Preface

This manual explains how to use the RTX51 Tiny Real-Time Operating System and gives an overview of the functionality of RTX51 Full. The manual is not a detailed introduction to real-time applications and assumes that you are familiar with Keil C51, A51, the related Utilities, the DOS operating system and the hardware and instruction set of the 8051 microcontrollers.

The following literature is recommended as an extensive introduction in the area of real-time programming:

Deitel, H.M., Operating Systems, second edition,
Addison-Wesley Publishing Company, 1990

Ripps, David, A Guide to Real-Time Programming, Englewood Cliffs, N.J,
Prentice Hall, 1988/

Allworth, S.T., Introduction to Real-Time Software Design,
Springer-Verlag Inc., New York

This user's guide contains 6 parts:

Part 1: **Overview,** describes the functionality of a the RTX51 real-time opeating systems and discusses the basic features and differences of RTX51 Tiny and RTX51 Full. Also included are the technical data of RTX51 Full and RTX51 Tiny.

Part 2: **Requirements and Definitions,** discusses the development tools and the target system requirements of RTX51 Tiny, explains the terms used in the the RTX51 Tiny manual and decribes the task definition.

Part 3: **Creating RTX51 Tiny Applicaitons,** describes the steps necessary to create RTX51 Tiny applications.

Part 4: **Library Functions,** provides a reference for all RTX51 Tiny library routines.

Part 5: **System Debugging,** describes the stack handling of RTX51 Tiny and contains information about the system debugging.

Part 6: **Applications Examples,** contains several examples using RTX51 Tiny and describes the software development process. This information can be used as a guideline for your real-time designs.

Notational Conventions

This manual uses the following format conventions:

Examples	Description
BL51	Bold capital texts used for the names of executable programs, data files, source files, environment variables, and other commands entered at the DOS command prompt. This text usually represents commands that you must type in literally. For example: CLS DIR DS51.INI C51 A51 SET Note that you are not actually required to enter these commands using all capital letters.
Courier	Text in this typeface is used to represent the appearance of information that would be displayed on the screen or printed on the printer. This typeface is also used within the text when discussing or describing items which appear on the command line.
KEYS	Text in this typeface represents actual keys on the keyboard. For example, “Press Enter to Continue.”
ALT+<x>	Indicates an Alt key combination; the Alt and the <x> key must be simultaneously pressed.
CTRL+<x>	Indicates an control key combination; the Ctrl and the <x> key must be simultaneously pressed.

Overview

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RTX51 is a multitasking real-time operating system for the 8051 family of processors. RTX51 simplifies software design of complex, time-critical projects.

There are two distinct versions of RTX51 available:

RTX51 Full Performs both round-robin and preemptive task switching using up to four task priorities. RTX51 works in parallel with interrupt functions. Signals and messages may be passed between tasks using a mailbox system. You can allocate and free memory from a memory pool. You can force a task to wait for an interrupt, time-out, or signal or message from another task or interrupt.

RTX51 Tiny Is a subset of RTX51 that will easily run on single-chip 8051 systems without any external data memory. RTX51 Tiny supports many of the features found in RTX51 with the following exceptions: RTX51 Tiny only supports round-robin and the use of signals for task switching. Preemptive task switching is not supported. No message routines are included. No memory pool allocation routines are available.

The remainder of this chapter uses RTX51 to refer to both variants. Differences between the two are so stated in the text as their need becomes applicable.

Introduction

Many microcontroller applications require simultaneous execution of multiple jobs or tasks. For such applications, a real-time operating system (RTOS) allows flexible scheduling of system resources (CPU, memory, etc.) to several tasks. RTX51 implements a powerful RTOS which is easy to use. RTX51 works with all 8051 derivatives.

You write and compile RTX51 programs using standard C constructs and compiling them with C51. Only a few deviations from standard C are required in order to specify the task ID and priority. RTX51 programs also require that you include the real-time executive header file and link using the BL51 Linker/Locator and the appropriate RTX51 library file.

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Single Task Program

A standard C program starts execution with the main function. In an embedded application, main is usually coded as an endless loop and can be thought of as a single task which is executed continuously. For example:

```
int counter;

void main (void) {
  counter = 0;

  while (1) {                          /* repeat forever */
    counter++;                         /* increment counter */
  }
}
```

Round-Robin Program

A more sophisticated C program may implement what is called a round-robin pseudo-multitasking scheme without using a RTOS. In this scheme, tasks or functions are called iteratively from within an endless loop. For example:

```
int counter;

void main (void) {
  counter = 0;

  while (1) {                          /* repeat forever */
    check_serial_io ();
    process_serial_cmds ();            /* process serial input */

    check_kbd_io ();
    process_kbd_cmds ();               /* process keyboard input */

    adjust_ctrlr_parms ();             /* adjust the controller */

    counter++;                         /* increment counter */
  }
}
```

Round-Robin Scheduling With RTX51

RTX51 also performs round-robin multitasking which allows quasi-parallel execution of several endless loops or tasks. Tasks are not executed concurrently but are time-sliced. The available CPU time is divided into time slices and RTX51 assigns a time slice to every task. Each task is allowed to execute for a predetermined amount of time. Then, RTX51 switches to another task that is ready to run and allows that task to execute for a while. The time slices are very short, usually only a few milliseconds. For this reason, it appears as though the tasks are executing simultaneously.

RTX51 uses a timing routine which is interrupt driven by one of the 8051 hardware timers. The periodic interrupt that is generated is used to drive the RTX51 clock.

RTX51 does not require you to have a main function in your program. It will automatically begin executing task 0. If you do have a main function, you must manually start RTX51 using the **os_create_task** function in RTX51 Tiny and the **os_start_system** function in RTX51.

The following example shows a simple RTX51 application that uses only round-robin task scheduling. The two tasks in this program are simple counter loops. RTX51 starts executing task 0 which is the function names **job0**. This function adds another task called **job1**. After **job0** executes for a while, RTX51 switches to **job1**. After **job1** executes for a while, RTX51 switches back to **job0**. This process is repeated indefinitely.

```
#include <rtx51tny.h>

int counter0;
int counter1;

void job0 (void) _task_ 0 {
  os_create (1);                    /* mark task 1 as ready */
  while (1) {                       /* loop forever */
    counter0++;                     /* update the counter */
  }
}

void job1 (void) _task_ 1 {
  while (1) {                       /* loop forever */
    counter1++;                     /* update the counter */
  }
}
```

RTX51 Events

Rather than waiting for a tasks time slice to be up, you can use the **os_wait** function to signal RTX51 that it can let another task begin execution. This function suspends execution of the current task and waits for a specified event to occur. During this time, any number of other tasks may be executing.

Using Time-outs with RTX51

The simplest event you can wait for with the **os_wait** function is a time-out period in RTX51 clock ticks. This type of event can be used in a task where a delay is required. This could be used in code that polled a switch. In such a situation, the switch need only be checked every 50ms or so.

The next example shows how you can use the **os_wait** function to delay execution while allowing other tasks to execute.

1

```
#include <rtx51tny.h>

int counter0;
int counter1;

void job0 (void) _task_ 0 {
  os_create (1);                    /* mark task 1 as ready */
  while (1) {                       /* loop forever */
    counter0++;                     /* update the counter */
    os_wait (K_TMO, 3);             /* pause for 3 clock ticks */
  }
}

void job1 (void) _task_ 1 {
  while (1) {                       /* loop forever */
    counter1++;                     /* update the counter */
    os_wait (K_TMO, 5);             /* pause for 5 clock ticks */
  }
}
```

In the above example, **job0** enables **job1** as before. But now, after incrementing **counter0**, **job0** calls the **os_wait** function to pause for 3 clock ticks. At this time, RTX51 switches to the next task, which is **job1**. After **job1** increments **counter1**, it too calls **os_wait** to pause for 5 clock ticks. Now, RTX51 has no other tasks to execute, so it enters an idle loop waiting for 3 clock ticks to elapse before it can continue executing **job0**.

The result of this example is that **counter0** gets incremented every 3 timer ticks and **counter1** gets incremented every 5 timer ticks.

Using Signals with RTX51

You can use the **os_wait** function to pause a task while waiting for a signal (or binary semaphore) from another task. This can be used for coordinating two or more tasks. Waiting for a signal works as follows: If a task goes to wait for a signal, and the signal flag is 0, the task is suspended until the signal is sent. If the signal flag is already 1 when the task queries the signal, the flag is cleared, and execution of the task continues. The following example illustrates this:

```
#include <rtx51tny.h>

int counter0;
int counter1;

void job0 (void) _task_ 0 {
  os_create (1);                    /* mark task 1 as ready */
  while (1) {                       /* loop forever */
    if (++counter0 == 0)            /* update the counter */
      os_send_signal (1);           /* signal task 1 */
  }
}
```

```
void job1 (void) _task_ 1 {
  while (1) {                          /* loop forever */
    os_wait (K_SIG, 0, 0);             /* wait for a signal */
    counter1++;                        /* update the counter */
  }
}
```

In the above example, **job1** waits until it receives a signal from any other task. When it does receive a signal, it will increment **counter1** and again wait for another signal. **job0** continuously increments **counter0** until it overflows to 0. When that happens, **job0** sends a signal to **job1** and RTX51 marks **job1** as ready for execution. **job1** will not be started until RTX51 gets its next timer tick.

Priorities and Preemption

One disadvantage of the above program example is that **job1** is not started immediately when it is signaled by **job0**. In some circumstances, this is unacceptable for timing reasons. RTX51 allows you to assign priority levels to tasks. A task with a higher priority will interrupt or pre-empt a lower priority task whenever it becomes available. This is called preemptive multitasking or just preemption.

NOTE *Preemption and priority levels are not supported by RTX51 Tiny.*

You can modify the above function declaration for **job1** to give it a higher priority than **job0**. By default, all tasks are assigned a priority level of 0. This is the lowest priority level. The priority level can be 0 through 3. The following example shows how to define **job1** with a priority level of 1.

```
void job1 (void) _task_ 1 _priority_ 1 {
  while (1) {                            /* loop forever */
    os_wait (K_SIG, 0, 0);               /* wait for a signal */
    counter1++;                          /* update the counter */
  }
}
```

Now, whenever **job0** sends a signal to **job1**, **job1** will start immediately.

Compiling and Linking with RTX51

RTX51 is fully integrated into the C51 programming language. This makes generation of RTX51 applications very easy to master. The previous examples are executable RTX51 programs. You do not need to write any 8051 assembly routines or functions. You only have to compile your RTX51 programs with C51 and link them with the BL51 Linker/Locator. For example, you should use the following command lines if you are using RTX51 Tiny.

```
C51 EXAMPLE.C
BL51 EXAMPLE.OBJ RTX51TINY
```

Use the following command lines to compile and link using RTX51.

```
C51 EXAMPLE.C
BL51 EXAMPLE.OBJ RTX51
```

Interrupts

RTX51 works in parallel with interrupt functions. Interrupt functions can communicate with RTX51 and can send signals or messages to RTX51 tasks. RTX51 Full allows the assignment of interrupts to a task.

Message Passing

RTX51 Full supports the exchange of messages between tasks with the functions: SEND & RECEIVE MESSAGE and WAIT for MESSAGE. A message is a 16-bit value, which can be interpreted as a number or as a pointer to a memory block. RTX51 Full supports variable sized messages with a memory pool system.

CAN Communication

Controller **A**rea **N**etworks are easily implemented with RTX51/CAN. RTX51/CAN is a CAN task integrated into RTX51 Full. A RTX51 CAN task implements message passing via the CAN network. Other CAN stations can be configured either with or without RTX51.

BITBUS Communication

RTX51 Full covers Master and Slave BITBUS tasks supporting message passing with the Intel 8044.

Events

RTX51 supports the following events for the WAIT function:

- **Timeout:** Suspends the running task for a defined amount of clock ticks.
- **Interval:** (RTX51 Tiny only) is similar to timeout, but the software timer is not reset to allow generation of periodic intervals (required for clocks).
- **Signal:** For inter task coordination.
- **Message:** (RTX51 Full only) for exchange of messages.
- **Interrupt:** (RTX51 Full only) A task can wait for 8051 hardware interrupts.
- **Semaphore:** (RTX51 Full only) binary semaphores for management of shared system resources.

RTX51 Functions

The following table shows all RTX51 functions; **RTX51 Tiny** supports only the functions marked with (*). (Timings are measured with RTX51 Full)

Function	Description	Execution Time (cycles)
os_create (*)	move a task to execution queue	302
os_delete (*)	remove a task from execution queue	172
os_send_signal (*)	send a signal to a task (call from tasks)	408 with task switch. 316 with fast task switch 71 without task switch
os_clear_signal (*)	delete a sent signal	57
isr_send_signal (*)	send a signal to a task (call from interrupt)	46
os_wait (*)	wait for event	68 for pending signal 160 for pending message
os_attach_interrupt	assign task to interrupt source	119
os_detach_interrupt	remove interrupt assignment	96
os_disable_isr	disable 8051 hardware interrupts	81
os_enable_isr	enable 8051 hardware interrupts	80
os_send_message/ os_send_token	send a message or set a semaphore (call from task)	443 with task switch 343 with fast task switch 94 without task switch
isr_send_message	send a message (call from interrupt)	53
isr_recv_message	receive a message (call from interrupt)	71 (with message)
os_create_pool	define a memory pool	644 (size 20 * 10 bytes)
os_get_block	get a block from a memory pool	148
os_free_block	return a block to a memory pool	160
os_set_slice	define RTX51 system clock value	67

Additional DEBUG and SUPPORT functions: check_mailboxes, check_task, check_tasks, check_mail, check_pool, set_int_mask, reset_int_mask.

CAN Functions (only available with RTX51 Full)

CAN controllers supported: Philips 82C200, 80C592 and Intel 82526 (more CAN controllers in preparation).

CAN Function	Description
can_task_create	create the CAN communication task
can_hw_init	CAN controller hardware initialization
can_def_obj	define the communication objects
can_start / can_stop	start and stop the CAN communication
can_send	send an object over the CAN bus
can_write	write new data to an object without sending it
can_read	read an objects data direct
can_receive	receive all not bound objects
can_bind_obj	bind an object to a task; task is started when object is received
can_unbind_obj	untie the binding between task and object
can_wait	wait for receiving of a bound object
can_request	send a remote frame for the specified object
can_get_status	get the actual CAN controller status

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Technical Data

Description	RTX51 Full	RTX51 Tiny
Number of tasks	256; max. 19 tasks active	16
RAM requirements	40 .. 46 bytes DATA 20 .. 200 bytes IDATA (user stack) min. 650 bytes XDATA	7 bytes DATA 3 * <task count> IDATA
Code requirements	6KB .. 8KB	900 bytes
Hardware requirements	timer 0 or timer 1	timer 0
System clock	1000 .. 40000 cycles	1000 .. 65535 cycles
Interrupt latency	< 50 cycles	< 20 cycles
Context switch time	70 .. 100 cycles (fast task) 180 .. 700 cycles (standard task) depends on stack load	100 .. 700 cycles depends on stack load
Mailbox system	8 mailboxes with 8 int entries each	not available
Memory pool system	up to 16 memory pools	not available
Semaphores	8 * 1 bit	not available

Requirements and Definitions

The following chapter describes the software and hardware requiremens of RTX51 Tiny and defines the terms used within this manual. RTX51 Tiny uses a combination of system calls as well as the **_task_** keyword for the task definition which is built in to the C51 compiler. The task definition and the major features of RTX51 Tiny are also described within this chapter.

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Development Tool Requirements

The following software products are required to operate RTX51 Tiny:

- C51 Compiler
- BL51 Code Banking Linker
- A51 Macro Assembler

The library file **RTX51TNY.LIB** must be stored in the library path specified with the DOS envirionment variable C51LIB. Usually this is the directory **C51\LIB**.

The include file **RTX51TNY.H** must be stored in the include path specified with the DOS envirionment variable C51INC. Usually this is the directory **C51\INC**.

Target System Requirements

RTX51 Tiny can run on single-chip 8051 systems without any external data memory. However the application can access external memory. RTX51 Tiny can use all memory models supported by C51. The selected memory model only influences the location of application objects. The RTX51 Tiny system variables and the stack area of the application are always stored in internal 8051 memory (DATA or IDATA). Typically, RTX51 Tiny applications are implemented in the SMALL model.

RTX51 Tiny performs round-robin task switching only. Preemptive task switching and task priorities are not supported. If your application needs preemptive task switching you need to use the RTX51 Full Real-Time Executive.

RTX51 Tiny is not designed for use with bank switching programs. If you require real-time multitasking in your code banking applications you need to use the RTX51 Full Real-Time Executive.

Interrupt Handling

RTX51 Tiny can operate parallel with interrupt functions. Similar to other 8051 applications, the interrupt source must be enabled in the 8051 hardware registers in order to trigger for an interrupt. RTX51 Tiny does not contain any management for interrupts; for this reason, the interrupt enable is sufficient to process interrupts.

RTX51 Tiny uses the 8051 timer 0 and the timer 0 interrupt of the 8051. Globally disabling all interrupts (EA bit) or the timer 0 interrupt stops therefore the operation of RTX51 Tiny. Except for a few 8051 instructions, the timer 0 interrupt should not be disabled.

Reentrant Functions

It is not allowed to call non-reentrant C functions from several tasks or interrupt procedures. Non-reentrant C51 functions store their parameters and automatic variables (local data) in static memory segments; for this reason, this data is overwritten when multiple function calls occur simultaneously. Therefore non-reentrant C functions can only be call for several tasks, if the user can ensure that they are not called recursive. Usally this means that the Round-Robin task scheduling must be disabled and that such functions do not call any RTX51 Tiny system functions.

C functions which are only using registers for parameter and automatic variables are inherently reentrant and can be called without any restrictions from different RTX51 Tiny tasks.

The C51 Compiler provides also reentrant functions. *Refer to the C51 User's Manual for more information.* Reentrant functions store their parameters and local data variables on a reentrant stack and the data are protected in this way against multiple calls. However, RTX51 Tiny does not contain any management for the C51 reentrant stack. If you are using reentrant functions in your application you must ensure that these functions do not call any RTX51 Tiny system functions and that reentrant functions are not interrupted by the Round-Robin task scheduling of RTX51 Tiny. The full version, RTX51 Full contains a stack management for reentrant functions.

C51 Library Functions

All C51 library functions which are reentrant can be used in all tasks without any restrictions.

For C51 library functions which are non-reentrant the same restrictions apply as for non-reentrant C functions. *Refer to Reentrant Functions for more information.*

Usage of Multiple Data Pointers and Arithmetic Units

The C51 compiler allows you to use Multiple Data Pointers and Arithmetic Units of various 8051 derivatives. Since RTX51 Tiny does not contain any management for these hardware components it is recommended that you are not using these components together with RTX51 Tiny. However you can use Multiple Data Pointers and Arithmetic Units if you can ensure that there is no round-robin task during the execution of program parts using such additional hardware components.

Registerbanks

RTX51 Tiny assigns all tasks to registerbank 0. For this reason, all task functions must be compiled with the default setting of C51, REGISTERBANK (0). The interrupt functions can use the remaining registerbanks. However, RTX51 Tiny requires 6 permanent bytes in the registerbank area. The registerbank used by RTX51 Tiny for these bytes can be defined with the configurarion variable **INT_REGBANK**. *Refer to chapter 3, RTX51 Tiny configuration for more information.*

Task Definition

Real-Time or multitasking applications are composed of one or more tasks that perform specific operations. RTX51 Tiny allows for up to 16 tasks. Tasks are simply C functions that have a **void** return type and a **void** argument list and are declared using the **_task_** function attribute using the following format

```
void func (void) _task_ num
```

where ***num*** is a task ID number from 0 to 15.

Example:

```
void job0 (void) _task_ 0 {
  while (1) {
    counter0++;                        /* increment counter */
  }
}
```

defines the function job0 to be task number 0. All that this task does is increment a counter and repeat. You should note that all tasks are implemented as endless loops in this fashion.

Task Management

Each task that you define for RTX51 Tiny can be in one of a number of different states. The RTX51 Tiny Kernel maintains the proper state for each task. Following is a description of the different states.

State	Description
RUNNING	The task currently being executed is in the RUNNING State. Only one task can be running at a time.
READY	Tasks which are waiting to be executed are in the READY STATE. After the currently running task has finished processing, RTX51 Tiny starts the next task that is ready.
WAITING	Tasks which are waiting for an event are in the WAITING STATE. If the event occurs, the task is placed into the READY STATE.
DELETED	Tasks which are not started are in the DELETED STATE.
TIME-OUT	Tasks which were interrupted by a round-robin time-out are placed in the TIME-OUT STATE. This state is equivalent to the READY STATE.

Task Switching

RTX51 Tiny performs round-robin multitasking which allows quasi-parallel execution of several endless loops or tasks. Tasks are not executed concurrently but are time-sliced. The available CPU time is divided into time slices and RTX51 Tiny assigns a time slice to every task. Each task is allowed to execute for a predetermined amount of time. Then, RTX51 Tiny switches to another task that is ready to run and allows that task to execute for a while. The duration of a time slice can be defined with the configurarion variable **TIMESHARING**. *Refer to chapter 3, RTX51 Tiny configuration for more information.*

Rather then wait for a taskś time slice to expire, you can use the **os_wait** system function to signal RTX51 Tiny that it can let another task begin execution. **os_wait** suspends the execution of the current task and waits for a specified event to occur. During this time, any number of other tasks may be executing.

The section of RTX51 Tiny which assigns the processor to a task is called the scheduler. The RTX51 Tiny scheduler defines which task is running according to the following rules:

The currently running task is interrupted if…

1. The task calls the **os_wait** function and the specified event has not occurred.
2. The task has executed for longer than the defined round-robin time-out.

Another task is started if…

1. No other task is running.
2. The task which is to be started is in the **READY** or **TIME-OUT** State.

Events

The **os_wait** function of RTX51 Tiny supports the following event types:

SIGNAL: Bit for task communication. A signal can be set or cleared using RTX51 Tiny system functions. A task can wait for a signal to be set before continuing. If a task calls the **os_wait** function to wait for a signal and if the signal is not set, the task is suspended until the signal gets set. Then, the task is returned to the **READY** State and can begin execution.

TIMEOUT: A time delay which is started by the os_wait function. The duration of the time delay is specified in timer ticks. The task who is calling the os_wait funciton with a TIMEOUT value is suspended until the time delay is over. Then, the task is returned to the **READY** State and can begin execution.

INTERVAL: A interval delay which is started by the os_wait function. The interval delay is also specified in in timer ticks. The difference to a timeout delay is that the RTX51 timer is not reset. Therefore the event INTERVAL works with a timer which is running permantly. An interval can be used if the task is to be executed in synchronous intervals; a simple example is a clock.

*Note: The event **SIGNAL** can be combined with the events **TIMEOUT** and so that RTX51 Tiny waits for both a signal and a time period.*

Creating RTX51 Tiny Applications

Writing RTX51 Tiny programs requires that you include the **RTX51TNY.H** header file found in the **\C51\INC** subdirectory in your C program and that you declare your tasks using the **_task_** function attribute.

RTX51 Tiny programs do not require a **main** C function. The linking process will include code that will cause execution to begin with task 0.

RTX51 Tiny Configuration

You can modify the RTX51 Tiny configuration file **CONF_TNY.A51** found in the **\C51\LIB** subdirectory. You can change the following parameters in this configuration file.

- Register bank used for the system timer tick interrupt
- Interval for the system timer
- Round-robin time-out value
- Internal data memory size
- Free stack size after RTX51 Tiny is started

A portion of this file is listed below.

```
;------------------------------------------
;  This file is part of the 'RTX51 tiny' Real-Time Operating System Package
;------------------------------------------
;  CONF_TNY.A51:  This code allows configuration of the
;                 'RTX51 tiny' Real Time Operating System
;
;  To translate this file use A51 with the following invocation:
;
;     A51 CONF_TNY.A51
;
;  To link the modified CONF_TNY.OBJ file to your application use the following
;  BL51 invocation:
;
;     BL51 <your object file list>, CONF_TNY.OBJ <controls>
;
;------------------------------------------
;
;  'RTX51 tiny' Hardware-Timer
;  ===========================
;
;  With the following EQU statements the initialization of the 'RTX51 tiny'
;  Hardware-Timer can be defined ('RTX51 tiny' uses the 8051 Timer 0 for
;  controlling RTX51 software timers).
;
;                           ; define the register bank used for the timer interrupt.
INT_REGBANK  EQU    1       ; default is Registerbank 1
;
;                           ; define Hardware-Timer Overflow in 8051 machine cycles.
INT_CLOCK    EQU    10000   ; default is 10000 cycles
;
;                           ; define Round-Robin Timeout in Hardware-Timer Ticks.
TIMESHARING  EQU    5       ; default is 5 ticks.
;                           ;
;                           ; note: Round-Robin can be disabled by using value 0.
;
```

```
;  Note:   Round-Robin Task Switching can be disabled by using '0' as
;          value for the TIMESHARING equate.
;---------------------------------------
;
;  'RTX51 tiny' Stack Space
;  ========================
;
;  The following EQU statements defines the size of the internal RAM used
;  for stack area and the minimum free space on the stack.  A macro defines
;  the code executed when the stack space is exhausted.
;
;                           ; define the highest RAM address used for CPU stack
RAMTOP       EQU    0FFH    ; default is address (256 - 1)
;
FREE_STACK   EQU    20      ; default is 20 bytes free space on stack
;
STACK_ERROR  MACRO
             CLR    EA      ; disable interrupts
             SJMP   $       ; endless loop if stack space is exhausted
             ENDM
;
;---------------------------------------
```


This configuration file defines a number of constants that may be modified to suit the requirements of your particular application. These are described in the following table.

Variable	Description
INT_REGBANK	indicates which register bank is to be used by RTX51 Tiny for the system interrupt.
INT_CLOCK	defines the interval for the system clock. The system clock generates an interrupt using this interval. The defined number specifies the number of CPU cycles per interrupt.
TIMESHARING	defines the time-out for the round-robin task switching. The value indicates the number of timer tick interrupts that must elapse before RTX51 Tiny will switch to another task. If this value is 0, round-robin multitasking is disabled.
RAMTOP	indicates the highest memory location in the internal memory of the 8051 derivative. For the 8051, this value would be 7Fh. For the 8052, this value would be 0FFh.
FREE_STACK	specifies the size of the free stack area in bytes. When switching tasks, RTX51 Tiny verifies that the specified number of bytes is available in the stack. If the stack is too small, RTX51 Tiny invokes the STACK_ERROR macro. The default value for FREE_STACK is 20. Values 0 .. 0FFH are allowed.
STACK_ERROR	is the macro that is executed when RTX51 Tiny detects a stack problem. You may change this macro to perform whatever operations are necessary for your application.

Compiling RTX51 Tiny Programs

RTX51 Tiny applications require no special compiler switches or settings. You should be able to compile your RTX51 Tiny source files just as you would ordinary C source files.

Linking RTX51 Tiny Programs

RTX51 Tiny applications must be linked using the BL51 code banking linker/locator. The **RTX51TINY** directive must be specified on the command line after all object files. *Refer to the RTX51TINY directive in Utilities manual.*

Optimizing RTX51 Tiny Programs

The following items should be noted when creating RTX51 applications.

- If possible, disable round-robin multitasking. Tasks which use round-robin multitasking require 13 bytes of stack space to store the task context (registers, etc.). This context storage is not required if task switching is triggered by the **os_wait** function. The **os_wait** function also produces an improved system reaction time since a task which is waiting for execution does not have to wait for the entire duration of the round-robin time-out.
- Do not set the timer tick interrupt rate too fast. Setting the tick rate to a low number increases the number of timer ticks per second. There is about 100 to 200 CPU cycles of overhead for each timer tick interrupt. Therefore, the timer tick rate should be set high enough to minimize interrupt latency.

RTX51 Tiny System Functions

A number of routines are included in the RTX51 Tiny Library file **RTX51TNY.LIB** that can be found in the **\C51\LIB** subdirectory. These routines allow you to create and destroy tasks, send and receive signals from one task to another, and delay a task for a number of timer ticks.

These routines are summarized in the following table and described in detail in the function reference that follows.

Routine	Description
isr_send_signal	Sends a signal to a task from an interrupt
os_clear_signal	Deletes a signal that was sent
os_create_task	Moves a task to the execution queue
os_delete_task	Removes a task from the execution queue
os_running_task_id	Returns the task ID of the task that is currently running
os_send_signal	Sends a signal to a task from another task
os_wait	Waits for an event
os_wait1	Waits for an event
os_wait2	Waits for an event

Function Reference

The following pages describe the RTX51 Tiny system functions. The system functions are described here in alphabetical order and each is divided into several sections:

Summary: Briefly describes the routine's effect, lists include file(s) containing its declaration and prototype, illustrates the syntax, and describes any arguments.

Description: Provides a detailed description of the routine and how it is used.

Return Value: Describes the value returned by the routine.

See Also: Names related routines.

Example: Gives a function or program fragment demonstrating proper use of the function.

isr_send_signal

Summary:

```
#include <rtx51tny.h>

char isr_send_signal (
     unsigned char task_id);          /* ID of task to signal */
```

Description:

The **isr_send_signal** function sends a signal to task *task_id*. If the specified task is already waiting for a signal, this function call will ready the task for execution. Otherwise, the signal is stored in the signal flag of the task.

The **isr_send_signal** function may be called only from interrupt functions.

Return Value:

The **isr_send_signal** function returns a value of 0 if successful and -1 if the specified task does not exist.

See Also:

os_clear_signal, os_send_signal, os_wait

Example:

```
#include <rtx51tny.h>
void tst_isr_send_signal (void) interrupt 2
{
.
.
isr_send_signal (8);        /* signal task #8 */
.
.
.
}
```

os_clear_signal

Summary:

```
#include <rtx51tny.h>

char os_clear_signal (
        unsigned char task_id);       /* task ID of signal to clear */
```

Description: The **os_clear_signal** function clears the signal flag for the task specified by *task_id*.

Return Value: The **os_clear_signal** function returns a value of 0 if the signal flag was successfully cleared. A value of -1 is returned if the specified task does not exist.

See Also: isr_send_signal, os_send_signal

Example:

```
#include <rtx51tny.h>
#include <stdio.h>            /* for printf */

void tst_os_clear_signal (void) _task_ 8
{
.
.
.
os_clear_signal (5);
/* clear signal flag in task 5 */
.
.
.
}
```

os_create_task

Summary:

```
#include <rtx51tny.h>

char os_create_task (
        unsigned char task_id);          /* ID of task to start */
```

Description: The **os_create_task** function starts the defined task function using the task number specified by *task_id*. The task is marked as ready and is executed according to the rules specified for RTX51 Tiny.

Return Value: The **os_create_task** function returns a value of 0 if the task was successfully started. A value of -1 is returned if the task could not be started or if no task was defined using the specified task number.

See Also: os_delete_task

Example:

```
#include <rtx51tny.h>
#include <stdio.h>            /* for printf */

void new_task (void) _task_ 2
{
.
.
.
}

void tst_os_create_task (void) _task_ 0
{
.
.
.
if (os_create_task (2))
  {
  printf ("Couldn't start task 2\n");
  }
.
.
}
```

os_delete_task

Summary:

```
#include <rtx51tny.h>

char os_delete_task (
     unsigned char task_id);     /* ID of task to stop and delete */
```

Description: The **os_delete_task** function stops the task specified by the *task_id* argument. The specified task is removed from the task list.

Return Value: The **os_delete_task** function returns a value of 0 if the task was successfully stopped and deleted. A return value of -1 indicates the specified task does not exist or had not been started.

See Also: os_create_task

Example:

```
#include <rtx51tny.h>
#include <stdio.h>            /* for printf */

void tst_os_delete_task (void) _task_ 0
{
.
.
.
if (os_delete_task (2))
  {
  printf ("Couldn't stop task 2\n");
  }
.
.
.
}
```

os_running_task_id

Summary:

#include <rtx51tny.h>

char os_running_task_id (void);

Description: The **os_running_task_id** function determines the task id of the currently executing task function.

Return Value: The **os_running_task_id** function returns the task ID of the currently executing task. This value is a number in the range 0 to 15.

See Also: os_create_task, os_delete_task

Example:

```
#include <rtx51tny.h>
#include <stdio.h>            /* for printf */

void tst_os_running_task (void) _task_ 3
{
unsigned char tid;

tid = os_running_task_id ();

/* tid = 3 */

}
```

os_send_signal

Summary:

```
#include <rtx51tny.h>

char os_send_signal (
     unsigned char task_id);          /* ID of task to signal */
```

Description: The **os_send_signal** function sends a signal to task *task_id*. If the specified task is already waiting for a signal, this function call readies the task for execution. Otherwise, the signal is stored in the signal flag of the task.

The **os_send_signal** function may be called only from task functions.

Return Value: The **os_send_signal** function returns a value of 0 if successful and -1 if the specified task does not exist.

See Also: isr_send_signal, os_clear_signal, os_wait

Example:

```
#include <rtx51tny.h>
#include <stdio.h>          /* for printf */

void signal_func (void) _task_ 2
{
.
.
os_send_signal (8);         /* signal task #8 */
.
.
}

void tst_os_send_signal (void) _task_ 8
{
.
.
os_send_signal (2);         /* signal task #2 */
.
.
}
```

os_wait

Summary:

```
#include <rtx51tny.h>

char os_wait (
    unsigned char event_sel,        /* events to wait for */
    unsigned char ticks,            /* timer ticks to wait */
    unsigned int dummy);            /* unused argument */
```

Description: The **os_wait** function halts the current task and waits for one or several events such as a time interval, a time-out, or a signal from another task or interrupt. The *event_sel* argument specifies the event or events to wait for and can be any combination of the following manifest constants:

Event constant	Description
K_IVL	Wait for a timer tick interval.
K_SIG	Wait for a signal.
K_TMO	Wait for a time-out.

The above events can be logically ORed using the vertical bar character (|). For example, **K_TMO | K_SIG**, specifies that the task wait for a time-out or for a signal.

The t*icks* argument specifies the number of timer ticks to wait for an interval event (**K_IVL**) or a time-out event (**K_TMO**).

The *dummy* argument is provided for compatibility with RTX51 and is not used in RTX51 Tiny.

Return Value: When one of the specified events occurs, the task is enabled for execution. Execution is restored and a manifest constant that identifies the event that restarted the task is returned by the **os_wait** function. Possible return values are:

Return Value	Description
SIG_EVENT	A signal was received.
TMO_EVENT	A time-out has completed or an interval has expired.
NOT_OK	The value of the *event_sel* argument is invalid.

See Also: os_wait1, os_wait2

Example:

```
#include <rtx51tny.h>
```

```
#include <stdio.h>          /* for printf */

void tst_os_wait (void) _task_ 9
{
while (1)
  {
  char event;

  event = os_wait (K_SIG + K_TMO, 50, 0);

  switch (event)
    {
    default:
      /* this should never happen */
      break;

    case TMO_EVENT:         /* time-out */
      /* 50 tick time-out occurred */
      break;

    case SIG_EVENT:         /* signal recvd */
      /* signal received */
      break;
    }
  }
}
```

os_wait1

Summary:

```
#include <rtx51tny.h>

char os_wait1 (
        unsigned char event_sel);          /* events to wait for */
```

Description: The **os_wait1** function halts the current task and waits for an event to occur. The **os_wait1** function is a subset of the **os_wait** function and does not allow all of the events that **os_wait** offers. The *event_sel* argument specifies the event to wait for and can have only the value **K_SIG** which will wait for a signal.

Return Value: When the signal events occurs, the task is enabled for execution. Execution is restored and a manifest constant that identifies the event that restarted the task is returned by the **os_wait1** function. Possible return values are:

Return Value	Description
SIG_EVENT	A signal was received.
NOT_OK	The value of the *event_sel* argument is invalid.

See Also: os_wait, os_wait2

Example: See **os_wait**.

os_wait2

Summary:

```
#include <rtx51tny.h>

char os_wait2 (
        unsigned char event_sel,        /* events to wait for */
        unsigned char ticks);           /* timer ticks to wait */
```

Description: The **os_wait2** function halts the current task and waits for one or several events such as a time interval, a time-out, or a signal from another task or interrupt. The *event_sel* argument specifies the event or events to wait for and can be any combination of the following manifest constants:

Event constant	Description
K_IVL	Wait for a timer tick interval.
K_SIG	Wait for a signal.
K_TMO	Wait for a time-out.

The above events can be logically ORed using the vertical bar character (|). For example, **K_TMO | K_SIG**, specifies that the task wait for a time-out or for a signal.

The *ticks* argument specifies the number of timer ticks to wait for an interval event (**K_IVL**) or a time-out event (**K_TMO**).

Return Value: When one of the specified events occurs, the task is enabled for execution. Execution is restored and the manifest constant that identifies the event that restarted the task is returned by the **os_wait2** function. Possible return values are:

Return Value	Description
SIG_EVENT	A signal was received.
TMO_EVENT	A time-out has completed or an interval has expired.
NOT_OK	The value of the *event_sel* argument is invalid.

See Also: os_wait, os_wait1

Example: See **os_wait**.

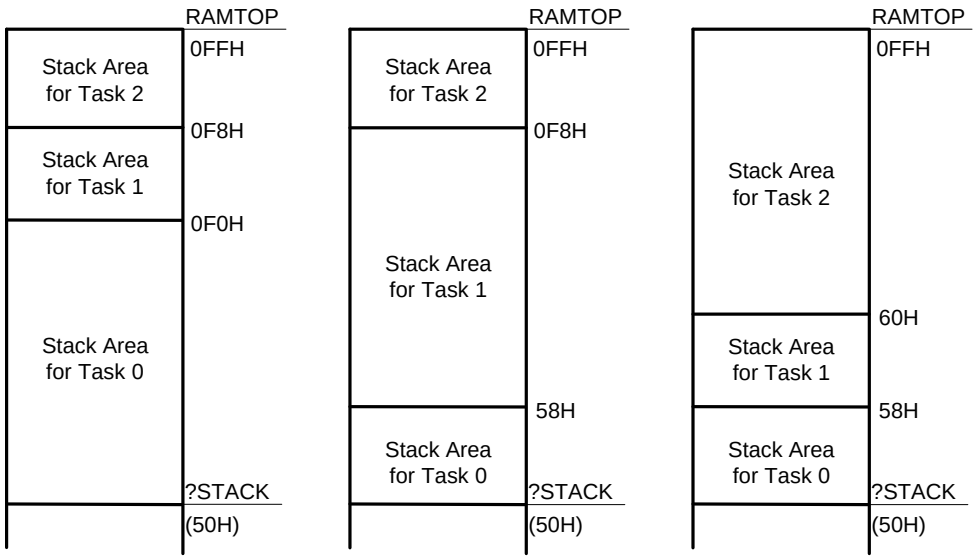
4

System Debugging

This chapter contains additonal information about the stack handling and the system debugging with dScope-51.

Stack Management

RTX51 Tiny reserves an individual stack area for each task. Due to the design of RTX51 Tiny which uses only the on-chip memory resources of the 8051, the entire stack is manage in the internal memory (IDATA) of the 8051. To allocate the largest available stack space to the current running task, the stack space used by other not running tasks is moved. The following figure illustrates the stack assignment of the individual tasks.



Stack Assignment for Task0 = Running Task | **Stack Assignment for Task1 = Running Task** | **Stack Assignment for Task2 = Running Task**

The figure illustrates that RTX51 Tiny always allocates the entiere free memory as a stacka area for thye currently running task. The memory used for the stack starts at the symbol ?STACK which denotes the start address of the ?STACK segment. The ?STACK symbol reserves the first unassigned byte in the internal memory.

Debugging with dScope-51

A RTX51 Tiny application can be tested using the dScope-51 Source-Level Debugger. The RTX51 system status is displayed using a debug function. The use of this debug function is explained in the following.

The debug function is defined in the file **DBG_TINY.INC** (for Windows dScope the file name is DBG_TINY.DSW) and is loaded within dScope-51 by entering the following commands. The RTX51 Tiny application must be loaded prior to defining this debug function. The debug function is activated by pressing the **F3-KEY** and displays then the status of RTX51 Tiny. In addition every task switch is displayed with a message.

Example:

```
DS51 TRAFFIC
>INCLUDE DBG_TINY.INC
>G
<F3-KEY>

+-------------------------------------------------------------------------+
| Task ID | Start | State   | Wait for Event   | Signal | Timer | Stack |
|---------+-------+---------+------------------+--------+-------+-------|
|     0   | 0026H | DELETED |                  |    0   |   131 |   84H |
|     1   | 00D1H | WAITING | SIGNAL           |    0   |   131 |   84H |
|     2   | 0043H | WAITING | TIMEOUT          |    0   |     5 |   86H |
|     3   | 0278H | DELETED |                  |    0   |   131 |   88H |
|     4   | 02ACH | WAITING | SIGNAL & TIMEOUT |    0   |   220 |   88H |
|     5   | 032BH | WAITING | TIMEOUT          |    0   |     1 |   8AH |
|     6   | 000EH | WAITING | SIGNAL           |    0   |   131 |   FBH |
+-------------------------------------------------------------------------+
```

Interpretation of the debug output:

Task ID Indicates the task number which is used in the task definition within the _task_ keyword of the C51 Compiler.

Start Indicates the start address of the task function.

State Indicates the state of the task. State can be one of the following:

State	Description
RUNNING	The task currently being executed is in the RUNNING State. Only one task can be running at a time.
READY	Tasks which are waiting to be executed are in the READY STATE. After the currently running task has finished processing, RTX51 Tiny starts the next task that is ready.
WAITING	Tasks which are waiting for an event are in the WAITING STATE. If the event occurs, the task is placed into the READY STATE.
DELETED	Tasks which are not started are in the DELETED STATE.
TIME-OUT	Tasks which were interrupted by a round-robin time-out are placed in the TIME-OUT STATE. This state is equivalent to the READY STATE.

Wait for Event Indicates which events the task is currently waiting for. The events can be a combination of the following:

Event	Description
TIMEOUT	The task is in the state **WAITING** until the Timer reaches the value 0. This event is displayed when the os_wait function is called with the K_TMO or K_IVL event selector.
SIGNAL	The task is in the state **WAITING** until the signal flag goes to one. This event is displayed when the os_wait function is called with the K_SIG event selector.

Signal Indicates the state of the signal flag: 1 for signal set, 0 for signal reset.

Timer Indicates the number of timer ticks which are required for a timeout. It should be noted that the Timer is free running and only set to the timeout value when the os_wait function is called with a K_TMO argument.

Stack Indicates the start address of the local task stack in the IDATA area. The layout of the RTX-51 tasks is described under *Stack Management* earlier in this chapter.

5

Application Examples

RTX_EX1: Your First RTX51 Program

The program RTX_EX1 demonstrates round-robin multitasking using RTX51 Tiny. This program is composed of only one source file **RTX_EX1.C** located in the **\C51V4\RTX_TINY\RTX_EX1** or **\CDEMO\51\RTX_TINY\RTX_EX1** directory. The contents of **RTX_EX1.C** is listed below.

```
/*----------------------------------------------------------------------------*/
/*                                                                            */
/*                   RTX_EX1.C:  The first RTX51 Program                      */
/*                                                                            */
/*----------------------------------------------------------------------------*/

#pragma CODE DEBUG OBJECTEXTEND

#include <rtx51tny.h>                 /* RTX51 tiny functions & defines      */

int counter0;                         /* counter for task 0                   */
int counter1;                         /* counter for task 1                   */
int counter2;                         /* counter for task 2                   */

/*----------------------------------------------------------------------------*/
/*       Task 0 'job0':  RTX51 tiny starts execution with task 0              */
/*----------------------------------------------------------------------------*/
job0 () _task_ 0  {
  os_create_task (1);                 /* start task 1                         */
  os_create_task (2);                 /* start task 2                         */

  while (1)  {                        /* endless loop                         */
    counter0++;                       /* increment counter 0                  */
  }
}

/*----------------------------------------------------------------------------*/
/*    Task 1 'job1':  RTX51 tiny starts this task with os_create_task (1)     */
/*----------------------------------------------------------------------------*/
job1 () _task_ 1  {
  while (1)  {                        /* endless loop                         */
    counter1++;                       /* increment counter 1                  */
  }
}

/*----------------------------------------------------------------------------*/
/*    Task 2 'job2':  RTX51 tiny starts this task with os_create_task (2)     */
/*----------------------------------------------------------------------------*/
job2 () _task_ 2  {
  while (1)  {                        /* endless loop                         */
    counter2++;                       /* increment counter 2                  */
  }
}
```

To compile and link RTX_EX1, type the following commands at the DOS command prompt.

```
C51 RTX_EX1.C DEBUG OBJECTEXTEND
BL51 RTX_EX1.OBJ RTX51TINY
```

Once RTX_EX1 is compiled and linked, you can test it using DS51. Type

```
DS51 RTX_EX1 INIT(RTX_EX1.INI)
```

The **INIT(RTX_EX1.INI)** directive loads an initialization file that configures the DS51 screen; loads the appropriate IOF driver file; initializes watchpoints for the variables **counter0**, **counter1**, and **counter2**; and finally starts execution of RTX_EX1.

As each task gets to execute, you will see the corresponding counter increase. The counter variables are displayed in the watch window at the top of the screen.

Enter **CTRL+C** to halt execution of RTX_EX1, then type

```
INCLUDE DBG_TINY.INC
```

at the DS51 command prompt. This will load an include file that allows you to display status information of the tasks. You may need to increase the size of the exe window using **ALT+U** so all of the task information is displayed.

Once the include file is loaded, press **F3** to display status information for the three tasks defined in this program.

```
+-------------------------------------------------------------------------+
| Task ID  | Start | State   | Wait for Event   | Signal | Timer | Stack |
|----------+-------+---------+------------------+--------+-------+-------|
|    0     | 000EH | TIMEOUT |                  |    0   |   217 |   20H |
|    1     | 0023H | RUNNING |                  |    0   |   217 |   2FH |
|    2     | 002EH | TIMEOUT |                  |    0   |   217 |   F0H |
+-------------------------------------------------------------------------+
```

RTX_EX2: A Simple RTX51 Application

The program RTX_EX2 demonstrates an RTX51 Tiny application that uses the **os_wait** function and signal passing. This program is composed of one source file **RTX_EX2.C** located in the **\C51V4\RTX_TINY\RTX_EX2** or **\CDEMO\51\RTX_TINY\RTX_EX2** directory. The contents of **RTX_EX2.C** is listed below.

```
/*----------------------------------------------------------------------------*/
/*                     RTX_EX2.C:  A RTX51 Application                        */
/*----------------------------------------------------------------------------*/

#pragma CODE DEBUG OBJECTEXTEND
#include <rtx51tny.h>                 /* RTX51 tiny functions & defines      */

int counter0;                         /* counter for task 0                   */
int counter1;                         /* counter for task 1                   */
int counter2;                         /* counter for task 2                   */
int counter3;                         /* counter for task 2                   */

/*----------------------------------------------------------------------------*/
/*       Task 0 'job0':  RTX51 tiny starts execution with task 0              */
/*----------------------------------------------------------------------------*/
job0 () _task_ 0  {
  os_create_task (1);                 /* start task 1                         */
  os_create_task (2);                 /* start task 2                         */
  os_create_task (3);                 /* start task 3                         */

  while (1)  {                        /* endless loop                         */
    counter0++;                       /* increment counter 0                  */
    os_wait (K_TMO, 5, 0);            /* wait for timeout: 5 ticks            */
  }
}

/*----------------------------------------------------------------------------*/
/*   Task 1 'job1':  RTX51 tiny starts this task with os_create_task (1)      */
/*----------------------------------------------------------------------------*/
job1 () _task_ 1  {
  while (1)  {                        /* endless loop                         */
    counter1++;                       /* increment counter 1                  */
    os_wait (K_TMO, 10, 0);           /* wait for timeout: 10 ticks           */
  }
}

/*----------------------------------------------------------------------------*/
/*    Task 2 'job2':  RTX51 tiny starts this task with os_create_task (2)     */
/*----------------------------------------------------------------------------*/
job2 () _task_ 2  {
  while (1)  {                        /* endless loop                         */
    counter2++;                       /* increment counter 2                  */
    if (counter2 == 0)  {             /* signal overflow of counter 2         */
      os_send_signal (3);             /* to task 3                            */
    }
  }
}

/*----------------------------------------------------------------------------*/
/*    Task 3 'job3':  RTX51 tiny starts this task with os_create_task (3)     */
/*----------------------------------------------------------------------------*/
job3 () _task_ 3  {
  while (1)  {                        /* endless loop                         */
    os_wait (K_SIG, 0, 0);            /* wait for signal                      */
    counter3++;                       /* process overflow from counter 2      */
  }
}
```

Enter the following commands at the DOS prompt to compile and link RTX_EX2.

```
C51 RTX_EX2.C DEBUG OBJECTEXTEND
BL51 RTX_EX2.OBJ RTX51TINY
```

When RTX_EX2 is compiled and linked, you can test it using DS51. Type

```
DS51 RTX_EX2
```

to run DS51 and load RTX_EX2. When DS51 is loaded, type the following commands at the DS51 command prompt.

```
WS counter0
WS counter1
WS counter2
WS counter3
G
```

This will set watchpoints for the four task counter variables and will begin execution of RTX_EX2. RTX_EX2 increments the four counters as follows:

counter0 incremented every 5 RTX51 timer ticks

counter1 incremented every 10 RTX51 timer ticks

counter2 incremented as fast as possible (this task gets most of the available CPUš time)

counter3 incremented for every overflow of **counter2**

Enter **CTRL+C** to halt execution of RTX_EX1 and enter **F3** to display status information for the four tasks defined in this program.

```
+-------------------------------------------------------------------------+
| Task ID  | Start | State   | Wait for Event   | Signal | Timer | Stack |
|----------+-------+---------+------------------+--------+-------+-------|
|     0    | 000EH | WAITING | TIMEOUT          |    0   |     5 |   28H |
|     1    | 0032H | WAITING | TIMEOUT          |    0   |    10 |   2AH |
|     2    | 0047H | RUNNING |                  |    0   |   196 |   2CH |
|     3    | 005DH | WAITING | SIGNAL           |    0   |   196 |   FDH |
+-------------------------------------------------------------------------+
```

RTX_EX2 uses the **os_wait** function to wait for events. The event that each task is waiting for is shown in the displayed task list shown above.

TRAFFIC: A Traffic Light Controller

The preceding examples, RTX_EX1 and RTX_EX2, show only the basic features of RTX51 Tiny. These examples could just as easily have been implemented without using RTX51. This example, a pedestrian traffic light controller, is more complex and can not be easily implemented without a multitasking real-time operating system like RTX51.

TRAFFIC is a time-controlled traffic light controller. During a user-defined clock time interval, the traffic light is operating. Outside this time interval, the yellow light flashes. If a pedestrian presses the request button, the traffic light goes immediately into a "walk" state. Otherwise, the traffic light works continuously.

Traffic Light Controller Commands

You can communicate with the traffic light controller via the serial port interface of the 8051. You can use the serial window of DS51 to test the traffic light controller commands.

The serial commands that are available are listed in the following table. These commands are composed of ASCII text characters. All commands must be terminated with a carriage return.

Command	Serial Text	Description
Display	D	Display clock, start, and ending times.
Time	T *hh*:*mm*:*ss*	Set the current time in 24-hour format.
Start	S *hh*:*mm*:*ss*	Set the starting time in 24-hour format. The traffic light controller operates normally between the start and end times. Outside these times, the yellow light flashes.
End	E *hh*:*mm*:*ss*	Set the ending time in 24-hour format.

Software

The TRAFFIC application is composed of three files that can be found in the **\C51V4\RTX_TINY\TRAFFIC** or **\CDEMO\51\RTX_TINY\TRAFFIC** directory.

TRAFFIC.C contains the traffic light controller program which is divided into the following tasks:

- **Task 0 Initialize**: initializes the serial interface and starts all other tasks. Task 0 deletes itself since initialization is only needed once.
- **Task 1 Command**: is the command processor for the traffic light controller. This task controls and processes serial commands received.
- **Task 2 Clock**: controls the time clock.
- **Task 3 Blinking**: flashes the yellow light when the clock time is outside the active time range.

- **Task 4 Lights**: controls the traffic light phases while the clock time is in the active time range (between the start and end times).
- **Task 5 Button**: reads the pedestrian push button and sends signals to the lights task.
- **Task 6 Quit**: checks for an ESC character in the serial stream. If one is encountered, this task terminates a previously specified display command.

SERIAL.C implements an interrupt driven serial interface. This file contains the functions **putchar** and **getkey**. The high-level I/O functions **printf** and **getline** call these basic I/O routines. The traffic light application will also operate without using interrupt driven serial I/O. but will not perform as well.

GETLINE.C is the command line editor for characters received from the serial port. This source file is also used by the MEASURE application.

TRAFFIC.C

```
/*****************************************************************************
*/
/*
*/
/*       TRAFFIC.C:     Traffic  Light  Controller  using  the  C51  Compiler
*/
/*
*/
/*****************************************************************************
*/

code char menu[] =
   "\n"
   "+***** TRAFFIC LIGHT CONTROLLER using C51 and RTX-51 tiny *****+\n"
   "| This program is a simple Traffic Light Controller.  Between  |\n"
   "| start time and end time the system controls a traffic light  |\n"
   "| with pedestrian self-service.  Outside of this time range    |\n"
   "| the yellow caution lamp is blinking.                         |\n"
   "+ command -+ syntax -----+ function --------------------------+\n"
   "| Display  | D           | display times                       |\n"
   "| Time     | T hh:mm:ss  | set clock time                      |\n"
   "| Start    | S hh:mm:ss  | set start time                      |\n"
   "| End      | E hh:mm:ss  | set end time                        |\n"
   "+----------+-------------+-------------------------------------+\n";


#include <reg52.h>                          /* special function registers 8052
*/
#include <rtx51tny.h>                      /* RTX-51 tiny functions & defines
*/
#include  <stdio.h>                                  /*  standard  I/O  .h-file
*/
#include  <ctype.h>                                    /*  character  functions
*/
#include <string.h>                           /* string and memory functions
*/
```

```
extern getline (char idata *, char);   /* external function:   input line
*/
extern serial_init ();                 /* external function:  init serial UART
*/

#define INIT        0                        /* task number of task:   init
*/
#define COMMAND    1                       /* task number of task:   command
*/
#define CLOCK       2                        /* task number of task:   clock
*/
#define BLINKING   3                      /* task number of task:   blinking
*/
#define LIGHTS     4                       /* task number of task:   signal
*/
#define KEYREAD    5                       /* task number of task:   keyread
*/
#define GET_ESC    6                     /* task number of task:   get_escape
*/

struct time   {                            /* structure of the time record
*/
  unsigned   char   hour;                                        /*   hour
*/
  unsigned   char   min;                                       /*   minute
*/
  unsigned   char   sec;                                       /*   second
*/
};

struct time ctime = { 12,   0,   0 };    /* storage for clock time values
*/
struct time start = {   7, 30,   0 };    /* storage for start time values
*/
struct time end    = { 18, 30,   0 };    /* storage for end    time values
*/

sbit   red     = P1^2;                     /* I/O Pin:   red     lamp output
*/
sbit   yellow = P1^1;                      /* I/O Pin:   yellow lamp output
*/
sbit   green   = P1^0;                     /* I/O Pin:   green   lamp output
*/
sbit   stop    = P1^3;                     /* I/O Pin:   stop    lamp output
*/
sbit   walk    = P1^4;                     /* I/O Pin:   walk    lamp output
*/
sbit   key     = P1^5;                   /* I/O Pin:  self-service key input
*/

idata     char inline[16];                /* storage for command input line
*/


/*************************************************************************
*/
/*                                    Task     0     'init':     Initialize
*/
/*************************************************************************
*/
```

```
init () _task_ INIT  {                    /* program execution starts here
*/
  serial_init ();                        /* initialize the serial interface
*/
  os_create_task  (CLOCK);                          /*  start  clock  task
*/
  os_create_task  (COMMAND);                       /*  start  command  task
*/
  os_create_task  (LIGHTS);                         /*  start  lights  task
*/
  os_create_task  (KEYREAD);                       /*  start  keyread  task
*/
  os_delete_task (INIT);               /* stop init task (no longer needed)
*/
}


bit display_time = 0;                 /* flag:  signal cmd state display_time
*/

/*************************************************************************
*/
/*                                                 Task      2      'clock'
*/
/*************************************************************************
*/
clock () _task_ CLOCK  {
  while (1)  {                                  /* clock is an endless loop
*/
    if  (++ctime.sec  ==  60)    {               /*  calculate  the  second
*/
      ctime.sec = 0;
      if  (++ctime.min  ==  60)    {             /*  calculate  the  minute
*/
        ctime.min = 0;
        if  (++ctime.hour  ==  24)    {          /*  calculate  the  hour
*/
          ctime.hour = 0;
        }
      }
    }
    if (display_time)  {                /* if command_status == display_time
*/
      os_send_signal (COMMAND);        /* signal to task command: time changed
*/
    }
    os_wait  (K_IVL,  100,  0);                /*  wait  interval:   1  second
*/
  }
}


struct time rtime;                       /* temporary storage for entry time
*/

/*************************************************************************
*/
/*           readtime: convert line input to time values & store in rtime
*/
/*************************************************************************
*/
bit readtime (char idata *buffer)  {
```

```
  unsigned char args;                                    /* number of arguments
*/

  rtime.sec = 0;                                              /* preset second
*/
  args = sscanf (buffer, "%bd:%bd:%bd",                    /* scan input line for
*/
                 &rtime.hour,                            /* hour, minute and second
*/
                 &rtime.min,
                 &rtime.sec);

  if (rtime.hour > 23   ||   rtime.min > 59   ||   /* check for valid inputs
*/
      rtime.sec > 59   ||  args < 2        ||  args == EOF)  {
    printf ("\n*** ERROR: INVALID TIME FORMAT\n");
    return (0);
  }
  return (1);
}



#define ESC   0x1B                                    /*  ESCAPE character code
*/

bit   escape;                               /* flag: mark ESCAPE character entered
*/

/*************************************************************************
*/
/*          Task 6 'get_escape': check if ESC (escape character) was entered
*/
/*************************************************************************
*/
get_escape () _task_ GET_ESC  {
  while (1)   {                                               /* endless loop
*/
    if (_getkey () == ESC)   escape = 1;          /* set flag if ESC entered
*/
    if (escape)  {                               /* if escape flag send signal
*/
      os_send_signal (COMMAND);                          /*  to task 'command'
*/
    }
  }
}


/*************************************************************************
*/
/*        Task 1 'command': command processor */
/*************************************************************************
*/
command () _task_ COMMAND  {
  unsigned char i;

  printf (menu);                                        /* display command menu
*/
  while (1)   {                                               /* endless loop
*/
    printf ("\nCommand: ");                                /* display prompt
*/
```

```
    getline (&inline, sizeof (inline));           /* get command line input
*/

    for (i = 0; inline[i] != 0; i++)   {          /* convert to uppercase
*/
      inline[i] = toupper(inline[i]);
    }

    for  (i  =  0;  inline[i]  ==  '  ';  i++);              /*  skip  blanks
*/

    switch (inline[i])  {                      /* proceed to command function
*/
      case 'D':                                      /* Display Time Command
*/
        printf ("Start Time: %02bd:%02bd:%02bd    "
                "End Time: %02bd:%02bd:%02bd\n",
                 start.hour, start.min, start.sec,
                 end.hour,   end.min,   end.sec);
        printf ("                        type ESC to abort\r");

        os_create_task (GET_ESC);                /* ESC check in display loop
*/
        escape = 0;                                        /* clear escape flag
*/
        display_time = 1;                             /* set display time flag
*/
        os_clear_signal (COMMAND);                   /* clear pending signals
*/

        while (!escape)  {                            /* while no ESC entered
*/
          printf ("Clock Time: %02bd:%02bd:%02bd\r",         /* display time
*/
                   ctime.hour, ctime.min, ctime.sec);
          os_wait (K_SIG, 0, 0);                  /* wait for time change or ESC
*/
        }

        os_delete_task (GET_ESC);                /* ESC check not longer needed
*/
        display_time = 0;                           /* clear display time flag
*/
        printf ("\n\n");
        break;

      case 'T':                                          /* Set Time Command
*/
        if (readtime (&inline[i+1]))   {            /* read time input and
*/
          ctime.hour  =  rtime.hour;                    /* store in 'ctime'
*/
          ctime.min  = rtime.min;
          ctime.sec  = rtime.sec;
        }
        break;

      case 'E':                                       /* Set End Time Command
*/
        if (readtime (&inline[i+1]))   {            /* read time input and
*/
          end.hour  =  rtime.hour;                       /* store in 'end'
*/
```

```
          end.min  = rtime.min;
          end.sec  = rtime.sec;
        }
        break;

      case 'S':                                /* Set Start Time Command */
        if (readtime (&inline[i+1]))   {            /* read time input and
*/
          start.hour = rtime.hour;                  /* store in 'start'
*/
          start.min  = rtime.min;
          start.sec  = rtime.sec;
        }
        break;

      default:                                          /* Error Handling
*/
        printf (menu);                             /* display command menu
*/
        break;
    }
  }
}


/*************************************************************************
*/
/*              signalon: check if clock time is between start and end
*/
/*************************************************************************
*/
bit signalon ()   {
  if (memcmp (&start, &end, sizeof (struct time)) < 0)  {
    if (memcmp (&start, &ctime, sizeof (struct time)) < 0  &&
        memcmp (&ctime, &end,   sizeof (struct time)) < 0)  return (1);
  }

  else  {
    if (memcmp (&end,   &ctime, sizeof (start)) > 0  &&
        memcmp (&ctime, &start, sizeof (start)) > 0)  return (1);
  }
  return (0);                                     /* signal off, blinking on
*/
}


/*************************************************************************
*/
/*        Task 3 'blinking': runs if current time is outside start & end time
*/
/*************************************************************************
*/
blinking () _task_ BLINKING   {                      /* blink yellow light
*/
  red     = 0;                                        /* all lights off
*/
  yellow = 0;
  green  = 0;
  stop   = 0;
  walk   = 0;

  while (1)   {                                         /* endless loop
*/
```

```
    yellow = 1;                                          /* yellow light on
*/
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    yellow = 0;                                           /* yellow light off
*/
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    if (signalon ())  {                              /* if blinking time over
*/
      os_create_task  (LIGHTS);                             /*  start  lights
*/
      os_delete_task  (BLINKING);                        /*  and  stop  blinking
*/
    }
  }
}


/*************************************************************************
*/
/*      Task 4 'lights': executes if current time is between start & end time
*/
/*************************************************************************
*/
lights () _task_ LIGHTS  {                          /* traffic light operation
*/
  red    = 1;                                         /* red & stop lights on
*/
  yellow = 0;
  green  = 0;
  stop   = 1;
  walk   = 0;
  while (1)   {                                             /* endless  loop
*/
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    if (!signalon ())  {                        /* if traffic signal time over
*/
      os_create_task  (BLINKING);                           /*  start  blinking
*/
      os_delete_task  (LIGHTS);                             /*  stop  lights
*/
    }
    yellow = 1;
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    red    = 0;                                        /* green light for cars
*/
    yellow = 0;
    green  = 1;
    os_clear_signal (LIGHTS);
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    os_wait (K_TMO + K_SIG, 250, 0);             /* wait for timeout & signal
*/
    yellow = 1;
    green  = 0;
    os_wait (K_TMO, 30, 0);                      /* wait for timeout: 30 ticks
*/
    red    = 1;                                        /* red light for cars
*/
    yellow = 0;
```

```
    os_wait (K_TMO, 30, 0);                     /* wait for timeout: 30 ticks
*/
    stop    = 0;                                   /* green light for walkers
*/
    walk    = 1;
    os_wait (K_TMO, 100, 0);                   /* wait for timeout: 100 ticks
*/
    stop    = 1;                                     /* red light for walkers
*/
    walk    = 0;
  }
}


/*****************************************************************************
*/
/*          Task 5 'keyread': process key stroke from pedestrian push button
*/
/*****************************************************************************
*/
keyread () _task_ KEYREAD  {
  while (1)   {                                                /* endless loop
*/
    if (key)   {                                             /* if key pressed
*/
       os_send_signal (LIGHTS);                  /* send signal to task lights
*/
    }
    os_wait (K_TMO, 2, 0);                      /* wait for timeout: 2 ticks
*/
  }
}
```

SERIAL.C

```
/*****************************************************************************
*/
/*
*/
/*          SERIAL.C:   Interrupt Controlled Serial Interface for RTX-51 tiny
*/
/*
*/
/*****************************************************************************
*/


#include <reg52.h>                           /* special function register 8052
*/
#include <rtx51tny.h>                       /* RTX-51 tiny functions & defines
*/

#define  OLEN  8                          /* size of serial transmission buffer
*/
unsigned char   ostart;                     /* transmission buffer start index
*/
unsigned char   oend;                         /* transmission buffer end index
*/
idata     char   outbuf[OLEN];              /* storage for transmission buffer
*/
unsigned char   otask = 0xff;                /* task number of output task
*/
```

```
#define  ILEN  8                          /* size of serial receiving buffer
*/
unsigned char  istart;                      /* receiving buffer start index
*/
unsigned char  iend;                         /* receiving buffer end index
*/
idata     char  inbuf[ILEN];                /* storage for receiving buffer
*/
unsigned char  itask = 0xff;                /* task number of output task
*/

#define    CTRL_Q  0x11                        /* Control+Q character code
*/
#define    CTRL_S  0x13                        /* Control+S character code
*/

bit   sendfull;                            /* flag: marks transmit buffer full
*/
bit   sendactive;                           /* flag: marks transmitter active
*/
bit   sendstop;                              /* flag: marks XOFF character
*/

/*************************************************************************
*/
/*            putbuf:   write a character to SBUF or transmission buffer
*/
/*************************************************************************
*/
putbuf (char c)  {
  if (!sendfull)  {                       /* transmit only if buffer not full
*/
    if (!sendactive && !sendstop)   {    /* if transmitter not active:
*/
      sendactive = 1;                  /* transfer the first character direct
*/
     SBUF = c;                             /* to SBUF to start transmission
*/
    }
    else   {                                                  /* otherwize:
*/
     outbuf[oend++ & (OLEN-1)] = c;  /* transfer char to transmission buffer
*/
     if (((oend ^ ostart) & (OLEN-1)) == 0)  sendfull = 1;
    }                                        /* set flag if buffer is full
*/
  }
}


/*************************************************************************
*/
/*                   putchar:     interrupt  controlled  putchar  function
*/
/*************************************************************************
*/
char putchar (char c)  {
  if (c == '\n')  {                          /* expand new line character:
*/
    while (sendfull)  {                /* wait for transmission buffer empty
*/
```

```
      otask   =   os_running_task_id   ();      /*   set   output   task   number
*/
      os_wait  (K_SIG,  0,  0);               /*  RTX-51  call:  wait  for  signal
*/
      otask  =  0xff;                             /*  clear  output  task  number
*/
    }
    putbuf (0x0D);                          /* send CR before LF for <new line>
*/
  }
  while (sendfull)  {                     /* wait for transmission buffer empty
*/
    otask   =   os_running_task_id   ();          /*   set   output   task   number
*/
    os_wait  (K_SIG,  0,  0);                 /*  RTX-51  call:  wait  for  signal
*/
    otask  =  0xff;                             /*  clear  output  task  number
*/
  }
  putbuf  (c);                                                /*  send  character
*/
  return (c);                               /* return character: ANSI requirement
*/
}


/*************************************************************************
*/
/*                            _getkey:        interrupt    controlled    _getkey
*/
/*************************************************************************
*/
char _getkey (void)  {
  while  (iend == istart)  {
    itask   =   os_running_task_id   ();          /*   set   input   task   number
*/
    os_wait  (K_SIG,  0,  0);                 /*  RTX-51  call:  wait  for  signal
*/
    itask  =  0xff;                               /*  clear  input  task  number
*/
  }
  return (inbuf[istart++ & (ILEN-1)]);
}


/*************************************************************************
*/
/*                   serial:     serial   receiver   /   transmitter   interrupt
*/
/*************************************************************************
*/
serial () interrupt  4  using  2   {       /* use registerbank 2 for interrupt
*/
  unsigned char c;
  bit   start_trans = 0;

  if  (RI)   {                                        /*  if  receiver  interrupt
*/
    c  =  SBUF;                                                /*  read  character
*/
    RI  =  0;                                    /* clear interrupt request flag
*/
```

```
   switch  (c)   {                                    /*  process  character
*/
     case CTRL_S:
       sendstop = 1;                      /* if Control+S stop transmission
*/
       break;

     case CTRL_Q:
       start_trans  =  sendstop;          /*  if  Control+Q  start  transmission
*/
       sendstop = 0;
       break;

      default:                          /* read all other characters into inbuf
*/
       if (istart + ILEN != iend)  {
         inbuf[iend++ & (ILEN-1)] = c;
       }
                                      /*   if   task   waiting:   signal   ready
*/
       if (itask != 0xFF) isr_send_signal (itask);
       break;
   }
  }

  if  (TI  ||  start_trans)   {                  /*  if  transmitter  interrupt
*/
    TI = 0;                                    /* clear interrupt request flag
*/
    if  (ostart  !=  oend)   {                /* if characters in buffer and
*/
      if  (!sendstop)   {                       /*  if  not  Control+S  received
*/
       SBUF  =  outbuf[ostart++  &  (OLEN-1)];          /*  transmit  character
*/
       sendfull  =  0;                              /*  clear  'sendfull'  flag
*/
                                     /*   if   task   waiting:   signal   ready
*/
       if (otask != 0xFF)  isr_send_signal (otask);
     }
    }
    else sendactive = 0;              /* if all transmitted clear 'sendactive'
*/
  }

}


/*************************************************************************
*/
/*                           serial_init:    initialize    serial    interface
*/
/*************************************************************************
*/
serial_init ()  {
  SCON  = 0x50;                        /* mode 1: 8-bit UART, enable receiver
*/
  TMOD  |= 0x20;                             /*  timer  1  mode  2:  8-Bit  reload
*/
  TH1    =  0xf3;                                  /*  reload  value  2400  baud
*/
```

```
  TR1     =  1;                                              /*  timer  1  run
*/
  ES      = 1;                                  /* enable serial port interrupt
*/
}
```

GETLINE.C

```
/*****************************************************************************
*/
/*
*/
/*                        GETLINE.C:        Line    Edited    Character    Input
*/
/*
*/
/*****************************************************************************
*/

#include <stdio.h>

#define CNTLQ      0x11
#define CNTLS      0x13
#define DEL        0x7F
#define BACKSPACE  0x08
#define CR         0x0D
#define LF         0x0A

/***************/
/* Line Editor */
/***************/
void getline (char idata *line, unsigned char n)  {
  unsigned char cnt = 0;
  char c;

  do  {
    if  ((c  =  _getkey  ())  ==  CR)    c  =  LF;         /*  read  character
*/
    if  (c  ==  BACKSPACE    ||    c  ==  DEL)    {       /*  process  backspace
*/
      if (cnt != 0)  {
        cnt--;                                            /*  decrement  count
*/
        line--;                                          /*  and  line  pointer
*/
        putchar  (0x08);                                  /*  echo  backspace
*/
        putchar (' ');
        putchar (0x08);
      }
    }
    else  if  (c  !=  CNTLQ  &&  c  !=  CNTLS)    {     /*  ignore  Control  S/Q
*/
      putchar (*line = c);                         /* echo and store character
*/
      line++;                                        /* increment line pointer
*/
      cnt++;                                                    /*  and  count
*/
    }
  }  while (cnt < n - 1   &&   c != LF);       /* check limit and line feed
*/
```

```
  *line = 0;                                          /* mark end of string
*/
}
```

Compiling and Linking TRAFFIC

Enter the following commands at the DOS prompt to compile and link TRAFFIC.

```
C51 TRAFFIC.C DEBUG OBJECTEXTEND RF (TRAFFIC.REG)
C51 SERIAL.C DEBUG OBJECTEXTEND RF (TRAFFIC.REG)
C51 GETLINE.C DEBUG OBJECTEXTEND RF (TRAFFIC.REG)

BL51 @TRAFFIC.LIN
```

Alternatively, there is a batch file called **TRAFFIC.BAT** that you can use to compile, link, and automatically run DS51.

Testing and Debugging TRAFFIC

Once you have compiled and linked TRAFFIC, you can test it using DS51. Type

```
DS51 TRAFFIC
```

to run DS51 and load including the **DS51.INI** initialization file. This file will automatically load the IOF driver, load the traffic program, load an include file for displaying task status, active watchpoints for the traffic lights, define a function for the pedestrian button (which is activated using **F4**), and start the TRAFFIC application. Following is the listing of **DS51.INI**.

```
load ..\..\ds51\8052.iof             /* load 8052 CPU driver*/
include dbg_tiny.inc   /* load debug function for RTX51 Tiny */

/* define watch variables */
ws red
ws yellow
ws green
ws stop
ws walk
/* set P1.5 to zero:  Key Input */
PORT1 &= ~0x20;

/* define a debug function for the pedestrian push button */
signal void button (void)  {
  PORT1 |= 0x20;                    /* set Port1.5   */
  twatch (50000);                   /* wait 50 ms    */
  PORT1 &= ~0x20;                   /* reset Port1.5 */
}

/* define F4 key as call to button () */
set F4="button ()"
```

You can start the execution of the application TRAFFIC with the GO command:

```
g
```

When DS51 starts executing TRAFFIC, the serial window will display the command menu and waits for you to enter a command. Change to the serial window with **Alt+S**; type **d** and press the **ENTER** key. This will display the current time and the start and end time range for the traffic light. For example:

```
Start Time: 07:30:00    End Time: 18:30:00
Clock Time: 12:00:11    type ESC to abort
```

As the program runs, you can watch the red, yellow, and green lamps of the traffic light change. The pedestrian button is simulated using **F4**. Press **F4** to see the traffic light switch to red and the walk light switch to on.

You can display the task status using **F3** much as before. The following task information will be displayed:

Task ID	Start	State	Wait for Event	Signal	Timer	Stack
0	0026H	DELETED		0	131	84H
1	00D1H	WAITING	SIGNAL	0	131	84H
2	0043H	WAITING	TIMEOUT	0	5	86H
3	0278H	DELETED		0	131	88H
4	02ACH	WAITING	SIGNAL & TIMEOUT	0	220	88H
5	032BH	WAITING	TIMEOUT	0	1	8AH
6	000EH	WAITING	SIGNAL	0	131	FBH

If the Exe window is not large enough to show the entire status text, you can press **ALT+R** to remove the register window. You can also increase the vertical size of the Exe window. Press **ALT+E** to select the Exe window then enter **ALT+U** several times to increase the size of the window.

When you are through using DS51, type **EXIT** at the DS51 command prompt.

A

B

C

D

E

F

I

K

L

M

N

O

P

R

S

T

U

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RTX51 TINY

REAL– TIME OPERATING SYSTEM

User's Guide 2.95