KEIL SOFTWARE

8051 Demo Kit

Getting Started with the 8051 Microcontroller Development Tools

User's Guide

Preface

This manual is an introduction to the Keil Software 8051 microcontroller software development tools. It introduces new users and interested readers to our product line. With nothing more than this book, you should be able to successfully run and use our tools. This user's guide contains the following chapters.

"Chapter 1. Introduction" gives an overview of this user's guide.

"Chapter 2. Installation" describes how to install our software and how to setup an operating environment for the tools.

"Chapter 3. 8051 Product Line" discusses the different products that we offer for the 8051 microcontroller. Read this chapter to determine which product provides the tools you need.

"Chapter 4. 8051 Development Tools" describes the major features of our 8051 development tools including the C compiler, assembler, debugger, and integrated development environment.

"Chapter 5. Using the 8051 tools" describes the provided sample programs along with a step-by-step guide that shows how to build them using our tools.

"Chapter 6. Hardware Products" introduces our hardware-based tools that you can use to aid in development and debugging. Our evaluation boards for the 80C517A and 87C520 and our EPROM emulator are discussed.

"Chapter 7. Real-Time Kernels" discusses the RTX-51 Tiny and RTX-51 Full real-time operating systems. This chapter provides an overview of multitasking systems, why they are desirable, and how they are used.

"Chapter 8. Command Reference" briefly describes the commands and controls for our 8051 development tools.

NOTE
This manual assumes that you are familiar with Microsoft Windows and the hardware and instruction set of the 8051 microcontroller.

Document Conventions

This document uses the following conventions:

Examples	Description
README.TXT	Bold capital text is used for the names of executable programs, data files, source files, environment variables, and commands you enter at the MS-DOS command prompt. This text usually represents commands that you must type in literally. For example: **CLS** **DIR** **BL51.EXE** Note that you are not required to enter these commands using all capital letters.
`Courier`	Text in this typeface is used to represent information that displays on screen or prints at the printer. This typeface is also used within the text when discussing or describing command line items.
Variables	Text in italics represents information that you must provide. For example, *projectfile* in a syntax string means that you must supply the actual project file name. Occasionally, italics are also used to emphasize words in the text.
Elements that repeat…	Ellipses (…) are used to indicate an item that may be repeated.

Omitted code
.
.
.
	Vertical ellipses are used in source code listings to indicate that a fragment of the program is omitted. For example:
	`void main (void) {`
	`.`
	`.`
	`.`
	`while (1);`

⟦*Optional Items*⟧	Optional arguments in command-line and option fields are indicated by double brackets. For example: `C51 TEST.C PRINT ⟦(filename)⟧`
{ *opt1* | *opt2* }	Text contained within braces, separated by a vertical bar represents a group of items from which one must be chosen. The braces enclose all of the choices and the vertical bars separate the choices. One item in the list must be selected.
Keys	Text in this sans serif typeface represents actual keys on the keyboard. For example, “Press **Enter** to continue.”
Point	Move the mouse until the mouse pointer rests on the item desired.
Click	Quickly press and release a mouse button while pointing at the item to be selected.
Drag	Press the left mouse button while on a selected item. Then, hold the button down while moving the mouse. When the item to be selected is at the desired position, release the button.
Double-Click	Click the mouse button twice in rapid succession.

Contents

Chapter 1. Introduction

Thank you for allowing Keil Software to provide you with software development tools for the 8051 family of microcontrollers. With our tools, you can generate embedded applications for the multitude of 8051 derivatives. Our 8051 development tools are listed below:

- C51 Optimizing C Cross Compiler,
- A51 Macro Assembler,
- 8051 Utilities (linker, object file converter, library manager),
- dScope for Windows™ Source-Level Debugger/Simulator,
- µVision for Windows™ Integrated Development Environment.

These tools are combined into the kits described in “Chapter 3. 8051 Product Line” on page 13. The individual tools are described in detail in “Chapter 4. 8051 Development Tools” on page 19.

In addition to the above development tools, we also provide real-time kernels, evaluation boards, and debugging hardware. Refer to “Chapter 7. Real-Time Kernels” on page 95 and “Chapter 6. Hardware Products” on page 91 for more information about these products. Our tools are designed for the professional software developer, but any level of programmer can use them to get the most out of the 8051 hardware.

Manual Topics

This manual discusses a number of topics including how to:

- Install the software on your system (see “Chapter 2. Installation” on page 5) and fine tune it for maximum performance (see “Improving System Performance” on page 10),
- Select the best tool kit for your application (see “Chapter 3. 8051 Product Line” on page 13),
- Use the 8051 development tools (see “Chapter 4. 8051 Development Tools” on page 19),
- Run the included sample programs (see “Chapter 5. Using the 8051 tools” on page 47).

If you want to get started immediately, you may do so by installing the software (refer to “Chapter 2. Installation” on page 5) and running the sample programs (refer to “Chapter 5. Using the 8051 tools” on page 47). This is all you need to do to begin using this kit.

Evaluation and Demo Kits

Keil Software provides two kits that let you evaluate our tools.

The **C51 Demo Kit** includes demonstration versions of our tools. The tools in the Demo Kit do not generate actual object code. They generate listing files where you can see the code generated by the compiler and other tools.

The **C51 Evaluation Kit** includes evaluation versions of our tools. The tools in the Evaluation Kit let you generate applications up to 2 Kbytes in size. You may use this kit to evaluate the effectiveness of our tools and to generate small target applications.

Both kits include this user’s guide and software. This user’s guide is also included in each of our tool kits.

Types of Users

This manual addresses three types of users: evaluation users, new users, and experienced users.

Evaluation Users are those users who have not yet purchased the software but have requested the evaluation package to get a better feel for what the tools do and how they perform. The evaluation package includes evaluation copies of the development tools. You may use the included sample programs to get real-world experience with our 8051 development tools. Even if you are only a evaluation user, take the time to read this manual. It explains how to install the software, provides you with an overview of the development tools, and introduces the sample programs.

New Users are those users who are purchasing our 8051 development tools for the first time. The included software provides you with the latest development tool versions as well as sample programs. If you are new to the 8051 or the tools, take the time to review the sample programs described in this manual. This manual provides a quick tutorial and helps new or inexperienced users quickly get started with the tools.

Experienced Users are those users who have previously used our 8051 development tools and are now upgrading to the latest 8051 tools. The software included with a product upgrade contains the latest development tools, the sample programs, and a full set of manuals.

Changes to the Documentation

Last minute changes and corrections to the software and manuals are listed in the **README.TXT** file which is included in the root directory of your installation. Take the time to read this file to determine if there are any changes that may impact your installation.

Requesting Assistance

We are dedicated to providing you with the best embedded development tools and documentation available. If you have suggestions or comments regarding any of the printed manuals accompanying this product, please contact us. If you think you have discovered a problem with the software, do the following before calling technical support.

1. Read the sections in this manual that pertain to the job or task you are trying to accomplish.

2. Make sure you are using the most current version of the software and utilities.

3. Isolate the problem to determine if it is a problem with the assembler, compiler, linker, library manager, or another development tool.

4. Isolate software problems by reducing your code to a few lines.

If, after following these steps, you are still experiencing problems, report them to our technical support group.

If you contact us by fax, be sure to include your name, your product serial number and version number, and telephone numbers (voice and fax) where we can reach you.

Try to be as detailed as possible when describing the problem you are having. The more descriptive your example, the faster we can find a solution. If you have a one-page code example demonstrating the problem, please fax it to us.

Chapter 2. Installation

This chapter explains how to setup an operating environment and how to install the software on your hard disk. Before starting the installation program, you must do the following:

- Verify that your computer system meets the minimum requirements.
- Make a copy of the installation diskette for backup purposes.

NOTE
This chapter refers to various MS-DOS commands which may be used to customize your operating environment. The **SET** *and* **PATH** *commands, for example, are used to initialize environment variables used by the compiler and utilities. If you are not familiar with these commands and other MS-DOS operations mentioned in this chapter, please refer to your DOS user's guide.*

System Requirements

There are minimum hardware and software requirements that must be satisfied to ensure that the compiler and utilities function properly.

For our Windows-based tools, you must have the following:

- 100% IBM compatible 386 or higher PC,
- Windows 3.1 or higher,
- 4 MB RAM minimum,
- Hard disk with 6 MB free disk space.

For our DOS-based tools, you must have the following:

- 100% IBM compatible 386 or higher PC with 640 KB RAM,
- MS-DOS Version 3.1 or higher,
- Hard disk with 6 MB free disk space.

The C compiler and utilities require that you have at least 20 files and 20 buffers defined in your **CONFIG.SYS** file. Additionally, you need enough environment space for the environment variables used by the compiler and utilities (see “Environment Settings” on page 9).

Your **CONFIG.SYS** file should look similar to the following:

```
BUFFERS=20
FILES=20
SHELL=C:\COMMAND.COM /e:1024 /p
```

If you receive the message **Out of environment space** from DOS, you can increase the amount of environment space by increasing the number **1024** in the above example. Refer to your DOS user’s guide for more information.

Backing Up Your Disks

We strongly suggest that you make a backup copy of the installation diskettes using the DOS **COPY** or **DISKCOPY** commands. Then, use the backup disks to install the software. Be sure to store the original disks in a safe place in case your backups are lost or damaged.

Installing the Software

All of our products come with an installation program which allows easy installation of our software.

Installing DOS-Based Products

To install DOS-based products, insert the first product diskette into Drive A and enter the following command line at the DOS prompt:

```
A:INSTALL
```

Then, follow the instructions displayed by the installation program.

Installing Windows-Based Products

To install Windows-based products…

- Insert the first product diskette into Drive A,
- Select the **Run…** command from the **File** menu in the Program Manager,
- Enter **A:SETUP** at the **Command Line** prompt,
- Select the **OK** button.

Then, follow the instructions displayed by the installation program.

Directory Structure

The installation program copies the development tools into subdirectories of the following base directories. The directory used depends on the kit being installed.

Directory	Description
\C51	8051 development tools.
\C51EVAL	8051 evaluation tools.

After creating the appropriate directory, the installation program copies the development tools into the subdirectories listed in the following table.

Subdirectory	Description
…\ASM	Assembler include files.
…\BIN	Executable files.
…\DS51	dScope-51 for DOS IOF drivers.
…\EXAMPLES	Sample applications.
…\RTX51	RTX-51 Full files.
…\RTX_TINY	RTX-51 Tiny files.
…\INC	C compiler include files.
…\LIB	C compiler library files and startup code.
…\MON51	Target monitor files.
…\TS51	tScope-51 for DOS IOT drivers.

This table lists a complete installation that includes the entire line of 8051 development tools. Your installation may vary depending on the products you purchased.

Environment Settings

The compiler and utilities require entries in the DOS environment table that specify the path to include files and libraries. In addition, you must include the ...**\BIN** directory in your **PATH.**

The following table lists the environment variables, their default paths, and a brief description.

Variable	Path	Description
PATH	**\C51\BIN**	Specifies the path of the 8051 development tools.
PATH	**\C51EVAL\BIN**	Specifies the path of the 8051 evaluation tools.
TMP		Specifies the path for temporary files generated. For best performance, the path specified should be a RAM disk. If this environment variable is specified, the path must exist. If the path does not exist, the tools abort reporting a fatal error.
C51INC	**\C51\INC**	Specifies the path where the standard C51 compiler include files are located.
C51LIB	**\C51\LIB**	Specifies the path where the standard C51 compiler library files are located.

NOTE
This manual makes references to programs and files in the ***\C51****... directory. This directory is equivalent to the* ***\C51EVAL****... directory.*

Typically, environment settings are automatically installed in your **AUTOEXEC.BAT** file by the installation program. If you wish to put these settings in a separate batch file, the environment settings must be entered as follows:

8051 Development Tools	8051 Evaluation Tools
`PATH=C:\C51\BIN;...`	`PATH=C:\C51EVAL\BIN;...`
`SET C51INC=C:\C51\INC`	`SET C51INC=C:\C51EVAL\INC`
`SET C51LIB=C:\C51\LIB`	`SET C51LIB=C:\C51EVAL\LIB`

Improving System Performance

There are two methods you can employ to improve performance of the C51 compiler and utilities. These techniques are generic and should help boost performance of most applications. You may:

- Provide a RAM disk for the compiler and utilities to use for temporary files,
- Use a disk cache to store the most recently accessed disk files.

Using a RAM Disk

If your computer has sufficient extended or expanded memory available, you should consider using a RAM disk. A RAM disk is a memory-based disk emulator. Because the contents of a RAM disk are stored in RAM, access is very fast.

If you are using a RAM disk, you can set the value of the **TMP** environment variables to the drive name of the RAM disk. This speeds up the execution of the many of the tools and utilities because they can use the RAM disk for temporary files.

A number of RAM disk software packages are available. **RAMDRIVE.SYS** and **VDISK.SYS** are the names of the RAM disk programs that are most commonly shipped with DOS. Refer to your DOS manual to learn how to install these programs.

Using a Disk Cache

A disk cache utilizes a large memory pool to temporarily store information read from disk. When the computer accesses the disk, it first checks the cache to see if the desired information is already in the cache. If it is, the information is read from the cache memory instead of from the disk. This is significantly faster than waiting for the disk drive to read the information.

Typically, software development involves an edit-compile-edit-compile… cycle. In these situations, a disk cache improves the performance of your editor, assembler, compiler, and linker. The editor, the compiler, source file, and object file can all be held in the cache, and disk accesses are kept to a minimum.

Version 5.0 and Version 6.0 of MS-DOS both come with a disk-caching utility called **SMARTDRV.SYS**. Refer to your DOS manual to learn how to install and use this program.

Chapter 3. 8051 Product Line

Keil Software provides the premier 8051 development tools in the industry. To help you become familiar with how we distribute our tools, we would like to introduce the concept of a tool kit.

A tool kit is comprised of several application programs that you use to create your 8051 application. You may use an assembler to assemble your 8051 assembly program, you may use a compiler to compile your C source code into an object file, and you may use a linker to create an absolute object module suitable for your in-circuit emulator.

While it makes little sense to have a compiler without a linker, it also makes little sense to have a linker without a compiler or assembler. Therefore, our tools are packaged into various kits.

Our 8051 kits are described below in the “8051 Development Tool Kits” section.

8051 Development Tool Kits

When you use the Keil Software tools, the 8051 project development cycle is roughly the same as for any software development project.

1. Create source files in C or assembly.

2. Compile or assemble source files.

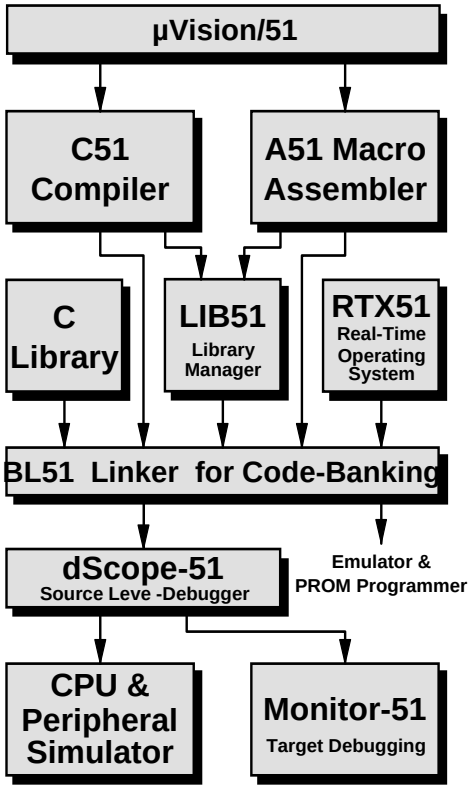
3. Correct errors in source files.

4. Link object files from compiler and assembler.

5. Test linked application.

Tool Kit Overview

The development cycle described above may be best illustrated by a block diagram of the complete 8051 tool set.



As shown in this figure, files are created by the µVision/51 IDE and then passed to the C51 compiler or A51 assembler. The compiler and assembler process source files and create relocatable object files.

Object files created by the compiler and assembler may be used by the LIB51 library manager to create a library. A library is a specially formatted, ordered program collection of object modules that the linker can process. When the linker processes a library, only the object modules in the library that are necessary for program creation are used.

Object files created by the compiler and assembler and library files created by the library manager are processed by the linker to create an absolute object module. An absolute object file or module is an object file with no relocatable code. All the code in an absolute object file resides at fixed locations.

The absolute object file created by the linker may be used to program EPROM or other memory devices. The absolute object module may also be used with the dScope-51 debugger/simulator or with an in-circuit emulator.

The dScope-51 source level debugger/simulator is ideally suited for fast, reliable high-level-language program debugging. The debugger contains a high-speed simulator and a target debugger that let you simulate an entire 8051 system including on-chip peripherals. By loading specific I/O drivers, you can simulate the attributes and peripherals of a variety of 8051 derivatives. In conjunction with Monitor-51, the debugger is even able to do source-level debugging on your target hardware.

The RTX-51 real-time operating system is a multitasking kernel for the 8051 family. The RTX-51 real-time kernel simplifies the system design, programming, and debugging of complex applications where fast reaction to time critical events is essential. The kernel is fully integrated into the C51 compiler and is easy to use. Task description tables and operating system consistency are automatically controlled by the BL51 code banking linker/locator.

Tool Kit Introduction

The preceding diagram shows the full extent of the Keil Software 8051 development tools. The tools listed in this diagram comprise the professional developer's kit described on the following pages. In addition to the professional kit, Keil Software provides a number of other tool kits for the 8051 developer. To best illustrate what is included in each tool kit, we describe the kits in decreasing order of capability. The most capable kit, the professional developer's kit is described first.

PK51-C51 Professional Developer's Kit

The PK51 C51 professional developer's kit includes everything the professional 8051 developer needs to create sophisticated embedded applications. This tool kit includes the following components:

- C51 Optimizing C Compiler,
- A51 Macro Assembler,
- BL51 Code Banking Linker/Locator,
- OC51 Banked Object File Converter,
- OH51 Object-Hex Converter,
- LIB51 Library Manager,
- dScope-51 Simulator/Debugger,
- tScope-51 Target Debugger,
- Monitor-51 ROM Monitor and Terminal Program,
- Integrated Development Environment,
- RTX-51 Tiny Real-Time Operating System.

In addition, the professional developer's kit includes the following tools for Windows users:

- dScope-51 Simulator/Debugger for Windows,
- µVision/51 Integrated Development Environment for Windows.

The professional developer's kit can be configured for all 8051 derivatives. The tools included in this kit run under DOS on any 100% IBM PC 386 or higher compatible computer.

DK51-C51 Developer's Kit

The DK51 C51 developer's kit is designed for users who need a complete DOS-based development system for the 8051. This kit lets you create sophisticated embedded applications using a DOS-based development platform. This tool kit includes the following components:

- C51 Optimizing C Compiler,
- A51 Macro Assembler,
- BL51 Code Banking Linker/Locator,
- OC51 Banked Object File Converter,
- OH51 Object-Hex Converter,
- LIB51 Library Manager,
- dScope-51 Simulator/Debugger,
- tScope-51 Target Debugger,
- Monitor-51 ROM Monitor and Terminal Program,
- Integrated Development Environment.

The developer's kit can be configured for all 8051 derivatives. The tools included in this kit run under DOS on any 100% compatible IBM PC 386 or higher computer.

CA51-C51 Compiler Kit

The CA51 C51 compiler kit is the best choice for developers who need a C compiler but not a debugging system. This kit lets you create 8051 C applications for your target hardware. The compiler kit can be configured for all 8051 derivatives. The tools included in this kit run under DOS on any 100% compatible IBM PC 386 or higher computer.

A51-A51 Macro Assembler Kit

The A51 assembler kit includes our 8051 assembler and all the utilities you need to begin creating 8051 application. The assembler kit is easily configured for all 8051 derivatives. The tools included in this kit run under DOS on any 100% compatible IBM PC 386 or higher computer.

DS51-dScope-51 Simulator Kit

The DS51 simulator kit provides a debugger/simulator for use with the A51 assembler kit and the CA51 compiler kit. With this kit, you can quickly locate problems in your 8051 application because the simulator lets you step through your code one instruction at a time. You can easily view program variables, SFRs, and memory locations. This tool kit includes the following components:

- dScope-51 Simulator/Debugger,
- tScope-51 Target Debugger,
- Monitor-51 ROM Monitor and Terminal Program.

The simulator kit comes with drivers for most popular 8051 derivatives. The tools included in this kit run under DOS on any 100% compatible IBM PC 386 or higher computer.

FR51-RTX-51 Full Real-Time Kernel

The RTX-51 Full kernel is a real-time operating system for the 8051 microcontroller. RTX-51 Full provides a superset of the features found in RTX-51 Tiny and also includes BITBUS and CAN communication protocol interface libraries. Refer to “Chapter 7. Real-Time Kernels” on page 95 for more information about RTX-51 Tiny.

Tool Kit Comparison Chart

The following table provides a check list of the features found in each of our development kits. Part numbers are listed across the top and features are listed down the side. Use this cross reference to select the kit that best suits your needs.

Support	PK51	DK51	A51
8051	✓	✓	✓
Assembler	✓	✓	✓
Compiler	✓	✓	
Simulator	✓	✓	
IDE	✓	✓	✓
RTX	✓		
Windows	✓		
DOS	✓	✓	✓

Chapter 4. 8051 Development Tools

This chapter discusses the features and advantages of the 8051 microprocessor family and the development tools available from Keil Software. We have designed our development tools to help you quickly and successfully complete your job. For this reason, our tools are easy to use and are guaranteed to help you achieve your design goals.

8051 Microcontroller Family

The 8051 has been available since the early 1980's. With a wide variety of outstanding features and peripherals, the 8051 CPU core is destined to see service well into the next century. More than 200 different 8051 derivatives are available today from a variety of chip vendors. More than half of all embedded projects with a CPU use members of the 8051 microcontroller family. As an embedded processor, the 8051 has no equal.

A typical 8051 family member contains the 8051 CPU core, data memory, code memory, and some versatile peripheral functions. A flexible memory interface lets you expand the capabilities of the 8051 using standard peripherals and memory devices.

8051 Development Tools

Keil Software provides the following development tools for the 8051:

- C51 Optimizing C Compiler (see page 21),
- A51 Macro Assembler (see page 38),
- BL51 Code Banking Linker/Locator (see page 40),
- OC51 Banked Object File Converter (see page 44),
- OH51 Object-Hex Converter (see page 44),
- LIB51 Library Manager (see page 44)
- dScope-51 for Windows (see page 45),
- µVision/51 for Windows (see page 45).

For information on the products which include these tools, refer to "Chapter 3. 8051 Product Line" on page 13.

NOTE
All of our 8051 tools utilize the Intel OMF51 object module format. The development environment can be expanded with all Intel compatible tools such as Intel PL/M-51 or iDCX-51 and with emulators from a wide range of manufactures.

C51 Optimizing C Cross Compiler

The C programming language is a general-purpose programming language that provides code efficiency, elements of structured programming, and a rich set of operators. C is not a *big* language and is not designed for any one particular area of application. Its generality, combined with its absence of restrictions, make C a convenient and effective programming solution for a wide variety of software tasks. Many applications can be solved more easily and efficiently with C than with other more specialized languages.

The Keil Software C51 optimizing cross compiler for the MS-DOS operating system is a complete implementation of the ANSI (American National Standards Institute) standard for the C language. The C51 compiler generates code for the 8051 microprocessor but is not a universal C compiler adapted for the 8051 target. It is a ground-up implementation dedicated to generating extremely fast and compact code for the 8051 microprocessor.

For most 8051 applications, the C51 compiler gives software developers the flexibility of programming in C while matching the code efficiency and speed of assembly language.

Using a high-level language like C has many advantages over assembly language programming. For example:

- Knowledge of the processor instruction set is not required. A rudimentary knowledge of the 8051's memory architecture is desirable but not necessary.
- Register allocation and addressing mode details are managed by the compiler.
- The ability to combine variable selection with specific operations improves program readability.
- Keywords and operational functions that more nearly resemble the human thought process can be used.
- Program development and debugging times are dramatically reduced when compared to assembly language programming.
- The library files that are supplied provide many standard routines (such as formatted output, data conversions, and floating-point arithmetic) that may be incorporated into your application.
- Existing routine can be reused in new programs by utilizing the modular programming techniques available with C.
- The C language is very portable and very popular. C compilers are available for almost all target systems. Existing software investments can be quickly and easily converted from or adapted to other processors or environments.

C51 Language Extensions

The C51 compiler is an ANSI compliant C compiler and includes all aspects of the C programming language that are specified by the ANSI standard. A number of extensions to the C programming language are provided to support the facilities of the 8051 microprocessor. The C51 compiler includes extensions for:

- Data Types,
- Memory Types,
- Memory Models,
- Pointers,
- Reentrant Functions,
- Interrupt Functions,
- Real-Time Operating Systems,
- Interfacing to PL/M and A51 source files.

The following sections briefly describe these extensions.

Data Types

The C51 compiler supports the data types listed in the following table. In addition to these scalar types, variables can be combined into structures, unions, and arrays. Except as noted, you may use pointers to access these data types.

Data Type	Bits	Bytes	Value Range
bit †	1		0 to 1
signed char	8	1	-128 to +127
unsigned char	8	1	0 to 255
enum	16	2	-32768 to +32767
signed short	16	2	-32768 to +32767
unsigned short	16	2	0 to 65535
signed int	16	2	-32768 to +32767
unsigned int	16	2	0 to 65535
signed long	32	4	-2147483648 to 2147483647
unsigned long	32	4	0 to 4294967295
float	32	4	±1.175494E-38 to ±3.402823E+38
sbit †	1		0 to 1
sfr †	8	1	0 to 255
sfr16 †	16	2	0 to 65535

† The **bit**, **sbit**, **sfr**, and **sfr16** data types are specific to the 8051 hardware and the C51 compiler. The are not a part of ANSI C and cannot be accessed through pointers.

The **sbit**, **sfr**, and **sfr16** data types are included to allow access to the special function registers that are available on the 8051. For example, the declaration: `sfr P0 = 0x80;` declares the variable `P0` and assigns it the special function register address of `0x80`. This is the address of PORT 0 on the 8051.

The C51 compiler automatically converts between data types when the result implies a different data type. For example, a bit variable used in an integer assignment is converted to an integer. You can, of course, coerce a conversion by using a type cast. In addition to data type conversions, sign extensions are automatically carried out for signed variables.

Memory Types

The C51 compiler supports the architecture of the 8051 and its derivatives and provides access to all memory areas of the 8051. Each variable may be explicitly assigned to a specific memory space.

Memory Type	Description
code	Program memory (64 Kbytes); accessed by opcode **MOVC @A+DPTR**.
data	Directly addressable internal data memory; fastest access to variables (128 bytes).
idata	Indirectly addressable internal data memory; accessed across the full internal address space (256 bytes).
bdata	Bit-addressable internal data memory; allows mixed bit and byte access (16 bytes).
xdata	External data memory (64 Kbytes); accessed by opcode **MOVX @DPTR**.
pdata	Paged (256 bytes) external data memory; accessed by opcode **MOVX @Rn**.

Accessing the internal data memory is considerably faster than accessing the external data memory. For this reason, you should place frequently used variables in internal data memory and less frequently used variables in external data memory.

By including a memory type specifier in the variable declaration, you can specify where variables are stored.

As with the **signed** and **unsigned** attributes, you may include memory type specifiers in the variable declaration. For example:

```
char data var1;
char code text[] = "ENTER PARAMETER:";
unsigned long xdata array[100];
float idata x,y,z;
unsigned int pdata dimension;
unsigned char xdata vector[10][4][4];
char bdata flags;
```

If the memory type specifier is omitted in a variable declaration, the default or implicit memory type is automatically selected. Function arguments and automatic variables which cannot be located in registers are also stored in the default memory area.

The default memory type is determined by the **SMALL**, **COMPACT** and **LARGE** compiler control directives. These directives specify the memory model to use for the compilation.

Memory Models

The memory model determines the default memory type used for function arguments, automatic variables, and variables declared with no explicit memory type. You specify the memory model on the command line using the **SMALL**, **COMPACT**, and **LARGE** control directives. By explicitly declaring a variable with a memory type specifier, you may override the default memory type.

SMALL In this model, all variables default to the internal data memory of the 8051. This is the same as if they were declared explicitly using the **data** memory type specifier. In this memory model, variable access is very efficient. However, all data objects, as well as the stack must fit into the internal RAM. Stack size is critical because the stack space used depends upon the nesting depth of the various functions. Typically, if the BL51 code banking linker/locator is configured to overlay variables in the internal data memory, the small model is the best model to use.

COMPACT Using compact model, all variables default to one page of external data memory. This is the same as if they were explicitly declared using the **pdata** memory type specifier. This memory model can accommodate a maximum of 256 bytes of variables. The limitation is due to the addressing scheme used, which is indirect through registers R0 and R1. This memory model is not as efficient as the small model, therefore, variable access is not as fast. However, the compact model is faster than the large model. The high byte of the address is usually set up via port 2. The compiler does not set this port for you.

LARGE In large model, all variables default to external data memory. This is the same as if they were explicitly declared using the **xdata** memory type specifier. The data pointer (**DPTR**) is used for addressing. Memory access through this data pointer is inefficient, especially for variables with a length of two or more bytes. This type of data access generates more code than the small or compact models.

NOTE
*You should always use the **SMALL** memory model. It generates the fastest, tightest, and most efficient code. You can always explicitly specify the memory area for variables. Move up in model size only if you are unable to make your application fit or operate using **SMALL** model.*

Pointers

The C51 compiler supports pointer declarations using the asterisk character ('*'). You may use pointers to perform all operations available in standard C. However, because of the unique architecture of the 8051 and its derivatives, the C51 compiler supports two different types of pointers: memory specific pointers and generic pointers.

Generic Pointers

Generic pointers are declared in the same way as standard C pointers. For example:

```
char *s;                                                    /* string ptr */
int *numptr;                                                   /* int ptr */
long *state;                                                  /* long ptr */
```

Generic pointers are always stored using three bytes. The first byte is for the memory type, the second is for the high-order byte of the offset, and the third is for the low-order byte of the offset.

Generic pointers may be used to access any variable regardless of its location in 8051 memory space. Many of the library routines use these pointer types for this reason. By using these generic untyped pointers, a function can access data regardless of the memory in which it is stored.

Memory Specific Pointers

Memory specific pointers always include a memory type specification in the pointer declaration and always refer to a specific memory area. For example:

```
char data *str;                                  /* ptr to string in data */
int xdata *numtab;                              /* ptr to int(s) in xdata */
long code *powtab;                              /* ptr to long(s) in code */
```

Because the memory type is specified at compile-time, the memory type byte required by untyped pointers is not needed by typed pointers. Typed pointers can be stored using only one byte (**idata**, **data**, **bdata**, and **pdata** pointers) or two bytes (**code** and **xdata** pointers).

Comparison: Memory Specific & Generic Pointers

You can significantly accelerate an 8051 C program by using 'memory specific' pointers. The following sample program shows the differences in code & data size and execution time for various pointer declarations.

Description	Idata Pointer	Xdata Pointer	Generic Pointer

Sample Program	`char idata *ip;`
	`char val;`
	`val = *ip;`
		`char xdata *xp;`
		`char val;`
		`val = *xp;`
			`char *p;`
			`char val;`
			`val = *p;`

8051 Program Code Generated	`MOV R0,ip`
	`MOV val,@R0`
		`MOV DPL,xp +1`
		`MOV DPH,xp`
		`MOV A,@DPTR`
		`MOV val,A`
			`MOV R1,p + 2`
			`MOV R2,p + 1`
			`MOV R3,p`
			`CALL CLDPTR`

Pointer Size	1 byte data	2 bytes data	3 bytes data
Code Size	4 bytes code	9 bytes code	11 bytes code + Lib.
Execution Time	4 cycles	7 cycles	13 cycles

Reentrant Functions

A reentrant function can be shared by several processes at the same time. When a reentrant function is executing, another process can interrupt the execution and then begin to execute that same reentrant function. Normally, C51 functions cannot be called recursively or in a fashion which causes reentrancy. The reason for this limitation is that function arguments and local variables are stored in fixed memory locations. The **reentrant** function attribute allows you to declare functions that may be reentrant and, therefore, may be called recursively. For example:

```
int calc (char i, int b) reentrant
  {
  int  x;
  x = table [i];
  return (x * b);
  }
```

Reentrant functions can be called recursively and can be called *simultaneously* by two or more processes. Reentrant functions are often required in real-time applications or in situations where interrupt code and non-interrupt code must share a function.

For each reentrant function, a reentrant stack area is simulated in internal or external memory depending on the memory model.

NOTE
*By selecting the **reentrant** attribute on a function by function basis, you can select the use of this attribute where it's needed without making the entire program **reentrant**. Making an entire program reentrant may cause it to be larger and consume more memory.*

Interrupt Functions

The C51 compiler provides you with a method of calling a C function when an interrupt occurs. This support allows you to create interrupt service routines in C. You need only be concerned with the interrupt number and register bank selection. The compiler automatically generates the interrupt vector and entry and exit code for the interrupt routine. The **interrupt** function attribute, when included in a declaration, specifies that the associated function is an interrupt function. Additionally, you can specify the register bank used for that interrupt with the **using** function attribute.

```
unsigned int interruptcnt;
unsigned char second;

void timer0 (void) interrupt 1 using 2 {
  if (++interruptcnt == 4000) {                    /* count to 4000 */
    second++;                                     /* second counter */
    interruptcnt = 0;                           /* clear int counter */
  }
}
```

Parameter Passing

The C51 compiler passes up to three function arguments in CPU registers. This significantly improves system performance since arguments do not have to be written to and read from memory. Argument passing can be controlled with the **REGPARMS** and **NOREGPARMS** control directives.

The following table lists the registers used for different arguments and data types.

Argument Number	char, 1-byte pointer	int, 2-byte pointer	long, float	generic pointer
1	R7	R6 & R7	R4 - R7	R1 - R3
2	R5	R4 & R5		
3	R3	R2 & R3		

If no registers are available for argument passing or too many arguments are involved, fixed memory locations are used for those extra arguments.

Function Return Values

CPU registers are always used for function return values. The following table lists the return types and the registers used for each.

Return Type	Register	Description
bit	Carry Flag	
char, **unsigned char, 1-byte pointer**	R7	
int, **unsigned int, 2-byte pointer**	R6 & R7	MSB in R6, LSB in R7
long, **unsigned long**	R4 - R7	MSB in R4, LSB in R7
float	R4 - R7	32-Bit IEEE format
generic pointer	R1 - R3	Memory type in R3, MSB R2, LSB R1

Register Optimizing

Depending on program context, the C51 compiler allocates up to 7 CPU registers for register variables. Any registers modified during function execution are noted by the C51 compiler within each module. The linker/locator generates a global, project-wide register file which contains information of all registers altered by external functions. Consequently, the C51 compiler *knows* the register used by each function in an application and can optimize the CPU register allocation of each C function.

Real-Time Operating System Support

The C51 compiler integrates well with both the RTX-51 Full and RTX-51 Tiny multitasking real-time operating systems. The task description tables are generated and controlled during the link process. For more information about the RTX real-time operating systems, refer to “Chapter 7. Real-Time Kernels” on page 95.

Interfacing to Assembly

You can easily access assembly routines from C and vice versa. Function parameters are passed via CPU registers or, if the **NOREGPARMS** control is used, via fixed memory locations. Values returned from functions are always passed in CPU registers.

You can use the **SRC** directive to direct the C51 compiler to generate a file ready to assemble with the A51 assembler instead of an object file. For example, the following C source file:

```
unsigned int asmfunc1 (unsigned int arg){
  return (1 + arg);
}
```

generates the following assembly output file when compiled using the **SRC** directive.

```
?PR?_asmfunc1?ASM1     SEGMENT CODE
PUBLIC                 _asmfunc1
                  RSEG  ?PR?_asmfunc1?ASM1
                  USING 0
_asmfunc1:
;---- Variable 'arg?00' assigned to Register 'R6/R7' ----
                  MOV   A,R7           ; load LSB of the int
                  ADD   A,#01H         ; add 1
                  MOV   R7,A           ; put it back into R7
                  CLR   A
                  ADDC  A,R6           ; add carry & R6
                  MOV   R6,A

?C0001:
                  RET                  ; return result in R6/R7
```

You may use the **#pragma asm** and **#pragma endasm** preprocessor directives to insert assembly instructions into your C source code.

Interfacing to PL/M-51

Intel's PL/M-51 is a popular programming language that is similar to C in many ways. You can easily interface routines written in C to routines written in PL/M-51. You can access PL/M-51 functions from C by declaring them with the **alien** function type specifier. All public variables declared in the PL/M-51 module are available to your C programs. For example:

```
extern alien char plm_func (int, char);
```

Since the PL/M-51 compiler and the Keil Software tools all generate object files in the OMF51 format, external symbols are resolved by the linker.

Code Optimizations

The C51 compiler is an aggressive optimizing compiler. This means that the compiler takes certain steps to ensure that the code generated and output to the object file is the most efficient (smaller and/or faster) code possible. The compiler analyzes the generated code to produce the most efficient instruction sequences. This ensures that your C program runs as quickly and effectively as possible in the least amount of code space.

The C51 compiler provides six different levels of optimizing. Each increasing level includes the optimizations of levels below it. The following is a list of all optimizations currently performed by the C51 compiler.

General Optimizations

- **Constant Folding**: Several constant values occurring in an expression or address calculation are combined as a single constant.
- **Jump Optimizing**: Jumps are inverted or extended to the final target address when the program efficiency is thereby increased.
- **Dead Code Elimination**: Code which cannot be reached (dead code) is removed from the program.
- **Register Variables**: Automatic variables and function arguments are located in registers whenever possible. No data memory space is reserved for these variables.
- **Parameter Passing Via Registers**: A maximum of three function arguments can be passed in registers.
- **Global Common Subexpression Elimination**: Identical subexpressions or address calculations that occur multiple times in a function are recognized and calculated only once whenever possible.

8051-Specific Optimizations

- **Peephole Optimization**: Complex operations are replaced by simplified operations when memory space or execution time can be saved as a result.
- **Access Optimizing**: Constants and variables are computed and included directly in operations.
- **Data Overlaying**: Data and bit segments of functions are identified as OVERLAYABLE and are overlaid with other data and bit segments by the BL51 code banking linker/locator.
- **Case/Switch Optimizing**: Depending upon their number, sequence, and location, **switch** and **case** statements can be further optimized by using a jump table or string of jumps.

Options for Code Generation

- **OPTIMIZE(SIZE)**: Common C operations are replaced by subprograms. Program code size is reduced at the expense of program speed.
- **OPTIMIZE(SPEED)**: Common C operations are expanded in-line. Program speed is increased at the expense of code size.
- **NOAREGS**: The C51 compiler no longer uses absolute register access. Program code is independent of the register bank.
- **NOREGPARMS**: Parameter passing is always performed in local data segments rather then dedicated registers. Program code created with this #pragma is compatible to earlier versions of the C51 compiler, the PL/M-51 compiler, and the ASM-51 assembler.

Global Register Optimization

The C51 compiler provides support for application wide register optimization which is also known as application register coloring. The following sample program compares the code generated by C51 version 5.0 using application register coloring to the code generated by C51 version 3.4 without application register coloring. With the application wide register optimization, the C compiler *knows* the registers used by external functions. Registers that are not altered in external functions are used for register variables. The generated code needs less data and code space and executes faster. In the following example *input* and *output* are external functions, which require only a few registers.

With Global Register Optimization	Without Global Register Optimization
main () { *unsigned char i;* *unsigned char a;* *while (1) {* *i = input ();*	*/* get number of values */*
?C0001: **LCALL input** **;- 'i' assigned to 'R6' -** **MOV R6,AR7**	**?C0001:** **LCALL input** **MOV DPTR,#i** **MOV A,R7** **MOV @DPTR,A**
do { *a = input ();*	*/* get input value */*
?C0005: **LCALL input** **;- 'a' assigned to 'R7' -** **MOV R5,AR7**	**?C0005:** **LCALL input** **MOV DPTR,#a** **MOV A,R7** **MOVX @DPTR,A**
output (a);	*/* output value */*
LCALL _output	**LCALL _output**
} while (--i);	*/* decrement values */*
DJNZ R6,?C0005	**MOV DPTR,#i** **MOVX A,@DPTR** **DEC A** **MOVX @DPTR,A** **JNZ ?C0005**
}	
SJMP ?C0001	**SJMP ?C0001**
}	
RET	**RET**
Code Size: 18 Bytes	**Code Size: 30 Bytes**

Debugging

The C51 compiler uses the Intel Object Format (OMF51) for object files and generates complete symbol information. Additionally, the compiler can include all the necessary information such as; variable names, function names, line numbers, and so on to allow detailed and thorough debugging and analysis with dScope-51 or Intel compatible emulators. All Intel compatible emulators may be used for program debugging. In addition, the **OBJECTEXTEND** control directive embeds additional variable type information in the object file which allows type-specific display of variables and structures when using certain emulators. You should check with your emulator vendor to determine if it is compatible with the Intel OMF51 object module format and if it can accept Keil object modules.

Library Routines

The C51 compiler includes seven different ANSI compile-time libraries which are optimized for various functional requirements.

Library File	Description
C51S.LIB	Small model library without floating-point arithmetic
C51FPS.LIB	Small model floating-point arithmetic library
C51C.LIB	Compact model library without floating-point arithmetic
C51FPC.LIB	Compact model floating-point arithmetic library
C51L.LIB	Large model library without floating-point arithmetic
C51FPL.LIB	Large model floating-point arithmetic library
80C751.LIB	Library for use with the Philips 8xC751 and derivatives.

Source code is provided for library modules that perform hardware-related I/O and is found in the **\C51\LIB** directory. You may use these source files to help you quickly adapt the library to perform I/O using any I/O device in your target.

Intrinsic Library Routines

The libraries included with the compiler include a number of routines that are implemented as intrinsic functions. Non-intrinsic functions generate **ACALL** or **LCALL** instructions to perform the library routine. Intrinsic functions generate in-line code (which is faster and more efficient) to perform the library routine.

Intrinsic Function	Description
crol	Rotate character left.
cror	Rotate character right.
irol	Rotate integer left.
iror	Rotate integer right.
lrol	Rotate long integer left.
lror	Rotate long integer right.
nop	No operation (8051 NOP instruction).
testbit	Test and clear bit (8051 JBC instruction).

Listing File Example

The C51 compiler produces a listing file that contains source code, directive information, an assembly listing, and a symbol table.

```
C51 COMPILER V5.02,  SAMPLE            07/01/95  08:00:00  PAGE 1

DOS C51 COMPILER V5.02, COMPILATION OF MODULE SAMPLE
OBJECT MODULE PLACED IN SAMPLE.OBJ
COMPILER INVOKED BY: C:\C51\BIN\C51.EXE SAMPLE.C CODE

stmt level source
   1       #include <reg51.h>   /* SFR definitions for 8051 */
   2       #include <stdio.h>   /* standard i/o definitions */
   3       #include <ctype.h>   /* defs for char conversion */
   4
   5       #define EOT  0x1A    /* Control+Z signals EOT */
   6
   7       void main (void)  {
   8   1      unsigned char c;
   9   1
  10   1      /* setup serial port hdw (2400 Baud @12 MHz) */
  11   1      SCON = 0x52;      /* SCON */
  12   1      TMOD = 0x20;      /* TMOD */
  13   1      TCON = 0x69;      /* TCON */
  14   1      TH1  = 0xF3;      /* TH1  */
  15   1
  16   1      while ((c = getchar ()) != EOF)  {
  17   2         putchar (toupper (c));
  18   2         }
  19   1      P0 = 0;   /* clear Output Port to signal ready */
  20   1      }

ASSEMBLY LISTING OF GENERATED OBJECT CODE

            ; FUNCTION main (BEGIN)
                                           ; SOURCE LINE # 7
                                           ; SOURCE LINE # 11
0000 759852        MOV     SCON,#052H
                                           ; SOURCE LINE # 12
0003 758920        MOV     TMOD,#020H
                                           ; SOURCE LINE # 13
0006 758869        MOV     TCON,#069H
                                           ; SOURCE LINE # 14
0009 758DF3        MOV     TH1,#0F3H
000C            ?C0001:
                                           ; SOURCE LINE # 16
000C 120000  E     LCALL   getchar
000F 8F00    R     MOV     c,R7
0011 EF            MOV     A,R7
0012 F4            CPL     A
0013 6008          JZ      ?C0002
                                           ; SOURCE LINE # 17
0015 120000  E     LCALL   _toupper
0018 120000  E     LCALL   _putchar
                                           ; SOURCE LINE # 18
001B 80EF          SJMP    ?C0001
001D            ?C0002:
                                           ; SOURCE LINE # 19
001D E4            CLR     A
001E F580          MOV     P0,A
                                           ; SOURCE LINE # 20
0020 22            RET
            ; FUNCTION main (END)


MODULE INFORMATION:   STATIC OVERLAYABLE
   CODE SIZE        =     33    ----
   CONSTANT SIZE    =   ----    ----
   XDATA SIZE       =   ----    ----
   PDATA SIZE       =   ----    ----
   DATA SIZE        =   ----       1
   IDATA SIZE       =   ----    ----
   BIT SIZE         =   ----    ----
END OF MODULE INFORMATION.


C51 COMPILATION COMPLETE.  0 WARNING(S),  0 ERROR(S)
```

The C51 compiler produces a listing file with page numbers as well as time and date of the compilation. Remarks about the compiler invocation and object file output are displayed in this listing.

The listing includes a line number for each statement and a nesting level for each block enclosed within curly braces ('{' and '}').

Error messages and warning messages are included in the listing file.

The **CODE** compiler option includes an assembly code listing in the listing file. Source line numbers are embedded within the generated code.

A memory overview provides information about the 8051 memory areas that are used.

The total number of errors and warnings is stated at the end of the listing file.

A51 Macro Assembler

The A51 assembler is a macro assembler for the 8051 microcontroller family. It translates symbolic assembly language mnemonics into relocatable object code where the utmost speed, small code size, and hardware control are critical. The macro facility speeds development and conserves maintenance time since common sequences need only be developed once. The A51 assembler supports symbolic access to all features of the 8051 architecture and is configurable for the numerous 8051 derivatives.

Functional Overview

The A51 assembler translates an assembler source file into a relocatable object module. If the **DEBUG** control is used, the object file contains full symbolic information for debugging with dScope or an in-circuit emulator. In addition to the object file, the A51 assembler generates a list file which may optionally include symbol table and cross reference information. The A51 assembler is fully compatible with Intel ASM-51 source modules.

Configuration

The A51 assembler supports all members of the 8051 family. The special function register (SFR) set of the 8051 is predefined. However, the **NOMOD51** control lets you override these definitions with processor-specific include files. The A51 assembler is shipped with include files for the 8051, 8051F*x*, 8051GB, 8052, 80152, 80451, 80452, 80515, 80C517, 80C515A, 80C517A, 8x552, 8xC592, 8xCL781, 8xCL410 and 80C320 microcontrollers. You can easily create include files for other 8051 family members.

Listing File Example

The following example shows a listing file generated by the A51 assembler during assembly. The listing file contains source code, machine code generated, directive information, and a symbol table.

```
A51 MACRO ASSEMBLER  Test Program        07/01/95 08:00:00 PAGE     1

DOS MACRO ASSEMBLER A51 V5.02
OBJECT MODULE PLACED IN SAMPLE.OBJ
ASSEMBLER INVOKED BY: C:\C51\BIN\A51.EXE SAMPLE.A51 XREF

LOC  OBJ       LINE  SOURCE
                  1  $TITLE ('Test Program')
                  2  NAME    SAMPLE
                  3
                  4  EXTRN CODE (PUT_CRLF, PUTSTRING, InitSerial)
                  5  PUBLIC  TXTBIT
                  6
                  7  PROG    SEGMENT         CODE
                  8  CONST   SEGMENT         CODE
                  9  BITVAR  SEGMENT         BIT
                 10
----             11          CSEG  AT     0
                 12
0000 020000   F  13  Reset:  JMP   Start
                 14
----             15          RSEG  PROG
                 16   ; *****
0000 120000   F  17  Start:  CALL  InitSerial ;Init Serial Interface
                 18
                 19  ; This is the main program. It is an endless
                 20  ; loop which displays a text on the console.
0003 C200     F  21          CLR   TXTBIT       ; read from CODE
0005 900000   F  22  Repeat: MOV   DPTR,#TXT
0008 120000   F  23          CALL  PUTSTRING
000B 120000   F  24          CALL  PUT_CRLF
000E 80F5        25          SJMP  Repeat
                 26  ;
----             27          RSEG  CONST
0000 54455354    28  TXT:    DB    'TEST PROGRAM',00H
0004 2050524F
0008 4752414D
000C 00
                 29
                 30
                 31
----             32          RSEG  BITVAR  ; TXTBIT=0 read from CODE
0000             33  TXTBIT: DBIT  1       ; TXTBIT=1 read from XDATA
                 34
                 35          END

XREF SYMBOL TABLE LISTING
---- ------ ----- -------

N A M E             T Y P E  V A L U E   ATTRIBUTES / REFERENCES

BITVAR . . . . . .  B SEG    0001H       REL=UNIT   9# 32
CONST. . . . . .  C SEG    000DH       REL=UNIT   8# 27
INITSERIAL . . . .  C ADDR   -----       EXT   4# 17
PROG . . . . . .  C SEG    0010H       REL=UNIT   7# 15
PUTSTRING. . . . .  C ADDR   -----       EXT   4# 23
PUT_CRLF . . . . .  C ADDR   -----       EXT   4# 24
REPEAT . . . . . .  C ADDR   0005H   R   SEG=PROG   22# 25
RESET. . . . . .  C ADDR   0000H   A      13#
SAMPLE . . . . . .  N NUMB   -----         2
START. . . . . .  C ADDR   0000H   R   SEG=PROG   13 17#
TXT. . . . . .  C ADDR   0000H   R   SEG=CONST   22 28#
TXTBIT . . . . . .  B ADDR   0000H.0 R   SEG=BITVAR   5 5 21 33#

REGISTER BANK(S) USED: 0

ASSEMBLY COMPLETE.  0 WARNING(S), 0 ERROR(S)
```

The A51 assembler produces a listing file with page numbers as well as the time and date of the assembly. Remarks about the assembler invocation and the object file output are displayed in this listing.

Typical programs start with EXTERN, PUBLIC, and SEGMENT directives.

The listing file includes a line number for each source line.

If a source line generates code, the HEX values are displayed at the beginning of the line.

Error messages and warning messages are included in the listing file. The position of each error is clearly marked.

The **XREF** assembler option produces a cross reference list. The cross reference report shows all symbols and the line numbers in which they are used. The line number where the symbol is defined is marked with a pound symbol ('#').

The register banks used, and the total number of warnings and errors is stated at the end of the listing file.

BL51 Code Banking Linker/Locator

The BL51 code banking linker/locator combines one or more object modules into a single executable 8051 program. The linker also resolves external and public references, and assigns absolute addresses to relocatable programs segments.

The BL51 code banking linker/locator processes object modules created by the Keil C51 compiler and A51 assembler and the Intel PL/M-51 compiler and ASM-51 assembler. The linker automatically selects the appropriate run-time library and links only the library modules that are required.

Normally, you invoke the BL51 code banking linker/locator from the command line specifying the names of the object modules to combine. The default controls for the BL51 code banking linker/locator have been carefully chosen to accommodate most applications without the need to specify additional directives. However, it is easy for you to specify custom settings for your application.

Data Address Management

The BL51 code banking linker/locator manages the limited internal memory of the 8051 by overlaying variables for functions that are mutually exclusive. This greatly reduces the overall memory requirement of most 8051 applications.

The BL51 code banking linker/locator analyzes the references between functions to carry out memory overlaying. You may use the **OVERLAY** directive to manually control functions references the linker uses to determine exclusive memory areas. The **NOOVERLAY** directive lets you completely disable memory overlaying. These directives are useful when using indirectly called functions or when disabling overlaying for debugging.

Code Banking

The BL51 code banking linker/locator supports the ability to create application programs that are larger than 64 Kbytes. Since the 8051 does not directly support more than 64 Kbytes of code address space, there must be external hardware that swaps code banks. The hardware that does this must be controlled by software running on the 8051. This process is known as bank switching.

The BL51 code banking linker/locator lets you manage 1 common area and 32 banks of up to 64 Kbytes each for a total of 2 Mbytes of bank-switched 8051 program space. Software support for the external bank switching hardware includes a short assembly file you can edit for your specific hardware platform.

The BL51 code banking linker/locator lets you specify the bank in which to locate a particular program module. By carefully grouping functions in the different banks, you can create very large, efficient applications.

Common Area

The common area in a bank switching program is an area of memory that can be accessed at all times from all banks. The common area cannot be physically swapped out or moved around. The code in the common area is either duplicated in each bank (if the entire program area is swapped) or can be located in a separate area or EPROM (if the common area is not swapped).

The common area contains program sections and constants which must be available at all times. It may also contain frequently used code. By default, the following code sections are automatically located in the common area:

- Reset and Interrupt Vectors,
- Code Constants,
- C51 Interrupt Functions,
- Bank Switch Jump Table,
- Some C51 Run-Time Library Functions.

Executing Functions in Other Banks

Code banks are selected by additional software-controlled address lines that are simulated using 8051 port I/O lines or a memory-mapped latch. The BL51 code banking linker/locator generates a jump table for functions in other code banks. When you call a function in a different bank, your program switches the bank, jumps to the desired function, and, when the function completes, restores the previous bank), and returns execution to the calling routine.

The bank switching process requires approximately 50 CPU cycles and consumes an additional 2 bytes of stack space. You can dramatically improve system performance by grouping interdependent functions in the same bank. Functions which are frequently invoked from multiple banks should be located in the common area.

Listing File Example

The following example shows a map file created by the BL51 code banking linker/locator:

```
BL51 BANKED LINKER/LOCATER V3.52        07/01/95  08:00:00  PAGE 1

MS-DOS BL51 BANKED LINKER/LOCATER V3.52, INVOKED BY:
C:\C51\BIN\BL51.EXE SAMPLE.OBJ

MEMORY MODEL: SMALL

INPUT MODULES INCLUDED:
  SAMPLE.OBJ (SAMPLE)
  C:\C51\LIB\C51S.LIB (?C_STARTUP)
  C:\C51\LIB\C51S.LIB (PUTCHAR)
  C:\C51\LIB\C51S.LIB (GETCHAR)
  C:\C51\LIB\C51S.LIB (TOUPPER)
  C:\C51\LIB\C51S.LIB (_GETKEY)


LINK MAP OF MODULE:  SAMPLE (SAMPLE)

     TYPE    BASE      LENGTH    RELOCATION   SEGMENT NAME
     -----------------------------------------------------

     * * * * * * *   D A T A   M E M O R Y   * * * * * * *
     REG     0000H     0008H     ABSOLUTE     "REG BANK 0"
     DATA    0008H     0001H     UNIT         ?DT?GETCHAR
     DATA    0009H     0001H     UNIT         _DATA_GROUP_
             000AH     0016H                  *** GAP ***
     BIT     0020H.0   0000H.1   UNIT         ?BI?GETCHAR
             0020H.1   0000H.7                *** GAP ***
     IDATA   0021H     0001H     UNIT         ?STACK

     * * * * * * *   C O D E   M E M O R Y   * * * * * * *
     CODE    0000H     0003H     ABSOLUTE
     CODE    0003H     0021H     UNIT         ?PR?MAIN?SAMPLE
     CODE    0024H     000CH     UNIT         ?C_C51STARTUP
     CODE    0030H     0027H     UNIT         ?PR?PUTCHAR?PUTCHAR
     CODE    0057H     0011H     UNIT         ?PR?GETCHAR?GETCHAR
     CODE    0068H     0018H     UNIT         ?PR?_TOUPPER?TOUPPER
     CODE    0080H     000AH     UNIT         ?PR?_GETKEY?_GETKEY


OVERLAY MAP OF MODULE:   SAMPLE (SAMPLE)

SEGMENT                          DATA_GROUP
  +--> CALLED SEGMENT          START    LENGTH
------------------------------------------------
?C_C51STARTUP                  -----    -----
  +--> ?PR?MAIN?SAMPLE

?PR?MAIN?SAMPLE                0009H    0001H
  +--> ?PR?GETCHAR?GETCHAR
  +--> ?PR?_TOUPPER?TOUPPER
  +--> ?PR?PUTCHAR?PUTCHAR

?PR?GETCHAR?GETCHAR            -----    -----
  +--> ?PR?_GETKEY?_GETKEY
  +--> ?PR?PUTCHAR?PUTCHAR


LINK/LOCATE RUN COMPLETE.  0 WARNING(S),  0 ERROR(S)
```

The BL51 code banking linker/locator produces a map file with the time and date of the link/locate run.

The invocation line and the selected memory module are listed.

The link-map contains a table of the memory usage of the physical 8051 memory area.

The overlay-map displays the structure of the program and the location of the bit and data segments of each function.

Error messages and warnings are listed at the end of the map file. These messages indicate possible problems during the link/locate run.

OC51 Banked Object File Converter

The OC51 banked object file converter creates absolute object modules for each code bank in a banked object module. Banked object modules are created by the BL51 code banking linker/locator when you create a bank switching application. Symbolic debugging information is copied to the absolute object files and can be used by dScope or an in-circuit emulator.

You may use the OC51 banked object file converter to create absolute object modules for the command area and for each code bank in your banked object module. You may then generate Intel HEX files for each of the absolute object modules using the OH51 object-hex converter.

OH51 Object-Hex Converter

The OH51 object-hex converter creates Intel HEX files from absolute object modules. Absolute object modules can be created by the BL51 code banking linker or by the OC51 banked object file converter. Intel HEX files are ASCII files that contain a hexadecimal representation of your application. They can be easily loaded into a device programmer for writing EPROMS.

LIB51 Library Manager

The LIB51 library manager lets you create and maintain library files. A library file is a formatted collection of one or more object files. Library files provide a convenient method of combining and referencing a large number of object files. Libraries can be effectively used by the BL51 code banking linker/locator.

The LIB51 library manager lets you create a library file, add object modules to a library file, remove object modules from a library file, and list the contents of a library file. The LIB51 library manager may be controlled interactively or from the command line.

dScope-51 for Windows

dScope-51 is a source level debugger and simulator for programs created with the Keil C51 compiler and A51 assembler and the Intel PL/M-51 compiler and ASM-51 assembler. dScope-51 is a software-only product that lets you simulate the features of an 8051 without actually having target hardware. You may use dScope-51 to test and debug your embedded application before actual 8051 hardware is ready. dScope-51 simulates a wide variety of 8051 peripherals including the internal serial port, external I/O, and timers.

Refer to “dScope Simulator/Debugger Overview” on page 55 for examples that show how to use dScope-51.

µVision/51 for Windows

µVision/51 is an integrated software development platform that includes a full-function editor, project manager, make facility, and environment control for the Keil 8051 tools. When you use µVision/51, you no longer have to learn the command-line syntax of any of the tools. µVision/51 speeds your embedded application development by providing the following:

- Standard Windows user interface,
- Dialog boxes for all environment and development tool settings,
- Multiple file editing capability,
- Full-function editor with user-definable key sequences,
- Application manager for adding external programs into the pull-down menu,
- Project manager for creating and maintaining projects,
- Integrated make facility for building target programs from your projects,
- On-line help system.

Refer to “µVision IDE Overview” on page 48 for examples that show how to use µVision/51.

Chapter 5. Using the 8051 tools

To make it easy for you to evaluate and become familiar with our 8051 product line, we provide an evaluation diskette with sample programs and limited versions of our tools. The sample programs are also included with our standard product kits.

This chapter introduces the primary user-interface products, µVision and dScope, and shows you how to use them to compile, link, and run the provided sample programs. The following sections are included in this chapter:

- Starting µVision and dScope,
- µVision integrated development environment overview,
- dScope simulator/debugger overview,
- Sample programs,
- Building and running the HELLO sample program,
- Building and running the MEASURE sample program,
- Building the BADCODE sample program.

The examples and descriptions in this chapter are illustrated using our Windows-based tools. These are the same tools distributed with our **C51 Demo Kit** and **C51 Evaluation Kit**. Contact sales/support if you would like a copy of our DOS-based evaluation kit.

NOTE
The C51 Evaluation Kit includes evaluation versions of our 8051 tools. The evaluation tools are limited in functionality and the code size of the application you can create. Refer to the "Eval Kit Notes" for more information on the limitations of the evaluation tools. For larger applications, you need to purchase one of our development kits. Refer to "Chapter 3. 8051 Product Line" on page 13 for a description of the kits that are available.

Starting µVision and dScope

Both µVision for Windows and dScope for Windows are standard Windows applications. You launch them by double-clicking on the appropriate icon in the program group created by the installation program.

µVision IDE Overview

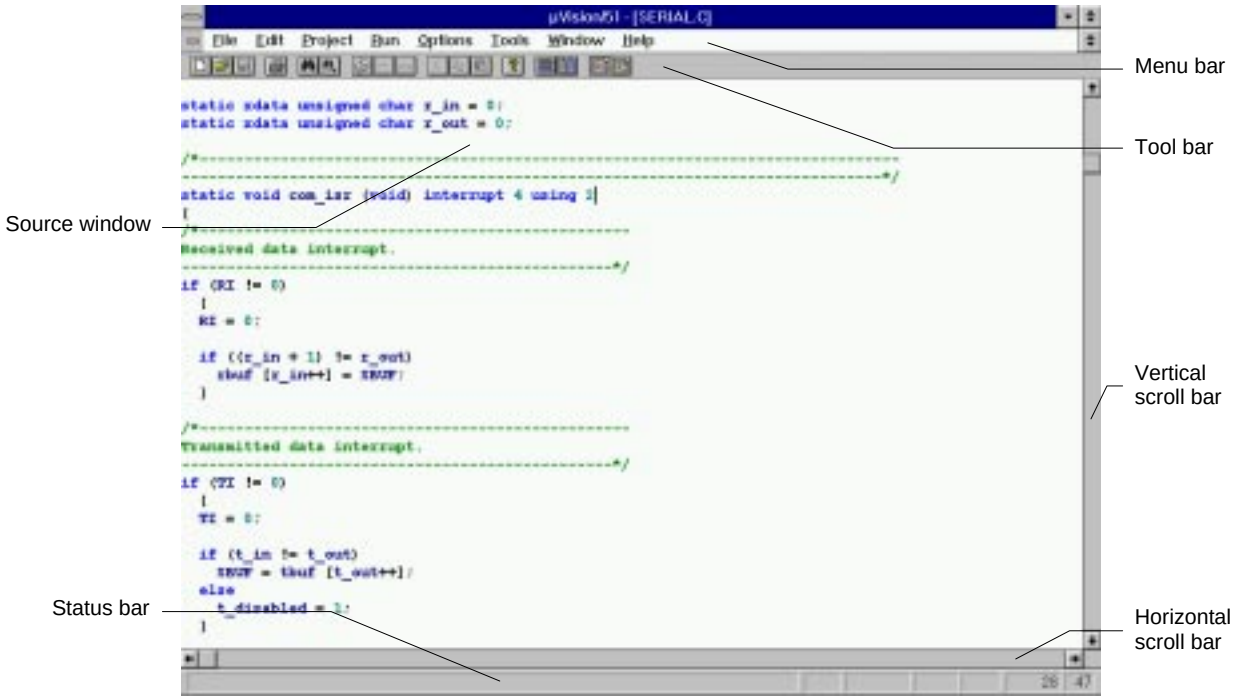
µVision is an integrated software development platform that combines a robust editor, project manager, and make facility. µVision supports all of the Keil tools for the 8051, 251, and 166. µVision helps expedite the development process of your embedded applications by providing the following:

- Full-function editor with user-definable key sequences,
- Application manager for linking external program files into the pull-down menu,
- Project manager for creating and maintaining your projects,
- Integrated make facility for assembling, compiling, and linking your embedded applications,
- Dialog boxes for all environment and development tool settings.

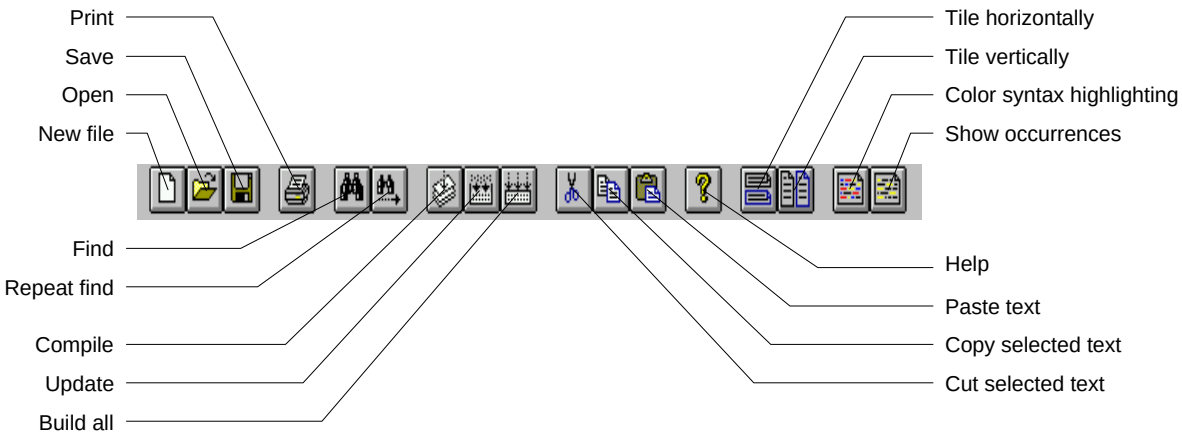
About the Environment

In µVision, you may use the keyboard or the mouse to select menu commands, settings, and options for the development tools. You may also use the keyboard to enter program text.

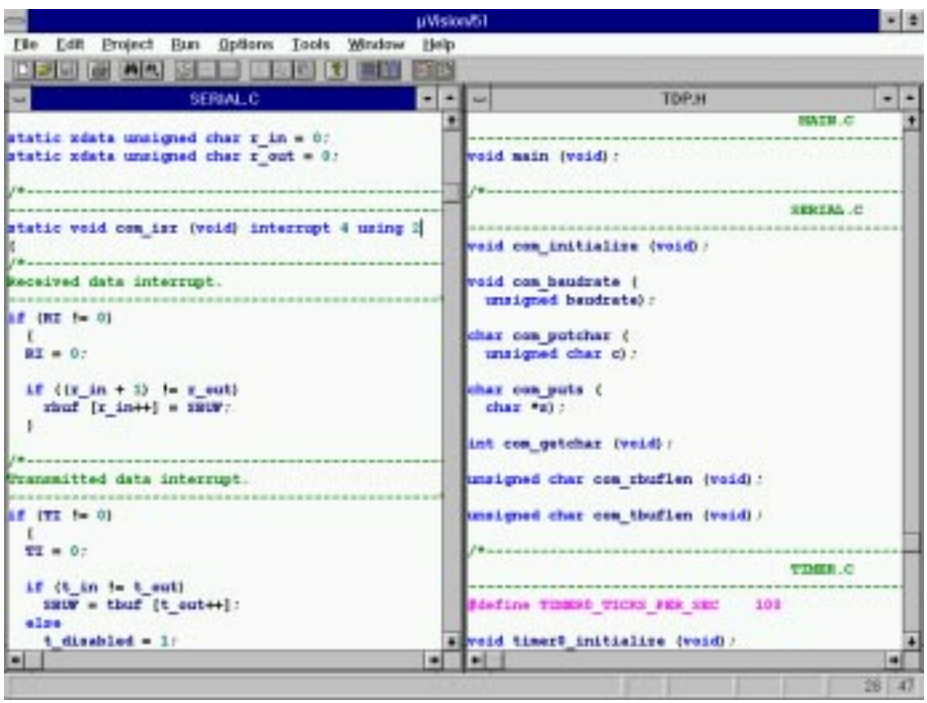
The µVision screen provides you with a menu bar for command entry, a tool bar where you can rapidly select command buttons, and one or more windows for source files, dialog boxes, and information displays.



You can quickly access many of the features of µVision using the buttons on the tool bar.



µVision lets you simultaneously open and view multiple source files. While writing part of your C program in one window, you can refer to header file information in another window. You can move and resize source windows using the mouse or keyboard.



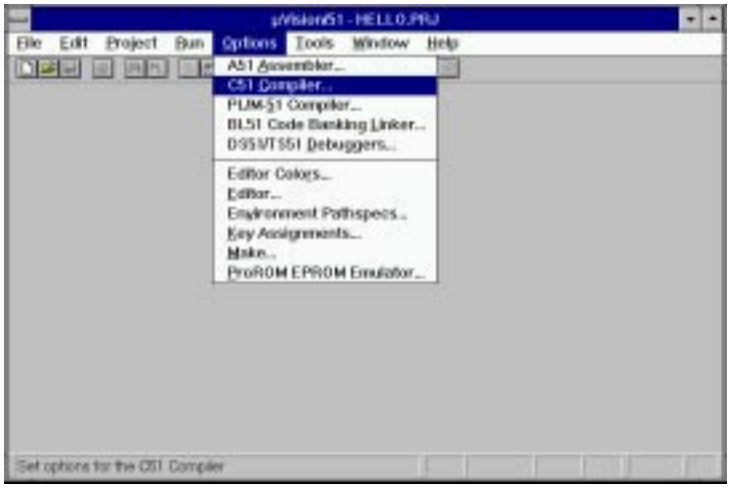
Editor

µVision's built-in editor can be customized to emulate many popular text editors. You can change key assignments for almost all editor functions. The following table lists a few of the editor functions that are available:

Beginning of File	Destructive Backspace	Next Error
Beginning of Line	End of File	Open File
Beginning of Page	End of Line	Page Down
Cascade Windows	End of Page	Page Up
Close File	Exclusive Mark	Paste from Clipboard
Copy to Clipboard	Forward Quick Search	Previous Error
Cursor Down	Forward Replace	Previous Window
Cursor Left	Full Search	Print File
Cursor Right	Insert Template	Repeat Last Search
Cursor Up	Mark Block	Reverse Quick Search
Cut to Clipboard	Mark Columns	Undo
Delete	Mark Lines	Word Left
Delete Line	Move/Resize Window	Word Right
Delete to End of Line	New File	

Menu Commands

Through pull-down menus on the menu bar and editor commands, you control the µVision operations. You may use either the mouse or the keyboard to access commands from the menu bar.



The menu bar provides you with access to menus for file operations, editor operations, project maintenance, external program execution (such as running the dScope debugger/simulator or another program), development tool option settings, window selection and manipulation, and on-line help.

Development Tool Options

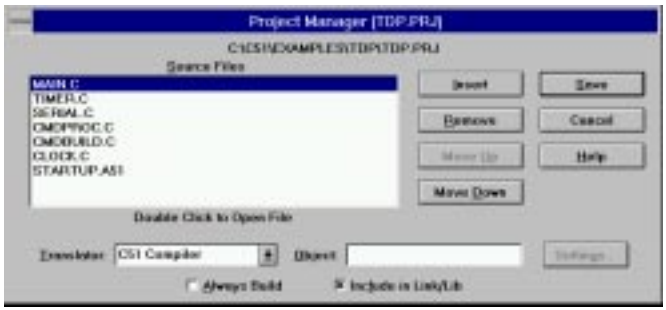
µVision lets you set options for software development tools such as the C51 compiler and A51 assembler. Simply select the appropriate item from the Options menu and use the mouse or the keyboard to change the options.

Project Manager

Most embedded programs are composed of several source files. This means that a project includes a large collection of individual files. Some files may require compilation with the C51 compiler, some files may require assembly, and some files may require custom translation in order to create a target program.

To accommodate the intricacies of project maintenance, µVision includes a project manager facility. The project manager gives you a method of creating and maintaining a project so that the target program is always up-to-date. The project manager can easily handle file-to-file dependencies, including file nesting, as well as the exact sequence of operations required to build the target.

Use the project manager dialog box to define the source files that make up the project; use the make commands from the Project menu to compile source files and to generate the target; then, use the simulator and emulator commands from the Run menu to execute, test, and debug your application.



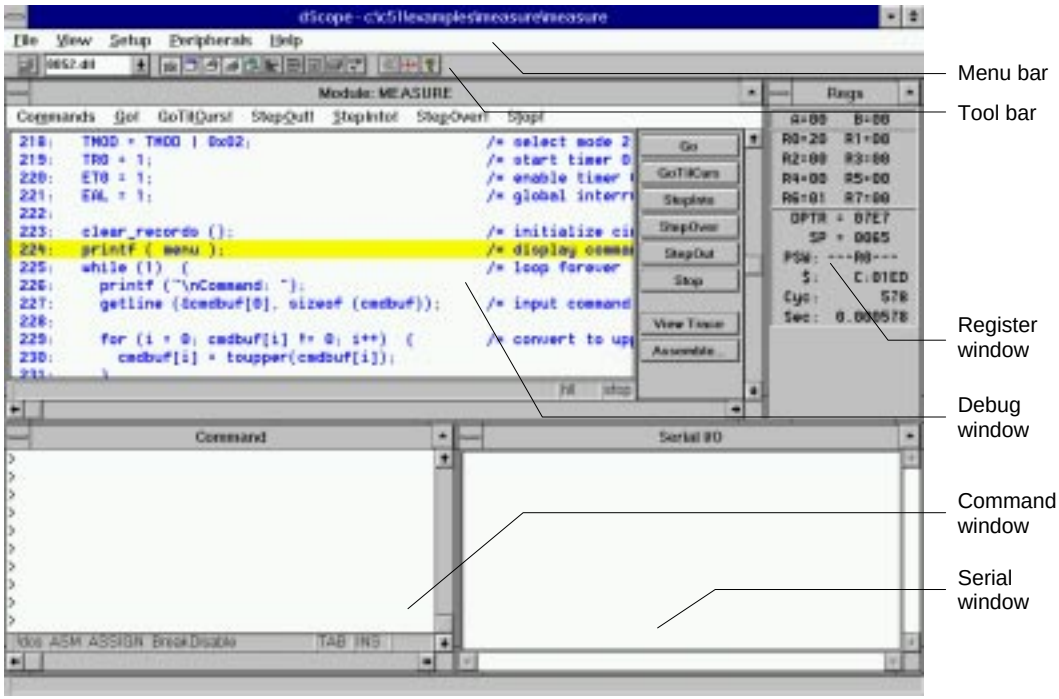
All aspects of a project are saved in a project file. The project file includes: the source files that make up the target program; the compiler, assembler, and linker command line options; the debugger and simulator options; and the make facility options.

dScope Simulator/Debugger Overview

dScope is a source level debugger/simulator for the entire Keil Software product line. You can use dScope to debug the applications you develop using the C51 and C251 compilers and A51 and A251 assemblers. In addition, dScope lets you debug application written using the Intel PL/M-51 compiler and the ASM-51 assembler.

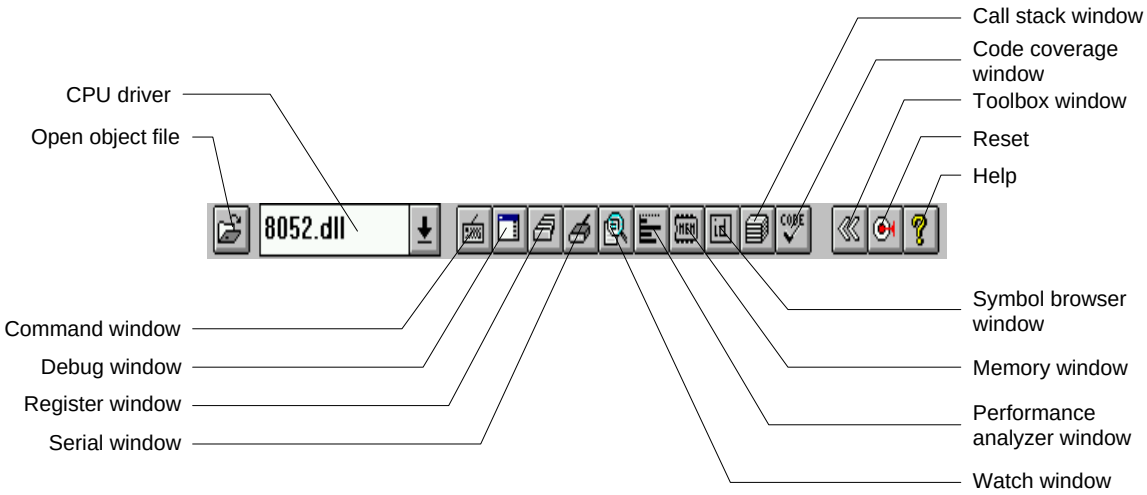
dScope is a software-only product that simulates most of the features of 8051 microcontroller without actually having target hardware. You can use dScope to test and debug your embedded application before the hardware is ready. dScope simulates a wide variety of 8051 peripherals including the serial port, external I/O, and timers. Support for the various microcontroller derivatives is provided through the use of dynamic link libraries (DLLs).

In addition to simulating the CPU, dScope interfaces directly to the 8051 monitor program MON51.



About the Debugger

In dScope, you may use the keyboard or the mouse to select menu commands, step through your application, and select debugging options. The dScope screen, pictured above, provides you with a menu bar for command entry, a tool bar where you can rapidly select command buttons, and several windows for displaying registers, memory contents, serial I/O, and commands. You can quickly display and hide the windows shown above with the buttons on the tool bar.



CPU Simulation

dScope simulates virtually every derivative of the 8051 microcontroller. Support for each CPU is provided through the use of DLLs. Before you load your target application, you must select the appropriate CPU driver from the CPU driver drop-down box on the tool bar. You may also select the Load CPU driver command from the File menu. The following CPU drivers are included with dScope.

CPU Driver DLLs	Supported Derivatives
80320.DLL	Dallas Semiconductor 80C320, 80C520, and 80C530.
8051.DLL	8051, 8031, 80C51, and 80C51
80515.DLL	80C515 and 80C535
80515A.DLL	80C515A and 80C535A
80517.DLL	80C517 and 80C537
80517A.DLL	80C517A and 80C537A
8051FX.DLL	8051FA, 8051FB, and 8051FC
8052.DLL	8052, 8032, 80C52, and 80C32
80552.DLL	8xC552
80751.DLL	8xC750, 8xC751, and 8xC752
80410.DLL	8xCL410
80781.DLL	8xCL781

dScope simulates up to 16 Mbytes of memory from which areas can be mapped for read, write, or code execution access. dScope traps and reports illegal memory accesses.

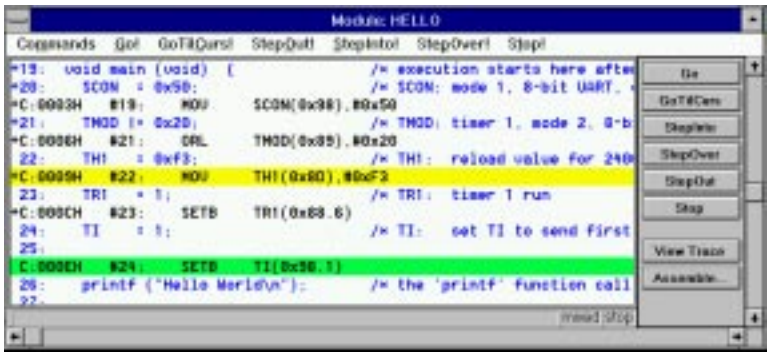
In addition to memory mapping, dScope also provides support for the integrated peripherals of the various 8051 derivatives. The CPU's on-chip peripherals are supported by the CPU driver in the DLL.

You can select and display the on-chip peripheral components using the Peripherals menu. You can also change the aspects of each peripheral using the controls in the dialog boxes.

The Debug Window

After you have loaded the appropriate CPU driver, you are ready to load your target program. You can use the button on the tool bar to open your object file, or you can use the Load object file command from the File menu.

Once your application is loaded, the dScope debug window displays your C, assembly, or PL/M-51 source text.



Three display formats are available from the Command menu in the debug window. They are:

- **View High Level**. This display format shows your original source text exactly as it appears in your source files.
- **View Mixed**. This display format shows your original source text mixed with the assembly code generated by the compiler or assembler.
- **View Assembly**. This display format shows only the assembly code generated for your source.

In addition to target program, the debug window can display a trace history of up to 512 previously executed instructions. To enable the trace history, select the Record Trace command from the Command menu in the debug window.

Command Window

You interact with dScope by entering commands from the keyboard and selecting options with the mouse. You can enter nearly all dScope commands in the command window. dScope responds to the commands you enter at the command prompt ('>').

You can interactively display and change variables, registers, and memory locations from the command window. You can also enter assembly code to patch or test parts of your program.

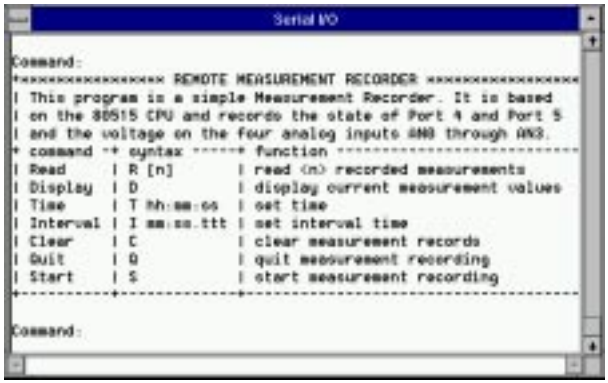
For example, you can type the following text commands at the command prompt:

Text	Effect
DPTR	Display the DPTR register.
R7 = 12	Assign the value 12 to register R7.
time.hour	Displays the hour member of the time structure.
time.hour++	Increments the hour member of the time structure.
index = 0	Assigns the value 0 to index.

You are not limited to using the command window to control dScope. You can also use the mouse to select pull-down menus from the menu bar and invoke commands from the tool bar.

Serial Window

dScope provides a serial window for serial input and output. Serial data output from the simulated CPU is displayed in this window. Characters you type in this window are input to the simulated CPU.



This lets you simulate the CPU's UART without the need for external hardware.

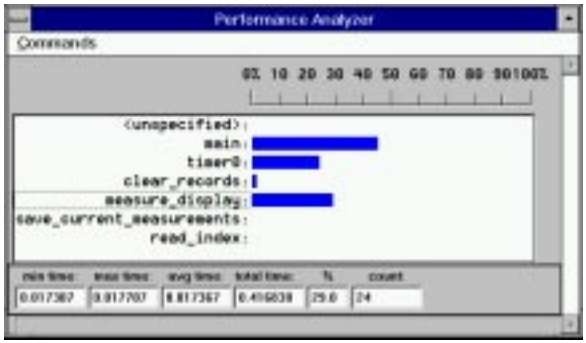
Watch Window

You can use the watch window to interactively display variables and complex structures. This is useful when you want to see the effects or your program on a buffer or data structure.

Not only can you watch the variables in your program, you can also change them using standard C expressions you enter at the command prompt in the command window.

Performance Analyzer Window

dScope has a built-in performance analyzer that lets you record timing statistics for functions and program blocks. Performance analysis results are displayed in the performance analyzer window.



The performance analyzer window shows the name of each function or memory range of each block along with a bar graph showing the percentage of time spent in that function or block. You may select a function to view statistics in the bottom portion of the performance analyzer window. The following statistics are maintained for each function or program block:

- **min time** Minimum time spent in the function or block,
- **max time** Maximum time spent in the function or block,
- **avg time** Average amount time spent in the function or block,
- **total time** Total time spent in the function or block,
- **count** Number of times the function or block was entered.

Other Features

In addition to the features described above, dScope offers numerous other functions that provide a robust debugging environment.

Functions

A powerful feature of dScope is its ability to let you define and use C-like functions for a wide variety of applications. For example, you can create dScope functions to manipulate the on-chip peripherals, extend the command set of dScope, and generate digital and analog input to hardware ports. There are three types of functions available to dScope:

- **User Functions** extend the command scope of the debugger,
- **Signal Functions** generate input to the 8051 peripherals,
- **Built-in Functions** provide convenient utility routines (like **printf** and **memset**) that you can use in user or signal functions.

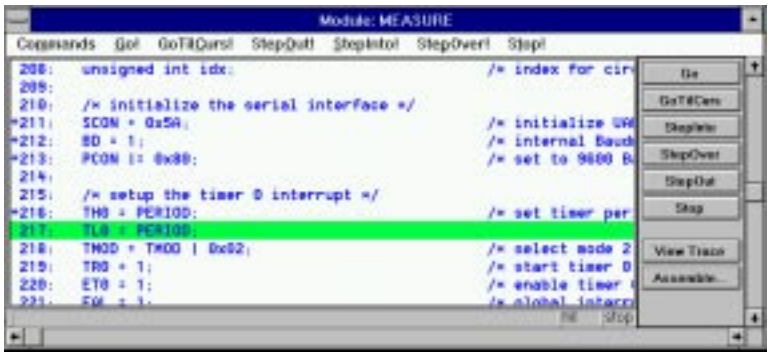
Refer to “Signal Functions” on page 83 for an example of how to use functions in dScope.

Breakpoints

It is easy to set breakpoints on high-level statements, assembler instructions, and conditional expressions. Simply move the mouse pointer to the line or instruction and double-click. You can even set a breakpoint based on the type of memory access type or repetition factor. When dScope reaches a breakpoint, it can perform a wide range of operations-from simple probing to running macro functions.

Code Coverage

dScope provides a code coverage function which marks the lines of code that have been executed. In the debug window, lines of code which have been executed are market with a plus sign (‘+’) in the left column.



You can use this feature when you test your embedded application to determine the sections of code that have not yet been exercised. The Code Coverage dialog box also provides useful information and code coverage statistics.

Sample Programs

This section describes the sample programs that are included in our evaluation kits and product kits. The sample programs are ready for you to run. You can use the sample programs to learn how to use our tools. Additionally, you can copy the code from our samples for your own use.

The sample programs are found in the **\C51\EXAMPLES** directory. Each sample program is stored in a separate subdirectory along with project files and batch files that help you quickly build and evaluate each sample program.

The following table lists the sample programs and their directories.

Directory	Description
\A51	A51 is a sample program for the A51 assembler.
\BADCODE	**BADCODE** is a sample program with a number of syntax errors. Use µVision to open the BADCODE.PRJ project file and compile. µVision takes you to each error in BADCODE.C. Refer to "BADCODE: An Example with Syntax Errors" on page 89 for more information about this sample program.
\BL51_EX1	**BL51_EX1** demonstrates a bank switching application written in C. This sample program invokes functions in different code banks. Build this program using the BL51_EX1.PRJ project file.
\BL51_EX2	**BL51_EX2** demonstrates a C program that has constant messages stored in different code banks. Build this program using the BL51_EX2.PRJ project file.
\BL51_EX3	**BL51_EX3** demonstrates a bank switching program that has only one module with functions located in different banks. Build this program using the BL51_EX3.PRJ project file.
\BL51_EX4	**BL51_EX4** demonstrates a bank switching, Intel PL/M-51 program that calls functions in different code banks. This program is the PL/M-51 equivalent to **BL51_EX1**. Build this program using the BL51_EX4.PRJ project file. The Intel PL/M-51 compiler is required.
\CSAMPLE	The **CSAMPLE** sample program demonstrates a simple addition and subtraction calculator. This sample program is a multiple module project that you can build using the CSAMPLE.PRJ project file.
\DHRY	The **DHRY** example is a DHRYSTONE benchmark program that calculates and displays the dhrystones per second for the host CPU. This example is mainly provided for benchmark enthusiasts. Build this program using the DHRY.PRJ project file.
\FIB	The **FIB** sample program generates fibonacci numbers and shows you how to use the reentrant function attribute to declare recursive functions. Build this sample program using the FIB.PRJ project file.
\HELLO	The **HELLO** sample program is the embedded 8051 C Hello World program. Use the HELLO.PRJ project file to build this program. Refer to "HELLO: Your First 8051 C Program" on page 66 for more information about this sample program.
\LSIEVE	**LSIEVE** demonstrates the large model version of the sieve of Eratosthenes prime number generator. This example is mainly provided for benchmark enthusiasts. Build this program using the LSIEVE.PRJ project file.

Directory	Description
\MEASURE	The **MEASURE** sample C program collects analog and digital data. It simulates a data acquisition system that might be found in a weather station or in a process control application. Build this program using the MEASURE.PRJ project file. Refer to "MEASURE: A Remote Measurement System" on page 73 for more information about this sample program.
\RTX_EX1	The **RTX_EX1** sample program demonstrates round-robin multitasking using RTX-51 Tiny. Build this program using the RTX_EX1.PRJ project file.
\RTX_EX2	The **RTX_EX2** sample program demonstrates an RTX-51 Tiny application that uses signals. Build this program using the RTX_EX2.PRJ project file.
\SAMPL517	The **SAMPL517** sample program provides an RPN-style calculator that takes advantage of the 80C517 arithmetic processor. Build this program using the SAMPL517.PRJ project file.
\SSIEVE	The **SSIEVE** sample program demonstrates the small model version of the sieve of Eratosthenes prime number generator. This example is mainly provided for benchmark enthusiasts. Build this program using the SSIEVE.PRJ project file.
\TDP	The **TDP** sample program demonstrates how to use interrupt-driven serial I/O to interface to an alarm clock driven by an interrupt-driven timer. Build this program using the TDP.PRJ project file.
\TRAFFIC	The **TRAFFIC** sample program shows how to control a traffic light using the RTX-51 Tiny real-time executive. Build this program using the TRAFFIC.PRJ project file.
\WHETS	The **WHETS** example is a WHETSTONE benchmark program that calculates and displays the number whetstones per second for the host CPU. This example is mainly provided for benchmark enthusiasts. Build this program using the WHETS.PRJ project file.

To begin using one of the sample files, you must switch to the directory in which the sample resides. Then, you may use either the provided DOS batch files or the µVision for Windows project file to build and test the sample program.

The following sections in this chapter describe how to use the tools to build the following sample programs:

- HELLO: Your First C51 Program
- MEASURE: A Remote Measurement System
- BADCODE: An Example with Syntax Errors

HELLO: Your First 8051 C Program

The HELLO sample program is located in the **\C51\EXAMPLES\HELLO** directory. HELLO does nothing more than print the text "Hello World" to the serial port. The entire program is contained in a single source file, **HELLO.C**, which is listed below.

```
/*---------------------------------------------------------------------------
HELLO.C

Copyright 1995 KEIL Software, Inc.
---------------------------------------------------------------------------*/

#pragma DEBUG OBJECTEXTEND CODE   /* pragma lines can contain                */
                                  /* command line directives                 */

#include <reg51.h>                /* special function register declarations  */
                                  /* for the intended 8051 derivative        */

#include <stdio.h>                /* prototype declarations for I/O functions */


/****************/
/* main program */
/****************/
void main (void)  {               /* execution starts here after stack init  */
  SCON  = 0x50;                   /* SCON: mode 1, 8-bit UART, enable rcvr   */
  TMOD |= 0x20;                   /* TMOD: timer 1, mode 2, 8-bit reload     */
  TH1   = 0xf3;                   /* TH1:  reload value for 2400 baud        */
  TR1   = 1;                      /* TR1:  timer 1 run                       */
  TI    = 1;                      /* TI:   set TI to send first char of UART */

  printf ("Hello World\n");       /* the 'printf' function call              */

  while (1) {                     /* An embedded program does not stop and   */
    ;  /* ... */                  /* never returns.  We've used an endless   */
  }                               /* loop.  You may wish to put in your own  */
}                                 /* code were we've printed the dots (...). */
```

This small application helps you confirm that you can compile, link, and debug an application. You can perform these operations from the DOS command line, using batch files, or from µVision for Windows using the provided project file.

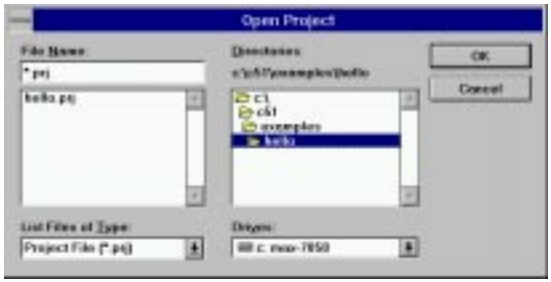
Hardware Requirements

The hardware for HELLO is based on the standard 8051CPU. The only on-chip peripheral used is the serial port. You do not actually need a target CPU because dScope lets you simulate the hardware required for this program.

HELLO Project File

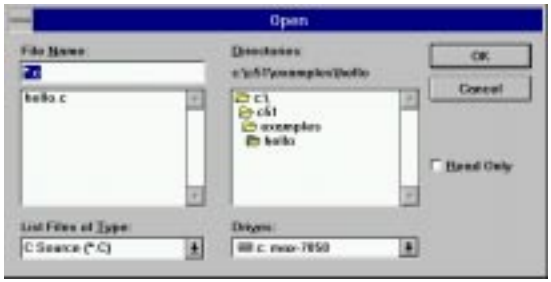
In µVision, applications are maintained in a project file. The project file contains names of all source files associated with the project and also tells the tools how to compile, assemble, and link to generate an executable target program.

A project file, called **HELLO.PRJ**, has been created for HELLO. To load this project file, select the Open command from the Project menu and open the **HELLO.PRJ** project file from the **\C51\EXAMPLES\HELLO** directory.

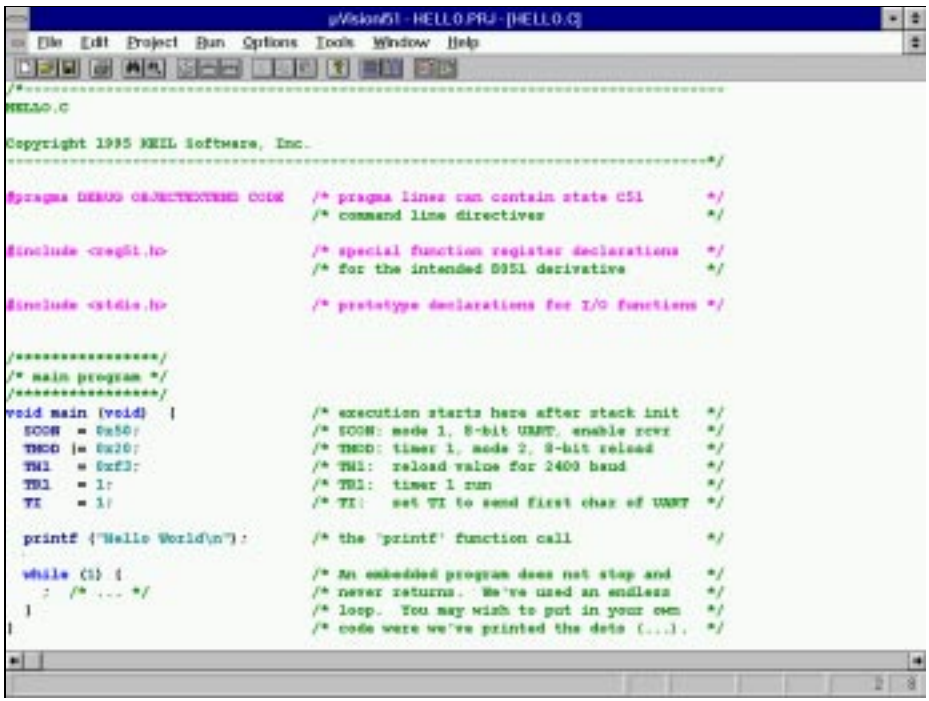


Editing HELLO.C

You can now edit **HELLO.C**. Select the Open command from the File menu. µVision prompts you with the Open File dialog box. Select **HELLO.C** from the files list and select the OK button.



µVision loads and displays the contents of **HELLO.C** in a window.



Compiling and Linking HELLO

When you are ready to compile and link your project, click on the Build All button on the tool bar or select the Make: Build Project command from the Project menu. µVision begins to compile and link the source files in your project and create an absolute object module that you can load into dScope for testing. During the build, µVision displays the status in a window.

When the build is complete, µVision displays a message indicating the build is finished.

You may press **Esc** at any time to halt the build.

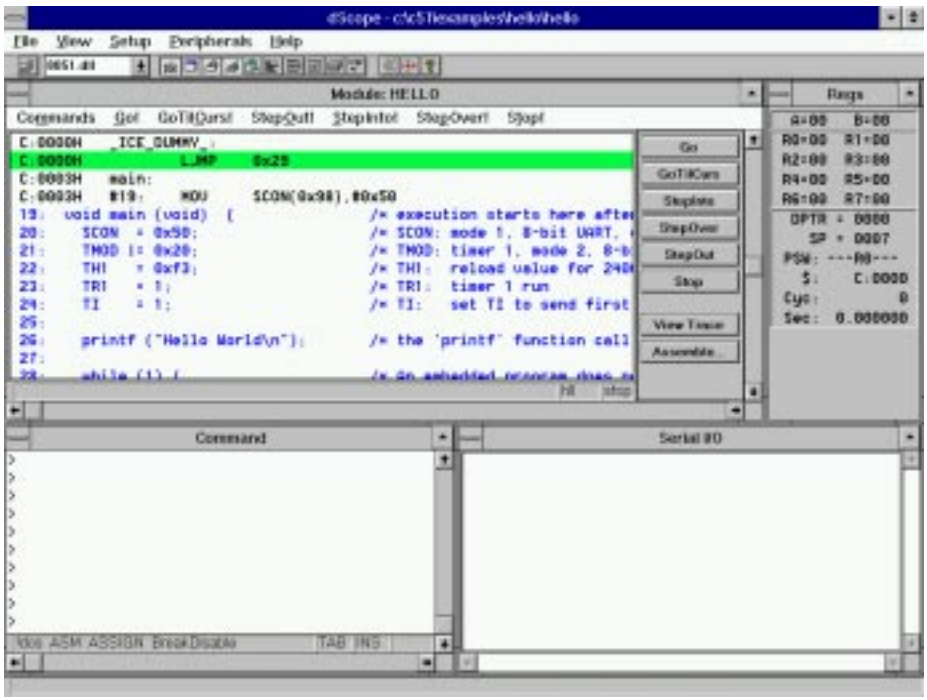
NOTE
You should encounter no errors when you use µVision with the provided sample projects. If µVision says it cannot find or run the compiler or linker, check your ***PATH*** *for the* ***\C51\BIN*** *directory. If it is not there, you must add it so that µVision can find the compiler and the other tools. You can add the path specifications in µVision when you select the Environment Pathspecs command from the Options menu.*

Testing HELLO With dScope

Once the HELLO program is compiled and linked, you can test it with the dScope debugger/simulator. In µVision, select the DS51 Simulator command from the Run menu and press **Enter** when the dScope Command Arguments dialog box displays.

µVision passes an initialization file (**HELLO.INI**) to dScope. This file contains commands for dScope that load the CPU driver DLL and the HELLO sample program.

When dScope loads, the following screen displays.



NOTE

The first time you invoke dScope, you may need to change the fonts and colors used for the different windows. Select the Colors and Fonts command from the Setup menu to configure the different windows in dScope.

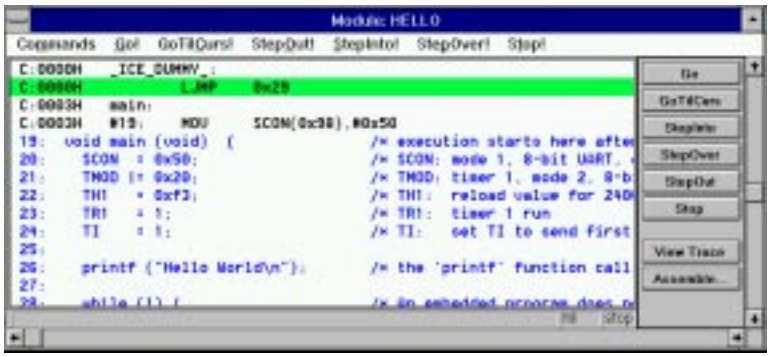
Running HELLO

To run the HELLO program, click on the Go button in the debug window or enter **g** at the command prompt. The HELLO program executes and displays the text “Hello World” in the serial window.

After HELLO outputs “Hello World,” it begins executing an endless loop. To halt execution, click on the Stop button in the debug window or type **Ctrl+C**. After you have halted program execution, you may type **exit** to leave the dScope debugger.

Single-Stepping Through HELLO

You can single-step through the HELLO program using the Step buttons in the debug window.



First, make sure to reset the CPU driver. To do this, make sure program simulation is halted, then type the following lines at the command prompt:

```
reset
g,main
```

The **`reset`** command resets the simulated 8051 CPU. The **`g,main`** command begins executing the program and stops when it reaches the main C function.

To step through the HELLO program, click on the StepOver button in the debug window. Each time you click on this button, the simulator executes one statement. The current instruction is always highlighted, but the highlight moves each time you step. You may continue stepping through your program by clicking on the StepOver button.

You may exit dScope at any time. To do so, halt execution of HELLO and enter **`exit`** at the command prompt.

MEASURE: A Remote Measurement System

The MEASURE sample program is located in the **\C51\EXAMPLES\MEASURE** directory. MEASURE runs a remote measurement system that collects analog and digital data like a data acquisition systems found in a weather stations and process control applications. MEASURE is composed of three source files: **GETLINE.C**, **MCOMMAND.C**, and **MEASURE.C**.

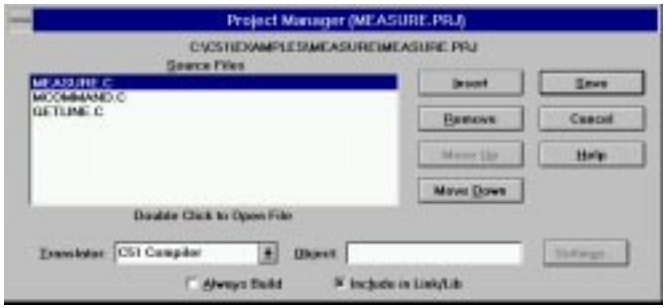
MEASURE records data from two 8-bit digital ports and four 8-bit analog-to-digital inputs. A timer controls the sample rate. The sample interval can be configured from 1 millisecond to 60 minutes. Each measurement saves the current time and all of the input channels to an 8 Kbyte RAM buffer.

Hardware Requirements

The hardware for MEASURE is based on the 80517 CPU. This microcontroller provides analog and digital input capability. Port 4 and port 5 are used for the digital inputs and AN0 through AN3 are used for the analog inputs. You do not actually need a target CPU because dScope lets you simulate all the hardware required for this program.

MEASURE Project File

The project file for the MEASURE sample program is called **MEASURE.PRJ**. To load this project file, select the Open command from the Project menu and open **MEASURE.PRJ** from the **\C51\EXAMPLES\MEASURE** directory. Select the Edit Project command from the Project menu to display the Project Manager dialog box.



The Project Manager dialog box shows the source files that compose the MEASURE project. There are three source files in this project.

MEASURE.C This source file contains the main C function for the measurement system and the interrupt routine for timer 0. The main function initializes all peripherals of the 80517 and performs command processing for the system. The timer interrupt routine, timer0, manages the real-time clock and the measurement sampling of the system. Timer 0 was used to maintain compatibility with the 8051 which can be used if fewer input channels are required.

MCOMMAND.C This source file processes the display, time, and interval commands. These functions are called from main. The display command lists the analog values in floating-point format to give a voltage between 0.00V and 5.00V.

GETLINE.C This source file contains the command-line editor for characters received from the serial port.

To open a source file from the Project Manager dialog box, double-click on the filename. To close the Project Manager dialog box, press **Esc** or click on the Cancel button.

Compiling and Linking MEASURE

When you are ready to compile and link MEASURE, click on the Build All button on the tool bar or select the Make: Build Project command from the Project menu. µVision begins to compile and link the source files in MEASURE and displays a message when the build is finished.

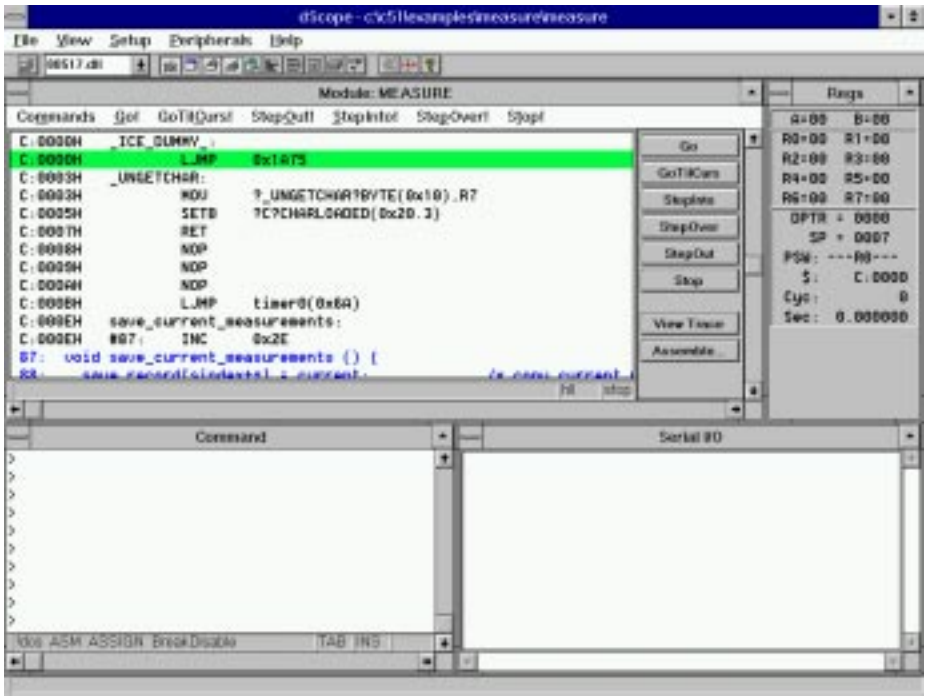
Once compiling and linking are complete, you are ready to begin testing the MEASURE sample program.

Testing MEASURE With dScope

The MEASURE sample program is designed to accept commands from the on-chip serial port. If you have actual target hardware, you can use a host computer or dumb terminal to communicate with the 80517 CPU. If you do not have target hardware, you can use dScope to simulate the hardware. You can also use the serial window in dScope to provide serial input.

Once the MEASURE program is compiled and linked, you can test it with dScope. In µVision, select the DS51 Simulator command from the Run menu and press **Enter** when the dScope Command Arguments dialog box displays.

The initialization file that µVision passes to dScope automatically loads the CPU driver and MEASURE program. Once these are loaded, dScope displays the following screen.



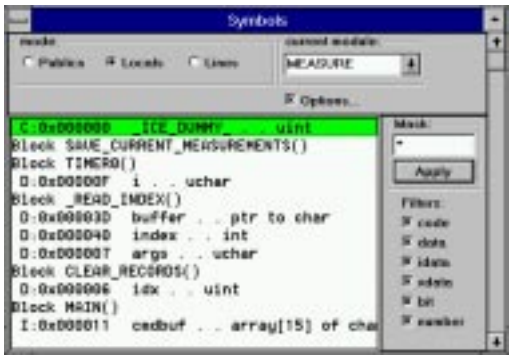
Remote Measurement System Commands

The serial commands that MEASURE supports 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
Clear	C	Clears the measurement record buffer.
Display	D	Displays the current time and input values.
Time	T *hh*:*mm*:*ss*	Sets the current time in 24-hour format.
Interval	I *mm*:*ss*.*ttt*	Sets the interval time for the measurement samples. The interval time must be between 0:00.001 (for 1ms) and 60:00.000 (for 60 minutes).
Start	S	Starts the measurement recording. After receiving the start command, MEASURE samples all data inputs at the specified interval.
Read	R [*count*]	Displays the recorded measurements. You may specify the number of most recent samples to display with the read command. If no count is specified, the read command transmits all recorded measurements. You can read measurements on the fly if the interval time is more than 1 second. Otherwise, the recording must be stopped.
Quit	Q	Quits the measurement recording.

Viewing Debug Symbols

The MEASURE sample program is configured for full debug information and includes public and local symbols, line numbers, and high-level type information. To view this information, click on the Symbol Browser button on the tool bar to open the symbol browser window. Then, select the Locals radio button and the Options check box as shown below.



dScope supports the drag and drop feature of Windows and lets you access the symbols this way. Use the mouse to drag and drop the **idx** symbol from the symbol browser window to the command window. The fully qualified symbol

name with module name and function name are inserted as shown. The qualifiers are separated by the backslash character ('\'). Select the command window and press **Enter**. dScope displays the value of **idx**.

You may filter the symbols displayed by selecting the memory space filter. If you clear the data check box, all symbols in the data memory area are removed from the display.

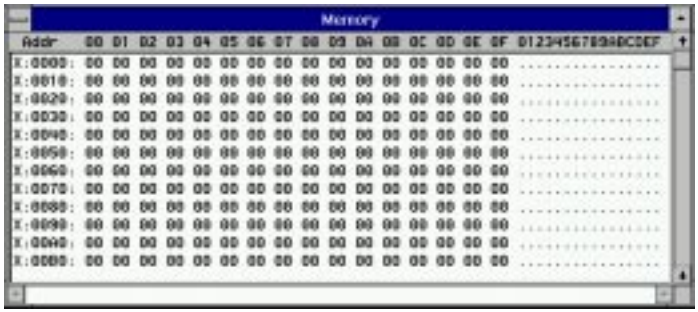
You can specify a search mask to limit the symbols displayed. To limit the symbol list to those beginning with the letter I, enter "I*" and click the Apply button.

Viewing Memory Contents

dScope displays memory in HEX and ASCII in the memory window. Open the memory window by clicking on the Memory button on the tool bar. In the command window, enter the address range you want to view, for example:

```
D X:0x0000, X:0xFFFF
```

Since the memory window cannot show the entire memory range at once, you may use the scroll bars to scroll through the memory area. The bounds for scrolling are defined by the address range specified, 0x0000 to 0xFFFF for this example.



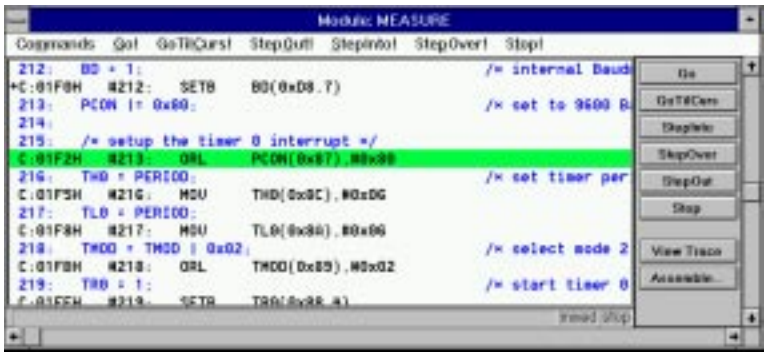
To display the on-chip data memory, enter the following in the command window.

```
D I:0x0000, I:0xFF
```

dScope can dynamically update the memory window while your application is running. To toggle dynamic updating, select the Update Memory window command from the Setup menu. When Update Memory window is checked, dynamic updating is enabled.

Changing the View Mode

dScope lets you change the view mode in the debug window. Display the debug window using the debug button on the tool bar. Then, to change the view mode, open the Commands menu in the debug window and select View High level, View Mixed, or View Assembly. For example, View Mixed changes to the mixed source and assembly display.



The debug window shows intermixed source and assembly lines.

Program Execution

Before you begin simulating the MEASURE program, use the Debug, Register, and Serial buttons on the tool bar to display the debug, register, and serial windows. You may disable other windows if your screen is not large enough.

From the toolbar, select the reset button to reset dScope. In the debug window, select the View Mixed command from the Commands menu. Then, click on the StepInto button once.

The StepInto button lets you single-step through your application and into function calls. Click on the StepInto button a few more times to get to the loop which clears the on-chip data space of the CPU.

To skip the initialization code and go directly to the main function, select the command window and enter “G,main”. dScope executes the startup code and halts on the first statement in the main function.

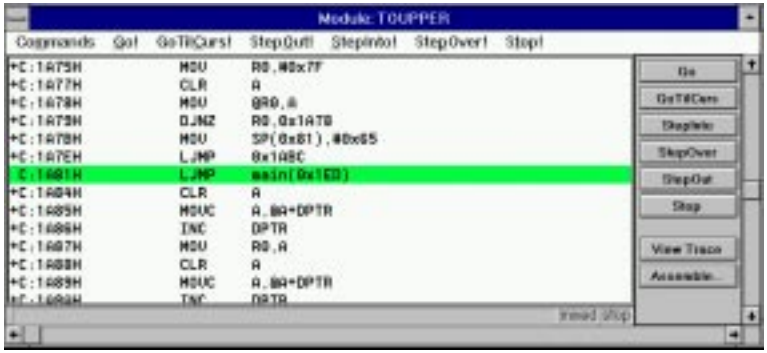
Go Until Current Cursor Line

The current cursor line is the line which marks the current assembly or high-level statement. You can move the line using the keyboard or the mouse.

dScope lets you use the current cursor line as a temporary breakpoint. Use this feature to skip over code in your application. For example, you can skip over the initialization code and stop one instruction before the main function is called. You can do this in one of two ways:

- **Variant 1:** Move the cursor line to the **LJMP main** instruction. You can use the cursor keys or you can click the mouse on that line. Click on the GoTilCurs button in the debug window. dScope starts execution at the current program counter and stops at the current cursor line.
- **Variant 2:** Double-click, with the right mouse button, on the **LJMP main** instruction. This makes the selected line the current cursor line, starts execution from the current PC, and stops when the current line is reached.

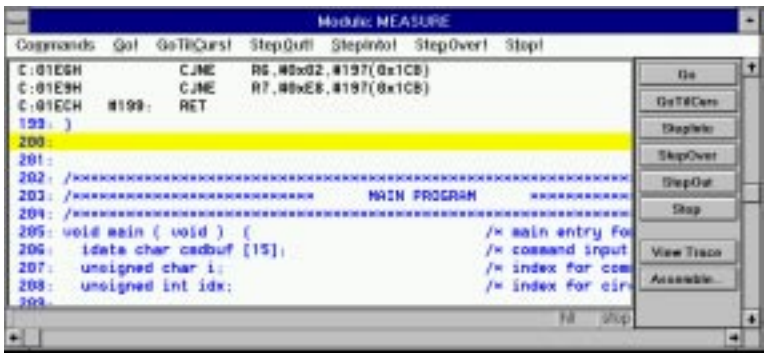
The program counter is now at the **LJMP main** instruction.



NOTE
After performing this command, the current cursor line and the current program counter (PC) line are the same. The background color used for the line is the PC highlight color.

Stepping Through High-Level Statements

Click on the StepInto button in the debug window and dScope jumps to the main function of the MEASURE sample program. Select the View High level command from the debug window Commands menu.



When viewing your application in high level mode, the meaning of a step changes to mean one high-level statement instead of one assembly instruction. Click on the StepInto button and watch as the current program counter line moves down the screen.

NOTE
The StepOver button operates much like the StepInto button with the exception that a function call is considered a single statement.

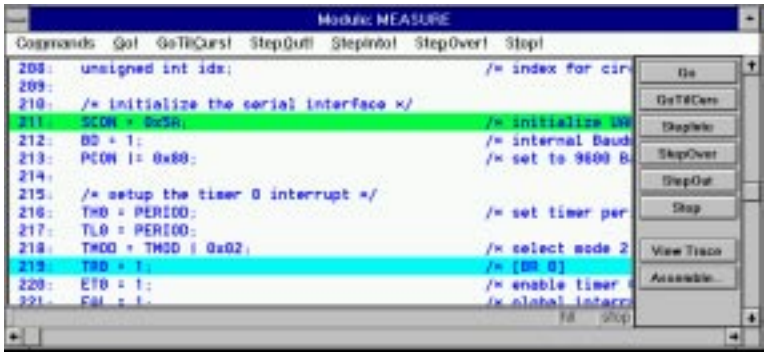
Stepping Out of a Function

On occasion, you may accidentally step into a function unnecessarily. You can use the StepOut button to complete execution of that function and return to the statement immediately following the function call.

NOTE
*You cannot **StepOut** from the main function because it is invoked by a long jmp (LJMP) rather than a call instruction.*

Setting and Removing Breakpoints

You can set an execution breakpoint in the debug window by double-clicking on the desired source line. The selected line is highlighted and a **`[BR n]`** label is displayed at the end of the line. If we set a breakpoint on the **`TR0 = 1`** statement, the debug window appears as follows:

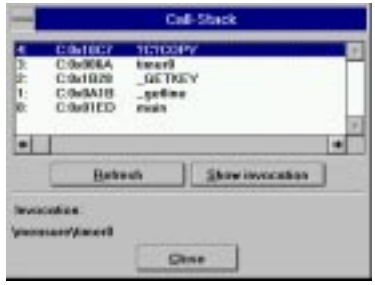


Click on the Go button and dScope starts execution from the current program counter and stops when the breakpoint is reached. To remove a breakpoint, double-click on the line containing the breakpoint.

Call Stack

dScope internally tracks function nesting as the program executes. You can view the function nesting at any time by opening the Call Stack window. Use the Call Stack button on the tool bar to display Call Stack window.

This dialog box lists all currently nested functions. Each line contains a nesting level number, the numeric address of the invoked function, and the symbolic name of the function if debug information is available.



You can display the caller of a function by selecting the function from the list. Then, you can use the Show invocation button to display the function call in the debug window.

Port Inputs

dScope provides two different ways to set digital and analog port inputs. You can use the Peripheral menu in the main window to view and change the status of input lines or you can enter I/O values in the command window. The following commands change port values in the command window.

```
PORT4=0x23                                  set digital input PORT3 to 0x23.
AIN1=3.3                                 set analog input AIN1 to 3.3 volts.
```

Signal Functions

dScope lets you create signal functions to provide an input signal for digital or analog inputs. To load a signal function, halt program execution by clicking on the Stop button in the debug window and enter the following command in the command window.

```
INCLUDE analog.inc
```

This loads the analog function from the file **ANALOG.INC**. This file defines a signal function that adjusts the analog value that appears on analog channel 0. This function appears as follows.

```
SIGNAL void analog0 (float limit) {
  float volts;

  printf ("ANALOG0 (%f) ENTERED\n", limit);
  while (1)  {                                                  /* forever */
    volts = 0;
    while (volts <= limit)  {
```

```
      ain0 = volts;                                    /* analog input-0 */
      twatch (30000);                            /* 30000 Cycles Time-Break */
      volts += 0.5;                                    /* increase voltage */
    }

    volts = limit-0.5;
    while (volts >= 0.5)  {
      ain0 = volts;
      twatch (30000);                            /* 30000 Cycles Time-Break */
      volts -= 0.5;                                    /* decrease voltage */
    }
  }
}
```

After loading the analog include file, enter the following commands in the command window.

```
ANALOG0 (5.0)
G
```

These commands set the limit for analog channel 0 to 5.0 volts and start program execution.

Select the serial window and type **D Enter**. You should see the analog channel 0 signal begin swinging from 0 to 5 volts.

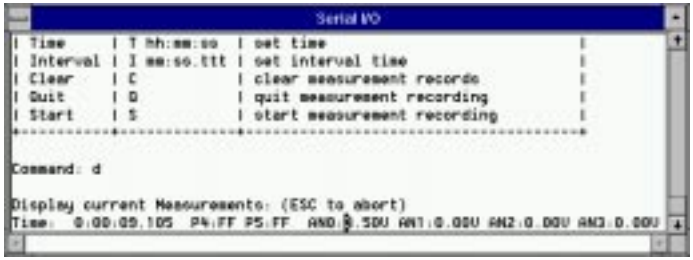
Trace Recording

It is common during debugging to reach a breakpoint where you require information like register values and other circumstances which led to the breakpoint. dScope provides trace recording for this purpose.

To enable trace recording, select the Record trace command from the Commands menu to toggle instruction trace recording. When trace recording is enabled, dScope records up to 512 assembly instructions and register contents.

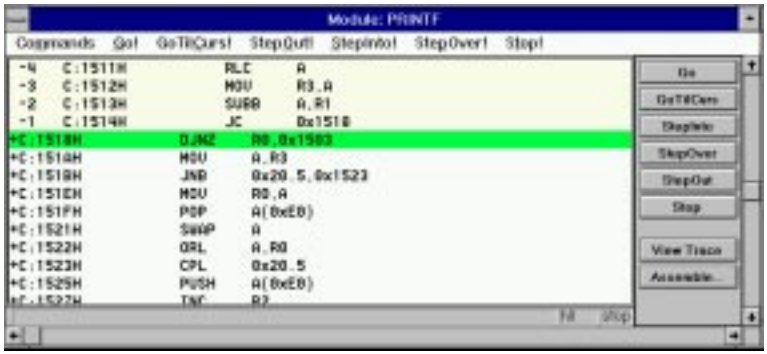
You can use trace recording with the MEASURE example. Start running the MEASURE program (click on the Go button in the debug window) and select the serial window. MEASURE displays a menu and waits for input after displaying **Command**. In the serial window, enter **d**.

When you enter this command, MEASURE begins to display measurement values, the record time, two port values, and finally the analog input values.



The serial window displays what you would see on a dumb terminal connected to the 80517's serial port.

Click on the Stop button in the debug window. This halts program execution immediately. Click on the View Trace button to view the trace buffer.



The upper portion of the debug window shows the trace history. The lower portion of the debug window shows instructions from the program counter. The program counter line is the delimiter between the trace history and instructions not yet executed.

The trace history lines begin with negative numbers. The newest trace buffer entry is -1. The oldest entry is -511. When the buffer overflows, the oldest entries are removed to make space for new entries.

You may scroll into the trace buffer using the keyboard or the mouse. The register window shows the register contents for the selected instruction in the trace buffer.

NOTE
Program execution must be stopped before you can view the trace buffer.

Watchpoints

Watchpoints are used to view the contents of simple variables, structures, and arrays. You may setup watchpoints using the Watchpoints dialog box. To display this dialog box, select the Watchpoints command from the Setup menu.

The following steps show you how to define two watchpoints: one for the variable **sindex** which is an unsigned int and one for the structure **current** which contains a nested **time** struct.

To add a watchpoint for **sindex**: Type `sindex` in the Expr input line and click on the Define watch button.

To add a watchpoint for **current**: Type `current` in the Expr input line, select the Multiple radio button to display structure members on separate lines, and click on the Define watch button.

The watch window now contains the two watch expressions just defined.

The first watch expression shows the value of **sindex** on a single line.

The second watch expression for **current** generates much more output. Structure members display on separate lines and are indented to reflect the nesting level. The last few lines display the data stored in the **analog** array.

The watch window updates at the end of each execution command (StepInto, StepOut, or Go). You may configure dScope to periodically update the watch window during execution by selecting the Update Watch Window command from the Setup menu.

Breakpoints

You use breakpoints to stop program execution on a given address or a specified condition. Execution breakpoints are the simplest form; a function address or line number specifies where to stop execution.

You may want to halt program execution when a variable contains a certain value. The following example shows you how to stop program execution when the **current.time.sec** structure member is set to 3.

Select the Breakpoints command from the Setup menu to display the Breakpoints dialog box. In the Expression input line, enter **`current.time.sec==3`**. In the Count input line, enter **`1`**. Select the Write check box (this option specifies that the break condition is tested only when the expression is written to).

When you are finished, click on the Define button to set the breakpoint. To test the breakpoint condition perform the following steps:

1. Reset dScope,

2. Begin executing the MEASURE sample program (click on the Go button in the debug window),

3. Press **Enter** in the serial window at the MEASURE command prompt.

After a few seconds, dScope halts execution. The program counter line in the debug window marks the line in which the breakpoint occurred.

Using the Performance Analyzer

dScope lets you perform timing analysis of your applications using the integrated performance analyzer. You can specify an address range or a function for dScope to use. To prepare for timing analysis, enter the following commands in the command window.

```
PA main
PA timer0
PA clear_records
PA measure_display
PA save_current_measurements
PA read_index
RESET PA                                          /* Initialize PA */
```

These commands create the performance analyzer address ranges for timing statistics. You may create or view the ranges with the Setup Performance Analyzer command in the Setup menu.

Perform the following steps to watch the performance analyzer in action:

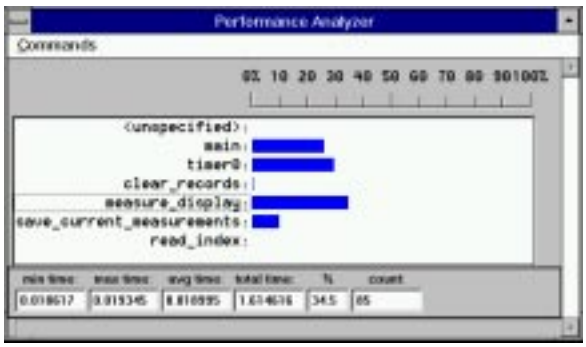
1. Open the performance analyzer window using the button on the tool bar. The display shows the ranges defined above. The **<unspecified>** line accumulates all execution time outside the defined ranges,

2. Reset dScope,

3. Start program execution by clicking on the Go button in the debug window,

4. Select the serial window and type **S Enter D Enter**.

The performance analyzer window shows a bar graph for each range.



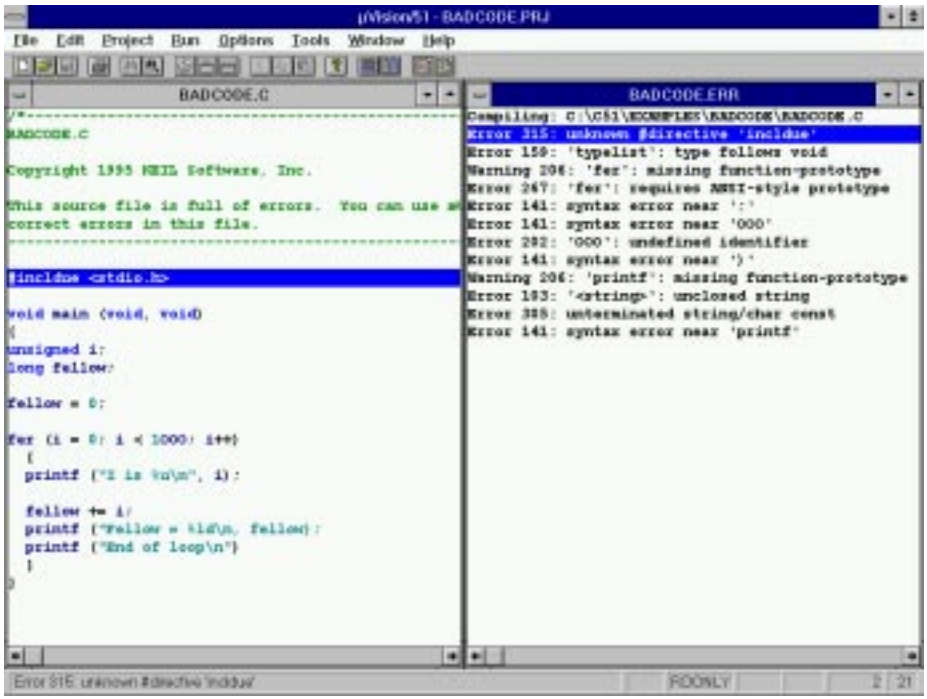
The bar graph is dynamically updated and shows the percent of the time spent executing code in each range. Click on the range to see timing statistics for each individual range.

BADCODE: An Example with Syntax Errors

The \C51\EXAMPLES\BADCODE\ directory contains a file called BADCODE.C. This file is used to demonstrate how µVision interacts with the compiler to help you locate errors and warnings in your source program.

Open the BADCODE.C file using the Open command in the File menu. Select the Compile File command from the Project menu to compile the file. After compilation, µVision determines that there are errors and displays an error window for you to peruse.

You may use the cursor keys in the error window to scroll through the errors generated by the compiler. As you move from line to line, the source window is updated to reflect the line on which the error was encountered.



When the error window displays, it may cover a portion of the source window. Use the tile vertical or tile horizontal button to display the windows side-by-side.

Chapter 6. Hardware Products

Keil Software offers a number of hardware products that you can use to assist in 8051 software development. Currently, our hardware products include:

- ProROM EPROM Emulator,
- MCB517A Evaluation Board,
- MCB520 Evaluation Board.

Each of these products is described in the following sections.

ProROM EPROM Emulator

ProROM is an EPROM emulator that connects between the parallel printer port of your PC and the ROM socket of your target hardware. With ProROM, you can rapidly develop and test your embedded target program.

It only takes a few seconds to download 64 Kbytes of program code to ProROM. You no longer have to rely on or wait for EPROM programmers and erasers that may take several minutes between software iterations.

ProROM comes with an easy to use loader program that downloads your binary or Intel HEX files. Additionally, you can use ProROM with the µVision development environment to automate your build and load development cycle.

The ProROM EPROM emulator comes complete with:

- User's Manual,
- Software and file conversion utilities,
- ProROM EPROM Emulator,
- 28-pin DIP interface cable,
- PC parallel-port cable.

ProROM provides a quick, convenient solution for rapid software development.

MCB517A Evaluation Board

The MCB517A evaluation board is a single board computer that supports the Siemens 80C517(A) microcontroller. The MCB517A lets you write and test code for the 80C517(A) using the Keil Software 8051 development tools and the 8051 monitor.

The MCB517A includes a user's manual that clearly describes the board and an evaluation kit that includes a 2 Kbyte size-limited tool set. The tools provided include:

- The C51 compiler,
- A51 assembler,
- µVision/51 IDE for Windows,
- dScope-51 simulator for Windows,
- 8051 Monitor program and dScope interface DLLs,
- all the necessary utilities,
- and several example programs.

The 8051 monitor lets you download and execute 8051 applications you develop using the tools included with the package. You can build applications using µVision and the C51 compiler and A51 assembler, and you can test and debug applications using dScope and the monitor.

The MCB517A is a complete starter package for anyone interested in the Siemens 517. Since the Siemens 517 CPU is a superset of the 8051 and 80515 the MCB517A board can be used also for projects using the 8051, 80C515(A) and 80C517(A). The MCB517A uses for communication with the Monitor the 2nd serial interface of the 517 CPU, this frees up the standard 8051 serial interface for the user application. The MCB517A is a complete starter package for anyone interested in the Siemens 517.

MCB520 Evaluation Board

The MCB520 evaluation board is a single board computer that supports the Dallas Semiconductor 87C520 microcontroller. The MCB520 lets you evaluate the performance characteristics of the 87C520. Board configuration is accomplished using clearly labeled DIP switches.

The MCB520 includes a user's manual that describes the board and data books that describe the 87C520 architecture. A 2 Kbyte size limited tool set is also included. The tools provided include:

- The C51 compiler,
- µVision/51 IDE for Windows,
- dScope-51 simulator for Windows,
- 8051 Monitor program and dScope interface DLLs,
- all the necessary utilities and example programs to help you get started.

The 8051 monitor program comes installed on the board. The monitor lets you download and execute 8051 applications you develop using the tools included with the package. You can build applications using µVision and the C51 compiler and you can test and debug applications using dScope and the monitor.

The MCB520 is a complete starter package for anyone interested in the Dallas Semiconductor 87C520.

Chapter 7. Real-Time Kernels

This chapter discusses the different real-time operating systems that are available for the 8051 microcontroller.

RTX-51 Real-Time Operating System

The RTX-51 real-time operating system is a multitasking kernel for the 8051 family of processors that simplifies the software design of complex, time-critical applications.

There are two distinct versions of RTX-51:

RTX-51 Full which performs both round-robin and preemptive task switching using up to four task priorities. RTX-51 Full 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.

RTX-51 Tiny which is a subset of RTX-51 Full. RTX-51 Tiny easily runs on single-chip 8051 systems without any external data memory. RTX-51 Tiny supports many of the features found in RTX-51 Full with the following exceptions:

1. Task switching is accomplished by round-robin multitasking and signals.
2. Preemptive task switching is not supported.
3. No message routines are included.
4. No memory pool allocation routines are available.

The rest of this section uses RTX-51 to refer to RTX-51 Full and RTX-51 Tiny. Differences between the two are stated where 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. RTX-51 implements a powerful RTOS which is easy to use. RTX-51 works with all 8051 derivatives.

You write and compile RTX-51 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. RTX-51 programs also require that you include the real-time executive header file and link using the BL51 code banking linker/locator and the appropriate RTX-51 library file.

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 RTX-51

RTX-51 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 RTX-51 assigns a time slice to every task. Each task is allowed to execute for a predetermined amount of time. Then, RTX-51 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.

RTX-51 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 RTX-51 clock.

RTX-51 does not require you to have a main function in your program. It automatically begins executing task 0. If you do have a main function, you must manually start RTX-51 using the **os_create_task** function in RTX-51 Tiny and the **os_start_system** function in RTX-51.

The following example shows a simple RTX-51 application that uses only round-robin task scheduling. The two tasks in this program are simple counter loops. RTX-51 starts executing task 0 which is the function names **`job0`**. This function adds another task called **`job1`**. After **`job0`** executes for a while, RTX-51 switches to **`job1`**. After **`job1`** executes for a while, RTX-51 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 */
  }
}
```

RTX-51 Events

Rather than waiting for a task's time slice to be up, you can use the **os_wait** function to signal RTX-51 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 RTX-51

The simplest event you can wait for with the **os_wait** function is a time-out period in RTX-51 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.

```
#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, RTX-51 switches to the next task, which is **job1**. After **job1** increments **counter1**, it too calls **os_wait** to pause for 5 clock ticks. Now, RTX-51 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 RTX-51

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 increments **counter1** and again waits for another signal. **job0** continuously increments **counter0** until it overflows to 0. When that happens, **job0** sends a signal to **job1** and RTX-51 marks **job1** as ready for execution. **job1** does not start until RTX-51 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. RTX-51 allows you to assign priority levels to tasks. When a higher priority task becomes available, it interrupts or preempts a lower priority task. This is called preemptive multitasking or just preemption.

NOTE
Preemption and priority levels are not supported by RTX-51 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** starts immediately.

Compiling and Linking with RTX-51

RTX-51 is fully integrated into the C51 programming language. This makes generating RTX-51 applications very easy to master. You do not need to write any 8051 assembly routines or functions. You only have to compile your RTX-51 programs with C51 and link them with the BL51 code banking linker/locator.

For example, you should use the following command lines with RTX-51 Tiny.

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

Use the following command lines to compile and link with RTX-51.

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

Interrupts

RTX-51 works in parallel with interrupt functions. Interrupt functions can communicate with RTX-51 and can send signals or messages to RTX-51 tasks. RTX-51 Full lets you assign an interrupt to a task.

Message Passing

RTX-51 Full supports message exchange between tasks with the following functions: **isr_recv_message**, **isr_send_message**, **os_send_message**, and **os_wait**.

A message is a 16-bit value which can be interpreted as a number or as a pointer to a memory block. RTX-51 Full supports variable sized messages using a memory pool system.

CAN Communication

Controller Area Networks are easily implemented with RTX-51/CAN. RTX-51/CAN is a CAN task integrated into RTX-51 Full. An RTX-51 CAN task implements message passing via the CAN network. Other CAN stations can be configured either with or without RTX-51.

BITBUS Communication

RTX-51 Full includes both master and slave BITBUS tasks supporting message passing with the Intel 8044.

Events

RTX-51 supports the following events for the **os_wait** function:

- A **Timeout** suspends the running task for a defined number of clock ticks.
- An **Interval** is similar to a **timeout**, however, the **interval** is intended for use with tasks that must execute synchronously.
- **Signals** are used for inter-task coordination.
- **Messages** are used for exchange of messages. †
- An **Interrupt** lets a task wait for an 8051 hardware interrupt. †
- **Semaphores** are used for management of shared system resources. †

† These events are available only in RTX-51 Full.

RTX-51 Functions

The following table lists some of the RTX-51 functions along with a brief description and execution timing (for RTX-51 Full).

Function	Description	CPU Cycles
isr_recv_message †	Receive a message (call from interrupt).	71 (with message)
isr_send_message †	Send a message (call from interrupt).	53
isr_send_signal	Send a signal to a task (call from interrupt).	46
os_attach_interrupt †	Assign task to interrupt source.	119
os_clear_signal	Delete a previously sent signal.	57
os_create_task	Move a task to execution queue.	302
os_create_pool †	Define a memory pool.	644 (size 20 * 10 bytes)
os_delete_task	Remove a task from execution queue.	172
os_detach_interrupt †	Remove interrupt assignment.	96
os_disable_isr †	Disable 8051 hardware interrupts.	81
os_enable_isr †	Enable 8051 hardware interrupts.	80
os_free_block †	Return a block to a memory pool.	160
os_get_block †	Get a block from a memory pool.	148
os_send_message †	Send a message (call from task).	443 with task switch
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_send_token †	Set a semaphore (call from task).	343 with fast task switch 94 without task switch
os_set_slice †	Set the RTX-51 system clock time slice.	67
os_wait	Wait for an event.	68 for pending signal 160 for pending message

† These functions are available only in RTX-51 Full.

Additional debug and support functions in RTX-51 Full include the following:

Function	Description
oi_reset_int_mask	Disables interrupt sources external to RTX-51.
oi_set_int_mask	Enables interrupt sources external to RTX-51.
os_check_mailbox	Returns information about the state of a specific mailbox.
os_check_mailboxes	Returns information about the state of all mailboxes in the system.
os_check_pool	Returns information about the blocks in a memory pool.
os_check_semaphore	Returns information about the state of a specific semaphore.
os_check_semaphores	Returns information about the state of all semaphores in the system.
os_check_task	Returns information about a specific task.
os_check_tasks	Returns information about all tasks in the system.

CAN Functions

The CAN functions are available only with RTX-51 Full. CAN controllers supported include the Philips 82C200 and 80C592 and the Intel 82526. More CAN controllers are in preparation.

CAN Function	Description
can_bind_obj	Bind an object to a task; task is started when object is received.
can_def_obj	Define communication objects.
can_get_status	Get CAN controller status.
can_hw_init	Initialize CAN controller hardware.
can_read	Directly read an object's data.
can_receive	Receive all unbound objects.
can_request	Send a remote frame for the specified object.
can_send	Send an object over the CAN bus.
can_start	Start CAN communications.
can_stop	Stop CAN communications.
can_task_create	Create the CAN communication task.
can_unbind_obj	Disconnect the binding between a task and an object.
can_wait	Wait for reception of a bound object.
can_write	Write new data to an object without sending it.

Technical Data

Description	RTX-51 Full	RTX-51 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 integer entries each	not available
Memory pool system	up to 16 memory pools	not available
Semaphores	8 * 1 bit	not available

Chapter 8. Command Reference

This chapter briefly describes the commands and controls for the Keil Software 8051 development tools. Commands and controls are listed in a tabular format along with a description. Underlined characters represent abbreviations for the particular control or directive.

A51 Macro Assemblers

Invocation:

```
A51 sourcefile [directives]
A51 @commandfile
```

where

sourcefile is the name of an assembler source file.

commandfile is the name of a file which contains a complete command line for the assembler including a **sourcefile** and **directives**. You may use a command file to make assembling a source file easier or when you have more directives than fit on the command line.

directives are parameters which are described in the following table.

A51 Controls	Meaning
DATE(*date*)	Places ***date*** string in header (9 characters maximum).
DEBUG	Includes debugging symbol information in the object file.
ERRORPRINT[(*filename*)]	Outputs error messages to ***filename***.
INCLUDE(*filename*)	Includes the contents of ***filename*** in the assembly.
MACRO	Enables standard macro processing.
MPL	Enables Intel-style macro processing.
NOAMAKE	Excludes **AutoMAKE** information from the object file.
NOCOND	Excludes unassembled conditional assembly code from the listing file.
NOGEN	Disables macro expansions in the listing file.
NOLINES	Excludes line number information from the object file.
NOLIST	Excludes the assembler source code from the listing file.
NOMACRO	Disables standard macro processing.
NOMOD51	Disables predefined 8051-specific special function registers.
NOSYMBOLS	Excludes the symbol table from the listing file.
NOSYMLIST	Excludes symbol definitions from the listing file.
OBJECT[(*filename*)], NOOBJECT	Enables or disables object file output. The object file is saved as ***filename*** if specified.
PAGELENGTH(*n*)	Sets maximum number of lines in each page of listing file.
PAGEWIDTH(*n*)	Sets maximum number of characters in each line of listing file.
PRINT[(*filename*)], NOPRINT	Enables or disables listing file output. The listing file is saved as ***filename*** if specified.
REGISTERBANK(*num, …*), NOREGISTERBANK	Indicates that one or more registerbanks are used or indicates that no register banks are used.
RESET (*symbol, …*)	Assigns a value of 0000h to the specified symbols.
SET (*symbol, …*)	Assigns a value of 0FFFFh to the specified symbols.
TITLE(*title*)	Includes ***title*** in the listing file header.
XREF	Includes a symbol cross reference listing in the listing file.

C51 Compiler

Invocation:

```
C51 sourcefile [directives]
C51 @commandfile
```

where

sourcefile is the name of a C source file.

commandfile is the name of a file which contains a complete command line for the compiler including a **sourcefile** and **directives**. You may use a command file to make compiling a source file easier or when you have more directives than fit on the command line.

directives are control parameters which are described in the following table.

C51 Controls	Meaning
CODE	Includes an assembly listing in the listing file.
COMPACT	Selects the **COMPACT** memory model.
DEBUG	Includes debugging information in the object file.
DEFINE	Defines preprocessor names on the command line.
FLOATFUZZY	Specifies the number of bits rounded during floating-point comparisons.
INTERVAL	Specifies the interval for interrupt vectors.
INTVECTOR(*n*), NOINTVECTOR	Specifies offset for interrupt table, using ***n***, or excludes interrupt vectors from the object file.
LARGE	Selects the **LARGE** memory model.
LISTINCLUDE	Includes the contents of include files in the listing file.
MAXARGS(*n*)	Specifies the number of bytes reserved for variable length argument lists.
MOD517	Enables support for the additional hardware of the Siemens 80C517 and its derivatives.
MODDP2	Enables support for the additional hardware of Dallas Semiconductor 80C320/520/530 and the AMD 80C521.
NOAMAKE	Excludes **AutoMAKE** information from the object file.
NOAREGS	Disables absolute register addressing using **AR*n*** instructions.
NOCOND	Excludes skipped conditional code from the listing file.
NOEXTEND	Disables 8051/251 extensions and processes only ANSI C constructs.
NOINTPROMOTE	Disables ANSI integer promotion rules.
NOREGPARMS	Disables passing parameters in registers.
OBJECT[(*filename*)], NOOBJECT	Enables or disables object file output. The object file is saved as ***filename*** if specified.

C51 Controls	Meaning
OBJECTEXTEND †	Includes additional variable type information in the object file.
OPTIMIZE	Specifies the level of optimization performed by the compiler.
ORDER	Locates variables in memory in the same order in which they are declared in the source file.
PAGELENGTH(*n*)	Sets maximum number of lines in each page of listing file.
PAGEWIDTH(*n*)	Sets maximum number of characters in each line of listing file.
PREPRINT[**(*filename*)**]	Produces a preprocessor listing file with all macros expanded. The preprocessor listing file is saved as ***filename*** if specified.
PRINT[**(*filename*)**], **NOPRINT**	Enables or disables listing file output. The listing file is saved as ***filename*** if specified.
REGFILE(*filename*)	Specifies the name of the generated file to contain register usage information.
REGISTERBANK	Selects the register bank to use functions in the source file.
ROM({SMALL|COMPACT|LARGE})	Controls generation of **AJMP** and **ACALL** instructions.
SMALL	Selects the **SMALL** memory model.
SRC	Creates an assembly source file instead of an object file.
SYMBOLS	Includes a list of the symbols used in the listing file.
WARNINGLEVEL(*n*)	Controls the types and severity of warnings generated.

L51/BL51 Linker/Locator

Invocation:

```
BL51 inputlist [TO outputfile] [directives]
L51 inputlist [TO outputfile] [directives]
BL51 @commandfile
L51 @commandfile
```

where

inputlist is a list of the object files and libraries, separated by commas, that the linker includes in the final 8051 application.

outputfile is the name of the absolute object module the linker creates.

commandfile is the name of a file which contains a complete command line for the linker/locator including an **inputlist** and **directives**. You may use a command file to make linking your application easier or when you have more input files or more directives than fit on the command line.

directives are control parameters which are described in the following table.

BL51 Controls	Meaning
BANKAREA ‡	Specifies the address range where the code banks are located.
BANK*x* ‡	Specifies the starting address, segments, and object modules for code banks 0 to 31.
BIT	Locates and orders **BIT** segments.
CODE	Locates and orders **CODE** segments.
COMMON ‡	Specifies the starting address, segments, and object modules to place in the common bank. This directive is essentially the same as the **CODE** directive.
DATA	Locates and orders **DATA** segments.
IDATA	Locates and orders **IDATA** segments.
IXREF	Includes a cross reference report in the listing file.
NAME	Specifies a module name for the object file.
NOAMAKE	Excludes AutoMAKE information from the object file.
NODEBUGLINES	Excludes line number information from the object file.
NODEBUGPUBLICS	Excludes public symbol information from the object file.
NODEBUGSYMBOLS	Excludes local symbol information from the object file.
NODEFAULTLIBRARY	Excludes modules from the run-time libraries.
NOLINES	Excludes line number information from the listing file.
NOMAP	Excludes memory map information from the listing file.

BL51 Controls	Meaning
NOOVERLAY	Prevents overlaying or overlapping local **BIT** and **DATA** segments.
NOPUBLICS	Excludes public symbol information from the listing file.
NOSYMBOLS	Excludes local symbol information from the listing file.
OVERLAY	Directs the linker to overlay local data & bit segments and lets you change references between segments.
PAGELENGTH(*n*)	Sets maximum number of lines in each page of listing file.
PAGEWIDTH(*n*)	Sets maximum number of characters in each line of listing file.
PDATA	Specifies the starting address for **PDATA** segments.
PRECEDE	Locates and orders segments that should precede all others in the internal data memory.
PRINT	Specifies the name of the listing file.
RAMSIZE	Specifies the size of the on-chip data memory.
REGFILE(*filename*)	Specifies the name of the generated file to contain register usage information.
RTX51 ‡	Includes support for the RTX-51 full real-time kernel.
RTX51TINY ‡	Includes support for the RTX-51 tiny real-time kernel.
STACK	Locates and orders **STACK** segments.
XDATA	Locates and orders **XDATA** segments.

‡ These controls are available only in the BL51 code banking linker/locator.

OC51 Banked Object File Converter

Invocation:

```
OC51 banked_file
```

where

banked_file is the name of a banked object file.

OH51 Object-Hex Converter

Invocation:

```
OH51 absfile [HEXFILE(hexfile)]
```

where

absfile is the name of an absolute object file.

hexfile is the name of the Intel HEX file to create.

LIB51 Library Manager

Invocation:

```
LIB51 [command]
```

where

command is a control command described in the following table. If no command is given, LIB51 enters an interactive command mode.

LIB51 Command	Meaning
ADD	Adds an object module to the library file.
CREATE	Creates a new library file.
DELETE	Removes an object module from the library file.
EXIT	Exits the library manager interactive mode.
HELP	Displays help information for the library manager.
LIST	Displays module and public symbol information stored in the library file.

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