioned in this chapter.	MQX Reference
Data types that are mentioned in this chapter.	MQX Reference

3.2 Initializing and Starting MQX

MQX is started with **_mqx**(), which takes the MQX initialization structure as its argument. Based on the values in the structure, MQX does the following:

- It sets up and initializes the data that MQX uses internally, including the default memory pool, ready queues, the interrupt stack, and task stacks.
- It initializes the hardware (for example, chip selects).
- It enables timers.
- It sets the default time slice value.
- It creates the Idle task, which will be active if no other task is ready.
- It creates tasks that the task template list defines as autostart tasks.
- It starts scheduling the tasks.

3.2.1 MQX Initialization Structure

The MQX initialization structure defines parameters of the application and target hardware.

```
typedef struct mqx_initialization_struct
{
  _mqx_uint                  PROCESSOR_NUMBER;
  pointer                    START_OF_KERNEL_MEMORY;
  pointer                    END_OF_KERNEL_MEMORY;
  _mqx_uint                  INTERRUPT_STACK_SIZE;
  TASK_TEMPLATE_STRUCT_PTR   TASK_TEMPLATE_LIST;
  _mqx_uint                  MQX_HARDWARE_INTERRUPT_LEVEL_MAX;
  _mqx_uint                  MAX_MSGPOOLS;
  _mqx_uint                  MAX_MSGQS;
  char   _PTR_               IO_CHANNEL;
  char   _PTR_               IO_OPEN_MODE;
  _mqx_uint                  RESERVED[2];
} MQX_INITIALIZATION_STRUCT, _PTR_ MQX_INITIALIZATION_STRUCT_PTR;
```

For a description of each field, see MQX Reference.

3.2.1.1 Default MQX Initialization Structure

You can either define your own initialization values of the MQX initialization structure or use the default initialization that is provided with each BSP. The default initialization variable is called **MQX_init_struct** and is in *mqx_init.c* in the appropriate BSP directory. The function has been compiled and linked with MQX.

CAUTION	For task-aware debugging host tools to work, the MQX initialization structure variable must be called **MQX_init_struct**.

The examples in this chapter use the following **MQX_init_struct**.

```
MQX_INITIALIZATION_STRUCT  MQX_init_struct =
{
/* PROCESSOR_NUMBER         */ BSP_DEFAULT_PROCESSOR_NUMBER,
/* START_OF_KERNEL_MEMORY   */ BSP_DEFAULT_START_OF_KERNEL_MEMORY,
/* END_OF_KERNEL_MEMORY     */ BSP_DEFAULT_END_OF_KERNEL_MEMORY,
/* INTERRUPT_STACK_SIZE     */ BSP_DEFAULT_INTERRUPT_STACK_SIZE,
/* TASK_TEMPLATE_LIST       */ (pointer)MQX_template_list,
/* MQX_HARDWARE_INTERRUPT_LEVEL_MAX*/
                     BSP_DEFAULT_MQX_HARDWARE_INTERRUPT_LEVEL_MAX,
/* MAX_MSGPOOLS             */ BSP_DEFAULT_MAX_MSGPOOLS,
/* MAX_MSGQS                */ BSP_DEFAULT_MAX_MSGQS,
/* IO_CHANNEL               */ BSP_DEFAULT_IO_CHANNEL,
/* IO_OPEN_MODE             */ BSP_DEFAULT_IO_OPEN_MODE
};
```

NOTE	Initialize both elements of the **RESERVED** field to zero.

3.2.2 Task Template List

The task template list, which is a list of task templates (**TASK_TEMPLATE_STRUCT**), defines an initial set of templates, from which tasks can be created on the processor.

At initialization, MQX creates one instance of each task, whose template defines it as an autostart task. In addition, while an application is running, it can create other tasks using a task template that either the task template list defines or the application defines dynamically. The end of the task template list is a zero-filled task template.

```
typedef struct task_template_struct
{
  _mqx_uint         TASK_TEMPLATE_INDEX;
  void  _CODE_PTR_  TASK_ADDRESS)(uint_32);
  _mem_size         TASK_STACKSIZE;
  _mqx_uint         TASK_PRIORITY;
  char _PTR_        TASK_NAME;
  _mqx_uint         TASK_ATTRIBUTES;
  uint_32           CREATION_PARAMETER;
  _mqx_uint         DEFAULT_TIME_SLICE;
} TASK_TEMPLATE_STRUCT,  _PTR_  TASK_TEMPLATE_STRUCT_PTR;
```

For a description of each field, see *MQX Reference*.

3.2.2.1 Assigning Task Priorities

CAUTION	If you assign priority zero to a task, the task runs with interrupts disabled. On some target processor platforms (e.g. ColdFire), certain task priority levels are reserved and are mapped to processor interrupt priority levels. Tasks running at such a special priority may prevent lower priority interrupts to be serviced. See more details about interrupt handling in section 3.10, “Handling Interrupts and Exceptions”.

When you assign task priorities in the task template list, note that:

- MQX creates one ready queue for each priority up to the lowest priority (highest number).
- While an application is running, it cannot create a task that has a lower priority (a higher number) than the lowest-priority task in the task template list.

3.2.2.2 Assigning Task Attributes

You can assign any combination of the following attributes to a task:

- Autostart — when MQX starts, it creates one instance of the task.
- DSP — MQX saves the DSP co-processor registers as part of the task’s context.
- Floating point — MQX saves floating-point registers as part of the task’s context.
- Time slice — MQX uses round robin scheduling for the task (the default is FIFO scheduling).

3.2.2.3 Default Task Template List

You can initialize your own task template list or use the default, which is called **MQX_template_list**.

3.2.2.4 Example: A Task Template List

```
TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
 { MAIN_TASK, world_task, 0x2000, 5, "world_task",
      MQX_AUTO_START_TASK,                       0L, 0},

 { HELLO,    hello_task, 0x2000, 5, "hello_task",
      MQX_TIME_SLICE_TASK,                       0L, 100},

 { FLOAT,    float_task, 0x2000, 5, "Float_task",
      MQX_AUTO_START_TASK | MQX_FLOATING_POINT_TASK, 0L, 0},

 { 0, 0, 0, 0, 0, 0, 0L, 0 }
};
```

world_task

The world_task is an autostart task. So, at initialization, MQX creates one instance of the task with a creation parameter of zero. The application defines the task template index (MAIN_TASK). The task is of priority five. The function **world_task()** is the code-entry point for the task. The stack size is 0x2000 single-addressable units.

hello_task

The hello_task task is a time-slice task with a time slice of 100, in milliseconds, if the default compile-time configuration options are used. For information about these options, see page 132.

Float_task

The Float_task task is both a floating-point task and an autostart task.

3.2.2.5 Example: Creating an Autostart Task

A single task prints Hello World and terminates.

```
/* hello.c */

#include <mqx.h>
#include <fio.h>

/* Task IDs */
#define HELLO_TASK     5

extern void hello_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { HELLO_TASK, hello_task, 500, 5, "hello",
        MQX_AUTO_START_TASK, 0L, 0},
   { 0,          0,          0,   0, 0,
        0,                   0L, 0}
};

void hello_task(uint_32 initial_data)
{
   printf("\n Hello World \n");
   _mqx_exit(0);
}
```

3.2.2.5.1 Compiling the Application and Linking it with MQX

1. Go to this directory:
   `mqx\examples\hello`
2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

The following appears on the output device:

```
Hello World
```

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. See the next section for steps needed to run the "Hello" application.

3.3 Using Freescale CodeWarrior Development Studio

This section describes the steps to use the CodeWarrior Development Studio to build, run, or debug your MQX application. The “Hello” demo application for the ColdFire M52259EVB board is used for the purpose of this demonstration.

See also the section Section 4.5, “Rebuilding Freescale MQX RTOS” for more information about using CodeWarrior to rebuild the MQX operating system and other core components.

1. Use the Windows Start menu to run the CodeWarrior Development Studio.
2. Using the File/Open... menu in CodeWarrior IDE, open the “Hello” application project created for M52259EVB board. By default, you should find the project file as:

```
C:\Program Files\Freescale\Freescale MQX\
mqx\examples\hello\codewarrior\hello_m52259evb.mcp
```

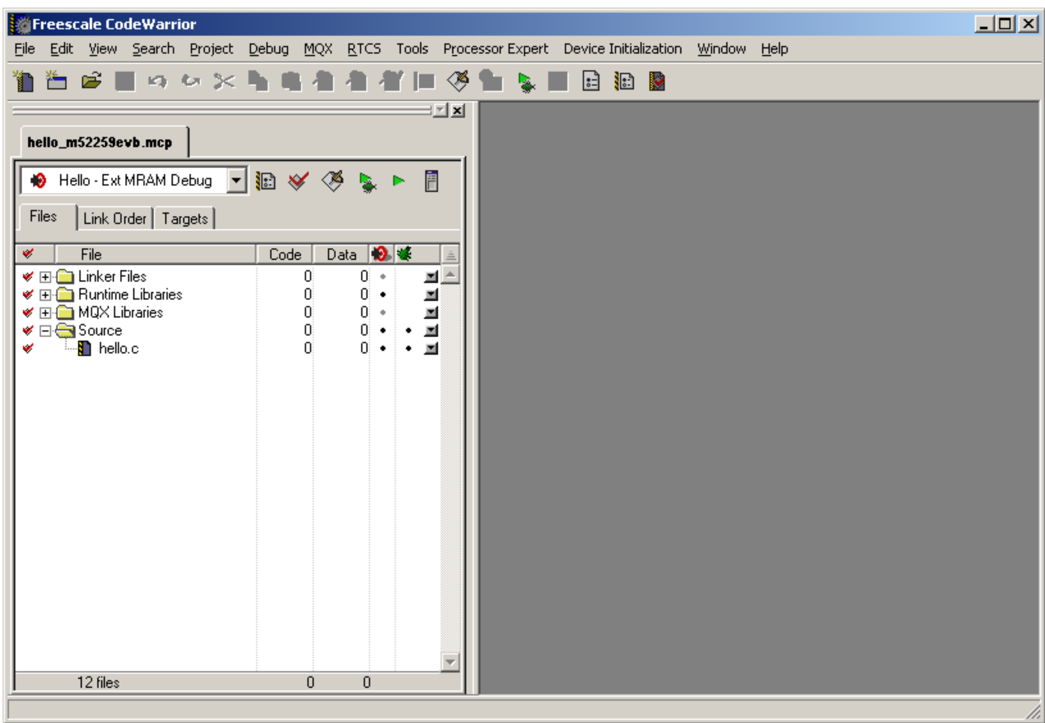
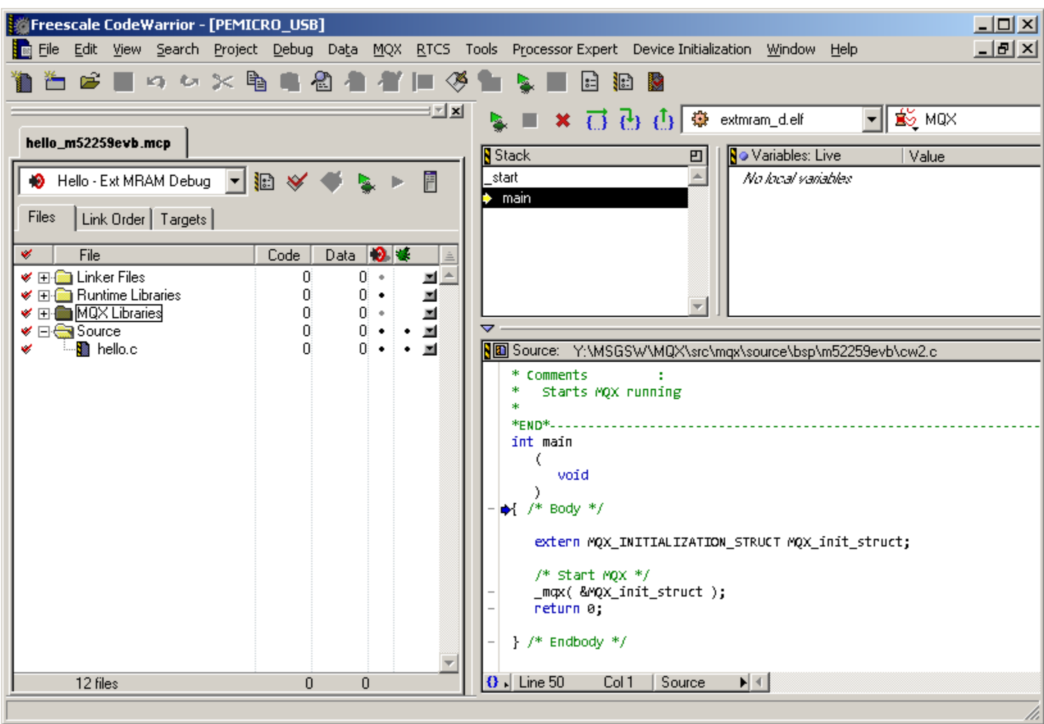


Figure 3-1. Locating Project File

3. Select the build target that best suits your needs. For example: with the M52259EVB board, you can use the Ext MRAM Debug target to simplify the code-download process. In this target, the external MRAM memory is used by the executable code (instead of internal flash), while the on-chip SRAM is used for data.
4. Press the **F7** key (menu **Project/Make**) to make the project.

NOTE	This procedure requires that you already have the MQX PSP and BSP libraries compiled on your host computer in the *lib* directory. The Freescale MQX comes with pre-compiled default libraries in the installation, so this condition should be satisfied. See the *lib/m52259evb.cw* directory in the Freescale MQX installation folder, and check if there are the libraries in the *mqx* subdirectory. If not, please recompile the MQX system as described in section Section 4.5, “Rebuilding Freescale MQX RTOS.”

5. When the build process completes, open the HyperTerminal or other serial terminal on your host PC.
6. In the terminal, open the serial line with the following configuration: 115200 bps, eight data bits, one stop bit, no parity.
7. In the CodeWarrior, press the F5 key (menu Project/Debug) to invoke the CodeWarrior debugger, and to download the executable application into the MRAM memory. The execution should stop at the default breakpoint in the **main()** function.



8. Press F5 to continue executing the application.
9. The Hello World appears on the terminal window.

See more details about the Freescale MQX projects created for CodeWarrior Development Studio in the later sections, in the Release Notes document, and in Lab step-by-step guider available for your Freescale evaluation board.

3.4 Managing Tasks

Multiple tasks, created from the same task template can coexist, and each task is a unique instance. MQX maintains each instance by saving its context; that is, its program counter, registers, and stack. Each task has an application-unique 32-bit task ID, which MQX and other tasks use to identify the task.

The section on initialization (page 23) shows how a task can be started automatically when MQX initializes. You can also create, manage, and terminate tasks, while the application runs.

_task_abort	Terminates the task after running its task exit handler and releasing its resources.
_task_check_stack	Determines whether the task's stack is out of bounds.
_task_create	Allocates and starts (makes ready) a new task.
_task_create_blocked	Allocates a new task in the blocked state.
_task_destroy	Terminates the task after freeing its resources.
_task_disable_fp	Disable floating-point context switching for the task, if the task is a floating-point task.
_task_enable_fp	Enables floating-point context switching for the task.
_task_errno	Gets the task error code for the active task.
_task_get_creator	Gets the task ID of the task that created the task.
_task_get_environment	Gets a pointer to the environment data for a task.
_task_get_error	Gets the task error code.
_task_get_error_ptr	Gets a pointer to the task error code.
_task_get_exit_handler	Gets a task's task exit handler.
_task_get_id	Gets the task ID.
_task_get_id_from_name	Gets the task ID of the first task with this name in the task template.
_task_get_index_from_id	Gets the task template index for the task ID.
_task_get_parameter	Gets the task-creation parameter.
_task_get_parameter_for	Gets the task-creation parameter for a task.
_task_get_processor	Gets the processor number on which a task resides.
_task_get_td	Converts a task ID to a pointer to a task descriptor.
_task_get_template_index	Gets the task template index of a task name.
_task_get_template_ptr	Gets a pointer to the task template for the task ID.
_task_restart	Restarts a task at the beginning of the task's function; keeps the same task descriptor, task ID, and task stack.
_task_set_environment	Sets a pointer to the environment data for a task.
_task_set_error	Sets the task error code.
_task_set_exit_handler	Sets the task's exit handler.

_task_set_parameter	Sets the task creation parameter.
_task_set_parameter_for	Sets the task creation parameter for a task.

3.4.1 Creating Tasks

Any task (creator) can create another task (child) by calling **_task_create()** or **_task_create_blocked()**, and passing the processor number, a task template index, and a task-creation parameter. The application defines one creation parameter, which is normally used to provide initialization information to the child. A task can also create a task that is not defined in the task template list, by specifying a template index of zero. In this case, MQX interprets the task-creation parameter as a pointer to a task template.

The functions initialize the child's stack. The function **_task_create()** puts the child in the ready queue for the task's priority. If the child is of higher priority than the creator, the child becomes the active task, because it is the highest-priority ready task. If the creator is of higher or equal priority, it remains the active task.

The function **_task_create_blocked()** creates a task that is blocked. The task is not ready to run, until another task calls **_task_ready**().

3.4.2 Getting Task IDs

A task can directly get its task ID with **_task_get_id()**. If a function takes a task ID as a parameter, you can specify **MQX_NULL_TASK_ID** to refer to the task ID of the active task.

A task can directly get the task ID of its creator with **_task_get_creator**(). The function **_task_create**() returns the child's task ID to the creator.

A task ID can also be determined from the task name in the task template, from which the task was created. This is done with **_task_get_id_from_name**(), which returns the task ID of the first task that matches the name in the task template list.

3.4.3 Setting a Task Environment

A task can save an application-specific environment pointer with **_task_set_environment**(). Other tasks can access the environment pointer with **_task_get_environment**().

3.4.4 Managing Task Errors

Each task has an error code (the task error code) associated with the task's context. Some MQX functions update the task error code when they detect an error.

If an MQX function detects an error and the application ignores the error, additional errors might still occur. Usually the first error best indicates the problem; subsequent errors might be misleading. To provide a reliable opportunity to diagnose problems after MQX sets the task error code to a value other than **MQX_OK**, MQX does not further change the task error code until the task explicitly resets it to **MQX_OK**.

A task can get its task error code from:

- **_task_get_error()**
- **_task_errno**

A task resets its task error code by calling **_task_set_error()** with **MQX_OK**. The function returns the previous task error code and sets the task error code to **MQX_OK**.

Using **_task_set_error()**, a task can attempt to set its task error code to a value other than **MQX_OK**. However, only if the current task error code is **MQX_OK**, does MQX change the task error code to the new value.

3.4.5 Restarting Tasks

An application can restart a task by calling **_task_restart()**, which restarts the task at the beginning of its function with the same task descriptor, task ID, and task stack.

3.4.6 Terminating Tasks

A task can terminate itself or any other task, whose task ID it knows. When a task is terminated, its children are not terminated. When a task is terminated, MQX frees the task's MQX-managed resources. These resources include:

- dynamically allocated memory blocks and partition blocks
- message queues
- messages
- mutexes
- non-strict semaphores
- strict semaphores after posting them
- queued connections are dequeued
- task descriptor

An application can terminate a task immediately (after MQX frees the task's resources) with **_task_destroy()** or gracefully with **_task_abort()**.

When a task is terminated gracefully, MQX puts the task in the appropriate ready queue, if the task is blocked. When the to-be-terminated task becomes active, an application-defined task exit handler runs. The exit handler could clean up resources that MQX does not manage.

The task exit handler is set with **_task_set_exit_handler()**, and obtained with **_task_get_exit_handler()**.

MQX also calls the task exit handler if the task returns from its task body.

3.4.7 Example: Creating Tasks

This example adds a second task (world_task) to the example on page 27. We modify that example's task template list to include information about world_task, and to change hello_task, so that it is not an autostart task. The world_task task is an autostart task.

When MQX starts, it creates world_task. The world_task then creates hello_task by calling **_task_create()** with hello_task as a parameter. MQX uses the hello_task template to create an instance of hello_task.

If **_task_create()** is successful, it returns the task ID of the new child task; otherwise, it returns **MQX_NULL_TASK_ID**.

The new hello_task task is put in the ready queue for the task's priority. Since it has a higher priority than world_task, it becomes active. The active task prints Hello. The world_task task then becomes active and checks to see whether hello_task was created successfully. If it was, world_task prints World; otherwise, world_task prints an error message. Finally, MQX exits.

If you change the priority of world_task to be of the same priority as hello_task, the output is World only. The world_task runs before hello_task, because world_task has the same priority and does not relinquish control with a blocking function. Since world_task calls **_mqx_exit()** after printing World, nothing else can be printed, because hello_task does not have the opportunity to run again.

3.4.7.1 Code for the Example

```
/*  hello2.c */

#include <mqx.h>
#include <fio.h>

/* Task IDs */
#define HELLO_TASK     5
#define WORLD_TASK     6

extern void hello_task(uint_32);
extern void world_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {WORLD_TASK, world_task, 500, 5, "world",
      MQX_AUTO_START_TASK, 0L, 0},
   {HELLO_TASK, hello_task, 500, 4, "hello",
      0,                   0L, 0},
   {0,         0,           0,   0,  0,
      0,                   0L, 0}
};

/*TASK*-----------------------------------------------------
*
* Task Name    : world_task
* Comments     :
*    This task creates hello_task and then prints "World".
*
*END*-----------------------------------------------------*/

void world_task(uint_32 initial_data)
{
   _task_id        hello_task_id;

   hello_task_id = _task_create(0, HELLO_TASK, 0);
   if (hello_task_id == MQX_NULL_TASK_ID) {
      printf("\n Could not create hello_task\n");
```

```
   } else {
      printf(" World \n");
   }
   _mqx_exit(0);
}
/*TASK*-----------------------------------------------------------
*
* Task Name    : hello_task
* Comments     :
*    This task prints "Hello".
*
*END*------------------------------------------------------------*/

void hello_task(uint_32 initial_data)
{
   printf("  Hello \n");
   _task_block();
}
```

3.4.7.2 Compiling the Application and Linking it with MQX

1. Go to this directory:

   `mqx\examples\hello2`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

The following appears on the output device:

```
Hello
World
```

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see the Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.5 Scheduling Tasks

MQX provides these task-scheduling policies:

- FIFO
- Round robin
- Explicit, using task queues (described in a subsequent section on page 79).

You can set the scheduling policy to FIFO or round robin for the processor and separately for each task. As a result, an application might consist of tasks that use any combination of FIFO or round robin scheduling.

3.5.1 FIFO Scheduling

FIFO is the default scheduling policy. With FIFO scheduling, the task that runs (becomes active) next is the highest-priority task that has been waiting the longest time. The active task runs, until any of the following occurs:

- The active task voluntarily relinquishes the processor, because it calls a blocking MQX function.
- An interrupt occurs that has higher priority than the active task.
- A task that has priority higher than the active task, becomes ready.

You can change the priority of a task with **_task_set_priority()**.

3.5.2 Round Robin Scheduling

Round robin scheduling is similar to FIFO scheduling, but with the additional constraint that each round robin task has a maximum amount of time (the time slice), during which it can be active.

A task uses round robin scheduling only if the **MQX_TIME_SLICE_TASK** attribute is set in its task template. The task's time slice is determined by the value of the template's **DEFAULT_TIME_SLICE**. However, if the value is zero, the task's time slice is the default time slice for the processor. Initially, the default time slice for the processor is ten times the interval of the periodic timer interrupt. Since the interval on most BSPs is five milliseconds, the initial default time slice for the processor is usually 50 milliseconds. You can change the default time slice for the processor with **_sched_set_rr_interval()** or **_sched_set_rr_interval_ticks()**, passing the task ID parameter as **MQX_DEFAULT_TASK_ID**.

When the time slice expires for an active round robin task, MQX saves the task's context. MQX then performs a dispatch operation, in which it examines the ready queues to determine, which task should become active. MQX moves the expired task to the end of the task's ready queue, an action that causes control to pass to the next task in the ready queue. If there are no other tasks in the ready queue, the expired task continues to run.

With round robin scheduling, tasks of the same priority can share the processor in a time-equitable manner.

Table 3-1. Summary: Getting and Setting Scheduling Info

_sched_get_max_priority	Gets the highest priority allowed for any task; always returns zero.
_sched_get_min_priority	Gets the lowest priority for any task.
_sched_get_policy	Gets the scheduling policy.
_sched_get_rr_interval	Gets the time slice in milliseconds.
_sched_get_rr_interval_ticks	Gets the time slice in tick time.
_sched_set_policy	Sets the scheduling policy.
_sched_set_rr_interval	Sets the time slice in milliseconds.
_sched_set_rr_interval_ticks	Sets the time slice in tick time.

Table 3-2. Summary: Scheduling Tasks

_sched_yield	Moves the active task to the end of its ready queue, which yields the processor to the next ready task of equal priority.
_task_block	Blocks the task.
_task_get_priority	Gets a task's priority.
_task_ready	Makes a task ready.
_task_set_priority	Sets a task's priority.
_task_start_preemption	Re-enables preemption for the task.
_task_stop_preemption	Disables preemption for the task.

Each task is in one of the following logical states:

- Blocked — task is not ready to become active, because it is waiting for a condition to occur; when the condition occurs, the task becomes ready.
- Ready — task is ready to become active, but it is not active, because it is of the same priority as, or lower priority than the active task.
- Active — task is running.

If the active task becomes blocked or is preemptied, MQX performs a dispatch operation, in which it examines the ready queues to determine, which task should become active. MQX makes the highest-priority ready task the active task. If more than one task of the same priority is ready, the task at the start of that ready queue becomes the active task. That is, each ready queue is in FIFO order.

3.5.2.1 Preemption

The active task can be preemptied. Preemption occurs, when a higher-priority task becomes ready, and thus becomes the active task. The previously active task is still ready, but is no longer the active task. Preemption occurs, when an interrupt handler causes a higher-priority task to become ready, or the active task makes a higher-priority task ready.

3.6 Managing Memory

3.6.1 Managing Memory with Variable-Size Blocks

By default, MQX allocates memory blocks from its default memory pool. Tasks can also create memory pools outside the default memory pool, and allocate memory blocks from them.

Both allocation processes are similar to using **malloc()** and **free()**, which are in most C run-time libraries.

NOTE	You cannot use a memory block as a message. You must allocate messages from message pools (see page 72).

A memory block can be a private memory block (a resource owned by the task that allocates it) or a system memory block (not owned by any task). When a task is terminated, MQX returns the task's private memory blocks to memory.

When MQX allocates a memory block, it allocates a block of at least the requested size (the block might be larger).

A task can transfer ownership of a memory block to another task (**_mem_transfer()**).

Table 3-3. Summary: Managing Memory with Variable-Size Blocks

_mem_alloc	Allocates a private memory block from the default memory pool.
_mem_alloc_from	Allocates a private memory block from the specified memory pool.
_mem_alloc_zero	Allocates a zero-filled private memory block from the default memory pool.
_mem_alloc_zero_from	Allocates a zero-filled private memory block from the specified memory pool.
_mem_alloc_system	Allocates a system memory block from the default memory.
_mem_alloc_system_from	Allocates a system memory block from the specified memory pool.
_mem_alloc_system_zero	Allocates a zero-filled system memory block from the default memory pool.
_mem_alloc_system_zero_ from	Allocates a zero-filled system memory block from the specified memory pool.
_mem_copy	Copies data from one memory location to another.
_mem_create_pool	Creates a memory pool outside the default memory pool.
_mem_extend	Adds additional memory to the default memory pool; the additional memory must by outside the current default memory pool, but need not be contiguous with it.
_mem_extend_pool	Adds additional memory to a memory pool that is outside the default memory pool; the additional memory must be outside the memory pool, but it needs not to be contiguous with the pool.
_mem_free	Frees a memory block that is inside or outside the default memory pool.
_mem_free_part	Frees part of a memory block (used if the memory block is larger than requested, or if it is larger than needed).
_mem_get_error	Gets a pointer to the memory block that caused **_mem_test()** to indicate an error.
_mem_get_error_pool	Gets a pointer to the last memory block that caused **_mem_test_pool()** to indicate an error.
_mem_get_highwater	Gets the highest memory address that has been allocated in the default memory pool (it might have since been freed).
_mem_get_highwater_ pool	Gets the highest memory pool address that has been allocated (it might have since been freed)

Table 3-3. Summary: Managing Memory with Variable-Size Blocks (continued)

_mem_get_size	Gets the size of a memory block; the size might be larger than the requested size.
_mem_swap_endian	Converts to the other endian format.
_mem_test	Tests the default memory pool; this is, checking the internal checksums to determine, whether the integrity of the memory has been violated (usually the cause of failure is that an application writes past the end of a memory block).
_mem_test_and_set	Tests and sets a memory location.
_mem_test_pool	Tests the memory pool for errors, as described for **_mem_test()**.
_mem_transfer	Transfers ownership of a memory block to another task.
_mem_zero	Sets all or part of a memory block to zero.

3.6.2 Managing Lightweight Memory with Variable-Size Blocks

Lightweight memory functions are similar to the functions for regular memory that are described in Section 3.6.1, "Managing Memory with Variable-Size Blocks." However, they have less overhead in data and code.

If you change an MQX compile-time configuration option, MQX uses the lightweight memory component when it allocates memory. For more information, see page 132.

Table 3-4. Summary: Managing Lightweight Memory with Variable-Size Blocks

Lightweight memory uses certain structures and constants, which are defined in *lwmem.h*.	
_lwmem_alloc	Allocates a private lightweight-memory block from the default lightweight-memory pool.
_lwmem_alloc_from	Allocates a private lightweight-memory block from the specified lightweight-memory pool.
_lwmem_alloc_zero	Allocates a zero-filled private lightweight-memory block from the default lightweight-memory pool.
_lwmem_alloc_zero_from	Allocates a zero-filled private lightweight-memory block from the specified lightweight-memory pool.
_lwmem_alloc_system	Allocates a system lightweight-memory block from the default lightweight-memory pool.
_lwmem_alloc_system_from	Allocates a system lightweight-memory block from the specified lightweight-memory pool.
_lwmem_alloc_system_zero	Allocates a zero-filled system lightweight-memory block from the default lightweight-memory pool.
_lwmem_alloc_system_zero_from	Allocates a zero-filled system memory block from the specified lightweight-memory pool.
_lwmem_create_pool	Creates a lightweight-memory pool.

Table 3-4. Summary: Managing Lightweight Memory with Variable-Size Blocks

_lwmem_free	Frees a lightweight-memory block.
_lwmem_get_size	Gets the size of a lightweight-memory block; the size might be larger than the requested size.
_lwmem_set_default_pool	Sets the pool to be used for the default lightweight-memory pool.
_lwmem_test	Tests all lightweight memory pools.
_lwmem_transfer	Transfers ownership of a lightweight-memory block to another task.

3.6.3 Managing Memory with Fixed-Size Blocks (Partitions)

With the partition component, you can manage partitions of fixed-size memory blocks, whose size the task specifies when it creates the partition. There are dynamic partitions (in the default memory pool) that can grow, and static partitions (outside the default memory pool) that cannot grow.

3.6.3.1 Creating the Partition Component for Dynamic Partitions

You can explicitly create the partition component with **_partition_create_component**(). If you do not explicitly create it, MQX creates it the first time an application creates a partition. There are no parameters.

3.6.3.2 Creating Partitions

There are two types of partitions.

Type of partition:	Created from:	By calling:
Dynamic	Default-memory pool	**_partition_create()**
Static	Outside default-memory pool	**_partition_create_at()**

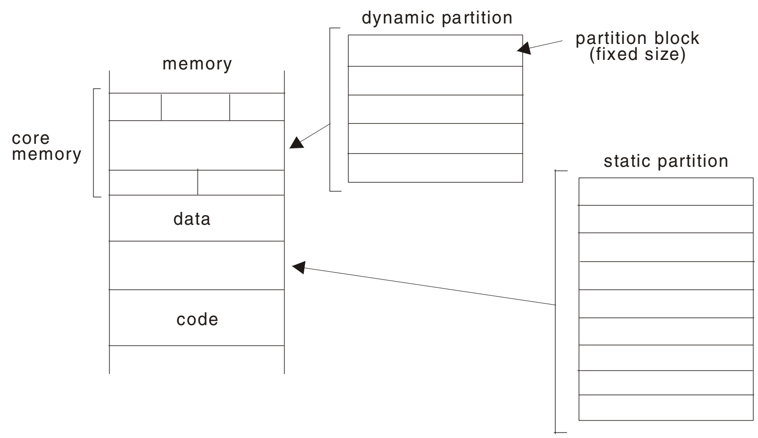
If you create a static partition, you must ensure that the memory does not overlap code or data space that your application uses.

3.6.3.3 Allocating and Freeing Partition Blocks

An application can allocate two types of partition blocks from either a dynamic or static partition.

Type of partition block:	Allocated by calling:	Is a resource of:	Can be freed by:
Private	**_partition_alloc()**	Task that allocated it	Owner only
System	**_partition_alloc_system()**	No one task	Any task

If the task is terminated, its private partition blocks are freed.



3.6.3.4 Destroying a Dynamic Partition

If all the partition blocks in a dynamic partition are freed, any task can destroy the partition by calling **_partition_destroy**(). You cannot destroy a static partition.

3.6.3.5 Example: Two Partitions

The following diagram shows one static partition and one dynamic partition.

Figure 3-2. Example: Two Partion

Table 3-5. Summary: Managing Memory with Fixed-Sixe Blocks (Partitions)

_partition_alloc	Allocates a private partition block from a partition.
_partition_alloc_system	Allocates a system partition block from a partition.
_partition_alloc_system_zero	Allocates a zero-filled system partition block from a partition.
_partition_alloc_zero	Allocates a zero-filled private partition block from a partition.
_partition_calculate_blocks	Calculates the number of partition blocks from the partition block size and the partition size (for static partitions).
_partition_calculate_size	Calculates the size of a partition from the partition block size and the number of blocks.
_partition_create	Creates a partition from the default memory pool (dynamic partition).
_partition_create_at	Creates a partition at a specific location outside the default memory pool (static partition).
_partition_create_component	Creates the partition component.
_partition_destroy	Destroys a dynamic partition that has no allocated partition blocks.

Table 3-5. Summary: Managing Memory with Fixed-Sixe Blocks (Partitions) (continued)

_partition_extend	Adds memory to a static partition; the added memory is divided into partition blocks that are the same size as other blocks in the partition.
_partition_free	Returns a partition block to a partition.
_partition_get_block_size	Gets the size of partition blocks in a partition.
_partition_get_free_blocks	Gets the number of free partition blocks in a partition.
_partition_get_max_used_ blocks	Gets the number of allocated partition blocks in a partition; this is, a highwater mark that indicates the maximum number that have been allocated simultaneously, not necessarily the number that are currently allocated.
_partition_get_total_blocks	Gets the number of partition blocks in a partition.
_partition_get_total_size	Gets the size of a partition, including extensions.
_partition_test	Tests the partition component.
_partition_transfer	Transfers ownership of a partition block to another task (including the system); only the new owner can free the partition block.

3.6.4 Controlling Caches

MQX functions let you control the instruction cache and data cache that some CPUs have.

So that you can write an application that applies to both cached and non-cached systems, MQX wraps the functions in macros. For CPUs that do not have the cache, the macros do not map to a function.
Some CPUs implement a unified cache (one cache is used for both data and code), in which case, the **_DCACHE_** and **_ICACHE_** macros map to the same function.

3.6.4.1 Flushing Data Cache

MQX uses the term *flush* to mean flushing the entire data cache. Unwritten data that is in the cache is written to physical memory.

3.6.4.2 Invalidating Data or Instruction Cache

MQX uses the term *invalidate* to mean invalidating all the cache entries. Data or instructions that are left in the cache, and have not been written to memory, are lost. A subsequent access reloads the cache with data or instructions from physical memory.

Table 3-6. Summary: Controlling Data Caches

_DCACHE_DISABLE	Disables the data cache.
_DCACHE_ENABLE	Enables the data cache.
_DCACHE_FLUSH	Flushes the entire data cache.
_DCACHE_FLUSH_LINE	Flushes the data-cache line containing the specified address.
_DCACHE_FLUSH_ MLINES	Flushes the data-cache lines containing the specified memory region.
_DCACHE_INVALIDATE	Invalidates the data cache.
_DCACHE_INVALIDATE_ LINE	Invalidates the data-cache line containing the specified address.
_DCACHE_INVALIDATE_ MLINES	Invalidates the data-cache lines containing the specified memory region.

Table 3-7. Summary: Controlling Instruction Caches

_ICACHE_DISABLE	Disables the instruction cache.
_ICACHE_ENABLE	Enables the instruction cache.
_ICACHE_INVALIDATE	Invalidates the instruction cache.
_ICACHE_INVALIDATE_ LINE	Invalidates the instruction cache line containing the specified address.
_ICACHE_INVALIDATE_ MLINES	Invalidates the instruction cache lines containing the specified memory region.

3.6.5 Controlling the MMU (Virtual Memory)

For some CPUs, you must initialize the memory management unit (MMU) before you enable caches. MQX functions let you initialize, enable, and disable an MMU, and add a memory region to it. MMU functions are not supported on all architectures.

You can control an MMU by using MMU page tables.

The virtual memory component lets an application control the MMU page tables.

The following diagram shows the relationship between virtual address, MMU page tables, MMU pages, physical page, and physical address.

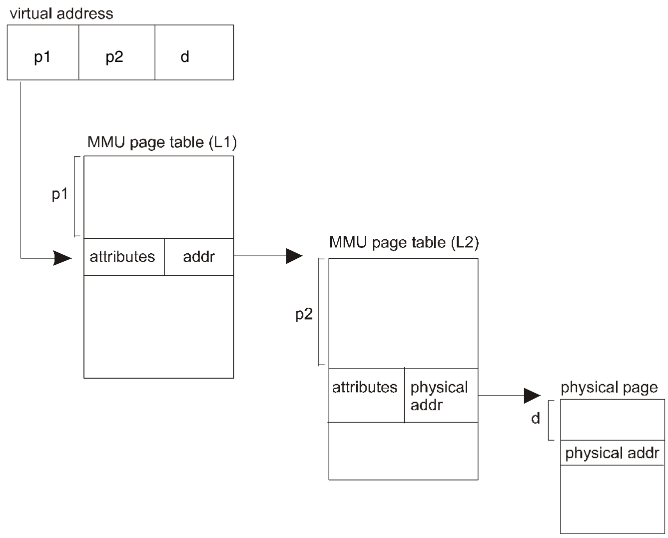


Figure 3-3.

With the virtual memory component, an application can manage virtual memory, which maps to physical addresses.

An application can use the virtual memory component to create a virtual context for a task. Virtual context provides memory that is private to a task, and is visible only while the task is the active task.

The functions are called when the BSP is initialized.

Table 3-8. Summary: Managing Virtual Memory

_mmu_add_vcontext	Adds a memory region to a virtual context.
_mmu_add_vregion	Adds a memory region to the MMU page tables that all tasks and MQX can use.
_mmu_create_vcontext	Creates a virtual context for a task.
_mmu_create_vtask	Creates a task with an initialized virtual context.
_mmu_destroy_vcontext	Destroys a virtual context for a task.
_mmu_get_vmem_attributes	Gets the virtual memory attributes of an MMU page.
_mmu_get_vpage_size	Gets the size of an MMU page.
_mmu_set_vmem_attributes	Modifies the virtual memory attributes of an MMU page.
_mmu_vdisable	Disables virtual memory.
_mmu_venable	Enables virtual memory.
_mmu_vinit	Initializes the MMU to use MMU page tables.
_mmu_vtop	Gets the physical address that corresponds to a virtual address.

3.6.5.1 Example: Initializing the MMU with Virtual Memory

Add a number of memory regions to support both instruction caching and data caching. All tasks can access the regions.

```
_mqx_uint _bsp_enable_operation(void)
{
   ...
   _mmu_vinit(MPC860_MMU_PAGE_SIZE_4K, NULL);

   /* Set up and initialize the instruction cache: */
   _mmu_add_vregion(BSP_FLASH_BASE, BSP_FLASH_BASE,
      BSP_FLASH_SIZE, PSP_MMU_CODE_CACHE | PSP_MMU_CACHED);
   _mmu_add_vregion(BSP_DIMM_BASE, BSP_DIMM_BASE, BSP_DIMM_SIZE,
      PSP_MMU_CODE_CACHE | PSP_MMU_CACHED);
   _mmu_add_vregion(BSP_RAM_BASE, BSP_RAM_BASE, BSP_RAM_SIZE,
      PSP_MMU_CODE_CACHE | PSP_MMU_CACHED);

   /* Set up and initialize the data cache: */
   _mmu_add_vregion(BSP_FLASH_BASE, BSP_FLASH_BASE,
      BSP_FLASH_SIZE, PSP_MMU_DATA_CACHE |
      PSP_MMU_CACHE_INHIBITED);
   _mmu_add_vregion(BSP_PCI_MEMORY_BASE, BSP_PCI_MEMORY_BASE,
      BSP_PCI_MEMORY_SIZE, PSP_MMU_DATA_CACHE |
      PSP_MMU_CACHE_INHIBITED);
   _mmu_add_vregion(BSP_PCI_IO_BASE, BSP_PCI_IO_BASE,
      BSP_PCI_IO_SIZE, PSP_MMU_DATA_CACHE |
      PSP_MMU_CACHE_INHIBITED);
   _mmu_add_vregion(BSP_DIMM_BASE, BSP_DIMM_BASE, BSP_DIMM_SIZE,
      PSP_MMU_DATA_CACHE | PSP_MMU_CACHE_INHIBITED);
   _mmu_add_vregion(BSP_RAM_BASE, BSP_RAM_BASE,
      BSP_COMMON_RAM_SIZE, PSP_MMU_DATA_CACHE |
      PSP_MMU_CACHE_INHIBITED);

   _mmu_venable();

   _ICACHE_ENABLE(0);
   _DCACHE_ENABLE(0);
   ...
}
```

3.6.5.2 Example: Setting Up a Virtual Context

Set the active task to access 64 KB of private memory at 0xA0000000.

```
...
{
pointer   virtual_mem_ptr;
uint_32   size;

virtual_mem_ptr = (pointer)0xA0000000;
size = 0x10000L;
...
result = _mmu_create_vcontext(MQX_NULL_TASK_ID);
if (result != MQX_OK) {
}
result = _mmu_add_vcontext(MQX_NULL_TASK_ID,
```

```
   virtual_mem_ptr, size, 0);
if (result != MQX_OK) {
}
...
```

3.6.5.3 Example: Creating Tasks with a Virtual Context

Create tasks with a virtual context and a copy of common data.

```
...
/* Task template number for the virtual-context task: */
#define VMEM_TTN         10

/* Global variable: */
uchar_ptr data_to_duplicate[0x10000] = { 0x1, 0x2, 0x3 };
...
{
pointer   virtual_mem_ptr;

virtual_mem_ptr = (pointer)0xA0000000;
...
result = _mmu_create_vtask(VMEM_TTN, 0, &data_to_duplicate,
   virtual_mem_ptr, sizeof(data_to_duplicate), 0);
if (result == MQX_NULL_TASK_ID) {
}
result = _mmu_create_vtask(VMEM_TTN, 0, &data_to_duplicate,
   virtual_mem_ptr, sizeof(data_to_duplicate), 0);
if (result == MQX_NULL_TASK_ID) {
  }
...
}
```

3.7 Synchronizing Tasks

You can synchronize tasks by using one or more of the following mechanisms, which are described in subsequent sections:

- Events — tasks can wait for a combination of event bits to become set. A task can set or clear a combination of event bits.
- Lightweight events — simpler implementation of events.
- Semaphores — tasks can wait for a semaphore to be incremented from non-zero. A task can post (increment) the semaphore. MQX semaphores prevent priority inversion by providing priority inheritance. For a discussion of priority inversion, see page 53.
- Lightweight semaphores — simple counting semaphores.
- Mutexes — tasks can use a mutex to ensure that only one task at a time accesses shared data. To access shared data, a task locks a mutex, waiting if the mutex is already locked. When the task is finished accessing the shared data, it unlocks the mutex. Mutexes prevent priority inversion by providing priority inheritance and priority protection. For details, see page 67.
- Message passing — lets tasks transfer data between themselves. A task fills a message with data and sends it to a particular message queue. Another task waits for messages to arrive at the message queue (receives messages).

- Task queues — let an application suspend and resume tasks.

3.7.1 Events

Events can be used to synchronize a task with another task or with an ISR.

The event component consists of event groups, which are groupings of event bits. The number of event bits in an event group is the number of bits in **_mqx_uint**.

Any task can wait for event bits in an event group. If the event bits are not set, the task blocks. Any other task or ISR can set the event bits. When the event bits are set, MQX puts all waiting tasks, whose waiting condition is met, into the task's ready queue. If the event group has autoclearing event bits, MQX clears the event bits as soon as they are set, and makes one task ready.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the event component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file, and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

There can be named event groups, which are identified by a unique string name, and fast event groups, which are identified by a unique number.

An application can open an event group on a remote processor by specifying the processor number in the string that it uses to open the event group. After opening the remote-processor event group, an application can set any event bit in the event group. An application cannot wait for event bits in a remote event group.

Table 3-9. Summary: Using the Event Component

Event[1]	Description
_event_clear	Clears the specified event bits in an event group.
_event_close	Closes a connection to an event group.
_event_create	Creates a named event group.
_event_create_auto_clear	Creates a named event group with autoclearing event bits.
_event_create_component	Creates the event component.
_event_create_fast	Creates a fast event group.
_event_create_fast_auto_clear	Creates a fast event group with autoclearing event bits.
_event_destroy	Destroys a named event group.
_event_destroy_fast	Destroys a fast event group.
_event_get_value	Gets the value of an event group.
_event_get_wait_count	Gets the number of tasks waiting for event bits in an event group.
_event_open	Opens a connection to a named event group.

Table 3-9. Summary: Using the Event Component (continued)

_event_open_fast	Opens a connection to a fast event group.
_event_set	Sets the specified event bits in an event group on the local processor or on a remote processor.
_event_test	Tests the event component.
_event_wait_all	Waits for all the specified event bits in an event group for a specified number of milliseconds.
_event_wait_all_for	Waits for all the specified event bits in an event group for a specified tick-time period (including hardware ticks).
_event_wait_all_ticks	Waits for all the specified event bits in an event group for a specified number of ticks.
_event_wait_all_until	Waits for all the specified event bits in an event group until a specified tick time.
_event_wait_any	Waits for any of the specified event bits in an event group for a specified number of milliseconds.
_event_wait_any_for	Waits for any of the specified event bits in an event group for a specified tick time period.
_event_wait_any_ticks	Waits for any of the specified event bits in an event group for a specified number of ticks.
_event_wait_any_until	Waits for any of the specified event bits in an event group until a specified tick time.

[1] Events use certain structures and constants, which are defined in event.h.

3.7.1.1 Creating the Event Component

You can explicitly create the event component with **_event_create_component**(). If you do not explicitly create it, MQX creates it with default values the first time an application creates an event group.

Parameter	Meaning	Default
Initial number	Initial number of event groups that can be created	8
Grow number	Number of additional event groups that can be created if all the event groups are created, until the maximum number is reached	8
Maximum number	If grow number is not 0, maximum number of event groups that can be created	0 (unlimited)

3.7.1.2 Creating an Event Group

Before a task can use the event component, it must create an event group.

To create this type of event group:	Call:	With:
Fast (with autoclearing event bits)	**_event_create_fast()** **_event_create_fast_auto_clear()**	Index (must be within the limits specified, when the event component was created)
Named (with autoclearing event bits)	**_event_create()** **_event_create_auto_clear()**	String name

If an event group is created with autoclearing event bits, MQX clears the bits as soon as they are set. This action makes ready any tasks that are waiting for the bits, without the tasks having to clear the bits.

3.7.1.3 Opening a Connection to an Event Group

Before a task can use the event component, it must open a connection to a created event group.

To open a connection to this type of event group:	Call:	With:
Fast	**_event_open_fast()**	Index, which must be within the limits that were specified, when the event component was created.
Named	**_event_open()**	String name

Both functions return a unique handle to the event group.

3.7.1.4 Waiting for Event Bits

A task waits for a pattern of event bits (a mask) in an event group with **_event_wait_all()** or **_event_wait_any()**. When a bit is set, MQX makes ready the tasks that are waiting for the bit. If the event group is created with autoclearing event bits (**_event_create_auto_clear()** or **_event_create_fast_auto_clear()**), MQX clears the bit so that the waiting tasks need not clear it.

3.7.1.5 Setting Event Bits

A task can set a pattern of event bits (a mask) in an event group with **_event_set()**. The event group can be local or on a remote processor. When an event bit is set, tasks waiting for the bit are made ready. If the event group is created with autoclearing event bits, MQX clears the bits as soon as they are set.

3.7.1.6 Clearing Event Bits

A task can clear a pattern of event bits (a mask) in an event group with **_event_clear()**. However, if the event group is created with autoclearing event bits, MQX clears the bits as soon as they are set.

3.7.1.7 Closing a Connection to an Event Group

When a task no longer needs to use an event group, it can close its connection to the group with **_event_close**().

3.7.1.8 Destroying an Event Group

If tasks are blocked, waiting for an event bit in the to-be-destroyed event group, MQX moves them to their ready queues.

3.7.1.9 Example: Using Events

Simulated_tick ISR sets an event bit each time it runs. Service task performs a certain action each time a tick occurs, and therefore waits for the event bit that Simulated_tick sets.

3.7.1.9.1 Code for the Example

```
/* event.c */

#include <mqx.h>
#include <fio.h>
#include <event.h>

/* Task IDs */
#define SERVICE_TASK 5
#define ISR_TASK     6

/* Function Prototypes */
extern void simulated_ISR_task(uint_32);
extern void service_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] = {
   {SERVICE_TASK, service_task, 500, 5, "service",
      MQX_AUTO_START_TASK, 0L, 0},
   {ISR_TASK, simulated_ISR_task, 500, 5, "simulated_ISR",
      0,                    0L, 0},
   {0,            0,            0,   0, 0,
      0,                    0L, 0}
};
/*TASK*-----------------------------------------------------
*
* Task Name    : simulated_ISR_task
* Comments     :
*    This task opens a connection to the event. After
*    delaying the event bits are set.
*END*-----------------------------------------------------*/
void simulated_ISR_task(uint_32  initial_data)
{
   pointer    event_ptr;

   /* open event connection */
   if (_event_open("global", &event_ptr) != MQX_OK) {
      printf("\nOpen Event failed");
      _mqx_exit(0);
   }
```

```
   while (TRUE) {
      _time_delay(1000);
      if (_event_set(event_ptr, 0x01) != MQX_OK) {
         printf("\nSet Event failed");
         _mqx_exit(0);
      }
   }
}

/*TASK*-----------------------------------------------------
*
* Task Name    : service_task
* Comments     :
*    This task creates an event and the simulated_ISR_task
*    task. It opens a connection to the event and waits.
*    After all bits have been set "Tick" is printed and
*    the event is cleared.
*END*-----------------------------------------------------*/

void service_task(uint_32 initial_data)
{
   pointer   event_ptr;
   _task_id  second_task_id;

   /* setup event */
   if (_event_create("global") != MQX_OK) {
      printf("\nMake event failed");
      _mqx_exit(0);
   }
   if (_event_open("global", &event_ptr) != MQX_OK) {
      printf("\nOpen event failed");
      _mqx_exit(0);
   }

   /* create task */
   second_task_id = _task_create(0, ISR_TASK, 0);
      if (second_task_id == MQX_NULL_TASK_ID) {
         printf("Could not create simulated_ISR_task \n");
         _mqx_exit(0);
      }
   while (TRUE) {
      if (_event_wait_all(event_ptr, 0x01, 0) != MQX_OK) {
         printf("\nEvent Wait failed");
         _mqx_exit(0);
      }

      if (_event_clear(event_ptr, 0x01) != MQX_OK) {
         printf("\nEvent Clear Failed");
         _mqx_exit(0);
      }

      printf(" Tick \n");
   }
}
```

3.7.1.9.2 Compiling the Application and Linking it with MQX

1. Go to this directory:

```
mqx\examples\event
```

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

Event task prints a message each time an event bit is set.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.7.2 Lightweight Events

Lightweight events are a simpler, low-overhead implementation of events.

The lightweight event component consists of lightweight event groups, which are groupings of event bits. The number of event bits in a lightweight event group is the number of bits in **_mqx_uint**.

Any task can wait for event bits in a lightweight event group. If the event bits are not set, the task blocks. Any other task or ISR can set the event bits. When the event bits are set, MQX puts all waiting tasks, whose waiting condition is met, into the task's ready queue. If the lightweight event group has autoclearing event bits, MQX clears the event bits as soon as they are set and makes one task ready.

Lightweight event groups are created from static-data structures and are not multi-processor.

Table 3-10. Summary: Using the Lightweight Event Component

Event[1]	Description
_lwevent_clear	Clears the specified event bits in a lightweight event group.
_lwevent_create	Creates a lightweight event group, indicating whether it has autoclearing event bits.
_lwevent_destroy	Destroys a lightweight event group.
_lwevent_set	Sets the specified event bits in a lightweight event group.
_lwevent_test	Tests the lightweight event component.
_lwevent_wait_for	Waits for all or any of the specified event bits in a lightweight event group for a specified tick-time period.
_lwevent_wait_ticks	Waits for all or any of the specified event bits in a lightweight event group for a specified number of ticks.
_lwevent_wait_until	Waits for all or any of the specified event bits in a lightweight event group until a specified tick time.

[1] Lightweight events use certain structures and constants, which are defined in lwevent.h.

3.7.2.1 Creating a Lightweight Event Group

To create a lightweight event group, an application declares a variable of type **LWEVENT_STRUCT**, and initializes it by calling **_lwevent_create()** with a pointer to the variable and a flag indicating, whether the event group has autoclearing event bits.

3.7.2.2 Waiting for Event Bits

A task waits a pattern of event bits (a mask) in a lightweight event group with one of the **_lwevent_wait** functions. If the waiting condition is not met, the function waits for a specified time to expire.

3.7.2.3 Setting Event Bits

A task sets a pattern of event bits (a mask) in a lightweight event group with **_lwevent_set()**. If tasks are waiting for the appropriate bits, MQX makes them ready. If the event group has autoclearing event bits, MQX makes ready only the first task that is waiting.

3.7.2.4 Clearing Event Bits

A task can clear a pattern of event bits (a mask) in a lightweight event group with **_lwevent_clear()**. However, if the lightweight event group is created with autoclearing event bits, MQX clears the bits as soon as they are set.

3.7.2.5 Destroying a Lightweight Event Group

When a task no longer needs a lightweight event group, it can destroy the event group with **_lwevent_destroy**().

3.7.3 About Semaphore-Type Objects

MQX provides lightweight semaphores (LWSems), semaphores, and mutexes.

You can use both types of semaphores for task synchronization and mutual exclusion. A task waits for a semaphore. If the semaphore count is zero, MQX blocks the task; otherwise, MQX decrements the semaphore count, gives the task the semaphore, and the task continues to run. When the task is finished with the semaphore, it posts the semaphore; the task remains ready. If a task is waiting for the semaphore, MQX puts the task in the task ready queue; otherwise, MQX increments the semaphore count.

You can use mutexes for mutual exclusion. A mutex is sometimes called a binary semaphore because its counter can be only zero or one.

3.7.3.1 Strictness

If a semaphore-type object is strict, a task must first wait for and get the object, before it can release the object. If the object is non-strict, a task does not need to get the object before it releases the object.

3.7.3.2 Priority Inversion

Task priority inversion is a classic condition, where the relative priorities of tasks appear to be reversed. Priority inversion might occur, when tasks use semaphores or mutexes to gain access to a shared resource.

3.7.3.3 Example: Priority Inversion

There are three tasks of three different priorities. The mid-priority task prevents the highest-priority task from running.

Sequence	Task_1 (highest priority P1)	Task_2 (mid priority P2)	Task_3 (lowest priority P3)
1 2			• Runs • Gets semaphore
3 4		• Is made ready • Preempties Task_3 and runs	
5 6 7 8	• Is made ready • Preempties Task_2 and runs • Tries to get semaphore that Task_3 has • Blocks, waiting for the semaphore		
9		• Runs and keeps running	

3.7.3.4 Avoiding Priority Inversion with Priority Inheritance

When you create an MQX semaphore or mutex, one of the properties that you can specify is priority inheritance, which prevents priority inversion.

If you specify priority inheritance, during the time that a task has locked a semaphore or mutex, the task's priority is never lower than the priority of any task that waits for the semaphore or mutex. If a higher-priority task waits for the semaphore or mutex, MQX temporarily raises the priority of the task that has the semaphore or mutex to the priority of the waiting task.

Table 3-11. Priority Inheritance Properties

Sequence	Task_1 (highest priority P1)	Task_2 (mid priority P2)	Task_3 (lowest priority P3)
1 2			• Runs • Gets semaphore

Table 3-11. Priority Inheritance Properties (continued)

3 4		• Is made ready • Preempties Task_3 and runs	
5 6 7 8	• Is made ready • Preempties Task_2 and runs • Tries to get semaphore that Task_3 has • Raises priority of Task_3 to P1 and blocks		
9 10 11			• Preempts Task_1 and runs • Finishes work and posts semaphore • Priority is lowered to P3
12 13	• Preempts Task_3 and Task_2 and runs • Gets semaphore		

3.7.3.5 Avoiding Priority Inversion with Priority Protection

When you create an MQX mutex, you can specify the mutex attributes of priority protection and a mutex priority. These attributes prevent priority inversion.

If the priority of a task that requests to lock the mutex is not at least as high as the mutex priority, MQX temporarily raises the task's priority to the mutex priority for as long, as the task has the mutex locked.

Table 3-12. Mutex Attributes

Sequence	Task_1 (highest priority P1)	Task_2 (mid priority P2)	Task_3 (lowest priority P3)
1 2			• Runs • Locks mutex (with priority P1); priority is boosted to P1
3 4		• Is made ready • Does not preempt Task_3	

Table 3-12. Mutex Attributes (continued)

5 6	• Is made ready • Does not preempt Task_3		
7			• Finishes with mutex and unlocks it
8			• Priority is lowered to P3
9 10	• Preempts Task_3 and runs • Locks mutex		

Table 3-13. Comparison of Lightweight Semaphores, Semaphores, and Mutexes

Feature	LWSem	Semaphore	Mutex
Timeout	Yes	Yes	No
Queuing	FIFO	FIFO Priority	FIFO Priority Spin only Limited spin
Strict	No	No or yes	Yes
Priority inheritance	No	Yes	Yes
Priority protection	No	No	Yes
Size	Smallest	Largest	Between lightweight semaphores and semaphores
Speed	Fastest	Slowest	Between lightweight semaphores and semaphores

3.7.4 Lightweight Semaphores

Lightweight semaphores are a simpler, low-overhead implementation of semaphores.

Lightweight semaphores are created from static-data structures, and are not multi-processor.

Table 3-14. Summary: Using Lightweight Semaphores

_lwsem_create	Creates a lightweight semaphore.
_lwsem_destroy	Destroys a lightweight semaphore.
_lwsem_poll	Polls for a lightweight semaphore (non-blocking).
_lwsem_post	Posts a lightweight semaphore.
_lwsem_test	Tests the lightweight semaphore component.
_lwsem_wait	Waits for a lightweight semaphore.

Table 3-14. Summary: Using Lightweight Semaphores (continued)

_lwsem_wait_for	Waits for a lightweight semaphore for a specified tick-time period.
_lwsem_wait_ticks	Waits for a lightweight semaphore for a specified number of ticks.
_lwsem_wait_until	Waits for a lightweight semaphore, until a specified number of ticks have elapsed.

3.7.4.1 Creating a Lightweight Semaphore

To create a lightweight semaphore, you declare a variable of type **LWSEM_STRUCT,** and initialize it by calling **_lwsem_create()** with a pointer to the variable and an initial semaphore count. The semaphore count, which indicates the number of requests that can be concurrently granted the lightweight semaphore, is set to the initial count.

3.7.4.2 Waiting for and Posting a Lightweight Semaphore

A task waits for a lightweight semaphore with **_lwsem_wait()**. If the semaphore count is greater than zero, MQX decrements it, and the task continues to run. If the count is zero, MQX blocks the task, until some other task posts the lightweight semaphore.

To release a lightweight semaphore, a task posts it with **_lwsem_post()**. If no tasks are waiting for the lightweight semaphore, MQX increments the semaphore count.

Since lightweight semaphores are non-strict, tasks can post without waiting first; therefore, the semaphore count is not bounded and can increase beyond the initial count.

3.7.4.3 Destroying a Lightweight Semaphore

When a task no longer needs a lightweight semaphore, it can destroy it with **_lwsem_destroy()**.

3.7.4.4 Example: Producers and Consumer

Producer and consumer tasks synchronize each other with lightweight semaphores.

1. Read task creates:
   - Multiple Write tasks and assigns a unique character to each.
   - One write LWSem.
   - One read LWSem.
2. Each Write task waits for the Write LWSem, before it writes a character into the buffer. When the character is written, each Write task posts the Read LWSem, signaling that a character is available to the Read task.
3. Read waits for the Read LWSem, before it consumes the character. After it consumes the character, it posts the Write LWSem, signaling that the buffer is ready for another character.

3.7.4.4.1 Definitions and Structures for the Example

```
/* read.h */

/* Number of Writer Tasks */
#define NUM_WRITERS  3

/* Task IDs */
#define WRITE_TASK   5
#define READ_TASK    6

/* Global data structure accessible by read and write tasks.
** Contains two lightweight semaphores that govern access to the
** data variable.
*/
typedef struct sw_fifo
{
   LWSEM_STRUCT   READ_SEM;
   LWSEM_STRUCT   WRITE_SEM;
   uchar          DATA;
} SW_FIFO, _PTR_ SW_FIFO_PTR;

/* Function prototypes */
extern void write_task(uint_32 initial_data);
extern void read_task(uint_32 initial_data);

extern SW_FIFO fifo;
```

3.7.4.4.2 Task Templates for the Example

```
/*  ttl.c */

#include <mqx.h>
#include <bsp.h>
#include "read.h"

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {WRITE_TASK, write_task, 600, 5, "write",
    0,                    0L, 0},
   {READ_TASK,  read_task,  500, 5, "read",
    MQX_AUTO_START_TASK, 0L, 0},
   {0,          0,           0,  0, 0,
    0,                    0L, 0}
};
```

3.7.4.4.3 Code for a Write Task

```
/* write.c */

#include <mqx.h>
#include <bsp.h>
#include "read.h"
/*TASK*-------------------------------------------------------
*
* Task Name : write_task
* Comments  : This task waits for the write semaphore,
```

```
**             then writes a character to “data” and posts a
*              read semaphore.
*END*-------------------------------------------------------*/

void write_task(uint_32 initial_data)
{

   printf("\nWrite task created: 0x%lX", initial_data);
   while (TRUE) {
      if (_lwsem_wait(&fifo.WRITE_SEM) != MQX_OK) {
         printf("\n_lwsem_wait failed");
         _mqx_exit(0);
      }
      fifo.DATA = (uchar)initial_data;
      _lwsem_post(&fifo.READ_SEM);
   }
}
```

3.7.4.4.4 Code for Read Task

```
/* read.c */

#include <mqx.h>
#include <bsp.h>
#include "read.h"

SW_FIFO     fifo;

/*TASK*---------------------------------------------------------
*
* Task Name : read_task
* Comments  : This task creates two semaphores and
*              NUM_WRITER write_tasks. Then it waits
*              on the read_sem and finally outputs the
*              "data" variable.
*END*-------------------------------------------------------*/

void read_task(uint_32 initial_data)
{
   _task_id    task_id;
   _mqx_uint   result;
   _mqx_uint   i;

   /* Create the lightweight semaphores */
   result = _lwsem_create(&fifo.READ_SEM, 0);
   if (result != MQX_OK) {
      printf("\nCreating read_sem failed: 0x%X", result);
      _mqx_exit(0);
   }

   result = _lwsem_create(&fifo.WRITE_SEM, 1);
   if (result != MQX_OK) {
      printf("\nCreating write_sem failed: 0x%X", result);
      _mqx_exit(0);
   }

   /* Create write tasks */
```

```
   for (i = 0; i < NUM_WRITERS; i++) {
      task_id = _task_create(0, WRITE_TASK, (uint_32)('A' + i));
      printf("\nwrite_task created, id 0x%lX", task_id);
   }

   while (TRUE) {
      result = _lwsem_wait(&fifo.READ_SEM);
      if (result != MQX_OK) {
         printf("\n_lwsem_wait failed: 0x%X", result);
         _mqx_exit(0);
      }
      putchar('\n');
      putchar(fifo.DATA);
      _lwsem_post(&fifo.WRITE_SEM);
   }
}
```

3.7.4.4.5 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\lwsem`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

The following appears on the output device:

```
A
A
B
C
A
B
...
```

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, “Using Freescale CodeWarrior Development Studio” for more details.

3.7.5 Semaphores

Semaphores can be used for task synchronization and mutual exclusion. The main operations that a task performs on a semaphore, are to wait for the semaphore and to post the semaphore.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Semaphore component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, “Rebuilding Freescale MQX RTOS” for more details.

Table 3-15. Summary: Using Semaphores

Semaphore[1]	Description
_sem_close	Closes a connection to a semaphore.
_sem_create	Creates a semaphore.
_sem_create_component	Creates the semaphore component.
_sem_create_fast	Creates a fast semaphore.
_sem_destroy	Destroys a named semaphore.
_sem_destroy_fast	Destroys a fast semaphore.
_sem_get_value	Gets the current semaphore count.
_sem_get_wait_count	Gets the number of tasks waiting for a semaphore.
_sem_open	Opens a connection to a named semaphore.
_sem_open_fast	Opens a connection to a fast semaphore.
_sem_post	Posts (frees) a semaphore.
_sem_test	Tests the semaphore component.
_sem_wait	Waits for a semaphore for a number of milliseconds.
_sem_wait_for	Waits for a semaphore for a tick-time period.
_sem_wait_ticks	Waits for a semaphore for a number of ticks.
_sem_wait_until	Waits for a semaphore until a time (in tick time).

[1] Semaphores use certain structures and constants, which are defined in sem.h.

3.7.5.1 Using a Semaphore

To use a semaphore, a task executes the following steps, each of which is described in subsequent sections.

1. Optionally, creates the semaphore component.
2. Creates the semaphore.
3. Opens a connection to the semaphore.
4. If the semaphore is strict, it waits for the semaphore.
5. When finished using the semaphore for the time being, it posts the semaphore.
6. If it no longer needs the semaphore, it closes its connection to the semaphore.
7. If the semaphore is protecting a shared resource that ceases to exist or is no longer accessible, the task can destroy the semaphore.

3.7.5.2 Creating the Semaphore Component

You can explicitly create the semaphore component with **_sem_create_component()**. If you do not explicitly create it, MQX creates it with default values the first time an application creates a semaphore.

The parameters and their default values are the same as for the event component, which is described on page 47.

3.7.5.3 Creating a Semaphore

Before a task can use a semaphore, it must create the semaphore.

Semaphore Type	Call	With
Fast	**_sem_create_fast()**	Index, which must be within the limits that were specified when the semaphore component was created.
Named	**_sem_create()**	String name

When the task creates the semaphore, it also specifies:

- Initial count — the initial value for the semaphore count represents the number of locks that the semaphore has. (A task can get multiple locks).
- Priority queuing — if priority queuing is specified, the queue of tasks waiting for the semaphore is in priority order, and MQX puts the semaphore to the highest-priority waiting task.
- If priority queuing is not specified, the queue is in FIFO order, and MQX puts the semaphore to the longest-waiting task.
- Priority inheritance — if priority inheritance is specified and a higher-priority task is waiting for the semaphore, MQX raises the priority of the tasks that have the semaphore to the priority of the waiting task. For more information, see the discussion on priority inheritance on page 53. To use priority inheritance, the semaphore must be strict.
- Strictness — if strictness is specified, a task must wait for the semaphore, before it can post the semaphore. If a semaphore is strict, the initial count is the maximum value of the semaphore count. If the semaphore is non-strict, the count is unbounded.

3.7.5.4 Opening a Connection to a Semaphore

Before a task can use a semaphore, it must open a connection to the semaphore.

Semaphore Type	Call	With
Fast	**_sem_open_fast()**	Index, which must be within the limits that were specified when the semaphore component was created.
Named	**_sem_open()**	String name

Both functions return a unique handle to the semaphore.

3.7.5.5 Waiting for a Semaphore and Posting a Semaphore

A task waits for a semaphore using one of the functions from the **_sem_wait_** family of functions. If the semaphore count is zero, MQX blocks the task, until another task posts (**_sem_post()**) the semaphore or the task-specified timeout expires. If the count is not zero, MQX decrements the count, and the task continues to run.

When a task posts a semaphore, and there are tasks waiting for the semaphore, MQX puts them in their ready queues. If there are no tasks waiting, MQX increments the semaphore count. In either case, the posting task remains ready.

3.7.5.6 Closing a Connection to a Semaphore

When a task no longer needs to use a semaphore, it can close its connection with the semaphore with **_sem_close**().

3.7.5.7 Destroying a Semaphore

When the semaphore is no longer needed, a task can destroy it.

Semaphore Type	Call	With
Fast	**_sem_destroy_fast()**	Index, which must be within the limits that were specified when the semaphore component was created.
Named	**_sem_destroy()**	String name

As well, the task can specify, whether to force destruction. If destruction is forced, MQX readies tasks that are waiting for the semaphore, and destroys the semaphore after all the tasks that have the semaphore post the semaphore.

If destruction is not forced, MQX destroys the semaphore after the last waiting task gets and posts the semaphore. (This is always the action if the semaphore is strict).

3.7.5.8 Example: Task Synchronization and Mutual Exclusion

This example builds on the lightweight semaphore example on page 56. It shows, how semaphores can be used for task synchronization and mutual exclusion.

The example manages a FIFO that multiple tasks can write to and read from. Mutual exclusion is required for access to the FIFO data structure. Task synchronization is required to block the writing tasks when the FIFO is full, and to block the reading tasks when the FIFO is empty. Three semaphores are used:

- Index semaphore for mutual exclusion on the FIFO.
- Read semaphore to synchronize the readers.
- Write semaphore to synchronize the writers.

The example consists of three tasks: Main, Read, and Write. Main initializes the semaphores, and creates Read and Write.

3.7.5.8.1 Definitions and Structures for the Example

```
/* main.h
** This file contains definitions for the semaphore example.
*/

#define MAIN_TASK    5
#define WRITE_TASK   6
```

```
#define READ_TASK    7
#define ARRAY_SIZE   5
#define NUM_WRITERS  2

/* Global data structure accessible by read and write tasks.
** Contains a DATA array that simulates a FIFO. READ_INDEX
** and WRITE_INDEX mark the location in the array that the read
** and write tasks are accessing. All data is protected by
** semaphores.
*/
typedef struct
{
   _task_id  DATA[ARRAY_SIZE];
   uint_32   READ_INDEX;
   uint_32   WRITE_INDEX;
} SW_FIFO, _PTR_ SW_FIFO_PTR;

/* Function prototypes */
extern void main_task(uint_32 initial_data);
extern void write_task(uint_32 initial_data);
extern void read_task(uint_32 initial_data);

extern   SW_FIFO fifo;
```

3.7.5.8.2 Task Templates for the Example

```
/*  ttl.c */

#include <mqx.h>
#include "main.h"

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {MAIN_TASK,  main_task,  1000, 5, "main",
      MQX_AUTO_START_TASK, 0L, 0},
   {WRITE_TASK, write_task, 600, 5, "write",
      0,                   0L, 0},
   {READ_TASK,  read_task,  1000, 5, "read",
      0,                   0L, 0},
   { 0,         0,          0,   0, 0,
      0,                   0L, 0}
};
```

3.7.5.8.3 Code for Main Task

The Main task creates:

- The semaphore component
- The Index, Read, and Write semaphores
- Read and Write tasks

```
/* main.c */

#include <mqx.h>
#include <bsp.h>
#include <sem.h>
#include "main.h"

SW_FIFO   fifo;

/*TASK*-----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*     This task initializes three semaphores, creates NUM_WRITERS
*     write_tasks, and creates one read_task.
*END*-----------------------------------------------------------*/
void main_task(uint_32 initial_data)
{
   _task_id   task_id;
   _mqx_uint  i;

   fifo.READ_INDEX = 0;
   fifo.WRITE_INDEX = 0;

   /* Create semaphores: */
   if (_sem_create_component(3, 1, 6) != MQX_OK) {
      printf("\nCreating semaphore component failed");
      _mqx_exit(0);
   }
   if (_sem_create("write", ARRAY_SIZE, 0) != MQX_OK) {
      printf("\nCreating write semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_create("read", 0, 0) != MQX_OK) {
      printf("\nCreating read semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_create("index", 1, 0) != MQX_OK) {
      printf("\nCreating index semaphore failed");
      _mqx_exit(0);
   }

   /* Create tasks: */
   for (i = 0; i < NUM_WRITERS; i++) {
      task_id = _task_create(0, WRITE_TASK, i);
      printf("\nwrite_task created, id 0x%lx", task_id);
   }

   task_id = _task_create(0, READ_TASK, 0);
   printf("\nread_task created, id 0x%lx", task_id);
}
```

3.7.5.8.4 Code for the Read Task

```
/* read.c */

#include <mqx.h>
```

```
#include <bsp.h>
#include <sem.h>
#include "main.h"

/*TASK*---------------------------------------------------------
* Task Name : read_task
* Comments  :
*     This task opens a connection to all three semaphores, then
*     waits to lock a read semaphore and an index semaphore. One
      element in the DATA array is displayed. The index and write
      semaphores are then posted.
*END*-------------------------------------------------------*/
void read_task(uint_32 initial_data)
{
   pointer  write_sem;
   pointer  read_sem;
   pointer  index_sem;

   /* Open connections to all semaphores: */
   if (_sem_open("write", &write_sem) != MQX_OK) {
      printf("\nOpening write semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_open("index", &index_sem) != MQX_OK) {
      printf("\nOpening index semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_open("read", &read_sem) != MQX_OK) {
      printf("\nOpening read semaphore failed");
      _mqx_exit(0);
   }

   while (TRUE) {
      /* Wait for the semaphores: */
      if (_sem_wait(read_sem, 0) != MQX_OK) {
         printf("\nWaiting for read semaphore failed");
         _mqx_exit(0);
      }
      if (_sem_wait(index_sem, 0) != MQX_OK) {
        printf("\nWaiting for index semaphore failed");
        _mqx_exit(0);
      }
      printf("\n 0x%lx", fifo.DATA[fifo.READ_INDEX++]);
      if (fifo.READ_INDEX >=ARRAY_SIZE) {
         fifo.READ_INDEX = 0;
      }
      /* Post the semaphores: */
      _sem_post(index_sem);
      _sem_post(write_sem);
   }
}
```

3.7.5.8.5 Code for the Write Task

```
/* write.c */

#include <mqx.h>
```

```
#include <bsp.h>
#include <sem.h>
#include "main.h"

/*TASK*-----------------------------------------------------------
* Task Name : write_task
* Comments  :
*     This task opens a connection to all three semaphores, then
*     waits to lock a write and an index semaphore. One element
*     in the DATA array is written to. The index and read
      semaphores are then posted.
*END*------------------------------------------------------------*/

void write_task(uint_32 initial_data)
{
   pointer  write_sem;
   pointer  read_sem;
   pointer  index_sem;

   /* Open connections to all semaphores: */
   if (_sem_open("write", &write_sem) != MQX_OK) {
      printf("\nOpening write semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_open("index", &index_sem) != MQX_OK) {
      printf("\nOpening index semaphore failed");
      _mqx_exit(0);
   }
   if (_sem_open("read", &read_sem) != MQX_OK) {
      printf("\nOpening read semaphore failed");
      _mqx_exit(0);
   }

   while (TRUE) {
      /* Wait for the semaphores: */
      if (_sem_wait(write_sem, 0) != MQX_OK) {
         printf("\nWaiting for write semaphore failed");
         _mqx_exit(0);
      }
      if (_sem_wait(index_sem, 0) != MQX_OK) {
         printf("\nWaiting for index semaphore failed");
         _mqx_exit(0);
      }
      fifo.DATA[fifo.WRITE_INDEX++] = _task_get_id();
      if (fifo.WRITE_INDEX >=ARRAY_SIZE) {
         fifo.WRITE_INDEX = 0;
      }
      /* Post the semaphores: */
      _sem_post(index_sem);
      _sem_post(read_sem);
   }
}
```

3.7.5.8.6 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\sem`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release notes.

Read task prints the data that is written to the FIFO.

Modify the program to remove priority inheritance, and run the application again.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.7.6 Mutexes

Mutexes are used for mutual exclusion, so that only one task at a time uses a shared resource such as data or a device. To access the shared resource, a task locks the mutex associated with the resource. The task owns the mutex, until it unlocks the mutex.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Mutex component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file, and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

Mutexes are compatible with POSIX.4a (threads extensions) and provide priority inheritance and priority protection to prevent priority inversion.

Table 3-16. Summary: Using Mutexes

Mutex[1]	Description
_mutex_create_component	Creates the mutex component.
_mutex_destroy	Destroys a mutex.
_mutex_get_priority_ceiling	Gets the priority of a mutex.
_mutex_get_wait_count	Gets the number of tasks that are waiting for a mutex.
_mutex_init	Initializes a mutex.
_mutex_lock	Locks a mutex.
_mutex_set_priority_ceiling	Sets the priority of a mutex.
_mutex_test	Tests the mutex component.
_mutex_try_lock	Tries to lock a mutex.
_mutex_unlock	Unlocks a mutex.

1 Mutexes use certain structures and constants, which are defined in mutex.h.

3.7.6.1 Creating the Mutex Component

You can explicitly create the mutex component with **_mutex_create_component()**. If you do not explicitly create it, MQX creates it the first time an application initializes a mutex. There are no parameters.

3.7.6.2 Mutex Attributes

A mutex can have attributes with respect to its waiting and scheduling protocols.

3.7.6.3 Waiting Protocols

A mutex can have one of several waiting protocols, which affect tasks that request to lock an already locked mutex.

Waiting protocol[1]	Description
Queuing (default)	Blocks, until another task unlocks the mutex. When the mutex is unlocked, the first task (regardless of priority) that requested the lock, locks the mutex.
Priority queuing	Blocks, until another task unlocks the mutex. When the mutex is unlocked, the highest-priority task that requested the lock, locks the mutex.
Spin only	Spins (is timesliced) indefinitely, until another task unlocks the mutex. This means that MQX saves the requesting task's context, and dispatches the next task in the same-priority ready queue. When all the tasks in this ready queue have run, the requesting task becomes active again. If the mutex is still locked, the spin repeats.
Limited spin	Spins for a specified number of times, or fewer, if another task unlocks the mutex first.

[1] If the mutex is already locked, the requesting task does this.

Spin-only protocol functions properly, only if the tasks that share the mutex are either:

- time-slice tasks
- the same priority

If non-time-slice tasks of different priority try to share a spin-only mutex, a higher-priority task that wants to lock the mutex that is locked by a lower-priority task will never get the lock (unless the lower-priority task blocks).

Spin-only protocol mutexes are prone to deadlock and are not recommended. MQX provides them for compatibility to POSIX.

3.7.6.4 Scheduling Protocols

A mutex can have special scheduling protocols that avoid priority inversion. The policies might affect the priority of a task during the time that the task has the mutex locked. The default is for neither protocol to be in effect.

Scheduling protocol	Meaning
Priority inheritance	If the priority of the task that has locked the mutex (task_A) is not as high as the highest-priority task that is waiting to lock the mutex (task_B), MQX raises the priority of task_A to be the same as the priority of task_B, while task_A has the mutex.
Priority protection	A mutex can have a priority. If the priority of a task that requests to lock the mutex (task_A) is not at least as high as the mutex priority, MQX raises the priority of task_A to the mutex priority for as long as task_A has the mutex locked.

3.7.6.5 Creating and Initializing a Mutex

A task creates a mutex by first defining a variable of type **MUTEX_STRUCT**.

To initialize the mutex with the default attributes of a queuing waiting protocol and no special scheduling protocols, the task calls **_mutex_init()** with a pointer to the mutex variable and a NULL pointer.

However, to initialize the mutex with attributes other than the default, the task does the following:

1. It defines a mutex attributes structure of type **MUTEX_ATTR_STRUCT**.
2. It initializes the attributes structure with **_mutatr_init()**.
3. It calls various functions to set the appropriate attributes, choosing from:
   - **_mutatr_set_priority_ceiling()**
   - **_mutatr_set_sched_protocol()**
   - **_mutatr_set_spin_limit()**
   - **_mutatr_set_wait_protocol()**
4. It initializes the mutex by calling **_mutex_init()** with pointers to the mutex and to the attributes structure. When the mutex is initialized, any task can use it.
5. It destroys the mutex attributes structure with **_mutatr_destro**y**()**.

Table 3-17. Summary: Using a Mutex Attributes Structure

_mutatr_destroy	Destroys a mutex attributes structure.
_mutatr_get_priority_ceiling	Gets the priority of a mutex attributes structure.
_mutatr_get_sched_protocol	Gets the scheduling protocol of a mutex attributes structure.
_mutatr_get_spin_limit	Gets the limited-spin count of a mutex attributes structure.
_mutatr_get_wait_protocol	Gets the waiting policy of a mutex attributes structure.
_mutatr_init	Initializes a mutex attributes structure.

Table 3-17. Summary: Using a Mutex Attributes Structure (continued)

_mutatr_set_priority_ceiling	Sets the priority value in a mutex attributes structure.
_mutatr_set_sched_protocol	Sets the scheduling protocol of a mutex attributes structure.
_mutatr_set_spin_limit	Sets limited-spin count of a mutex attributes structure.
_mutatr_set_wait_protocol	Sets the waiting protocol of a mutex attributes structure.

3.7.6.6 Locking a Mutex

To access a shared resource, a task can lock the mutex that is associated with the resource by calling **_mutex_lock()**. If the mutex is not already locked, the task locks it and continues to run. If the mutex is already locked, depending on the mutex waiting protocols that are described on page 68, the task might block until the mutex is unlocked.

To be sure that it does not block, a task can try to lock a mutex with **_mutex_trylock()**. If the mutex is not already locked, the task locks it and continues to run. If the task is already locked, the task does not get the mutex, but continues to run.

3.7.6.7 Unlocking a Mutex

Only the task that has locked a mutex can unlock it (**_mutex_unlock**()).

3.7.6.8 Destroying a Mutex

If a mutex is no longer needed, a task can destroy it with **_mutex_destroy()**. If any tasks are waiting for the mutex, MQX puts them in their ready queues.

3.7.6.9 Example: Using a Mutex

A mutex is used for mutual exclusion. There are two time-slice tasks, both of which print to the same device. A mutex prevents the output from being interleaved.

3.7.6.9.1 Code for the Example

```
/* main.c */

#include <mqx.h>
#include <bsp.h>
#include <mutex.h>

/* Task IDs */
#define MAIN_TASK   5
#define PRINT_TASK  6

extern void main_task(uint_32 initial_data);
extern void print_task(uint_32 initial_data);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
```

```
   {MAIN_TASK,  main_task,  600, 5, "main",
      MQX_AUTO_START_TASK, 0L, 0},
   {PRINT_TASK, print_task, 600, 6, "print",
      MQX_TIME_SLICE_TASK, 0L, 3},
   {0,          0,          0,    0, 0,
      0,                    0L, 0}
};

MUTEX_STRUCT   print_mutex;

/*TASK*-------------------------------------------------------
*
* Task Name : main_task
* Comments  : This task creates a mutex, and then two
*             instances of the print task.
*END*-------------------------------------------------------*/

void main_task(uint_32 initial_data)
{
    MUTEX_ATTR_STRUCT   mutexattr;
    char* string1 = "Hello from Print task 1\n";
    char* string2 = "Print task 2 is alive\n";

   /* Initialize mutex attributes: */
   if (_mutatr_init(&mutexattr) != MQX_OK) {
      printf("Initializing mutex attributes failed.\n");
      _mqx_exit(0);
   }

   /* Initialize the mutex: */
   if (_mutex_init(&print_mutex, &mutexattr) != MQX_OK) {
      printf("Initializing print mutex failed.\n");
      _mqx_exit(0);
   }
   /* Create the print tasks */
   _task_create(0, PRINT_TASK, (uint_32)string1);
   _task_create(0, PRINT_TASK, (uint_32)string2);

}

/*TASK*-------------------------------------------------------
*
* Task Name : print_task
* Comments  : This task prints a message. It uses a mutex to
*             ensure I/O is not interleaved.
*END*-------------------------------------------------------*/

void print_task(uint_32 initial_data)
{
   while(TRUE) {
      if (_mutex_lock(&print_mutex) != MQX_OK) {
         printf("Mutex lock failed.\n");
         _mqx_exit(0);
     }
      _io_puts((char *) initial_data);
      _mutex_unlock(&print_mutex);
   }
```

```
}
```

3.7.6.9.2 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\mutex`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release notes.

3.7.7 Messages

Tasks can communicate with each other by exchanging messages. Tasks allocate messages from message pools. Tasks send messages to message queues, and receive messages from message queues. Messages can be assigned a priority or marked urgent. Tasks can send broadcast messages.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Message component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file, and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, “Rebuilding Freescale MQX RTOS” for more details.

Table 3-18. Summary: Using Messages

Messages use certain structure definitions and constants, which are defined in *message.h*.	
_msg_alloc	Allocates a message from a private-message pool.
_msg_alloc_system	Allocates a message from a system-message pool.
_msg_available	Gets the number of free messages in a message pool.
_msg_create_component	Creates the message component.
_msg_free	Frees a message.
_msg_swap_endian_data	Converts the application-defined data in a message to the other endian format.
_msg_swap_endian_header	Converts the message header to the other endian format.
_msgpool_create	Creates a private-message pool.
_msgpool_create_system	Creates a system-message pool.
_msgpool_destroy	Destroys a private-message pool.
_msgpool_test	Tests all message pools.
_msgq_close	Closes a message queue.
_msgq_get_count	Gets the number of messages in a message queue.
_msgq_get_id	Converts a queue number and processor number to a queue ID.

Table 3-18. Summary: Using Messages (continued)

_msgq_get_notification_ function	Gets the notification function that is associated with a message queue.
_msgq_get_owner	Gets the task ID of the task that owns a message queue.
_msgq_open	Opens a private-message queue.
_msgq_open_system	Opens a system-message queue.
_msgq_peek	Gets a pointer to the message that is at the head of a message queue (does not dequeue the message).
_msgq_poll	Poll (non-blocking) for a message in a message queue.
_msgq_receive	Receives a message from a message queue, and waits for a specified number of milliseconds.
_msgq_receive_for	Receives a message from a message queue, and waits for a specified tick-time period.
_msgq_receive_ticks	Receives a message from a message queue, and waits for a specified number of ticks.
_msgq_receive_until	Receives a message from a message queue, and waits for a specified tick time.
_msgq_send	Sends a message to a message queue.
_msgq_send_broadcast	Sends a message to multiple message queues.
_msgq_send_priority	Sends a priority message to a message queue.
_msgq_send_queue	Sends a message directly to a message queue (circumvents inter-processor routing).
_msgq_send_urgent	Sends an urgent message to a message queue.
_msgq_set_notification_ function	Sets the notification function for a message queue.
_msgq_test	Tests message queues.

3.7.7.1 Creating the Message Component

You can explicitly create the message component with **_msg_create_component()**. If you do not explicitly create it, MQX creates it the first time that an application creates a message pool or opens a message queue.

3.7.7.2 Using Message Pools

Tasks allocate messages from message pools, which a task must first create. A task can create a private-message pool (**_msgpool_create()**) or a system-message pool (**_msgpool_create_system()**).

A task specifies the following info, when it creates a message pool:

- Size of the messages in the pool.

- Initial number of messages in the pool.
- Grow factor: the number of additional messages that MQX adds to the pool, if tasks have allocated all the messages.
- Maximum number of messages in the pool (if the grow factor is not zero, zero means here that the pool can contain an unlimited number of messages).

The function **_msgpool_create_system()** can be called multiple times to create multiple system-message pools, each with different characteristics.

The function **_msgpool_create()** returns a pool ID, which any task can use to access the private-message pool.

	System-message pool	**Private-message pool**
Create a message pool	**_msgpool_create_system()**	**_msgpool_create()**
Allocate a message	**_msg_alloc_system()** (MQX searches all system-message pools.)	**_msg_alloc()** (MQX searches only the specified private-message pool.)
Free a message (message owner only)	**_msg_free()**	**_msg_free()**
Destroy a message pool	A system-message pool cannot be destroyed.	**_msgpool_destroy()** (By any task with the pool ID after all messages in the pool are freed.)

3.7.7.3 Allocating and Freeing Messages

Before a task sends a message, it allocates a message (**_msg_alloc_system()** or **_msg_alloc()**) of the appropriate size from a system- or private-message pool.

System-message pools are not the resource of any task, and any task can allocate a message from them. Any task with the pool ID can allocate a message from a private-message pool.

When a task allocates a message from either type of pool, the message becomes the resource of the task, until the task frees the message (**_msg_free()**) or puts it in a message queue (**_msgq_send** family of functions). When a task gets a message from a message queue (**_msgq_poll()** or **_msgq_receive** family), the message becomes the resource of the task. Only the task that has the message as its resource can free the message.

Messages begin with a message header (**MESSAGE_HEADER_STRUCT**) that defines the information that MQX needs to route the message. Application-defined data follows the message header.

```
typedef struct message_header_struct
{
  _msg_size  SIZE;
#if MQX_USE_32BIT_MESSAGE_QIDS
  uint_16    PAD;
#endif
  _queue_id  TARGET_QID;
  _queue_id  SOURCE_QID;
  uchar      CONTROL;
```

```
#if MQX_USE_32BIT_MESSAGE_QIDS
  uchar       RESERVED[3];
#else
  uchar       RESERVED;
#endif
} MESSAGE_HEADER_STRUCT, _PTR_ MESSAGE_HEADER_STRUCT_PTR;
```

For a description of each field, see MQX Reference.

3.7.7.4 Sending Messages

After a task allocates a message and fills in the message header fields and any data fields, it sends the message with **_msgq_send()**, which sends the message to the target message queue that is specified in the message header. Sending a message is not a blocking action.

3.7.7.5 Message Queues

Tasks use message queues to exchange messages. There can be private message queues and system message queues. When a task opens a message queue (specified by a message queue number), MQX returns an application-unique queue ID, which tasks subsequently use to access the message queue.

A task can convert a queue number to a queue ID with **_msgq_get_id()**.

3.7.7.5.1 16-Bit Queue IDs

The most-significant byte of a 16-bit queue ID contains the processor number, and the least-significant byte contains the queue number.

bit position	15 8	7 0
queue ID	processor number	queue number

3.7.7.5.2 32-Bit Queue IDs

The most significant word of a 32-bit queue ID contains the processor number, and the least significant word contains the queue number.

bit position	31	16	15 0
queue ID	processor number		queue number

3.7.7.6 Using Private Message Queues to Receive Messages

A task can send a message to any private message queue, but only the task that opened a private message queue can receive messages from it. Only one task at a time can have the private message queue open.

A task opens a private message queue (**_msgq_open()**) by specifying its queue number, which is a value between eight and the maximum queue number that is specified in the MQX initialization structure. (Queue numbers of one through seven are reserved.) If a task calls **_msgq_open()** with queue number zero, MQX opens any of the task's unopened private message queues.

The task that opened a private message queue can close it with **_msgq_close()**, which removes all messages from the message queue and frees the messages.

A task receives a message from one of its private message queues with a function from the **_msgq_receive** family, which removes the first message in the specified queue and returns a pointer to the message. If the task specifies queue ID zero, it receives a message from any of its open message queues. Receiving a message from a private message queue is a blocking action, unless the task specifies a timeout, which is the maximum time the task will wait for a message.

3.7.7.7 Using System Message Queues to Receive Messages

System message queues are not owned by a task, and a task does not block waiting to receive a message from one. Since it is not possible to block waiting for a message in a system message queue, ISRs can use system message queues. A task or ISR opens a system message queue with **_msgq_open_system()**.

A task or ISR receives messages from a system message queue with **_msgq_poll()**. If there are no messages in the system message queue, the function returns NULL.

3.7.7.8 Determining the Number of Pending Messages

A task can determine how many messages are in a system message queue or in one of its private message queues with **_msgq_get_count**().

3.7.7.9 Notification Functions

With both system and private message queues, a task can specify a notification function that runs, when a message is sent to the queue. For system message queues, the task specifies the notification function when it opens the queue. For private message queues, the task sets the notification function with **_msgq_set_notification_function()**, after it opens the queue. Applications can use notification functions to couple another synchronization service (such as an event or semaphore) to a message queue.

3.7.7.10 Example: Client/Server Model

This client/server model shows communication and task synchronization using message passing.

Server task blocks waiting for a request message from Client task. When Server receives the request, it executes the request and returns the message to Client. Two-way message exchange is used, in order to block Client while Server runs.

Server opens an input message queue that it will use to receive requests from Client tasks and creates a message pool, from which it allocates request messages. Server then creates a number of Client tasks. In a real application, the Client tasks most likely would not be created by Server.

When Server has opened its message queue and created its message pool, it enters a loop, receiving messages from the message queue, acting on them (in this case, printing the data), and returning the message to Client.

Client also opens a message queue. It allocates a message from the message pool, fills in the message field, sends the message to Server, and waits for a response from Server.

3.7.7.10.1 Message Definition

```
/* server.h */

#include <mqx.h>
#include <message.h>

/* Number of clients */
#define NUM_CLIENTS 3

/* Task IDs */
#define SERVER_TASK  5
#define CLIENT_TASK  6

/* Queue IDs */
#define SERVER_QUEUE       8
#define CLIENT_QUEUE_BASE  9

/* This struct contains a data field and a message struct. */
typedef struct {
   MESSAGE_HEADER_STRUCT   HEADER;
   uchar                   DATA[5];
} SERVER_MESSAGE, _PTR_ SERVER_MESSAGE_PTR;

/* Function prototypes */
extern void server_task(uint_32 initial_data);
extern void client_task(uint_32 initial_data);
extern _pool_id message_pool;
```

3.7.7.10.2 Task Templates for the Example

```
/*  ttl.c */

#include <mqx.h>
#include <bsp.h>
#include "server.h"

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {SERVER_TASK, server_task, 600, 5, "server",
     MQX_AUTO_START_TASK, 0L, 0},
   {CLIENT_TASK, client_task, 600, 5, "client",
     0,                     0L, 0},
   {0,           0,            0,   0,  0,
     0,                     0L, 0}
};
```

3.7.7.10.3 Code for Server Task

```
/* server.c */

#include <mqx.h>
#include <bsp.h>
#include "server.h"

/* Declaration of a global message pool: */
_pool_id            message_pool;
```

```
/*TASK*-----------------------------------------------------------
*
* Task Name   : server_task
* Comments    : This task creates a message queue for itself,
* allocates a message pool, creates three client tasks, and
  then waits for a message. After receiving a message, the
  task returns the message to the sender.
*END*-----------------------------------------------------------*/

void server_task(uint_32 param)
{
   SERVER_MESSAGE_PTR   msg_ptr;
   uint_32              i;
   _queue_id            server_qid;

   /* Open a message queue: */
   server_qid = _msgq_open(SERVER_QUEUE, 0);

   /* Create a message pool: */
   message_pool = _msgpool_create(sizeof(SERVER_MESSAGE),
      NUM_CLIENTS, 0, 0);

   /* Create clients: */
   for (i = 0; i < NUM_CLIENTS; i++) {
      _task_create(0, CLIENT_TASK, i);
   }

   while (TRUE) {
      msg_ptr = _msgq_receive(server_qid, 0);
      printf(" %c \n", msg_ptr->DATA[0]);

      /* Return the message: */
      msg_ptr->HEADER.TARGET_QID = msg_ptr->HEADER.SOURCE_QID;
      msg_ptr->HEADER.SOURCE_QID = server_qid;
      _msgq_send(msg_ptr);
   }
}
```

3.7.7.10.4 Code for Client Task

```
/* client.c */

#include <string.h>
#include <mqx.h>
#include <bsp.h>
#include "server.h"

/*TASK*-----------------------------------------------------------
*
* Task Name    : client_task
* Comments      This task creates a message queue and allocates
   a message in the message pool. It sends the message to the
   server_task and waits for a reply. It then frees the message.
*END*-----------------------------------------------------------*/

void client_task(uint_32 index)
```

```
{

   SERVER_MESSAGE_PTR   msg_ptr;
   _queue_id            client_qid;

   client_qid  = _msgq_open((_queue_number)(CLIENT_QUEUE_BASE +
      index), 0);

   while (TRUE) {
   /* Allocate a message: */
      msg_ptr = (SERVER_MESSAGE_PTR) _msg_alloc(message_pool);
      if(msg_ptr == NULL){
         printf("\nCould not allocate a message\n");
         _mqx_exit(0);
      }/* if */

      msg_ptr->HEADER.SOURCE_QID = client_qid;
      msg_ptr->HEADER.TARGET_QID = _msgq_get_id(0, SERVER_QUEUE);
      msg_ptr->HEADER.SIZE = sizeof(MESSAGE_HEADER_STRUCT) +
         strlen((char_ptr)msg_ptr->DATA) + 1;
      msg_ptr->DATA[0] = ('A'+ index);

      printf("Client Task %d\n",  index);
      _msgq_send(msg_ptr);

      /* Wait for the return message: */
      msg_ptr = _msgq_receive(client_qid, 0);

      /* Free the message: */
      _msg_free(msg_ptr);
   }
}
```

3.7.7.10.5 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\msg`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, “Using Freescale CodeWarrior Development Studio” for more details.

3.7.8 Task Queues

You can use a task queue to:

- Schedule a task from an ISR.
- Do explicit task scheduling.
- Implement custom synchronization mechanisms.

Table 3-19. Summary: Using Task Queues

_taskq_create	Creates a task queue with the specified queuing policy (FIFO or priority).
_taskq_destroy	Destroys a task queue (and puts any waiting tasks in the appropriate ready queues).
_taskq_get_value	Gets the size of a task queue.
_taskq_resume	Restarts a task that is suspended in a task queue, or restarts all tasks that are in a task queue (and puts them in their ready queues).
_taskq_suspend	Suspends a task and puts it in the specified task queue (and removes it from the task's ready queue).
_taskq_suspend_task	Suspends the non-blocked task and puts it in the specified task queue (and removes it from the task's ready queue).
_taskq_test	Tests all task queues.

3.7.8.1 Creating and Destroying Task Queues

Before an application can perform explicit task scheduling, it must first initialize a task queue by calling **_taskq_create**() with the queuing policy for the task queue. MQX creates the task queue and returns a queue ID, which the task subsequently uses to access the task queue.

A task queue is not a resource of the task that created it. It is a system resource and is not destroyed when its creating task is terminated.

A task can explicitly destroy a task queue with **_taskq_destroy**(). If there are tasks in the task queue, MQX moves them to their ready queues.

3.7.8.2 Suspending a Task

A task can suspend itself in a specific task queue with **_taskq_suspend**(). MQX puts the task in the queue (blocks the task) according to the queuing policy of the task queue.

3.7.8.3 Resuming a Task

A task calls **_taskq_resume()** to remove either one or all tasks from a specific task queue. MQX puts them in their ready queues.

3.7.8.4 Example: Synchronizing Tasks

A task is synchronized with an ISR. A second task simulates the interrupt.

The service_task task waits for a periodic interrupt, and prints a message every time the interrupt occurs. The task first creates a task queue, then suspends itself in the queue. The simulated_ISR_task task simulates a periodic interrupt with **_time_delay**(), and when the timeout expires, it schedules service_task.

3.7.8.4.1 Code for the Example

```
/* taskq.c */

#include <mqx.h>
#include <fio.h>

/* Task IDs */
#define SERVICE_TASK 5
#define ISR_TASK     6

extern void simulated_ISR_task(uint_32);
extern void service_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {SERVICE_TASK, service_task,       600, 5, "service",
     MQX_AUTO_START_TASK, 0L, 0},
   {ISR_TASK,     simulated_ISR_task, 600, 5, "simulated_ISR",
     0,                   0L, 0},
   {0,            0,                  0,   0, 0,
     0,                   0L, 0}
};

pointer   my_task_queue;

/*TASK*-----------------------------------------------------
*
* Task Name    : simulated_ISR_task
* Comments     :
*    This task pauses and then resumes the task queue.
*END*-----------------------------------------------------*/

void simulated_ISR_task(uint_32 initial_data)
{
   while (TRUE) {
      _time_delay(200);
      _taskq_resume(my_task_queue, FALSE);
   }
}

/*TASK*-----------------------------------------------------
*
* Task Name    : service_task
* Comments     :
*    This task creates a task queue and the simulated_ISR_task
*    task. Then it enters an infinite loop, printing "Tick" and
*    suspending the task queue.
*END*-----------------------------------------------------*/

void service_task(uint_32 initial_data)
{
   _task_id second_task_id;

   /* Create a task queue: */
   my_task_queue = _taskq_create(MQX_TASK_QUEUE_FIFO);
   if (my_task_queue == NULL) {
      _mqx_exit(0);
```

```
    }

    /* Create the task: */
    second_task_id = _task_create(0, ISR_TASK, 0);
       if (second_task_id == MQX_NULL_TASK_ID) {
          printf("\n Could not create simulated_ISR_task\n");
          _mqx_exit(0);
       }

    while (TRUE) {
          printf(" Tick \n");
         _taskq_suspend(my_task_queue);
    }
}
```

3.7.8.4.2 Compiling the Application and Linking It with MQX

1. Go to this directory:
   `mqx\examples\taskq`
2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.8 Communication Between Processors

With the inter-processor communication (IPC) component, tasks can do the following on remote processors:

- exchange messages
- create tasks (blocked or not blocked)
- destroy tasks
- open and close named event groups
- set event bits in named event groups

All the processors need not be directly connected or be of the same type. The IPC component routes messages through intermediate processors and converts them to the appropriate endian format. The IPC component communicates over packet control block (PCB) device drivers.

When MQX with the IPC component initializes, it initializes IPC message drivers and builds message routing tables, which define the paths that messages take to go from one processor to another. For information that might be specific to your hardware, refer to the release notes that accompany your MQX release.

Table 3-20. Summary: Setting Up Inter-Processor Communication

_ipc_add_ipc_handler	Adds an IPC handler for an MQX component.
_ipc_add_io_ipc_handler	Adds an IPC handler for an I/O component.
_ipc_msg_route_add	Adds a route to the message routing table.
_ipc_msg_route_remove	Removes a route from the message routing table.
_ipc_pcb_init	Initializes an IPC for a PCB driver.
_ipc_task	Task that initializes IPCs, and processes remote service requests.

3.8.1 Sending Messages to Remote Processors

As well as having a message routing table, each processor has one or more IPCs, each of which consists of:

- input function
- output function
- output queue

When a task sends a message to a message queue, MQX examines the destination processor number, which is part of the queue ID. If the destination processor is not local, MQX checks the routing table.

If there is a route, the table indicates the output queue of the IPC to use, in order to reach the destination processor. MQX then directs the message to that output queue. The output function runs and transmits the message on the IPC.

When an IPC receives a message, the input function runs. The input function assembles the message and calls **_msgq_send()**. The input function needs not to determine, whether the input message is for the local processor. If the message is not for the local processor, MQX routes the message to the destination processor.

3.8.1.1 Example: Four-Processor Application

The diagram shows a simple, four-processor application. The numbers in the table are arbitrary, but processor-unique, output queue numbers.

Each processor has two IPCs. There are two possible routes between each processor; for example, processor one has one IPC to processor two, and one to processor four. The routing table supports one route, so the best route should be selected. The table illustrates one possibility for each of the processor's routing tables.

3.8.1.1.1 Routing Table for Processor 1

Source processor	Destination processor			
	1	2	3	4
1	—	10	10	11
2	21	—	20	20
3	31	31	—	30
4	40	41	41	—

As in the table, when a task on processor one sends a message to a message queue on processor three, MQX sends the message from processor one to processor two using queue ten, and then from processor two to processor three using queue 20. When the IPC on processor three receives the message, MQX directs the message to the destination (target) message queue.

3.8.2 Creating and Destroying Tasks on Remote Processors

With IPC component, a task can create and destroy tasks on a remote processor by sending service requests to IPC task on that processor. IPC task runs the request, and responds to the requesting processor.

3.8.3 Accessing Event Groups on Remote Processors

With the IPC component, a task can open and close a named event group on a remote processor and set event bits in the event group. However, a task cannot wait for event bits on a remote processor.

Event groups are opened on remote processors by specifying the processor number (followed by a colon) in the name of the event. The following example would open the event Fred on processor number four:

```
_event_open("4:fred", &handle);
```

3.8.4 Creating and Initializing IPC

For tasks to communicate across processors, the application must create and initialize the IPC component on each processor, as summarized in the following steps. Each step is described in subsequent sections using information from the routing table previous example.

1. Build the IPC routing table.
2. Build the IPC protocol initialization table.
3. Provide IPC protocol initialization functions and data.
4. Create IPC task (**_ipc_task()**).

3.8.4.1 Building an IPC Routing Table

The IPC routing table defines the routes for inter-processor messages. There is one routing table per processor and it is called _ipc_routing_table. In the previous example, on processor two, messages for processor one are directed to queue number 20; messages for processors three and four are directed to queue number 21.

The routing table is an array of routing structures and ends with a zero-filled entry.

```
typedef struct ipc_routing_struct
{
  _processor_number  MIN_PROC_NUMBER;
  _processor_number  MAX_PROC_NUMBER;
  _queue_number      QUEUE;
} IPC_ROUTING_STRUCT, _PTR_ IPC_ROUTING_STRUCT_PTR;
```

The fields are described in *MQX Reference*.

3.8.4.1.1 Routing Table for Processor One

```
IPC_ROUTING_STRUCT _ipc_routing_table[] =
   { {2, 3, 10},
     {4, 4, 11},
     {0, 0, 0}};
```

3.8.4.1.2 Routing Table for Processor Two

```
IPC_ROUTING_STRUCT _ipc_routing_table[] =
   { {1, 1, 21},
     {3, 4, 20},
     {0, 0, 0}};
```

3.8.4.1.3 Routing Table for Processor Three

```
IPC_ROUTING_STRUCT _ipc_routing_table[] =
   { {1, 2, 31},
     {4, 4, 30},
     {0, 0, 0}};
```

3.8.4.1.4 Routing Table for Processor Four

```
IPC_ROUTING_STRUCT _ipc_routing_table[] =
   { {1, 1, 40},
     {2, 3, 41},
     {0, 0, 0}};
```

3.8.4.2 Building an IPC Protocol Initialization Table

The IPC protocol initialization table defines and initializes the protocols that implement the IPC. Each IPC output queue in the routing table refers to an IPC that must have a corresponding entry in the protocol initialization table, defining the protocol and communication path that implement the IPC.

NOTE	The **IPC_OUT_QUEUE** field in **IPC_PROTOCOL_INIT_STRUCT** must match the **QUEUE** field in **IPC_ROUTING_STRUCT**.

The protocol initialization table is an array of protocol initialization structures and ends with a zero-filled entry.

```
typedef struct ipc_protocol_init_struct
{
  _mqx_uint (_CODE_PTR_  IPC_PROTOCOL_INIT)(
              struct ipc_protocol_init_struct _PTR_ ipc_init_ptr,
              pointer ipc_info_ptr);
              pointer ipc_info_ptr);
  pointer                IPC_PROTOCOL_INIT_DATA;
  char _PTR_             IPC_NAME;
  _queue_number          IPC_OUT_QUEUE;
} IPC_PROTOCOL_INIT_STRUCT, _PTR_ IPC_PROTOCOL_INIT_STRUCT_PTR;
```

The fields are described in MQX Reference.

When MQX with the IPC component initializes, it calls the **IPC_PROTOCOL_INIT** function for each IPC in the table. It passes to the IPC the **IPC_PROTOCOL_INIT_DATA**, which contains IPC-specific initialization information.

3.8.4.3 IPC Using I/O PCB Device Drivers

While you can develop special-purpose IPCs, MQX provides a standard IPC that is built on I/O packet control block (PCB) device drivers.

Using this IPC, an application can use any I/O PCB device driver to receive and send messages (See Section 3.8.4.5, “Example: IPC Initialization Information”).

Here is an **IPC_PROTOCL_INIT_STRUCT** that is set up to use the standard MQX IPC over PCB device drivers:

```
{ _ipc_pcb_init, &pcb_init, "Pcb_to_test2", QUEUE_TO_TEST2 },
   { NULL, NULL, NULL, 0}
```

3.8.4.4 Starting IPC Task

IPC task examines the IPC protocol initialization table and starts the IPC server, which initializes each IPC driver. The IPC server accepts messages from other processors to perform remote procedure calls.

The application must define IPC task as an autostart task in the MQX initialization structure for each processor. The task template for IPC task is:

```
{ IPC_TTN, _ipc_task, IPC_DEFAULT_STACK_SIZE, 6,
  "_ipc_task", 0, 0L, 0}
```

3.8.4.5 Example: IPC Initialization Information

In this example, two processors set up IPC communication over an asynchronous serial port using the PCB device drivers that accompany MQX. Each processor is connected by interrupt-driven asynchronous character device drivers "ittyb:". The IPC uses the PCB_MQXA driver, which sends and receives packets that have an MQX-defined format.

The ipc_init_table uses the MQX IPC over PCB I/O driver initialization function **_ipc_pcb_init()** and the data structure needed for its initialization, pcb_init, which defines:

- The PCB I/O driver name to use when opening the driver.
- The installation function to call, in this case **_io_pcb_mqxa_install()** (needs not to be specified, if the PCB I/O driver was previously installed).
- The PCB I/O driver-specific initialization pcb_mqxa_init.

3.8.4.5.1 IPC Initialization Information

```
/* ipc_ex.h */

#define TEST_ID            1
#define IPC_TTN            9
#define MAIN_TTN          10
#define QUEUE_TO_TEST2    63
#define MAIN_QUEUE        64
#define TEST2_ID           2
#define RESPONDER_TTN     11
#define QUEUE_TO_TEST     67
#define RESPONDER_QUEUE   65

typedef struct the_message
{
   MESSAGE_HEADER_STRUCT  HEADER;
   uint_32                DATA;
} THE_MESSAGE, _PTR_ THE_MESSAGE_PTR;
```

3.8.4.5.2 Code for Processor One

```
/* ipc1.c */

#include <mqx.h>
#include <bsp.h>
#include <message.h>
#include <ipc.h>
#include <ipc_pcb.h>
#include <io_pcb.h>
#include <pcb_mqxa.h>
#include "..\ipc_ex.h"

extern void main_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
  { IPC_TTN,  _ipc_task, IPC_DEFAULT_STACK_SIZE, 6,
    "_ipc_task", MQX_AUTO_START_TASK, 0, 0},
  { MAIN_TTN, main_task, 2000,                   8,
    "Main",      MQX_AUTO_START_TASK, 0, 0},
  { 0,        0,         0,                      0,
    0,           0,                    0, 0 }
};

MQX_INITIALIZATION_STRUCT  MQX_init_struct =
{
  TEST_ID,
```

```
  BSP_DEFAULT_START_OF_KERNEL_MEMORY,
  BSP_DEFAULT_END_OF_KERNEL_MEMORY,
  BSP_DEFAULT_INTERRUPT_STACK_SIZE,
  (pointer)MQX_template_list,
  BSP_DEFAULT_MQX_HARDWARE_INTERRUPT_LEVEL_MAX,
  BSP_DEFAULT_MAX_MSGPOOLS,
  BSP_DEFAULT_MAX_MSGQS,
  BSP_DEFAULT_IO_CHANNEL,
  BSP_DEFAULT_IO_OPEN_MODE
};

IPC_ROUTING_STRUCT _ipc_routing_table[] =
{
   { TEST2_ID, TEST2_ID, QUEUE_TO_TEST2 },
   { 0, 0, 0 }
};

IO_PCB_MQXA_INIT_STRUCT pcb_mqxa_init =
{
   /* IO_PORT_NAME */          "ittyb:",
   /* BAUD_RATE    */          19200,
   /* IS POLLED */             FALSE,
   /* INPUT MAX LENGTH */      sizeof(THE_MESSAGE),
   /* INPUT TASK PRIORITY */   7,
   /* OUPUT TASK PRIORITY */   7
};

IPC_PCB_INIT_STRUCT pcb_init =
{
   /* IO_PORT_NAME */             "pcb_mqxa_ittyb:",
   /* DEVICE_INSTALL? */          _io_pcb_mqxa_install,
   /* DEVICE_INSTALL_PARAMETER*/  (pointer)&pcb_mqxa_init,
   /* IN_MESSAGES_MAX_SIZE */     sizeof(THE_MESSAGE),
   /* IN MESSAGES_TO_ALLOCATE */  8,
   /* IN MESSAGES_TO_GROW */      8,
   /* IN_MESSAGES_MAX_ALLOCATE */ 16,
   /* OUT_PCBS_INITIAL */         8,
   /* OUT_PCBS_TO_GROW */         8,
   /* OUT_PCBS_MAX */             16
};

IPC_PROTOCOL_INIT_STRUCT _ipc_init_table[] =
{
   { _ipc_pcb_init, &pcb_init, "Pcb_to_test2", QUEUE_TO_TEST2 },
   { NULL, NULL, NULL, 0}
};

/*TASK*-----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*     This task creates a message pool and a message queue then
*     sends a message to a queue on the second CPU.
*     It waits for a return message, validating the message before
*     sending a new message.
*END*-----------------------------------------------------------*/
```

```
void main_task
   (
      uint_32 dummy
   )
{
   _pool_id        msgpool;
   THE_MESSAGE_PTR msg_ptr;
   _queue_id       qid;
   _queue_id       my_qid;
   uint_32         test_number = 0;

   my_qid  = _msgq_open(MAIN_QUEUE,0);
   qid     = _msgq_get_id(TEST2_ID,RESPONDER_QUEUE);
   msgpool = _msgpool_create(sizeof(THE_MESSAGE), 8, 8, 16);
   while (test_number < 64) {
      msg_ptr = (THE_MESSAGE_PTR)_msg_alloc(msgpool);
      msg_ptr->HEADER.TARGET_QID = qid;
      msg_ptr->HEADER.SOURCE_QID = my_qid;
      msg_ptr->DATA = test_number++;
      putchar('-');
      _msgq_send(msg_ptr);
      msg_ptr = _msgq_receive(MSGQ_ANY_QUEUE, 10000);
      if (msg_ptr == NULL) {
         puts("Receive failed\n");
         _mqx_exit(1);
      } else if (msg_ptr->HEADER.SIZE != sizeof(THE_MESSAGE)) {
         puts("Message wrong size\n");
         _mqx_exit(1);
      } else if (msg_ptr->DATA != test_number) {
         puts("Message data incorrect\n");
         _mqx_exit(1);
      }
      _msg_free(msg_ptr);
   }
   puts("All complete\n");
   _mqx_exit(0);
}
```

3.8.4.5.3 Code for Processor Two

```
/* ipc2.c */

#include <mqx.h>
#include <bsp.h>
#include <message.h>
#include <ipc.h>
#include <ipc_pcb.h>
#include <io_pcb.h>
#include <pcb_mqxa.h>
#include "ipc_ex.h"

extern void responder_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
  { IPC_TTN,       _ipc_task,      IPC_DEFAULT_STACK_SIZE, 6,
     "_ipc_task", MQX_AUTO_START_TASK, 0L, 0},
```

```
  { RESPONDER_TTN, responder_task, 2000,                   9,
     "Responder", MQX_AUTO_START_TASK, 0, 0},
  { 0,             0,              0,                      0,
     0,            0,                   0, 0 }
};

MQX_INITIALIZATION_STRUCT  MQX_init_struct =
{
   TEST2_ID,
   BSP_DEFAULT_START_OF_KERNEL_MEMORY,
   BSP_DEFAULT_END_OF_KERNEL_MEMORY,
   BSP_DEFAULT_INTERRUPT_STACK_SIZE,
  (pointer)MQX_template_list,
   BSP_DEFAULT_MQX_HARDWARE_INTERRUPT_LEVEL_MAX,
   BSP_DEFAULT_MAX_MSGPOOLS,
   BSP_DEFAULT_MAX_MSGQS,
   BSP_DEFAULT_IO_CHANNEL,
   BSP_DEFAULT_IO_OPEN_MODE
};

IPC_ROUTING_STRUCT _ipc_routing_table[] =
{
   { TEST_ID, TEST_ID, QUEUE_TO_TEST },
   { 0, 0, 0 }
};

IO_PCB_MQXA_INIT_STRUCT pcb_mqxa_init =
{
   /* IO_PORT_NAME */          "ittyb:",
   /* BAUD_RATE    */          19200,
   /* IS POLLED */             FALSE,
   /* INPUT MAX LENGTH */      sizeof(THE_MESSAGE),
   /* INPUT TASK PRIORITY */   7,
   /* OUTPUT TASK PRIORITY */  7
};

IPC_PCB_INIT_STRUCT pcb_init =
{
   /* IO_PORT_NAME */             "pcb_mqxa_ittyb:",
   /* DEVICE_INSTALL? */          _io_pcb_mqxa_install,
   /* DEVICE_INSTALL_PARAMETER*/  &pcb_mqxa_init,
   /* IN_MESSAGES_MAX_SIZE */     sizeof(THE_MESSAGE),
   /* IN MESSAGES_TO_ALLOCATE */  8,
   /* IN MESSAGES_TO_GROW */      8,
   /* IN_MESSAGES_MAX_ALLOCATE */ 16,
   /* OUT_PCBS_INITIAL */         8,
   /* OUT_PCBS_TO_GROW */         8,
   /* OUT_PCBS_MAX */             16
};

IPC_PROTOCOL_INIT_STRUCT _ipc_init_table[] =
{
   { _ipc_pcb_init, &pcb_init, "Pcb_to_test", QUEUE_TO_TEST },
   { NULL, NULL, NULL, 0}
};

/*TASK*-----------------------------------------------------
```

```
*
* Task Name : responder_task
* Comments  :
*     This task creates a message queue then waits for a message.
*     Upon receiving the message the data is incremented before
*     the message is returned to the sender.
*END*-----------------------------------------------------------*/

void responder_task(uint_32 dummy) {
   THE_MESSAGE_PTR    msg_ptr;
   _queue_id          qid;
   _queue_id          my_qid;

   puts("Receiver running...\n");
   my_qid = _msgq_open(RESPONDER_QUEUE, 0);
   while (TRUE) {
      msg_ptr = _msgq_receive(MSGQ_ANY_QUEUE, 0);
      if (msg_ptr != NULL) {
         qid      = msg_ptr->HEADER.SOURCE_QID;
         msg_ptr->HEADER.SOURCE_QID = my_qid;
         msg_ptr->HEADER.TARGET_QID = qid;
         msg_ptr->DATA++;
         putchar('+');
         _msgq_send(msg_ptr);
      } else {
         puts("RESPONDER RECEIVE ERROR\n");
         _mqx_exit(1);
      }
   }
}
```

3.8.4.5.4 Compiling the Application and Linking It with MQX

1. Refer to your MQX Release Notes document for instructions on how to build and run the application.
2. Go to this directory to compile for processor one:

   `mqx\examples\ipc\cpu1\`

3. Build the project.
4. Go to this directory to compile for processor two:

   `mqx\examples\ipc\cpu2\`

5. Build the project.
6. Connect ttyb: of processor one to ttyb: of processor two.
7. Run the applications according to the instructions in the release notes.
   Start processor two before processor one.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.8.5 Endian Conversion of Message Headers

When a processor receives a message from a remote processor, the IPC input function examines the **CONTROL** field in the message header to determine, whether the message is from a processor that uses the other endian format. If the message is, the input function converts the message header to the local processor's own endian format, and sets the **CONTROL** field to specify its endian format.

```
MESSAGE_HEADER_STRUCT  msg_ptr;
...
if (MSG_MUST_CONVERT_HDR_ENDIAN(msg_ptr->CONTROL)){
   _msg_swap_endian_header(msg_ptr);}
```

CAUTION	The IPC cannot convert the data portion of the message to the other endian format, because it does not know the format of the data. It is the responsibility of the application to convert the data portion of received messages to the other endian format. To check whether conversion is necessary, use the macro **MSG_MUST_CONVERT_DATA_ENDIAN**. To convert the message data, use **_msg_swap_endian_data()**. Both functions are defined in *message.h*. For more information, see MQX Reference.

3.9 Timing

MQX provides the core-time component, which can be extended with optional timer and watchdog components.

3.9.1 Rollover of MQX Time

MQX keeps the time internally as a 64-bit count of the number of tick interrupts, since the application started to run. This provides a very long time before MQX time rolls over. For example, if the tick rate was once per nanosecond, the MQX time rolls over when 584 years have passed.

3.9.2 Accuracy of MQX Time

MQX keeps the time internally as a 64-bit count of the number of tick interrupts, but when an application requests the tick time, the time also includes a 32-bit number that represents the number of hardware "ticks" that have occurred since the last tick interrupt. Typically, MQX reads this value from the hardware counter that is used to program the timer. As a result, the application receives the time as accurately, as it can possibly be determined.

3.9.3 Time Component

Time is a core component that offers time as elapsed time and absolute time, expressed as seconds and milliseconds (second/millisecond time), as ticks (tick time), or as a date (date time and extended date time).

Table 3-21. Summary: Using the Time Component

_ticks_to_time	Converts tick time to second/millisecond time.
_time_add_day_to_ticks	Adds days to tick time.
_time_add_hour_to_ticks	Adds hours to tick time.
_time_add_min_to_ticks	Adds minutes to tick time.
_time_add_msec_to_ticks	Adds milliseconds to tick time.
_time_add_nsec_to_ticks	Adds nanoseconds to tick time.
_time_add_psec_to_ticks	Adds picoseconds to tick time.
_time_add_sec_to_ticks	Adds seconds to tick time.
_time_add_usec_to_ticks	Adds microseconds to tick time.
_time_delay	Suspends the active task for the specified number of milliseconds.
_time_delay_for	Suspends the active task for the specified tick-time period (including hardware ticks).
_time_delay_ticks	Suspends the active task for the specified number of ticks.
_time_delay_until	Suspends the active task until the specified tick time.
_time_dequeue	Removes a task (specified by its task ID) from the timeout queue.
_time_dequeue_td	Removes a task (specified by its task descriptor) from the timeout queue.
_time_diff	Gets the second/millisecond time difference between two second/millisecond time structures.
_time_diff_days	Gets the time difference in days between two tick times.
_time_diff_hours	Gets the difference in hours between two tick times.
_time_diff_microseconds	Gets the difference in microseconds between two tick times.
_time_diff_milliseconds	Gets the difference in milliseconds between two tick times.
_time_diff_minutes	Gets the difference in minutes between two tick times.
_time_diff_nanoseconds	Gets the difference in nanoseconds between two tick times.
_time_diff_picoseconds	Gets the difference in picoseconds between two tick times.
_time_diff_seconds	Gets the difference in seconds between two tick times.
_time_diff_ticks	Gets the tick-time difference between two tick times.
_time_from_date	Gets second/millisecond time from date time.
_time_get	Gets the absolute time in second/millisecond time.

Table 3-21. Summary: Using the Time Component (continued)

_time_get_ticks	Gets the absolute time in tick time (includes ticks and hardware ticks).
_time_get_elapsed	Gets the second/millisecond time that has elapsed, since the application started on this processor.
_time_get_elapsed_ticks	Gets the tick time that has elapsed, since the application started on this processor.
_time_get_hwticks	Gets the number of hardware ticks since the last tick.
_time_get_hwticks_ per_tick	Gets the number of hardware ticks per tick.
_time_get_microseconds	Gets the calculated number of microseconds, since the last periodic timer interrupt.
_time_get_nanoseconds	Gets the calculated number of nanoseconds, since the last periodic timer interrupt.
_time_get_resolution	Gets the resolution of the periodic timer interrupt.
_time_get_ticks_per_sec	Gets the frequency (in ticks per second) of the clock interrupt.
_time_init_ticks	Initializes a tick-time structure with a number of ticks.
_time_normalize_xdate	Normalizes an extended date structure.
_time_notify_kernel	Called by the BSP, when a periodic timer interrupt occurs.
_time_set	Sets the absolute time in second/millisecond time.
_time_set_hwticks_per_ tick	Sets the number of hardware ticks per tick.
_time_set_ticks	Sets the absolute time in tick time.
_time_set_resolution	Sets the frequency of the periodic timer interrupt.
_time_set_timer_vector	Sets the periodic timer interrupt vector that MQX uses.
_time_set_ticks_per_sec	Sets the frequency (in ticks per second) of the clock interrupt.
_time_ticks_to_xdate	Converts ticks to an extended date since 0:00:00.000 Jan. 1, 1970.
_time_to_date	Converts second/millisecond time to date time.
_time_to_ticks	Converts second/millisecond time to tick time.
_time_xdate_to_ticks	Converts an extended date to ticks since 0:00:00.000 Jan. 1, 1970.

3.9.3.1 Second/Millisecond Time

Time is available in seconds and milliseconds. To process second/millisecond time is more complex and CPU intensive, than processing tick time.

```
typedef struct time_struct
{
  uint_32  SECONDS;
  uint_32  MILLISECONDS;
} TIME_STRUCT, _PTR_ TIME_STRUCT_PTR;
```

The fields are described in MQX Reference.

3.9.3.2 Tick Time

Time is available in tick time. To process tick time is simpler and less CPU intensive, than processing second/millisecond time.

```
typedef struct mqx_tick_struct
{
  _mqx_uint  TICKS[MQX_NUM_TICK_FIELDS];
  uint_32    HW_TICKS;
} MQX_TICK_STRUCT, _PTR_ MQX_TICK_STRUCT_PTR;
```

The fields are described in *MQX Reference*.

3.9.3.3 Elapsed Time

Elapsed time is the amount of time since MQX started on the processor. A task can get the elapsed time in second/millisecond time with **_time_get_elapsed**(), and in tick time with **_time_get_elapsed_ticks**().

3.9.3.4 Time Resolution

When MQX starts, it installs the periodic timer ISR, which sets the time resolution for the hardware. The resolution defines, how often MQX updates time, or how often a tick occurs. The resolution is usually 200 ticks per second or five milliseconds. A task can get the resolution in milliseconds with **_time_get_resolution()** and in ticks per second with **_time_get_resolution_ticks**().

A task can get elapsed time in microsecond resolution by calling **_time_get_elapsed()**, followed by **_time_get_microseconds**(), which gets the number of microseconds since the last periodic timer interrupt.

A task can get elapsed time in nanosecond resolution by calling **_time_get_elapsed()** followed by **_time_get_nanoseconds()**, which gets the number of nanoseconds since the last periodic timer interrupt.

A task can also get the number of hardware ticks since the last interrupt by calling **_time_get_hwticks**(). A task can get the resolution of the hardware ticks by calling **_time_get_hwticks_per_tick()**.

3.9.3.5 Absolute Time

So that the tasks on different processors can exchange information that is timestamped from a common reference, the time component offers absolute time.

Initially, absolute time is the time since the reference date of 0:00:00.000 January 1, 1970. An application can change the absolute time by changing the reference date in second/millisecond time with **_time_set()**, or in tick time with **_time_set_ticks**().

A task gets the absolute time in second/millisecond time with **_time_get()** or in tick time with **_time_get_ticks**().

Unless an application changes the absolute time, the following pairs of functions return the same values:

- **_time_get**() and **_time_get_elapsed**()
- **_time_get_ticks**() and **_time_get_elapsed_ticks**()

CAUTION	A task should use elapsed time to measure an interval or implement a timer. This prevents the measurement from being affected by other tasks that might call **_time_set()** or **_time_set_ticks()**, and thereby change the absolute time.

3.9.3.6 Time in Date Formats

To help you set and interpret absolute time that is expressed in second/millisecond time or tick time, the time component offers time expressed in a date format and an extended date format.

3.9.3.6.1 DATE_STRUCT

```
typedef struct date_struct
{
  uint_16       YEAR;
  uint_16       MONTH;
  uint_16       DAY;
  uint_16       HOUR;
  uint_16       MINUTE;
  uint_16       SECOND;
  uint_16       MILLISEC;
} DATE_STRUCT, _PTR_ DATE_STRUCT_PTR;
```

The fields are described in MQX Reference.

3.9.3.6.2 MQX_XDATE_STRUCT

This structure represents a date in a format that is more detailed than **DATE_STRUCT**. You can convert between **MQX_XDATE_STRUCT** and **MQX_TICK_STRUCT** with **_time_ticks_to_xdate()** and **_time_xdate_to_ticks**().

```
typedef struct mqx_xdate_struct
{
   uint_16 YEAR;
   uint_16 MONTH;
   uint_16 MDAY;
   uint_16 HOUR;
   uint_16 MIN;
   uint_16 SEC;
   uint_16 MSEC;
   uint_16 USEC;
   uint_16 NSEC;
   uint_16 PSEC;
```

```
   uint_16 WDAY;
   uint_16 YDAY;
} MQX_XDATE_STRUCT, _PTR_ MQX_XDATE_STRUCT_PTR;
```

The fields are described in MQX Reference.

3.9.3.7 Timeouts

A task can supply the time as a timeout parameter to several MQX components, for example, functions in the **_msgq_receive** and **_sem_wait** families. A task can also explicitly suspend itself by calling a function from the **_time_delay** family. When the time expires, MQX puts the task in the task's ready queue.

3.9.4 Timers

Timers are an optional component that extends the core-time component. An application can use timers:

- To cause a notification function to run at a specific time — when MQX creates the timer component, it starts Timer task, which maintains timers and their application-defined notification functions. When a timer expires, Timer Task calls the appropriate notification function.
- To communicate that a time period has expired.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Timer component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

A task can start a timer at a specific time or at some specific time after the current time. Timers can use elapsed time or absolute time.

There are two types of timers:

- One-shot timers, which expire once.
- Periodic timers, which expire repeatedly at a specified interval. When a periodic timer expires, MQX resets the timer.

Table 3-22. Summary: Using Timers

Timers use certain structures and constants, which are defined in *timer.h.*	
_timer_cancel	Cancels an outstanding timer request.
_timer_create_component	Creates the timer component.
_timer_start_oneshot_after	Starts a timer that expires once after a time delay in milliseconds.
_timer_start_oneshot_after_ticks	Starts a timer that expires once after a time delay in ticks.
_timer_start_oneshot_at	Starts a timer that expires once at a specific time (in second/millisecond time).

Table 3-22. Summary: Using Timers (continued)

_timer_start_oneshot_at_ticks	Starts a timer that expires once at a specific time (in tick time).
_timer_start_periodic_at	Starts a periodic timer at a specific time (in second/millisecond time).
_timer_start_periodic_at_ticks	Starts a periodic timer at a specific time (in tick time).
_timer_start_periodic_every	Starts a periodic timer every number of milliseconds.
_timer_start_periodic_every_ ticks	Starts a periodic timer every number of ticks.
_timer_test	Tests the timer component.

3.9.4.1 Creating the Timer Component

You can explicitly create the timer component by calling **_timer_create_component()** with the priority and stack size for Timer task, which MQX creates, when it creates the timer component. Timer task manages timer queues and provides a context for notification functions.

If you do not explicitly create the timer component, MQX creates it with default values the first time an application starts a timer.

Parameter	Default
Priority of Timer task	1
Stack size for Timer task	500

3.9.4.2 Starting Timers

A task starts a timer with one of the following:

- **_timer_start_oneshot_after()**, **_timer_start_oneshot_after_ticks()**
- **_timer_start_oneshot_at()**, **_timer_start_oneshot_at_ticks()**
- **_timer_start_periodic_at()**, **_timer_start_periodic_at_ticks()**
- **_timer_start_periodic_every()**, **_timer_start_periodic_every_ticks()**

When a task calls one of these functions, MQX inserts a timer request into the queue of outstanding timers. When the timer expires, the notification function runs.

CAUTION	The stack space for Timer task should include the stack space that the notification function needs.

3.9.4.3 Cancelling Outstanding Timer Requests

A task can cancel an outstanding timer request by calling **_timer_cancel()** with the timer handle that was returned from one of the **_timer_start** family of functions.

3.9.4.4 Example: Using Timers

Simulate a LED being turned on and off every second. One timer turns the LED on, and another turns it off. The timers expire every two seconds, offset by one second.

3.9.4.4.1 Code for Timer Example

```
/* main.c */

#include <mqx.h>
#include <bsp.h>
#include <fio.h>
#include <timer.h>

#define TIMER_TASK_PRIORITY  2
#define TIMER_STACK_SIZE     1000

#define MAIN_TASK   10

extern void main_task(uint_32);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   {MAIN_TASK, main_task, 2000, 8, "Main", MQX_AUTO_START_TASK,
     0L, 0},
   {0,         0,          0,     0,  0,      0,
     0L, 0 }
};

/*FUNCTION*------------------------------------------------------
*
* Function Name  : LED_on
* Returned Value : none
* Comments       :
*     This timer function prints "ON"
*END*-------------------------------------------------------------*/

void LED_on
   (
      _timer_id id,
      pointer data_ptr,
      MQX_TICK_STRUCT_PTR tick_ptr
   )
{
   printf("ON\n");
}

/*FUNCTION*------------------------------------------------------
*
* Function Name  : LED_off
* Returned Value : none
* Comments       :
*     This timer function prints "OFF"
*END*-------------------------------------------------------------*/

void LED_off
   (
```

```
      _timer_id id,
      pointer data_ptr,
      MQX_TICK_STRUCT_PTR tick_ptr
   )
{
   printf("OFF\n");
}

/*TASK*-----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*     This task creates two timers, each of a period of 2 seconds,
*     the second timer offset by 1 second from the first.
*END*------------------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   MQX_TICK_STRUCT ticks;
   MQX_TICK_STRUCT dticks;
   _timer_id       on_timer;
   _timer_id       off_timer;

   /*
   ** Create the timer component with more stack than the default
   ** in order to handle printf() requirements:
   */
   _timer_create_component(TIMER_DEFAULT_TASK_PRIORITY, 1024);

   _time_init_ticks(&dticks, 0);
   _time_add_sec_to_ticks(&dticks, 2);

   _time_get_ticks(&ticks);
   _time_add_sec_to_ticks(&ticks, 1);
   on_timer = _timer_start_periodic_at_ticks(LED_on, 0,
      TIMER_ELAPSED_TIME_MODE, &ticks, &dticks);
   _time_add_sec_to_ticks(&ticks, 1);
   off_timer = _timer_start_periodic_at_ticks(LED_off, 0,
      TIMER_ELAPSED_TIME_MODE, &ticks, &dticks);

   _time_delay_ticks(600);
   printf("\nThe task is finished!");

   _timer_cancel(on_timer);
   _timer_cancel(off_timer);

   _mqx_exit(0);
}
```

3.9.4.4.2 Compiling the Application and Linking It with MQX

1. Go to this directory:

```
mqx\examples\timer
```

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

A message is printed each time the timer notification function runs.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.9.5 Lightweight Timers

Lightweight timers are an optional component that extends the core time component. Lightweight timers provide periodic notification to the application.

A task can create a periodic queue and add timers to it. The timers expire at the same rate as the queue's period, but offset from the period's expiry time.

Table 3-23. Summary: Using Lightweight Timers

Lightweight timers use certain structures and constants, which are defined in *lwtimer.h.*	
_lwtimer_add_timer_to_queue	Adds a lightweight timer to a periodic queue.
_lwtimer_cancel_period	Removes all the timers from a periodic queue.
_lwtimer_cancel_timer	Removes a timer from a periodic queue.
_lwtimer_create_periodic_queue	Creates a periodic queue (with a period of a specified number of ticks), to which lightweight timers can be added.
_lwtimer_test	Tests all the periodic queues and their timers.

3.9.5.1 Starting Lightweight Timers

A task starts a lightweight timer by first creating a periodic queue by calling **_lwtimer_create_periodic_queue()** with a pointer to a variable of type **LWTIMER_PERIOD_STRUCT**, which specifies the queue's period (in ticks). It then adds a timer to the queue by calling **_lwtimer_add_timer_to_queue()** with the address of the periodic queue variable and a pointer to a variable of type **LWTIMER_STRUCT**, which specifies the function that is called when the timer expires.

When the timer expires, the notification function specified by the timer runs.

CAUTION	Because the notification function runs in the context of the kernel timer ISR, it is subject to the same restrictions as the ISR (see page 107). The MQX interrupt stack size should include the stack space that the notification function needs.

3.9.5.2 Cancelling Outstanding Lightweight Timer Requests

A task can cancel an outstanding lightweight timer request by calling **_lwtimer_cancel_timer()** with the address of the **LWTIMER_STRUCT**.

A task can cancel all the timers on a lightweight timer queue by calling **_lwtimer_cancel_period()** with the address of the **LWTIMER_PERIOD_STRUCT**.

3.9.6 Watchdogs

Most embedded systems have a hardware watchdog timer. If the application does not reset the timer within a certain time (perhaps because of deadlock or some other error condition), the hardware generates a reset operation. As such, a hardware watchdog timer monitors the entire application on a processor; it does not monitor individual tasks.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Watchdog component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, “Rebuilding Freescale MQX RTOS” for more details.

The MQX watchdog component provides a software watchdog for each task. If a single task starves or runs beyond certain timing constraints, the watchdog provides a way to detect the problem. Initially, the task starts its watchdog with a specific time value, and if the task fails to stop or restart the watchdog before that time expires, MQX calls a processor-unique, application-supplied expiry function that can initiate error recovery.

Table 3-24. Summary: Using Watchdogs

Watchdogs use certain structures and constants, which are defined in *watchdog.h.*	
_watchdog_create_component	Creates the watchdog component.
_watchdog_start	Starts or restarts the watchdog (time is specified in milliseconds).
_watchdog_start_ticks	Starts or restarts the watchdog (time is specified in ticks).
_watchdog_stop	Stops the watchdog.
_watchdog_test	Tests the watchdog component.

3.9.6.1 Creating the Watchdog Component

Before a task can use the watchdog component, the application must explicitly create it by calling **_watchdog_create_component()** with the interrupt vector of the periodic timer device and a pointer to the function that MQX will call, if a watchdog expires.

3.9.6.2 Starting or Restarting a Watchdog

A task starts or restarts its watchdog by calling either:

- **_watchdog_start()** with the number of milliseconds, before the watchdog expires.
- **_watchdog_start_ticks()** with the number of ticks, before the watchdog expires.

If the task does not restart or stop its watchdog before the watchdog expires, MQX calls the expiry function.

3.9.6.3 Stopping a Watchdog

A task can stop its watchdog with **_watchdog_stop()**.

3.9.6.4 Example: Using Watchdogs

A task creates the watchdog component on the periodic timer interrupt vector and specifies the expiry function (**handle_watchdog_expiry()**). Then it starts a watchdog that will expire after two seconds. To prevent its watchdog from expiring, the task must either stop or restart the watchdog within two seconds.

```
/*watchdog.c */

#include <mqx.h>
#include <bsp.h>
#include <watchdog.h>

#define MAIN_TASK       10

extern void    main_task(uint_32);
extern void    handle_watchdog_expiry(pointer);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { MAIN_TASK, main_task, 2000, 8, "Main", MQX_AUTO_START_TASK,
      0L, 0 },
   { 0,         0,         0,     0, 0,     0,
      0L, 0 }
};
/*FUNCTION*------------------------------------------------------
*
* Function Name  : handle_watchdog_expiry
* Returned Value : none
* Comments       :
*     This function is called when a watchdog has expired.
*END*----------------------------------------------------------*/

void handle_watchdog_expiry(pointer td_ptr)
{
```

```
    printf("\nwatchdog expired for task: %p", td_ptr);
}

/*FUNCTION*-----------------------------------------------------
*
* Function Name  : waste_time
* Returned Value : input value times 10
* Comments       :
*     This function loops the specified number of times,
*     essentially wasting time.
*END*---------------------------------------------------------*/

_mqx_uint waste_time
   (
      _mqx_uint n
   )
{
   _mqx_uint          i;
   volatile _mqx_uint result;

   result = 0;
   for (i = 0; i < n; i++) {
      result += 1;
   }
   return result*10;
}

/*TASK*---------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*   This task creates a watchdog, then loops, performing
*   work for longer and longer periods until the watchdog fires.
*END*---------------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   MQX_TICK_STRUCT ticks;
   _mqx_uint       result;
   _mqx_uint       n;

   _time_init_ticks(&ticks, 10);

   result = _watchdog_create_component(BSP_TIMER_INTERRUPT_VECTOR,
      handle_watchdog_expiry);
   if (result != MQX_OK) {
      printf("\nError creating watchdog component");
      _mqx_exit(0);
   }

   n = 100;
   while (TRUE) {
      result = _watchdog_start_ticks(&ticks);
      n = waste_time(n);
```

```
        _watchdog_stop();
        printf("\n %d", n);
    }
}
```

3.9.6.4.1 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\watchdog`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

When the watchdog expires, the Main task prints a message to the output device.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, “Using Freescale CodeWarrior Development Studio” for more details.

3.10 Handling Interrupts and Exceptions

MQX handles hardware interrupts and exceptions with interrupt service routines (ISRs). An ISR is not a task; it is a small, high-speed routine that reacts quickly to hardware interrupts or exceptions. ISRs are usually written in C. The duties of an ISR might include:

- servicing a device
- clearing an error condition
- signaling a task

When MQX calls an ISR, it passes a parameter, which the application defines, when the application installs the ISR. The parameter might, for example, be a pointer to a configuration structure that is specific to the device.

CAUTION	The parameter should not point to data on a task’s stack, because this memory might not be available to the ISR.

The ISR might run with some interrupts disabled, depending on the priority of the interrupt being serviced. Therefore, it is important that the ISR performs a minimal number of functions. The ISR usually causes a task to become ready. It is the priority of this task that then determines, how quickly the information gathered from the interrupting device can be processed. The ISR can ready a task in a number of ways: through events, lightweight semaphores, semaphores, messages, or task queues.

MQX provides a kernel ISR, which is written in assembly language. The kernel ISR runs before any other ISR, and does the following:

- It saves the context of the active task.
- It switches to the interrupt stack.

- It calls the appropriate ISR.
- After the ISR has returned, it restores the context of the highest-priority ready task.

When MQX starts, it installs the default kernel ISR (**_int_kernel_isr()**) for all possible interrupts.

When the ISR returns to the kernel ISR, the kernel ISR performs a task dispatch operation if the ISR readied a task that is of higher priority, than the one that was active at the time of the interrupt. This means that the context of the previously active task is saved, and the higher-priority task becomes the active task.

The following diagram shows, how MQX handles interrupts.

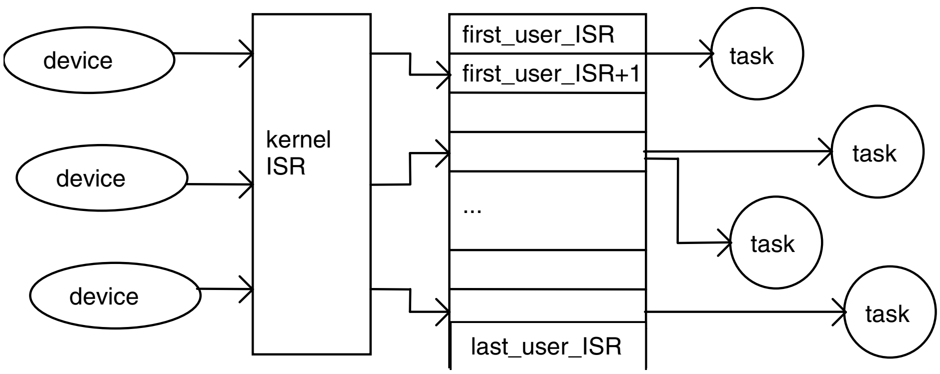


Table 3-25. Summary: Handling Interrupts and Exceptions

_int_disable	Disables hardware interrupts.
_int_enable	Enables hardware interrupts.
_int_get_isr	Gets the ISR for a vector number.
_int_get_isr_data	Gets the data pointer associated with an interrupt.
_int_get_isr_depth	Gets the current ISR nesting depth.
_int_get_kernel_isr	Gets the kernel ISR for an interrupt.
_int_get_previous_vector_ table	Gets a pointer to the interrupt vector table that is stored when MQX starts.
_int_get_vector_table	Gets a pointer to the current interrupt vector table.
_int_install_isr	Installs an application-defined ISR.
_int_install_kernel_isr	Installs a kernel ISR.
_int_install_unexpected_isr	Installs **_int_unexpected_isr()** as the default ISR.
_int_kernel_isr	The default kernel ISR.
_int_set_isr_data	Sets the data associated with a specific interrupt.
_int_set_vector_table	Changes the location of the vector table.

3.10.1 Initializing Interrupt Handling

When the MQX starts, it initializes its ISR table, which has an entry for each interrupt number. Each entry consists of:

- A pointer to the ISR to call.
- Data to pass as a parameter to the ISR.
- A pointer to an exception handler for that ISR.

Initially, the ISR for each entry is the default ISR **_int_default_isr()**, which blocks the active task.

3.10.2 Installing Application-Defined ISRs

With **_int_install_isr()**, an application can replace the ISR with an application-defined, interrupt-specific ISR, which MQX calls, when the interrupt occurs. The application should do the replacement before it initializes the device.

The parameters for **_int_install_isr()** are:

- interrupt number
- pointer to the ISR function
- ISR data
- An application-defined ISR usually signals a task, which can be done by:
  - Setting an event bit (**_event_set**()).
  - Posting a lightweight semaphore (**_lwsem_post**()).
  - Posting a non-strict semaphore (**_sem_post()**).
  - Sending a message to a message queue. An ISR can also receive a message from a system message queue (**_msgq_send** family).

TIP	The most efficient way to allocate a message from an ISR is to use **_msg_alloc()**.

- dequeuing a task from a task queue, which puts the task in the task's ready queue. Task queues let you implement signaling methods that are customized for your application (**_taskq_resume()**).

3.10.3 Restrictions on ISRs

The following table contains information about ISR restrictions.

3.10.3.1 Functions That the ISR Cannot Call

MQX returns an error, if the ISR calls any of the following functions.

Component	Function
Events	**_event_close()** **_event_create()** **_event_create_auto_clear()** **_event_create_component()** **_event_create_fast()** **_event_create_fast_auto_clear()** **_event_destroy()** **_event_destroy_fast()** **_event_wait_all** family **_event_wait_any** family
Lightweight events	**_lwevent_destroy()** **_lwevent_test()** **_lwevent_wait** family
Lightweight logs	**_lwlog_create_component()**
Lightweight semaphores	**_lwsem_test()** **_lwsem_wait()**
Logs	**_log_create_component()**
Messages	**_msg_create_component()** **_msgq_receive** family
Mutexes	**_mutex_create_component()** **_mutex_lock()**
Names	**_name_add()** **_name_create_component()** **_name_delete()**
Partitions	**_partition_create_component()**
Semaphores	**_sem_close()** **_sem_create()** **_sem_create_component()** **_sem_create_fast()** **_sem_destroy()** **_sem_destroy_fast()** **_sem_post()** (for strict semaphores only) **_sem_wait family**
Task queues	**_taskq_create()** **_taskq_destroy()** **_taskq_suspend()** **_taskq_suspend_task()** **_taskq_test()**
Timers	**_timer_create_component()**
Watchdogs	**_watchdog_create_component()**

3.10.3.2 Functions That ISRs Should Not Call

ISRs should not call MQX functions that might block or take a long time to run. These include:

- most functions from the **_io_** family
- **_event_wait** family
- **_int_default_isr()**
- **_int_unexpected_isr()**
- **_klog_display()**
- **_klog_show_stack_usage()**
- **_lwevent_wait** family
- **_lwsem_wait** family
- **_msgq_receive** family
- **_mutatr_set_wait_protocol()**
- **_mutex_lock()**
- **_partition_create_component()**
- **_task_block()**
- **_task_create()** and **_task_create_blocked()**
- **_task_destroy()**
- **_time_delay** family
- **_timer_start** family

3.10.3.3 Non-Maskable Interrupts

Non-Maskable Interrupts (NMI) are defined as interrupts that cannot be disabled (masked) by software. It is possible to use such interrupts in MQX applications, but NMI service routines must be installed directly to vector table as kernel ISRs (use **_int_install_kernel_isr()** instead of _int_install_isr()). The NMI service routines are not allowed to call any MQX API function.

Note that _int_install_kernel_isr() call is only enabled if the vector table is located in RAM memory (see MQX_ROM_VECTORS configuration option in section 3.14, “Configuring MQX at Compile Time”).

3.10.3.4 MQX_HARDWARE_INTERRUPT_LEVEL_MAX Configuration Parameter

On some processor platforms an internal concept of disabling “all interrupt levels” may be re-configured in a way that only interrupt levels up to the MQX_HARDWARE_INTERRUPT_LEVEL_MAX (field in the MQX_INITIALIZATION_STRUCT) are disabled. This effectively enables critical interrupt requests above that maximum level to be serviced asynchronously to MQX kernel execution and with minimum possible latency. From the MQX perspective, such an interrupt is considerred a non-maskable interrupt and the same restrictions as for NMI apply.

The following Table 3-26 summarizes values written into the SR register when switching to the task with the defined priority, considering the value of the MQX_HARDWARE_INTERRUPT_LEVEL_MAX. This table is valid for ColdFire platforms only. As an example, when

MQX_HARDWARE_INTERRUPT_LEVEL_MAX is set to 7 switching to the task with the priority of 4 causes the SR register is loaded by the value of 2. It means that this task can not be interrupted by the interrupts with the priority lower that 3.

Table 3-26. SR Register Values for Different Task Priorities and Different Values of MQX_HARDWARE_INTERRUPT_LEVEL_MAX

MQX_HARDWARE_INTERRUPT_ LEVEL_MAX	Task Priority							
	0	1	2	3	4	5	6	7
0	NOT ALLOWED, EFFECTIVELLY CHANGES TO MQX_HARDWARE_INTERRUPT_LEVEL_MAX=1							
1	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0
3	2	1	0	0	0	0	0	0
4	3	2	1	0	0	0	0	0
5	4	3	2	1	0	0	0	0
6	5	4	3	2	1	0	0	0
7	6	5	4	3	2	1	0	0
8	NOT ALLOWED, EFFECTIVELLY CHANGES TO MQX_HARDWARE_INTERRUPT_LEVEL_MAX=7							

3.10.4 Changing Default ISRs

When MQX handles an interrupt, it calls **_int_kernel_isr()**, which calls a default ISR with the interrupt number, if either of these conditions is true:

- The application has not installed an application-defined ISR for the interrupt number.
- The interrupt number is outside the range of the ISR table.

The application can get a pointer to the default ISR with **_int_get_default_isr**().

The application can change the default ISR as described in the following table.

Default ISR	Description	Modify or install with
_int_default_isr	MQX installs it as the default ISR, when MQX starts. It blocks the task.	To modify: **_int_install_default_ isr()**
_int_exception_isr	Implements MQX exception handling.	To install: **_int_install_exception_ isr()**
_int_unexpected_ isr	Similar to **_int_default_isr()**, but also prints a message to the default console, identifying the unhandled interrupt.	To install: **_int_install_unexpected_ isr()**

3.10.5 Handling Exceptions

To implement MQX exception handling, an application should call **_int_install_exception_isr()**, which installs **_int_exception_isr()** as the default ISR. Thus, **_int_exception_isr()** is called, when an exception or unhandled interrupt occurs. The function **_int_exception_isr()** does the following when an exception occurs:

- If the exception occurs when a task is running and a task exception ISR exists, MQX runs the ISR; if a task exception ISR does not exist, MQX aborts the task by calling **_task_abort()**.
- If the exception occurs when an ISR is running and an ISR exception ISR exists, MQX aborts the running ISR and runs the ISR's exception ISR.
- The function walks the interrupt stack looking for information about the ISR or task that was running before the exception occurred..

CAUTION	If the MQX exception ISR determines that the interrupt stack contains incorrect information, it calls **_mqx_fatal_error()** with error code **MQX_CORRUPT_INTERRUPT_STACK**.

3.10.6 Handling ISR Exceptions

An application can install an ISR exception handler for each ISR. If an exception occurs while the ISR is running, MQX calls the handler and terminates the ISR. If the application has not installed an exception handler, MQX simply terminates the ISR.

When MQX calls the exception handler, it passes:

- current ISR number
- data pointer for the ISR
- exception number
- address on the stack of the exception frame

Table 3-27. Summary: Handling ISR Exceptions

_int_get_exception_handler	Gets a pointer to the current exception handler for the ISR.
_int_set_exception_handler	Sets the address of the current ISR exception handler for the interrupt.

3.10.7 Handling Task Exceptions

A task can install a task-exception handler, which MQX calls, if the task causes an exception that is not supported.

Table 3-28. Summary: Handling Task Exceptions

_task_get_exception_handler	Gets the task-exception handler.
_task_set_exception_handler	Sets the task-exception handler.

3.10.8 Example: Installing an ISR

Install an ISR to intercept the kernel timer interrupt. Chain the ISR to the previous ISR, which is the BSP-provided periodic timer ISR.

```
/* isr.c */

#include <mqx.h>
#include <bsp.h>

#define MAIN_TASK       10
extern void main_task(uint_32);
extern void new_tick_isr(pointer);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { MAIN_TASK, main_task, 2000, 8, "Main",
      MQX_AUTO_START_TASK, 0L, 0 },
   { 0,         0,         0,     0, 0,
      0,                   0L, 0 }
};

typedef struct
{
   pointer  OLD_ISR_DATA;
   void     (_CODE_PTR_ OLD_ISR)(pointer);
   _mqx_uint  TICK_COUNT;
} MY_ISR_STRUCT, _PTR_ MY_ISR_STRUCT_PTR;

/*ISR*-----------------------------------------------------------
*
* ISR Name : new_tick_isr
* Comments :
*   This ISR replaces the existing timer ISR, then calls the
*   old timer ISR.
*END*-----------------------------------------------------------*/

void new_tick_isr
   (
      pointer user_isr_ptr
   )
{
   MY_ISR_STRUCT_PTR  isr_ptr;

   isr_ptr = (MY_ISR_STRUCT_PTR)user_isr_ptr;
   isr_ptr->TICK_COUNT++;

   /* Chain to previous notifier */
   (*isr_ptr->OLD_ISR)(isr_ptr->OLD_ISR_DATA);
}

/*TASK*----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*   This task installs a new ISR to replace the timer ISR.
*   It then waits for some time, finally printing out the
```

```
*   number of times the ISR ran.
*END*-----------------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   MY_ISR_STRUCT_PTR  isr_ptr;

   isr_ptr = _mem_alloc_zero(sizeof(MY_ISR_STRUCT));

   isr_ptr->TICK_COUNT   = 0;
   isr_ptr->OLD_ISR_DATA =
      int_get_isr_data(BSP_TIMER_INTERRUPT_VECTOR);
   isr_ptr->OLD_ISR      =
      int_get_isr(BSP_TIMER_INTERRUPT_VECTOR);

   _int_install_isr(BSP_TIMER_INTERRUPT_VECTOR, new_tick_isr,
      isr_ptr);

   _time_delay_ticks(200);

   printf("\nTick count = %d\n", isr_ptr->TICK_COUNT);

   _mqx_exit(0);
}
```

3.10.8.1 Compiling the Application and Linking It with MQX

1. Go to this directory:
   `mqx\examples\isr`
2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

Main task displays the number of times the application ISR was called.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.11 Instrumentation

Instrumentation includes the following components:

- logs
- lightweight logs
- kernel log
- stack usage utilities

3.11.1 Logs

Many real-time applications need to record information about significant conditions, such as events, state transitions, or function entry and exit information. If the application records the information as it occurs, you can analyze the sequence to determine whether the application processed conditions correctly. If each piece of information has a timestamp (in absolute time), you can determine, where the application spends processing time, and therefore, which code should be optimized.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Log component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

With the log component, you can store data into and retrieve it from a maximum of 16 logs. Each log has a predetermined number of entries. Each entry contains a timestamp (in absolute time), a sequence number, and application-defined data.

Table 3-29. Summary: Using Logs

Logs use certain structures and constants, which are defined in *log.h.*	
_log_create	Creates a log.
_log_create_component	Creates the log component.
_log_destroy	Destroys a log.
_log_disable	Disables logging.
_log_enable	Enables logging.
_log_read	Reads from a log.
_log_reset	Resets the contents of a log.
_log_test	Tests the log component.
_log_write	Writes to a log.

3.11.1.1 Creating the Log Component

You can explicitly create the log component with **_log_create_component()**. If you do not explicitly create it, MQX creates it the first time an application creates a log or kernel log.

3.11.1.2 Creating a Log

To create a log, a task calls **_log_create()** and specifies:

- Log number, in range of zero through 15.
- Maximum number of **_mqx_uint** quantities to be stored in the log (this includes headers).
- What happens when the log is full. The default behavior is that no additional data is written. Another behavior is that new entries overwrite the oldest ones.

3.11.1.3 Format of a Log Entry

Each log entry consists of a log header (**LOG_ENTRY_STRUCT**), followed by application-defined data.

```
typedef struct
{
  _mqx_uint  SIZE;
  _mqx_uint  SEQUENCE_NUMBER;
  uint_32    SECONDS;
  uint_16    MILLISECONDS;
  uint_16    MICROSECONDS;
} LOG_ENTRY_STRUCT, _PTR_ LOG_ENTRY_STRUCT_PTR;
```

The fields are described in *MQX Reference*.

3.11.1.4 Writing to a Log

Tasks write to a log with **_log_write**().

3.11.1.5 Reading From a Log

Tasks read from a log by calling **_log_read()**, and specifying, how to read the log. Possible ways to read the log are:

- To read the newest entry.
- To read the oldest entry.
- To read the next entry from the previous one read (used with read oldest).
- To read the oldest entry and delete it.

3.11.1.6 Disabling and Enabling Writing to a Log

Any task can disable logging to a specific log with **_log_disable**(). Any task can subsequently enable logging to the log with **_log_enable**().

3.11.1.7 Resetting a Log

A task can reset the contents of a log to its initial state of no data with **_log_reset**().

3.11.1.8 Example: Using Logs

```
/* log.c */
#include <mqx.h>
#include <bsp.h>
#include <log.h>

#define MAIN_TASK  10
#define MY_LOG     1
extern void main_task(uint_32 initial_data);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { MAIN_TASK, main_task, 2000, 8, "Main",
      MQX_AUTO_START_TASK, 0, 0},
```

```
   { 0,         0,         0,    0, 0,
     0,                    0, 0 }
};

typedef struct entry_struct
{
   LOG_ENTRY_STRUCT   HEADER;
   _mqx_uint          C;
   _mqx_uint          I;
} ENTRY_STRUCT, _PTR_ ENTRY_STRUCT_PTR;

/*TASK*----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*   This task logs 10 keystroke entries then prints out the log.
*END*-----------------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   ENTRY_STRUCT entry;
   _mqx_uint    result;
   _mqx_uint    i;
   uchar        c;

   /* Create the log component. */
   result = _log_create_component();
   if (result != MQX_OK) {
      printf("Main task - _log_create_component failed!");
      _mqx_exit(0);
   }

   /* Create a log */
   result = _log_create(MY_LOG,
      10 * (sizeof(ENTRY_STRUCT)/sizeof(_mqx_uint)), 0);
   if (result != MQX_OK) {
      printf("Main task - _log_create failed!");
      _mqx_exit(0);
   }

   /* Write data into the log */
   printf("Please type in 10 characters:\n");
   for (i = 0; i < 10; i++) {
      c = getchar();
      result = _log_write(MY_LOG, 2, (_mqx_uint)c, i);
      if (result != MQX_OK) {
         printf("Main task - _log_write failed!");
      }
   }

   /* Read data from the log */
   printf("\nLog contains:\n");
   while (_log_read(MY_LOG, LOG_READ_OLDEST_AND_DELETE, 2,
     (LOG_ENTRY_STRUCT_PTR)&entry) == MQX_OK)
```

```
   {
      printf("Time: %ld.%03d%03d, c=%c, i=%d\n",
         entry.HEADER.SECONDS,
         (_mqx_uint)entry.HEADER.MILLISECONDS,
         (_mqx_uint)entry.HEADER.MICROSECONDS,
         (uchar)entry.C & 0xff,
         entry.I);
   }

   /* Delete the log */
   _log_destroy(MY_LOG);

   _mqx_exit(0);
}
```

3.11.1.8.1 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\log`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.
4. Type ten characters on the input console.

The program logs the characters, and displays the log entry on the console.

FREESCALE MQX	With Freescale MQX, the CodeWarrior Development Studio is the preferred environment for MQX development and build. Please see Section 3.3, "Using Freescale CodeWarrior Development Studio" for more details.

3.11.2 Lightweight Logs

Lightweight logs are similar to logs (see "Section 3.11.1, "Logs"), but with the following differences:

- All entries in all lightweight logs are the same size.
- You can create a lightweight log at a particular memory location.
- Lightweight logs can be timestamped in tick time or second/millisecond time, depending on how the MQX was configured at compile time (for more information, see "Section 3.14, "Configuring MQX at Compile Time").

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the LWLog component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

Table 3-30. Summary: Using Lightweight Logs

Lightweight logs use certain structures and constants, which are defined in *lwlog.h.*	
_lwlog_calculate_size	Calculates the size needed for a lightweight log with a specified maximum number of entries.
_lwlog_create	Creates a lightweight log.
_lwlog_create_at	Creates a lightweight log at a location.
_lwlog_create_component	Creates the lightweight log component.
_lwlog_destroy	Destroys a lightweight log.
_lwlog_disable	Disables logging to lightweight logs.
_lwlog_enable	Enables logging to lightweight logs.
_lwlog_read	Reads from a lightweight log.
_lwlog_reset	Resets the contents of a lightweight log.
_lwlog_test	Tests the lightweight log component.
_lwlog_write	Writes to a lightweight log.

3.11.2.1 Creating the Lightweight Log Component

You can explicitly create the lightweight log component with **_lwlog_create_component()**. If you do not explicitly create it, MQX creates it the first time an application creates a lightweight log or kernel log.

3.11.2.2 Creating a Lightweight Log

A task can create a lightweight log at a particular location (**_lwlog_create_at()**), or let MQX choose the location (**_lwlog_create()**).

With either function, the task specifies:

- Log number in the range of one through 15 (zero is reserved for kernel log).
- Maximum number of entries in the log.
- What happens when the log is full. The default behavior is that no additional data is written. Another behavior is that new entries overwrite the oldest ones.

In the case of **_lwlog_create_at()**, the task also specifies the address of the log.

3.11.2.3 Format of a Lightweight Log Entry

Each lightweight log entry has the following structure.

```
typedef struct lwlog_entry_struct
  _mqx_uint         SEQUENCE_NUMBER;

#if MQX_LWLOG_TIME_STAMP_IN_TICKS == 0
  /* Time at which the entry was written: */
  uint_32           SECONDS;
  uint_32           MILLISECONDS;
  uint_32           MICROSECONDS;
#else
  /* Time (in ticks) at which the entry was written: */
  MQX_TICK_STRUCT  TIMESTAMP;
#endif
  _mqx_max_type     DATA[LWLOG_MAXIMUM_DATA_ENETRIES];
  struct lwlog_entry_struct _PTR_ NEXT_PTR;
} LWLOG_ENTRY_STRUCT, _PTR_ LWLOG_ENTRY_STRUCT_PTR;
```

The fields are described in *MQX Reference*.

3.11.2.4 Writing to a Lightweight Log

Tasks write to a lightweight log with **_lwlog_write()**.

3.11.2.5 Reading From a Lightweight Log

Tasks read from a lightweight log by calling **_lwlog_read()** and specifying, how to read the log. Possible ways to read the log are:

- To read the newest entry.
- To read the oldest entry.
- To read the next entry from the previous one read (used with read oldest).
- To read the oldest entry and delete it.

3.11.2.6 Disabling and Enabling Writing to a Lightweight Log

Any task can disable logging to a specific lightweight log with **_lwlog_disable()**. Any task can subsequently enable logging to the lightweight log with **_lwlog_enable()**.

3.11.2.7 Resetting a Lightweight Log

A task can reset the contents of a lightweight log to its initial state of no data with **_lwlog_reset()**.

3.11.2.8 Example: Using Lightweight Logs

```
/* lwlog.c */

#include <mqx.h>
#include <bsp.h>
```

```
#include <lwlog.h>

#define MAIN_TASK  10
#define MY_LOG     1

extern void main_task(uint_32 initial_data);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { MAIN_TASK, main_task, 2000, 8, "Main",
      MQX_AUTO_START_TASK, 0, 0},
   { 0,         0,         0,    0, 0,
      0,                   0, 0}
};

/*TASK*-----------------------------------------------------
*
* Task Name : main_task
* Comments  :
*   This task logs 10 keystroke entries in a lightweight log,
*   then prints out the log.
*END*-----------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   LWLOG_ENTRY_STRUCT entry;
   _mqx_uint          result;
   _mqx_uint          i;
   uchar              c;

   /* Create the lightweight log component */
   result = _lwlog_create_component();
   if (result != MQX_OK) {
      printf("Main task: _lwlog_create_component failed.");
      _mqx_exit(0);
   }

   /* Create a log */
   result = _lwlog_create(MY_LOG, 10, 0);
   if (result != MQX_OK) {
      printf("Main task: _lwlog_create failed.");
      _mqx_exit(0);
   }

   /* Write data to the log */
   printf("Enter 10 characters:\n");
   for (i = 0; i < 10; i++) {
      c = getchar();
      result = _lwlog_write(MY_LOG, (_mqx_max_type)c,
         (_mqx_max_type)i, 0, 0, 0, 0, 0);
      if (result != MQX_OK) {
         printf("Main task: _lwlog_write failed.");
      }
   }
```

```
   /* Read data from the log */
   printf("\nLog contains:\n");
   while (_lwlog_read(MY_LOG, LOG_READ_OLDEST_AND_DELETE,
      &entry) == MQX_OK)
   {
      printf("Time: ");
#if MQX_LWLOG_TIME_STAMP_IN_TICKS
      _psp_print_ticks((PSP_TICK_STRUCT_PTR)&entry.TIMESTAMP);
#else
      printf("%ld.%03ld%03ld", entry.SECONDS, entry.MILLISECONDS,
         entry.MICROSECONDS);
#endif
      printf(, c=%c, I=%d\n", (uchar)entry.DATA[0] & 0xff,
         (_mqx_uint)entry.DATA[1]);
   }

   /* Destroy the log */
   _log_destroy(MY_LOG);

   _mqx_exit(0);
}
```

3.11.2.8.1 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\lwlog`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.
4. Type ten characters on the input console.

The program logs the characters and displays the log entry on the console.

3.11.3 Kernel Log

Kernel log lets an application log any combination of:

- Function entry and exit information for all calls to MQX functions.
- Function entry and exit information for specific function calls.
- Context switches.
- Interrupts.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the KLog component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file, and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, “Rebuilding Freescale MQX RTOS” for more details.

Performance tool uses kernel log data to analyze, how an application operates and how it uses resources. For more information, see MQX Host Tools User's Guide.

Table 3-31. Summary: Using Kernel Log

Kernel log uses certain structures and constants, which are defined in *log.h, lwlog.h,* and *klog.h.*	
_klog_control	Control kernel logging.
_klog_create	Creates kernel log.
_klog_create_at	Creates kernel log at a specific location.
_klog_disable_logging_task	Disables kernel logging for the specified task.
_klog_enable_logging_task	Enables kernel logging for the specified task.
_klog_display	Displays an entry in kernel log.

3.11.3.1 Using Kernel Log

To use kernel log, an application follows these general steps.

1. Optionally create the lightweight log component as described on page 118.
2. Create kernel log with **_klog_create()**. This is similar to creating a lightweight log, which is described on page 118. You can also create kernel log at a specific location with **_klog_create_at()**.
3. Set up control for logging by calling **_klog_control()**, and specifying any combination of bit flags, as described in the following table.

Table 3-32.

Select flags for:		
• MQX component	Select for:	These functions are logged:
	Errors	For example, **_mqx_exit(), _task_set_error(), _mqx_fatal_error()**.
	Events	Most from the **_event** family.
	Interrupts	Certain ones from the **_int** family.
	LWSems	The **_lwsem** family.
	Memory	Certain ones from the **_mem** family.
	Messages	Certain ones from the **_msg, _msgpool,** and **_msgq** families.
	Mutexes	Certain ones from the **_mutatr** and **_mutex** families.
	Names	The **_name** family.
	Partitions	Certain ones from the **_partition** family.
	Semaphores	Most from the **_sem** family.

Table 3-32. (continued)

	Tasking	The **_sched, _task, _taskq**, and **_time** families.
	Timing	The **_timer** family; certain ones from the **_time** family.
	Watchdogs	The **_watchdog** family.
• Specific tasks only (task qualified)	For each task to log, call one of: **_klog_disable_logging_task()** **_klog_enable_logging_task()**	
• Interrupts • Periodic timer interrupts (system clock) • Context switches		

3.11.3.2 Disabling Kernel Logging

Kernel logging can make your application use more resources and run slower. After you have tested and verified the application, you might want to create a version that does not include the ability to log to kernel log. To remove kernel logging for any part of MQX, you must recompile MQX with the **MQX_KERNEL_LOGGING** option set to zero. For more information, see Section 3.14.1, "MQX Compile-Time Configuration Options." The complete procedure for recompiling MQX is described in Section 4.5, "Rebuilding Freescale MQX RTOS."

3.11.3.3 Example: Using Kernel Log

Log all calls to the timer component and all periodic timer interrupts.

```
/* klog.c */

#include <mqx.h>
#include <bsp.h>
#include <log.h>
#include <klog.h>

extern void main_task(uint_32 initial_data);

TASK_TEMPLATE_STRUCT  MQX_template_list[] =
{
   { 10, main_task,  2000,  8, "Main",
     MQX_AUTO_START_TASK, 0, 0},
   { 0,  0,          0,     0, 0,
     0,                    0, 0 }
};
```

```
/*TASK*-----------------------------------------------------------
*
* Task Name : main_task
* Comments  :
*   This task logs timer interrupts to the kernel log,
*   then prints out the log.
*END*------------------------------------------------------------*/

void main_task
   (
      uint_32 initial_data
   )
{
   _mqx_uint result;
   _mqx_uint i;

   /* Create kernel log */
   result = _klog_create(4096, 0);
   if (result != MQX_OK) {
      printf("Main task - _klog_create failed!");
      _mqx_exit(0);
   }

   /* Enable kernel log */
   _klog_control(KLOG_ENABLED | KLOG_CONTEXT_ENABLED |
      KLOG_INTERRUPTS_ENABLED| KLOG_SYSTEM_CLOCK_INT_ENABLED |
      KLOG_FUNCTIONS_ENABLED | KLOG_TIME_FUNCTIONS |
      KLOG_INTERRUPT_FUNCTIONS, TRUE);

   /* Write data into kernel log */
   for (i = 0; i < 10; i++) {
      _time_delay_ticks(5 * i);
   }

   /* Disable kernel log */
   _klog_control(0xFFFFFFFF, FALSE);

   /* Read data from kernel log */
   printf("\nKernel log contains:\n");
   while (_klog_display()){
   }

   _mqx_exit(0);
}
```

3.11.3.3.1 Compiling the Application and Linking It with MQX

1. Go to this directory:
   `mqx\examples\klog`
2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

After about three seconds, **Main_task()** displays the contents of kernel log.

3.11.4 Stack Usage Utilities

MQX offers core utilities that let you examine and refine the size of the interrupt stack and the size of each task's stack.

Table 3-33. Summary: Stack Usage Utilities

To use these utilities, you must have configured MQX with MQX_MONITOR_STACK. For more information, see Section 3.14.1, "MQX Compile-Time Configuration Options." The complete procedure for recompiling MQX is described in Section 4.5, "Rebuilding Freescale MQX RTOS."	
_klog_get_interrupt_stack_usage	Gets the interrupt stack boundary and the total amount of stack used.
_klog_get_task_stack_usage	Gets the stack size and the total amount of the stack used for a specific task.
_klog_show_stack_usage	Calculates and displays the amount of stack used by each task and the interrupt stack.

3.12 Utilities

Utilities include:

- queues
- name component
- run-time testing
- additional utilities

3.12.1 Queues

The queue component lets you manage doubly linked lists of elements.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Queue component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

Table 3-34. Summary: Using Queues

_queue_dequeue	Removes the element that is at the start of the queue.
_queue_enqueue	Adds the element to the end of the queue.
_queue_get_size	Gets the number of elements in the queue.
_queue_head	Gets (but doesn't remove) the element that is at the start of the queue.
_queue_init	Initializes the queue.
_queue_insert	Inserts the element in the queue.
_queue_is_empty	Determines, whether the queue is empty.

Table 3-34. Summary: Using Queues (continued)

_queue_next	Gets (but doesn't remove) the next element in the queue.
_queue_test	Tests the queue.
_queue_unlink	Removes the specific element from the queue.

3.12.1.1 Queue Data Structures

The queue component requires two data structures, which are defined in *mqx.h*:

- **QUEUE_STRUCT** — keeps track of the size of the queue, and pointers to the start and end of the queue. MQX initializes the structure, when a task creates the queue.
- **QUEUE_ELEMENT_STRUCT** — defines the structure of a queue element. The structure is the header structure of an application-defined object that the task wants to queue.

3.12.1.2 Creating a Queue

A task creates and initializes a queue by calling **_queue_init()** with a pointer to a queue object and the maximum size of the queue.

3.12.1.3 Adding Elements To a Queue

A task adds an element to the end of a queue by calling **_queue_enqueue()** with pointers to the queue and to queue element object, which is the header structure of the object that the task wants to queue.

3.12.1.4 Removing Elements From a Queue

A task gets and removes an element from the start of a queue by calling **_queue_dequeue()** with a pointer to the queue.

3.12.2 Name Component

With the name component, tasks can associate a 32-bit number with a string or symbolic name. MQX stores the association in a names database that all tasks on the processor can use. The database avoids global variables.

FREESCALE MQX	To optimize code and data memory requirements on some target platforms, the Name component is not compiled in the MQX kernel by default. To test this feature, you need to enable it first in the MQX user configuration file and recompile the MQX PSP, BSP, and other core components. Please see Section 4.5, "Rebuilding Freescale MQX RTOS" for more details.

Table 3-35. Summary: Using the Name Component

The name component uses certain structures and constants, which are defined in ***name.h***.	
_name_add	Adds a name to the names database (a name is a NULL-terminated string, max length 32 characters, including NULL).
_name_create_component	Creates the name component.
_name_delete	Deletes a name from the names database.
_name_find	Looks up a name in the names database and gets its number.
_name_find_by_number	Looks up a number in the names database and gets its name.
_name_test	Tests the name component.

3.12.2.1 Creating the Name Component

An application can explicitly create the name component with **_name_create_component()**. If you do not explicitly create it, MQX creates it with default values the first time an application uses the names database.

The parameters and their default values are the same as for the event component, which is described on page 47.

3.12.3 Run-Time Testing

MQX provides core run-time testing that tests the integrity of most MQX components.

A test determines, whether the data that is associated with the component is valid and not corrupted. MQX considers the data in a structure valid, if the structure's **VALID** field is a known value. MQX considers data in a structure corrupted, if its **CHECKSUM** field is incorrect or pointers are incorrect.

An application can use run-time testing during its normal operation.

Table 3-36. Summary: Run-Time Testing

_event_test	Events
_log_test	Logs
_lwevent_test	Lightweight events
_lwlog_test	Lightweight logs
_lwmem_test	Lightweight memory with variable-size blocks
_lwsem_test	Lightweight semaphores
_lwtimer_test	Lightweight timers
_mem_test	Memory with variable-size blocks
_msgpool_test	Message pools

Table 3-36. Summary: Run-Time Testing (continued)

_msgq_test	Message queues
_mutex_test	Mutexes
_name_test	Name component
_partition_test	Memory with fixed-size blocks (partitions)
_queue_test	Application-implemented queue
_sem_test	Semaphores
_taskq_test	Task queues
_timer_test	Timers
_watchdog_test	Watchdogs

3.12.3.1 Example: Doing Run-Time Testing

The application uses all MQX components. A low-priority task tests all the components. If it finds an error, it stops the application.

```
/* test.c */

#include <mqx.h>
#include <fio.h>
#include <event.h>
#include <log.h>
#include <lwevent.h>
#include <lwlog.h>
#include <lwmem.h>
#include <lwtimer.h>
#include <message.h>
#include <mutex.h>
#include <name.h>
#include <part.h>
#include <sem.h>
#include <timer.h>
#include <watchdog.h>

extern void background_test_task(uint_32);

TASK_TEMPLATE_STRUCT MQX_template_list[] =
{
   { 10, background_test_task, 800, 8, "Main",
     MQX_AUTO_START_TASK, 0L, 0},
   { 0,  0,                    0,   0, 0,
     0,                   0L, 0}
};

/*TASK*---------------------------------------------------------
*
* Task Name : background_test_task
* Comments  :
*   This task is meant to run in the background testing for
* integrity of MQX component data structures.
*END*----------------------------------------------------------*/
```

```
void background_test_task
   (
      uint_32  parameter
   )
{
   _partition_id  partition;
   _lwmem_pool_id lwmem_pool_id;
   pointer        error_ptr;
   pointer        error2_ptr;
   _mqx_uint      error;
   _mqx_uint      result;

   while (TRUE) {
      result = _event_test(&error_ptr);
      if (result != MQX_OK){
         printf("\nFailed _event_test: 0x%X.", result);
         _mqx_exit(1);
      }
      result = _log_test(&error);
      if (result != MQX_OK){
         printf("\nFailed _log_test: 0x%X.", result);
         _mqx_exit(2);
      }
      result = _lwevent_test(&error_ptr, &error2_ptr);
      if (result != MQX_OK){
         printf("\nFailed _lwevent_test: 0x%X.", result);
         _mqx_exit(3);
      }
      result = _lwlog_test(&error);
      if (result != MQX_OK){
         printf("\nFailed _lwlog_test: 0x%X.", result);
         _mqx_exit(4);
      }
      result = _lwsem_test(&error_ptr, &error2_ptr);
      if (result != MQX_OK){
         printf("\nFailed _lwsem_test: 0x%X.", result);
         _mqx_exit(5);
      }
      result = _lwmem_test(&lwmem_pool_id, &error_ptr);
      if (result != MQX_OK){
         printf("\nFailed _lwmem_test: 0x%X.", result);
         _mqx_exit(6);
      }
      result = _lwtimer_test(&error_ptr, &error2_ptr);
      if (result != MQX_OK){
         printf("\nFailed _lwtimer_test: 0x%X.", result);
         _mqx_exit(7);
      }
      result = _mem_test_all(&error_ptr);
      if (result != MQX_OK){
         printf("\nFailed _mem_test_all,");
         printf("\nError = 0x%X, pool = 0x%X.", result,
            (_mqx_uint)error_ptr);
         _mqx_exit(8);
      }
      /*
```

```
      ** Create the message component.
      ** Verify the integrity of message pools and message queues.
      */
      if (_msg_create_component() != MQX_OK){
         printf("\nError creating the message component.");
         _mqx_exit(9);
      }
      if (_msgpool_test(&error_ptr, &error2_ptr) != MQX_OK){
         printf("\nFailed _msgpool_test.");
         _mqx_exit(10);
      }
      if (_msgq_test(&error_ptr, &error2_ptr) != MQX_OK){
         printf("\nFailed _msgq_test.");
         _mqx_exit(11);
      }
      if (_mutex_test(&error_ptr) != MQX_OK){
         printf("\nFailed _mutex_test.");
         _mqx_exit(12);
      }
      if (_name_test(&error_ptr, &error2_ptr) != MQX_OK){
         printf("\nFailed _name_test.");
         _mqx_exit(13);
      }
      if (_partition_test(&partition, &error_ptr, &error2_ptr)
         != MQX_OK)
      {
         printf("\nFailed _partition_test.");
         _mqx_exit(14);
      }
      if (_sem_test(&error_ptr) != MQX_OK){
         printf("\nFailed _sem_test.");
         _mqx_exit(15);
      }
      if (_taskq_test(&error_ptr, &error2_ptr) != MQX_OK){
         printf("\nFailed _takq_test.");
         _mqx_exit(16);
      }
      if (_timer_test(&error_ptr) != MQX_OK){
         printf("\nFailed _timer_test.");
         _mqx_exit(17);
      }
      if (_watchdog_test(&error_ptr, &error2_ptr) != MQX_OK){
         printf("\nFailed _watchlog_test.");
         _mqx_exit(18);
      }
      printf("All tests passed.");
      _mqx_exit(0);
   }
}
```

3.12.3.1.1 Compiling the Application and Linking It with MQX

1. Go to this directory:

   `mqx\examples\test`

2. Refer to your MQX Release Notes document for instructions on how to build and run the application.
3. Run the application according to the instructions in the release note.

3.12.4 Additional Utilities

Table 3-37. Summary: Additional Utilities

_mqx_bsp_revision	Revision of the BSP.
_mqx_copyright	Pointer to the MQX copyright string.
_mqx_date	Pointer to the string that indicates, when MQX was built.
_mqx_fatal_error	Indicates that an error has been detected that is severe enough that MQX or the application can no longer function properly.
_mqx_generic_revision	Revision of the generic MQX code.
_mqx_get_counter	Gets a processor-unique 32-bit number.
_mqx_get_cpu_type	Gets the processor type.
_mqx_get_exit_handler	Gets a pointer to the MQX exit handler, which MQX calls when it exits.
_mqx_get_kernel_data	Gets a pointer to kernel data.
_mqx_get_system_task_id	Gets the task ID of System task descriptor.
_mqx_get_tad_data	Gets the **TAD_RESERVED** field from a task descriptor.
_mqx_idle_task	Idle task.
_mqx_io_revision	I/O revision for the BSP.
_mqx_monitor_type	Monitor type.
_mqx_psp_revision	Revision of the PSP.
_mqx_set_cpu_type	Sets the processor type.
_mqx_set_exit_handler	Sets the address of the MQX exit handler, which MQX calls, when it exits.
_mqx_set_tad_data	Sets the **TAD_RESERVED** field in a task descriptor.
_mqx_version	Pointer to the string that indicates the version of MQX.
_mqx_zero_tick_struct	A constant zero-initialized tick structure that an application can use to initialize one of its tick structures to zero.
_str_mqx_uint_to_hex_ string	Converts an **_mqx_uint** value to a hexadecimal string.
_strnlen	Calculates the length of a limited-length string.

3.13 Embedded Debugging

There are several ways how to debug the MQX-based applications:

- Using plain debugger environment, which is not aware about the MQX operating system. This simple approach may work well, when using breakpoints and single-stepping through application code.
- Using opearating system awareness in the debugger (so called task-aware debugger or TAD). This approach helps to see the debugged code in the context of individual tasks. It also helps to examine the internal MQX data strucutres in a user-friendly way.
- Using the EDS server in the target code and using the EDS client (Freescale MQX Remote Debug Tool). This tool connects to the target system over the serial line, TCP/IP, or other kind of communication interface, and provides information similar to the TAD.

FREESCALE MQX	For more information about the Freescale MQX Remote Debug Tool, please see the Freescale MQX Host Tools User's Guide. The Freescale MQX does not support the IPC component required for native EDS communication. Use the EDSerial or TCP/IP servers.

3.14 Configuring MQX at Compile Time

MQX is built with certain features that you can include or exclude by changing the value of compile-time configuration options. If you change any configuration value, you must recompile the MQX and relink it with your target application.

As the Board Support Package (BSP) library may also depend on some MQX configuration options, it must be typically recompiled as well.

Like BSP, there are also other code components that use the MQX OS services (for example RTCS, MFS, USB). These components need to be re-compiled after the MQX and BSP.

FREESCALE MQX	Comparing with original ARC versions, Freescale MQX introduces a different method of compile-time configuration of the MQX OS and other components. Original method used the compiler command-line -D options or *source\psp\platform\psp_cnfg.asm* file. In Freescale MQX, there is a central user configuration file *user_config.h* in the *config\<board>* directory, which can be used to override default configuration options. The same configuration file is used by other system components like RTCS, MFS, or USB.

3.14.1 MQX Compile-Time Configuration Options

This section provides a list of MQX configuration options. The default value of any of these options can be overridden in the *config\<board>\user_config.h* file.

The default values are defined in the *mqx\source\include\mqx_cnfg.h* file.

NOTE	Do not change the *mqx_cnfg.h* file directly. Always use the board-specific or project-specific *user_config.h* file in your *config* directory.

MQX_CHECK_ERRORS
Default is one.

One: MQX components perform error checking on all their parameters.

MQX_CHECK_MEMORY_ALLOCATION_ERRORS
Default is one.

One: MQX components check all memory allocations for errors and verify that the allocations are successful.

MQX_CHECK_VALIDITY
Default is one.

One: MQX checks the **VALID** field of all structures when it accesses them.

MQX_COMPONENT_DESTRUCTION
Default is one.

One: MQX includes the functions that allow MQX components (such as the semaphore component or event component) to be destroyed. MQX reclaims all the resources that the component allocated.

MQX_DEFAULT_TIME_SLICE_IN_TICKS
Default is one.

One: Default time slice in the task template structure is in units of ticks.

Zero: Default time slice in the task template structure is in milliseconds.

The value also affects the time-slice field in the task template, because the value is used to set a task's default time slice.

MQX_EXIT_ENABLED
Default is one.

One: MQX includes code to allow the application to return from the **_mqx()** call.

MQX_HAS_TIME_SLICE
Default is one.

One: MQX includes code to allow time-slice scheduling of tasks at the same priority.

MQX_HAS_DYNAMIC_PRIORITIES
Default is one.

One: MQX includes code to change task priorities dynamically by **_task_set_priority()** call or by priority inheritance or priority boosting.

MQX_HAS_EXCEPTION_HANDLER
Default is one.

One MQX includes code to handle exceptions (see psp/<psp>/int_xcpt.c) and to set/get task exception handler routine by using the **_task_set_exception_handler** and **_task_get_exception_handler** calls.

MQX_HAS_EXIT_HANDLER
Default is one.

One: MQX includes code to execute task exit handler before the task exits. Also the **_task_set_exit_handler** and **_task_get_exit_handler** calls are included.

MQX_HAS_HW_TICKS
Default is one.

One: MQX includes support for hardware ticks and associated calls: **_time_get_hwticks**, **_time_get_hwticks_per_tick** and **_psp_usecs_to_ticks**. Note that hardware ticks also need to be supported by the BSP.

MQX_HAS_TASK_ENVIRONMENT
Default is one.

One: MQX includes code to set and get task environment data pointer:**_task_set_environment** and **_task_get_environment**.

MQX_HAS_TICK
Default is one. It is recommended to leave this option enabled.

One: MQX includes support for tick time and all related functionality of delaying tasks, waiting for synchronization objects with timeout etc.

MQX_KD_HAS_COUNTER
Default is one.

One: The MQX kernel maintains the counter value, which is automatically increamented any time the value is queried by the **_mqx_get_counter** call.

MQX_TD_HAS_PARENT
Default is one.

One: The MQX task descriptors maintain the task's creator ID, which is available through **_task_get_creator** call.

MQX_TD_HAS_TEMPLATE_INDEX
Default is one.

One: The MQX task descriptors maintain the original index value coming from the TASK_TEMPLATE_STRUCT array. This value is maintained for backward compatiblity only and is not used by MQX kernel.

MQX_TD_HAS_TASK_TEMPLATE_PTR
Default is one.

One: The MQX task descriptors maintain the pointer to original TASK_TEMPLATE_STRUCT structure used for task creation. This pointer is used by task restart call **_task_restart()** and by several lookup functions like **_task_get_id_from_name**().

MQX_TD_HAS_ERROR_CODE
Default is one.

One: The MQX task descriptors maintain the error code which is accessible with **_task_set_error** and

_task_get_error calls.

MQX_TD_HAS_STACK_LIMIT
Default is one.

One: The MQX task descriptors maintain the task limit value which is needed by various stack overflow checking calls like **_task_check_stack**.

MQX_INCLUDE_FLOATING_POINT_IO
Default is zero.

One: **_io_printf**() and **_io_scanf**() include floating point I/O code.

MQX_IS_MULTI_PROCESSOR
Default is one.

One: MQX includes code to support multi-processor MQX applications.

MQX_KERNEL_LOGGING
Default is one.

One: Certain functions in each component write to kernel log, when they are entered and as they exit. The setting reduces performance, only if you enable logging for the component. You can control, which component is logged with **_klog_control**().

MQX_LWLOG_TIME_STAMP_IN_TICKS
Default is one.

One: Timestamp in lightweight logs is in ticks.

Zero: Timestamp is in seconds, milliseconds, and microseconds.

MQX_MEMORY_FREE_LIST_SORTED
Default is one.

One: MQX sorts the freelist of memory blocks by address. This reduces memory fragmentation, but increases the time MQX takes to free memory.

MQX_MONITOR_STACK
Default is one.

One: MQX initializes all task and interrupt stacks to a known value, so that MQX components and debuggers can calculate how much stack is used. The setting reduces performance, only when MQX creates a task.

You must set the option to one in order to make use of:

- **_klog_get_interrupt_stack_usage()**
- **_klog_get_task_stack_usage()**
- **_klog_show_stack_usage()**

MQX_MUTEX_HAS_POLLING
Default is one.

One: MQX includes code to support the mutex options **MUTEX_SPIN_ONLY** and **MUTEX_LIMITED_SPIN**.

MQX_PROFILING_ENABLE

Default is zero.

One: Code to support an external profiling tool is compiled into MQX. Profiling adds to the size of the compiled image, and MQX runs slower. You can use profiling, only if the toolset that you are using supports profiling.

MQX_RUN_TIME_ERR_CHECK_ENABLE

Default is zero.

One: Code to support an external run-time error-checking tool is compiled into MQX. This adds to the size of the compiled image, and MQX runs slower. You can use run-time error checking, only if the toolset that you are using supports it.

MQX_ROM_VECTORS

Default is zero.

One: The interrupt vector table is not copied into RAM. The ROM-based table is set up correctly to handle all interrupts by the default MQX interrupt dispatcher. The application will still be able to install interrupt service routine by using the **_int_install_isr** call. However, the **_int_install_kernel_isr** call can not be used to install the low-level interrupt service routines directly in the vector table.

MQX_SPARSE_ISR_TABLE

Default is zero.

One: The MQX interrupt service routine table is allocated as an "array of linked lists" instead of linear array. This option is independent on the MQX_ROM_VECTORS as it deals with the "logical" table managed by the interrupt dispatcher in MQX. With the sparse ISR table, only the ISRs installed by the **_int_install_isr** call consume RAM memory. Interrupt latency increases as the MQX needs to walk the list to find user ISR to be invoked.

MQX_SPARSE_ISR_SHIFT

Default is 3.

When MQX_SPARSE_ISR_TABLE is defined as 1, this MQX_SPARSE_ISR_SHIFT option determines the number of bits the vector number is shifted to get index of ISR linked list root. For example, with 256 potential interrupt sources and with shift value of 3, it makes 256>>3=32 lists each with maximum depth of eight ISR entries. Shift value of 8 would yield one big linked list of all ISR entries.

MQX_TASK_CREATION_BLOCKS

Default is one. The option applies to multi-processor applications only.

One: A task blocks, when it calls **_task_create()** to create a task on another processor. The creating task blocks, until the new task is created and an error code is returned.

MQX_TASK_DESTRUCTION

Default is one.

One: MQX allows tasks to be terminated. As a result, MQX includes code that frees all the MQX-managed resources that terminated tasks own.

MQX_TIMER_USES_TICKS_ONLY

Default is zero.

One: Timer task processes periodic-timer and one-shot timer requests using tick time for timeout reporting, rather than second/millisecond time.

MQX_USE_32BIT_MESSAGE_QIDS

Default is zero.

Zero: Message-component data types (**_queue_number** and **_queue_id**) are **uint_16**.

One: Message-component data types (**_queue_number** and **_queue_id**) are **uint_32**. This allows for more than 256 message queues on a processor and more than 256 processors in a multi-processor network.

MQX_USE_IDLE_TASK

Default is one.

One: the kernel will create the idle task which will execute when no other tasks are ready, otherwise, the processor will stop when there are no tasks to run.

MQX_USE_INLINE_MACROS

Default is one.

One: Some internal functions that MQX calls are changed from function calls to in-line code. The setting optimizes MQX for speed.

Zero: MQX is optimized for code size.

MQX_USE_IO

Default is one.

One: the MQX implements the I/O subsystem calls needed by I/O drivers. Without the I/O subsystem, no driver can be installed or used and tasks are not able to use stdin/stdout/stderr handles.

MQX_USE_LWMEM_ALLOCATOR

Default is zero.

One: Calls to the **_mem** family of functions are replaced with calls to the corresponding function in the **_lwmem** family.

3.14.2 Recommended Settings

The settings you choose for compile-time configuration options depend on the requirements of your application.

FREESCALE MQX	The MQX build process and its compile-time configuration is specific for given target board (set in *config/<board>/user_config.h* directory). You may want to create your own configurations, specific to the custom board or even the application. Please see more details about this process in Section 4.6, "Creating Custom MQX Configurations and Build Projects."

The following table shows common settings you can use as you develop your application.

Table 3-38. Compile-time Configuration Setting

Option	Default	Debug	Speed	Size
MQX_ALLOW_TYPED_MEMORY	1	1	0	0,1
MQX_CHECK_ERRORS	1	1	0	0

MQX_CHECK_MEMORY_ALLOCATION_ ERRORS	1	1	0	0
MQX_CHECK_VALIDITY	1	1	0	0
MQX_COMPONENT_DESTRUCTION	1	0*, 1	0*	0*
MQX_DEFAULT_TIME_SLICE_IN_TICKS	0	0, 1	1	1
MQX_EXIT_ENABLED	1	0, 1	0	0
MQX_HAS_DYNAMIC_PRIORITIES	1	0, 1	0	0
MQX_HAS_EXIT_HANDLER	1	0, 1	0	0
MQX_HAS_TASK_ENVIRONMENT	1	0, 1	0	0
MQX_HAS_TIME_SLICE	1	0, 1	0	0
MQX_INCLUDE_FLOATING_POINT_IO	0	0, 1	0	0
MQX_IS_MULTI_PROCESSOR	1	0, 1	0	0
MQX_KD_HAS_COUNTER	1	0, 1	0, 1	0
MQX_KERNEL_LOGGING	1	1	0	0
MQX_LWLOG_TIME_STAMP_IN_TICKS	1	0	1	1
MQX_MEMORY_FREE_LIST_SORTED	1	1	0	0
MQX_MONITOR_STACK	1	1	0	0
MQX_MUTEX_HAS_POLLING	1	0, 1	0	0
MQX_PROFILING_ENABLE	0	1	0	0
MQX_ROM_VECTORS	0	0, 1	0, 1	1
MQX_RUN_TIME_ERR_CHECK_ENABLE	0	1	0	0
MQX_SPARSE_ISR_TABLE	0	0, 1	0	1
MQX_SPARSE_ISR_SHIFT (in range 1-8)	3	any	lower	higher
MQX_TASK_CREATION_BLOCKS (for multiprocessor applications)	1	1	0	0, 1
MQX_TASK_DESTRUCTION	1	0, 1	0	0
MQX_TD_HAS_ERROR_CODE	1	0, 1	0	0
MQX_TD_HAS_PARENT	1	0, 1	0	0
MQX_TD_HAS_STACK_LIMIT	1	0, 1	0	0
MQX_TD_HAS_TASK_TEMPLATE_PTR	1	0, 1	0	0
MQX_TD_HAS_TEMPLATE_INDEX	1	0, 1	0	0
MQX_TIMER_USES_TICKS_ONLY	0	0,1	1	1
MQX_USE_32BIT_MESSAGE_QIDS	0	0, 1	1	1
MQX_USE_IDLE_TASK	1	0, 1	0, 1	0
MQX_USE_INLINE_MACROS	1	0, 1	1	0

MQX_USE_LWMEM_ALLOCATOR	0	0, 1	1	1
MQX_VERIFY_KERNEL_DATA	1	1	0	0

Chapter 4 Rebuilding MQX

4.1 Why to Rebuild MQX?

Rebuilding MQX is useful to enable convenient source-level debugging of the MQX kernel. When using factory-precompiled libraries from MQX distribution, the debugger may face difficulty in evaluating the path of the source files.

You need to rebuild MQX if you do any of the following:

- If you change compiler options (for example optimization level).
- If you change MQX compile-time configuration options in the *config/<board>/user_config.h* file.
- If you develop a new BSP (for example by adding a new I/O driver).
- If you incorporate changes that you made to MQX source code.

CAUTION	Do not modify MQX data structures. If you do, some MQX host tools might not perform properly. Modify MQX data structures only if you are well experienced with MQX. If you modify MQX data structures, you must recompile MQX and rebuild it.

4.2 Before You Begin

Before you compile or build MQX:

- Read the MQX Release Notes that accompany Freescale MQX, to get information that is specific to your target environment.
- Ensure you have the required tools for your target environment:
  - compiler
  - assembler
  - linker
  - librarian
- Be familiar with the MQX directory structure and re-build instructions, as they are described in the release notes document and also the instructions provided later in this section.

FREESCALE MQX	Freescale MQX can be conveniently built by using one of the supported development environments, for example Freescale CodeWarrior Development Studio.

4.3 Freescale MQX Directory Structure

FREESCALE MQX	With a few exceptions, the Freescale MQX directory structure is the same as it was in the previous MQX releases. The major difference is that multiple components (MQX, MFS, RTCS, USB, ..) are installed together in one top-level directory, and they share the common *config* and *lib* directories.

Figure 4-1 shows the directory structure of the whole Freescale MQX RTOS distribution.

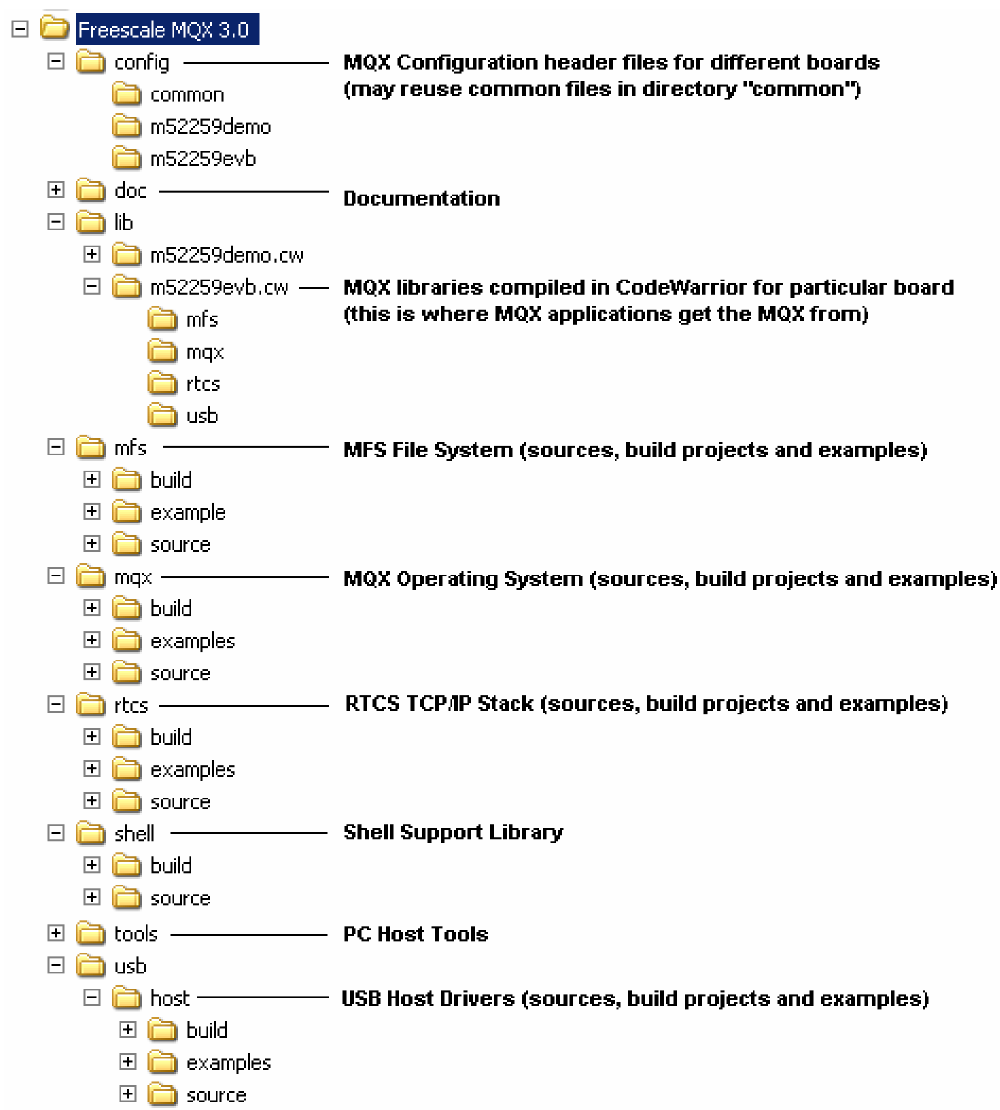


Figure 4-1. Directory Structure of Freescale MQX RTOS

4.3.1 MQX RTOS Directory Structure

Figure 4-2 shows the directory structure of the MQX RTOS component located in the top-level *mqx* directory in more detail.

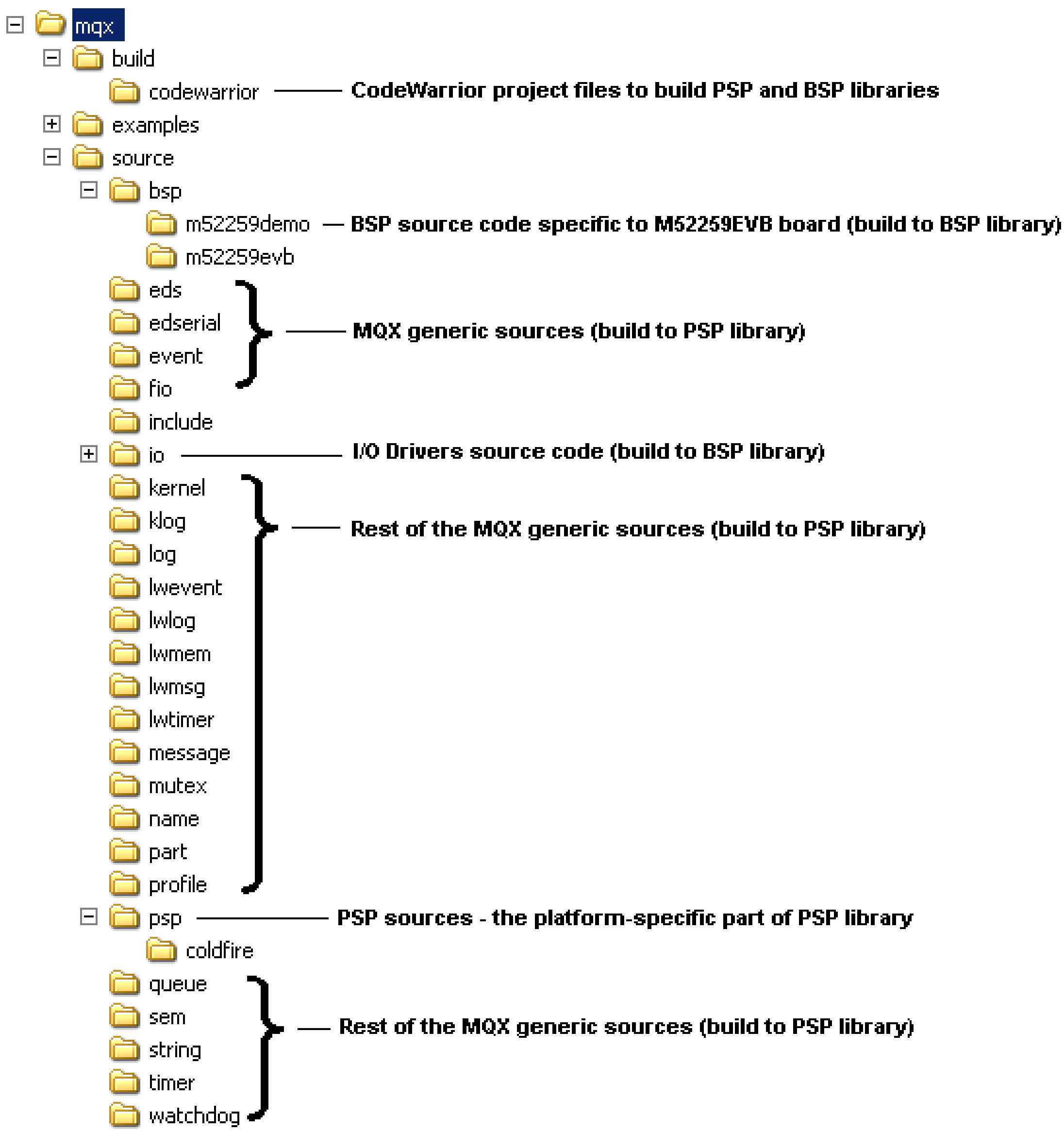


Figure 4-2. MQX RTOS Directory Structure

4.3.2 PSP Subdirectories

The *mqx\source\psp* directory contains the platform-dependent code of the PSP library. For example, the ColdFire subdirectory contains the MQX kernel parts, specific to the Freescale ColdFire architecture (for example, core initialization, register save/restore code for interrupt handling, stack handling, cache control functions and so on). In addition, this directory also contains processor definition files for each supported processor derivative.

4.3.3 BSP Subdirectories

The subdirectories in *mqx\source\bsp* typically follow the name of the board, and contain low-level startup code, processor, and board initialization code. The BSP also contains data structures used to initialize various I/O drivers in a way suitable for a given board.

This code compiles (together with the I/O drivers code) into the BSP library.

4.3.4 I/O Subdirectories

Subdirectories in the *mqx\source\io* contain source code for MQX I/O drivers. Typically, source files in each I/O driver directory are further split to device-specific and device-independent. The I/O drivers, suitable for given board, are part of the BSP build project, and are compiled into the BSP library.

4.3.5 Other Source Subdirectories

All other directories in the source contain generic parts of the MQX RTOS. Together with the platform-dependent PSP code, the generic sources are compiled into the PSP library.

4.4 Freescale MQX Build Projects

All necessary build projects are located in the *mqx\build\<compiler>* directory. For each board, there are two build projects available, PSP and BSP. The BSP project contains board-specific code, while PSP is platform-specific (for example ColdFire) only. The PSP project does not contain any board-specific code. Despite this, both projects refer to the board name in their file names, and both also generate the binary output file into the same board-specific directory *lib\<board>.<compiler>*.

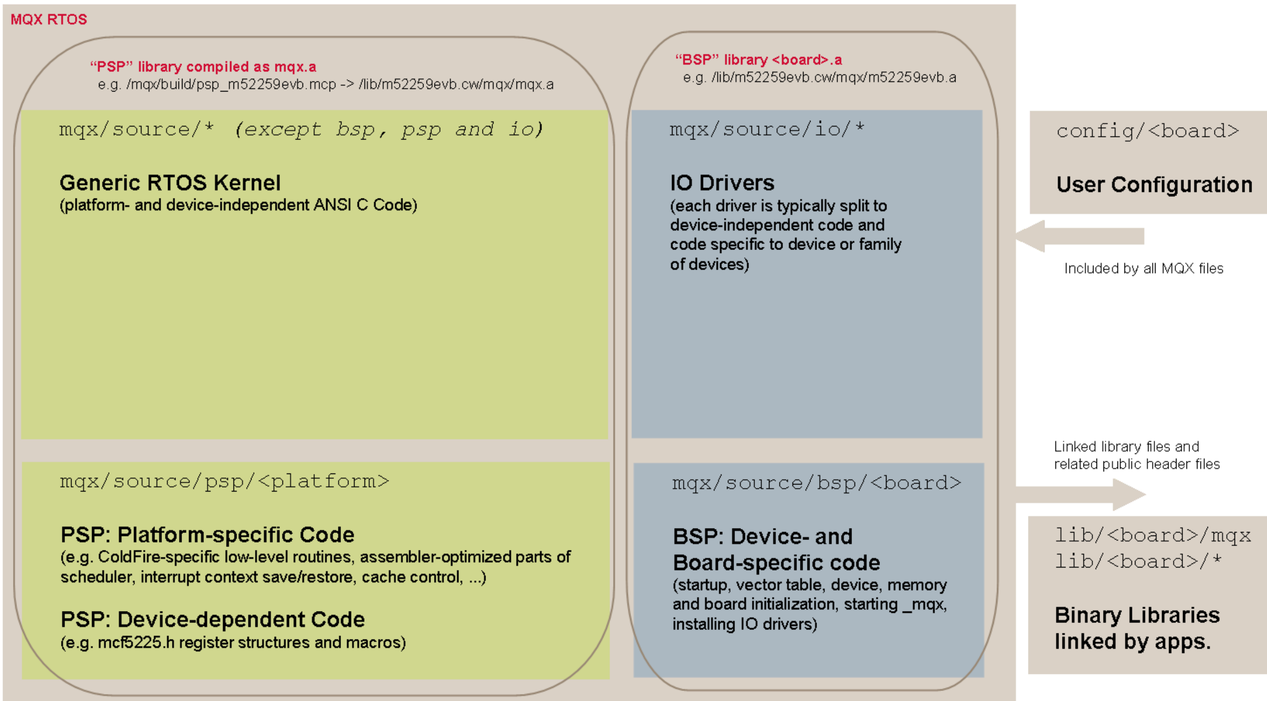
The board-independent PSP library is also compiled to board-specific output directory because the compile-time configuration file is taken from board-specific directory *config\<board>*. In other words, even if the PSP source code itself does not depend on the board features, the user may want to build a different PSP for different boards.

4.4.1 PSP Build Project

The PSP project is used to build the PSP library, which contains the platform-dependent parts from *mqx\source\psp* and also contains generic MQX RTOS code.

4.4.2 BSP Build Project

The BSP project is used to build the BSP library, which contains the board-specific code from *mqx\source\bsp\<board>* and also the selected I/O drivers from *mqx\source\io* directory.



4.4.3 Post-Build Processing

All build projects are configured to generate the resulting binary library file in the top-level *lib\<board>.<compiler>* directory. For example, the CodeWarrior libraries for the M52259EVB board are built into the *lib\m52259evb.cw* directory.

Both BSP and PSP build projects are also set up to execute post-build batch file, which copies all the public header files to the destination *lib* directory. This makes the output */lib* folder the only place accessed by the MQX application code. The MQX application build projects do not need to make any reference to the MQX RTOS source tree at all.

4.4.4 Build Targets

CodeWarrior development environment enables you to have multiple build configurations, called build targets. All projects in the Freescale MQX RTOS contain at least two build targets:

- **Debug** target — Compiler optimizations are set low to enable easy debugging. Libraries built using this target are named with "_d" postfix (for example *lib\m52259evb.cw\mqx\mqx_d.a*).
- **Release** target — Compiler optimizations are set to maximum, to achieve the smallest code size and fast execution. The resulting code is very hard to debug. Generated library name does not get any postfix (for example *lib\m52259evb.cw\mqx\mqx.a*).

4.5 Rebuilding Freescale MQX RTOS

Rebuilding the MQX RTOS libraries is a simple task that involves opening the proper build projects for PSP and BSP in the development environment and building them. Do not forget to select the proper build target to be built or build all targets.

For specific information about rebuilding MQX and the examples that accompany it, see the release notes that accompany the MQX.

4.6 Creating Custom MQX Configurations and Build Projects

4.6.1 Why Creating a New Configuration?

Typical scenarios when you need to create a new set of build projects, include:

- You want to have two or more different kernel configurations for a single board being used simultaneously in different applications. This is a rather simple task of "cloning" the existing configuration directory, and modifying the existing build projects (changing name and output folder).
- You need to create a new BSP for custom board. This is more complex task, and may involve some new I/O driver development, or advanced configuration changes. However, the first step is to start with the most similar existing BSP, clone it to assign a new name, and further modify.

4.6.2 Cloning Existing Configuration

As described in the previous sections, both the PSP and BSP build projects (as well as projects for other MQX core components like RTCS, MFS, or USB) are bound to the target board name. Using an example of M52259EVB board, the following items depend on this name:

- User configuration is taken from *config\<board>* directory (for example *config\m52259evb*).
- Build project include-search paths are set to point to the user configuration directory.
- Build projects are set up to produce resulting binary library files in *lib\<board>.<compiler>* output directory (for example *lib\m52259evb.cw*).
- Build projects are named to reflect the board name *mqx\build\<compiler>\bsp_<board>.<prj>* (for example *mqx\build\cwcf72\bsp_m52259evb.mcp*)
- Post-link batch files set in build projects are also specific to the board. (for example *mqx\build\bat\bsp_m52259evb.bat*).

The steps to clone (copy) an existing configuration and save it under a different name are demonstrated on the M52259EVB example used with CodeWarrior build tools:

- Copy existing *config\m52259evb* directory, and assign a new board-specific or configuration-specific name to it (for example *config\m52259evb_test*).
- Create new output directory in the *lib* folder (for example *lib\m52259evb_test.cw*).
- Create a copy of BSP and PSP build projects (*mqx\build\cw72\bsp_m52259evb.mcp* and *psp_m52259evb.mcp*), and assign a new name to both of these files.

- Open project settings, and change include-search paths referencing the old user-configuration directory (i.e. edit the *config\m52259evb* search path to *config\m52259evb_test*).
- In the project settings, change the output directory to the one newly created in the *lib* directory (from *lib\m52259evb.cw* to *lib\m52259evb_test.cw*).
- Consider, if you also want to clone the post-link batch files, and change the project settings accordingly. This step is not required in case your new BSP has the same set of drivers).
- Ensure you have done the project settings change in all build targets available (Debug and Release).
- Repeat all the steps above for other MQX libraries like RTCS, MFS, or USB if needed.

Having a new configuration and build projects ready, you may start modifying the build-time configuration without affecting the original BSP libraries. In case you want to create a completely new BSP, you will need to create new BSP source files and change the content of the "cloned" BSP project.

Chapter 5, "Developing a New BSP" describes the new BSP development.

Chapter 5 Developing a New BSP

5.1 What is a BSP?

A board support package (BSP) is a collection of hardware-dependent files that rely on the specific features of a single-board computer. You may want to develop BSP that is not yet available. Also, if your target hardware is customization of the one that is supported, it is recommended to develop a new BSP.

In the last section, you have learnt how to clone an existing BSP, and build projects for the new hardware configuration. This section further describes what to keep in mind, when developing a new BSP code.

5.2 Overview

To develop a new BSP:

1. Select a baseline BSP to modify.
2. Clone selected BSP (and PSP) projects, configuration, and source code.
3. Prepare BSP-specific Debugger Configuration.
4. Modify BSP-specific include files.
5. Modify startup code.
6. Modify source code.
7. Create default initialization for I/O device drivers.

5.3 Selecting a Baseline BSP

It is usually easiest to select an existing baseline BSP, and modify the baseline to suit your hardware. In most cases, select a baseline BSP that uses the same or similar processor.

1. Create a new BSP source directory, for example:

   source\bsp\my52259board

2. Go to the baseline directory, for example:

   source\bsp\m52259evb

3. Copy the contents of the baseline directory to the new directory.
4. In the new directory, rename the old board-specific names <*board*>.* to the name of the new BSP.
5. Create additional files and directories related to the new BSP
   - New BSP configuration directory

     config\bsp*my52259board*
   - New build output directory

     lib*my52259board*

6. Clone BSP and PSP build projects as described in 4.6.2, "Cloning Existing Configuration". Do not forget to change the project settings in *each* build target. This is namely
   - remove the old board-specific source code files from the project (<*board*>.*) and add the newly-created files.
   - redirect the include search paths to the new configuration directory
   - redirect the output library path to the new output directory
   - optionally change the name of the output library file being built
   - clone the batch files in the `build\bat` directory and select them in the project settings as a new post-linker action.
7. In the all files, change all occurrences (uppercase and lowercase) of the name of the old BSP or processor to the name of the new BSP/processor.

5.4 Editing the Debugger Configuration Files

The board-specific configuration files are stored with the BSP sources (in the */dbg* subdirectory) and they are copied into the output */lib* folder by the post-linker batch. The BSP project itself makes no other use of the debugger configuration files. It is the application project, built with a particular BSP, which refers to the debugger files in its project.

You might need to modify debugger initialization files, such as *.*cfg* or *.*mem* to support the new board. Typical changes needed in the debugger initialization file include external memory setup (external bus signals, timing, memory area location etc).

TIP	Use the debugger configuration files for evaluation boards based on the same processor device coming with the debugger tool as an example.

5.5 Modifying BSP-Specific Include Files

BSP-specific include files are in:

mqx\source\bsp\<board>

where <*board*> is the BSP name.

The following table shows the effort needed to modify BSP source files for a new board.

Table 5-1. Effort in Modifying BSP Source Files

File	Effort if porting to the same microprocessor	Effort if porting to a similar processor within the same sub-family	Effort if porting to a different processor (same code and PSP)
bsp.h	medium	medium	**high**
init_hw.c (bsp_init.c)	medium	medium	**high**
bsp_prv.h	medium	medium	**high**
bsp_rev.h	low	low	low
enet_ini.c	low	medium	**high**

get_usec.c	low	low	low
gpio_init.c	medium	**high**	**high**
init_bsp.c	medium	**high**	**high**
init_<driver_name>.c	low	low	low
<board_name>.h	low	medium	**high**
mqx_init.c	low	low	low
vectors.c	low	medium	medium
Compiler-specific code cw/*.c	low	low	low
Linker configuration cw/*.lcf	low	medium	**high**
Debugger configuration cw/dbg/*.mem, *.cfg	low	medium	**high**
PSP processor files	low	**high**	**high**

5.5.1 bsp_prv.h

The file contains:

- Prototypes for private functions that the BSP uses.
- Prototypes for device-initialization structures for devices in the BSP (in *source\io*).

5.5.2 bsp.h

The file includes **#include** statements for files the applications can use to access board resources and device driver API. It also declares prototypes of public BSP functions exported to be used by applications or by IO drivers (e.g. board-specific pin initialization functions).

- processor-specific header file *<board>.h*
- processor-specific source code files
- *.h* files for device driver API

5.5.3 *<board>*.h

The *<board>.h* file (where *<board>* is the name of the target board) declares board-specific definitions for:

- The board type
- Memory map symbols of the board, such as the base addresses and size of different memory areas (Flash, RAM, External memory etc.).
- Resolution and frequency of the periodic timer interrupt.
- Bus clock and system clock values.
- Range of interrupts for which an application can install ISRs.

- Interrupt vector numbers and interrupt priorities for device drivers, including the periodic timer.
- Default values for the MQX initialization structure.
- All other hardware definitions that are unique to the board, such as board-specific registers, symbolic names for buttons, LEDs, Analog channels etc.
- Default configuration options for the I/O drivers.

5.6 Modifying Startup Code

A BSP provides default startup functions that set up the run-time environment and then call **_mqx()**, which starts MQX. The startup code is located in a compiler-specific subdirectory within the BSP. Depending on the implementation, it may partly reuse code from a standard startup process available in the compiler-specific runtime library.

5.6.1 boot.* *and <compiler>*.c

The boot file (either coded in C or Assembler) and the *<compiler>.c* file (where *<compiler>* is an abbreviated name of the compiler tool) implement the compiler-dependent code required for starting up the processor and for run-time board setup. These files are typically located in a subdirectory with other compiler-dependent source and configuration files.

The code in the *boot.** file handles the reset condition:

- It disables interrupts.
- It sets up a initial stack for the rest of the boot up process.
- It initializes the hardware registers such as vector base address, peripheral register base address, internal memory base address etc.
- It sets up key processor resources such as clock source, PLL, external bus etc.
- It passes the control to the standard compiler-specific startup function which takes care about C variable initialization and invoking the main() function.

The main() function is implemented in the BSP source code (in the *mqx_main.c* file). Body of the *main()* function passes control to the MQX kernel by calling the *_mqx()* function.

```
int main
   (
      void
   )
{ /* Body */

   extern const MQX_INITIALIZATION_STRUCT MQX_init_struct;

   /* Start MQX */
   _mqx( (MQX_INITIALIZATION_STRUCT_PTR) &MQX_init_struct );
   return 0;

} /* Endbody */
```

5.7 Modifying Source Code

This section describes key BSP files, which needs to be modified when supporting a different board or processor.

5.7.1 init_bsp.c

The file contains:

- Initialization function that is specific to the board (**_bsp_enable_card()**).
- Periodic timer ISR (**_bsp_timer_isr()**).
- MQX exit handler (**_bsp_exit_handler()**).
- Support for hardware-tick time if available (**_bsp_get_hwticks()**).
- Initialize hardware watchdog if available (**_bsp_setup_watchdog()**).

5.7.1.1 _bsp_enable_card()

Part way through initialization, MQX calls the function to do the following:

- Initialize processor-support facilities.
  A PSP can provide facilities for managing CPU resources such as CPU-based memory or baud-rate generators
- Initialize interrupt support.
  The function **_psp_int_init()** creates and installs the MQX interrupt table.
- Initialize cache and MMU and optionally enable them.
  The PSP provides support functions for CPUs that have caches and MMUs.
- Install and initialize the periodic timer ISR.
- Install I/O device drivers and initialize the I/O subsystem. This code uses conditional compilation to install selected I/O drivers only. See *<board>.h* for drivers enabled by default. The settings can be changed in the user_config.h or directly in the *<board>.h* file.

5.7.1.2 _bsp_timer_isr()

This function is the interrupt service routine for the periodic timer interrupt. It clears the interrupt and, if required, restarts the timer. It calls **_time_notify_kernel()**, so that MQX knows that the interrupt occurred.

The **_bsp_timer_isr** handler services also the hardware watchdog counter if this is available.

5.7.1.3 _bsp_exit_handler()

This function is called, when an application calls **_mqx_exit()**. It shuts down the devices that are no longer used.

5.7.2 get_usec.c

5.7.2.1 _time_get_microseconds()

This function returns the number of microseconds since the last periodic timer interrupt. If it is not possible to determine the time since the last periodic timer interrupt, the function should return zero.

Modify the function only if you are using a different timer; in which case, call its **_timer_get_usec** function.

5.7.3 get_nsec.c

5.7.3.1 _time_get_nanoseconds()

The function returns the time in nanoseconds since the last periodic timer interrupt. If it is not possible to determine the time since the last periodic timer interrupt, the function returns zero.

Modify the function only if you are using a different timer. In this case, call its **_timer_get_nsec** function.

5.7.4 mqx_init.c

This file contains the board's default MQX initialization structure so that simple applications or applications that use default values (defined in *target.h*) need not define an initialization structure. An application can create a new MQX initialization structure that uses some of the default values and overrides others.

CAUTION	For MQX host tools to work properly, the MQX initialization structure variable must be called **MQX_init_struct**.

5.8 Creating Default Initialization for I/O Drivers

A number of initialization files might be needed to provide default information, when I/O drivers are installed with **_bsp_enable_card**().

5.8.1 init_*<dev>*.c

The *init_<dev>.c* files, where *<dev>* is the name of a device driver, which provides default initialization structure and other information needed to install specific I/O drivers.

Chapter 6 FAQs

6.1 General

My application stopped. How do I tell if MQX is still running?

If the time is being updated, MQX is processing the periodic timer interrupt. If Idle task is running, MQX is running.

6.2 Events

Two tasks use an event group. The connection works for one task, but not for the other. Why?

The tasks are probably sharing the same global connection, rather than having their own local, individual connection. Each task should call **_event_open()** or **_event_open_fast()** to get its own connection.

6.3 Global Constructors

I need to initialize some global constructors, which use the 'new' operator, before I call 'main'; that is, before I start MQX. The 'new' operator calls malloc(), which I redefine to call the MQX function _mem_alloc(). How do I do this?

Initialize the constructors from **_bsp_enable_card()** (in *init_bsp.c*), which MQX calls after it initializes the memory management component.

6.4 Idle Task

What happens if Idle task blocks because of an exception?

If Idle task blocks, System task, which is really a system task descriptor that has no code, becomes the active task. System task descriptor sets up the interrupt stack, then re-enables interrupts. As a result, the application can continue to run.

6.5 Interrupts

An interrupt comes at periodic intervals that my application must respond to very quickly — quicker than MQX allows. What can I do?

Call **_int_install_kernel_isr()** to replace the kernel ISR (**_int_kernel_isr()**). Your replacement ISR must:

- Save all registers on entry, and restore them on exit.
- It must not call any MQX functions.
- Pass information to other tasks (if required) by an application-implemented mechanism (usually ring buffers with head and tail pointers and total size fields).

My application consists of several tasks that should run only when a certain signal comes in by an interrupt. How can my ISR that handles the interrupt communicate to the appropriate tasks?

If the target hardware allows it, set the priority of the interrupt to be higher than what MQX uses, when it disables interrupts (see the **MQX_HARDWARE_INTERRUPT_LEVEL_MAX** field in the **MQX_INITIALIZATION_STRUCT**). If you do so, the interrupt will be able to interrupt an MQX-critical section. For example, on an ARCtangent processor, MQX can be configured to never disable level-2 interrupts and to use only level-1 interrupts to disable/enable in critical sections.

If the target hardware does not allow you to set the priority of the interrupt as described in the preceding paragraph, use the event component to send a signal from the ISR to several tasks. The tasks open connections to an event group, and one of the tasks gives the ISR the connection. Each task calls **_event_wait_any**() or **_event_wait_all()** and blocks. The ISR calls **_event_set()** to unblock the tasks.

When I save, and then restore an ISR for a specific interrupt, how do I get the value of the data pointer that was associated with the original ISR?

Call **_int_get_isr_data()** before you install the temporary ISR. This function returns a pointer to the data of the specific vector that you pass to it.

6.6 Memory

How does a task transfer a memory block that it does not own?

Although the task that owns the memory is the one that usually transfers it, a non-owner can do so with **_mem_transfer**().

My task allocates a 10-byte memory block, but it always gets more. Why?

When MQX allocates a memory block, it aligns the block to the appropriate memory boundary and associates an internal header with the block. It also enforces a minimum size.

Can a task allocate a memory block for another task?

No. Tasks allocate their own memory. However, a task can subsequently transfer the memory to another task.

If _partition_test() detects a problem, does it try to repair the problem?

No. This indicates that memory is corrupted. Debug the application to determine the cause.

When I extend the default memory pool, must the additional memory be contiguous with the existing end of the pool?

No. The additional memory can be anywhere.

What does _mem_get_highwater() return, if I extend the default-memory pool with non-contiguous memory?

The highwater mark is the highest memory location, from which MQX has allocated a memory block.

I have tasks on several processors that need to share memory. How can I provide mutual exclusion to the memory?

Depending on your hardware, you might be able to use a spin mutex to protect the shared memory. Spin mutexes call **_mem_test_and_set**(), which is multi-processor safe, when the hardware supports locking shared memory.

6.7 Message Passing

How can I guarantee that target message queue IDs are associated with the correct task?

Create one task that uses the names database to associate each message queue number with a name. Each task then gets the queue number by specifying the name.

Can I send messages between a PC and my target hardware?

Yes. Create a program to run on your PC that sends and receives data packets to/from the application either serially, over PCI, or over ethernet. As long as the packets are formatted correctly, MQX passes on any that it receives.

My task successfully calls _msgq_send() several times with a newly allocated message each time. Eventually _msgq_send() fails.

You have probably run out of messages. Each time you allocate a new message to send, check whether the return is NULL. If it is, the receiving task is probably not freeing the messages, or is not getting an opportunity to run.

6.8 Mutexes

What happens, when the task that owns a mutex data structure is destroyed? Do tasks that are waiting to lock the mutex wait forever?

No. All components have cleanup functions. When a task is terminated, the cleanup function determines what resources the task is using and frees them. If a task has a mutex locked, MQX unlocks the mutex when it terminates the task. A task should not own the mutex structure memory; it should create the structure as a global variable or allocate it from a system memory block.

6.9 Semaphores

What happens if I “force destroy” a strict semaphore?

If the force destroy flag is set when you destroy a strict semaphore, MQX does not destroy the semaphore, until all the waiting tasks get and post the semaphore. (If the semaphore is non-strict, MQX immediately readies all the tasks that are waiting for the semaphore.)

Two tasks use a semaphore. The connection works for one task, but not for the other. Why?

The tasks are probably sharing the same global connection, rather than having their own local, individual connection. Each task should call **_sem_open()** or **_sem_open_fast()** to get its own connection.

6.10 Task Exit Handler Versus Task Exception Handler

What is the difference between the two?

MQX calls the task exit handler when a task calls **_task_abort()**, or when a task returns from its task body. If MQX exception handling is installed, MQX calls the task exception handler, if the task causes an exception that is not supported.

6.11 Task Queues

My application puts several tasks of the same priority in a priority task queue? How are they ordered?

Tasks are in FIFO order within a priority.

6.12 Tasks

Do I always need at least one autostart task?

Yes. In an application, at least one autostart application task is required in order to start the application. In a multi-processor application (the application can create tasks remotely), each image need not have an autostart application task; however, each image must include IPC task as an autostart task in the task template list. If no application task is created on a processor, Idle task runs.

One autostart task creates all my other tasks and initializes global memory. Can I terminate it without affecting the child tasks?

Yes. When MQX terminates the creator, it frees the creator's resources (memory, partitions, queues, and so on) and stack space. The resources of the child tasks are independent of the creator and are not affected.

Does the creator task own its child task?

No. The only relationship between the two is that the child can get the task ID of its creator. The child has its own stack space and automatic variables.

What are tasks, and how are they created?

Tasks share the same code space, if they execute the same root function. A task always starts executing at the entry point of the root function even if the function is its creator's root function. This is not the same behavior as **fork()** in UNIX.

Can I move a created task to another processor?

No.

6.13 Time Slices

How does MQX measure a time slice? Is the time slice absolute or relative? That is, if a task has a 10 ms time slice and starts at time = 0 ms, does it give up the processor at time = 10 ms, or does it give up the processor after 10 ms of execution?

With a 10 ms time slice, MQX counts the number of periodic timer interrupts that have occurred, while the task is active. If the equivalent of ten or more milliseconds have expired, MQX effectively runs **_sched_yield()** for the task. As a result, a task does not get 10 ms of linear time since higher-priority tasks will preempt it. Also, if the task calls a scheduling function (for example **_task_block()** or **_sched_yield()**), MQX sets the task's time-slice counter back to zero.

As with timeouts, the time that MQX allocates is plus or minus **BSP_ALARM_FREQUENCY** ticks per second.

6.14 Timers

My application is on more than one processor. I have a master processor that sends a synchronization message to the other processors that causes them to reset their time. How can I make sure that the reset messages don't interfere with the timers that the application uses?

So that timers are not affected by changes to absolute time (**_time_set()**), start timers with relative time (**TIMER_ELAPSED_TIME**), rather than absolute time (**TIMER_KERNEL_TIME_MODE**).

What happens if _timer_start_oneshot_at() is given an expiry time that is in the past?

MQX puts the element in the timer queue. When the next periodic timer interrupt occurs, MQX determines that the current time is greater than, or equal to the expiry time, so the timer triggers and MQX calls the notification function.

Glossary

A

active task
The task that is currently running on the processor; that is, the highest-priority ready task.

address
See *logical address*, *physical address*, and *virtual address*.

application
The application consists of code that developers write, compile, and link with MQX. If the application runs on only one processor, it consists of one image. If it runs on multiple processors, it consists of multiple images.

application queue
A queue that an application initializes and uses through the queue component. See also *message queue*, *ready queue*, *task queue*, and *timeout queue*.

application task
A task that an application developer writes and, at the application's instruction, that MQX creates and starts. See also *autostart task* and *MQX task*.

autoclearing event bits
If a task creates an event group with autoclearing event bits, MQX clears the bits as soon as they have been set. If the event group does not have autoclearing event bits, it is the responsibility of the application to clear the bits.

autostart task
If the task template in the task-template list defines a task as an autostart task, MQX creates an instance of the task when MQX starts.

B

BAT
Block address translation; an MMU translation register.

big-endian
The most significant byte is the first byte in the word. See also *little-endian*.

block (verb)
When the active task blocks, MQX removes it from the ready queue and makes another task active. See also *dispatch*.

board
Also called a single-board computer. A board can have multiple processors.

BSP
Board support package. A group of files that are specific to a particular type of processor on a particular type of board. It includes drivers. See also *PSP*.

bus snooping
The cache monitors bus activity. If the application performs a write operation to an address that is a cache entry, the cache updates its cache. If the application performs a read operation for an address that is a cache entry, the cache supplies the data.

byte
See *single-addressable unit*.

C

cache
A region of fast memory that holds copies of data (data cache) or instructions (instruction cache, sometimes called code cache). Access to the cached copy is usually more efficient, than access to the original. Some CPUs have a unified cache, which they use for both data and code.

callback function
See *notification function*.

checksum, CHECKSUM
Many MQX data structures include a **CHECKSUM** field. If the field is incorrect, MQX considers the data within the structure corrupted. See also *valid*.

child
A task that this task created. See also *creator*.

code cache
See *cache*.

component
A group of MQX functions that offers a “service,” such as the mutex component or the watchdog component. Components can be core or optional.

context
MQX maintains context for each instance of each task and for the current ISR. Context includes the program counter, registers, stack, task state, and task resources.

corrupted
MQX considers data within a structure corrupted, if its checksum is incorrect, or pointers are incorrect. See also *invalid*.

CPU family
See *processor family*.

CPU type
A processor family includes CPU types. For example, the PowerPC family includes, in part, PowerPC 403, PowerPC 603, and PowerPC 750.

creator
The task that created a task. See also *child*.

D

data cache
See *cache*.

default-memory pool
Area within kernel memory, from which MQX allocates memory when an application calls **_mem_alloc()**, **_mem_alloc_zero()**, **_mem_alloc_system()**, or **_mem_alloc_system_zero()**. An application can extend the area by calling **_mem_extend()**.

dispatch (verb)
When MQX dispatches a task, it is in the process of examining the ready queues to determine, which task it will make active. MQX makes active the highest-priority task that has been the longest in the ready queue. See also *block* and *schedule*.

dynamic partition
A partition that is in the default-memory pool (created with **_partition_create()**). The partition is dynamic because it can have a grow factor, whereby MQX increases the partition size, if all the partition blocks have been allocated. See also *static partition*.

E

endian format
One of big-endian or little-endian format.

event group
An event group lets tasks synchronize and communicate. Event bits are grouped into 32-bit event groups. Tasks can wait for event bits to be set; they can also set and clear event bits. There are *fast event group*s and *named event group*s.

explicit scheduling
Application-defined scheduling that uses task queues. See also *FIFO scheduling* and *round robin scheduling*.

F

FALSE
Not TRUE; that is, zero.

family (of processors)
See *processor family*.

fast event group
An event group that is identified by a number, rather than by a name; also called an indexed event group. See also *named event group*.

fast semaphore
A semaphore that is identified by a number, rather than by a name; also called an indexed semaphore. See also *named semaphore*.

FIFO scheduling

First in, first out queuing protocol. With FIFO scheduling, the active task is the highest-priority task that has been ready the longest. See also *explicit scheduling* and *round robin scheduling*.

fragmentation of memory

Small deallocated (freed) memory blocks have become interspersed with allocated memory blocks.

H

hardware tick

A periodic timer interrupt uses a counter. A hardware tick occurs, when the counter increments or decrements.

home processor

See *local*.

host

The hardware and its operating system (for example, a desktop personal computer), on which you develop your application. See also *target*.

I

Idle task

The MQX task that runs, if no other tasks are ready.

image

An application has one image for each processor, on which the application runs. The image includes application code and MQX code.

indexed event group

See *fast event group*.

indexed semaphore

See *fast semaphore*.

instance

MQX creates an instance of an application task, if the task is an autostart task, or if an application calls **_task_create()**. The instance is uniquely identified by its task ID and task descriptor. Unless it would create confusion, the instance of the task is simply called the task. The POSIX term is *thread*.

instruction cache

See *cache*.

invalid

MQX considers data invalid, if the **VALID** field in its structure is not the same as what MQX set it to. See also *checksum*, *corrupted*, and *valid*.

I/O

Generally refers to the transfer of commands or data across a device interface.

IPC
Inter-processor communication. The mechanism by which multiple processors communicate.

IPC task
The MQX task that is required on each processor of a multi-processor application.

ISR
Interrupt service routine. A small, high-speed routine that reacts quickly to hardware interrupts.

K

KB
kilobyte

kernel data
Data structure, where MQX stores all internal information that it needs. The information is stored either directly or as pointers to other data structures.

kernel ISR
The assembly-language routine that saves the current context, switches from the task's stack to the interrupt stack, runs the appropriate ISR, and after that ISR completes, makes ready the highest-priority ready task.

kernel log
The log that can record MQX function calls, context switches, and interrupts, and associate them with a timestamp (in absolute time) and sequence number. See also *log*.

kernel memory
Initially defined by the MQX initialization structure (from **START_OF_KERNEL_MEMORY** to **END_OF_KERNEL_MEMORY**), but an application can extend it by calling **_mem_extend**(). MQX allocates memory for tasks, stacks, and its own use from kernel memory.

L

lightweight log
Similar to logs, except all entries have the same size, and you can create a lightweight log at a particular location in memory.

lightweight memory
Lightweight memory has fewer interface functions and smaller code and data sizes than the regular memory component.

lightweight semaphore
A lightweight semaphore is faster and needs less memory than a semaphore; it also has less functionality. See also *mutex* and *semaphore*.

lightweight timer
Lightweight timers provide a low-overhead mechanism for calling application functions at periodic intervals. Lightweight timers are installed by creating a periodic queue, then adding a timer to expire at some offset from the start of the period.

limited spin
If a limited-spin mutex is already locked when a task requests to lock it, MQX reschedules the requesting task a limited number of times before the request fails. See also *spin only.*

line
A quantity of information in the data cache or in the instruction cache. The quantity depends on the CPU.

little-endian
The most significant byte is the last byte in the word. See also *big-endian*.

local
Pertaining to the processor, on which the task runs. See also *remote*.

lock (verb)
When a task locks a mutex, it gets (owns) the mutex. When a task unlocks a mutex, it releases the mutex. See also *post* and *wait.*

log
Logs let applications log and retrieve application-specific information, and associate it with timestamps. Sometimes called user logs. See also *kernel log*, *lightweight log*.

logical address
An address that is generated by the CPU. When it is different from its physical address, it is called a virtual address.

LWLog
See *lightweight log*.

LWMem
See *lightweight memory.*

LWSem
See *lightweight semaphore*.

LWTimer
See *lightweight timer.*

M

memory
Anywhere in the addressable memory range of the hardware. See also *memory block*, *physical memory*, *virtual memory*, and *lightweight memory.*

memory block
A memory block is memory that a task has allocated and that MQX manages. Memory blocks are not a fixed size, and can be inside or outside the default-memory pool. See also *memory*, *memory block*, *partition*, and *partition block*.

message pool
Messages are allocated from message pools.

memory management unit
See *MMU*.

memory pool
An area of memory that an application can optionally create, and from which it can allocate memory blocks.

memory region
Defined by a start address and an end address, or by a start address and a size. A memory region has attributes that are defined by the hardware. A memory region might consist of multiple memory spaces and can be in physical memory or virtual memory.

memory space
A part of a memory region, to which MQX gives logical attributes. A memory space can be in physical memory or virtual memory. Examples include code space and data space.

MMU
Memory management unit; a hardware device.

MMU page number
A part of a virtual address that is an index into an MMU page table.

MMU page offset
The part of a virtual address that is an offset into an MMU page.

MMU page table
Contains the base addresses of each page in physical memory. The base address is combined with the MMU page offset to determine the physical address that is sent to the MMU.

MMU translation registers
Examples include BAT, TLB, and TTR.

MQX
MQX. An RTOS for single-processor, multi-processor, and distributed-processor embedded real-time applications.

MQX initialization structure
Defines parameters of the application and target hardware for each image. MQX uses the information, when it starts.

MQX task
A task that MQX creates for its internal use. MQX tasks include Idle task, System task, and, depending on the application, IPC task and Timer task. In multi-processor applications, the application includes IPC task as an autostart task in the task template list for each processor.

mutex
A mutex provides mutually exclusive access to a shared resource. Before a task accesses the resource, it requests to lock the mutex that is associated with the resource. If the mutex is not already locked, the task locks it and continues to run. If the mutex is already locked, depending on the attributes of the mutex, the task might wait until another task unlocks the mutex. See also *lightweight semaphore* and *semaphore*.

N

named event group
An event group that is identified by a name. See also *fast event group.*

named semaphore
A semaphore that is identified by a name. See also *fast semaphore*.

name component
Let tasks map a string name to a number.

non-strict
If a semaphore-type object is non-strict, a task can release the object without waiting for and getting the object. Lightweight semaphores are non-strict, mutexes are strict, and semaphores can be strict or non-strict.

normalized date
Date that is defined by **MQX_XDATE_STRUCT**, where each field is within its maximum limit.

normalized time
Time that is defined by **TIME_STRUCT**, where the **MILLISECONDS** field is less than 1000.

notification function
An application-provided function that MQX calls, when a particular condition occurs.

O

object
Examples include mutexes, lightweight semaphores, semaphores, messages, and queues.

P

page
See *MMU page* and *physical page*.

page number
See *MMU page number*.

page offset
See *MMU page offset*.

parent
See *creator*.

partition
Consists of partition blocks, which are fixed-size pieces of memory. There are *dynamic partition*s and *static partition*s.

partition block
Fixed-size block from a partition. Partition blocks are useful, when an application needs to allocate and free same-size pieces of memory quickly. There are private partition blocks and system partition blocks. See also *memory block*.

pending
A message is pending, if it is in a message queue; that is, if it has not been received by a task.

periodic timer device
The hardware device that generates timer interrupts at a specific interval. It is defined by the BSP. MQX uses the interrupts to maintain time. Sometimes called the system clock.

Do not confuse the periodic timer device with the periodic timers that tasks can start by calling functions from the **_timer_start_periodic_at** family or **_timer_start_periodic_every** family.

physical address
An address that is seen by the MMU; that is, an address that is loaded into the memory address register. See also *logical address* and *virtual address*.

POSIX
Portable Operating System Interface, produced by IEEE and standardized by ANSI and ISO. MQX conforms to POSIX.1 (basic OS interfaces), POSIX.4 (real-time extensions), and POSIX.4a (threads extensions).

post (verb)
When a task posts a semaphore or lightweight semaphore, it releases the semaphore. See also *wait*, *lock*, and *unlock*.

MQX
An RTOS for single-processor, multi-processor, and distributed-processor embedded real-time applications.

preempt
When MQX preempts the active task, the task is no longer the active task. MQX then performs a dispatch operation. See also *dispatch*.

priority-based preemptive scheduling
See *FIFO scheduling*.

priority inheritance
Priority inheritance prevents priority inversion. While a task has locked a semaphore or a mutex that has priority inheritance, MQX boosts the priority of the task to the priority of the highest-priority task that is waiting for the semaphore or mutex. See also *priority protection*.

priority inversion
Might occur, if tasks of different priority synchronize on objects such as semaphores. The relative priorities of tasks are effectively inverted because a higher-priority task is blocked, waiting for a lower-priority task to release the object. See also *priority inheritance*, *priority protection*.

priority protection
Priority protection prevents priority inversion. A mutex can have a priority. If the priority of a task that requests to lock the mutex (task_A) is not at least as high as the mutex priority, MQX raises the priority of task_A to the mutex priority for as long, as task_A has the mutex locked. See also *priority inheritance*.

priority queuing
MQX grants the semaphore or mutex to the highest-priority task that is waiting for the semaphore or mutex. Within a priority, tasks are queued in FIFO order.

private resource
A resource that an application task owns because either the task allocated the resource as a non-system resource, or because another task transferred (or effectively transferred) ownership of the resource. MQX frees the resource when the task is terminated. Private resources include memory blocks, messages, message pools, message queues, and partition blocks. See also *system resource*.

processor
The physical CPU device, on which the image runs. It is identified by its processor number. See also *board*, *CPU type*, *processor family*, *PSP*, and *SBC*.

processor family
Examples of processor families are ARCtangent, MC68060, and PowerPC. Within a family are CPU types. Also called CPU family. See also *PSP*.

processor number
Application-unique number that the application assigns in the MQX initialization structure for each image.

processor type
See *CPU type*.

program
See *application*.

PSP
Processor Support Package. A group of files that are specific to a CPU type. See also *BSP*.

Q

queue ID
Application-unique, MQX-generated number that identifies a message queue. It is a combination of the queue number and processor number.

queue number
Processor-unique, application-defined number that identifies a message queue. See also *queue ID*.

R

ready queue
There is a linked list of ready queues, one ready queue for each task priority. Each ready queue holds tasks that have the specific priority, and that are in the ready state. To distinguish it from other ready queues, the ready queue that a task is in, is referred to as the task's ready queue.

region
See *memory region*.

remote
Pertaining to a processor other than the local processor.

round robin interval
See *time slice*.

round robin scheduling
Guarantees that a task is not active for longer than the duration of the task's time slice. With round robin scheduling, the active task is the highest-priority task that has been ready the longest, without consuming its time slice. Sometimes called time-slice scheduling. See also *explicit scheduling* and *FIFO scheduling*.

round robin task
A task that uses round robin scheduling.

RR
Round robin. See *round robin scheduling*.

RTOS
Real-time operating system.

run
When a task is the active task, it runs on the processor.

S

schedule (verb)
MQX finds the next ready task, and makes it the active task.

scheduling
See *explicit scheduling*, *FIFO scheduling*, and *round robin scheduling*.

semaphore
A semaphore lets tasks synchronize access to shared resources. There are *named semaphore*s and *fast semaphore*s. See also *lightweight semaphore* and *mutex*.

semaphore-type objects
Include lightweight semaphores, semaphores, and mutexes.

single-addressable unit
The smallest quantity (in bits) that a CPU can address. Traditionally, it has been eight bits or one byte; however, some CPUs and DSPs define it to be up to 32 bits.

space
See *memory space*.

spin only
If a spin-only mutex is already locked when a task requests to lock it, MQX effectively timeslices the task until the mutex is unlocked. See also *limited spin*.

static partition
A partition that is outside the default-memory pool (created with **_partition_create_at()**). The partition is static, because it cannot have a grow factor, which means that MQX does not increase the partition size, if all the partition blocks have been allocated. The application must explicitly extend the partition. See also *dynamic partition*.

strict
If a semaphore-type object is strict, a task must first wait for and get the object, before it can release the object. Lightweight semaphores are non-strict, mutexes are strict, and semaphores can be strict or non-strict.

system
Usually used to include the application and all its target hardware.

system resource
A resource that an application task allocates, but does not own. MQX does not free the resource, when the task is terminated. Examples of system resources include system memory blocks, system message pools, system message queues, and system partition blocks. See also *private resource*.

System task
The MQX task that is really simply a task descriptor. See *System task descriptor*.

System task descriptor
MQX uses System task descriptor to store initialization errors. Subsequently, MQX uses the task descriptor, so that it can own system resources.

system timer
See *periodic timer device*.

T

target
Hardware, on which the application runs. It is defined by the BSP. See also *host*.

task
A body of C code (usually an infinite loop) that performs some function. There are application tasks and MQX tasks. An application task is defined by its task template. There can be multiple instances of a task. Unless it would create confusion, the instance of the task is simply called the task. See also *autostart task*.

task descriptor
Context information for an instance of a task.

task error code
Each task has a task error code associated to it. A task error code can be **MQX_OK** (or **MQX_EOK** for mutexes) or a code that indicates that an error has occurred.

task ID
Application-unique, MQX-generated number that identifies an instance of a task.

task template
Application-defined template that MQX uses to create instances of a task. The application either defines the template in the task template list of an MQX initialization structure, or supplies the template at run-time.

task template list
The list of task templates that is defined in the MQX initialization structure for the processor. Abbreviated as TTL.

thread
POSIX term for an instance of a task.

tick
A tick is considered to have occurred each time a periodic timer interrupts.

timeout queue
Queue of tasks that are waiting for a specific length of time, after which MQX returns them to their ready queues.

Timer task
The MQX task that MQX creates, if the application uses the timer component.

time slice
Maximum time that a round robin task is active before MQX preempts it, and attempts to reschedule another task of the same priority.

time-slice scheduling
See *round robin scheduling*.

time-slice task
See *round robin task*.

TLB
Translation lookaside buffer; an MMU translation register.

TRUE
Not FALSE; that is, any value that is not zero.

TTL
Task template list.

TTR
Transparent translation register; an MMU translation register.

U

unified cache
Some CPUs have a unified cache, which they use for both data and code.

unlock
When a task unlocks a mutex, it releases the mutex. See also *lock*, *post*, and *wait*.

user log
See *log* and *lightweight log*.

V

valid, VALID
Many MQX data structures include a **VALID** field. MQX considers the data in the structure valid, if the field is set to a known value. See also *checksum*, *corrupted*, and *invalid*.

virtual address
When a logical address is different from its physical address, it is called a virtual address.

virtual context
A virtual context for a task is created by calling **_mmu_create_vcontext()** and added to by calling **_mmu_add_vcontext**(). A task with a virtual context (virtual-context task) is created by calling **_mmu_create_vtask**(). A virtual context exists, only while the task is the active task, and can be used only by that task.

virtual-context task
A task that is created by calling **_mmu_create_vtask**().

virtual memory component
MQX functions that let an application manage virtual memory. The names of the functions start with **_mmu_** and contain **v**.

W

wait

When a task waits for and gets a semaphore or lightweight semaphore object, it owns the object. When it is finished, it posts (releases) the object. See also *lock* and *unlock*.

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