RSC-FORTH

User's Manual

Fehler im FMTRK x68D E000
auf E100
ändern

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PREFACE

This manual describes the operation and use of the Rockwell Single-Chip FORTH (RSC-FORTH) system as implemented in the Rockwell R65F11 (40-pin) and R65F12 (64-pin) FORTH-based one-chip Microcomputers and in the Rockwell R65FR1 FORTH Development ROM.

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RSC-FORTH ERRATA

RSC-FORTH V1.5

The RSC-FORTH Version 1.5 (V1.5) described in this manual is contained in the following parts:

R65F11 FORTH Microcomputer (R1100-11 or R1100-14, 1 MHz)
or
R65F12 FORTH Microcomputer (R1200-11, 1MHz)
and
R65FR1 Development ROM (R2952-12, 1MHz)

Errors in this version can be corrected as follows:

1. ADMP leaves two undefined bytes on the stack.
   Redefine the word as:
   ```
   : ADMP ADMP 2DROP ;
   ```
2. FORMAT is inoperative.
   Redefine the word as:
   ```
   : FORMAT 2 * SWAP 0 DO DUP 1+ SELECT I SEEK 1 I FMTRK DUP
     SELECT 0 I FMTRK LOOP DROP ;
   ```
3. IRQVEC returns the value for INTVEC .
   Redefine the word as:
   ```
   HEX
   : IRQVEC 0040 ;
   ```
4. I contains a reference to the Development ROM and can not be used in stand-alone code.
   Solution is to use R instead.
5. NOT contains a reference to the Development ROM and can not be used in stand-alone code.
   Solution is to use 0= instead.
6. CREATE has an error which can cause the CFA of a word to straddle a page boundary, which is an error condition for the 6502 CPU.
   Solution is to test a suspected word with:
   ```
   HEX ' NAME CFA .
   ```
   and verify that the address is not "XXFF". If the address is "XXFF" the word should be forgotten and a "1 ALLOT" inserted before redefining the word.

RSC-FORTH V1.6

RSC-FORTH V1.6 corrects the ADMP and FORMAT errors mentioned above in V1.5. RSC-FORTH V1.6 is implemented in ROM devices for use with either the R6501Q or R6511Q ROM-less microcomputer. The R65FK3 is the Kernel ROM that operates in conjunction with the R6501Q or R6511Q and functions like the R65F11 or R65F12 FORTH microcomputer (with internal ROM). The R65FR3 Development ROM operates with the R6501Q/R6511Q microcomputer and R65FK3 Kernel ROM in a similar manner as the R65FR1 Development ROM operates with the R65F11/R65F12 FORTH Microcomputer. These parts are identified as:

R65FK3 Kernel ROM (R327H-11, 1 or 2 MHz)

and

R65FR3 Development ROM (R2953-11, 1 or 2 MHz)

RSC-FORTH V1.7

RSC-FORTH V1.7 corrects all the errors mentioned above in V1.5.

RSC-FORTH V1.7 is implemented in the following parts:

R65F11 FORTH Microcomputer (R1100-15, 1 MHz or R1100-16, 2 MHz)

or

R65F12 FORTH Microcomputer (R1200-13, 1 MHz or R1200-14, 2 MHz)

and

R65FR1 Development ROM (R2952-13, 1 or 2 MHz)

SECTION 1

INTRODUCTION

FORTH is a unique programming system that is well suited to a variety of applications. Because it was originally developed for real-time control applications, FORTH has features that make it ideal for machine and process control, data acquisition, energy and environmental management, automatic testing, and other similar applications. The speed performance of assembly language is required in many of these applications, however a high-level language is often desired to improve program development productivity and program reliability. FORTH is designed to satisfy both speed and programming efficiency requirements.

FORTH can be called a computer language, an operating system, an interactive compiler, a data structure, or an interpreter, depending upon your point of view. It was designed to combine the strengths of both compilers and interpreters. The result is a unique language based on pre-defined operations that minimizes software development time and costs, supports structured programming and program modularity, compiles interactively to ease debugging and to reduce programming errors, compacts into small object code, and executes extremely fast. Additional words may be defined to allow usage by non-programmers.

When all of the features of the FORTH language are combined with the utility of the RSC-FORTH single-chip microcomputer hardware, the result is a powerful tool for the dedicated computer system designer. Many extensions have been added to RSC-FORTH that allow a very low cost, few chip system to be both the development system and the final target system.

1.1 RSC-FORTH USER'S MANUAL DESCRIPTION

This manual is designed to provide both introductory instruction and detail language reference information. If you are new to FORTH, be sure to read and follow the manual chapter-bychapter using a system which includes the R65F11 or R65F12 microcomputer, and the R65FR1 FORTH Development ROM as a teaching aid in order to learn the FORTH language and operation concepts. If you already know the FORTH language you can probably skip certain sections and still use the language, however it is recommended to review all sections to become familiar with the RSC-FORTH mechanization and unique features.

Section 1, Introduction, introduces the RSC-FORTH language and the RSC-FORTH User's Manual.

Section 2, Functional Description, explains the hardware of the RSC-FORTH system and how a RSC-FORTH system can be constructed.

Section 3, FORTH Concepts, provides a general overview into FORTH concepts and advantages. This is a good chapter to read if you are new to FORTH.

Section 4, Elementary Operations, leads you through elementary and common FORTH operations. By following this section step-by-step you will learn how FORTH operates to a sufficient level to implement simple applications in FORTH.

Section 5, Advanced Operations, takes you into more complex FORTH operations once you have become familiar with the elementary FORTH operations described in Section 4.

Section 6, Special Operations, details the unique features of RSC-FORTH, not found in other FORTH systems, designed to ease development in a single-chip microcomputer system.

Section 7, RSC-FORTH Assembler, describes concepts and operating procedures associated with the RSC-FORTH Assembler.

Section 8, Handling Interrupts in FORTH, explains how to use machine level and interpretive interrupts in FORTH.

Section 9, Programming the R65F11 I/O, explains how to use FORTH to program the R65F11 input/output section. These techniques can be used directly with the R6511 and can easily be applied to other peripheral devices.

Section 10, Notes on Style and Program Development, discusses the general approach to programming in FORTH and provides an example program.

Section 11, Preparing an Application Program for PROM Installation, tells how to structure and locate a FORTH application program in a PROM which will operate in conjunction with the R65F11 and R65F12 FORTH-based microcomputers.

Section 12, Interfacing to Mass Storage, tells how to prepare programs to store and retrieve program and data from mass storage. Blocks, screens, and buffers are described. The technique to handle program overlays is also explained.

Appendix A, RSC-FORTH Functional Summary, summarizes FORTH word operation by general area of usage.

Appendix B, RSC-FORTH Glossary, defines each FORTH word in ASCII sort order.

Appendix C, RSC-FORTH Assembler Functional Summary, summarizes FORTH assembler word operation by area of usage.

Appendix D, RSC-FORTH Assembler Glossary, defines each FORTH Assembler word in ASCII sort order.

Appendix E, Error Messages and Recovery, identifies each FORTH error number and/or message, defines the error meaning, and describes the recovery action.

Appendix F, Page Zero Memory Map, defines the address, variable name and general usage of page zero parameters.

Appendix G, User Variables RAM Map, defines the address, variable name and purpose of each user variable. The cold and warm start initialization values are also listed.

Appendix H, ASCII Character Set, provides a list of 7-bit ASCII codes in decimal and hexadecimal corresponding to 32 control functions and the 96 upper and lower case alphabetic, numeric and special characters.

Appendix I, FORTH String Handling Words, describes how to create string handling functions in FORTH.

Appendix J, User 24-Hour Clock Program in FORTH, illustrates a program written in FORTH colon- and CODE-definitions, i.e., FORTH high-level words and 6500 assembly language.

Appendix K, Utility Functions, explains how to determine the time it takes for a FORTH word to execute.

Appendix L, RSC-FORTH Versus FIG-FORTH, identifies words incorporated in each FORTH that are not included in the other FORTH.

Appendix M, Selected Bibliography, lists references to many popular and tutorial FORTH articles and books.

1.2 REFERENCE DOCUMENTS

Rockwell

29650N30 Order No. 202	R6500 Programming Manual
29650N31 Order No. 201	R6500 Hardware Manual
29651N49 Order No. 2146	R65F11 and R65F12 FORTH Based Microcomputer Product Description
29651N59 Order No. 2156	RSC-FORTH Reference Card
29651N65 Order No. 2162	Application Note; A Low-cost Development Module for the R65F11 FORTH Microcomputer

SECTION 2

FUNCTIONAL DESCRIPTION

The RSC-FORTH system integrates a complete ROM-based FORTH system consisting of microprocessor, memory and peripheral hardware elements and RSC-FORTH software into a single-chip microcomputer for runtime applications and a two-chip set for application software development. The RSC-FORTH software includes a Software Kernel, comprised of an RSC-FORTH Operating System and runtime portions of the RSC-FORTH language, which is masked into ROM in the one-chip microcomputer. Two versions of this microcomputer are available: the R65F11 and R65F12. Each version has the same Software Kernel but different input/output capabilities. The other portions of the RSC-FORTH software, not required at runtime, are provided in a separate and supporting R65FR1 Development ROM for use during application program development. The hardware elements of the microcomputer and the features of the operating system are presented first so the interaction with the runtime and development portions of the RSC-FORTH language can be fully understood.

2.1 RSC-FORTH HARDWARE

2.1.1 R65F11 and R65F12 Microcomputers

The Rockwell R65F11 and R65F12 are complete, high-performance, 8-bit NMOS single chip microcomputers, and are compatible with all members of the R6500 family.

The R65F11 and R65F12 consist of an enhanced R6502 CPU, an internal clock oscillator, 3K-bytes of masked Read-Only Memory (ROM), 192 bytes of Random Access Memory (RAM), and versatile interface circuitry. The interface circuity includes two 16-bit programmable timer/counters, 16 bidirectional input/output lines (including four edge-sensitive lines and input latching on one 8-bit port), a full-duplex serial I/O channel, ten interrupts and bus expandability.

The innovative architecture and the demonstrated high performance of the R6502 CPU, as well as instruction simplicity, results in system cost-effectiveness and a wide range of computational power. These features in combination with the RSC-FORTH high level operating system make the R65F11 and R65F12 ideal for microcomputer applications.

The R65F11, with its two 8-bit ports, is housed in a 40-pin DIP. For systems requiring additional I/O ports, the 64-pin QUIP version, the R65F12, provides three additional 8-bit ports.

The kernel of the high level Rockwell Single Chip FORTH (RSC-FORTH) language is contained in the preprogrammed ROM of the R65F11 and R65F12. RSC-FORTH is based on the popular fig-FORTH model with extensions. All of the runtime functions of RSC-FORTH are contained in the ROM, including 16- and 32-bit mathematical, logical and stack manipulation, plus memory and input/output operators. The RSC-FORTH Operating System allows an external user program

written in RSC-FORTH or Assembly Language to be executed from external EPROM, or development of such a program under the control of the R65FR1 RSC-FORTH Development ROM.

2.1.2 Configuring an R65F11/R65F12-Based System

There are several wasy to configure an R65F11 or R65F12-based system. A minimum system includes the R65F11 or R65F12 microcomputer, a crystal, application program in PROM/ROM and application input/output interface. Such a system can be expanded in memory up to the 16K address limit of the R65F11/R65F12. The R65F1 Development ROM may be included in any RSC-FORTH system by providing proper decoding logic.

There are two basic configurations of RSC-FORTH based systems:

a. Using an R65F11. An external addressing space of 16K bytes is possible with the use of an eight-bit latch. The R65FR1 (at address $2000-$3FFF) may be used as a development ROM. Two I/O Ports (A & B) are available to the user.

b. Using an R65F12. Five I/O ports (A, B, E, F and G) are available to the user. All other comments the same as for the R65F11.

Additional ROM, RAM and I/O devices can be added to the external memory map as desired. Figure 2-1 shows a RSC-FORTH memory map. Figure 2-2 shows a typical maximum electrical hook-up for an R65F11 system with and R65FR1 Development ROM and RS-232C serial interface for connection to a CRT/keyboard terminal. Wiring for an R65F12 system would be almost identical.

2.2 RSC-FORTH SOFTWARE

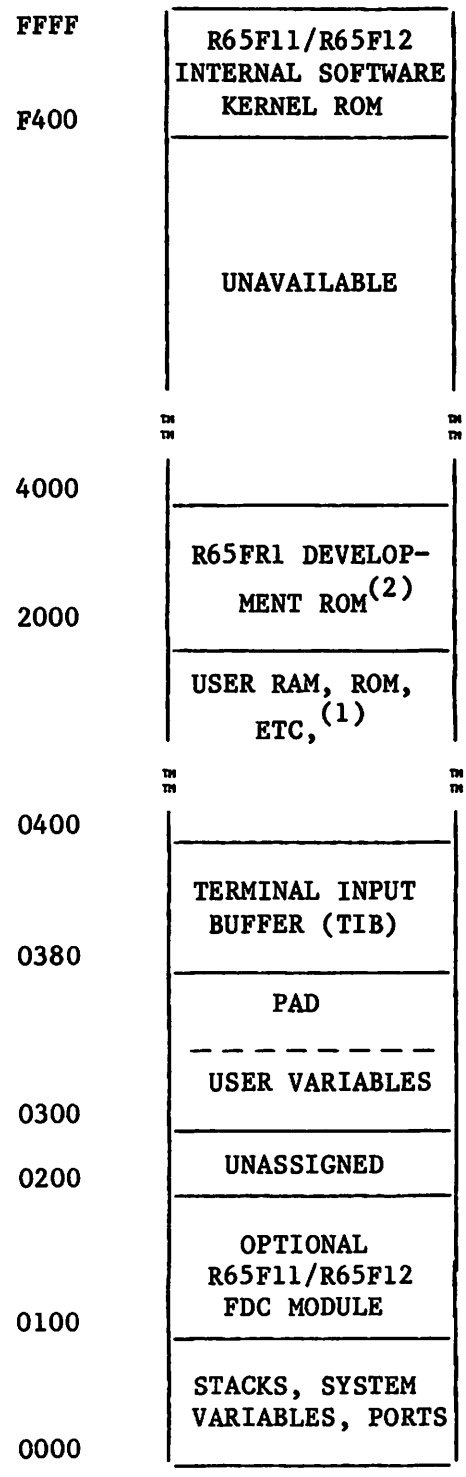
2.2.1 Operating System

Much of the philosophy needed to build a RSC-FORTH microcomputer system can be understood by looking at the RSC-FORTH operating system.

Many cost effective, eight-bit memory devices are available to the system designer today. These ROMs, RAMs, EPROMs and EEROMs usually come in multiples of 1K-byte increments. The most popular are the 2K-byte versions such as the 2016, 6116 and similar RAM devices and the 2716 type EPROMs. The RSC-FORTH Operating System is designed to work with these memory products.

The purpose of an operating system is to initiate operation in an orderly manner during power on or reset, the (loading and) starting of user functions and allocation of system resources. The RSC-FORTH Operating System provides these and many other services. Since the RSC-FORTH system is designed to serve in a dedicated application, the operating system's unique power up procedures are most interesting.

Upon reset, the reset vector in the kernel ROM directs processor execution to a section of machine code in the FORTH word COLD . This initializes the microcomputer for operation. Register values are established and interrupt sources disabled. The serial channel of the micrcomputer is set up for 1200



NOTES:

(1) Required in every system configuration.

(2) Optional.

Figure 2-1. RSC-FORTH Memory Map

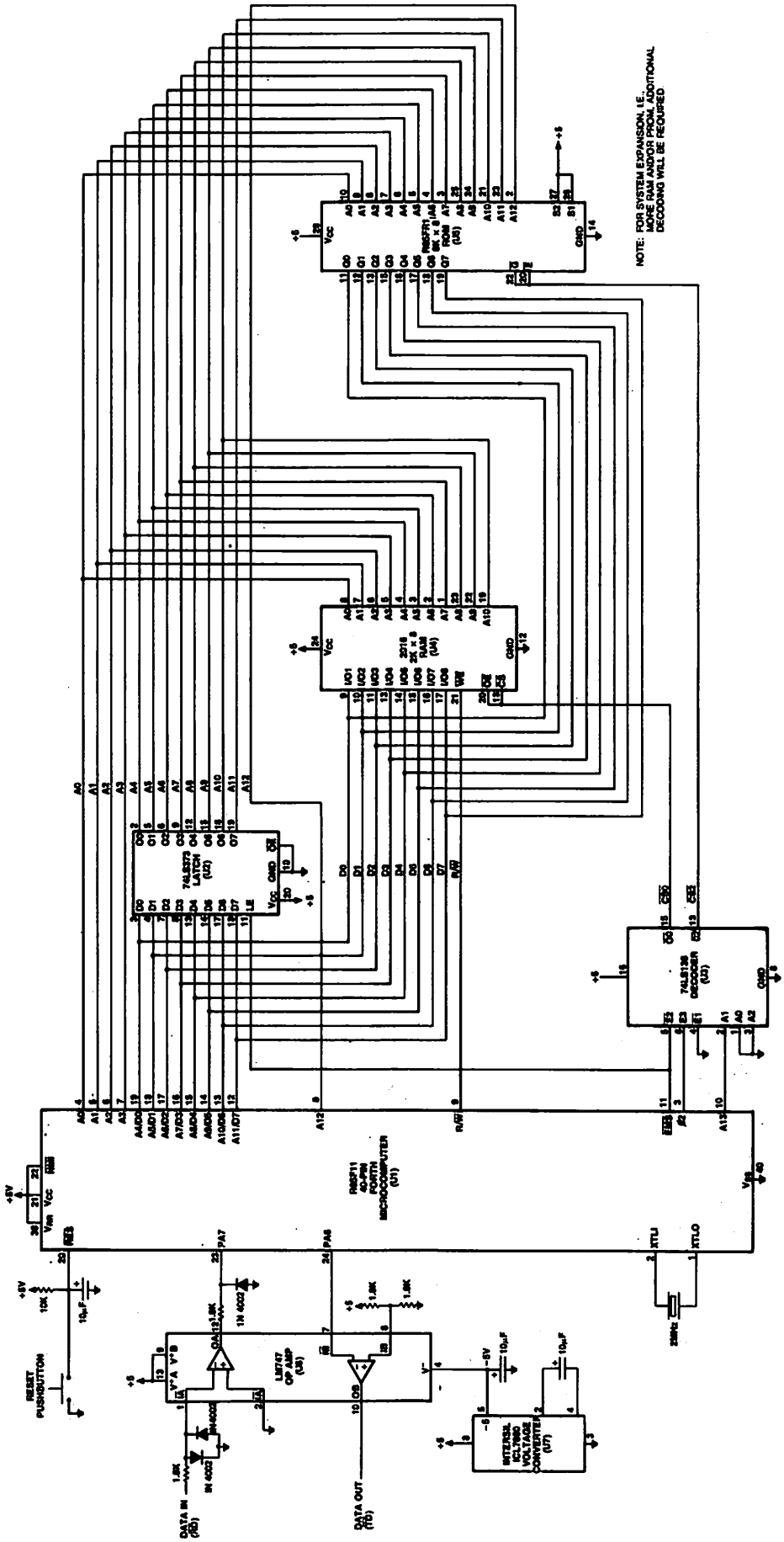


Figure 2-2. Typical R65F11 Microcomputer Minimum Hookup with R65FR1 Development ROM

baud asynchronous transmission (assuming a 1 MHz internal clock) with seven data bits, no parity, and two stop bits. System variables including pointers that make the serial channel the system method of input/output are down-loaded from ROM to zero page in RAM for read/write operation.

A test is made to determine the reset status. If a user variable, CLD/WRM , in memory location $030E, contains a value other than $A55A, a cold reset is assumed. In this case, the low level IRQ vector (IRQVEC), the low level NMI vector (NMIVEC), and the high level interrupt vector (INTVEC) are forced to point to the system reset routine. This prevents and unintentionally generated interrupt from crashing the system. System variables TIB , RO , SO , UC/L , UPAD , UR/W and BASE are also initialized to their default values. If a warm start is detected, only TIB , RO and SO are reset to default values (The meanings of these variables are described in Appendix A.

2.2.2 Application Program Auto-Start

Whether a warm or cold reset, the memory map is then examined at every 1K-byte boundary starting at location $0400, i.e. $0400, $0500, $0600, etc., through $3F00. The first two bytes at each boundary are compared to an $A55A bit pattern. This pattern indicates an auto-start ROM is installed. If the auto-start pattern is present, the next two bytes must point to the Parameter Field of a high level RSC-FORTH word to be executed upon reset. Assembly language routines can also be autostarted by using a series of indirect pointers. Details on auto-start ROM patterns are shown in Figure 2-3.

2.2.3 Development ROM Startup

The R65FR1 Development ROM is an example of an auto-start ROM. If there is no other auto-start pattern lower in the memory map, when the operating system finds the R65FR1 Development ROM, the familiar start up of the RSC-FORTH will occur and the message

```
RSC-FORTH V1.5
```

is displayed. FORTH words can now be entered interactively (see Section 3.1).

2.2.4 Bootstrap Program Load

If no development ROM is found, the message "NO ROM" is issued by the operating system. Providing no interruption from the operator at that point, the RSC-FORTH System attempts to load a bootstrap program from floppy disk. The first 128 bytes of Track 0 Sector 1 is loaded into RAM starting at address $005F. After loading, execution is turned over to the boot program at $005F. The boot program can be any machine code program that will fit in 128 bytes. Clever programmers will even be able to restart FORTH (since it was a FORTH word that called the boot) and execute a high level boot.

2.2.5 Micro Monitor

When the system issues the "NO ROM" message, before actually calling the boot program, the serial input channel is checked for a CNTL R character ($12). Normally, as the micrcomputer powers up, the contents of the serial input

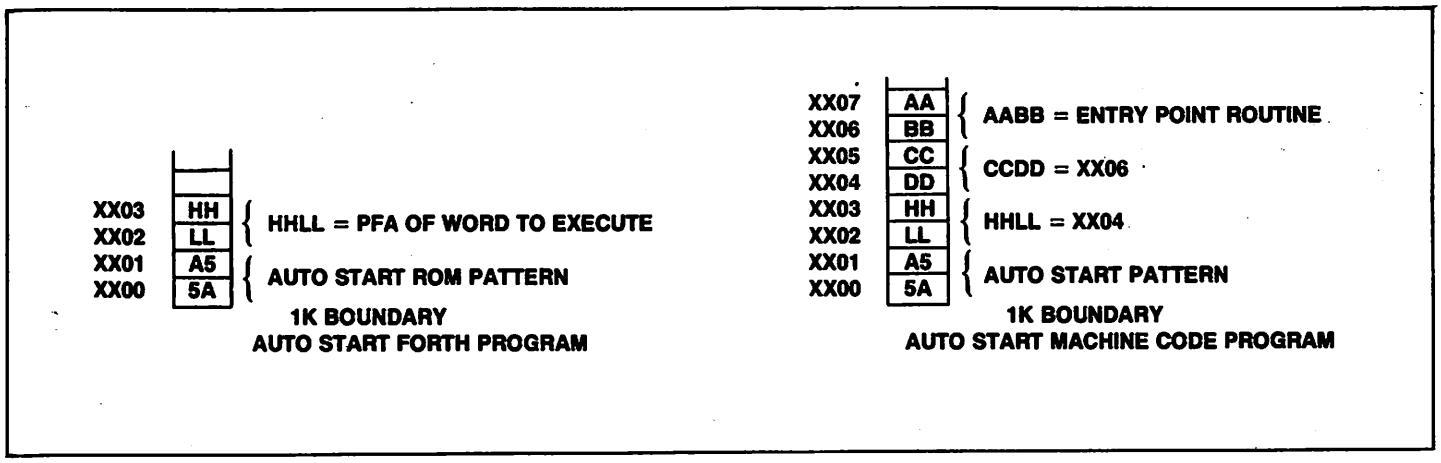


Figure 2-3. Auto-Start ROM Code Example

register will be some other value, thus boot from floppy disk will be initiated. If a CNTL R key combination is received from the serial input channel then RESET pressed, a program called the "Micro Monitor" is entered. The Micro Monitor is completely selfcontained in the kernel. The microcomputer with the kernel requires only RAM from address $0300 through $3FF to run the Micro Monitor. The external RAM is required for FORTH user variables, PAD and the Terminal Input Buffer (TIB).

The Micro Monitor outputs a "greater than" sign, ">", to the system terminal at the beginning of a new line then waits for an input line from the operator. The Micro Monitor is actually a very simple FORTH interpreter. Much like the full FORTH interpreter, the Micro Monitor allows the operator to enter FORTH words to be executed and numbers to be placed on the stack. Since it is stand alone and operates without the aid of a development ROM, FORTH words must be referenced by their Parameter Field Addresses, rather than their name. The way words and numbers are distinguished by the Micro Monitor is by the first character in the input stream on the line. If that character is an "N", it is processed as a number and placed on the data stack. If the character is a "W", the entry is considered to be a FORTH word which is immediately executed. The characters following the first character must be hex digits. The line entry is terminated with a carriage return. Only one entry, i.e., number or FORTH word, can be made per line.

Entry into the Micro Monitor can also be gained by executing the FORTH word MON from the R65FR1 Development ROM. As an example of the use of Micro Monitor, the following sequence shows the entry of two numbers, their addition, and the outputting of the results. The Micro Monitor was entered by either sending CNTL R then pressing RESET without an auto-start ROM in the system, or by commanding MON in the development system.

```
>N1111          (The > indicates the Micro Monitor is ready  )
                (for input. The N1111 entered by the operator)
                (puts a $1111 on the data stack.             )

>N222           (The Micro Monitor returns the > after the   )
                (last command is finished.  The operator     )
                (enters the second number, $0222.            )

>WF778          (The W entered by the operator indicates the )
                (following number is a FORTH word to be exe- )
                (cuted.  The address $F778 is the Parameter  )
                (Field Address of the FORTH word  +  .  The  )
                (Micro Monitor causes the two numbers to be  )
                (added therefore and the result left on the  )
                (stack.                                      )

>WFEE4 1333     (The operator enters another FORTH word to   )
                (be executed.  This one is the  .  command   )
                (which outputs the top value from the data   )
                (stack.  The outputted result is displayed   )
                (on the same line.  After command completion )
                (the Micro Monitor displays the  > , to      )
                (indicate that it is ready for another input.)
```

A list of all the available FORTH words available in the kernel with their Parameter Field Addresses are listed in Table 2-1. There are many useful words that can be accessed by the user with the Micro Monitor. It is possible to examine I/O ports, load programs from disk and even program EPROMs under direction of the Micro Monitor. It should be easy to imagine many uses for the Micro Monitor when making field modifications to existing products based on RSC-FORTH.

Table 2-1. RSC-FORTH Kernel Words with their Parameter Field Addresses

!	F858	2DUP	F7EF	D+-	FC42	MOD	FCD4
#	FE7D	3	F8BB	D.	FECE	NEGATE	F7A5
#>	FE5C	4	F8BF	D.R	FEB0	OR	F6CE
#S	FEA0	;S	F717	DABS	FC56	OVER	F7C5
(+LOOP)	F4D0	<	F954	DECIMAL	F9BC	PAD	F8F0
(.")	FA31	<#	FE52	DIGIT	F50D	PICK	F98F
(DO)	F4F8	=	F938	DISK	FD08	QUERY	FAAC
(FIND)	F535	>	F96C	DNEGATE	F7B5	R	F73F
(LOOP)	F4AF	>R	F734	DPL	F8E2	R>	F73F
<NUMBER)	FB06	.?	FEEC	DREAD	F056	RP!	F6FD
*	FCB6	?TERMINAL	F60A	DROP	F7CF	RP@	F80C
*/	FCE8	@	F83B	DUP	F7E5	R0	F8CD
*/MOD	FCDC	ABS	FC4E	DWRITE	FDBE	ROT	F974
+	F778	AND	F6BE	EEC!	FEF4	S->D	FC2C
+!	F818	BANKC!	FF42	EMIT	F5D4	S0	F8CA
+-	FC36	BANKC@	FF4A	ENCLOSE	F591	SEEK	FE11
-	F96C	BANKEEC!	FF52	ERASE	FAE4	SELECT	FD43
-DUP	F9A5	BANKEXECUTE	FF5A	EXECUTE	F471	SIGN	FE6C
-TRAILING	FA0B	BASE	F8D9	EXPECT	FA45	SP!	F6F3
.	FEE4	BL	F8C3	FILL	FABE	SP@	F6EA
.R	FED8	BLANKS	FAEC	HEX	F9B1	SPACE	F99D
/	FCCA	BOUNDS	F803	HLD	F8E5	SPACES	FE3A
/MOD	FCBE	BRANCH	F480	HOLD	FAF4	SWAP	F7D3
0	F8AF	C!	F868	IN	F8DF	TIB	F8C&
0<	F76B	C/L	F8E8	INIT	FDF1	TOGGLE	F830
0=	F7A5	C@	F84B	KEY	F5F6	TYPE	F93F
0BRANCH	F497	CLD/WRM	F8DC	LEAVE	F722	U*	F646
1	F8B3	CLIT	F458	LIT	F40E	U/	F67B
1+	F8F8	CMOVE	F626	M*	FC7E	U<	F940
1-	F913	COLD	FB48	M/	FC94	UC/L	F8D0
2	F8B7	COUNT	F9E3	M/MOD	FCF2	UPAD	F8D3
2+	F820	CR	F613	MAX	FC6E	UR/W	F8D6
2-	F920	D+	F787	MIN	FC5E	XOR	F6DC
2DROP	F7D1						

SECTION 3

FORTH CONCEPTS

FORTH is quite different from more conventional languages such as BASIC, FORTRAN, or Pascal. It creates a computing environment with unique strengths, tools, and styles. Some of the structures of FORTH have little correspondence with those of other languages. This overview of the language and the RSC-FORTH implementation provides background for the how-to-do-it chapters which follow.

3.1 FEATURES OF FORTH

FORTH is EXTENSIBLE, meaning that you add your own operations to the language. New words (operations) are defined in terms of previously defined words (or assembly language), until a single word represents the entire user's program. The program word can then be executed by typing its name or made to auto-start upon reset. Except that your words may be defined in RAM, (or user provided PROM or ROM), there is no distinction between your new operations and those originally part of the language. Extensibility allows users to define libraries or even their own languages for particular applications, greatly facilitating maintenance as requirements change.

FORTH keeps all definitions in a DICTIONARY. The dictionary includes virtually all the object code of the system itself and of your applications. Your own data structures may be in the dictionary or outside it, at your option. The internal structure of the dictionary is uniform and much simpler than the internals of most other languages; therefore, application programmers typically learn much more of the inner workings of the FORTH system.

Compiled FORTH code is extremely COMPACT in memory, even compared to machine language. The overhead associated with most FORTH systems is nearly non-existent in RSC-FORTH. Since the runtime portions of RSC-FORTH are in internal ROM, there is no kernel to add to the user's code. RSC-FORTH can target compile user code and remove all the overhead of the dictionary structures. By referring to the internal runtime kernel and user defined function, RSC-FORTH's hierarchical structure allows application code to build on itself, increasing the memory advantage for larger programs, and with little loss in speed.

FORTH code is recursive, suited to multi-tasking applications, and can be programmed in RAM, PROM or ROM.

FORTH is STRUCTURED. There is no GOTO statement in the language. IF and ELSE control structures, and DO, UNTIL, and WHILE loops are provided; all of these can be nested to any practical depth.

FORTH uses a STACK and its associated POSTFIX NOTATION, also called Reverse Polish Notation (RPN), in which the operation codes are written after the operands which they use. For example, <2+2> in BASIC would be written <2 2 +> in FORTH. Why does FORTH use a stack explicitly when most other languages hide their stacks from the user and avoid postfix in favor of more conventional notation?

Part of the answer is that the stack allows very low overhead for linking between subroutines. FORTH reduces the cost of subroutines to very little, and the whole language is built around subroutine calls. Routines can accept and return any number of arguments, without the complexity or other overhead of formal parameter or local variable declarations.

The stack encourages extremely MODULAR programming, which can be debugged with great reliability. Consider FORTH's programming environment. Each module (i.e., word or procedure) has only one entry and one exit point. Usually all communication with the outside world is through the stack, so there are no side effects on other modules, variables, etc., unless explicitly programmed. Usually each module is short; commonly three to five lines. The smaller a module is, the easier it is to test all paths through it.

FORTH is INTERACTIVE. Testing is immediate, because almost all FORTH words can be executed directly as commands from the keyboard, and will behave exactly the same in this mode as when compiled into later definitions. Any arguments required can simply be typed onto the stack before the test, or generated by other operations, and results can be observed or printed immediately. Usually each component of the new definition can also be executed interactively from the keyboard, to aid in debugging.

FORTH debugging seldom requires examining any code except the single definition being tested. Documentation of the behavior of the defined words in glossary form is required, i.e., inputs, outputs, and actions, but there is no need for their code to be listed. Fewer listings are therefore required during FORTH program development than with other languages. Everything you need to work with is directly in front of you.

FORTH allows easy MACHINE ACCESS, unlike most other high-level languages. All of memory and I/O (data ports and control registers) can be addressed, although run-time protection can be implemented simply by redefining appropriate system or user words to include run-time bounds or other checks during testing. Except for direct access to machine-specific registers (A, X, Y, etc. in the R6502 CPU) which require assembly language subroutines, FORTH can do anything machine language can do. And FORTH runs fast enough that usually no assembly language subroutines are necessary.

But if full machine speed is needed, RSC-FORTH includes an assembler. It also allows machine language subroutines to be tested immediately as soon as the assembly source has been typed in or otherwise entered, with no waiting for separate assembly and linking passes. It encourages structured programming even in assembly language; IF...ELSE and BEGIN...UNTIL macros are provided. Users can define their own macros, and use the full power of FORTH for address arithmetic and other assembly-time utilities. All R6502 and R6511Q op codes and addressing modes are available. This one-pass assembler is implemented in about 1.5K bytes, illustrating the compactness of FORTH's object code.

The routines created by this assembler have FORTH names and behave exactly like regular FORTH definitions. The user needn't know which words are programmed in assembly language. Therefore, an application can first be written entirely in high level using FORTH words, and, if more speed is necessary, parts can be converted to assembly language code with no changes required elsewhere.

FORTH code is extremely TRANSPORTABLE between machines. It is common for substantial programs to be moved between different computers such as 6502, 8080, and PDP-11 with very little change or none at all. The RSC-FORTH system follows the FORTH Interest Group (FIG) language model, probably the most common dialect of FORTH, and one closely aligned with the International Standard for the language. The FIG model is available on the common small computers and is rapidly being implemented on others. Therefore the R65F11/R65F12 microcomputer in conjunction with the R65FR1 Development ROM can be used to develop software for other computers, and it can use published FIG-model code regardless of the machine on which it was developed. Published programs are commonly written entirely in FORTH with no machine code or other dependencies, but designed so that short, time critical words can be rewritten in assembly language for optimization on any particular host machine. These programs can first be run unchanged, then optimized only if needed.

As in any programming, good style makes the application program easier to debug and verify, and easier to read and modify when requirements change. Many recommended FORTH practices are familiar from other language environments, but some are different. Practices such as top-down design and bottom-up coding and testing, short modules, indentation of control structures, and a glossary as the principal documentation during development, are discussed throughout this manual.

3.2 DEBUGGING

The FORTH environment's convenient and powerful debugging and error control features are an important advantage of the system. FORTH allows complete access to the machine, without the restrictions of many other languages such as BASIC and Pascal which try to guard the programmer against mistakes. Most users report that FORTH allows them to quickly produce and modify programs which are exceptionally reliable.

Although RSC-FORTH includes extensive compile-time checking which detects most of the detectable errors (see Appendix E), the most important error control is in the tools which the FORTH environment itself gives to the programmer.

Like most other modern languages, FORTH encourages "structured programming" design techniques, which helps to control errors. FORTH is extremely modular, even compared to other structured languages; each software module can be tested and debugged independently. Usually all communication between a module and the outside world is through an internal stack. Each module relies on earlier modules which have already been debugged, and in turn, the new testing helps catch any errors that may still be hidden in the earlier work.

Testing is immediate and interactive; simply type arguments onto the stack, execute the word, and output the results. If more elaborate test data is needed, a special word can generate it. This ease of testing means that a large number of tests can be run quickly.

Each module should be short, in the programming style preferred by most FORTH users, so that all possible paths of control can be tested easily.

If correct results are not obtained, it is possible to step through the definition by executing each component word individually, checking the stack whenever desired. RSC-FORTH has a special word, .S , which non-destructively prints the stack contents to help in this kind of debugging. Any unexpected results can be localized to a particular component word, which in turn can then be examined in detail. Because FORTH words work identically when compiled, or when executed as commands, the programmer can debug at either a batch or interactive operation mode.

Because FORTH is extensible, words can be re-defined to perform their original functions and, in addition, give special debug print-outs or do run-time error checks. These redefinitions can be inserted into programs for testing and removed later; nothing else in the program need be changed.

RSC-FORTH also includes a memory dump and other words for examining or changing memory. These commands can be compiled into programs or executed from the keyboard.

In contrast to most other operating systems, all of these tools are part of the normal FORTH environment. No special syntax or command language must be learned for debugging.

Each FORTH word is documented by a glossary (see Appendix B) which lists the arguments it takes from the stack and the results returned, and gives a short verbal description (usually one to three sentences) of its action. Such a glossary completely describes the word as it is seen by any other part of the program. When a new word is being tested, all earlier words should have these descriptions available. Therefore, the programmer seldom needs to look at the source code of any other word; the glossary fully describes its functions. During testing and debugging, only one word at a time needs to be examined -- this greatly cuts down the need for program listings during development.

One important debugging procedure applies only to FORTH. After a word appears to work correctly it must be tested to make sure that it does not take any unexpected numbers off the stack, or return unexpected results. One way to check is to leave markers, easily-recognized numbers, such as 1, 2 and 3, on the stack and then execute the word being debugged. After an operation, use .S to make sure that the markers are still on the stack, below any arguments returned by the test word. This check is important because otherwise the word may look like it works, but causes later program crashes at unexpected and seemingly random places making the problem hard to debug.

SECTION 4

ELEMENTARY OPERATIONS

This section provides a step-by-step description of elementary RSC-FORTH operations, such as:

- Performing simple arithmetic and comparisons
- Entering and retrieving data from memory
- Using the stack
- Compiling interactively or in a batch mode from memory
- Defining new FORTH words
- Performing looping and conditional sequences

A major portion of FORTH is the FORTH dictionary itself. Each word in the FORTH dictionary causes specfic actions or operations to be performed. The use of FORTH is explained primarily by describing how each word operates and how to use it, either individually or with other words. Let's start by seeing what is in the FORTH dictionary.

List the contents of the FORTH dictionary by running a VLIST . Type

```
VLIST
```

and then press the <RETURN> key. The entire FORTH dictionary will be displayed.

Terminate the listing at any time by pressing any key. The entire VLIST is shown in Figure 4-1. Note that the words do not appear to be in any general order; the words are listed by their address in the R65FR1 Development ROM. (The FORTH dictionary structure is explained in detail in Section 5.5, but leave that for later.) These FORTH words are described in ASCII sort order for convenient lookup in the glossary in Appendix B and summarized by associated function in Appendix A.

RSC-FORTH may be readily learned by performing the following procedure. As each new FORTH word is encountered in this section, read the explanation and perform the accompanying examples. Then read the word definition in the Appendix B glossary. Repeat the examples, but vary one or more of the parameters until you thoroughly understand the operation of the described FORTH word.

As you are learning FORTH, you may make errors that either cause an error message to be displayed or cause the microcomputer to hang up or to run away. If an error occurs with a displayed error message or number, refer to Appendix E for the error definition and suggested recovery. If the program appears to hang up or run away, press the <RESET> key to reinitialize the microcomputer. You can then try the example again. You may have to back up a few steps, however, to recover the example initialization.

```
VLIST
  40B TASK          3844 ADMP          3805 ;DUMP         37CF FORMAT
 367E FMTRK         3674 BANKEXECUTE   3664 BANKEEC!      3657 BANKC@
 364C BANKC!        3641 EEC!          361E CASE:         35FD MEMTOP
 35ED SCDR          35DF SCSR          35D1 SCCR          35C3 MCR
 35B6 IER           35A9 IFR           359C PG            3590 PF
 3584 PE            3578 PD            356C PC            3560 PB
 3554 PA            3548 NMIVEC        3538 IRQVEC        3528 INTVEC
 3518 INTFLG        34EF C,CON         34AC .S            349F MON
 345B VLIST         33EC INDEX         33A0 LIST          3397 ?
 3391 .             338B .R            3384 D.            337D D.R
 3375 #S            336E #             3368 SIGN          335F #>
 3358 <#            3351 SPACES        333E WHILE         331A ELSE
 3301 IF            32E8 REPEAT        32CF AGAIN         32BF END
 32A9 UNTIL         3291 +LOOP         3279 LOOP          3264 DO
 3257 THEN          323A ENDIF         3226 BEGIN         3185 FORGET
 3149 AUTOSTART     3110 ?KERNEL       30BC HWORD         3086 H/C
 306E ' `           3068 SEEK          305F INIT          3056 DWRITE
 304B DREAD         3041 SELECT        3036 DISK          3023 R/W
 3017 B/SCR         3009 B/BUF         2FED -BCD          2FC9 -->
 2F99 LOAD          2F40 MESSAGE       2F0F >LINE         2EFB .LINE
 2ED7 (LINE)        2E94 DUMP          2E69 FLUSH         2E09 BLOCK
 2DBF BUFFER        2D9A EMPTY-BUFFERS  2D72 UPDATE        2D41 +BUF
 2D38 M/MOD         2D2E */            2D27 */MOD         2D1D MOD
 2D15 /             2D0F /MOD          2D06 *             2D00 M/
 2CF9 M*            2CF2 MAX           2CEA MIN           2CE2 DABS
 2CD9 ABS           2CD1 D+-           2CC9 +-            2CC2 S->D
 2CB9 COLD          2C4C ABORT         2C1D QUIT          2C0B (
 2BF9 DEFINITIONS   2BE1 ASSEMBLER     2BC9 FORTH         2B97 VOCABULARY
 2B7D IMMEDIATE     2B2D INTERPRET     2B02 ?STACK        2AE5 DLITERAL
 2AB2 LITERAL       2A94 [COMPILE]     29F1 CREATE        29C8 ID.
 298B ERROR         2977 (ABORT)       2949 -FIND         28F1 NUMBER
 28E6 (NUMBER)      2894 WORD          288B HOLD          2882 BLANKS
 2877 ERASE         286D FILL          2846               2840 QUERY
 2836 EXPECT        2804 ."            27FD (.")          27F4 -TRAILING
 27E6 TYPE          27DD COUNT         27C1 DOES>         27AF <BUILDS
 2795 ;CODE         277D (;CODE)       2771 DECIMAL       2765 HEX
 2753 SMUDGE        273D ]             272D [             2715 COMPILE
 26F8 ?CSP          26E4 ?PAIRS        26CC ?EXEC         26B3 ?COMP
 269B ?ERROR        2686 !CSP          2670 PFAPTR        2656 NFA
 2646 CFA           263C LFA           262A LATEST        2604 TRAVERSE
 25F7 -DUP          25EE SPACE         25E4 PICK          25DB ROT
 25D3 >             25CD <             25C7 U<            25C0 =
 25BA -             25A8 C,            2595 ,             2587 ALLOT
 2575 HERE          2560 ,/            2551 ALLOT/        253E HERE/
 2524 DP/           251C 2-            2515 1-            250E 2+
 2507 1+            2500 PAD           24F0 LIMIT         24DE FIRST
 24D4 C/L           24C9 KHZ           24BE MODE          24B2 CSP
 24A7 STATE         249A CURRENT       248B CONTEXT       247C SCR
 2471 BLK           2466 PREV          245A USE           244F UABORT
 243B VOC-LINK      242B HEADERLESS    2419 DP            240F FENCE
 2402 WARNING       23F3 WIDTH         23E6 OFFSET        23D8 ULIMIT
```

Figure 4-1. VLIST of RSC-FORTH Words

```
23CA UFIRST      23BC B/SIDE      23AE CYLINDER    239E DISKNO
2393 HLD         238B DPL         2383 IN          237C CLD/WRM
2370 BASE        2367 UR/W        235E UPAD        2355 UC/L
234C R0          2345 S0          233E TIB         2336 BL
232F 4           2329 3           2323 2           231D 1
2317 0           2303 USER        22EC CODE        22D9 VARIABLE
22BE CONSTANT    22A3 ;           2285 :           226F C!
2268 !           2262 C@          225B @           2255 TOGGLE
224A +!          2243 BOUNDS      2238 2DUP        222F DUP
2227 SWAP        221E 2DROP       2214 DROP        220B OVER
2202 DNEGATE     21F6 NEGATE      21EB D+          21E4 +
21DE 0<          21D5 NOT         21CD 0=          21C6 R
21C0 R>          21B9 >R          21B2 LEAVE       21A8 ;S
21A1 RP@         2199 RP!         2191 SP!         2189 SP@
2181 XOR         2179 OR          2172 AND         216A U/
2163 U*          215C CMOVE       2145 FINIS       20F9 SOURCE
20E6 XOFF        20D5 XON         20CD CR          20C6 ?TERMINAL
20B8 KEY         20B0 EMIT        20A7 ENCLOSE     209B (FIND)
2090 DIGIT       2084 I           207E (DO)        2075 (+LOOP)
2069 (LOOP)      205E 0BRANCH     2052 BRANCH      2047 EXECUTE
203B CLIT        2032 LIT         OK
```

Figure 4-1. VLIST of RSC-FORTH Words (Cont'd)

In the following descriptions, a FORTH word comprising of letters and numbers is written in upper case. Since some FORTH words contain special characters that may be confused with sentence structure, e.g., periods, commas, or apostrophes, the FORTH words are set off by spaces, e.g., .S . These single spaces are not part of the FORTH word and should not be entered.

4.1 SIMPLE ARITHMETIC

FORTH arithmetic, like that of advanced pocket slide rule calculators, uses a stack to store operands and results. Operations such as + - * / (add, subtract, multiply, and divide) take their arguments from the stack, and return their results to it.

To see how the stack works, give FORTH a cold restart by typing

```
COLD
```

and pressing the <RETURN> key. The system will display

```
 RSC-FORTH V1.5
```

Now type the following five numbers

```
1  22  333  -44  5
```

and terminate the input by pressing the <RETURN> key. <RETURN> at the end of a line signals that your input is complete. (The <RETURN> is shown in the initial examples, but is not shown in later examples, except where needed to clarify data or command entry.) Be sure to insert one or more spaces between each number. Now the numbers 1 through 5 are separate numbers stored on the stack with 5 at the top. FORTH responds to your input by displaying OK . OK means that the system has correctly acted on your command and is waiting for another command to be entered. (The OK is not shown in most of the examples, however, it is implied in all operations.) After <RETURN> is pressed, the following is displayed

```
1  22  333  -44  5 OK
```

Notice that the cursor indicates the input character position. A typing error during FORTH command or data entry can be corrected by pressing the <DEL>, key <BACK SPACE> or <RUB OUT> on the terminal as necessary.

4.1.1 Examine Stack Contents with .S

The word .S (pronounced dot-s) may be used at any time to examine the contents of the stack without altering the values or removing the numbers from the stack. Try it by typing

```
.S <RETURN>
```

The numbers entered in the prior section will be displayed (in some examples the displayed data is underlined to distinguish it from entered data)

```
5
-44
333
22
1 OK
```

The .S word is very useful when learning RSC-FORTH or debugging a FORTH program to determine the stack contents immediately prior to and/or after executing a FORTH word.

4.1.2 Print from the Stack using .

The print command removes a number from the stack and displays it (and prints it if the printer is ON) in the current I/O number base. In FORTH, the print command is represented by a period and is called "dot". Type

```
. <RETURN>
```

The 5 will be displayed and removed from the stack.

```
. 5 OK
```

Verify this by typing .S and <RETURN> to show the new contents of the stack.

```
-44
333
22
1 OK
```

The next dot (and <RETURN>) will print the -44. Multiple commands separated by spaces, can be typed on one line like this

```
. . <RETURN>
```

to display two numbers from the stack, e.g.,

```
. . <RETURN> 333  22 OK
```

Now only 1 is left on the stack. Output it with

```
. <RETURN>
```

which displays

```
. 1 OK
```

Trying to examine or print the stack contents when there are no numbers on the stack will result in an error message. Try .S which will show

```
.S <RETURN>
EMPTY OK
```

Note that the word . will now cause a stack underflow and will display an indeterminate value along with a stack empty message. Try it now

```
. 0  (typical number)
. ? STACK EMPTY
```

Similar FORTH operations trying to pull a number from an empty stack will result in this error message. This error message, as well as others, are described in Appendix E.

Notice that the data was displayed on the same line as the commands, i.e., the FORTH word . in this case. Many times it is desired to display and print data on a new line. The FORTH word CR issues a carriage return to the terminal. Repeat the previous examples but insert CR before the . word and note that the numbers are displayed on separate lines. Also try CR after the . and observe the results.

Perform a cold restart before continuing.

```
COLD
 RSC-FORTH V1.5
```

4.1.3 Clearing the Stack

It is sometimes desirable to delete data from the stack without performing a COLD restart. The stack may be cleared by trying to execute a word that is not currently defined in the FORTH dictionary. This causes an error condition in which FORTH echoes the missing word followed by a "?" (see Appendix E for error descriptions) and then clears the stack. Initially, the word Q is not defined in the FORTH dictionary and can be conveniently used to clear the stack.

Note also that entering a word that is not in the dictionary will also delete data that you may want on the stack -- so be careful with your word entries or you may have to re-enter data or repeat prior steps.

Enter some numbers on the stack and display the stack contents.

```
678 356
.S
356
678 OK
```

Type Q now and verify that the stack is cleared.

```
Q
Q ?
.S
EMPTY OK
```

4.1.4 Add + and Subtract -

Let's now perform some simple arithmetic. Put two numbers on the stack, say

```
12809 135 <RETURN>
```

Now type the add command

```
+ <RETURN>
```

The + takes whatever two numbers are on top of the stack and adds them. It removes those numbers (by convention, most FORTH operations destroy their arguments on the stack), and replaces them with their sum. Type

```
. <RETURN>
```

to verify this. The sum will be displayed as

```
. 12944 OK
```

As before, multiple operations can be placed on one line, e.g.,

```
12809 135 + . <RETURN> 12944 OK
```

Subtract works in a similar manner. Try

```
12809 135 - . <RETURN> 12674 OK
```

Repeat these last two examples but, insert CR before and after the word . to display the result on a separate line.

4.1.5 Multiply * and Divide /

Multiply and divide also work in a similar manner. Try the following

```
38 78 * . <RETURN> 2964 OK
```

The word * multiplies the top two items on the stack and leaves only the result on the stack. The word / divides the second item on the stack by the top item. Try

```
13036 50 / . <RETURN>
```

which displays

```
13036 50 / . 260 OK
```

Note also that the divide limited the result to an integer value (the full answer is 260 with a remainder of 36). Other operations allow the remainder to be saved (see Section 5.1). In all FORTH arithmetic and comparison words requiring two data items, the operator behaves as if it were between the top two values on the stack. Thus, 13036 50 / behaves as if it were 13036 / 50.

Each number on the stack is 16 bits wide, therefore these single numbers have the range -32768 to 32767 since the most significant bit (bit 15) is used for the arithmetic sign. This is enough for many applications, but RSC-FORTH also has double-precision (32-bit) numbers which are discussed in Section 5.1.

4.1.6 Postfix Notation and Stack Operation

Note that in the preceding examples, the operators (+ , - , * and /) were typed after their arguments, not between them. This style of arithmetic notation is called POSTFIX or Reverse Polish Notation (RPN). It can represent complex formulas without any use of parentheses. For instance

```
(42-50)*(128-1090/3)
```

would appear in postfix as

```
42 50 - 128 1090 3 / - *
```

Note that the operands (the numbers) are in the same order in the postfix and infix (ordinary arithmetic) expressions. Don't forget to type . and <RETURN> to display/print the result.

If you are new to postfix, you may want to follow this example by using stack diagrams, as shown in Figure 4-2. This illustration shows the successive states of the stack after each number or operation has been processed. Each column shows the stack at one time. The number on top is the most accessible number on the stack, ready to be used first by any operation which takes a number from the stack. We say that this number is at the TOP of the stack.

In the execution of the postfix formula shown above, 42 is placed on the stack (first column of Figure 4-2) -- then 50 is entered. The subtraction destroys those arguments and leaves the difference, -8. You can follow the rest of the process similarly.

Each column in Figure 4-2 shows the stack at the time after each successive number or operation of the formula has been processed. Note that any numbers which may have been below these numbers on the stack will be undisturbed. Repeat the above example but insert .S after each number and operator to examine the stack contents after each operation.

Only numbers go on the stack. Strings or other data structures do not reside there directly -- although some data such as pointers (addresses), length and offset information, ASCII values, are frequently on the stack.

How many numbers can reside on the stack at one time? RSC-FORTH limits the stack depth to 50 16-bit values in order to keep the parameter stack in zero page to maximize the R65F11 CPU execution speed. Except for certain recursion problems, very few programs ever need a stack depth of more than about 20.

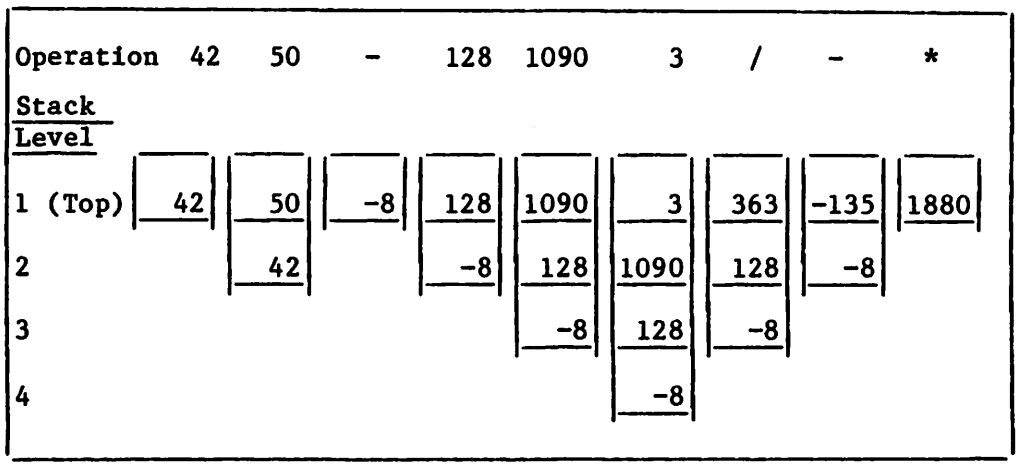


Figure 4-2. Stack Diagram of Postfix Example

4.1.7 Decimal and Hexadecimal Number Base

Up to now we have been working in DECIMAL . FORTH allows input and output data to be represented in different number bases. We will consider only two pre-defined bases now -- DECIMAL and HEX . FORTH is initialized to DECIMAL (base 10) during initial entry or upon commanding COLD . DECIMAL is best used when working with numeric calculations. HEX operates in hexadecimal (base 16) and is most useful when working with addresses or logical operations on individual bits.

Type DECIMAL or HEX to change FORTH to the desired base before entering or displaying data in that base. FORTH will stay in the selected base until the base is changed or until FORTH is reinitialized (to DECIMAL). Note that DECIMAL and HEX affect the input and output data representation and not internal data handling.

Reinitialize FORTH and put the following numbers on the stack and print them using different combinations of DECIMAL and HEX .

```
COLD <RETURN> ( Initializes DECIMAL )
 RSC-FORTH V1.5
```

Press <RETURN> after the word . in each of the following examples

```
16 . 16 OK
16 HEX . 10 OK
10 DECIMAL . 16 OK
255 . 255 OK
255 HEX . FF OK
DECIMAL 32767 . 32767 OK
32767 HEX . 7FFF OK
DECIMAL -32768 . -32768 OK
-32768 HEX . -8000 OK
```

Note that DECIMAL numbers -1 to -32768 entered on the stack will be displayed in HEX in 2's complement form with a leading minus sign.

We will examine other number bases later (see Section 4.11.3).

4.2 STACK MANIPULATION

Since most FORTH words use the stack to hold input or output numbers, let's explore some FORTH words that are used to rearrange or copy numbers near the top of the stack. While these functions are sometimes necessary, you should avoid using them where possible. FORTH code is more readable when less stack manipulation is used. Common stack manipulation words are discussed here, however, to give you additional experience in working with the stack before proceeding into other FORTH word descriptions.

4.2.1 DUP , DROP , SWAP and OVER

The most common stack manipulation words are DUP , DROP , SWAP and OVER . Let's explore these, but first place some markers on the stack for reference

```
DECIMAL 333 222 111 <RETURN>
```

If we accidently pull too many numbers from the stack we will know where we are. Type .S to check

```
.S <RETURN>
111
222
333 OK
```

DUP pushes a copy of the top number onto the stack to create a new top number. In sequence

```
123 DUP . . <RETURN>
```

duplicates 123 on the stack then displays both numbers

```
123 DUP . . 123 123 OK
```

DROP deletes the top number from the stack. Try this with

```
456 789 DROP . <RETURN>
```

which deletes 789 and displays

```
456 789 DROP . 456 OK
```

SWAP exchanges the top two numbers on the stack. Put two numbers on the stack

```
456 789 <RETURN>
```

Use .S to look at the stack

```
.S <RETURN>
789
456
111
222
333 OK
```

Now swap the numbers on top the stack and examine the stack with

```
SWAP .S <RETURN>
```

which displays

```
456
789
111
222
333 OK
```

Notice that the top two numbers are reversed. Now try OVER which copies the second item to be the new top

```
OVER .S <RETURN>
789
456
789
111
222
333 OK
```

4.2.2 Test and Duplicate with -DUP

A related word -DUP duplicates the top number on the stack only if it is non-zero; otherwise -DUP does nothing. Continuing from the prior example, type

```
-DUP .S <RETURN>
```

to show that the top number was duplicated.

```
789
789
456
789
111
222
333 OK
```

Let's remove and display the top four numbers from the stack before continuing

```
CR . . . . <RETURN>
```

which displays

```
789 789 456 789 OK
```

Now, enter

```
0 -DUP CR .S <RETURN>
```

which displays

```
0
111
222
333 OK
```

Notice that the top number was not duplicated. -DUP is usually used before an IF (see Section 4.8.1). In the non-zero case, some action is usually performed using the value; the extra copy made by -DUP is therefore removed by the IF processing. In the zero case, no additional action is performed, thus, the extra copy of the top number is not needed.

4.2.3 Delete the Top Stack Item with DROP

The word DROP deletes the top item on the stack. Drop the zero now and check the stack contents

```
DROP .S <RETURN>
111
222
333 OK
```

4.2.4 Rotate Stack Items with ROT

ROT rotates the top three items, moving the third item to the top, the previous top item to the second, and the previous second item to the third.

For example,

```
800 700 600 .S <RETURN>
600
700
800
111
222
333 OK
```

Now rotate and display with

```
ROT .S <RETURN>
```

which outputs

```
800
600
700
111
222
333 OK
```

Now remove and display the top three numbers

```
CR . . . <RETURN>
800 600 700 OK
```

4.2.5 Copy a Stack Item with PICK

PICK looks down any depth into the stack and copies the nth number from the top (not counting the n itself) and places it on top.

```
1 PICK
```

is the same as DUP , and

```
2 PICK
```

is the same as OVER . Put several numbers on the stack and check them

```
40 50 60 70 80 .S <RETURN>
80
70
60
50
40
111
222
333 OK
```

Now pick the 4th item (i.e., 50), and look at the results

```
4 PICK .S <RETURN>
50
80
70
60
50
40
111
222
333 OK
```

4.3 MEMORY OPERATIONS

Several FORTH words move data between the stack and memory, or from memory to memory.

4.3.1 16-Bit Store ! and Fetch @

The FORTH word

```
!
```

(pronounced "store") takes an address from the top of the stack and the 16-bit value beneath it and stores the value into the address (and address +1).

A corresponding word

```
@
```

(pronounced "fetch") takes an address from the top of the stack, fetches the 16-bit data from that address (and address +1) and replaces the address on top of the stack with the data from memory. Both the address and the data are specified in the current number base. Initialize FORTH and try

```
COLD
 RSC-FORTH V1.5
HEX OK
30FF 200 ! OK
200 @ CR .
30FF OK
```

which stores 30FF into addresses $200 and $201 with ! , fetches the contents of addresses $200 and $201 with @ and displays it with . . Try

```
DECIMAL
16000 HEX 200 ! OK
```

to store a decimal number in an address entered in hexadecimal. Now display the data in decimal by

```
200 @ DECIMAL CR .
16000 OK
```

which fetches the contents of addresses $200 and $201 and stores it on the stack, switches to the decimal mode, and outputs the data in decimal when . is commanded.

Now fetch and display the value in hexadecimal by

```
HEX 200 @ CR .
3E80 OK
```

4.3.2 8-Bit Store C! and Byte Fetch C@

Similar words allow byte length data to be stored and fetched. The word

```
C!
```

("c-store") stores the least significant 8-bits of the second item on the stack into the address determined by the number on top of the stack. The word

```
C@
```

("c-fetch") accesses the 8-bits stored at the address on top of the stack and stores it on top of the stack (replacing the address). Try

```
HEX OK
41 200 C! OK
F4 201 C! OK
```

which stores 41 and F4 into addresses $200 and $201, respectively. Display the contents of those address with

```
200 C@ 201 C@ CR . .
F4 41 OK
```

4.3.3 Initializing Memory with ERASE , BLANKS and FILL

Three words allow a block of memory to be initialized to various values.

ERASE fills memory with zeros ($00) starting at a specified address (second on the stack) and continuing through the number of bytes specified (top number on stack)

```
HEX 200 100 ERASE OK
```

Spot check with

```
200 @ 2FE @ CR . .
0 0 OK
```

Note that if the contents of $2FF were fetched, a non-zero number may be displayed since '@' fetches two bytes ($2FF and $300) and address $300 was not erased. The last byte could have been checked with

```
2FF C@ CR .
0 OK
```

BLANKS works like ERASE except that memory is initialized to ASCII blank ($20) instead of zeros. Try

```
HEX 200 100 BLANKS OK
200 C@ 2FF C@ CR . .
20 20 OK
```

FILL allows memory to be initialized to a desired value. In addition to the starting address (third on the stack) and the number of bytes to fill (second on the stack), the fill bit pattern (top of the stack) is specified). Try

```
HEX 200 100 FF FILL OK
200 C@ 2FF C@ CR . .
FF FF OK
```

Try

```
200 @ 2FE @ CR . .
-1 -1 OK
```

Notice that the 2's complement value (-1) was displayed when 16-bit numbers were accessed.

Note also that HEX is not required if FORTH is already in the HEX mode.

4.3.4 Dumping Memory with DUMP

A block of memory can be displayed using DUMP . A starting address (second on the stack) and the number of bytes to be dumped (top of the stack) are specified. Try

```
HEX
200 14 F8 FILL OK  ( Fill 14 hex locations with $F8 )
```

Enter

```
200 14 DUMP <RETURN>  ( Starting at $200)
```

to display

```
  200  F8 F9 F8 F8 F8 F8 F8 F8 F8 F8 F8 F8 F8 F8 F8 F8
  210  F8 F8 F8 F8 FF FF FF FF FF FF FF FF FF FF FF FF
OK
```

4.3.5 Moving a Block of Memory with CMOVE

It is often useful to move a block of data from one area of memory to another. This can be done with the word CMOVE which takes three arguments on the stack: a from-address, a to-address, and a byte count. It moves the given number of bytes starting with the first address to the area of memory starting at the second address.

Try

```
200 40 80 FILL OK
240 40 FF FILL OK
200 280 8 CMOVE OK
240 288 8 CMOVE OK
280 10 DUMP
  280  80 80 80 80 80 80 80 80 FF FF FF FF FF FF FF FF
OK
```

CMOVE works from the left to right, so be careful if the "from" and "to" memory areas overlap.

4.4 DEFINING YOUR OWN OPERATIONS

FORTH allows you to create your own operations. These new FORTH words become an integral part of the language, just like those which are pre-defined in RSC-FORTH. Your new words can take any number of arguments from the stack, and return any number of results.

The names of your operations can have up to 31 characters. They can use any ASCII characters except blank, delete, null and carriage return. For instance, an operation name could be a number, or even be non-displaying or non-printing control characters, although such names are discouraged. Even names already used by the system may be redefined as something else; therefore there is no reserved word list in FORTH. When a name is redefined, the old definition becomes inaccessible for later use in the program (although all earlier references to that name will remain as before). So, do not redefine a name if you want to use the old definition later.

Names which are descriptive of the function they perform make the code easier to read. Good choice of names is important for later use of the code, especially by other programmers.

As new words are defined, they are added to the FORTH vocabulary (described in more detail in Section 5.6). These definitions are normally stored in RAM starting at address $0404 and build upward in memory. (They can also be stored in PROM/ROM in normal or headerless target compiled format as described in Section 11.) The FORTH word VLIST allows you to check what words have been added to the FORTH vocabulary.

4.4.1 Colon-Definition

Suppose we want an operation to take the number on top of the stack, multiply it by 5, and print the result. Let's pick the name TEST-OP . We could define it simply as

```
: TEST-OP 5 * . ; <RETURN> OK
```

(Later we will rewrite this definition, using indentation and commenting conventions for more readable code). Enter the colon-definition as follows

a. Start the definition with a colon which tells FORTH to look ahead in the input stream for the word name. Follow the colon with a space.

b. Enter the word name (up to 31 characters). The FORTH word here is TEST-OP .

c. Enter the definition of the word. TEST-OP does the following

   1. Puts 5 on the stack
   2. Multiplies the top two numbers, i.e., the number on top of the stack when TEST-OP is executed by the 5 put on the stack by TEST-OP .

3. Prints the result, i.e., the top number on the stack.

d. End the definition with a semi-colon (be sure to insert a space first). A FORTH definition may be continued on as many lines as needed.

This TEST-OP operation takes one number from the stack, as we have seen. It does not return any result (but if the . were omitted, the product would stay on the top of the stack). Note that no formal parameters are used to show the inputs and outputs of an operation. These are implicit -- TEST-OP takes one argument because it puts one number (5) on the stack then performs a multiply which uses two numbers (the 5 and one other). Check the operation of TEST-OP by placing a value on the stack and executing TEST-OP , e.g.

```
6 TEST-OP <RETURN> 30 OK
8 TEST-OP <RETURN> 40 OK
```

If the word being defined is already in the vocabulary dictionary, the message <name> NOT UNIQUE will be displayed. The NOT UNIQUE message is displayed only as a reminder that you have redefined a word which was previously defined and has no effect on the compilation process, e.g.

```
: TEST-OP 10 * . ;
TEST-OP NOT UNIQUE OK
```

Now test it with

```
6 TEST-OP <RETURN> 60
8 TEST-OP <RETURN> 80
```

Note that only the new definition of TEST-OP is found and executed.

4.4.2 Find a Word in the Dictionary with '

Use the word ' (pronounced "tick") to find if a word is already contained in the dictionary and to return its parameter field pointer address (PFAPTR). (Note: This varies from most FORTH systems which return the parameter field pointer (PFA). This additional level of indirection is necessary to run separated heads and codes).

Type the word <name> after the word ' , i.e.

```
' <name>
```

FORTH will respond with OK for a found word and put the word's parameter field pointer address on the stack (See Section 5.5 for description of the parameter field pointer address). If not found, the name is echoed with a "?" and the stack is cleared.

Check TEST-OP now (and print the address in the dictionary)

```
HEX OK
' TEST-OP <RETURN> OK
.S
432 OK
```

We can also run a VLIST to determine if TEST-OP is in the dictionary and to verify the address returned by ' . This is easy in this case since only two colon-definitions have been added to the dictionary and these two entries are printed immediately. Press any key to terminate VLIST.

```
VLIST
    432 TEST-OP   41B TEST-OP   40B TASK   3844 ADMP
   3805 ;DUMP    37CF FORMAT  367E FMTRK  3674 BANKEXECUTE
    ( A key was pressed here)
OK
```

While both versions of TEST-OP are listed, only the version at address 432 is valid since it was defined last.

4.4.3 Print a Message with ."

You can print a message of up to 127 characters with the word ." (dot-quote). Start the message one or more spaces after the ." word. Terminate the message with " (a double quote). Be sure to leave a space after the ." .

Now define a new word to use ."

```
: MULTIPLY
CR ." ANSWER=" 5 * . ; <RETURN> OK
```

and test it

```
DECIMAL
108 MULTIPLY
ANSWER=540 OK
1345 MULTIPLY
ANSWER=6725 OK
```

4.4.4 Commenting

Because the inputs and outputs are not explicit in FORTH code, it is very important to show them in the documentation. It is recommended that they be included as comments in the code and also in a separate glossary of operations. Each glossary entry should include the inputs, outputs and a short description of what the operation does -- usually two or three sentences are enough.

Comments in FORTH are enclosed in parentheses. A space must follow the left parenthesis because the left parenthesis is itself a FORTH word, which causes FORTH to look for a closing delimiter. The closing right parenthesis need not be preceded by a space however, since it is a delimiter and not an operation.

A <RETURN> also acts like a right parenthesis to terminate a comment. FORTH comments can be included on as many lines as needed; however, the comment must start with a left parenthesis followed by a space on each new line.

A conventional form of comment first lists the inputs, then three dashes, then the outputs. A period may be used to separate the last output word from the words of any description of the function of the operation. Therefore the TEST-OP definition could look like

```
: TEST-OP  ( N --- .  MULT BY 5 AND PRINT)
    5 * . ;
```

A common style is to have only the colon, the word being defined, and the comment on the first line, then indent subsequent lines three columns. If the comment is too long, put it on the second line. There is no compiled code penalty for including comments and spaces so they can be used freely to improve readability when preparing object code for mass storage; or if a listing is being made of the source. When interactively entering commands from the keyboard comments are not very useful.

When there is more than one input or output in a command, the right-most numbers are toward the top of the stack. A comment for a definition of a multiply operation might therefore be

```
: MPY   ( N1 N2 --- .  MULTIPLY & PRINT )
   * CR . ;
```

Note that an empty comment must consist of at least a left parenthesis, two spaces, and a right parenthesis. The reason is that the parsing word (WORD in FORTH) skips over leading occurrences of the delimiter. So if you leave only one space as in

```
( )
```

the first character encountered by WORD is the right parenthesis, therefore the system skips it and continues looking for another right parenthesis.

4.5 EXECUTING AND COMPILING USING SOURCE

Up to now you have been operating in a manner where FORTH operations are compiled or executed immediately upon entry in an interpretive mode. If a new FORTH word is formed using a colon-definition (see Section 4.4) the word is immediately compiled and entered into the FORTH vocabulary upon completion of entry. Upon commanding the new FORTH word, the defined function is executed.

FORTH words can also be compiled and executed in a batch mode. In this mode, the FORTH words are compiled or executed upon entry from mass storage. The source program for colon-definitions is not lost upon compilation with this technique, therefore, changes can easily be made without requiring re-entry of the whole program.

There are two methods of batch compiling in RSC-FORTH. The first method uses the standard FORTH technique of multiple RAM buffers and 1024 byte screens. This technique is commonly used for manipulating, saving, and retrieving data files on mass storage. This method is discussed in Section 12.

The second method of batch compiling accepts an input from an intelligent terminal, or download from another computer. Entering the word SOURCE causes the RSC-FORTH system to enter an XON-OFF protocol. It begins by transmitting an XON character when SOURCE is first executed and accepts inputs until a null or carriage return is received, or until the number of characters per line limit is reached. It then transmits an XOFF character and interprets the received line. When interpretation is finished for that line, an XON is transmitted to reestablish communications for another line. When the word FINIS is executed, or an error is detected, the compilation stops and control is returned to FORTH. Characters sent to the RSC-FORTH system are not echoed to the sending unit. Most terminals and computer systems that have the XON-XOFF protocol can be used with SOURCE.

4.6 DO LOOPS

4.6.1 DO ... LOOP

The DO and LOOP statements allow repeated execution of a block of code. For example, the following definition creates a word SERIES , which prints a series of 25 numbers, zero through 24:

```
: SERIES   ( --- .  PRINT A SERIES )
   CR 25 0 DO I . LOOP ;
```

Now execute

```
SERIES
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 17 18 19 20 21 22 23 24 OK
```

DO must always be paired with either LOOP or +LOOP (described in Section 4.6.2). The code section which they enclose can be of any length. This code is executed repeatedly, and an index value, I, is available.

When DO sets up the loop (at run-time), it always takes two arguments from the stack. The top stack number (0) is the initial index value of the loop, and the second argument (25) is the final value plus one. If the initial value is zero, as is often the case, the second argument is the number of times around the loop. Also, ordering the loop limits this way makes the loop upper limit more accessible from outside a definition. We can see how this is done in the definition of NSERIES, below.

The loop index value is kept by the system and incremented automatically. The FORTH word I retrieves this index and copies it onto the stack. In the example above, the index value is zero the first time through the loop, then it is 1, 2, etc. through 24. In this example, the index is printed each time. SERIES takes no arguments from the stack and returns no results.

The recommended code-writing style for using DO and LOOP is to have the entire loop in a single line if possible; if not, LOOP should be indented to the same column as its corresponding DO . This style makes the program's structure easier to see.

The definition

```
: NSERIES   ( N --- .  VARIABLE SERIES)
   CR 0 DO I . LOOP ;
```

creates NSERIES , which is almost like SERIES , except that it takes one argument from the stack, the number of times around the loop.

Now execute NSERIES

```
10 NSERIES
0 1 2 3 4 5 6 7 8 9 OK
```

Redefine SERIES now in terms of NSERIES , as

```
: SERIES   ( ---.  PRINT A SERIES)
   20 NSERIES ;
```

This redefinition will cause a "NOT UNIQUE" warning message to be printed. The warning can be ignored in this case; remember, its purpose is to let you know that the word has also been defined previously. As mentioned before, FORTH allows any word to be redefined -- even the system words such as DO itself. Any further use of the word will refer to the latest definition, but all earlier uses still refer to the definition which was in effect when the earlier references were compiled.

Execute SERIES now.

```
SERIES
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 17 18 19 OK
```

In the examples above, notice that the only difference between SERIES and NSERIES is that the latter does not place a loop terminating value on the stack. Instead, it uses whatever was on the stack when NSERIES was executed. The NSERIES example also shows that the arguments to DO , the loop initial and terminating values, need not be literal numbers; instead they can be computed or obtained in any way. DO doesn't care how its arguments got onto the stack. This feature helps keep FORTH code modular and reduces side effects when changes are made.

DO ... LOOP , and the other control structures which will be introduced later, can only be used inside colon-definitions, i.e., they cannot be executed directly as commands at the terminal. DO and LOOP are in a special class of words called immediate words. These are not compiled like other words used in colon-definitions, but instead they execute at compile time to handle special compilation functions, e.g., to compile an internal branch back from the LOOP to its corresponding DO. Immediate words are discussed in Section 5.

An example of DO ... LOOP is a one millisecond time delay word (this example assumes a 1 MHz internal clock rate):

```
: MS   ( N --- .  MILLISECOND DELAY)
   0 DO 5 0 DO LOOP LOOP
   CR ."  TIME-UP" CR ;
```

This word will cause delays of n milliseconds when used by putting n on the stack and then typing the word. To execute a 9 millisecond delay, simply enter

```
9 MS
```

At the end of the delay, the message

```
TIME-UP
```

is displayed. Try it with larger delays, e.g., 1000, to visually notice the delay time.

4.6.2 +LOOP

The DO ... LOOP index always increments by 1. Another word, +LOOP , allows other increments. Each time around the loop, it takes a number off the stack for the increment, DO ... 2 +LOOP would increment by 2. The increment can be computed and it can change during loop execution. It can also be negative. The following word causes an odd number in the range 1 to N to be printed.

```
: ODD-SERIES   ( N --- .  PRINT ODD SERIES)
   1 CR DO I . 2 +LOOP ;
```

Execute ODD-SERIES with 25 as the input number (don't forget to put the input number on the stack or a STACK EMPTY error may occur.

```
25 ODD-SERIES
1 3 5 7 9 11 13 15 17 19 21 23 OK
```

4.6.3 LEAVE

LEAVE is another word used with DO loops. If LEAVE is executed within a loop, it will set the limit to the index value, causing the loop to exit when LOOP or +LOOP is next executed. LEAVE (and also the index I) can only be used inside a DO loop.

4.7 COMPARISON AND LOGIC OPERATIONS

The DO loop is one form of structured control in FORTH. Other structures described later (IF ... THEN , ELSE ... THEN , BEGIN ... UNTIL , BEGIN ... WHILE ... REPEAT , and BEGIN ... AGAIN) may test Boolean values (truth values) to control program execution. Comparison and logic words place Booleans on the stack and then the control words use these values.

4.7.1 < , > and =

Simple FORTH comparison words are < (less than), > (greater than) and = (equal). Each of these operations takes two arguments from the stack (destroying those arguments) and returns one result (a Boolean) to the stack. The second item on the stack is compared to the top item in accordance with the FORTH word. If the comparison is true, a true ("1") is returned; if false, a false ("0") value.

4.7.2 U< , 0< and 0=

Other comparison operations are U< , 0< and 0= . U< (unsigned less than) compares the top two stack numbers as unsigned 16-bit integers (see Section 5.1). 0< (zero less than) and 0= (zero equals) differ from the others in taking only one argument from the stack; it is tested for being less than zero, or equal to zero, respectively. 0< leaves a true on the stack if the number is less than zero, otherwise a false is left. 0= returns a true if the number equals zero, otherwise a false is returned. 0= works the same as

```
0 =
```

written as two words; similarly for 0< . The one-word forms are more efficient, however.

0= is equivalent to a logical "not", because it reverses the truth value of the top stack item (it changes 0 to 1, and 1 or any other non-zero value to 0).

Experiment with the comparison operations

```
HEX
10 20 < . <RETURN> 1 OK
20 10 = . <RETURN> 0 OK
5 0= . <RETURN> 0 OK
5 5 - 0= . <RETURN> 1 OK
10 -10 < . <RETURN> 0 OK
10 -10 U< . <RETURN> 1 OK
1 0= 0= . <RETURN> 1 OK
8 0= 0= . <RETURN> 1 OK
```

Note that the Boolean false value is always zero and any non-zero value (not only '1') is taken as a Boolean true. However, the value returned by these comparisons is always 0 or 1.

4.7.3 Logical Operations

Logical operations AND , OR , and XOR (exclusive OR) are provided. These are bit-wise operations. Each takes two arguments from the stack and returns one result. Each of the 16 bits of the result is obtained by applying the logical operation to the corresponding bits of the arguments. All bit positions are treated independently.

```
HEX
F7 01 AND . <RETURN> 1
08 01 OR . <RETURN> 9
F7 01 XOR . <RETURN> F6
```

The word NOT is provided as a synonym for 0= (see Section 4.7.2) to improve readability in logic expressions. Note that NOT is not a bit-wise operation; it is only a Boolean inversion and just returns the right-most bit of the word. To negate all the bits of a word (i.e., to take its one's complement), use

```
-1 XOR
```

For example

```
HEX
AAAA -1 XOR . <RETURN> 5555
AAAA FFFF XOR . <RETURN> 5555
```

These logical operations can also be applied to truth values returned by comparisons; in this case, only the right-most bit of each word is important. For example, suppose that a word ?HOT has already been defined to return a value of true if a sensor detects a temperature higher than a pre-set limit, false otherwise. Also suppose that a voltage value is previously stored on the stack. The test

```
8 > ?HOT OR
```

will return true if the voltage (on the stack) is greater than 8, or the temperature is high, or both. In this example the voltage value on the stack is first compared to 8 by use of the relational operator. This results in a Boolean value left on the stack. Then ?HOT puts another Boolean on the stack and the two Boolean values are OR'ed together.

Note that

```
?HOT 8 > OR
```

would be erroneous in this case, because the Boolean left on the stack by ?HOT would be compared with the 8 and the result of that comparison (always false) would be OR'ed with the voltage that was on the stack before this phrase was extended.

4.8 CONDITIONAL CONTROL STRUCTURES

The following FORTH control structures test a Boolean result generated by the comparison or logical operations, and direct the flow of program execution accordingly.

4.8.1 IF ... ELSE ... THEN

As with other control structures, the IF and THEN must be used as a pair; if they are not, error message #19 or #20 will be generated (see Appendix E) at compile-time. Any correct block of FORTH programming may occur between the IF and the THEN .

The IF takes one argument, a Boolean value, from the stack. If it is true (non-zero), the code between IF and THEN is executed; if false (zero), that code is skipped. In either case control resumes with the THEN . For instance,

```
GET-VOLTAGE 8 > ?HOT OR
IF SHUT-DOWN THEN
```

will execute the (predefined) operation SHUT-DOWN if the previously defined word GET-VOLTAGE returns a value greater than 8 or ?HOT returns true (or both).

An optional ELSE clause allows a block of code to be executed only if a test is false. For example, the simple control loop

```
10000 0                              ( Loop 10000 times)
DO
   GET-VOLTAGE 8 > ?HOT OR           ( Danger?)
   IF GO-SLOWER ELSE GO-FASTER THEN
LOOP
```

repeatedly tests whether temperature or voltage exceed their limits, and executes predefined operations GO-SLOWER or GO-FASTER accordingly.

4.8.2 Nesting Control Structures

The previous example shows that control structures can be nested; an IF ... ELSE ... THEN is inside a DO ... LOOP . Any of FORTH's control structures can be nested within any other to any practical depth. The recommended coding technique is to keep each definition short and simple, breaking complex operations into two or more shorter ones. For this reason, great depth of nesting is not normally used. For instance, in the examples above, operating like GO-SLOWER and GO-FASTER may themselves contain complicated control, it is best to define them as separate words to avoid cluttering a single word with many levels of nesting. Also, this is an example of top down coding as GET-VOLTAGE , GO-SLOWER , GO-FASTER and ?HOT may not exist in final form yet as the programmer experiments with the overall design of the control loop.

Of course GET-VOLTAGE , GO-FASTER and ?HOT must exist in some form at least before the loop would compile in a definition. If not, the first unknown word name encountered would cause the error message

```
<name>?
```

to be output.

Another recommended coding style is to indent IF ... THEN or IF ... THEN ... ELSE like DO ... LOOP . Keep the whole structure on one line if it is short enough, otherwise, indent the IF , ELSE (if present) and THEN to line up vertically. Each new level of nesting structure should be indented at least one space.

4.8.3 Masking and Setting Bits

The operations used for masking -- selecting certain bits within a 16-bit word, and turning them OFF or ON, or complementing or testing them -- were largely covered in Section 4.7.3. This section further explores these operations in many of the control applications to which the R65F11 and R65F12 microcomputer is well suited.

Mask values are best presented in hexadecimal. In hexadecimal, the values 0000 through FFFF can be input; a minus sign can also be used to input numbers 8000 to FFFF (-8000 to -1). The dot (period) works for output, but if the first bit is set, use the phrase

```
0 D.
```

(zero, double-precision print) instead, to avoid having the number interpreted as negative. This makes the top stack item a double integer, whose most significant 16 bits are zero, and then uses the double integer print word to output the resulting positive 32-bit integer.

In the following examples we will be changing or testing the last three bits of a word; i.e., the mask value will be 0007 (last three bits set, all others off). This value could be written simply as 7, but the leading zeros are conventionally used on both address and mask values for program clarity. The mask of course need not be a literal value as shown in these illustrations; it could be computed, perhaps by previous logical operations, or input from the terminal, etc.

To turn ON the last three bits of the word on top of the stack (leaving all other bits unchanged), execute

```
0007 OR
```

The OR operation, as described earlier, does a logical OR of each bit independently. The sign bit is treated like any other. (In these examples, we will assume that HEX has been executed to set the number base to 16.)

Similarly to turn OFF the last three bits, use

```
FFF8 AND
```

To test if any of the last three are ON, use

```
0007 AND
```

The stack top will now be zero if none of the last three bits were ON, and non-zero otherwise. This value can be used as a Boolean by IF , UNTIL , or WHILE , but be careful if the value is used as input to another AND or OR ; input to these operations should be a Boolean zero vs. one, not zero vs. non-zero. If such further logic is to be done, use

```
0= 0=
```

which leaves the truth-value unchanged but converts the zero/non-zero result into a more correct zero/one Boolean. Use

```
0007 AND 0= 0=
```

or

```
0007 XOR
```

to complement (reverse values of) the last three bits of the top stack word.

To complement all bits. Use

```
FFFF XOR
```

(which could also be written

```
-1 XOR
```

because the numeric representations FFFF and -1 are the same in 16-bit 2's-complement arithmetic.)

With the operations AND , OR , and XOR , any truth-value functions of one, two or more arguments can be used.

4.8.4 BEGIN ... Loops

In a BEGIN ... UNTIL loop, the UNTIL takes a Boolean value from the stack. If false, it loops back to the BEGIN ; if true, it terminates the loop, i.e., the loop continues UNTIL a condition is true. The following loop executes until ?HOT is true (non-zero).

```
BEGIN
   PERFORM-AN-ACTION
   ?HOT ( STOP IF HOT)
UNTIL
```

The BEGIN ... WHILE ... REPEAT loop is almost opposite; it will continue to execute the statement(s) between WHILE and REPEAT while the condition between BEGIN and WHILE is true. WHILE tests the Boolean; if true, it does nothing, allowing control to remain in the BEGIN ... REPEAT loop; if false, it branches out of the loop (to beyond the REPEAT). The REPEAT always branches back to the BEGIN . The following loop is almost the same as the UNTIL loop above

```
BEGIN
   ?HOT 0=
WHILE
   PERFORM-AN-ACTION
REPEAT
```

The difference is that the words contained between WHILE and REPEAT loop can execute zero times, but the words in the BEGIN ... UNTIL loop will always execute at least once since the test is made at the end of the loop, not the beginning. Note the use of 0= (equivalent to a logical NOT) to reverse the truth-value returned by ?HOT.

A BEGIN ... AGAIN structure creates an infinite loop. AGAIN takes no arguments from the stack -- it always causes control to return to its corresponding BEGIN . This structure could be used in a real-time control program to execute a final procedure until interrupted. It is also possible to exit this loop with a ;S word.

All of these structures can be nested within any others. Again, avoid long or complicated definitions. Short definitions make programs easier to read, debug, and modify.

4.9 DATA STORAGE

How can you get an address of available memory to use for data storage?

One way to find available memory for data structures is to use the top of your RAM memory and work down, since your word definitions start at $411 and work up. For instance, if you have 8K of RAM, addresses such as $1F00-$1FFF might be used for data, depending on the size of your program (i.e., the number and size of your word definitions).

Another approach is to allocate memory for data within the dictionary -- the words CONSTANT , VARIABLE and ALLOT , described in the next chapter, do this.

4.9.1 Find Next Dictionary Location with HERE

The word HERE returns the address of the next available dictionary location. HERE can be used to determine the size, i.e., the memory required of a colon-definition.

The procedure is to type:

```
HERE ( puts current dictionary address on stack)
```

Enter the colon-definition

```
: <name> ---- ;
```

Enter the current dictionary address on stack, swap to subtract the smaller address from the larger, and then print the size of the defined word.

```
HERE SWAP - .
```

Enter the following example of a square function. Note the first available dictionary location before and after entry of the SQUARE colon-definition. The length of the colondefinition in the dictionary is $15.

```
HEX OK
HERE DUP . <RETURN> 411 OK
: SQUARE DUP * . ; OK
HERE DUP . <RETURN> 426 OK
SWAP - . <RETURN> 15 OK
```

Check the operation of the SQUARE word.

```
DECIMAL
4 SQUARE <RETURN> 16
```

4.9.2 Use PAD for Temporary Storage

A common location for temporary storage in most FORTH systems is the address returned by the word PAD , and the memory above. In RSC-FORTH, PAD returns a starting address two bytes below the Terminal Input Buffer (TIB) in the USER area of RAM. PAD must be used with caution therefore in RSC-FORTH: the space below PAD is used by RSC-FORTH itself for temporary storage. Let's restart and check the starting address of the FORTH dictionary using HERE and the starting address of the temporary storage area using PAD .

```
COLD
 RSC-FORTH V1.5
PAD HERE HEX .S
411
37E OK
```

In most FORTH systems PAD starts 68 bytes above the start of the FORTH dictionary. To make RSC-FORTH compatible with other FORTH systems, define PAD as follows:

```
DECIMAL
: PAD HERE 68 + ;
```

Since PAD is located relative to the current top of the RAM dictionary it will change when any new words are defined, or when words already in the dictionary are forgotten. Usually this is not a problem because any particular test or run would move data into its temporary storage at PAD , and not rely on data stored there previously.

As an example, add a word to the FORTH dictionary that can be used to check where HERE and PAD are located, as other words are either added or deleted from the dictionary. Then use it first to check itself.

```
: CK-PAD ( ---. CHECK PAD & HERE)
  PAD HERE HEX
  CR ." HERE=" .
  CR ." PAD=" . ;
```

Enter CK-PAD and compare the results

```
CK-PAD
HERE=43D
PAD=481  OK
```

Now the memory fetch and store words can be tested, using PAD as available memory. Try the sequence

```
DECIMAL OK
PAD 20 BLANKS OK
15 PAD ! OK
15 PAD 10 + C! OK
PAD 10 HEX DUMP
  XXX   F  0 20 20 20 20 20 20 20 20  F 20 20 20 20 20
OK
```

The output shows the blanks (ASCII $20), the 15 ($000F) stored as a word (with the bytes reversed by the 6502 CPU so it looks like 0F00),and the 15 ($F) stored as a byte 10 bytes later. The

```
10 +
```

shows use of an offset to an address; this technique can be used to create data structures such as arrays, records and fields, etc.

4.9.3 Increment Memory with +!

A very useful memory modification word is +! (pronounced "plus store"). +! takes a stack value and a memory address and adds the value to the contents of the address; for example, it is used for incrementing counters in memory.

Define the word BUMP to increment the contents of address $600 by one, eight times, and prints the contents of $600 after each increment.

```
HEX
: BUMP
  CR 8 0 DO 1 600
  +! 600 C@ . LOOP ;
```

Initialize $600 to zero and execute BUMP

```
0 600 C!

BUMP
1 2 3 4 5 6 7 8 OK
```

Try it again but first initialize $600 to $10

```
10 600 C!
BUMP
11 12 13 14 15 16 17 18 OK
```

Define another function UPBY6 to increment the memory contents by six and display the results

```
: UPBY6
  CR 8 0 DO 6 600
  +! 600 C@ . LOOP ;
```

Clear $600 contents and try it.

```
0 600 C! OK
UPBY6
6 C 12 18 1E 24 28 30 OK
```

4.9.4 Exclusive-OR Memory Using TOGGLE

TOGGLE takes an address and a one-byte mask as arguments; it does an exclusive-OR between the byte and the address contents, updating the latter.

Experiment with TOGGLE by first initializing $600 to $F0

```
HEX OK

F0 600 C! OK
```

TOGGLE the value

```
600 55 TOGGLE OK
```

Print the result

```
600 C@ . <RETURN> A5 OK
```

Note that both +! and TOGGLE could be performed otherwise using multiple FORTH words, however, these words are convenient, and use less memory than multiple definitions.

4.10 CONSTANTS AND VARIABLES

4.10.1 CONSTANT

The word CONSTANT creates a new FORTH word which returns a value to the stack whenever it is executed. For example,

```
50 CONSTANT X
```

creates a constant named X . When this new word is executed, it will return 50 to the stack. Print the value of X with

```
X . <RETURN> 50
```

Constants are commonly used to give names to values which are fixed parameters in programs.

The same result could also have been accomplished by using a colon-definition,

```
: X 50 ;
```

But the former is more efficient in both memory use and run-time speed.

If it is necessary to change the value of a CONSTANT in RAM before storage of the program in ROM it can be done using the following technique

```
<new value> ' <name> !
```

For example, to change the 50 in the prior example to 78, use

```
78 ' X @ !
```

check it now with

```
X . <RETURN> 78
```

Note that trying to change the value of a constant, by putting a new definition of the constant in the dictionary after compiling a word using it, will not work since existing linkage to the prior value will not change.

4.10.2 VARIABLE

VARIABLE is like CONSTANT , but the word it creates returns the address of a value instead of the value itself. Therefore new values can be stored into the variable. Try

```
50 VARIABLE Y          ( Define variable Y, initialize
                         to 50 )
Y @ . <RETURN> 50      ( Fetch and print Y )
60 Y !                 ( Store 60 into Y )
Y @ . <RETURN> 60      ( Fetch and print Y )
```

Although this example illustrates the use of the word VARIABLE to initialize the value (to 50), the better practice is to always create the variable as zero or some dummy value, and initialize if necessary in an initialization section of the code. If the program is later moved to ROM, the variable location will have to be in RAM, where it cannot be initialized at compile time (see Section 4.10.4).

4.10.3 Defining Words

CONSTANT and VARIABLE are both in a special class of words called "defining words". Defining words add new words to the dictionary. The only other defining word we have seen so far is the colon used to begin colon definitions. As with the colon, the names created by CONSTANT and VARIABLE can be up to 31 characters long and can redefine other names.

The RSC-FORTH system includes eight defining words which are commonly used: the colon, CONSTANT , VARIABLE , USER , VOCABULARY , CODE , <BUILDS ... DOES> , and ;CODE . Each defining word is equivalent to a data type or class of operations. Later we will learn how the user can create entirely new data types (new defining words) by using the special operations <BUILDS ... DOES> or ;CODE .

4.10.4 USER

USER is a defining word which creates a different kind of variable. A user variable, like an ordinary variable, returns an address of where a value is stored. But user variables store their values in a special "user area" which is normally in RAM from address $300 through $37F; not in the dictionary (which may be in ROM). (The name "user area" originated on large, multi-user FORTH systems. Each user has a unique memory area for system variables, e.g., the number base currently in effect for that user, and the programmer's own variables.) The user variables are defined in Appendix G.

USER , like CONSTANT and VARIABLE , takes one argument from the stack, but the argument is not an initial value; instead it is an offset from $300 into the user area. For example,

```
60 HEX USER A
62 HEX USER B
```

creates two variables, A and B, with offsets of $60 and $62 bytes, respectively, from the user variables base address at ($300). USER is configured to allow offsets of 0-255 ($FF).

Offsets between $54 and $60 should be used however, to place the USER variables at $354 through $360. Note that offset values below 84 ($54) and particularly above 96 ($60) may cause conflict with other system user variables, PAD , or the Terminal Input Buffer (see Appendix G). Be sure that your assignment allows one word (two bytes) for each user variable.

4.10.5 ALLOT

FORTH programs can use arrays, records, virtual arrays (if mass storage is available), and other data structures. The most elegant way to create such structures is described in the chapter on user-defined data types. But a simple method which is sometimes good enough uses VARIABLE and another word, ALLOT .

ALLOT takes one argument from the stack and leaves space for that many bytes in the dictionary. For example,

```
0 VARIABLE RECORD
```

creates a variable called RECORD ; two bytes are available for the value. Suppose 100 bytes are needed. Then

```
0 VARIABLE RECORD 98 ALLOT
```

would create the variable RECORD and leave the 98 extra bytes for it.

Suppose RECORD were to be used for a customer name and address; the programmer could create such operations as

```
: LAST-NAME 0 + ;
: FIRST-NAME 20 + ;
: MIDDLE-INITIAL 30 + ;
: ADDRESS1 31 + ;
: ADDRESS2 51 + ;
```

Then

```
RECORD FIRST-NAME
```

would return the address of the start of the FIRST-NAME field.

In a similar manner, arrays can be generated and manipulated. To define an array of 300 bytes, use

```
0 VARIABLE ARRAY 298 ALLOT
```

To fetch the nth value of this array, one can use

```
: GETN ARRAY SWAP 2 * + @ ;
```

Type

```
41 GETN
```

to place the value of the 41st element onto the stack.

4.11 CHANGING THE NUMBER BASE

We have already seen the words DECIMAL and HEX , which set the number base to 10 and 16, respectively. FORTH can work in any number base (even above 16) but in practice only 10, 16, 2, and perhaps 8 are commonly used.

The number base can be changed by storing the desired base value into the user variable BASE , which is available as part of the system. For example,

```
2 BASE !
```

sets FORTH terminal input and output to binary. The user could define a word to do this,

```
: BINARY 2 BASE ! ;
```

and then later just execute

```
BINARY
```

The words DECIMAL and HEX similarly change BASE ; for convenience, these words are already defined in the system as supplied.

Note that BASE only affects input and output. Internal computation is always in binary so there is no computation-speed penalty for using different bases. Also note that the base will remain as set until changed again.

You can easily determine the current I/O number base with

```
BASE @ DUP DECIMAL .
```

The word @ puts the value of BASE on the stack. DUP duplicates the base value for the later restore. DECIMAL converts the I/O number conversion base to decimal and . prints the base and removes it from the stack.

If you need to check the base often, you can define a colon-definition word to do it, such as

```
: BASE? BASE @ DUP DECIMAL . BASE ! ;
```

When a colon-definition is compiled, the base in effect at compile time is the one that counts. Notice that the following code is erroneous and fails to compile:

```
DECIMAL
: MASK HEX 00FF OR ;
00FF?
```

The 00FF is unrecognized because the base is decimal at compile time; the word HEX does not change the base immediately (as was intended), but compiles as part of the definition of MASK. It will change the base when MASK was executed. The correct code is

```
HEX
: MASK 00FF OR ;
DECIMAL
```

A possible source of confusion is the fact that in binary, the numbers 2, 3 and 4 (as well as 0 and 1) are correctly recognized on input. This happens because the numbers 0-4 are so commonly used that they were made into constants to save memory space. Since these common numbers are FORTH words in the dictionary, they are recognized regardless of the number base in effect.

4.12 OUTPUT WORDS

4.12.1 Print Right-Justified with .R

We have already seen the word . (dot) used for printing numbers. Other operators are available to output singleprecision and double-precision numbers left-justified and right-justified.

The word .R prints a 16-bit number right-justified in a field of a given width. It takes two arguments, the number and the desired field width; the latter is on top of the stack. For example,

```
4734 CR 26 .R  CR
                          4734
OK
```

prints 4734 right-justified 26 columns. Note the use of CR to cause OK to print on the following line.

Later (in Section 5.2.2) you will see that the corresponding double-precision (32-bit) output word D. prints a double-precision signed number left-justified, while D.R prints a double-precision signed number right-justified.

4.12.2 Output Spaces with SPACE and SPACES

The word SPACE outputs one space, and SPACES takes one argument from the stack and outputs that number of spaces; such as

```
CR ." TEXT1" 4 SPACES ." TEXT2" CR
TEXT1    TEXT2
OK
```

4.12.3 Output a Character with EMIT

Use the word EMIT to take the top stack number as an ASCII value and output it. For example

```
DECIMAL 65 EMIT
```

outputs A to the terminal.

Use EMIT in conjunction with the input word KEY (see Section 4.13.1) to display an entered character. Try it with

```
KEY <RETURN> <input character> OK
EMIT "Entered character" OK
```

Note that the input character (from the keyboard) is not output by the word KEY -- only by EMIT. Now, define one word to do both

```
: ?KEY KEY CR EMIT CR ;
```

Check it with

```
?KEY <RETURN> A
A
OK
?KEY <RETURN> #
#
OK
```

Now try a few other characters of your own choice -- try lower case letters also.

4.12.4 Output a String with TYPE

To display an ASCII string given its address and length (length on top of the stack), use TYPE . Try

```
HEX 600 10 TYPE
```

which displays 16 bytes starting from HEX address 600.

This will convert whatever is in these locations to ASCII and output it -- which will display random characters and spaces until known data is placed in these locations.

Try it after first entering in string of data from the keyboard in RAM using the word EXPECT (see Section 4.13.2).

```
DECIMAL 600 40 CR EXPECT
<character string> <RETURN> ( if less than 40 characters)
600 40 CR TYPE
```

Try it with a message of up to 40 characters. Note that if the string is less than 40 characters, whatever is in memory between the last entered character through the 40th character will be converted and displayed.

4.12.5 Prepare to Output a String with COUNT

Sometimes a string is stored as a length byte followed by the string itself, and only the address of the string (of the length byte) is on the stack; this is an alternate form for storing a string.

To convert from this form, the word COUNT takes the address and return the arguments required by TYPE. Therefore,

```
COUNT TYPE
```

displays a string given the address of its length byte. Try the following

```
HERE COUNT CR TYPE
TYPE
```

More advanced output operations are discussed in Section 5.3, "Output Formatting". These allow you to create your own output formats which may include such characters as decimal points, dollar signs, and commas. More on string handling is discussed in Section 5.4.

4.13 INPUT WORDS

FORTH handles input by taking all characters (tokens) separated by spaces and first trying to look them up in the dictionary. If the token is not in the dictionary, the system tries to make a number of it, using the number base currently in effect. Then if the token contains a non-digit character, the system reports an error condition by typing the token followed by a question mark, indicating an unrecognized word (see Appendix E).

Most programs can use the FORTH system itself for terminal input. You type the numbers onto the stack and execute operations to use them. Many programs run without a terminal so no special input is needed. You seldom need to write operations to accept input from the keyboard, except for turnkey programs which do not run under the FORTH interpreter (i.e., which do not give the 'OK' to the user). When special input is required, several primitive operations are available.

4.13.1 Input a Character from the Terminal with KEY

The word KEY accepts a single character from the keyboard, returning its ASCII value to the top of the stack. It is the opposite of EMIT (see Section 4.12.3). It is often used to accept a single-letter menu choice from the user. The entry procedure is

```
KEY <RETURN> <character>
```

Note that the entered character is not displayed. Upper or lower case letters may be entered, however, FORTH words must be in upper case.

Clear the stack with an undefined word, enter a character, and check the entered value on the stack.

```
Q
Q ?
HEX KEY <RETURN> A    ( Type A)
.S
41
```

Notice the hexadecimal representation of the ASCII code for the entered number. Change the I/O base to DECIMAL and check the value again

```
DECIMAL .S
65
```

Use EMIT now to output the numbers to the display.

```
EMIT <RETURN> A
```

You can use the words KEY and . along with the I/O base to easily convert the ASCII code for an entered character into the number base of your choice. This is especially useful if you do not have an ASCII/HEX/DECIMAL conversion table handy.

To enter a number and display it in hexadecimal, use

```
KEY <RETURN> <input character> HEX .
```

To display an entered number in decimal, use

```
KEY <RETURN> <input character> DECIMAL .
```

A word can easily be defined to display the entered number in both bases.

```
: ASC
KEY DUP DUP CR EMIT HEX . DECIMAL . ;
```

The input procedure is

```
ASC <RETURN> <character>
```

Try it with a couple of numbers.

```
ASC <RETURN> A     ( A will not be displayed)
A 41 65
ASC <RETURN> 1
1 31 49
ASC <RETURN> ?
? 3F 63
```

Experiment with a few other numbers and compare your results with Appendix H.

4.13.2 Input a String from the Terminal with EXPECT

The word EXPECT accepts a one-line string from the terminal. EXPECT takes two arguments from the stack, a starting address in RAM and a maximum length of the input string; it returns no result to the stack. When executed, EXPECT waits for the terminal input; it keeps accepting characters until you press <RETURN>, or until the maximum length is reached. Note that EXPECT terminates the input string with a null byte ($00); be sure there is room for it in the input area.

For example, use EXPECT to prepare to input 15 characters, enter the data, then dump the input data in hexadecimal which represents the ASCII code for the input data (see Appendix H). After you type EXPECT , FORTH will wait for your input -- 15 characters maximum. Press <RETURN> to end the input early. Notice that the last byte dumped is the null byte.

```
HEX 600 OK
DECIMAL OK
15 CR EXPECT
1234567890123450K
HEX 600 10 DUMP
  600  31 32 33 34 35 36 37 38 39 30 31 32 33 34 35 0
OK
```

Use TYPE to display the input data as it was entered:

```
HEX 600
DECIMAL OK
15 CR TYPE
1234567890123450K
```

Using the two preceding examples as a guide, set up an input of 40 characters and display it in HEX and in ASCII.

4.13.3 Test for Character Input with ?TERMINAL

The word ?TERMINAL tests the terminal keyboard and leaves a true flag (1) on the stack if any key is depressed. An example of a word that waits for a key depression is

```
: ANY-KEY?  BEGIN  ?TERMINAL UNTIL ;
```

SECTION 5

ADVANCED OPERATIONS

5.1 OTHER SINGLE-PRECISION ARITHMETIC OPERATIONS

There are other FORTH arithmetic words that perform simple operations. While these words are not required for many elementary arithmetic operations, they simplify implementation of more complex functions.

5.1.1 Modulus Operators MOD and /MOD

The word MOD takes a dividend (second on the stack) and a divisor (top of the stack), and leaves only the remainder of a division on the stack; for example,

```
22 7 MOD . <RETURN> 1
```

The word "/MOD" ("divide-mod") leaves both the quotient (top of the stack) and the remainder (second on the stack), for example

```
22 7 /MOD CR . .
3 1
```

5.1.2 Absolute ABS and Negate NEGATE

To get the absolute value of a number use the word ABS. For example, take the absolute values of both a positive and a negative number

```
 22 ABS . <RETURN> 22
-22 ABS . <RETURN> 22
```

To reverse the sign of a number use the word NEGATE. Negate both a positive and a negative word; for example,

```
-33 NEGATE . <RETURN> 33
 33 NEGATE . <RETURN> -33
```

5.1.3 Simple Increment and Decrement 1+ , 2+ , 1- , 2-

Four words are included for convenience of incrementing or decrementing a value on the stack by one or by two. They are

```
1+  ("one-plus") Increment by 1
2+  ("two-plus") Increment by 2
1-  ("one-minus") Decrement by 1
2-  ("two-minus") Decrement by 2
```

Try the following examples,

```
1 1+ . <RETURN> 2
2 2+ . <RETURN> 4
3 1- . <RETURN> 2
5 2- . <RETURN> 3
```

5.1.4 Minimum MIN and Maximum MAX

When you wish to limit the range of number between a lower and upper value, the words MAX and MIN will compare the values of the top two numbers on the stack and leave only the greater, or smaller number, respectively.

```
 1  2 MIN . <RETURN> 1
-10 5 MIN . <RETURN> -10

 4  7 MAX . <RETURN> 7
-10 5 MAX . <RETURN> 5
```

A word that will limit numbers to a range between 1 and 9 uses the following colon-definition:

```
: RANGE 1 MAX 9 MIN ;
```

For example:

```
 6 RANGE . <RETURN> 6
 1 RANGE . <RETURN> 1
 0 RANGE . <RETURN> 1     ( 0 is smaller than 1)
 9 RANGE . <RETURN> 9
10 RANGE . <RETURN> 9     ( 10 is larger than 9)
```

5.2 UNSIGNED, MIXED AND DOUBLE-PRECISION ARITHMETIC

The FORTH stack is 16 bits wide, and the numbers we have seen so far are signed values internally formatted in 2's complement binary arithmetic. In this number representation, bit 15 (the most significant bit) contains the arithmetic sign, and bits 0 to 14 contain the numeric magnitude value. A '0' in the sign bit indicates a positive number while a '1' indicates a negative number. A positive signed 16-bit number may range from 0 ($0000) to 32,767 ($7FFF) while a signed negative number may vary from -1 ($FFFF) to -32,768 ($8000). Signed values are used most often for arithmetic calculations.

16 bits can also hold an unsigned number, where bit 15 is interpreted as an additional order of magnitude rather than the arithmetic sign. In this case, bit 15 represents a value of 32,768 (2^{15}) with the sign implicitly positive. The value of a 16-bit unsigned number may, therefore, range from 0 ($0000) to 65,535 ($FFFF). Unsigned values are used most often for addresses.

5.2.1 Entering Double-Precision Numbers

RSC-FORTH also supports 32-bit (double-precision) 2's complement numbers. These are represented as two 16-bit numbers on the stack, with the high-order number on top. Double-precision allows positive or negative decimal integers in the range -2147483648 to 2147483647 to be used.

FORTH interprets an input number as double-precision if there is a decimal point anywhere in it. The location of the decimal point does not affect the value of the input number (although the number of decimal places is saved in the system variable DPL in case you need to know it, see Appendix G). For example, '555555555.' and '.555555555' are input as the same number -- only DPL is different. Input the following numbers in double-precision format and display the contents of DPL to check the number of decimal places in the input number:

```
100. DPL @ . <RETURN> 0
156.7 DPL @ . <RETURN> 1
365.12 DPL @ . <RETURN> 2
496.436752 DPL @ <RETURN> 6
```

Double-precision numbers are integers, with the decimal point used only as a flag to indicate double-precision; the programmer must keep track of any implicit decimal point information.

Input the following small numbers in double-precision format and print out the two 16-bit numbers that make up the number. Notice that the most significant 16-bits is zero for positive numbers and is -1 ($FFFF) for negative numbers (consistent with 2's complement notation).

```
456. . . <RETURN> 0 456
23145. . . <RETURN> 0 23145
-879. . . <RETURN> -1 -879
-1289.4 . . <RETURN> -1 -12894
```

Change to hexadecimal and repeat the examples. Notice the difference since each hexadecimal digit represents four binary bits.

```
HEX
456. . . <RETURN> 0 456
23145. . . <RETURN> 2 3145
-879. . . <RETURN> -1 -879
-1289.4 . . <RETURN> -2 -2894
```

5.2.2 Printing Double-Precision Numbers

Now that you understand how double-precision numbers are stored on the stack, let's look at two FORTH words that print the data in double-precision format. The word D. (pronounced "d-dot") prints the top two numbers on the stack as a 32-bit number, left-justified. Repeat the previous examples in decimal.

```
DECIMAL
456. CR D.
456
23145. CR D.
23145
-879. CR D.
-879
-1289.4 CR D.
-12894
```

It is often desirable to print the data right-justified. The word D.R ("d-dot-r") prints a double-precision number, right-justified in a variable width field. The top number on the stack is the column in which the least significant digit of the data is to be printed, while the second number is the double-precision number (the data) to be printed. Try the example data one more time, but right-justify it in the 30-column field as follows (if the number prints in the wrong column, you forgot to switch back to decimal)

```
456. 30 CR D.R
                                456
23145. 30 CR D.R
                              23145
-879. 30 CR D.R
                               -879
-1289.4 30 CR D.R
                             -12894
```

Define a word to print multiple double-precision numbers right-justified 15 columns.

```
: PRINT-RIGHT ( N---.)
  0 DO CR 30 D.R LOOP CR ;
```

Enter the data on the stack and print it with PRINT-RIGHT . Place the numbers and the number of items on the stack before calling PRINT-RIGHT .

```
456. 23145. -879. -12894.
4 PRINT-RIGHT
                             -12894
                               -879
                              23145
                                456
```

5.2.3 Other 32-Bit FORTH Operators

There are several other double-precision FORTH words which are analogous to the single-precision operations.

Double-precision add D+ ("d-plus") operates in the same manner as + , except it uses the top two double-precision numbers on the stack as inputs and leaves one double-precision number, e.g.,

```
3456. 6576. D+ D. <RETURN> 10032
```

DABS ("d-abs") returns the absolute value of a doubleprecision number similar to the single-precision word ABS.

```
-76543. DABS D. <RETURN> 76543
```

DNEGATE ("d-negate") changes the sign of the double-precision number on the stack, allowing subtraction.

```
-768945. DNEGATE D. <RETURN> 768945
```

The word S->D ("s-to-d") converts a single-precision number on the top of the stack to double-precision number.

```
6758 DUP CR .
6758
S->D CR D.
6758
```

The operation D+- ("d-plus-minus") applies the sign of the single-precision number on top of the stack to the double-precision number beneath it. Note that a minus number on top always changes the sign of the double-precision number below. Note also that the single-precision number is removed by the D+- operation.

```
56789. -78 D+- D. <RETURN> -56789
```

5.2.4 Unsigned Compare U<

Addition and subtraction are the same for signed or unsigned single precision numbers so there are no special operations for these. Comparison is different, however, so an unsigned compare word U< ("u-less-than") should be used instead of the signed compare word < . Using < in a comparison where one number exceeds 32,767 will result in an incorrect answer. The comparison

```
20000 40000 < . <RETURN> 0
```

gives 0 (Boolean false), because 40,000 as a signed 16-bit number is negative and is therefore less than 20,000. The comparison

```
20000 40000 U< . <RETURN> 1
```

yields 1 (Boolean true) which is the correct result. Use U< to compare addresses, unless you are sure both of them will be below 32,768, or both above it.

5.2.5 Unsigned Multiply U* and Divide U/

Two other unsigned operations are provided. The unsigned multiply word U* ("u-times") multiplies two unsigned single-precision numbers to give an unsigned double-precision number. For example,

```
40000 40000 U* CR D.
1600000000
```

The unsigned divide word U/ ("u-divide") divides an unsigned double-precision number (second on stack), by an unsigned single-precision number (top of stack), to give an unsigned single-precision quotient (top of stack) and unsigned single-precision remainder (second on stack).

The following example gives a positive quotient and unsigned remainder.

```
120031. 4 U/  . .  <RETURN> 30007  3
```

Note that another example,

```
140035. 4 U/  . .  <RETURN> -30528 3
```

appears to give a negative quotient and unsigned remainder. In the single-precision format a number between 32,768 and 65,535 is displayed as negative unless printed as a double-precision number. The following example forces the quotient to a double-precision number and prints it along with the remainder.

```
140035. 4 U/ 0 D. . <RETURN> 35008 3
```

5.2.6 Mixed-Mode Operations M* , M/ , and M/MOD

Some mixed-mode operations are also available. The operator M* ("m-times") multiples two signed numbers and returns a signed double-precision product. Two examples illustrate the operation.

```
4532 8765 M* D. <RETURN> 39722980
4876 -5467 M* D. <RETURN> -26657092
```

The operator M/ ("m-divide") divides a double-precision number (second on stack), by the single-precision number (on top of the stack), and returns a signed single-precision remainder (second on stack) and signed single-precision quotient (top of stack). Try this example:

```
564755. 500 M/ . . <RETURN> 1129 255
```

The word M/MOD ("m-divide-mod") divides a positive double-precision number (second on stack) by a positive single-precision number (top of stack), returning an unsigned single-precision remainder (second on stack) and an unsigned double-precision quotient (top of stack). Examine with

```
54000. 5000 M/MOD D. . <RETURN> 10 4000
```

5.2.7 Scaling

Suppose you are working with 16-bit integers and want to multiply one by a scaling factor such as the sine of 45 degrees. Since we are using only integers, this sine value (0.7071) could be represented as multiplied by 10000, i.e., 7071. We want to multiply our number by 7071 and divide it by 10000 -- the problem is that the intermediate product is too large to represent as 16 bits --- so FORTH provides an operation */ ("times-divide")

which multiplies the third term on the stack by the second item and then divides the result by the top of stack item, while keeping a 32-bit intermediate product. This is illustrated by

```
12345 7071 10000 */ . <RETURN> 8729
```

Another operation */MOD ("times-divide-mod") performs the same operation but also returns the remainder as the second number on the stack. Repeat the last example but also print the remainder.

```
12345 7071 10000  */MOD . . <RETURN> 8729 1495
```

5.3 OUTPUT FORMATTING

The numeric output commands described in Section 4.11.1 are enough for most programs. However, some applications need special formats such as decimal points and dollar signs with printed numbers, or colons within numbers to indicate degrees, minutes, and seconds. FORTH includes special output operations which let you define your own numeric formats.

5.3.1 S->D , <# , #S , SIGN and #>

To use these operations, first get a double-precision number on the stack. Then a special operation <# ("less-sharp") starts numeric conversion. Digits are converted from the right, i.e., least significant digit first. ASCII characters such as decimal points and dollar signs can be added where needed. Then another special operation #> ("sharp-greater") closes the conversion. Between the <# and the #> a double-precision number from the stack is converted into a string of ASCII characters representing the number's value. Depending on the program, this conversion can be done a character at a time or several characters at once. The least significant digit is converted first and builds in memory starting at PAD and moving down as the string grows.

For example, the following definition creates and tests a word .PRINT , which works like the print command . . This example illustrates a fairly simple case with no added character.

```
: .PRINT
   S->D SWAP OVER DABS
   <# #S SIGN #>
   TYPE SPACE ;
```

Enter a number to test .PRINT

```
12345 .PRINT <RETURN> 12345
```

First, S->D converts the top stack number to doubleprecision. The SWAP OVER , in effect, makes an extra copy of the high-order 16-bit part below the double-precision number of the stack; this is required to preserve the sign information since the numeric conversion itself requires a positive number -- hence the DABS.

The <# sets up the output conversion followed by the #S ("sharp-S") which converts all digits of the number to ASCII. The SIGN word then places an ASCII minus sign if necessary; it uses the extra copy of the high-order part of the doubleprecision number to detect if that number was originally negative.

The #> closes the conversion, and leaves stack arguments set up for TYPE -- i.e., the number of characters to type on top of the stack, and the address of the first one below it. The SPACE word leaves one space after the number to separate it from the next one.

5.3.2 # and HOLD

Here is an example showing creation of a word D$. which prints a double-precision number with decimal point and dollar sign. Besides the above operations, it also uses . # ("sharp") , which places a single digit into a string being created. It also uses HOLD which takes an ASCII value from the stack and places that character into the number being formed. Remember that the string builds from the least significant digits first.

The following colon-definition shows how to convert digits, individually, placing additional characters such as decimal points and dollar signs where desired within a number.

```
DECIMAL
: D$. ( D ---)
   SWAP OVER DABS
   <# # # 46 HOLD     ( 46 is the decimal point)
   #S 36 HOLD SIGN #> ( 36 is the dollar sign)
   TYPE SPACE ;
```

The following examples show that the leading zeros are handled properly.

```
555. D$. <RETURN> $5.55
5. D$. <RETURN> $0.05
```

If three places after the decimal point were desired, one additional # would be necessary before the '46'.

Let's define another word that uses D$. to print multiple numbers

```
: PRINT-D$.
   CR 0 DO D$. CR LOOP ;
```

Now put four numbers on the stack and print them

```
123. 45678.
3456. 23456.
4 PRINT-D$.              ( Print four numbers)
$234.56
$34.56
$456.78
$1.23
```

The following word prints a mixed number when the integer double-precision number is on top of the stack and the position of the decimal point is held in the user variable DPL .

```
HEX
: XN.
SWAP OVER DABS          ( Set form for sign and
                          conversion)
<# DPL @ -DUP           ( Convert digits to right of
IF 0 DO # LOOP THEN       decimal point)
2E HOLD #S SIGN #>      ( Convert decimal point and
                          and remainder of digits)
TYPE SPACE ;            ( Print results)
DECIMAL
```

Verify proper conversion with an example such as:

```
34.786  XN.  <RETURN> 34.786
```

5.4 STRINGS

FORTH does not have a standardized package of string-handling operators, but it does have primitive operations from which string routines can be built. For many applications the primitives themselves are enough. A series of string handling functions that can easily be constructed in FORTH is described in Appendix I.

Because there is no ready-made standard, you can decide how to represent strings internally. Two formats are already in use within the system. In one, a length byte is followed by the string itself; string length cannot exceed 255 characters. The address of the string is the address of the length byte (this is used to store names of words in the dictionary). In the other format, only the string itself is stored in memory; its address is the address of its first character. The length is stored separately, and kept above the string address on the stack.

5.4.1 Address String Data with COUNT

The COUNT word returns the address (second on stack) of a character string and the number of characters, e.g., bytes, in the string (top of the stack). The character string can be up to 255 bytes in length. COUNT operates on the address preceding the first byte of the character data which must contain the number of bytes of the character data.

5.4.2 Output String Data with TYPE

The word TYPE takes the address of the first data byte (second on stack) and the data byte count (top of stack) and outputs it to the active output device. TYPE is usually preceded by COUNT which sets up the data address and byte count in a compatible format.

5.4.3 Input String Data with EXPECT

The word EXPECT (see Section 4.11.2) can be used to read a string into memory. Unfortunately it does not return the actual length of the input string; however, you can find this length if it is needed by searching for the trailing nulls (binary zero bytes).

5.4.4 Suppress Trailing Blanks with -TRAILING

To eliminate trailing blanks of a message, the word -TRAILING is used. If -TRAILING is given an address of a string (second on stack) and a count (top of stack) such as that output by COUNT , then -TRAILING will adjust the count to commands if necessary to eliminate any trailing blanks in the string. For example,

```
HEX 9
600 9 EXPECT <RETURN>
```

allows nine characters to be entered into memory starting at $600. Enter

```
ONLY5 (followed by four spaces)
```

immediately after the <RETURN> following EXPECT (note that OK will not be displayed until after nine characters are entered). A five character message with four trailing blanks is now in RAM. Check it with

```
600 9 DUMP
  600  4F 4E 4C 59 35 20 20 20 20 0 XX XX XX XX XX XX
OK
```

Notice the terminating null character ($0) placed after the entered data. Now enter

```
600 9 -TRAILING .S
5                ( character count less trailing blanks)
600              ( starting address)
```

To see the full message less trailing blanks, enter

```
CR TYPE
ONLY5  OK
```

5.4.5 Interpret a Number with (NUMBER)

Most of the words needed for terminal input are described in Section 4.11. This section covers the special situation of accepting a numeric string as input and interpreting it as a number. Such special input is seldom necessary, because most programs can accept input from the FORTH system itself (i.e., numbers typed onto the stack), if they use a terminal at all. This special terminal input is most often for turnkey programs not run under the direct control of FORTH (in which the user should not see the OK).

First use EXPECT to accept a string from the user (see Section 4.11.2). Then use (NUMBER) to interpret part or all of that string as a number (the parentheses are part of the name). This operation is a bit complicated. It needs a double-precision zero on the stack, as well as the address of the first ASCII character of the number minus one, i.e., the address of one byte before the number begins. This address must be on top of the stack. (NUMBER) then returns the value of the number; it is accumulated into the double-precision zero. The address on top of the stack is incremented to point to the first non-numeric character, i.e., to the terminator of the number; the program may test this terminator, which would normally be a blank, and if it is an unexpected quantity, e.g., a letter erroneously typed by the terminal operator, error handling can be performed.

For example,

```
: INPUT
   600 10 EXPECT 0 0 600 1 - (NUMBER) ;
```

defines a word

```
INPUT
```

which when executed, accepts a number, returning the address just beyond the number, and the number itself in doubleprecision form (as two numbers on the stack). (NUMBER) will not skip leading blanks or handle minus signs; you must do so if necessary. By defining INPUT , you have handled the difficult part of (NUMBER) just once. Subsequent inputs can be processed easily by using the INPUT word.

5.4.6 Input a Number with NUMBER

The word NUMBER (written without the parentheses) will handle leading blanks and the minus sign. But if the string being converted is in error (e.g., contains alphabetic letters), FORTH will handle the error itself by echoing the unrecognized string with a question mark; the user cannot get control to process the error differently. Therefore the more primitive (NUMBER) is usually preferred for turnkey applications.

5.5 DICTIONARY STRUCTURE

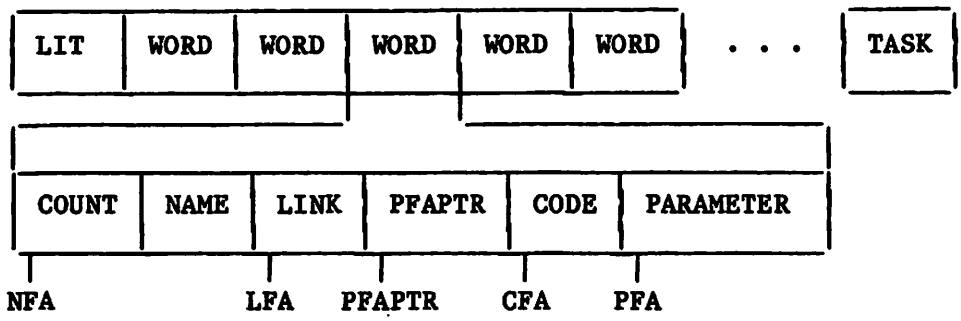
As you are well aware by now, FORTH consists primarily of a dictionary of words. The FORTH words were listed using VLIST in Section 4 and are shown in Table 4-1. This section describes the structure of the words in the dictionary. RSC-FORTH allows some very useful ways to manipulate the dictionary, not found in other FORTH systems. These unique features are discussed in Section 6.

5.5.1 FORTH Word Structure

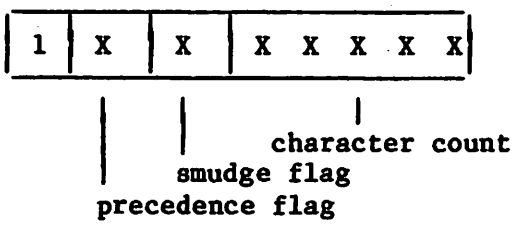
The FORTH words are arranged one after the other, starting with LIT to TASK , followed by all user-created words. Each word is composed of six sections:

- flag bits and name character count
- name
- link address
- parameter field pointer
- code address
- parameter field

Here is a picture of the dictionary with a word expanded with its sections:



The first byte of a word begins the name field and contains the number of characters in the word's name along with two flag bits:



The MSB is set to indicate the start of a name. The precedence flag indicates if the word is for compile or immediate execution. The smudge flag prevents the word from being found in the dictionary during compilation. If the compilation finishes successfully, the smudge bit is reset to zero allowing the name to be recognized. "SMUDGED" words will show up in a VLIST, however. To eliminate a "SMUDGED" word from the dictionary, toggle the "SMUDGE" bit by using the word SMUDGE and then use FORGET to eliminate the word from the dictionary.

The name field continues with the ASCII characters of the name with the MSB of the last character set to indicate the end of the name.

The link address is the address of the count byte of the previous word (i.e., the beginning of the previous name field). This allows the dictionary to be scanned, word-by-word, beginning with the most recent word and moving back. The last word in the dictionary has a link address of zero.

The parameter field pointer is a two-byte pointer that points from the dictionary portion of the definition to the actual code of the definition. This field is unique to RSC-FORTH. It is this pointer that allows RSC-FORTH to operate with a separated kernel in ROM. This provides the link from the dictionary to the kernel. Note that there is no reciprocal link from the kernel back to the dictionary. This is done to save space in the kernel. This means it is possible to use the PFAPTR to find the parameter field, but not vice versa.

The code address indicates the code to be executed depending on the type of word, i.e.,

```
code  =  $F874          for  "colon-definition" words
      =  $F8A0          for  USER words
      =  $F894          for  VARIABLE words
      =  $F889          for  CONSTANT words
      =  $F9C5          for  DOES> words
      =  next address   for  "CODE-definition" words
```

The parameter field changes meaning depending on type of word. If the word is a "colon-definition" word, the parameter field contains the addresses of the FORTH words (their CFA's) that make up the definition. If the word is a "CODE-definition" word then the parameter field contains the actual R6500 assembly code for the logic to be performed.

Examine the TASK word; as an example,

```
FORGET TASK OK
: TASK ; OK
HEX OK
404 10 DUMP
  404  84 54 41 53 CB 3D 38  F  4 74 F8 17 F7  4 44 55
OK
```

Now look at its component parts:

```
404  84            ( 8 =   MSB = 1 = start of a word)
                   ( 4 =   Number of characters in TASK)

405  54 41 53 CB   ( ASCII characters for  TASK  with MSB)
                   ( of last character set to 1)

409  3D 38         ( Link address of $383D links to  ADMP)
                   ( word in the RSC-FORTH Development ROM)

40B  0F 04         ( Parameter Field Pointer address links)
                   ( to Parameter Field location)

40D  74 F8         ( Code address of $F874 indicates)
                   ( colon-definition)

40F  17 F7         ( Parameter address of $F717 indicates)
                   (  the end of a colon-definition,)
                   ( i.e., ';')
```

For both CONSTANT and VARIABLE words, the parameter field is two bytes long and contains the value of the constant or variable. For USER words, the parameter field is one byte long and contains the offset into the user area for the USER variable.

5.5.2 Handling FORTH Word Addresses

There are five FORTH words concerned with finding the address of the various word fields. They are:

```
'       ( tick)
PFAPTR  ( Parameter Field Pointer Address)
CFA     ( Code Field Address)
LFA     ( Link Field Address)
NFA     ( Name Field Address)
```

a. ' leaves the parameter field pointer address (PFAPTR) of the word following it on the stack.

b. NFA converts the parameter field pointer address on the stack into the name field address (NFA).

c. LFA converts the PFAPTR into the link field address (LFA).

d. CFA converts the PFAPTR into the code field address (CFA).

e. PFAPTR converts the name field address (NFA) to the parameter field pointer address.

5.5.3 FORTH Word Handling Examples

To print the contents of LFA of CLIT , perform

```
HEX
' CLIT  LFA @ 0 CR D.
202C
```

To print the name of LIT , perform

```
' LIT NFA COUNT 1F AND CR TYPE
LIT
```

To print the topmost word name in the dictionary, perform

```
LATEST CR ID.
TASK
```

A simple list of all words in the FORTH dictionary can be obtained with

```
: DIR CR LATEST
  BEGIN
  DUP ID. CR
  PFAPTR LFA @ DUP
  0= UNTIL ; OK
  DIR <RETURN>
  DIR
  TASK
  .S              ( Press <RESET> to terminate list)
```

5.6 VOCABULARIES

Vocabularies are groupings of FORTH words. They are used to allow the same names to be used for different operations in different application areas. If a name is redefined in the same vocabulary, only the latest definition will be accessible. But, if the same name is used in two or more different vocabularies, all the definitions can be selected.

The RSC-FORTH system as supplied includes two vocabularies: FORTH , which is the default vocabulary, where the example definitions illustrated earlier in this manual were all placed, and ASSEMBLER , which contains definitions of R6500 instruction mnemonics, mode symbols, and other operations only used for the assembler (See Section 6). For example, RSC-FORTH has two words, 0= and 0< , which are defined in both vocabularies and used differently (see Section 4.7.2 and 6.6) depending on which vocabulary is selected (see Section 6.1).

5.6.1 More on VLIST

As mentioned at the beginning of Section 4, you can list the FORTH vocabulary by executing the word

```
VLIST
```

Press any key to terminate the VLIST . VLIST can also be used to list the words contained in the assembler vocabulary (see Section 6). Enter

```
ASSEMBLER VLIST
```

which will print the ASSEMBLER vocabulary (and then link to the FORTH vocabulary and print that also). The FORTH link word (no name) is shown at address $338 in the VLIST. Then it is wise to execute

```
FORTH
```

to set the vocabulary back to FORTH .

Vocabularies are effective only at compile time; they have no meaning after object code has been compiled. They only affect the search for names of words in the dictionary and have no bearing on headerless code.

5.6.2 CONTEXT and CURRENT Specify Vocabularies

At any given time, two vocabularies are in effect: CONTEXT and CURRENT . CONTEXT specifies the vocabulary in which dictionary searches begin, while CURRENT gives the vocabulary into which new definitions are placed. Often CONTEXT and CURRENT are the same; e.g., when RSC-FORTH is initialized (initial entry or COLD word), both of them point to the FORTH vocabulary. But when a CODE-definition is being assembled, the CONTEXT vocabulary is ASSEMBLER , while CURRENT is usually FORTH or something else (CURRENT would be ASSEMBLER only if you were adding new capabilities, e.g., macros, to the assembler).

To set the CONTEXT , just execute the name of a vocabulary; e.g.,

```
ASSEMBLER
```

switches to the ASSEMBLER vocabulary. To set the CURRENT , the word

```
DEFINITIONS
```

changes the CURRENT to the CONTEXT . So to change both of them to ASSEMBLER , execute

```
ASSEMBLER DEFINITIONS
```

Now any new colon-, CODE- , or other definition will go into the ASSEMBLER vocabulary. Remember to get back by executing

```
FORTH DEFINITIONS
```

after you are done extending the assembler.

Incidentally, any colon or other new definition will set CONTEXT back to CURRENT . This is done to help the programmer avoid errors. So if you are in FORTH and then execute just

```
ASSEMBLER
```

without DEFINITIONS , and then define any new words, they will go into FORTH , and also the CONTEXT will be set back to FORTH ; i.e., executing ASSEMBLER alone will have had little effect.

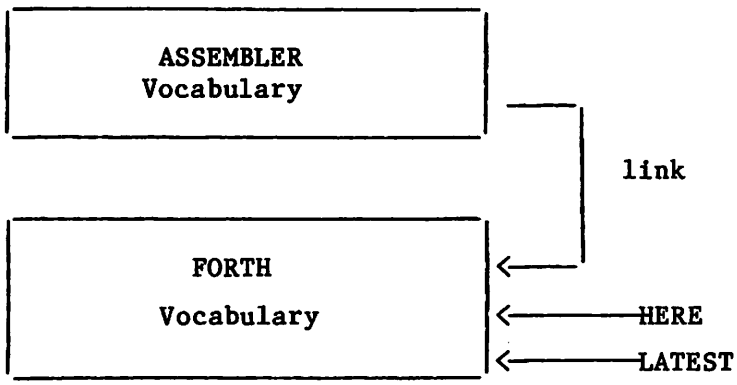
5.6.3 Use LATEST and HERE to Check Directory Addresses

The word LATEST leaves on the stack the name field address of the last word pointed to by CURRENT . Do a COLD start and check the FORTH dictionary

```
HEX LATEST <RETURN> . 404
```

The word HERE leaves on the stack the next available dictionary address where new words can be added.

```
HERE . <RETURN> 411
```



5.6.4 Application Libraries

You can create your own vocabularies, in order to keep different application libraries separate from each other. Just execute

```
VOCABULARY <name>
```

where <name> is the name (up to 31 characters) you want the new vocabulary to have. Then you would usually say

```
<name> DEFINITIONS
```

and begin putting your application library words into the <name> vocabulary.

In the RSC-FORTH system, the new vocabulary will be linked to whatever vocabulary it was created in (usually FORTH). All vocabularies form a tree, allowing subvocabularies nested to any depth. All vocabularies from CONTEXT along the branching path back to the root of the tree (which is always FORTH) will be searched whenever a name is entered into the FORTH system for execution or compilation.

To create a new vocabulary, use the word VOCABULARY along with the vocabulary name to change CONTEXT to point to its last word, e.g.,

```
VOCABULARY NEW
```

To add words to NEW, now type

```
NEW DEFINITIONS
```

because DEFINITIONS sets CURRENT equal to CONTEXT allowing new words to be added to the NEW vocabulary.

Now add a new word

```
: MYWORD ." NEW VOC" ;
```

and type VLIST and get

```
 42C MYWORD          336              417             40B TASK
3844 ADMP          3805 ;DUMP       37CF FORMAT     367E FMTRK
3674 BANKEXECUTE   3664 BANKEEC!   3657 BANKC@     OK
( <SPACE> bar pressed here)
```

Now type FORTH , this will set CONTEXT back to the FORTH vocabulary and MYWORD will not show up on a VLIST but it will execute.

Now type FORTH DEFINITIONS , changing both CURRENT and CONTEXT to the FORTH dictionary. Now MYWORD will not show up in VLIST and will not execute. To use MYWORD one needs only to link the NEW vocabulary to FORTH by typing NEW .

It is generally recommended that use of subvocabularies be avoided and all user-defined vocabularies be created in FORTH. This is for compatibility with many other FORTH systems which only allow one level of vocabulary nesting.

Vocabularies are optional, needed for advanced users only. Most programs only use the default FORTH vocabulary, and the programmers do not even need to know that vocabularies exist.

5.7 IMMEDIATE WORDS

Most FORTH words will be compiled, not executed, when they are used inside a colon-definition. Immediate words are the exception. They are executed even at compile time.

The words used for conditional branching and looping (e.g., IF , THEN , DO , LOOP , BEGIN , etc.) are all immediate words. They execute at compile time in order to handle forward or backward branch references, various error checks, and other functions. Some of these words such as DO and LOOP place special run-time words, not used directly by the programmer, into the object code. But some, (e.g., BEGIN) place nothing at all in the object code.

To define a new immediate word, use IMMEDIATE after its definition, i.e., after the semicolon. This causes the last word defined to be immediate.

On rare occasions the programmer must force compilation of an immediate word. To do this, use [COMPILE] (the brackets are part of the name before the immediate word to be compiled.)

For example, suppose you want to run source code written for an older version of FORTH which used the name ENDIF for THEN (RSC-FORTH supports both of these words). You don't want to go through the code and make all the changes. It would be wrong to define ENDIF by

```
: ENDIF THEN ; IMMEDIATE
```

because the THEN would try to compute a conditional branch and cause an error message because there is no corresponding IF . The correct form would be

```
: ENDIF [COMPILE] THEN ; IMMEDIATE
```

This defines ENDIF to work the same as THEN .

5.8 CREATING YOUR OWN DATA/OPERATION TYPES

The RSC-FORTH system includes several 'defining words'; that is, words which create new words. The most important of those are: : (the colon), CODE , CONSTANT , VARIABLE , USER , and VOCABULARY . The defining words C , CON and CASE: are unique to RSC-FROTH and are discussed separately in Section 6.

You may want to create new defining words. In general, each new defining word creates a new type of data structure of operation. Examples might be ARRAY , MATRIX , CUSTOMERRECORD , and VIRTUAL-ARRAY . FORTH assemblers use similar structures for classes of instructions, such as one and two-byte addresses.

New data or operation types are usually created by the pair words <BUILDS and DOES> ; these words are always used together. The word ;CODE is an alternative way to create new data structures; they run faster but require use of the assembler (see Section 6.9).

For example, suppose we want a word to create arrays of 2-byte (16-bit) memory locations numbered from zero. We want to say, e.g.,

```
50 ARRAY X
10 ARRAY Y
```

to create arrays 'X' and 'Y' with 50 and 10 elements, respectively. Then we want to use these arrays as

```
0 X             (0th element of ARRAY X)
49 X            (49th element of ARRAY X)
0 Y             (0th element of ARRAY Y)
9 Y             (9th element of ARRAY Y)
```

to return the addresses of the first (0th) and last elements of X and Y. We can then use the arrays to store and fetch data using ! and @ . Note that there are 50 elements in ARRAY X (numbered from 0 to 49) and, similiarly, there are 10 elements in ARRAY Y (numbered from 0 to 9).

How do we define ARRAY to do this? We could use

```
: ARRAY
<BUILDS 2 * ALLOT
DOES> SWAP 2 * + ;
```

How does this definition work?

The <BUILDS part tells what happens at compile time. The argument (on top of the stack) to ARRAY (50 or 10 in the above example) is multiplied by two, and ALLOT leaves that many bytes of space in the dictionary. Note that when X or Y or any other array is being defined, the appropriate number of bytes must be alloted for it.

The DOES> part tells what happens when X or Y is executed. At execution of 0 X , 49 X , etc., DOES> automatically causes the system to place the address of where the array begins on top of the stack; any arguments (0 , 49 or 9 in these examples) are below that address. The SWAP brings the array index to the top of the stack, where it is multiplied by two to get its byte offset from the beginning of the array. This offset is then added to the address of the array to get the desired address of the particular element.

To see how the allocation works, after entering the definition of ARRAY , type:

```
DECIMAL HERE .
```

to see where the next dictionary entry will occur . Then enter

```
50 ARRAY X HERE .
```

to how much dictionary space has been used by the array. Note that there are 10 bytes of overhead plus the 100 bytes for the array.

If you now enter

```
10 ARRAY Y HERE .
```

you will see that 20 bytes of array plus 10 bytes of overhead has been allocated. Entering

```
1234 5 X !
```

will now store 1234 in the fifth element in the X array. And entering

```
5 X @
```

will now place 1234 on the top of the stack.

The data to go in an array may be loaded at compile time by the following technique:

```
: VECTOR <BUILDS 0 DO ,
  LOOP DOES>
  SWAP 2 * + ;
```

The data on the stack is in inverse order and the top value on the stack is the number of elements in the vector. Thus,

```
data   data   --- data
   n-1    n-2         0
n VECTOR ALPHA
```

creates a vector with n elements called ALPHA . For example:

```
55 4444 -33 2222 1111 0
6 VECTOR ALPHA
```

Now check the element data

```
3 ALPHA @ . <RETURN> -33
0 ALPHA @ .  <RETURN> 0
2 ALPHA @ .  <RETURN> 2222
```

These elements may be changed if so desired if the dictionary is in RAM, e.g.,

```
1010 0 ALPHA !
```

Check with

```
0 ALPHA @ . <RETURN> 1010
```

In the definition of VECTOR , a loop is executed the number of times indicated by the top value on the stack. The only function performed by the loop is to use the , command to store the current top value of the stack into the dictionary entry. This is repeated until all of the vector elements are stored in the dictionary definition. The remainder of the operation is the same as the definition. The remainder of the operation is the same as the prior example for ARRAY .

<BUILDS and DOES> can be used to create much more elaborate data types such as special array definitions which do bounds or other error checks at run-time. These definitions could be used during debugging and replaced with the regular (faster) definitions for production use, once you are assured that no out-of-bounds error will occur.

SECTION 6

SPECIAL OPERATIONS

RSC-FORTH has many extensions not found in other standard FORTH packages. Basically these extentions can be grouped into five categories of new words; system constants, new defining words, target compilation/dictionary control, disk interface and general utilities.

6.1 SYSTEM CONSTANTS

There are a number of significant addresses in RSC-FORTH corresponding to microcomputer functions such as input/output ports, mode controls and serial channel controls. These locations are of importance to the designer of RSC-FORTH systems for dedicated applications since these designs usually require the construction of I/O structures not covered by the use of KEY and EMIT . A list of these words is given with definitions in Table 6-1.

These addresses are named in RSC-FORTH by a special type of defining word. Later in this section it will be made clear that applications which are programmed for a target system must reference only words that are in the kernel. Referring to a word not in the kernel will cause system failure when the R65FR1 Development ROM is removed.

Although none of these system addresses are actually defined in the kernel, they may be used in the development of dedicated application code. This is possible because the defining word used to create the system constants interprets their use differently when compiling. Used outside a colon definition these words perform exactly as constants do.

TABLE 6-1. System Address Constants

Word	Function	Address
PA	Port A	$0000
PB	Port B	$0001
PC	Port C	$0002
PD	Port D	$0003
PE	Port E	$0004
PF	Port F	$0005
PG	Port G	$0006
IFR	Interrupt Flag Register	$0011
IER	Interrupt Enable Register	$0012
MCR	Mode Control Register	$0014
SCCR	Serial Communications Control Register	$0015
SCSR	Serial Communications Status Register	$0016
SCDR	Serial Communications Data Register	$0017
INTFLG	High Level Interrupt Flag Register	$004A
INTVEC	High Level Interrupt Vector	$005B
IRQVEC	Low Level Interrupt Request (IRQ) Vector	$0040
NMIVEC	Low Level Non-Maskable Interrupt (NMI) Vector	$0042

For example, enter

```
PB .
```

A 1 will be displayed. Port B is at address $0001. To see the value in Port B, enter

```
HEX PB C@ .
```

An FF will be displayed if Port B has not been modified since reset. A check of the words in the kernel shows that PB is not one of them. The application programmer can, however, access PB . The following definition does not cause system failure when the Development ROM is removed:

```
: PB? PB C@ . ;
```

The interpreter detects that PB is being used inside a colon definition and, rather than compile the CFA of PB into the definition, instead, compiles a primitive that indicates the byte following it is a constant to be put on the stack and then puts the value of PB in the next byte. This is exactly what happens if you look up the actual address of Port B and use that number in the definition. The following definition produces identical code to the previous example

```
: PB? 1 C@ . ;
```

Each of the system variables function in this fashion.

6.2 DEFINING WORDS

6.2.1 Creating Address Constants with C,CON

The defining word used to create the system address constant is available for general use. Its name is C,CON . It is used in the same format as CONSTANT . For example:

```
12 C,CON TWELVE
```

causes a new system address constant to be added to the vocabulary. Unless you are working with special cases of target compiled code, C,CON has no advantage over CONSTANT . It should be noted that C,CON uses only byte values which limits its use to zero page addresses.

6.2.2 Selecting Words with CASE:

The other new defining word of RSC-FORTH is very useful. There are many instances when a program needs to perform one of several actions based on a known condition. For instance, programs are often required to perform one of several possible functions when an operator pushes a key. The defining word CASE: allows a very compact structure to be easily constructed. When a word defined with CASE: is executed, a number is taken from the stack and is used to pick that numbered word from the definition and execute it.

To illustrate the use of CASE: , assume that several possible functions are already defined: UP , DOWN , LEFT , RIGHT , TO , and FROM . A selective case structure could be built by defining as follows:

```
CASE:  MOVE-IT UP DOWN LEFT RIGHT TO FROM ;
```

Assuming the names of the functions imply their actions, an entry of 0 MOVE-IT causes an upward movement (using UP)and 2 MOVE-IT causes a movement to the left (using LEFT). When used in a large definition, on operator could push a coded key to evoke the desired response. The definition could be as follows:

```
: MOVE-LOOP BEGIN KEY 30 - MOVE-IT AGAIN ;
```

MOVE-LOOP makes it possible for you to enter the keys 0 through 5 and command movements up, down, left, right, to and from repeatedly, one per keystroke.

A word of caution when using a CASE: definition is needed. CASE: performs no error checking on the entries made into the list. An entry other than 0-5 in the last example would in all probability cause system failure or, at a minimum, undesired side effects. Error checking was omitted from interpreter in CASE: to save room, increase the operating speed and give the programmer maximum flexibility. Error checking can easily be accomplished as in the following expanded definition of MOVE-LOOP:

```
: MOVE-LOOP BEGIN KEY 6 OVER U< IF MOVE-IT ELSE . . "?" THEN AGAIN ;
```

More elaborate forms of error checking are also possible.

The code that interprets CASE: definitions is itself the product of a <BUILDS DOES> structure. The DOES> portion, the interpreter, is actually in the kernel. Therefore, even though CASE: is not in the kernel, words defined with CASE: can be used in standalone, target compiled systems without the support of the Development ROM.

6.3 TARGET COMPILATION/DICTIONARY CONTROL

Although FORTH code by its very nature is compact, it is often desirable to compress code even further by target compilation. The process of target compilation in conventional FORTH systems usually implies a disk to disk operation. The compiling program supplies a runtime kernel of fixed size (usually 2K to 5K bytes). FORTH structures are then compiled onto the kernel from FORTH source code on disk screens. Since the operating target compilation program itself is so large the resultant program generally is assembled on disk.

More advanced target compiling systems are not limited to fixed size kernels. These programs generate a new kernel that contains only the functions required by the application dictionary. The finished program is usually much smaller, on the order of 2K bytes for a simple program. The compiling program is much more complicated and takes more memory in the compiling system and a much longer time to compile.

6.3.1 Headerless Code Generation

The RSC-FORTH system has an advanced method of FORTH target compilation. You have the option when your code is entered of selecting either in-line dictionary code or target compiled code with separated dictionary headers. The latter is called "headerless" code. The unique field called the PFAPTR relieves RSC-FORTH from having its dictionary header information (heads for short) in line with its code portion (codes for short). The RSC-FORTH kernel in ROM inside the R65F11 or R65F12 single chip computer is always available and need not be added as overhead to the target compiled system. Simple programs can be made as small as a few hundred bytes. As long as the operator is careful not to write definitions referring to words outside the kernel the resultant program can stand alone. The R65FR1 Development ROM will not be needed in the final system. See Table 2-1 for a list of kernel words. Programs that do not need external RAM can be installed in target systems consisting only of the R65F11 or R65F12, a 74LS373 and the program in a ROM or EPROM. Programs that require the use of the disks or serial channel will need one additional RAM chip and decoding to hold buffers, etc.

Unlike other FORTH systems, the dictionary information is not lost in target compilation, but rather is stored in separate memory. It, too, may be saved if desired. This can be an invaluable feature for debugging the compiled program. Since the target compiled program can be run directly, in whole or in parts, when the dictionary is still present, thorough testing is possible. The code is, however, in final format and requires no changes before storage in PROM or ROM.

The option of using the target compilation features is totally at the discretion of the user. Either way, after target compilation is set up, there is no detectable difference in the operation of the RSC-FORTH system. There are basically three reasons to choose target compilation. The most obvious is to save room in the target storage ROM. Another desirable feature is that target compilation provides an immediate level of program security. Only the most sophisticated program pirates will be able to reconstruct program flow without the dictionary header information, and even then there will be a severe penalty in time required to decompile the target code. Finally, by selectively target compiling some words and normally compiling others, a limited vocabulary can be created. Other languages can even be written in FORTH.

The programmer has complete control over the state of compilation. A system variable called HEADERLESS contains a boolean value determining if the words entered are either normal or target compiled. When HEADERLESS is zero, normal codes with heads are generated. When HEADERLESS is a one, codes are generated in one memory area, controlled by DP , and heads in another, accessible by reference to DP/ .

6.3.2 Target Compilation with H/C

Normally, direct reference to HEADERLESS is not required. The word H/C initiates the entire target compilation process. H/C forces a boolean one into HEADERLESS and takes one user-supplied number from the stack to be the memory location where the heads are generated. It then displays the address HEADS/XXXX on one line, where XXXX is the address of heads dictionary, and

CODES/YYYY on the next line, where YYYY is the address codes dictionary. XXXX is the same as the operator supplied number and is displayed for verification. YYYY is the value of DP at the time H/C is executed.

In effect, using H/C creates two dictionaries, one for heads and one for the codes. With such an arrangement additional dictionary control words are needed to access both memory files. The words DP , HERE , ALLOT and , are sufficient for normal FORTH code. Their counterparts added for headerless code dictionary control are DP/ , HERE/ , ALLOT/ and ,/ . When HEADERLESS is a zero, these words have exactly the same effect as their counterparts. When HEADERLESS is a one, these words work on the heads dictionary instead.

To test the effects of the above words, try the following examples. First, after reset, run a short VLIST .

Now, find the end of the dictionary:

```
HERE . <RETURN> 411 OK
```

Remember HERE is defined as DP @ , so

```
DP @ . <RETURN> 411 OK
```

has the same effect. Before beginning target compilation, verify the operation of DP/ and HERE/ to be the same as DP and HERE .

```
DP/ @ . <RETURN> 411 OK
HERE/ . <RETURN> 411 OK
```

If you begin target compilation now, TASK will be left in the codes dictionary. Temporarily drop TASK from the dictionary:

```
FORGET TASK
```

Begin target compilation by specifying a heads dictionary address:

```
HEX 600 H/C
```

Now add TASK back to the dictionary with a colon definition and run a short VLIST .

```
 607 TASK        3844 ADMP       3805  ;DUMP    37CF FORMAT
367E FMTRK <RETURN> OK
```

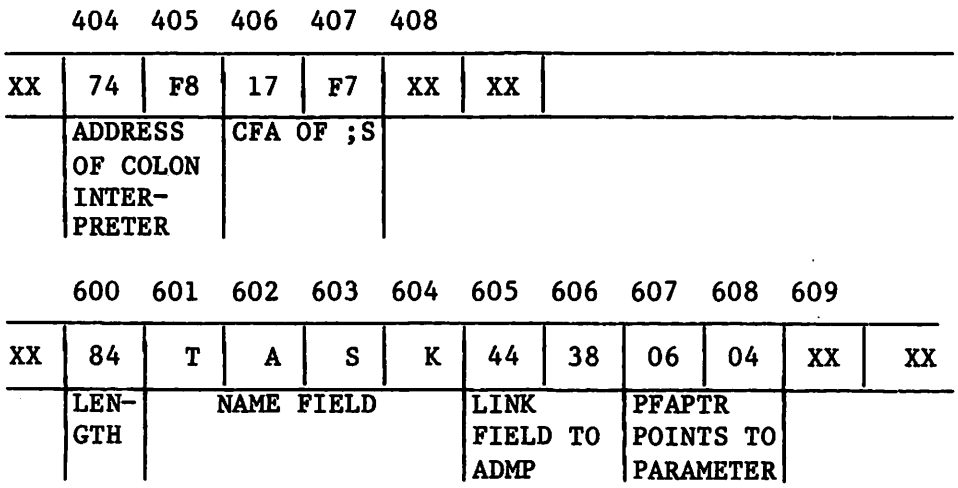
Note that the VLIST shows the PFAPTR of TASK to be at $607. Displaying the CFA of TASK shows where the actual code is in memory:

```
' TASK CFA . <RETURN> 404 OK
```

You can verify that HEADERLESS is indeed a true value now and test the functions of the dictionary control words mentioned above:

```
HEADERLESS ? <RETURN> 1 OK
DP ? <RETURN> 408 OK
DP/ ? <RETURN> 609 OK
HERE . <RETURN> 408 OK
HERE/ . <RETURN> 609 OK
```

Examining memory at $400 and $600 with the DUMP command can be useful. The breakdown of the two memory spaces is as follows:



It is evident here that the codes are being generated at the $400 memory space and the heads at $600. By this example and comparison of the two memory sections it should be clear that target compilation can save a great deal of space in codes area.

6.3.3 Codes Versus Heads Dictionary Words

In the target compile mode (HEADERLESS contains a one) ALLOT provides free space in the codes area while ALLOT/ reserves bytes in the heads dictionary. Similarly, , puts a 16-bit value in the codes area whereas ,/ puts a 16-bit value in the heads dictionary. Any of these words modify the system variables at the addresses of DP and DP/ . The physical addresses of DP and DP/ are adjacent in memory.

```
DP . 32A <RETURN> OK
DP/ . 32C <RETURN> OK
```

The words ending in "/" simply use DP plus two if HEADERLESS is non-zero.

6.3.4 Move a Definition from Codes to Heads with HWORD

A useful dictionary control word, HWORD , picks up a definition from the target codes area and places it in line in the heads dictionary. HWORD works on the last definition entered. Try entering HWORD now. Since the last entry was TASK , the code for TASK will no longer be in the codes area. This can be verified by checking its CFA:

```
' TASK CFA . <RETURN> 609 OK
```

HWORD is often useful for moving the code for a test word out of the target area. PROM programmer loops and other utilities can likewise be picked out of the codes area before final preparation for a ROM code.

The question of whether a particular word is in or out of the kernel can be quite important when preparing target standalone programs. No references can be made to words defined in the Development ROM if the program is to stand alone. Checking the CFA of a word to be used in a definition can be tedious. The word ?KERNEL followed by a word name performs a quick check. ?KERNEL responds with a simple IN or OUT message, indicating location.

6.3.5 Preparing for Autostart

After a program is target compiled and thoroughly tested, just prior to being transferred to EPROM, you may want to prepare it for autostart of your program on power on reset. In order to do this, a $A55A pattern must be placed on a 1K-byte boundary followed by the PFA of the word to be started. This will usually be the first four bytes of your final EPROM. The word AUTOSTART was added to RSC-FORTH to simplify the process. To use AUTOSTART the address of the 1K-boundary being used must be on the stack. AUTOSTART should be followed by the high level FORTH word that defines the entire process to be run. A strong word of caution is in order: AUTOSTART should be used with care. Once it is executed, there is no way to return the Development ROM using a reset.

Try the following example to see AUTOSTART in action. First, start fresh by entering COLD . Then type:

```
FORGET TASK HEX 600 H/C <RETURN>
```

Notice that the codes are listed starting at $404. This is because at reset RSC-FORTH reserves the first four bytes at $400 for an autostart vector to be added later. Now enter this program:

```
: PROGRAM 0 BEGIN 1+ DUP . <RETURN> AGAIN ;
```

Test the program by entering PROGRAM but be ready to press reset because this is an endless loop. PROGRAM displays all the possible numbers, starting from 1.

Now, prepare PROGRAM for autostart by entering

```
400 AUTOSTART PROGRAM <RETURN>
```

This sets up the autostart pattern in memory $400. Look for the autostart pattern by performing:

```
400 20 DUMP <RETURN>
```

Now press reset. PROGRAM will run automatically. In fact, the only way to stop PROGRAM from running is to turn off power and turn it on again. This will cause a cold reset of the Development ROM. PROGRAM was an example of a dedicated application control program. Although it has no real world application, it nicely demonstrates target compiled, autostarting code. PROGRAM took only 16 bytes in code.

6.4 DISK INTERFACING

Perhaps the most unique feature of the RSC-FORTH Kernel is the built-in floppy disk handler. This firmware allows a RSC-FORTH Microcomputer to control up to four quad-density 5-1/4" disk drives with 2.4 megabytes of on-line virtual disk memory. The words inside the kernel are designed to read or write a 1K-byte block in memory either from or to the floppy disk drive.

As is common with most FORTH systems, all mass storage is designated in groups of bytes called "blocks". Each block on the disk has an identifying number. Blocks are labeled from zero to "n-1", where n = (number of blocks per side) x (number of sides per disk) x (number of disks).

6.4.1 High Level Mass Storage Words

The higher level words used for mass storage all eventually refer to a word that, internally, calls the appropriate disk handler primitives. The word is R/W and has no function other than to pass control from the calling routine to the disk handler via a vector contained in UR/W . The higher level mass storage words of RSC-FORTH, such as LOAD , BLOCK , BUFFER , etc., are contained in the R65FR1 Development ROM. R/W is the last word outside the kernel. All the disk handler primitives are contained in the kernel.

UR/W is a system variable in the kernel that is initialized to point to DISK . R/W does not remove any parameters from the stack, but expects to be passed three numbers. The lowest of the three on the stack is the memory address to be used, the second is the block number of the data on disk and the top is a boolean value telling whether to read or write. To read block 20 from the disk into memory location $800, an entry of

```
HEX
800 20 1 R/W
```

has the same effect as

```
800 20 1 DISK
```

DISK initiates the correct sequence of events to access the disk using the four lower level disk handling words SELECT , SEEK , DREAD and DWRITE .

6.4.2 Disk System Variables

There are three system variables that are very important to disk operations; DISKNO , CYLINDER and B/SIDE . DISKNO holds the number of the last disk selected. This is used as an index when looking into CYLINDER . These are actually four bytes reserved in CYLINDER , one byte for each disk. The track last used on each disk is recorded in its corresponding byte. The variable B/SIDE holds the number representing the number of 1K-byte blocks per side of a disk. The default value of B/SIDE is 360, for a quad-density disk. The disk handlers will work with double- or quad-density disk drives.

By the number of the block passed to it, using B/SIDE , DISK computes the number of the drive to be selected. That number, between zero through three, is passed to SELECT . SELECT turns on the motors, if necessary, and waits for them to come up to speed. The active disk drive number is stored in DISKNO .

DISK calls SEEK after the appropriate drive is selected. SEEK is passed to the number of the track which contains the data. If the number for the current disk track stored in CYLINDER is out of range, SEEK will recalibrate before trying to attain correct head positioning.

After the correct disk is selected and the head has been moved over the desired track, DISK calls either DREAD , if the boolean value passed to it on the top of the stack is a one, or DWRITE , if it is a zero. Both DREAD and DWRITE are passed the original memory address which was passed to DISK , and the number of the 1K-byte group of multiple sections to read. Since there are 16 sectors per track, that number will be zero through three.

The word INIT sets all disk drive track information in CYLINDER to $FF's in order to force recalibration if so chosen by the programmer.

An error on READ or WRITE will cause the displaying of an error message and return to the calling routine. If more elaborate error handling or other mass storage techniques are desired, it is up to the programmer to write his, or her, own versions of these primitives. Control can be taken from these routines by modifying the vector in UR/W .

The words SELECT , SEEK , DREAD , DWRITE , DISK and INIT are all in the kernel. The variables DISKNO , CYLINDER and B/SIDE are not, but are referred to where needed by actual address in page 3.

6.5 GENERAL UTILITIES

6.5.1 Formatting a Disk

A number of words best described as utilities have been added to RSC-FORTH to allow more complete use of the facilities of a single chip application. Two are directly related to disk operations.

The code required to format a disk is quite extensive, over 300 bytes. For that reason the format routine is not in the kernel, but in the Development ROM instead. FORMAT formats a complete disk on both sides. Two parameters must be passed to FORMAT , the drive number to format on the top of the stack

and the number of tracks to format second on the stack. FORMAT calls a lower level primitive FMTRK which formats a single track. Although it is doubtful that many will use this primitive directly, it is available for execution.

6.5.2 Screen Modification

Although most standard FORTH systems allow examination of mass storage by block, with words like LIST , INDEX and .LINE , few, if any, have words that allow the blocks to be modified. Normally you must load a screen editor to perform such functions. RSC-FORTH has a utility word added to allow simple screen modification directly. The word is >LINE (pronounced "to-line"). To use >LINE , first list a screen (this has the same meaning as showing a block). Any line on that screen can be replaced by typing the line number and >LINE followed by a carriage return. >LINE then accepts up to 64 characters from the terminal and places them on the screen at the specified line.

6.5.3 Dumping a Memory Block

A pair of high and low level utility words are ADMP and ;DUMP . ADMP causes the system to dump the contents of a memory block in a standard format to the system terminal. Data can be transferred to one of several commercially available PROM programmers for permanent storage. In this format, every record begins with a semicolon followed by a two ASCII character representation of the number of bytes (in hex) in this record. Next is the four ASCII character number starting address (in hex) for this record. The individual bytes follow, each byte represented in the form of two ASCII characters as the hex value. A 16-bit checksum is sent as the final field with four digits (in hex). Multiple records are sent until all of the memory designated is dumped. A final record is sent with zeros for the number of bytes (in hex) and address and a final total 16-bit checksum (in hex). This is the same format used by the AIM 65, AIM 65/40 and KIM-1 Microcomputers for a memory dump.

The primitive used by ADMP to output an individual record is ;DUMP . Both words are easily exercised. ;DUMP requires two parameters from the stack, the starting address and the number of bytes to dump. To test it try dumping a record that contains the first few bytes of the Development ROM with DUMP and ;DUMP .

```
HEX CR 2000 10 DUMP
 2000  5A A5 6E 2C FF FF FF FF 40  1 F8 17  0 20  0  0
OK

CR 2000 10 ;DUMP
;1020005AA56E2CFFFFFFFF4001F81700200000735
OK
```

Now try ADMP over a larger area of memory. ADMP requires a starting and ending address.

```
2000 207F OK
ADMP
;1820005AA56E2CFFFFFFFF4001F817002000001F000000040411040779
;182018000000003C0381A00404000081A0C73F36034E2C834C49D0467E
;182030000010F484434C49D42C205AF487455845435554C53420730917
;182048F4864252414E43C83D2082F487304252414E43C8492099F40AD6
;18206086284C4F4F50A95420B1F487282B4C4F4F50A96020D2F4840AC9
;08207828444F196B20FAF4047D
;0000070007
OK
```

6.5.4 Using EEC! to Program a PROM

Although it may be quite convenient to use commerical PROM programmers for permanent program storage, particularly when the program is large in respect to the addressing space available on the R65F11 or R65F12, they are expensive and not always readily available. It is possible to use the R65F11 or R65F12 to program EPROMs or EEROMS directly in-circuit. The word EEC! accomplishes this for a single byte at a time by manipulating the address and data bus to be stable for the period required for programming. In fact, a Rockwell 5213/2816 EEROM can be programmed directly in a socket without extra programming voltages. To program PROMs that require a larger programming voltage (VPP) than +5V, a minimal amount of external hardware must be added to apply VPP to the device during programming. The 2764 variety PROMs have a separate VPP pin and are easily handled. The 2732 family has a combination VPP and $\overline{OE}$ pin and requires more elaborate circuitry to multiplex the normal $\overline{OE}$ TTL signal and VPP. The 2716 family is very difficult to program because the programming pulse is positive going and not readily generated with R/$\overline{W}$ alone.

Three parameters must be supplied to $\overline{EEC}$! . The first (lowest on the stack) is the data byte to be put in PROM, followed by the address that it is to be programmed into. The top value on the stack is the number of clock cycles to hold the bus stable while the PROM programs. For example, assume that a Rockwell 5213/2816 EEROM is in a socket previously set up and tested for a 6116 type RAM device. Chip select is generated by decoding the address bus when $\overline{EMS}$ is low. Output Enable ($\overline{OE}$) is the logical NAND of Ø2 and R/$\overline{W}$. The 2K-byte device is located at address $0800. In order to program the second byte with a $55 pattern the following entry is required:

```
HEX 55 801 DECIMAL 10000
```

The 10000 assumes a 1 MHz clock to give a 10 millisecond programming pulse.

In order to transfer an entire program from RAM at address $400 to EEROM at address $800 a small programming word must be entered.

```
HEX
: MOVE-TO-PROM 800 400 DO I C@ I 400 + 2710 EEC! LOOP ;
```

MOVE-TO-PROM runs a loop from $400 to $7FF, picking up bytes and programming them at addresses $800 to $BFF. The data is held stable for $2710 (10000) clock cycles. Similar words can be made for about any programming requirement using EEC! .

6.5.5 Bank Switching

Most dedicated applications will find the 16K-byte addressing range of the R65F11 and R65F12 to be quite sufficient. Occasionally there will be designs that require even more space. For these occasions RSC-FORTH has four words that can be used to bank switch the external memory map to give a virtual memory capability of nearly four megabytes. To accomplish this, Port B must be used as upper address lines.

The bank switching words allow a byte to be fetched from a particular bank, stored in a particular bank, and programmed into PROM in a particular bank. A word in another bank can be executed, also. Unlike most other bank switching schemes, these bank switching words alter the bank port during operation, but return to the original calling bank upon completion. Although this takes more processor time, the programming of bank functions in high level is greatly simplified.

The bank switching words BANKC! , BANKC@ , BANKEEC! and BANKEXECUTE are all in the kernel and can be used in standalone applications. The function of each of these words is identical to its non-banking namesake except one additional parameter tops the stack. That is the number of the bank to perform the action on. For instance

```
1234 6 BANKC@
```

fetches the contents of location 1234 in bank 6 and returns its value to the stack. The entry

```
22 1234 6 BANKC!
```

places a byte value of 22 at memory location 1234 in bank 6. When working with large programs that make it difficult to have the Development ROM, the target program in RAM and a PROM in the memory map at one time, BANKEEC! may be invaluable. After the program is complete, it can be programmed into PROM in another bank with no problem of address translation. The programming word shown here could transfer all the program in RAM from $400 right up to the Development ROM to a 2764 in bank 1:

```
: BANK-PROM 2000 400 DO I C@ I C350 1 BANKEEC! LOOP ;
```

Note that $C350 was used for the cycles to program because the 2764 requires 50 milliseconds per byte.

Once programmed, the word can even be tested by calling the main word while still in the PROM in bank 1. Assume the word to be tested is RUN , then test it with:

```
RUN CFA 1 BANKEXECUTE
```

Caution should be observed concerning system variables unless RAM has been provided and initialized at $300 in bank 1.

Bank 256 ($FF) is the main bank since this is the value of Port B at reset. In order for bank switching to work, Port B must be used in the chip select decoding of all memory chips, or the "window" in which the bank switching can occur must be limited to those in which it is.

6.5.6 Specifying Top of Memory

Finally , MEMTOP is provided to initialize the values of FIRST and LIMIT if it is not a full RAM system. Note that LIMIT is $2000 and FIRST is $17F4 at power on. These can be changed by entering

```
n MEMTOP
```

where n is the last location of RAM available plus one.

SECTION 7

RSC-FORTH ASSEMBLER

The RSC-FORTH structured assembler allows the creation of machine language procedures that may be more time efficient than if defined in high-level FORTH colon-definitions. A separate ASSEMBLER vocabulary provides the op-codes, addressing modes, conditionals, and other support words necessary to program functions in R6500 assembly language. A function written in assembly language is entered into a vocabulary in a similar manner as a FORTH colon-definition. It is also executed in the same manner by referring to the word name. It is recommended that assembly language, or "code", as it is often referred to in FORTH terminology, be structured and written similar to high-level FORTH for clarity of expression. A function can first be rapidly written and debugged in FORTH, tested for proper operation, and then recoded in assembly language for faster execution with a minimum of restructuring.

7.1 THE ASSEMBLY PROCESS

The RSC-FORTH assembler vocabulary is selected by the word ASSEMBLER or by the word CODE (explained in the following paragraphs). A separate ASSEMBLER vocabulary is linked ahead of the FORTH vocabulary. The words in the ASSEMBLER vocabulary are defined in Appendix D, RSC-FORTH Assembler Glossary, in ASCII sort order.

To examine the assembler words, perform a cold start, command ASSEMBLER , and run a VLIST . The Assembler VLIST is shown in Figure 7-1. Note that the ASSEMBLER VLIST continues into the FORTH vocabulary upon completion of the ASSEMBLER word list. Press any key to terminate the VLIST before completion.

Code assembly consists of interpreting entered words with the ASSEMBLER vocabulary as CONTEXT (see Section 5.6.2). Thus, each word in the input stream is matched according to the FORTH practice of searching CONTEXT first, then CURRENT .

The vocabulary search order is:

Order	Vocabulary	
1	ASSEMBLER	(Now CONTEXT)
2	FORTH	(Chained to ASSEMBLER)
3	User's Vocabulary	(CURRENT if one exits)
4	FORTH	(Chained to user's vocabulary)
5	Literal Number	

The above sequence is the usual action of FORTH's text interpreter, which remains in control during assembly.

```
3FDC END-CODE   3FCB 0<         3FC0 0 =        3FB5 VS
3FAA CS         3F9B NOT        3F73 ELSE,      3F63 THEN,
3F37 ENDIF,     3F1E IF,        3EFC REPEAT,    3EE6 AGAIN,
3ECD WHILE,     3EAC UNTIL,     3E99 BEGIN,     3E79 BITCLR
3E4B BITSET     3E29 RMB,       3DF1 SMB,       3DE1 BIT,
3DD1 JMP,       3DC1 JSR,       3DB1 STY,       3DA1 LDY,
3D91 LDX,       3DB1 CPY,       3D71 CPX,       3D61 STX,
3D51 ROR,       3D41 ROL,       3D31 LSR,       3D21 INC,
3D11 DEC,       3D01 ASL,       3CF1 STA,       3CE1 SBC,
3CD1 ORA,       3CC1 LDA,       3DB1 EOR,       3CA1 CMP,
3C91 AND,       3C81 ADC,       3C73 TXS,       3C65 TYA,
3C57 TXA,       3C49 TSX,       3C3B TAY,       3C2D TAX,
3C1F SEI,       3C11 SED,       3C03 SEC,       3BF5 RTS,
3BE7 RTI,       3BD9 PLP,       3BCB PLA,       3BBD PHP,
3BAF PHA,       3BA1 NOP,       3B93 INY,       3B85 INX,
3B77 DEY,       3B69 DEX,       3B5B CLV,       3B4D CLI,
3B3F CLD,       3B31 CLC,       3B23 BRK,       3A54 RP)
3A44 SEC        3A34 TOP        3A27 )          3A1C )Y
3A10 X)         3A04 ,Y         39F8 ,X         39EC MEM
39DF #          39D4 ,A         39A1 SETUP      3993 BINARY
3984 PUTOA      3976 PUSHOA     3967 POPTWO     3958 POP
394C PUT        3940 PUSH       3933 NEXT       3926 XSAVE
3918 UP         390D W          3903 IP         38F8 N
```

Figure 7-1. VLIST of RSC-FORTH Assembler Words

7.1.1 CODE Definitions

The CODE word defines a word written in assembly code (called a CODE-definition) in a similar manner as the : word defines a word written in FORTH (a colon-definition). The assembler vocabulary is automatically selected as CONTEXT when CODE is encountered. The name following CODE is entered into the dictionary as the FORTH word for the CODE-definition. Assembly language routines or program segments in CODE-definition form are often referred to as "CODE" or "code" in general FORTH literature. Assembly language instructions in RPN format (see Section 7.2) are then entered along with any instructions to save and restore return stack values (see Section 7.4) and conditionals (see Section 7.6) The END-CODE word terminates a CODE-definition in a similar manner as the ; terminates a FORTH colon-definition.

During assembly of CODE-definitions, FORTH continues interpretation of each word encountered in the input stream (not in the compile mode). These assembler words specify operands, address modes, and op-codes. END-CODE concludes the CODE-definition. An error check verifies correct completion then "unsmudges" the definition's name to make it available for dictionary searches.

7.1.2 Assembly-time Versus Run-time

It is important to understand at what time a particular word definition executes. During assembly, each assembler word interpreted executes. Its function at that instant is called 'assembling' or 'assembly-time'. This function includes op-code generation from mnemonics, address calculation, address mode selection, and relative branch calculation.

The later execution of the generated code is called 'run-time'. This distinction is particularly important with the conditionals. At 'assembly-time', each word (i.e., IF, UNTIL, BEGIN, etc.) 'runs' to produce machine code (conditional branch and/or jump instructions) which will later execute at 'run-time' when its CODE-definition name is used.

7.1.3 CODE-Definition Example

As a practical example, here's a simple program that increments the value in Port A by one. Enter the following words.

```
CODE POPA
PA INC,
NEXT JMP,
END-CODE
```

a. The word CODE is first encountered and executed by FORTH. CODE builds the name POPA into a dictionary header and calls ASSEMBLER as the CONTEXT vocabulary. Note that the <name> after CODE must be on the same line.

b. INC, is next found in the assembler vocabulary as the op-code. When INC, executes, it assembles the byte value E6 into the dictionary as the INC instruction machine code. This causes the R6502 CPU to read the value from Port A, increment the value, and then return the new value to Port A.

   Note that the FORTH assembler word names end with a ",". The significance of this is:

   (1) The comma distinguishes assembler control words from FORTH control words, e.g., IF, versus IF , etc.

   (2) The comma shows the conclusion of a logical grouping that would be one line of classical assembly source code.

   (3) "," compiles into the dictionary; thus, a comma implies the point at which code is generated.

   (4) The "," distinguishes op-codes from possible hexadecimal numbers ADC, ADD, and BCC.

c. FORTH executes your word definitions under control of the address interpreter, named NEXT . This short code routine moves execution from one definition to the next. At the end of your CODE-definition, you must return control to NEXT or else to other code which returns to NEXT.

   NEXT is a constant that specifies the machine address of FORTH's address interpreter (at $F428). Here NEXT is the operand for JMP, . As JMP, executes, it assembles a machine code jump to the address of NEXT from the assembly time stack value. If control is not returned to this FORTH address as the last instruction in the CODE-definition, improper operation of the microcomputer and possible alteration of your program may result.

d. The END-CODE word terminates the CODE-definition with a SMUDGE of the name. It also exits the ASSEMBLER making CONTEXT the same as CURRENT .

The object code of our example is:

```
84                              ( Name letter count with MSB set)
45 58 49 D4     POPA            ( Name with MSB of last digit set)
00 08           link field
14 08           code field
E6 00           INC PORTA       ( location $00)
4C 6F C0        JMP NEXT
```

7.2 ASSEMBLER OP-CODES

The bulk of the assembler consists of dictionary entries for the R6500 mnemonic op-codes. Refer to Appendix B in the R6500 Programming Manual to see the machine code that is generated by each mnemonic op-code.

7.2.1 Single Mode Op-Codes

The R6500 single mode op-codes are:

```
BRK,   CLC,   CLD,   CLI,   CLV,   DEX,   DEY,   INX,
INY,   NOP,   PHA,   PHP,   PLA,   PLP,   RTI,   RTS,
SEC,   SED,   SEI,   TAX,   TAY,   TSX,   TXS,   TXA,
TYA,
```

When any of these op-codes are executed, the corresponding machine code byte is assembled into the dictionary.

7.2.2 Multi-Mode Op-Codes

The multi-mode op-codes are:

```
ADC,   AND,   CMP,   EOR,   LDA,   ORA,   SBC,   STA,
ASL,   DEC,   INC,   LSR,   ROL,   ROR,   STX,   CPX,
CPY,   LDX,   LDY,   STY,   JSR,   JMP,   BIT,   RMB,
SMB,
```

These op codes take an operand which must already be on the stack. An address mode may also be specified. If none is given, the op-code uses z-page (when appropriate) or absolute addressing.

7.3 ADDRESSING MODES

The addressing modes are specified by:

FORTH Word	Addressing Mode	
.A	accumulator	none
#	immediate	8 bits only
,X	indexed X	z-page or absolute
,Y	indexed Y	z-page or absolute
X)	indexed indirect X	z-page only
)Y	indirect indexed Y	z-page only
)	indirect	absolute only
none	memory	z-page or absolute

Here are examples of FORTH vs. conventional assembler. Note that the operand comes first, usually followed by any addressing mode modifier, and then the op-code mnemonic. This makes best use of the stack at assembly-time. Also, each assembler word is set off by blanks, as is required for all FORTH source text.

FORTH	Conventional Assembler	
.A ROL,	ROL A	(.A distinguishes A
1 # LDY,	LDY #1	from hex number 0A)
DATA ,X STA,	STA DATA,X	
DATA ,Y CMP,	CMP DATA,Y	
60 X) ADC,	ADC (60,X)	
POINT)Y STA,	STA (POINT),Y	
VECTOR) JMP,	JMP (VECTOR)	

The words DATA , POINT , and VECTOR specify machine addresses defined by prior VARIABLE or CONSTANT words. In the case of "60 X) ADC," the operand memory address $0060 was given directly. This is occasionally done if the usage of a value does not justify devoting the dictionary space to a symbolic value.

7.4 R6502 CONVENTIONS

7.4.1 Stack Addressing

The parameter stack is located in z-page, and is usually addressed by "Z-PAGE,X". This stack starts at $00C2 and grows physically downward. The X index register is the data stack pointer. Thus, incrementing X by two removes a data stack value; decrementing X twice makes room for one new data stack value.

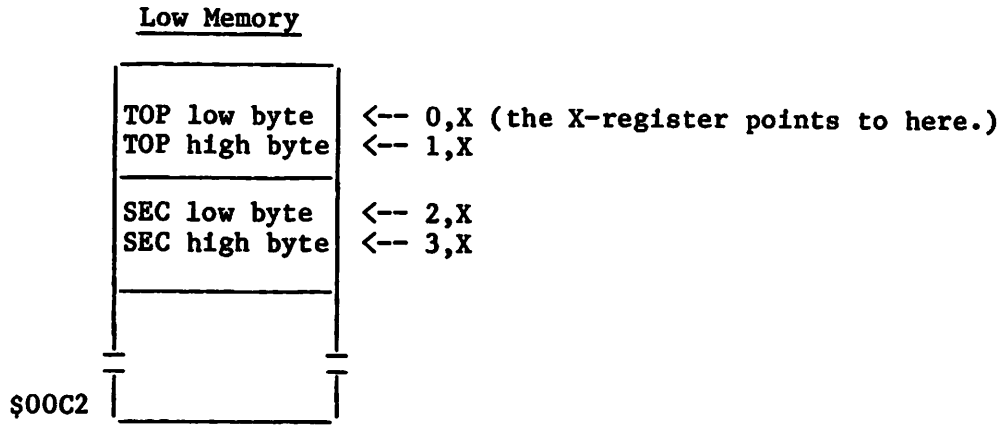
16-bit values are placed on the stack according to the R6500 convention; the low byte is at low memory, with the high byte following. This allows "indexed, indirect X" instructions to be executed directly off of a stack value.

The top and second stack values are referenced often enough that the support words TOP and SEC are included. Using

```
TOP LDA,  assembles  LDA (0,X)  and
SEC ADC,  assembles  ADC (2,X)
```

TOP leaves 0 on the stack and sets the address mode to ,X . SEC leaves 2 on the stack and also sets the address mode to ,X .

Here is a pictorial representation of the parameter stack in z-page (see Appendix F).



The 0 or 2 left by TOP or SEC is the base address above which X register indexes. You may further modify this at assembly-time to address at any byte in the parameter stack.

Here is an example of assembly code to "or" together the top four bytes on the stack:

FORTH	Conventional Assembler
TOP LDA,	LDA (0,X)
TOP 1+ ORA,	ORA (1,X)
SEC ORA,	ORA (2,X)
SEC 1+ ORA,	ORA (3,X)

To obtain the 14-th byte on the stack, use:

```
TOP 13 + LDA,
```

7.4.2 Return Stack

The FORTH Return Stack (and the machine stack) is located in the R6500 machine stack area in Page Zero. It starts at $00FF and builds physically downward. No lower bound is set or checked. This implementation has sufficient capacity for most non-recursive applications with 30 levels of entry.

By R6500 convention the CPU's S register points to the next free byte below the bottom of the Return Stack. The byte order follows the convention of low significance byte at the lower address.

Return stack values may be obtained by: PLA, PLA, which will pull the low byte, then the high byte from the Return Stack. To operate on arbitrary bytes, the method is:

a. Save X in XSAVE .

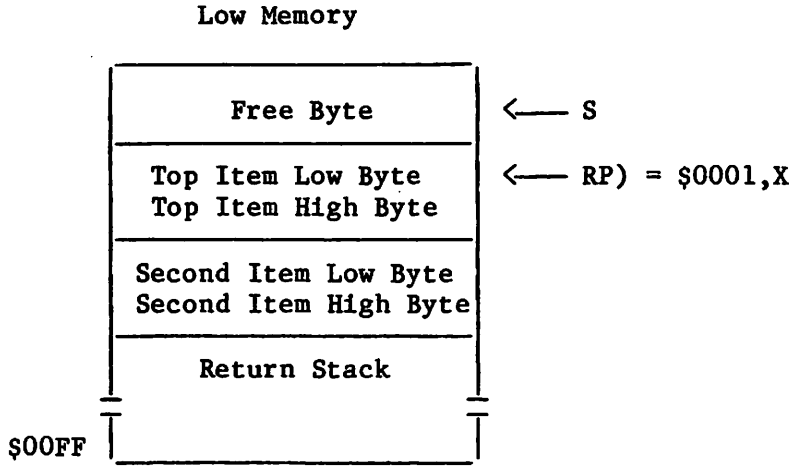
b. Execute TSX, to move the S register contents to the X register.

c. Use RP) to address the lowest byte of the return stack. Offset the value to address higher bytes. (The address mode is automatically set to ,X .)

d. Restore X from XSAVE .

As an example, this CODE-definition non-destructively tests the second item on the Return Stack (also the machine stack), to see if it is zero.

```
CODE IS-IT          ( Is second item on Return Stack zero?)
     XSAVE STX,     ( Setup for Return Stack)
     TSX,
     RP) 2+ LDA,    ( Or second item's bytes together)
     RP) 3 + ORA,
     0= IF,         ( If zero, increment Y by one)
       INY,
     THEN,
     TYA,           ( Save low byte)
     XSAVE LDX,     ( Restore data stack)
     PUSHOA JMP,    ( Push Boolean and zero onto data stack)
     END-CODE
```



7.5 FORTH REGISTERS

7.5.1 Assembly Registers

Several FORTH registers are available only at the assembly level and have been given names that return their memory addresses. These are:

IP Address of the Interpretive Pointer, specifying the next FORTH address which will be interpreted by NEXT .

W Address of the pointer to the code field of the dictionary definition just interpreted by NEXT . W-1 contains $6C, the op-code for the indirect jump instruction. Therefore, jumping to W-1 will indirectly jump via W to the machine code for the definition.

UP User Pointer containing the address of the base of the user area.

N A utility area in z-page from N-1 thru N+7.

7.5.2 CPU Registers

When FORTH execution leaves NEXT to execute a CODE-definition, the following conventions apply:

a. The Y register is zero. It may be freely used.

b. The X register defines the low byte of the bottom data stack item relative to machine address $0000. X must point to the correct item upon returning to FORTH.

c. The CPU stack pointer S points one byte below the low byte of the bottom item in the Return Stack. Executing PLA, will pull this byte to the accumulator.

d. The accumulator may be freely used.

e. The CPU is in the binary (i.e., not decimal) mode and must be returned in the binary mode (with a CLD prior to return, as needed).

7.5.3 XSAVE

XSAVE is a byte buffer in z-page, for temporary storage of the X register. Typical usage, with a call to a previously defined code word USER , which will change X, is:

```
CODE DEMO
  XSAVE STX,
  ' USER JSR,
  XSAVE LDX,
  NEXT JMP,
  END-CODE
```

7.5.4 N Area

When absolute memory registers are required, use the 'N Area' in Page Zero. These registers may be used to store pointers for indexed/indirect addressing or to store temporary values.

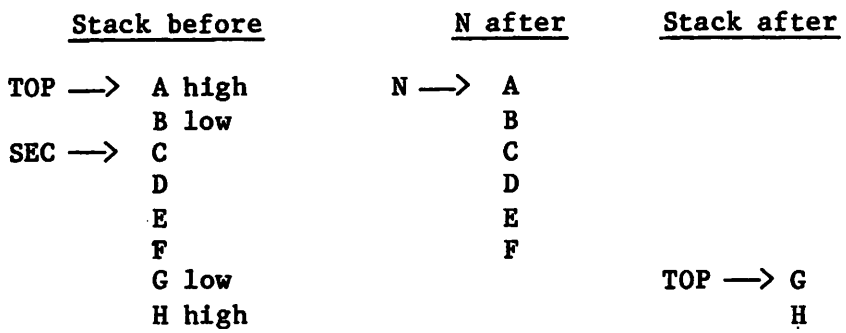
The assembler word N returns the base address ($0051). The N area spans 9 bytes, from N-1 thru N+7. Conventionally, N-1 holds one byte and N, N+2, N+4, N+6 are pairs which may hold 16-bit values. See SETUP for help on moving values to the N Area.

It is very important to note that many FORTH procedures use N . Thus, N may only be used within a single CODE-definition. Never expect that a value will remain within N outside a single definition!

7.5.5 SETUP

Often we wish to move stack data values to the N area. The word SETUP has been provided for this purpose. Upon entering SETUP the accumulator specifies the quantity of 16-bit stack values to be moved to the N area. That is, A may be 1, 2, 3, or 4 only:

```
3 # LDA,
SETUP JSR,
```



7.6 CONTROL FLOW

FORTH discards the usual convention of assembler labels. Instead, two replacements are used. First, each FORTH definition name is permanently included in the dictionary. This allows procedures to be located and executed by name at any time as well as be compiled within other definitions.

Secondly, within a CODE-definition, execution flow is controlled by label-less branching according to "structured programming". This method is identical to the form used in colon-definitions. Branch calculations are done at assembly-time by temporary stack values placed by the control words:

```
BEGIN,          THEN,
UNTIL,          AGAIN,
IF,             WHILE,
ELSE,           REPEAT,
```

Here again, the assembler words end with a comma, to indicate that code is being produced and to clearly differentiate from the high-level form.

One major difference occurs! High-level flow is controlled by run-time Boolean values on the data stack. Assembly flow is controlled instead by processor status bits. You must indicate which status bit to test with one or two FORTH condition code (cc) words, just before a conditional branching word i.e., IF, UNTIL, or WHILE, .

The conditional specifiers for the CPU are:

FORTH Condition Code (cc) Words	Test Function	Processor Status Bit
CS	carry set	C=1
0<	less than zero	N=1
0=	equal to zero	Z=1
VS	overflow set	V=1
CS NOT	carry clear	C=0
0< NOT	positive	N=0
0= NOT	not equal zero	Z=0
VS NOT	overflow clear	V=0
BITCLR	state of bit in zero page location	N/A
BITSET	state of bit in zero page location	N/A

7.6.1 Conditional Looping

A conditional loop is formed at assembler level by placing the instructions to be repeated between BEGIN, and UNTIL, . Precede UNTIL, by a conditional specifier, e.g., 0< . The assembler generates the proper conditional branch machine instruction, e.g., BEQ, to test the processor status and to conditionally branch back to the machine instruction immediately after the BEGIN, .

The general format is:

```
BEGIN,
<assembly code>
<cc> UNTIL,
<continuing assembly code>
```

For example, enter the CODE-definition for LOOP-TEST :

```
HEX
0 VARIABLE TICK
CODE LOOP-TEST
  6 # LDA,
  N STA,
    BEGIN,
    TICK DEC,
    N DEC,
    0=  UNTIL,
  NEXT JMP,
END-CODE
```

Note where the variable TICK and LOOP-TEST are located in the FORTH dictionary by using VLIST

```
VLIST
  42A LOOP-TEST     418 TICK       40B TASK    3844 ADMP
 3805 ;DUMP        37CF FORMAT    367E FMTRK   3674 BANKEXECUTE
 3664 BANKEEC!     3657 BANKC@   OK ( <SPACE> bar pressed)
```

Also, find the start of the next dictionary entry

```
HERE . <RETURN> 43C
```

A disassembly of the code is as follows:

```
042E A9 06          LDA #$06
0430 85 51          STA $51
0432 CE 1C 04       DEC $041C        ( Address of  TICK)
0435 C6 51          DEC $51
0437 D0 F9          BNE $0432
0439 4C 28 F4       JMP $F428
```

This shows you how the assembly code is generated for a typical conditional loop.

First, the temporary storage byte at address N is loaded with the value 6. The beginning of the loop is marked (at assembly-time) by BEGIN, . Memory at TICK is decremented, then the loop counter in N is decremented. Of course, the CPU updates its status register as N is decremented. Finally, a test for Z=1 is made; if N hasn't reached zero, execution returns to BEGIN, . When N reaches zero (after executing TICK DEC, 6 times) execution continues ahead after UNTIL, . Note that BEGIN, generates no machine code, but is only an assembly-time locator. In this example, 0 = UNTIL, generated a BNE instruction to the address located by BEGIN, .

7.6.2 Conditional Execution

Paths of execution may be chosen at assembly in a similar fashion as done in colon-definitions. In this case, the branch is chosen based on a processor status condition code. The general format is (using 0= as a typical condition code word):

```
PORT LDA,
0= IF,
  <code for zero set>
THEN,
<continuing code>
```

In this example, the accumulator is loaded from PORT . The zero status is tested and, if set (Z=1), the code for zero set is executed. Whether the zero status is set or not, execution will resume at THEN, .

The conditional branching also allows a specific action for the false case. Here we see the addition of the ELSE, part.

```
PORT LDA,
0= IF,
  <assembly code for zero set>
ELSE,
  <assembly code for zero clear>
THEN,
<continuing assembly code>
```

The test of PORT will select one of two execution paths, before resuming execution after THEN, . The next example increments N based on bit D7 of a port:

```
PORT LDA,                    ( Fetch one byte )
0< IF,
  N DEC,                     ( If D7=1, decrement N )
ELSE,
  N INC,                     ( If D7=0, increment N )
THEN,                        ( Continue on )
```

7.6.3 Conditional Nesting

Conditionals may be nested, according to the conventions of structured programming. That is, each conditional sequence begun (IF, BEGIN,) must be terminated (THEN, UNTIL,) before the next earlier conditional is terminated. An ELSE, must pair with the immediately preceding IF, .

```
BEGIN,
<code always executed>
  CS IF,
  <code if carry flag set>
  ELSE,
  <code if carry flag clear>
THEN,
<loop until zero flag is non-zero>
0= NOT UNTIL,
<code that continues onward>
```

Next is an error that the assembler security will reveal.

```
CODE <name>
  BEGIN,
  PORT LDA,
    0= IF,
    TOP INC,
    0= UNTIL,
    ENDIF,
```

The UNTIL, will not complete the pending BEGIN, since the immediately preceeding IF, is not completed. An error trap will occur at UNTIL, and error number 19 "conditionals not paired" will be generated. To delete the erroneous code from the dictionary, first SMUDGE the word to allow finding it, then FORGET it, and correct the source code and recompile.

7.6.4 Some Nesting Examples

a. An 8-Bit Counter

An 8-bit counter illustrates simple conditional looping.

```
0 VARIABLE COUNTS
-1 ALLOT
CODE COUNT-DOWN
0 # LDA,
COUNTS STA,
BEGIN,
  COUNTS DEC,
  0= UNTIL,
NEXT JMP,
END-CODE
```

Execute the counter:

```
COUNT-DOWN <RETURN> OK
```

Dump the machine code for examination:

```
HEX ' COUNT-DOWN NFA 20 DUMP
  41F  8A 43 4F 55 4E 54 2D 44 4F 57 CE 11  4 30  4 30
  42F   4 A9  0 8D 1E  4 D0 FE 4C 28 F4  4 44 55 4D 50
OK
```

The breakdown of the machine code is:

```
41E 00                                ( COUNTS Variable)
41F 8A                                ( Name Field = Start)
420 43 4F 55 4E 54 2D 44 4F 57 CE     ( COUNT-DOWN Name)
42A 11 04                             ( Link Field = $0411)
42C 30 04                             ( PFAPTR = $0430)
42E 30 04                             ( Code Field = $0430)
430 A9 00       LDA #$00              ( Parameter Field)
432 8D 1E 04    STA $041E
435 CE 1E 04    DEC $041E
438 D0 FB       BNE $0435             ( Next)
43A 4C 28 F4    JMP $F428
```

In this example we use part of the RAM dictionary for the counter (COUNTS) . This counter is only 8 bits, however, so after we create the 16-bit named dictionary location COUNTS , we use ALLOT to back up over the extra byte and recover it for use.

The definition of the word COUNT-DOWN is a simple loop, decrementing COUNTS until it hits zero then jump to NEXT . First, of course, we clear COUNTS to its initial value by the LDA, and STA, instructions. The initializing to zero is no problem because right after we clear counts to zero we decrement it and it becomes FF. This way we loop 256 times before finally exiting when we decrement to zero.

b. A 16-Bit Counter.

This counter is similar to the 8-bit one except that:

- COUNTS is the right size to begin with therefore ALLOT is unnecessary.
- We initialize two bytes to zero to start with.
- We use two nested loops to do the decrementing.

The assembly code is:

```
0 VARIABLE COUNTS
CODE COUNT-DOWN
0 # LDA,
COUNTS STA,
COUNTS 1+ STA,
  BEGIN,
    BEGIN,
    COUNTS DEC,
    0= UNTIL,
  COUNTS 1+ DEC,
  0= UNTIL,
NEXT JMP,
END-CODE
```

Execute the counter:

```
COUNT-DOWN <RETURN> OK
```

The machine code is:

```
041E 00 00                              ( COUNTS Variable)
0420 8A                                 ( Name Field Start)
0421 43 4F 55 4E 54 2D 44 4F 57 CE ( COUNT-DOWN Name)
042B 11 04                              ( Link Field = $0411)
042D 31 04                              ( PFAPTR = $0431
042F 31 04                              ( Code Field = $0431)
0431 A9 00          LDA #$00            ( Parameter Field)
0432 8D 1E 04       STA $041E
0435 8D 1F 04       STA $041F
0438 CE 1E 04       DEC $041E
043B D0 FB          BNE $0432
043D CE 1F 04       DEC $041F
0440 D0 F6          BNE $0432
0442 4C 28 F4       JMP $F428
```

c. A 24-Bit Counter

The value of indenting the loops for visual clarity is more obvious here than in the previous example. This example uses a three byte counter and so one more byte of dictionary space is allotted and three nested loops do the work.

```
0 VARIABLE COUNTS
1 ALLOT
CODE COUNT-DOWN
0 # LDA,
COUNTS STA,
COUNTS 1+ STA,
COUNTS 2+ STA,
  BEGIN,
    BEGIN,
      BEGIN,
        COUNTS DEC,
        0= UNTIL,
      COUNTS 1+ DEC,
      0= UNTIL,
    COUNTS 2+ DEC,
    0= UNTIL,
NEXT JMP,
END-CODE
```

Execute the counter:

```
COUNT-DOWN <RETURN> OK                ( About 2 1/2 min.)
```

The breakdown of the machine code is:

```
041F 00 00 00                         ( COUNTS Variable)
0422 8A                               ( Name Field Start)
0423 43 4F 55 4E 54 2D 44 4F 57 CE    ( COUNT-DOWN Name)
042C 11 04                            ( Link Field = $0411)
042E 32 04                            ( PFAPTR = $0432)
0430 32 04                            ( Code field = $0432)
0432 A9 00          LDA #$00          ( Parameter Field)
0434 8D 1F 04       STA $041F
0437 8D 20 04       STA $0420
043A 8D 21 04       STA $0421
043D CE 1F 04       DEC $041F
0440 D0 FB          BNE $043D
0442 CE 20 04       DEC $0420
0445 D0 F6          BNE $043D
0447 CE 21 04       DEC $0421
044A D0 F1          BNE $043D
044C 4C 28 F4       JMP $F428
```

7.7 RETURN OF CONTROL

When concluding a CODE-definition, several common stack manipulations are often needed. These functions are already in the nucleus, so we may share their use just by knowing their return points. Each of these words ultimately returns control to NEXT .

POP	Remove one 16-bit stack value.
POPTWO	Remove two 16-bit stack values.
PUSH	Push two bytes to the data stack.
PUT	Write two bytes to the data stack, replacing the present top of the stack.
PUSH0A	Push a zero and the accumulator to the data stack.
PUT0A	Replace the top of the stack with a zero and the accumulator.
BINARY	Combines the action of POPTWO and PUSH .

Our next example complements a byte in memory. The bytes' address is on the stack when INVERT is executed.

```
CODE INVERT          ( Code to invert a memory byte )
  HEX                ( Change I/O base to HEX)
  TOP X) LDA,        ( Fetch byte addressed by stack )
  FF  # EOR,         ( Complement accumulator )
  TOP X) STA,        ( Replace in memory )
  POP JMP,           ( Discard pointer from stack )
  END-CODE           ( Return to NEXT )
```

A new stack value may result from a CODE-definition. We could place it on the stack by:

```
CODE ONE             ( Code to put 1 on the stack )
  DEX,
  DEX,               ( Make room on the data stack )
  1 # LDA,
  TOP STA,           ( Store low byte )
  TOP 1+ STY,        ( High byte stored from Y since = zero )
  NEXT JMP,
  END-CODE
```

A simpler version could use PUSH :

```
CODE ONE             ( Code to put 1 on the stack )
  1 # LDA,
  PHA,               ( Push low byte to machine stack )
  TYA,               ( High byte to accumulator )
  PUSH JMP,          ( Push to data stack )
  END-CODE
```

The convention for PUSH , BINARY and PUT is:

- Push the low byte on to the machine stack.
- Leave the high byte in the accumulator.
- Jump to PUSH , BINARY or PUT .

PUSH will place the two bytes at the new bottom of the data stack. PUT will over-write the present bottom of the stack with the two bytes. BINARY first pops two stack values (four bytes) then does a push. Failure to push exactly one byte on the machine stack will disrupt execution upon usage!

The simplest version would use PUSHOA :

```
CODE ONE
  1 # LDA,
  PUSHOA JMP,
  END-CODE
```

If the high byte of a result to be placed on the stack is zero, and the low byte is in the accumulator, the words PUSHOA and PUTOA are convenient. They work the same as PUSH and PUT but add to, or replace, the data on the stack with a zero in the high byte position and the contents of the accumulator in the low byte position.

7.8 ASSEMBLER SECURITY

7.8.1 Assembler Tests

Numerous tests are made by the assembler to detect errors in structure and syntax. These tests verify that

a. All parameters used in CODE-definitions are removed.
b. Conditionals are properly nested and paired.
c. Op-codes are valid.
d. Address modes and operands are allowable for the op-codes.

Note that a possible error not detectable by the assembler, is referencing a word in the wrong vocabulary, e.g., referring to 0= in the FORTH vocabulary rather than the Assembler vocabulary.

7.8.2 Bypassing Security

Occasionally we may want to generate unstructured code. We can then control the assembly-time security checks, as follows: First, we must note the parameters utilized by the control structures at assembly-time. The notation below is taken from the assembler glossary in Appendix D. The "---" indicates assembly-time execution and separates input stack values from the output stack values.

```
BEGIN,  -->                 --- addrB 1
UNTIL,  -->          addrB 1 <cc> ---
AGAIN,  -->          addrB 1 ---
WHILE,  -->          addrB 1 --- addrB 1 addrW 3
REPEAT, -->          addrB 1 addrW 3 ---
IF,     -->          <cc>   --- addrI 2
ELSE,   -->          addrI 2 --- addrE 2
THEN,   -->          addrI 2 ---
                     or addrE 2 ---
```

Where the address values indicate the machine location of the corresponding "B"EGIN, , "I"F, , or "E"LSE, and <cc> represents the condition code to select the processor status bit referenced. The digit 1, 2 or 3 is tested for conditional pairing.

The general method of security control is to drop off the check digit and manipulate the addresses at assembly-time. The security against errors is less, but the programmer is usually paying intense attention to detail during this effort.

7.9 ADDING ASSEMBLY CODE TO A DEFINING WORD

The word ;CODE is used in a colon-definition to stop compiling and to add assembly code to the definition. The format is as follows:

```
: <name> [FORTH words] ;CODE [assembly code] END-CODE
```

where the [FORTH words] are run at compile time and the [assembly code] is executed at run-time.

When <name> is used later to define new words, this assembly code address will be put into the code sequence of the new words. Thus, the new words will cause this assembly code to be executed. For example,

```
: VALUE CREATE SMUDGE C,
  ;CODE
  0 X) LDA,
  PUSHOA JMP,
  END-CODE
```

When used by typing 80 VALUE EIGHTY , the word EIGHTY is created which, when executed with a "dot" to print the stack top,

```
EIGHTY .
```

will yield

```
80 OK
```

Achtung IRQVEC ist im
Rom auf 5B aufgesetzt !
muß jedoch 40 sein

SECTION 8

HANDLING INTERRUPTS IN FORTH

8.1 TYPES OF INTERRUPT HANDLERS

Interrupts can easily be handled in FORTH using one of two methods: machine level or interpretive interrupt processing. A machine level, or conventional, interrupt handler is written in assembly language and performs the entire interrupt processing before returning to the interrupted routine. NMI interrupts must be serviced with a machine level interrupt handler, as shown in the flowchart in Figure 8-1. The IRQ interrupts can also be serviced with a machine level interrupt handler. The general flowchart for using this method on the R65F11/R65F12 microcomputer is shown in Figure 8-2. This approach provides the fastest response to an interrupt, however, since it is written in assembly language it may take longer to develop and check out.

An interpretive IRQ interrupt has a minimum length assembly language subroutine to service the interrupt and to initiate interrupt processing, which is written in high level FORTH and is executed under control of the FORTH inner-interpreter, NEXT . The general flowchart for this approach is shown in Figure 8-3. Although the response to an interrupt may be longer with this approach, the development and checkout may be done quicker and easier since the main interrupt processing is done in FORTH.

When developing interrupt dependent software (regardless of the type of interrupt) try to take small steps between checkout. Carefully determine when system interrupts should be disabled or enabled. Avoid using any interrupt service routine that has not been first tested for logical integrity.

8.2 MACHINE LEVEL INTERRUPT HANDLING

Write a machine level interrupt handler in assembly language either as a CODE-definition (see Section 7.1) or as a code fragment (described in Sections 8.2.1 and 8.2.2). If written as a CODE-definition, assign a name to the interrupt handler and later address it by that name to load the interrupt vector. If written as a code fragment, include the assembly code directly into the dictionary, but first save the starting address for later loading into the interrupt vector. The code fragment (also called an orphan) eliminates the slight overhead of the dictionary header. In either case, terminate the interrupt handler with an RTI, to return to the interrupted program rather than NEXT JMP, which returns control to the inner-interpreter. Before continuing you may want to review the R6500 interrupt processing features discussed in Chapter 9 of the R6500 Programming Manual.

The R65F11/R65F12 interrupt vectors normally available to the user are:

IRQ ~~NMI~~ - $0040 (NMIVEC)
NMI ~~IRQ~~ - $0042 (IRQVEC)

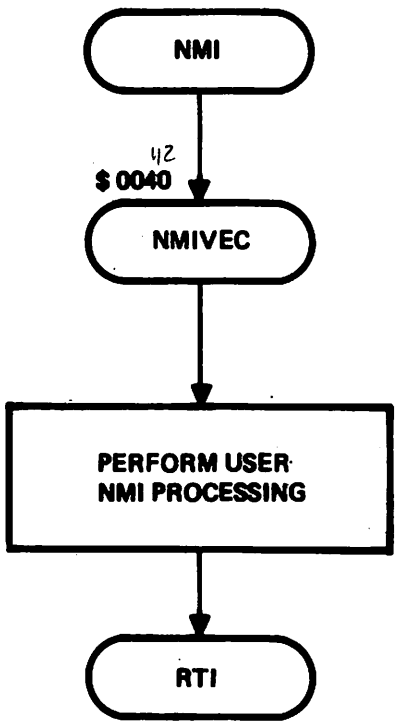


Figure 8-1. Machine Level NMI Interrupt Handling

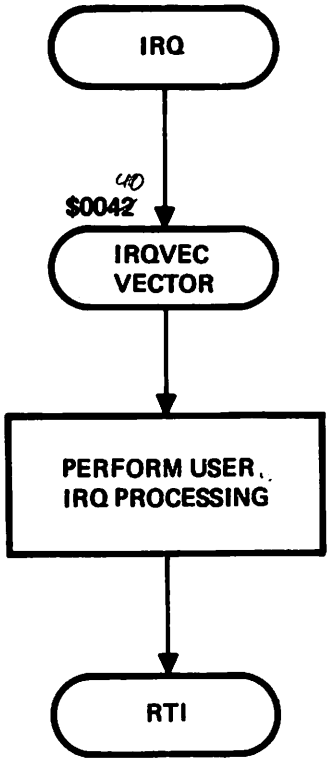


Figure 8-2. Machine Level IRQ Interrupt Handling

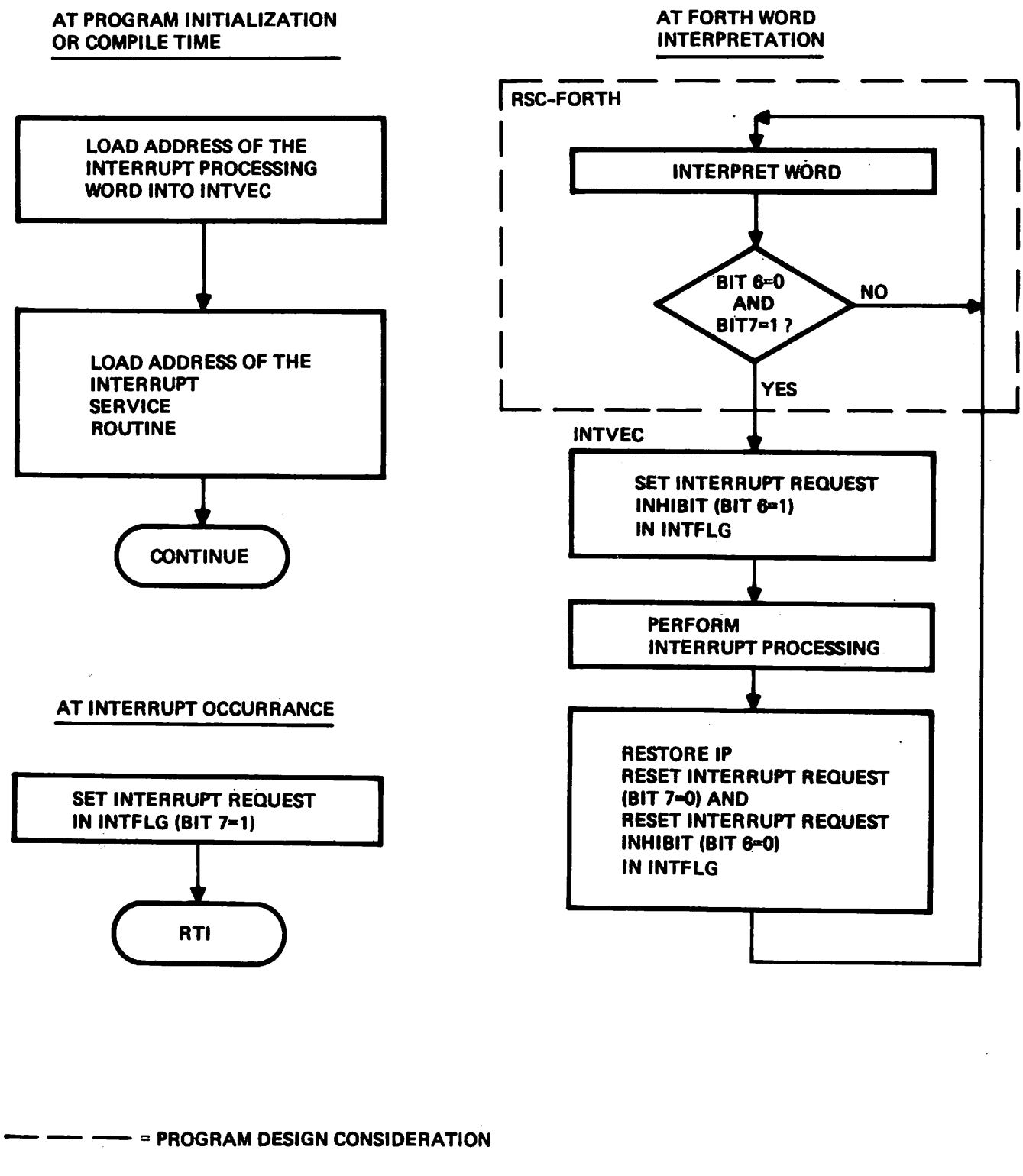


Figure 8-3. Interpretive IRQ Interrupt Handling

Unless modified by the user, these vectors normally point to COLD , so that an unintentionally generated interrupt will not totally crash the system.

8.2.1 CODE-Definition Form

The form for an interrupt handler written as a CODE-definition is

```
HEX
CODE <name>
<assembly code>
<for interrupt>
<handler>
RTI,
END-CODE
' <name> @ 004X !        ( Set interrupt vector)
```

where X = 0 or 2

Don't forget the END-CODE as it completes the CODE-definition and makes <name> available for use to load the interrupt handler address in the interrupt vector.

The word ' ("tick") fetches the parameter field pointer address (PFAPTR) of the word <name> to the stack. The PFAPTR obtained is a pointer to the starting address of the executable machine code. The @ retrieves the actual address. The 004X ! stores it in the appropriate vector.

8.2.2 Code Fragment Form

The form for a machine level interrupt handler written as a code fragment is:

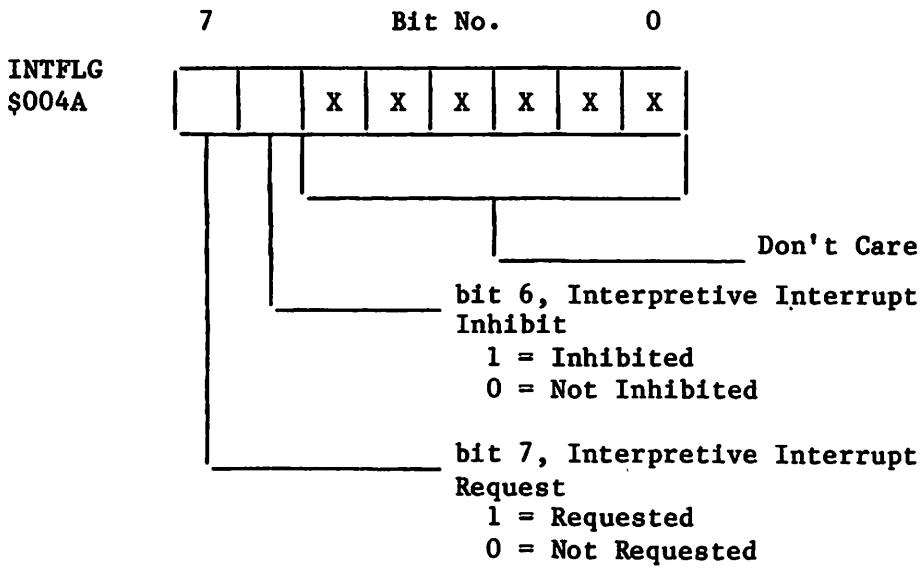
```
HEX
ASSEMBLER               ( Include assembler vocabulary)
HERE                    ( Locate dictionary address)
<assembler code>
<for interrupt>
<handling>
RTI,
004X !                  ( Store dictionary address in
                          interrupt vector)
```

Since the interrupt handler is not named, the starting address of the machine code is saved on the stack by the word HERE until the coding is complete, then it is stored in the appropriate interrupt vector. Notice that in both the above cases the interrupt vector was loaded after the interrupt handler was assembled. This method allows an IRQ or NMI interrupt occurring immediately after the interrupt vector is loaded (and the IRQ interrupt is enabled) to be processed correctly.

8.3 INTERPRETIVE INTERRUPT HANDLING PROCEDURE

8.3.1 Interrupt Service Routine

To write a minimum length interrupt service routine using the procedure described in Section 8.2 to load the R65F11/R65F12 interrupt vectors, this routine needs only to set bit 7 in the FORTH interrupt flag INTFLAG (at $004A) to one and return to the interrupted routine. The format of the INTFLAG variable word is



8.3.2 Interrupt Processing Word

The desired IRQ interrupt processing procedure uses a high level FORTH colon-definition word. Load the code field address (CFA) of this interrupt handler word into the FORTH interrupt vector INTVEC , a two-byte user variable located at $005D and $005E. Note that upon FORTH initial entry, or upon executing FORTH word COLD , this vector is initialized to $FB4A, which points to COLD processing.

When FORTH is executing its inner-interpreter, i.e., NEXT , it examines the interrupt request and inhibits bits of INTFLG . When the interrupt inhibit (bit 6) of INTFLG is ON, the interrupt request (bit 7) is ignored and NEXT executes the FORTH word. When the interrupt inhibit is OFF, the interrupt request (bit 7) of INTFLG is tested. If the interrupt request is OFF, then NEXT executes the next FORTH word. If the interrupt request is ON, then NEXT passes execution to the word whose CFA is in INTVEC , i.e., the interpretive interrupt service word, and sets the inhibit bit.

The interpretive interrupt word now processes the service required without interruption (inhibit bit is set). When the interpretive interrupt word has finished, it must reset the inhibit bit to zero, restore the interrupted word to the interpretive pointer, and jump to NEXT to continue the interrupted execution. Remember to keep the assembly interrupt code as short and simple as possible. For example, if you are reading data values at specific times,

read them and put them away in, say, a FORTH variable using a small interrupt routine for just that purpose. Meanwhile, a high level FORTH routine examines that variable for new data and processes it when it appears. FORTH is fast enough for much of the work to be done in high level which will speed program development time.

If FORTH is not fast enough for some purposes, a powerful technique is to first develop the program logic in high level FORTH and test the logic at reduced speed. When it works correctly, code in assembly language only those FORTH words that are required to bring the speed performance to the desired level. By this technique, program development time is reduced to the minimum.

8.3.3 Example

An example of an interpretive interrupt handler is shown in Figure J-3. Only two short CODE-definition words are defined; one to set the request bit in INTFLG when an IRQ interrupt occurs due to Timer 3 timeout, and one to clear the inhibit bit in INTFLG when the interpretive interrupt word completes execution.

The changes to the 24-Hour Clock to use interpretive interrupts involve replacing the code interrupt handling routine with a colon-definition or code fragment service word, writing the interpretive interrupt arm and trigger words and then the FORTH interrupt processing word. The conventional interrupt handler from PHA, to RTI, is replaced with two smaller code routines, one a code fragment and the other the ARM word that goes at the end of the FORTH interrupt processing word.

The code fragment is the interrupt service subroutine that is executed with each IRQ interrupt. It sets the interrupt request bit in INTFLG and clears the Timer's IRQ request bit which caused the interrupt. This code fragment serves as a typical example of all that is necessary to do at the code level for a wide variety of high level FORTH interrupt words.

The CODE word ARM turns OFF the interpretive interrupt inhibit bit (bit 6) of INTFLG , restores the FORTH interpretive pointer into the interrupted FORTH word and then jumps to FORTH's inner-interpreter NEXT to continue execution. ARM could be written in high level FORTH using C@ , C! and ; words but it must not be interfered with by a high level interrupt. This interference cannot occur if the functions are done within a CODE-definition.

The FORTH interpretive interrupt word for the 24-Hour Clock is T+ . Another FORTH word, +!L is used often by T+ . These two words comprise the entire interpretive interrupt service word. T+ does just what the CODE-definition interrupt routine did; i.e., increment the hundredth's of a second byte by 5 and when it reaches 100, increment the seconds, minutes, etc. The utility word +!L increments a certain byte by a given amount and checks it against the given limit. If the limit is exceeded, it zeros the byte and returns a true value so that the next byte can be incremented. The arguments on the stack for +!L are:

```
limit 1-  byte-address  increment --- T/F
```

The CODE-definition word ARM stops execution of T+ . The word [switches FORTH from the compiling state to the interpreting state so that the word SMUDGE will be executed, which makes the name of T+ available in the FORTH dictionary.

In order for the interpretive interrupts to work, the code field address (CFA) of the interpretive interrupt word must be loaded into INTVEC . This is accomplished in this example by the following:

```
' T+            ( Obtain the PFA of T+)
CFA             ( Change it to the CFA)
ASSEMBLER       ( Switch to the FORTH assembler vocabulary)
INTVEC          ( Obtain the address of  INTVEC )
!               ( Store the CFA of 'T+' in  INTVEC )
FORTH           ( Return to the FORTH only vocabulary)
```

which follows the definition of T+ .

Note that if the microcomputer is executing machine code for an appreciable amount of time and not frequently executing NEXT , the FORTH interrupt routine will not be executed and interrupt requests may pile up or be lost (depending on the interrupt service subroutine). This can happen when using the printer or waiting for a key.

The proper choice of machine level or interpretive (or both) interrupt service routines can make a very flexible approach to control situations or understanding computer interrupts.

8.3.4 Points to Remember

a. Define and code all required words before loading INTVEC , or requesting an interpretive interrupt. The required CODE words are (see text for more detail):

   1 - the IRQ or NMI code fragment
   2 - the ARM word to rearm the interrupt, etc.
   3 - the ENABLE and DISABLE words for IRQ (if using IRQ).

   A colon-definition level FORTH word is also required to run at interrupt request. The last word executed by this word is ARM , above.

b. See that NMI and IRQ do not contend for the interpretive interrupt -- there is no stacking and they can get lost.

c. Do not alter any of FORTH's floating buffers (at HERE and PAD) or any of the USER variables (BASE , DPL , IN , etc.) or leave anything on the stack between interrupts.

d. Use caution when using interpretive interrupts -- think the sequence through before acting. If it does not operate correctly, perhaps you are overwriting something that FORTH needs. Try using a do-nothing word like

```
: DUMMY ARM [ SMUDGE
```

for the interpretive interrupt word and see if that works.

e. The X register contents must be saved if X is used during the interrupt processing, but not in XSAVE or any of the other regular FORTH "registers". For example, use the Return Stack instead, such as TXA,
PHA, .

SECTION 9

PROGRAMMING THE R65F11 MICROPROCESSOR I/O IN FORTH

Programming the R65F11 and R65F12 single chip microcomputer I/O functions in FORTH is similar to programming individual members of the R6500 peripheral devices family. Special consideration must be given, however, to the specific operation characteristics of the R65F11 and R65F12 parallel I/O ports, serial I/O channel and timers. The techniques described can, however, be applied to other Rockwell single chip microcomputers, e.g., the R6511, as well as peripheral devices, such as:

R6520 Peripheral Interface Adapter (PAI)
R6522 Versatile Interface Adapter (VIA)
R6551 Asynchronous Communications Interface Adapter (ACIA)
R6545 CRT Controller (CRTC)

The R65F11 and R65F12 Microcomputers are organized as shown in Figure 9-1 with its registers accupying 32 addresses as listed in Table 9-1. R65F11/R65F12 interface operates in accordance with the settings of four internal control registers.

a. The Mode Control Register (MCR) determines the type bus structure selected, latching of Port B, and the operating modes of Timers A and B.

b. The Serial Channel Control Register (SCCR) determines serial transmitter and receiver enable and operation mode, the number of characters per data word, parity enable and parity odd/even settings.

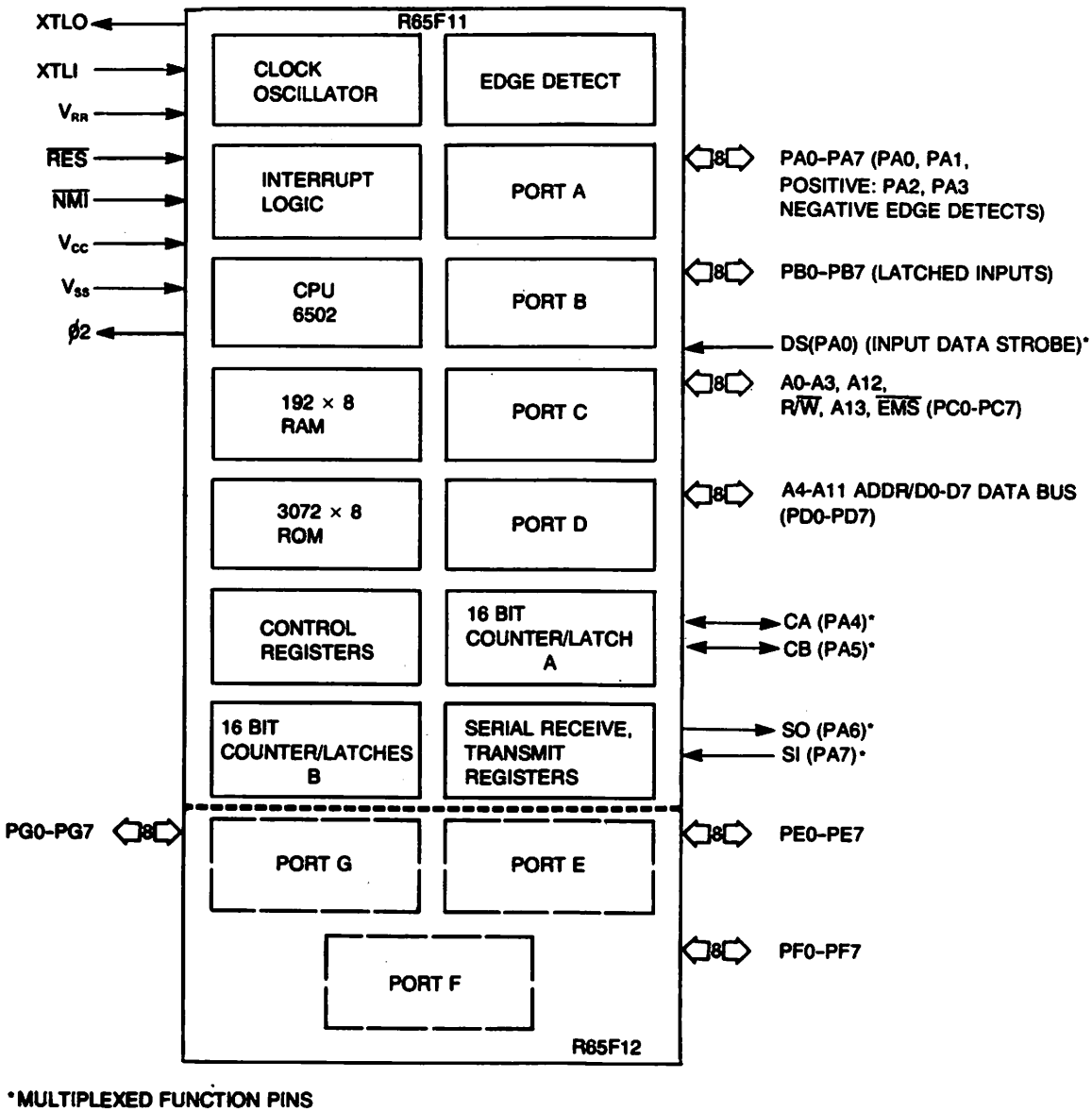
c. The Serial Channel Status register (SCSR) controls End of Transmission and Wake Up statuses of the serial channel.

d. The Interrupt Enable Register (IER) determines the ability of a particular hardware event to cause an $\overline{IRQ}$ interrupt.

See Figure 9-2 for the detail bit assignments of these registers. Note that unlike most other R6500 peripheral devices, the single chip microcomputers do not have data direction registers to control the I/O ports. The port is put in a reset state when $\overline{RES}$ is driven from low to high. The registers and I/O ports are configured as shown in Figure 9-3 before an external ROM is autostarted.

9.1 PARALLEL I/O

The R65F11 has 16 I/O lines grouped into two 8-bit ports. These two ports, Port A and Port B, may be used either for input or output. Each port line may be programmed as an input or an output, either independently or in groups of any combination. A number of the I/O pins are multifunction. For example, the serial channel lines use the Port A lines PA6 and PA7. These are protected from normal port I/O instructions when they are programmed to perform special functions.



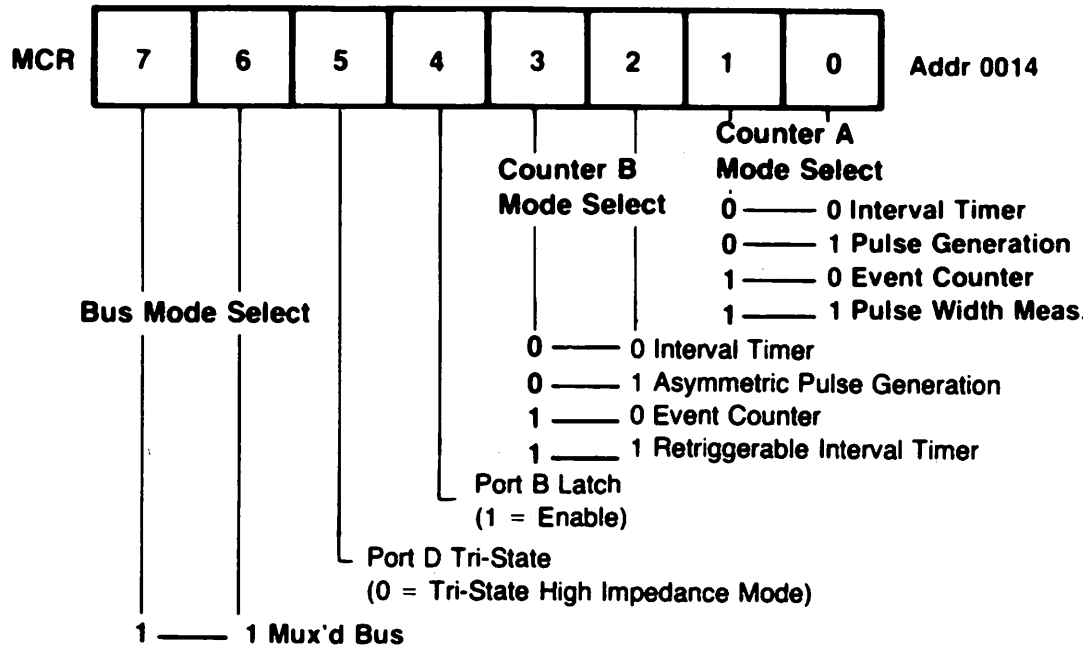
*MULTIPLEXED FUNCTION PINS

Figure 9-1. R65F11 and R65F12 Interface Diagram

Table 9-1. I/O and Internal Register Addresses

ADDRESS (HEX)	READ	WRITE
001F	— —	— —
1E	Lower Counter B	Upper Latch B, Cntr B←Latch B, CLR Flag
1D	Upper Counter B	Upper Latch B, Latch C←Latch B
1C	Lower Counter B, CLR Flag	Lower Latch B.
1B	— —	— —
1A	Lower Counter A	Upper Latch A, Cntr A←Latch A, CLR Flag
19	Upper Counter A	Upper Latch A
18	Lower Counter A, CLR Flag	Lower Latch A
17	Serial Receiver Data Register	Serial Transmitter Data Register
16	Serial Comm. Status Register	Serial Comm. Status Reg. Bits 4 & 5 only
15	Serial Comm. Control Register	Serial Comm. Control Register
14	Mode Control Register	Mode Control Register
13	— —	— —
12	Interrupt Enable Register	Interrupt Enable Register
11	Interrupt Flag Register	— —
10	Read FF	Clear Int Flag (Bits 0-3 only, Write 0's only)
0F	— —	— —
0E	— —	— —
0D	— —	— —
0C	— —	— —
0B	— —	— —
0A	— —	— —
09	— —	— —
08	— —	— —
07	— —	— —
06	Port G*	Port G*
05	Port F*	Port F*
04	Port E*	Port E*
03	— —	— —
02	— —	— —
01	Port B	Port B
0000	Port A	Port A

NOTE: *R65F12 Only



Mode Control Register

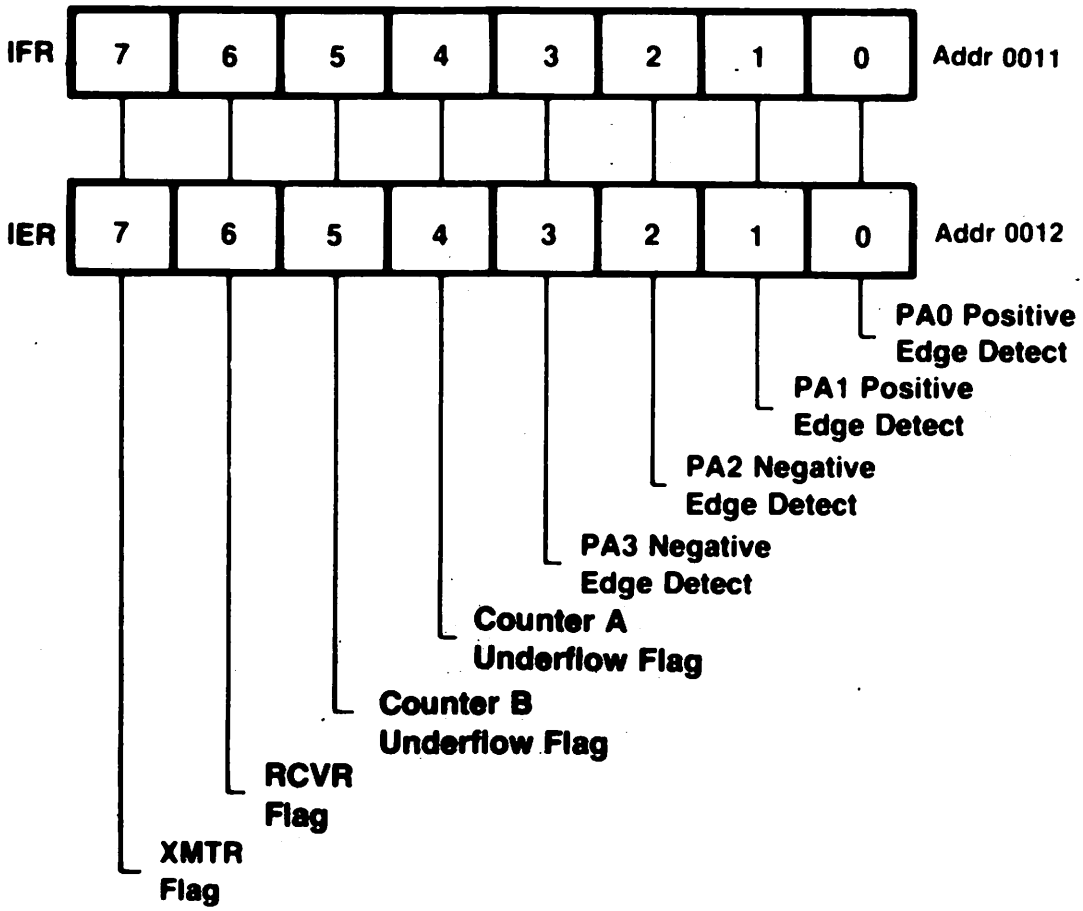
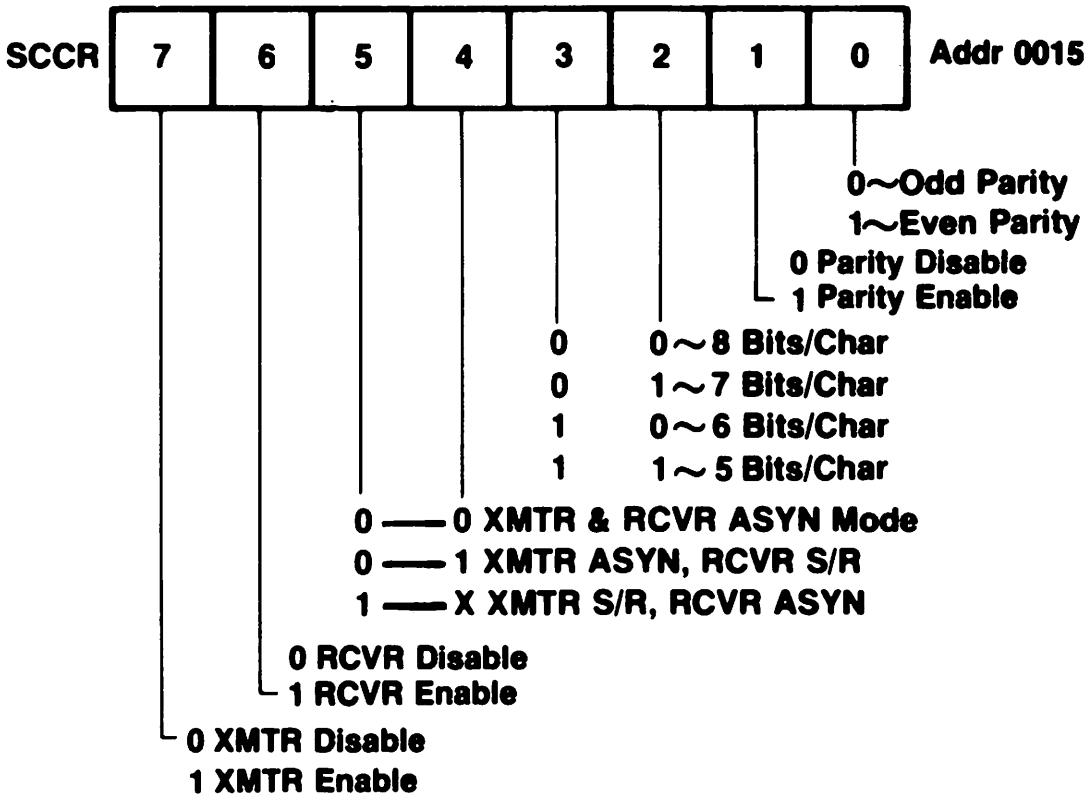
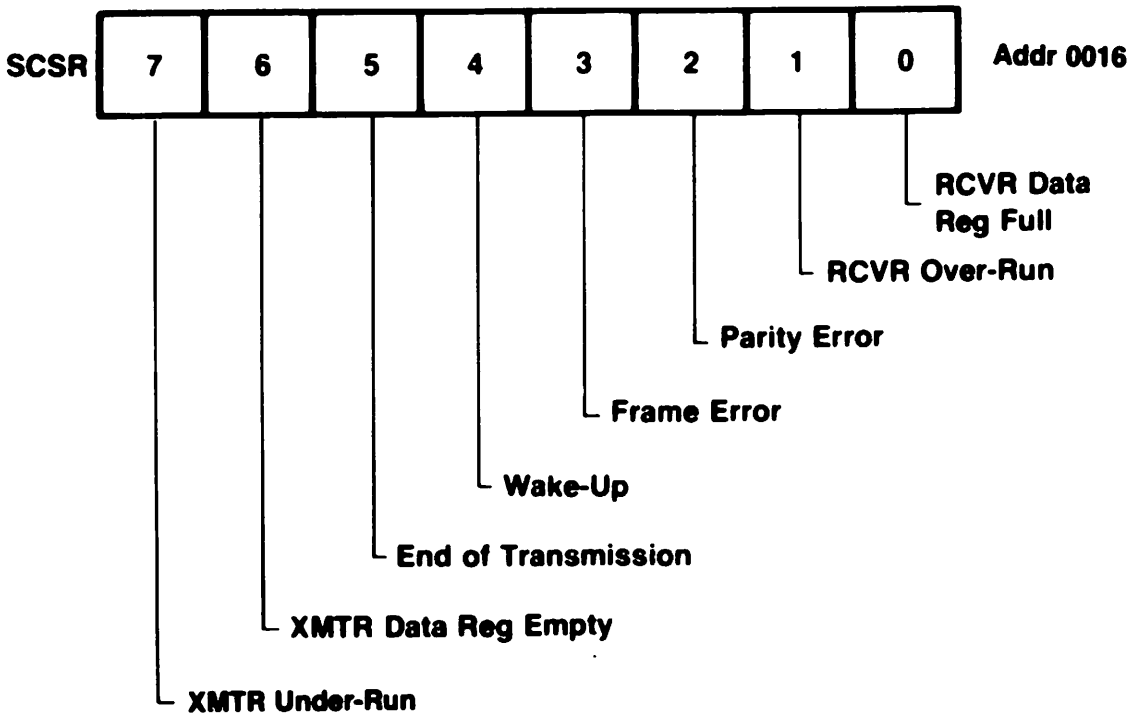


Figure 9-2. Register Bit Assignments



Serial Communications Control Register



Serial Communications Status Register

Figure 9-2. Register Bit Assignments (Continued)

The direction of the I/O lines are controlled by 8-bit port registers located in page zero. There are no direction registers associated with the I/O ports, which simplifies I/O handling. The I/O addresses are shown in Table 9-2.

Table 9-2. I/O Port Addresses

Port	Address	Notes
PA PB PC PD	$0000 $0001 $0002 $0003	R65F11 and R65F12
PE PF PG	$0004 $0005 $0006	R65F12 Only

Register/Port	Bit Position							
	7	6	5	4	3	2	1	0
REGISTERS								
Mode Control (MCR)	1	1	1	0	0	0	0	0
Interrupt Enable (IER)	0	0	0	0	0	0	0	0
Interrupt Flag (IFR)	0	0	0	0	0	0	0	0
Serial Communication Control (SCCR)	1	1	0	0	0	1	0	0
Serial Communication Status (SCSR)	0	1	0	0	0	0	0	0
PORTS								
PA Latch	1	1	1	1	1	1	1	1
PB Latch	1	1	1	1	1	1	1	1

Figure 9-3. $\overline{\text{RES}}$ Initialization of I/O Ports and Registers

Inputs for Ports A and B are enabled by storing logic 1's into all I/O port register bits. This can be accomplished by entering:

```
HEX FF PA C! FF PB C!
```

Since the two ports, Port A and Port B are adjacent in the memory map,

```
FFFF PA!
```

accomplishes the same thing. A low input (<0.8V) signal causes a logic 0 to be read when the contents of the port is fetched. A high input (>2.0V) causes a logic 1 to be read. A reset forces all I/O port registers to logic 1's thus initially treating all I/O lines as inputs. The status of the input lines can be read at any time, i.e.,

```
PB C@
```

Note that this returns the actual status of the input lines, not the data stored in the I/O port register.

Port outputs are controlled by storing the desired I/O line output states into the corresponding I/O port register bit positions. A logic 1 forces a high output (>2.4V) while a logic 0 forces a low output (<0.4V).

The settings of the Mode Control Register (MCR) and the Serial Channel Control Register (SCCR) determine whether Port A operates as a standard 8-bit, bit independent I/O port or serial I/O lines, counter I/O lines, or input data strobe for Port B latching. Table 9-3 tabulates the control bit settings and usage of Port A.

In addition to their normal I/O functions, PA0 and PA1 can detect positive going edges, and PA2 and PA3 can detect negative going edges. A proper transition on these pins will set a corresponding status bit in the IFR.

Port B can operate as an 8-bit, bit independent I/O port. This port also has a useful function when used as an input port in that the input values can be latches at a particular point in time based on a hardware event. If MCR bit 4 is set to a 1, reading Port B gives the value present the last time PA0 was pulsed (PA0 is positive edge sensitive.) By using this feature the processor does not have to continuously polled for an event on Port A to know when to read Port B. The value on Port B is instead preserved by the event in the Port B latches until the processor has time to read the port. Caution should be exercised when using Port B since the bank switch instructions also use Port B. If the bank instructions are not used, however, there is no conflict.

Table 9-3. Port A Control and Usage

R65F11/R65F12 PORT[5]	PA0 I/O		PORT B LATCH MODE	
	MCR4 = 0		MCR4 = 1	
	SIGNAL		SIGNAL	
	NAME	TYPE	NAME	TYPE
PA0[2]	PA0	I/O	PORT B LATCH STROBE	INPUT[1]

	PA1-PA3 I/O	
	SIGNAL	
	NAME	TYPE
PA1[2] PA2[3] PA3[3]	PA1 PA2 PA3	I/O I/O I/O

PA4	PA4 I/O		COUNTER A I/O			
	MCR0 = 0 MCR1 = 0 SCCR7 = 0 RCVR S/R MODE = 0[4]		MCR0 = 1 MCR1 = 0 SCCR7 = 0 RCVR S/R MODE = 0[4]		SCCR7 = 0 SCCR6 = 0 MCR1 = 1	
	SIGNAL		SIGNAL		SIGNAL	
	NAME	TYPE	NAME	TYPE	NAME	TYPE
	PA4	I/O	CNTA	OUTPUT	CNTA	INPUT (1)
	SERIAL I/O SHIFT REGISTER CLOCK					
	SCCR7 = 1 SCCR5 = 1			RCVR S/R MODE = 1[4]		
	SIGNAL			SIGNAL		
	NAME	TYPE		NAME	TYPE	
	XMTR CLOCK	OUTPUT		RCVR CLOCK	INPUT (1)	

PA5	PA5 I/O		COUNTER B I/O			
	MCR3 = 0 MCR2 = 0		MCR3 = 0 MCR2 = 1		MCR3 = 1 MCR2 = X	
	SIGNAL		SIGNAL		SIGNAL	
	NAME	TYPE	NAME	TYPE	NAME	TYPE
	PA5	I/O	CNTB	OUTPUT	CNTB	INPUT (1)

PA6	PA6 I/O		SERIAL I/O XMTR OUTPUT	
	SCCR7 = 0		SCCR7 = 1	
	SIGNAL		SIGNAL	
	NAME	TYPE	NAME	TYPE
	PA6	I/O	XMTR	OUTPUT

PA7	PA7 I/O		SERIAL I/O RCVR INPUT	
	SCCR6 = 0		SCCR6 = 1	
	SIGNAL		SIGNAL	
	NAME	TYPE	NAME	TYPE
	PA7	I/O	RCVR	INPUT (1)

(1) HARDWARE BUFFER FLOAT
(2) POSITIVE EDGE DETECT
(3) NEGATIVE EDGE DETECT
(4) RCVR S/R MODE = 1 WHEN SCCR6 · SCCR5 · SCCR4 = 1
(5) APPLIES TO EITHER R65F11 OR R65F12 PORT (SEE PIN DIAGRAM)

9.2 SERIAL I/O

The R65F11/R65F12 Microcomputers provide a full duplex serial I/O channel with programmable bit rates and operating modes. The serial I/O functions are controlled by the Serial Channel Control Register (SCCR). The SCCR bit assignments are shown in Figure 9-2. The bit rate, sometimes referred to as baud rate, is determined by Counter/Timer A for all modes except the Receiver Shift Register mode which requires an external clock. The maximum data rate using the internal clock is 62.5K bits per second. This assumes a 2 MHz internal clock. The transmitter and receiver can be independently operated in different modes. They can also be independently enabled or disabled.

The RSC-FORTH Operating System initializes the serial channel for asynchronous operation with both the receiver and transmitter enabled, seven bits per character and no parity. Counter/Timer A is set to the interval timer. With the one exception of the Receiver Shift Register Mode, which uses the external clock, all transmitter and receiver bits rates occur at one sixteenth of the Counter/Timer A interval timer rate. Counter/Timer A is forced into the interval timer mode whenever one of these other serial modes is selected. Counter/Timer A must be loaded with the correct value for the desired serial rate. The RSC-FORTH Operating System sets the baud rate for 1200 baud (assuming a 1 MHz internal clock) at power up. The operator or an application program can change the baud rate to whatever value desired.

Table 9-4 shows values for standard baud rates. The serial channel can be altered to these values as illustrated by

```
HEX XXXX 18 !
```

where XXXX is the desired hex value from Table 9-4 and 18 is the address of Counter/Timer A.

The transmitter operation and the transmitter related control/status functions are enabled by bit 7 of the SCCR. The transmitter, when in asynchronous mode, automatically adds a start bit, one or two stop bits, and when enabled, a parity bit to the transmitted data. A word of transmitted data in the asynchronous mode can have 5, 6, 7 or 8 bits of data. The nine possible data modes are shown in Figure 9-4. When parity is disabled, the 5, 6, 7 or 8 bits are terminated with two stop bits. When parity is enabled words with 4, 6, or 7 bits end with two stop bits. Those with 8 bits are allowed only one stop bit.

To calculate a desired baud rate in FORTH enter the following:

```
DECIMAL  1000000.  ( . means double-precision)
         16  9600  *
         U/  DROP  .
```

Instead of a final print command, . , enter HEX 18 C! to establish the baud rate.

Table 9-4. Counter A Values for Baud Rate Selection

STANDARD BAUD RATE	HEXADECIMAL VALUE		ACTUAL BAUD RATE AT		CLOCK RATE NEEDED TO GET STANDARD BAUD RATE	
	1 MHz	2 MHz	1 MHz	2 MHz	1 MHz	2 MHz
50	04E1	09C3	50.00	50.00	1.0000	2.0000
75	0340	0682	75.03	74.99	1.0000	2.0000
110	0237	046F	110.04	110.04	1.0000	2.0000
150	01A0	0340	149.88	150.06	1.0000	2.0000
300	00CF	01A0	300.48	299.76	1.0000	2.0000
600	0067	00CF	600.96	600.96	1.0000	2.0000
1200	0033	0067	1201.92	1201.92	1.0000	2.0000
2400	0019	0033	2403.85	2403.85	1.0000	2.0000
3600	0010	0021	3676.47	3676.47	0.9792	1.9584
4800	000C	0019	4807.69	4807.69	1.0000	2.0000
7200	0008	0010	6944.44	7352.94	1.0368	1.9584
9600	0006	000C	8928.57	9615.38	1.0752	2.0000

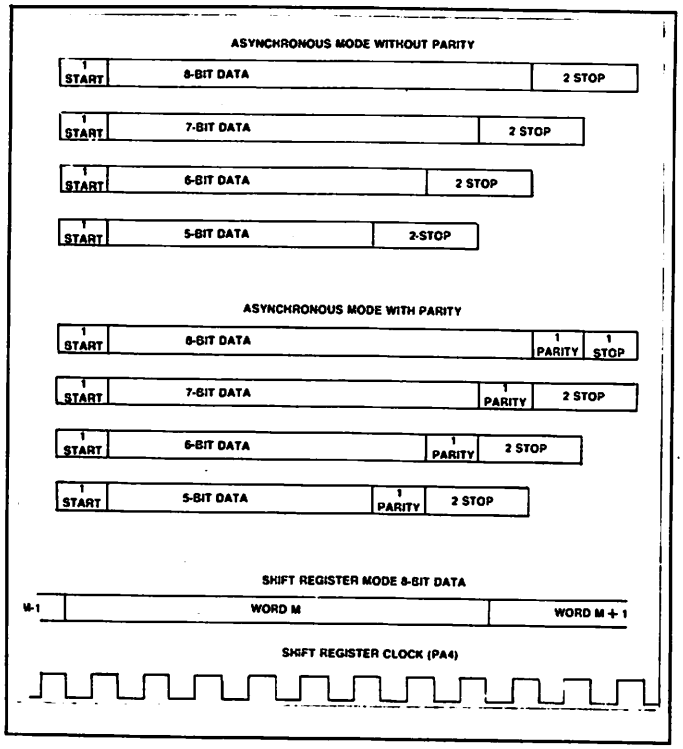


Figure 9-4. Serial Communication Bit Allocations

In the Shift Register Mode, eight data bits are always used. The serial data is shifted out via the SO output on pin PA6, as it is in the asynchronous mode. The serial clock, however, is available at the CA line, PA4, only in the transmitter shift register mode.

The receiver and its selected control and status functions are enabled when the SCCR Bit 6 is set to a 1. In the asynchronous mode incoming words must have one start bit, the appropriate number of data bits and parity, and one stop bit.

Framing error, over-run and parity error conditions, or a Receiver Data Register Full condition, will set the appropriate bits in the Serial Channel Status Register (SCSR). If enabled, and $\overline{IRQ}$ will be generated whenever any of these bits, SCSR0-SCSR3, are true. Serial words received are available in the Serial Channel Data Register (SCDR) by character fetch. Words can be transmitted by character storing bytes in the SCDR when the status flags indicate transmitter data register empty.

9.3 COUNTER TIMERS

The R65F11/R65F12 Microcomputers contain two 16-bit counter/timers and three 16-bit latches. Each of the two counters, A and B, can be independently programmed to operate in one of four selectable modes. Counter A supports an Interval Timer, Event Counter, Pulse Width Measurement and Pulse Generation Mode. Counter B has an Internal Timer, Event Counter, Retriggerable Interval Timer and Asynchronous Pulse Generation Mode.

The operating modes of the counter/timers are controlled by the Mode Control Register (MCR). All counting begins at the initialized values and decrements from there. When modes are selected requiring a counter input/output line, PA4 is automatically selected for Counter A and PA5 for Counter B.

9.3.1 Counter A

Counter A consists of a 16-bit counter and a 16-bit latch organized as follows: Lower Counter A (LCA), Upper Counter A (UCA), Lower Latch A (LLA), and Upper Latch A (ULA). The counter contains the count of either Ø2 clock pulses or external events, depending on the counter mode selected. The contents of Counter A may be read any time by executing a read at location 0019 for the Upper Counter A and at location 001A or location 0018 for the Lower Counter A. A read at location 0018 also clears the Counter A Underflow Flag (IFR4).

The 16-bit latch contains the counter initialization value,and can be loaded at any time by executing a write to the Upper Latch A at location 0019 and the Lower Latch A at location 0018. In either case, the contents of the accumulator are copied into the applicable latch register.

Counter A can be started at any time be writing to address 001A. The contents of the accumulator will be copied into the Upper Latch A before the contents of the 16-bit latch are transferred to Counter A. Counter A is set to the latch value whenever Counter A underflows. When Counter A decrements from 0000 the next counter value will be the latch value, not FFFF, and the Counter A Underflow Flag (IFR4) will be set to a 1. This bit may be cleared by

reading the Lower Counter A at location 0018, by writing to address location 002A, or by $\overline{RES}$. Counter A operates in any of four modes. These modes are selected by the Counter A Mode Control bits in the Control Register. See Table 9-5.

Table 9-5. Counter A Control Bits

MCR1 (bit 1)	MCR0 (bit 0)	Mode
0	0	Interval Timer
0	1	Pulse Generation
1	0	Event Counter
1	1	Pulse Width Measurement

The Interval Timer, Pulse Generation, and Pulse Width Measurement Modes are Ø2 clock counter modes. The Event Counter Mode counts the occurrences of an external event on the CNTR line.

a. Interval Timer Mode

The Counter is set to the Interval Timer Mode (00) when a $\overline{RES}$ signal is generated.

In the Interval Timer mode, the Counter is initialized to the Latch value by either of two conditions:

1. When the Counter is decremented from 0000, the next Counter value is the Latch value (not FFFF).

2. When a write operation is performed to the Load Upper Latch and Transfer Latch to Counter address 001A, the Counter is loaded with the Latch value. Note that the contents of the Accumulator are loaded into the Upper Latch before the Latch value is transferred to the Counter.

The Counter value decrements by one count at the Ø2 clock rate. The 16-bit Counter can hold from 1 to 65535 counts. The Counter Timer capacity is therefore 1 us to 65.535 ms at the 1 MHz Ø2 clock rate or 0.5 us to 32.767 ms at the 2 MHz Ø2 clock rate. Time intervals greater than the maximum Counter value can be easily measured by counting $\overline{IRQ}$ interrupt requests in the application program $\overline{IRQ}$ interrupt routine.

When Counter A decrements from 0000, the Counter A Underflow (IFR4) is set to logic 1. If the Counter A Interrupt Enable Bit (IER4) is also set, an $\overline{IRQ}$ interrupt request will be generated. The Counter A Underflow bit in the Interrupt Flag Register can be examined in the $\overline{IRQ}$ interrupt routine to determine that the $\overline{IRQ}$ was generated by the Counter A Underflow.

While the Timer is operating in the Interval Timer Mode, PA4 operates as a PA I/O bit.

A timing diagram of the Interval Timer Mode is shown in Figure 9-5.

b. Pulse Generation Mode

In the Pulse Generation mode, the CA line operates as a Counter Output. The line toggles from low to high or from high to low whenever a Counter A Underflow occurs, or a write is performed to address 001A.

The normal output waveform is a symmetrical square-wave. The CA output is initialized high when entering the mode and transitions low when writing to 001A.

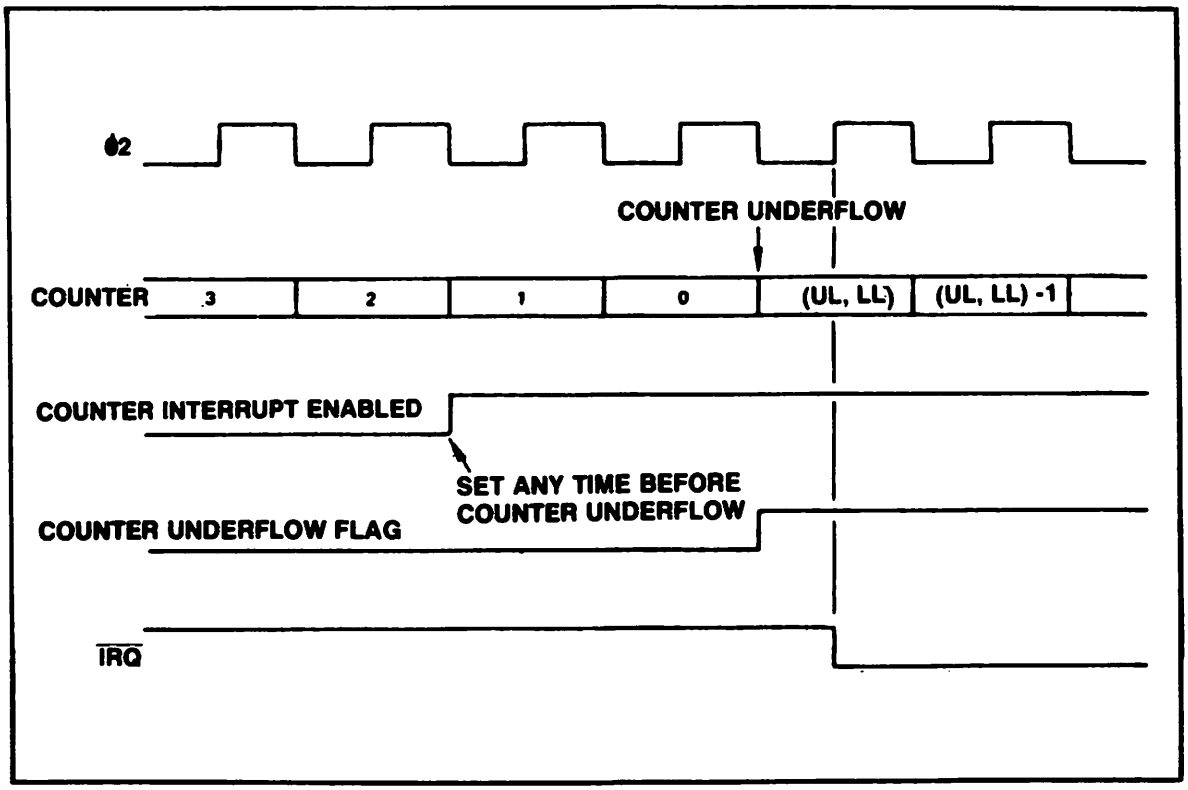


Figure 9-5. Interval Timer Timing Diagram

Asymmetric waveforms can be generated by changing from Pulse Generation to Interval Timer mode after only one occurrence of the output toggle condition.

c. Event Counter Mode

In the Event Counter mode, CA is used as an Event Input line, and the Counter decrements with each rising edge detected on this line. The maximum rate at which this edge can be detected is one-half the Ø2 clock rate.

The Counter can count up to 65,535 occurrences before underflowing. As in the other modes, the Counter A Underflow bit (IER4) is set to logic 1 if the underflow occurs. See Figure 9-6.

d. Pulse Width Measurement Mode

This mode allows the accurate measurement of a low pulse duration on the CA line. The Counter decrements by one count at the Ø2 clock rate as long as the CA line is held in the low state. The Counter is stopped when CA is in the high state.

The Counter A underflow flag is set only when the count in the timer reaches zero. Upon reaching zero the timer is loaded with the latch value and continues counting down as long as the CA pin is held low. After the counter is stopped by a high level on CA, the count holds as long as CA remains high. Any further low levels on CA will again cause the counter to count down from its present value. The state of the CA line can be determined by testing the state of PA4.

A timing diagram for the Pulse Width Measurement Mode is shown in Figure 9-7.

e. Serial I/O Data Rate Generation

As mentioned earlier, Counter A also provides clock timing for the Serial I/O which establishes the data rate for the Serial I/O port. When the Serial I/O is enabled, Counter A is forced to operate at the internal clock rate. Counter A is not required for the Receiver S/R mode. The Counter I/O (PA4) may also be required to support the Serial I/O.

Table 9-4 identifies the values to be loaded in Counter A for selecting standard data rates with a Ø2 clock rate of 1 MHz and 2 MHz. Although Table 9-4 identifies only the more common data rates, any data rate from 1 to 62.5K bps can be selected by using the formula:

$$N = \frac{Ø2}{16 \times bps} - 1$$

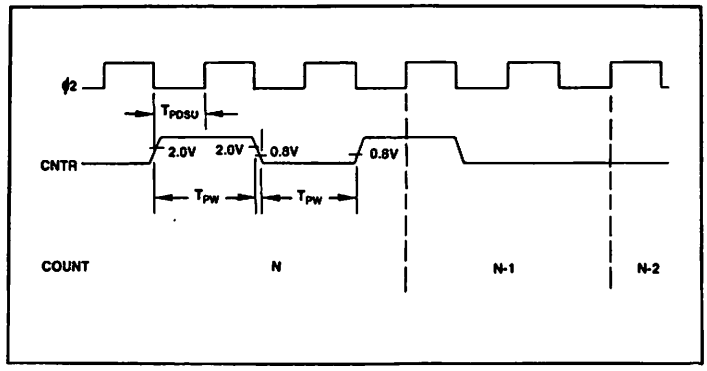


Figure 9-6. Event Counter Mode

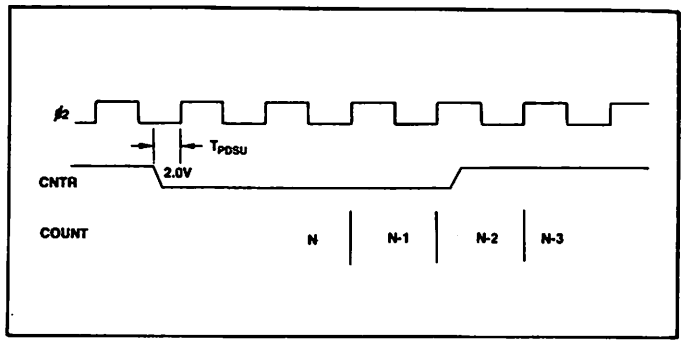


Figure 9-7. Pulse Width Measurement

where

N = decimal value to be loaded into Counter A using its hexadecimal equivalent.
Ø2 = the clock frequency (1 MHz or 2 MHz)
bps = the desired data rate.

In Table 9-4 you will notice that the standard data rate and the actual data rate may be slightly different. Transmitter and receiver errors of 1.5% or less are acceptable. A revised clock rate is included in Table 9-4 for those baud rates which fall outside the limit.

9.3.2 Counter B

Counter B consists of a 16-bit counter and two 16-bit latches organized as follows: Lower Counter B (LCB), Upper Counter B (UCB), Lower Latch B (LLB), Upper Latch B (ULB), Lower Latch C (LLC), and Upper Latch C (ULC). Latch C is used only in the asymmetrical pulse generation mode. The counter contains the count of either 22 clock pulses or external events depending on the counter mode selected. The contents of Counter B may be read any time by executing a read at location 001D for the Upper Counter B and at location 001E or 001C for the Lower Counter B. A read at location 001C also clears the Counter B Underflow Flag.

Latch B contains the counter initialization value, and can be loaded at any time by executing a write to the Upper Latch B at location 001D and the Lower Latch B at location 001C. In each case, the contents of the accumulator are copied into the applicable latch register.

Counter B can be initialized at any time by writing to address 001E. The contents of the accumulator is copied into the Upper Latch B before the value in the 16-bit Latch B is transferred to Counter B. Counter B is also be set to the latch value and the Counter B Underflow Flag bit (IFR5) is set to a 1 whenever Counter B underflows below 0000.

IFR5 may be cleared by reading the Lower Counter B at location 001C, by writing to address location 001E, or by $\overline{RES}$. Counter B operates in the same manner as Counter A in the Interval Timer and Event Counter modes. The Pulse Width Measurement Mode is replaced by the Retriggerable Interval Timer mode and the Pulse Generation mode is replaced by the Asymmetrical Pulse Generation Mode.

a. Retriggerable Interval Timer Mode

When operating in the Retriggerable Interval Timer mode, Counter B is initialized to the latch value by writing to address 001E, by a Counter B underflow, or whenever a positive edge occurs on the CB pin (PA5). The Counter B interrupt flag will be set if the counter

underflows before a positive edge occurs on the CB line. Figure 9-8 illustrates the operation.

b. Asymmetrical Pulse Generation Mode

Counter B has a special Asymmetrical Pulse Generation Mode whereby a pulse train with programmable pulse width and period can be generated without processor intervention once the latch values are initialized.

In this mode, the 16-bit Latch B is initialized with a value which corresponds to the duration between pulses (referred to as D in the following description). The 16-bit Latch C is initialized with a value which corresponds to the desired pulse width (referred to as P in the following description). The initialization sequence for Latch B and C and the starting of a counting sequence are as follows (see Figure 9-9):

1. The lower 8 bits of P are loaded into LLB by writing to address 001C, and the upper 8 bits of P are loaded into ULB and the full 16 bits are transferred to Latch C by writing to address location 001D. At this point both Latch B and Latch C contain the value of P.

2. The lower 8 bits of D are loaded into LLB by writing to address 001C, and the upper 8 bits of D are loaded into ULB by writing to address location 001E. Writing to address location 001E also causes the contents of the 16-bit Latch B to be downloaded into the Counter B and caused the CB output to go low as shown in Figure 9-9.

3. When the Counter B underflow occurs the contents of the Latch C is loaded into the Counter B, and the CB output toggles to a high level and stays high until another underflow occurs. Latch B is then down-loaded and the CB output toggles to a low level repeating the whole process.

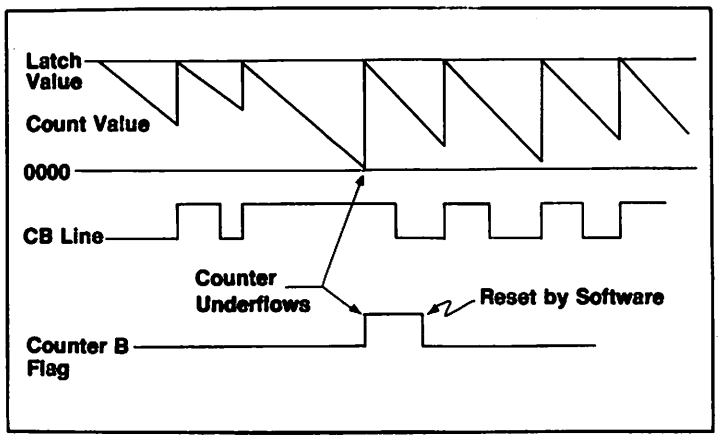


Figure 9-8. Counter B Retriggerable Interval Timer Mode

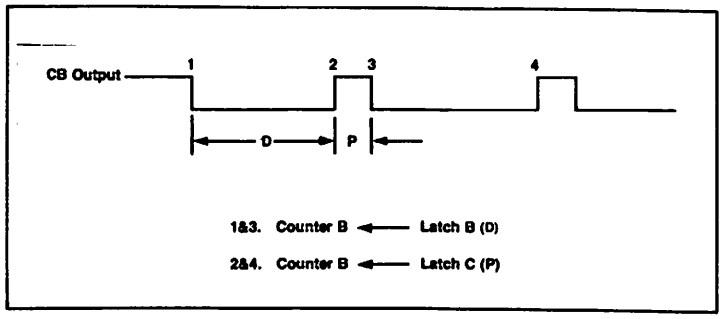


Figure 9-9. Counter B Pulse Generation

SECTION 10

NOTES ON STYLE AND PROGRAM DEVELOPMENT

10.1 GENERAL

Like most other programming languages FORTH is not particularly readable to someone who is not familiar with it. Because FORTH is unique among programming languages even experienced programmers have difficulty at first -- FORTH is unlike their past experience. After reading this manual FORTH should be understandable and some practice in coding will sharpen the eye. The key to easily readable FORTH code lies in logical factoring of key words and in choosing appropriate names for words.

Correct FORTH code should read in an almost natural English way for the higher level key words if these practices are followed. Factoring means writing a word as a collection of lower level words that actually name the functions performed by this word. These lower level words in turn are made up of other still lower level words which more precisely define the task accomplished by the word. Finally, you will arrive at a level which uses mostly regular FORTH words and is the most fundamental level, not particularly obvious to anyone but the system programmer, and then only when coding the word and for a short time afterwards.

Comments are necessary to understanding the operation of words. What may be perfectly clear to you today will not be next month or to another equally qualified programmer at any time. Comment in simple statements using the appropriate FORTH word names adjacently where you can. Be a bit more detailed than you think necessary when you write them, since they will be a bit too obscure later if you don't. However, comments are not tutorials to the novice or non-programmer. Too much verbage obscures the program flow in a sea of text. Commentary documentation that must speak to the non-programmer should be written elsewhere in a companion document.

Comments given at the start of a FORTH word should include a simple statement about what the word takes from and leaves on the stack.

10.2 EXAMPLE PROGRAM

To illustrate the style and comment forms described above, look at the many examples elsewhere in this manual and you will see the top-down approach in use, and reasonable comments that can be included on a printer. This section takes as an example simple problem of figuring the miles a car traveled per gallon of fuel from data kept in a common automobile record book.

a. Problem Definition

Start with the definition

$$\text{mpg} = \frac{\text{miles traveled}}{\text{gallons used}}$$

which is fine if you record mileage and gallons and you aren't particular about accuracy. For the newer automobiles, an error of a tenth of a gallon can cause an error of 0.5 mpg in the result.

For best accuracy you should accumulate mileage and gasoline used over several fill-ups. This averages your error in filling the tank non-uniformly and then by recording the data carefully you can have an accurate picture of your gas mileage.

$$mpg = \frac{miles}{gallons}, \text{ but gallons} = \frac{amount}{price},$$

so

$$mpg = \frac{\frac{miles}{amount}}{price} = \frac{miles(price)}{amount}$$

However, miles is not the odometer reading, it is the miles traveled, and the odometer will require a correction factor, so

$$miles = (m_1 - m_0)k$$

m_0 = last odometer reading
m_1 = current odometer reading
K = correction factor

therefore,

$$mpg = \frac{(m_1 - m_0)kp}{a}$$

p = price
a = amount

But price is either in cents per gallon or cents per liter, and since you are probably interested in miles per gallon you will have to multiply any cents per liter prices by 3.785 to correct to cents per gallon.

Finally,

$$mpg = \frac{(m_1 - m_0)kp}{a} \text{ for cents/gallon}$$

or

$$mpg = \frac{(m_1 - m_0)k}{a} \left(\frac{3785p}{1000}\right) \text{ for cents/gallon}$$

To be efficient when doing more than one gas mileage check, the current odometer reading should be saved as m_0 for the next calculation.

b. Scaling

To correctly scale the calculation for integer computation, you must first decide the level of precision desired in the answer. If you want mpg to a tenth of a mile per gallon, distance in miles, price to a tenth of a cent and amounts in cents, then

$$mpg(10) = \frac{(m_1-m_0)p(10)}{a}$$

If we enter p without the decimal, we get p times 10 automatically and the result will come out in 10's of mile per gallon as desired.

c. Program Design, Coding and Checkout

If the data are recorded in a data book as miles, price, and amount, it is convenient to enter them as written, therefore the stack would look like this:

m_1 p a

and they would all be 16-bit numbers.

Given the data on the stack as described above and the odometer correction and price adjustment necessary, the principle word looks (without any comments) like this:

```
: ?MPT   ROT   TRUE-MILES   ROT   CENTS/GAL
         ROT   */   .MPG  ;
```

where the ROT words bring the stack values up to be operated on by the fairly obvious correction and adjustment words. The */ computes the final operation

$$\frac{mp}{a}$$

and the word .MPG prints the answer out in a nice format with a decimal point where we expect it.

Now that we have the 'top' level structure, let us define the lower level words TRUE-MILES , CENTS/GAL and .MPG

It is not necessary but a convenience to use two memory storage locations in this calculation, one constant for k and a variable where we can store the current odometer reading (m_1) to use as the last odometer reading (m_0) for the next calculation.

Start with the word .MPG and use the normal FORTH output formatting words except include a decimal point in the output text string with the phrase 46 HOLD and embellish the result with the ending "MPG" .

Enter the program source code in a FORTH screen if mass storage is available. Notice that blank lines (enter <SPACE> followed by <RETURN>) aid in source code readability.

```
( MPG PROGRAM )

( CONST & VARIABLES )
103 CONSTANT K
  0 VARIABLE OLD

: .MPG ( MPG * 10 ---. DISPLAY MPG )
S->D <# # ( 1 DIG. )
46 HOLD ( DEC. PT. )
#S #> ( FINISH IT)
CR TYPE ." MPG " ;
```

The test of .MPG puts a few numbers on the stack before the test number 456 and then execute .MPG along with .S to see that the stack contents have not been altered.

```
1 2 3 456 .MPG .S
45.6 MPG
3
2
1 OK
```

With .MPG working correctly, define TRUE-MILES which uses */ as a scaling operator. The constant k (derived for each odometer and set of tires separately) is multiplied by the miles traveled (M - OLD) and then divided by 100. The decision point for CENTS/GAL tells if the price for a gallon or liter is $1.00 and should be correct for a while yet. The adjustment for liter prices is

$$p\frac{3785}{1000}$$

which results in cents per gallon equivalent.

Now enter the rest of the code-definitions:

```
: TRUE-MILES ( ODOMETER ---. ADJUST MILEAGE )
OLD @ ( OLD #)
OVER OLD ! ( NEW #)
- ( MILES)
K ( CORRECTION )
100 */ ( ADJUST) ;

: CENTS/GAL ( PRICE ---. CONVERT PRICE )
DUP ( FOR COMPARE)
1000 < ( ? < $1.00)
IF ( CENTS/LITER)
  3785 100 */
THEN ;
```

```
: ?MPG ( ODO PRICE AMT ---. DISPLAY MPG )
ROT ( GET ODOMETER)
TRUE-MILES
ROT ( GET PRICE)
CENTS/GAL
ROT ( GET AMOUNT)
*/ ( COMPUTE MPG)
.MPG ( & PRINT) ;
<RETURN>
```

If any errors occur during compilation, check the source code for entry errors. Compile each word separately, if needed, to verify proper coding by bracketing each word with parenthesis before the word (before the :) and after the word (after the ;) as comments.

d. **Program Final Testing**

The testing of ?MPG involves entering some known values into it and observing the results. Don't forget to set the OLD value for the odometer reading first, as shown below. Then enter test values on the stack for the current odometer reading, the price, and the miles traveled.

```
3198 OLD ! OK
3457 1199 841 ?MPG
37.9 MPG OK
3665 1169 1038 ?MPG
24.1 MPG OK
3839 1199 1063 ?MPG
20.1 MPG OK
4017 1339 1150 ?MPG
21.3 MPG OK
4200 1329 997 ?MPG
25.0 MPG OK
OLD ? 4200 OK
```

Finally, if you want to put the decimal points in the input numbers, remember that RSC-FORTH interprets this as a 32-bit number. So, for every number with a decimal point in it, you will have two 16-bit numbers on the stack.

e. **Program Enhancement**

You can redefine word ?MPG which will take such numbers and rearrange them to be acceptable to the original ?MPG . This time the input is in whole miles, cents and a tenth and dollars.

The 32-bit numbers go on the stack with the most significant part on top. Since none of the numbers are even close to using the most significant 16-bit part, simply drop them off the stack at the appropriate place and use the old version of ?MPG .

```
: ?MPG ( ODO CENTS $ ---. COMPUTE MPG)
DROP ( UNUSED WD.)
SWAP ( OTHER ONE)
DROP ( IT TOO)
?MPG ( USE IT OVER)
;
<RETURN>
```

Now test it with miles, cents and a tenth, and dollars.

```
3198 OLD ! OK
3457 119.9 8.41 ?MPG

37.9 MPG OK
```

Check to be sure OLD was updated.

```
OLD ? 3457 OK
```

SECTION 11

PREPARING AN APPLICATION PROGRAM FOR PROM INSTALLATION

It is often desirable to install an application program written in FORTH into one or more PROM/ROM devices for immediate operation upon microcomputer power turn-on, i.e., without requiring entry into the FORTH interpreter, or recompilation of the application FORTH source code. This section describes a method to develop an application program written in FORTH as normal or target compiled headerless code, how to locate it for execution from either RAM or PROM/ROM, and how to cause one word to be autostart executed at power on or reset.

The RSC-FORTH System was designed to easily autostart a dedicated program. The RSC-FORTH Operating System initializes all variables required by the kernel at reset then searches for an external user program to autostart. Functions included in the development ROM that make preparation of programs for PROM/ROM easy.

11.1 PROGRAM DEVELOPMENT

The first step in preparing an application for PROM is, naturally, to develop the program itself. There are a number of viable options to choose from, but some sort of development system must be created. The RSC-FORTH system is truly unique in that the target system which the program is being developed for, can actually be the system used to do the development. The only additional cost in designing a product that can be its own development system is the overhead required to support the development ROM, a 28-pin socket and decode logic.

It is entirely possible to do complete developments for small systems just as stated. Mass storage, however, is certainly required when the program size increases. There are two likely ways to accommodate mass storage. One is to have the mass storage be a part of the RSC-FORTH system, e.g., add a floppy disk controller and associated circuitry. The other is to stick with a minimal RSC-FORTH system and use a host system to download source code to the target system. This host could be another RSC-FORTH system, an AIM 65 Microcomputer, AIM 65/40 Microcomputer or other microcomputer system with mass storage. The only real requirement on such a host system is that text can be entered and edited, then transfered over a serial channel compatible with the RSC-FORTH serial channel and respond to XON/XOFF protocol. It would also be desirable if the host could act as a terminal so direct communications with the R65F11 of R65F12 could be used during testing.

Most of the considerations made for PROM-based systems depend on the nature of the target system. The deciding factor is largely the memory allocation. First, it must be determined if the final target system requires any external RAM. Dedicated applications that do all I/O functions by manipulating the port lines (for example: a traffic light controller) can rely entirely on the stack to provide temporary storage. Applications that require a small array area (i.e., magnetic badge readers) can directly refer to the lower stack area. Locations $0060 to $00A0 are usually safe since normal stack depths do not exceed 16 words at a time.

The print functions such as . , ? , D.R , # , etc., make use of the area of PAD and therefore must use external RAM at 0300. The terminal input routines, such as QUERY , EXPECT , etc., use the Terminal Input Buffer (TIB) at address $0380. For these and other applications that require disk operations or large block of memory external RAM is a must.

The R65FR1 Development ROM initializes RSC-FORTH to start its dictionary at $0400, the first 1K-byte boundary. If no RAM is required in the final system and the program is small, i.e., less than 1K bytes, the RSC-FORTH development system can be as simple as the one shown in Figure 2-2. The program can then be developed in the RAM and dumped to a PROM programmer. After PROM programming, the RAM device can be removed and replaced with the PROM, such as a 2716. Only the last half of the PROM would be used, but this would still be a very cost effective solution.

If RAM is required in the final system, or more than 1K-byte of program is to be generated, an additional RAM will have to be added to the development system shown in Figure 2-2. Decoding logic will also need to be changed accordingly. The program will be developed in the second RAM, at address $0800 to $0FFF and replaced with a EPROM.

To move the program to the second RAM at power on, enter:

```
FORGET TASK HEX 400 ALLOT  : TASK ;
```

The lower addressed RAM can remain in the target system if needed. By allotting blocks in multiples of $0400, any 1K-byte boundary can be used for the autostart vector.

Another independent question to be addressed is that of normal or target compiled code. No action is required if normal code is desired. In order to initiate target compilation, action must be taken at power on. The sequence

```
FORGET TASK HEX 600 H/C  : TASK ;
```

causes codes to be generated at address $0404 and up and dictionary heads to be placed at $0600 and up.

Depending on the system configuration and RAM available the codes might need to be at other addresses. A combination of the two methods above might be required.

For example:

```
FORGET TASK HEX 400 ALLOT 1800 H/C  : TASK;
```

puts the codes at address $0800 and the heads at $1800.

After a program has been entered, tested and debugged and re-entered in the correct memory location and compiled format, it is ready to have the autostart pattern added. This is the very last step before transferring the image to PROM. This should be done with great caution. Once a program is set for program autostart, the development ROM cannot be reeentered by RESET.

Addition of the autostart pattern is extremely easy. The word AUTOSTART generates the autostart pattern and loads the vector to the definition to be autostarted. AUTOSTART requires only an address specifying where the autostart pattern is to be placed and the name of the routine to autostart. For example, if GO-TO-IT was the main routine of a dedicated application;

```
800 AUTOSTART GO-TO-IT
```

puts A55A at address $800 followed by a pointer that identifies the location of the PFA of GO-TO-IT. The value stored there is the equivalent of ' GO-TO-IT @ .

Once the RAM image is established the PROM can be made by using ADMP to transfer the RAM image to a PROM programmer or using the EEC! functions described in Section 6.

In summary, the steps to enter a program into EPROM is as follows:

a. Write, enter, test and debug the application program on the development system. Save the source code.

b. Enter COLD to initialize the RSC-FORTH System. Enter

c. Enter FORGET TASK to remove the linkage to TASK .

d. If moving the address of the target code area, enter

```
XXXX ALLOT or YYYY DP!
```

where XXXX = number of bytes to move the starting address from $0400.
YYYY = actual starting address to be used.

NOTES: XXXX must be multiple of 1024 ($400).
YYYY should be four bytes from a 1K-boundary (i.e., $804, $C04, $1004, etc.) to leave room for a preceding autostart pattern.
Watch the number base when entering.

e. If using target compiled code, enter

```
ZZZZ H/C
```

where ZZZZ = the address to put the dictionary heads to be generated. These do not necessarily need to be saved for the final system.

f. Re-enter the source code to recompile. This can be done with LOAD from disk or SOURCE from a host computer.

g. Add the autostart pattern, i.e., enter

    AAAA AUTOSTART <name>

    where AAAA = 1K-page boundary to be used and <name> is the main starting point-routine.

h. Transfer the image to PROM with ADMP or EEC! as described in Section 6.

SECTION 12

INTERFACING TO MASS STORAGE

12.1 OVERVIEW

RSC-FORTH includes all of the fundamental words needed to interface with, and effectively use, mass storage devices. This chapter provides directions and guidelines on how to interface to a floppy disk, however, the procedure may be easily modified to include other peripherals.

Before you begin, you must have a mass storage device in correct functioning order, and you must have enough memory added to the R65F11 or R65F12 microcomputer to hold two FORTH screens. The minimum RAM requirement for buffers is 2056 bytes, but a practical minimum for the system is 4K bytes, although 6K is more reasonable and a full 8K is better.

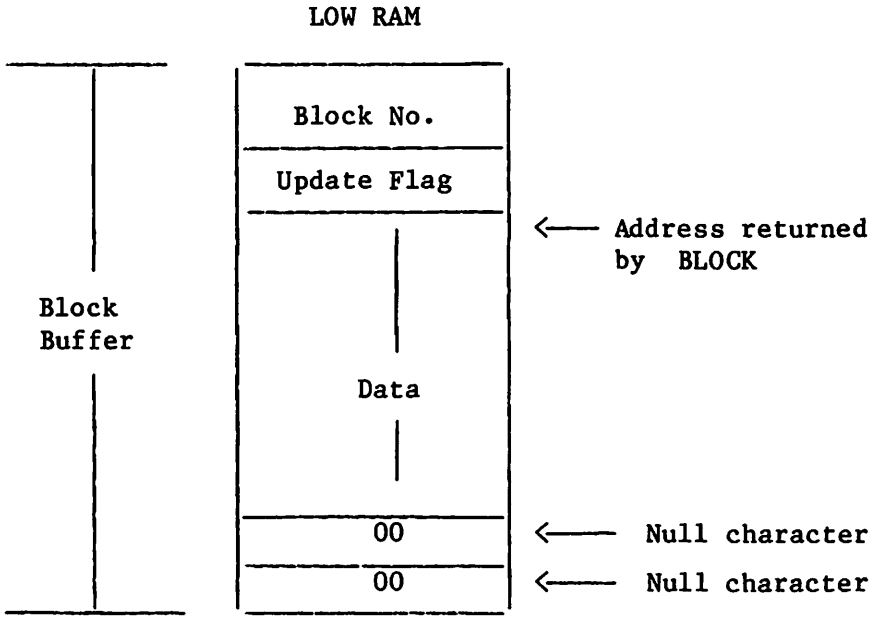
12.1.1 Mass Storage Terminology

FORTH accesses mass storage in uniformly-sized pieces called blocks, and keeps data, or source code, in RAM in 1024-byte pieces called screens. If the block buffer is 1024 bytes, then the terms 'block' or 'screen' are often used interchangeably. Since these block sizes are commonly the size of a floppy disk sector of 128 or 256 bytes, there are normally eight or four blocks per screen, respectively, however, in RSC-FORTH, the floppy interface reads multiple sectors from the floppy at once. Therefore, the block size and the buffer size is the same as the screen size.

a. Block Buffer

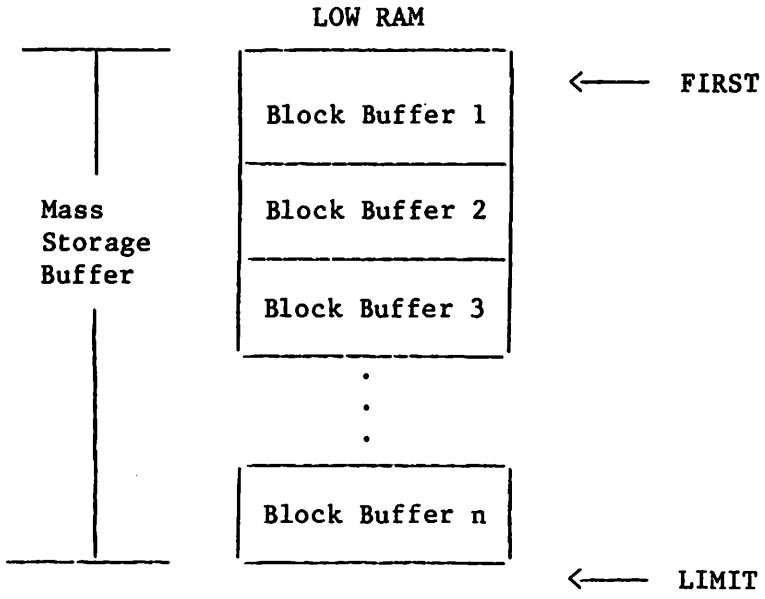
A particular block is referenced by the FORTH word BLOCK which takes the block number as the argument. If the block of data is in RAM, BLOCK returns immediately with the address of the buffer where the data is to be found. If the block is not in RAM, BLOCK uses R/W (described below) to fetch it from mass storage and put it in a buffer in RAM, then returns the address of that buffer. BLOCK also checks to see if the data in a particular buffer needs to be written out to mass storage before it uses the buffer for new data.

Each block buffer in RAM is four bytes larger than the mass storage block size. Two of these extra bytes are at the end of the buffer and both contain ASCII null characters ($00) to mark the end of data. The other two bytes, located at the start of the buffer, contain the block number and a one-bit flag (MSB) that indicates whether or not the buffer contains data that must be written to mass storage before the buffer can be used for new data. The layout of a block buffer is:



b. Data Buffer

The RAM area reserved for use by mass storage, commonly called the data buffer area, or the mass storage buffer area, must contain two or more of the block buffers described above. The first byte of the entire mass storage buffer area is referenced by the word FIRST and is stored in the variable UFIRST . The last byte of the entire buffer area is located at LIMIT -1 and the value returned by the word LIMIT is kept in ULIMIT . The layout of the buffer area is:



c. Screen Size

Conventionally, when a screen of source code is listed on a CRT display, it appears as 16 lines of 64 characters each. The lines are numbered 0 to 15 on the left of the text.

12.1.2 Buffer Variables

The number of blocks and the size and location of the data buffer in RSC-FORTH is controlled by two user variables (UFIRST and ULIMIT). The logic of which one to use at any given time is controlled by three other variables (PREV , USE , and OFFSET). The names, description and access words for these variables are given in Table 12-1.

12.2 SETTING UP BLOCK AND DATA BUFFERS

R/W is the primary word that interfaces FORTH to mass storage. All of the FORTH logic which automatically handles the locating, reading and writing of mass storage data ultimately winds up using R/W . However, before R/W can work properly, it must have a set of data buffers to use. As explained earlier, RSC-FORTH needs at least two buffers in order for the buffer rotation logic to work correctly.

The general steps in the process of setting up the block and data buffers is a simple procedure as summarized below; the details are given in the following section.

1. Set the top (high RAM) of the data buffer area into ULIMIT .
2. Compute and set the start of the data buffer area into UFIRST .
3. Set USE and PREV to FIRST . → FIRST PREV !
4. Clear the data buffer. EMTY-BUFFERS FIRST USE !
5. Initialize the block offset value.

In many cases, steps 1 and 2 can be omitted. The default value of the top of RAM for ULIMIT is a good choice, unless special circumstances dictate that another value should be used.

In steps 3 and 4, it is convenient to use FORTH to compute the actual values to store and to setup and clear the buffers to use. The FORTH word EMPTY BUFFERS performs both these functions.

Steps 1, 2, 3 and 4 can be replaced if a standard two-buffer memory area is desired. Entering XXX MEMTOP , where XXX is the word that would be put in ULIMIT from step 1, accomplishes all the above tasks automatically.

Step 5 is necessary if a value other than zero is desired as FORTH adds this offset value to each block number requested via R/W . The utility of OFFSET is in setting it to the first block number in an extra mass storage device. Then the block numbers of media inserted in that device will be the same to the user as when OFFSET is zero and the media is in the primary device.

Table 12-1. Buffer Variables, Constants, and Access Words

Variable	Access Word	Default Value	Description
UB/BUF	B/BUF	1024	Holds the number of bytes of data in each block buffer. The actual buffer size is four bytes larger than this value. This number is a constant in RSC-FORTH and cannot be changed.
UB/SCR	B/SCR	1	Holds the number of block buffers per FORTH screen, 1. This number is a constant in RSC-FORTH and cannot be changed.
UFIRST	FIRST	$13F8	Holds the location of the start of the data buffer.
ULIMIT	LIMIT	$2000	Holds the location of the end of the data buffer plus one.
PREV	none*	FIRST	Holds the address of the block buffer most recently referenced.
USE	none*	FIRST	Holds the address of the block buffer to use next.
OFFSET	none*	0000	Holds a value to be added to the block number given to BLOCK .

NOTES

*Variables without a special access word to fetch the value are treated like any other FORTH variable. Use @ to fetch the data from its address and ! to put data into its address. Any variable can be accessed in this manner; the special access words are only for convenience.

12.3 USING MASS STORAGE

The simplicity of the disk interface and FORTH's ability to customize to a particular application allows mass storage devices to be easily used in powerful ways. Two such ways are described in this section. Remember all mass storage operations must use diskettes that are first formatted with either FORMAT or a similar word.

12.3.1 Data Storage and Retrieval - the Virtual RAM

Data storage and retrieval using a mass storage device is quite simple. Just think of the data as an array of numbers, and, given the element number of a data item in the array, compute the required block number and offset into that block. Knowing the block number, all that is left to do is to access the block and add the offset to the address returned by BLOCK .

Suppose you want to process an array of 250 16-bit numbers and you wish the data to start at block 25. If the disk uses 256-byte blocks, a word that would supply the RAM address of a given array element number (0-249) would look like:

```
: DATA 128 /MOD 25 + BLOCK SWAP 2 * + ;
```

The address produced by DATA can then be used like any other variable address. The normal FORTH words @ and ! would then fetch and store data as if it were always in RAM. One extra modification would be appropriate here -- the word ! should automatically indicate that data was put into a disk buffer so that the buffer will be written out automatically. This is easily done by redefining ! and @ as U! and U@ :

```
( value index ---   )
: U! DATA ! UPDATE ;
( index --- value )
: U@ DATA @ ;
```

The actual use of DATA is shown by a couple of examples. To print the 153rd number, simply type:

```
153 U@ .
```

To clear out the entire array use:

```
: CLEAR 250 0 DO 0 I U! LOOP FLUSH ;
```

(The word FLUSH at the end writes all updated buffers out to the mass storage device.)

12.3.2 Program Loading and Overlays

Once a screen has been written with a FORTH program, it is necessary to compile the program into the dictionary. This is done with LOAD , which takes the screen number from the stack and begins compiling that screen, starting at line 0 and continues until a ;S is encountered. The ;S terminator may be placed at any position, and any number of ;S words may appear on a screen, but FORTH will always stop compiling at the first ;S encountered.

Programs of more than one screen may be compiled but only if the screens are contiguous. Each screen, except for the last, must end with the word --> , and the last screen must be terminated with ;S . Compilation starts with a LOAD of the first screen in the sequence.

With a disk connected to an RSC-FORTH microcomputer with 18K-bytes of RAM, you can run quite large programs in FORTH by dividing the program into convenient-sized pieces and using program overlays. The techniques for using program overlays are -- like the disk data storage -- quite straightforward. Use the FORTH words FORGET and LOAD to overlay programs.

Suppose you have a program that consists of three parts: input, processing and output. If these three parts do not need to be resident in RAM all at the same time, they can be loaded and run sequentially.

First, construct what is called a load screen, which contains the directions for loading and executing the entire program. Suppose the source code of the input part of the program is in screens 12, 13 and 14, the source code for the processing part is in screens 30, 31 and 32, and the output source code is in screens 33 to 35. Further suppose that some data manipulating words are in screen 102 and 103, and that these words are commonly used by the three overlays of the program. The resulting load screen might look like this:

```
FORGET TASK   : TASK ;  ( CLEANS DICTIONARY)
102 LOAD  103 LOAD  ( DATA WORDS)
: INPUT   12 LOAD  13 LOAD  14 LOAD ;
: PROCESS   30 LOAD  31 LOAD  32 LOAD ;
: OUTPUT   33 LOAD  34 LOAD  35 ;
: LEVEL ;   INPUT
```

Each of the three overlay programs, INPUT , PROCESS and OUTPUT , should have the phrase

```
FORGET LEVEL : LEVEL ;
```

in the first screen to be loaded. This phrase discards the previous overlay and makes room in the dictionary for the next overlay. The process of overlays is started by interpreting the word INPUT in the load screen. Note that the three overlay words are defined before the dummy word LEVEL . This ensures that the overlay words will not be forgotten by the overlays themselves.

The process of overlaying can be a manually directed one, or if desired, the next overlay can be called as the last action of the current overlay. The process of overlaying can then continue indefinitely and unattended.

The methods outlined above for enhanced use of mass storage are very useful in actual practice even though the methods are quite simple. FORTH is capable of much more. By using the defining words <BUILDS and DOES>, different classes of new FORTH words can be created to take advantage of other mass storage or external facilities.

12.4 SOURCE CODE EDITING

The many different mass storage devices, terminals and user preferences make it impossible to provide more than a start at putting source code onto FORTH screens. Four useful words for manipulating character data are already supplied in RSC-FORTH, namely (LINE) , .LINE , >LINE and LIST . The following code defines a word useful for initializing screens used for text, called WIPE .

```
SCR # 13
  0 ( WORD TO CLEAR SCREENS>)
  1
  2 ( S - S WIPE BLANKS etc.
  3 : WIPE BLOCK 1024 BLANKS
  4    UPDATE FLUSH;
  5
  6
  7
  8
  9
 10
 11
 12
 13
 14
 15  ;S
```

The words LIST and >LINE work together in that a screen should be listed before text is placed in it with >LINE . The act of listing a screen makes that screen the current screen and operations are directed to it.

The word LIST uses .LINE to output 16 lines of 64 characters each. LIST also prints the screen number and the number of each line, for reference when placing text in that screen. Given the line number as a parameter, the word >LINE fetches the current screen number then places blanks in that line before moving the following text string into it. Once the text is in the proper buffer, >LINE flags the buffer as having new data in it, and that data will automatically be written to mass storage if the buffer is needed.

The word WIPE takes the screen number left on the stack and fills all of its blocks with spaces, thus preparing the screen for editing. Because WIPE overwrites anything written in the screen, it must be used with caution.

The words are used like this:

```
10 WIPE
```

places blanks in screen 10, and

```
10 LIST
```

verifies this.

To enter text, use >LINE like this:

```
3 >LINE THIS LINE OF TEXT GOES ON LINE 3.
```

This text will be placed on line 3, and the rest of line 3 will be blanked, in case there was old text on it.

Use >LINE to place text into screens to make a simple editor. Test these words by loading the screens and trying them out. Then use the simple editor to make a enhanced editor that takes advantage of any features that your particular setup has.

After a screen has been created or edited, the new information must be written to the disk before that screen is compiled. This can be done with a FLUSH before the LOAD .

APPENDIX A

RSC-FORTH FUNCTIONAL SUMMARY

This appendix contains a summary of the RSC-FORTH word definitions, grouped by area of primary function. Consult Appendix B for the detailed definition of each word.

Stack Notation

The stack operation is denoted in the parentheses. The symbols on the left indicate the order in which input parameters must be placed on the stack prior to FORTH word execution. Three dashes (---) indicates the FORTH word execution point. Any parameters left on the stack after execution are listed on the right. The top of the stack is to the right.

Symbol Definition

n,n1,...	16-bit signed number
d,d1,...	32-bit signed number
u,u1,...	16-bit unsigned number
ud,ud1,...	32-bit unsigned number
addr,addr1...	address
b	8-bit byte (with eight high bits zero)
c	7-bit ASCII character value (with nine high bits zero)
f	Boolean flag (zero - false, non-zero = true)
ff	Boolean false flag (value = zero)
tf	Boolean true flag (value = non-zero)

A.1 STACK MANIPULATION

DUP	(n --- n n)	Duplicate the number on the stack.
2DUP	(d --- d d) or (n1 n2 --- n1 n2 n1 n2)	Duplicate the top double number (or the top two numbers) on the stack.
DROP	(n ---)	Delete the top number on the stack.
2DROP	(d ---) or (n1 n2 ---)	Delete the top double number (or the top two numbers) on the stack.
SWAP	(n1 n2 --- n2 n1)	Exchange the top two numbers on the stack.
OVER	(n1 n2 --- n1 n2 n1)	Copy second number on the stack to the top.
ROT	(n1 n2 n3 --- n2 n3 n1)	Rotate the third number on the stack to the top.
-DUP	(n --- n ?)	Duplicate the top number on the stack only if it is non-zero.

A.1 STACK MANIPULATION (Continued)

>R	(n ---)	Move top item to Return Stack.
R>	(--- n)	Retrieve item from Return Stack.
R	(--- n)	Copy top of Return Stack onto stack.
PICK	(n --- nth)	Copy the nth item to top.
SP@	(--- addr)	Return address of stack top position.
RP@	(--- addr)	Return address of the return stack pointer.
.S	(---)	Display stack contents without modifying the stack.
SP!	(---)	Initialize Parameter Stack.

A.2 NUMERIC REPRESENTATION

DECIMAL	( )	Set decimal base.
HEX	( )	Set hexadecimal base.
BASE	(--- addr)	System variable containing number base.
DIGIT	(---)	Convert ASCII to binary.
0	(--- 0)	The number zero.
1	(--- 1)	The number one.
2	(--- 2)	The number two.
3	(--- 3)	The number three.
4	(--- 4)	The number four.

A.3 ARITHMETIC AND LOGICAL

+	(n1 n2 --- sum)	Add two 16-bit numbers.
D+	(d1 d2 --- sum)	Add two 32-bit numbers.
-	(n1 n2 --- diff)	Subtract (n1-n2).
*	(n1 n2 --- prod)	Multiply.
/	(n1 n2 --- quot)	Divide (n1/n2).
MOD	(n1 n2 --- rem)	Modulo (i.e., remainder from division).
/MOD	(n1 n2 --- rem quot)	Divide, giving remainder and quotient.
*/MOD	(n1 n2 n3 --- rem quot)	Multiply, then divide (n1*n2/n3), with double intermediate.
*/	(n1 n2 n3 --- quot)	Like */MOD , but give quotient only.
U*	(u1 u2 --- ud)	Unsigned multiply leaves double product.
U/	(ud u1 --- u2 u3)	Unsigned remainder and quotient from double dividend.
M*	(n1 n2 --- d)	Signed multiplication leaving double product.
M/	(d n1 --- n2 n3)	Signed remainder and quotient from double dividend.
M/MOD	(ud1 u2 --- u3 ud4)	Unsigned divide leaving double quotient and remainder from double dividend and single divisor.
MAX	(n1 n2 --- max)	Maximum.

A.3 ARITHMETIC AND LOGICAL (Continued)

MIN	(n1 n2 --- min)	Minimum.
+-	(n1 n2 --- n3)	Set sign, n3 = n1 times the sign of n2.
D+-	(d1 n --- d3)	Set sign of double number.
ABS	(n --- absolute)	Absolute value.
DABS	(d --- absolute)	Absolute value of double number.
NEGATE	(n --- -n)	Change sign.
DNEGATE	(d --- -d)	Change sign of double number.
S->D	(n --- d)	Sign extend single number to double number.
1+	(n1 --- n1+1)	Increment by 1.
2+	(n1 --- n1+2)	Increment by 2.
1-	(n1 --- n1-1)	Decrement by 1.
2-	(n1 --- n1-2)	Decrement by 2.
AND	(n1 n2 --- and)	Logical AND (bitwise).
OR	(n1 n2 --- or)	Logical OR (bitwise).
XOR	(n1 n2 --- xor)	Logical exclusive OR (bitwise).
-BCD	(u1 --- u2)	Connect a number to its BCD equivalent.
BOUNDS	(addr n --- addr r + n addr)	Convert start addr and count to start and stop addresses.

A.4 COMPARISON OPERATORS

<	(n1 n2 --- f)	True if n1 less than n2.
>	(n1 n2 --- f)	True if n1 greater than n2.
=	(n1 n2 --- f)	True if top two numbers are equal.
0<	(n --- f)	True if top number negative.
0=	(n --- f)	True if top number zero (i.e., reverses truth value).
U<	(u1 u2 --- f)	True if u1 less than u2.
NOT	(f --- f')	Reverse Boolean value (same as 0 =).

A.5 CONTROL STRUCTURES

DO ... LOOP	(end+1 start --- ... loop)	Set up loop, given index range.
DO ... n +LOOP	(end+1 start --- ... n +loop)	Like DO...LOOP , but and stack value (instead of always '1') to index.
I	(--- index)	Place current index value on stack.
LEAVE	(---)	Terminate loop at next LOOP or +LOOP .
BEGIN ... UNTIL	BEGIN ... f UNTIL	Loop back to BEGIN until true at UNTIL .
BEGIN ... WHILE ... REPEAT	BEGIN ... f WHILE ... REPEAT	Loop while true at WHILE ; REPEAT loops unconditionally to BEGIN .
BEGIN ... AGAIN		Unconditional loop.
IF ... THEN	if: (f ---)	If top of stack true, execute.

A.5 CONTROL STRUCTURES (Continued)

IF ... ELSE	if: (f ---)	Same, except that if top
... THEN		stack false, execute ELSE clause.
END		Alias for UNTIL .
ENDIF		Alias for THEN .
BANKEXECUTE	(addr n ---)	Execute the definition with CFA of addr from bank n. Return to current bank.

A.6 MEMORY

@	(addr --- n)	Replace word address by contents.
!	(n addr ---)	Store second word at address on top.
C@	(addr --- b)	Fetch one byte only.
C!	(b addr ---)	Store one byte only.
?	(addr ---)	Print contents of address.
+!	(n addr ---)	Add second number on stack to contents of address on top.
CMOVE	(from to n ---)	Move n bytes in memory.
FILL	(addr n b ---)	Beginning at addr, fill n bytes in memory with b.
ERASE	(addr n ---)	Beginning at addr, fill n bytes in memory with Zeroes.
BLANKS	(addr n ---)f	Beginning at addr, fill n bytes in memory with blanks.
TOGGLE	(addr b ---)	Exclusively OR byte at addr with byte b.
EEC!	(b addr n ---)	Program byte b into addr for n clock cycles.
BANKC@	(addr n --- b)	Fetch one byte at addr from bank n.
BANKC!	(b addr n ---)	Store one byte b at addr in bank n.
BANKEEC!	(b addr n1 n2 ---)	Program byte b into addr for n1 clock cycles, in bank n2.

A.7 INPUT-OUTPUT

.	(n ---)	Print number ASCII string.
CR	(---)	Output a carriage return and line feed to the AIM 65/40 printer and display.
SPACE	(---)	Type one space.
SPACES	(n ---)	Type n spaces.
."	(---)	Print message (terminated by ").
DUMP	(addr n ---)	Dump n bytes starting at address using current base.
TYPE	(addr n ---)	Type string of n characters starting at address.
?TERMINAL	(--- f)	True if any key is depressed.
KEY	(--- c)	Read key, put ASCII value on stack.
EMIT	(c ---)	Output ASCII value from stack.
EXPECT	(addr n ---)	Read n characters (or until carriage return) from input to address.
WORD	(c ---)	Read the next text character string.
IN	(--- addr)	User variable containing current offset within input buffer.

A.7 INPUT-OUTPUT (Continued)

BL	(--- c)	Put a SPACE character (ASCII $20) on the stack.
C/L	(--- n)	Maximum number of characters/line.
TIB	(--- addr)	Terminal Input Buffer start addr.
QUERY	(---)	Input text from terminal.
ID.	(addr ---)	Print <name> given name field address (NFA).
;DUMP	(addr n ---)	Dump n bytes starting at addr in ASCII format in one semicolon record.
ADMP	(addr1 addr2 ---)	Dump bytes from addr1 to addr2 in ASCII format in as many semicolon records as required. Also send closing record.
" "(NULL)	(---)	Executed at end of each input or screen line. Not used by user.

A.8 OUTPUT FORMATTING

NUMBER	(addr --- d)	Convert string at address to double-precision number.
<#	(---)	Start output string.
#	(|d| --- |d|)	Convert next digit of double-precision number and add character to output string.
#S	(|d| --- 0 0)	Convert all significant digits of double-precision number to output string.
SIGN	(n |d| --- |d|)	Insert sign of n into output string.
#>	(|d| --- addr u)	Terminate output string (ready for TYPE).
HOLD	(c ---)	Insert ASCII character into output string.
HLD	(--- addr)	Hold pointer, user variable.
-TRAILING	(addr n1 --- addr n2)	Suppress trailing blanks.
.LINE	(line SCR ---)	Display line of text from mass storage.
COUNT	(addr1 --- addr+1 n)	Count and address of message text.
.R	(n fieldwidth ---)	Print number ASCII string right-justified in field.
D.	(d ---)	Print double number ASCII string.
D.R	(d fieldwidth ---)	Print double number ASCII string right-justified in field.
DPL	(--- addr)	Address of number of digits to the right of decimal point.

A.9 MONITOR

COLD	(---)	RSC-FORTH cold start.
MON	(---)	Exit to RSC-FORTH Monitor.
CLD/WRM	(--- addr)	User variable containing the COLD/WARM flag. When equal to A55A, reset does warm start, otherwise does cold start.
SOURCE	(---)	Interpret input from active input device with XON/XOFF protocol.
FINIS	(---)	End of file marker for input via SOURCE .
XON	(---)	Restores input vector. Emits "ON" character for XON/XOFF protocol.
XOFF	(---)	Emits "OFF" character for XON/XOFF protocol.

A.10 COMPILER-TEXT INTERPRETER

;S	(---)	Stop interpretation.
[COMPILE]	(<name> ---)	Force compilation of IMMEDIATE word.
LITERAL	(n --- n)	Compile a number into a literal.
DLITERAL	(d --- d)	Compile a double number into a literal.
EXECUTE	(addr ---)	Execute the definition CFA on top of stack.
[	(---)	Suspend compilation, enter execution.
]	(---)	Resume compilation.
IMMEDIATE	(<name> ---)	Forces execution when compiling.
INTERPRET		The Text Interpreter executes or compiles.
STATE	(--- addr)	User variable containing compilation state.

A.11 DICTIONARY CONTROL

CREATE	(---)	Create a dictionary header.
FORGET	(<name> ---)	FORGET all definitions from <name>.
HERE	(--- addr)	Returns address of next unused byte in the dictionary.
ALLOT	(n ---)	Leave a gap of n bytes in the dictionary.
TASK	(---)	A dictionary marker null word.
'	(<name> --- addr)	Find the PFA of <name> in the dictionary.
-FIND	found: (<name> --- PFA b tf) <name> not found: (<name> --- ff)	Search dictionary for <name>.

A.11 DICTIONARY CONTROL (Continued)

C,	(b ---)	Compiles byte into dictionary.
,	(n ---)	Compile a number into the dictionary.
PAD	(--- addr)	Pointer to temporary buffer.
LATEST	(--- addr)	Leave name field address (NFA) of top word in CURRENT .
SMUDGE	(---)	Toggle name SMUDGE bit.
HERE/	(--- addr)	Returns address of next unused byte in heads dictionary or codes dictionary.
ALLOT/	(n ---)	Leave a gap of n bytes in the heads dictionary or codes dictionary.
,/	(n ---)	Compile a number into the heads dictionary or codes dictionary.
HEADERLESS	(--- addr)	User variable containing headerless code flag. If equal to one, above "/" words, use code dictionary; if not, use heads dictionary.
AUTOSTART	(addr <name> ---)	Prepare autostart vector at addr which will cause <name> to be executed upon reset. Note: addr must be on a 1K-byte boundary.
TRAVERSE	(addr n --- addr)	Adjust addr positively or negatively until contents of addr is greater then $7F.
?KERNEL	(<name> ---)	Checks <name> to see if code is in kernel. Display IN or OUT accordingly.
H/C	(addr ---)	Separates heads and codes portions of definition to different place in memory.
HWORD	(---)	Moves codes portion of last defined word from the codes memory to the heads memory.
NFA	(pfaptr --- nfa)	Alter parameter field pointer address to name field address.
PFAPTR	(nfa --- pfaptr)	Alter name field address to parameter field pointer address.
LFA	(pfaptr --- lfa)	Alter parameter field pointer address to link field address.

A.12 DEFINING WORDS

: <name>	(---)	Begin colon definition of <name>.
;	(---)	End colon definition.
VARIABLE	Compilation: (n --- <name>) Execution: (<name> --- addr)	Create a variable named <name> with initial value n; returns address when executed.

A.12 DEFINING WORDS (Continued)

CONSTANT	Compilation: (n --- <name>) Execution: (<name> --- n)	Create a constant named <name> with value n; returns value when executed.
CODE <name>	(---)	Begin definition of assembly-language primitive operation named <name>.
;CODE	(---)	Used to create a new defining word, with execution-time "code routine" for this data type in assembly.
<BUILDS... DOES>	Compilation: <BUILDS ... Execution: ... DOES> ...	Used to create a new defining word, with execution-time routine for this data type in higher-level FORTH.
USER	Offset user <name>	Create a user variable.
CASE: <name>	(---)	Begin case statement definition.
C,CON	Compilation: (n --- <name>) Execution (<name> --- address)	Create byte constant named <name> with value n; returns address when executed.

A.13 VOCABULARIES

CONTEXT	(--- addr)	Returns address of pointer to CONTEXT vocabulary.
CURRENT	(--- addr)	Returns address of pointer to CURRENT vocabulary.
FORTH	(---)	Main FORTH vocabulary (execution of FORTH sets CONTEXT vocabulary).
ASSEMBLER	(---)	Assembler vocabulary; sets CONTEXT .
DEFINITIONS	(<name> ---)	Sets CURRENT vocabulary to CONTEXT .
VOCABULARY	(--- <name>)	Create new vocabulary named <name>.
VLIST	(---)	Print names of all words in CONTEXT vocabulary.
VOC-LINK	(--- addr)	Most recently defined vocabulary.

A.14 MASS STORAGE

LOAD	(screen ---)	Load editing screen into buffer and compile or execute. Automatically saves prior buffer contents if necessary.
BLOCK	(block --- addr)	Load editing screen into buffer and compile or execute. Automatically stores prior contents of buffer if necessary.

A.14 MASS STORAGE (Continued)

B/BUF	(--- n)	System constant giving mass storage block size in bytes.
B/SCR	(--- n)	Number of blocks/editing screen.
BLK	(--- addr)	System variable containing current block number.
SCR	(--- addr)	System variable containing current screen number.
UPDATE	(---)	Mark last buffer accessed as updated.
FLUSH	(---)	Write all updated buffers to disk.
EMPTY-BUFFERS	(---)	Erase all buffers.
+BUF	(addr1 --- addr2 f)	Increment buffer address.
BUFFER	(n --- addr)	Fetch next memory buffer.
LIST	(n ---)	List a screen to the current output device.
-->	(---)	Interpret next screen.
R/W	(addr blk f ---)	User read/write linkage.
USE	(--- addr)	Variable containing address of next buffer.
PREV	(--- addr)	Variable containing address of latest buffer.
FIRST	(--- n)	Leaves address of first block buffer.
LIMIT	(--- n)	Top of memory.
OFFSET	(--- addr)	User variable block offset to mass storage.
MEMTOP	(n ---)	Sets LIMIT to n, FIRST to n-$C0C.
DISKNO	(--- addr)	User variable currently selected disk.
CYLINDER	(--- addr)	User variable four bytes, each byte holds current track for each of four disk drives.
B/SIDE	(--- addr)	User variable blocks per side per drive.
DISK	(addr n b ---)	Accesses disk, read if b=1, write if b=0 block number n at addr.
SELECT	(n ---)	Selects disk drive n, n=0-3.
SEEK	(n ---)	Seeks track n on selected drive.
DREAD	(addr n --- err)	Reads multiple (4) disk sectors starting at sector 4n + 1 of selected disk, current track to addr and leaves the disk error byte.
DWRITE	(addr n --- err)	Writes multiple (4) disk sectors starting at sector 4n + 1 of selected disk, current track to addr and leaves the disk error byte.
INIT	(---)	Sets current tracks in CYLINDER to $FF's), which forces recalibration on next disk access.
FORMAT	(n1 n2 ---)	Format n1 tracks on disk number n2.
FMTRK	(n1 n2 ---)	Format track n1 on side n2 of the selected disk.
>LINE	(n <text> ---)	Puts text following into line n of current screen in buffer.

A.14 MASS STORAGE (Continued)

INDEX	(n1 n2 ---)	List the first lines of all screens n1 thru n2.

A.15 MISCELLANEOUS AND SYSTEM

(<comment>)	(---)	Begin comment, terminate by right parentheses on same line.
CFA	(pfaptr --- cfa)	Alter parameter field pointer address to code field address.
QUIT	(---)	Clear Return Stack and return to terminal.
SCDR	(--- addr)	Returns addr of Serial Channel Data Register.
SCSR	(--- addr)	Returns addr of Serial Channel Status Register.
SCCR	(--- addr)	Returns addr of Serial Channel Control Register.
MCR	(--- addr)	Returns addr of Mode Control Register.
IER	(--- addr)	Returns addr of Interrupt Enable Register.
IFR	(--- addr)	Returns addr of Interrupt Flag Register.
PG	(--- addr)	Returns addr of Port G.
PF	(--- addr)	Returns addr of Port F.
PE	(--- addr)	Returns addr of Port E.
PD	(--- addr)	Returns addr of Port D.
PC	(--- addr)	Returns addr of Port C.
PB	(--- addr)	Returns addr of Port B.
PA	(--- addr)	Returns addr of Port A.
NMIVEC	(--- addr)	Returns addr of low level Non-Maskable Interrupt (NMI) vector.
IRQVEC	(--- addr)	Returns addr low level Interrupt Request (IRQ) vector.
INTVEC	(--- addr)	Returns addr high level FORTH interrupt vector.
INTFLG	(--- addr)	Returns addr of high level FORTH interrupt flag.

A.16 SECURITY

!CSP	(---)	Store stack position into check stack pointer.
?COMP	(---)	Error if not compiling.
?CSP	(---)	Check stack position.
?ERROR	(---)	Outputs error message.
?EXEC	(---)	Not executing error.
?PAIRS	(---)	Conditional not paired error.
?STACK	(---)	Stack out of bounds error.
CSP	(---)	User variable for check stack pointer.
ABORT	(---)	Error ...operation terminates.

A.16 SECURITY (Continued)

ERROR	(line --- in blk)	Execute error notification and restart system.
MESSAGE	(n ---)	Displays message number n.
WARNING	(--- addr)	Flag for to message routine.
FENCE	(--- addr)	Prevents FORGET below this point.
WIDTH	(--- addr)	Controls the number of significant characters of <name>.

A.17 PRIMITIVES

(.")	(---)	Run-time procedure compiled by ." .
(;CODE)	(---)	Run-time procedure compiled by ;CODE .
(+LOOP)	(n ---)	Run-time procedure compiled by +LOOP .
(ABORT)	(---)	Run-time procedure compiled by ABORT .
(DO)	(limit+1 start ---)	Run-time procedure compiled by DO .
(FIND)	(addr1 addr2 --- pfa b ff) (addr1 addr2 --- ff)	Searches the dictionary.
(LINE)	(n1 n2 ---) addr count)	Virtual storage line primitive.
(LOOP)	(---)	Run-time procedure compiled by LOOP .
(NUMBER)	(---)	Converts ASCII to numeric.
OBRANCH	(f ---)	Run-time conditional branch.
BRANCH	(---)	Run-time unconditional branch.
CLIT	(---)	Indicates single character literal.
ENCLOSE	(addr c --- addr n1 n2 n3)	Text scanning by WORD .
R0	(--- addr)	Location of Return Stack base.
S0	(--- addr)	Location of Parameter Stack base.
RP!	(---)	Initializes Return Stack.
LIT	(--- n)	Place 16-bit literal on the stack.

A.18 PARAMETER

DP	(--- addr)	Puts Dictonary Pointer address on stack.
DP/	(--- addr)	Puts Dictionary Pointer address of Heads on stack.
UABORT	(--- addr)	Puts address of code field for Abort on stack.
UC/L	(--- addr)	Puts address of number of characters/line on stack.
UFIRST	(--- addr)	Puts first address of data buffer on stack.
ULIMIT	(--- addr)	Puts last +1 address of data buffer on stack.
UPAD	(--- addr)	Puts address of temporary storage PAD on stack.

A.18 PARAMETER (Continued)

UR/W	(--- addr)	Puts code field address on stack.
KHZ	(--- addr)	Unused user variable.
MODE	(--- addr)	Assembler variable.

APPENDIX B

RSC-FORTH GLOSSARY

This glossary contains the definition of all words in the RSC-FORTH vocabulary. The definitions are presented in ASCII sort order.

Stack Notation

The first line of each entry shows a symbolic description of the action of the procedure on the parameter stack. The symbols on the left indicate the order in which input parameters have been placed on the stack. Three dashes "---" indicate the execution point; any parameters left on the stack after execution are listed on the right. In this notation, the top of the stack is to the right.

Symbol Definition

addr,addrl,...	memory address
b	8-bit (with high eight bits zero)
c	7-bit ASCII character (with high nine bits zero)
d,di,...	32-bit signed double integer, most significant portion with sign on top of stack
flag	Boolean flag (0=false, non-zero=true)
ff	Boolean false flag (value = 0)
n,nl,...	16-bit signed integer number
u,ul,...	16-bit unsigned integer number
ud,udi,...	32-bit unsigned number
tf	Boolean true flag (value = non-zero)

Pronunciation

The natural language pronunciation of FORTH names is given in double quotes (").

Integer Format

Unless otherwise noted, all references to numbers are for 16-bit signed integers. The high byte of a number is on top of the stack, with the sign in the left-most bit. For 32-bit signed double numbers, the most significant part (with the sign) is on top.

All arithmetic is implicitly 16-bit signed integer math, with error and underflow indication unspecified.

Capitalization

Word names as used within the glossary are conventionally written in upper case characters. Lower case is used when reference is made to the run-time machine codes (not directly accessible), e.g., VARIABLE is the user word to create a variable. Each use of that variable makes use of a code sequence 'variable' which executes the function of the particular variable.

Attributes (ATTR)

Capital letters show definition characteristics:

C May only be used within a colon-definition. A digit indicates number of memory addresses used, if other than one.
E Intended for execution only.
I Indicates that the word is IMMEDIATE and will execute during compilation, unless special action is taken
P Has precedence bit set. Will execute even when compiling.
U A user variable.

Group Key Words (GROUP)

The following key words identify the functional group (see Appendix A) that each word is most related to.

STACK	Stack Manipulation
NUMERIC	Numeric Representation
ARITHMETIC	Arithmetic and Logical
COMPARISON	Comparison Operators
CONTROL	Control Structures
MEMORY	Memory
I/O	Input/Output
FORMAT	Output Formatting
MONITOR	Monitor
COMPILER	Compiler - Text Interpreter
DICTIONARY	Dictionary Control
DEFINING	Defining Words
VOCABULARY	Vocabularies
MASS	Mass Storage
MISC	Miscellaneous and System
SECURITY	Security
PRIMITIVE	Primitives
ASSEMBLER	Assembler Dictionary
PARAMETER	Parameter Used in FORTH

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

! — n addr --- — MEMORY

"store"

Stores 16-bit number n into addr.

!CSP — --- — SECURITY

"store CSP"

Stores the stack position in CSP . Used as part of the compiler security. See CSP .

— udl --- ud2 — FORMAT

"sharp"

Generates the next ASCII character placed in an output string from udl. Result ud2 is the quotient after division by BASE, and is maintained for further processing. Use between <# and #> . See #S .

#> — d --- addr n — FORMAT

"sharp-greater"

Terminates numeric output conversion by dropping d, leaving the text address and character count n suitable for TYPE .

#S — ud --- 0 0 — FORMAT

"sharp-s"

Converts all digits of a ud adding each to the pictured numeric output text, until the remainder is zero, A single zero is added to the output string if the number was initially zero. Use only between <# and #> .

' — --- addr — DICTIONARY — I

"tick"

Used in the form:

' <name>

If executing, leaves the parameter field address of the next word accepted from the input stream. If compiling, compiles this address as a literal; later execution will place this value on the stack.

If the word is not found after a search of CONTEXT and FORTH vocabularies an error message is displayed.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
(		MISC	I

"paren"
Used in the form:

(cccc)

Accepts and ignores comment characters from the input stream, until the next right parenthesis. As a word, the left parenthesis must be followed by one blank. It may be freely used while executing or compiling. An error condition exists if the input stream is exhausted before the right parenthesis.

(.") PRIMITIVE

The run-time procedure, compiled by ."", which transmits the following in-line text to the selected output device.
See ." .

(;CODE) PRIMITIVE

The run-time procedure, compiled by ;CODE , that rewrites the code field of the most recently defined word to point to the following machine code sequence. See ;CODE .

(+LOOP) PRIMITIVE

The run-time procedure compiled by +LOOP , which increments the loop index by n and tests for loop completion. See +LOOP .

(ABORT) PRIMITIVE

Executes after an error when WARNING is -1. This word normally executes ABORT , but may be altered (with care) to a user's alternative procedure. See ABORT .

(DO) limit +1 start --- PRIMITIVE

The run-time procedure, compiled by DO , which moves the loop control parameters to the return stack. See DO .

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

(FIND) PRIMITIVE

```
addr1  addr2  ---  pfa  byte  tf  (ok)
addr1  addr2  ---  ff          (bad)
```

Searches the dictionary starting at the name field address addr2, matching to the text at addr1. Returns parameter field address, length of name field byte and Boolean true for a good match. If no match is found, only a Boolean false is left. See -FIND .

(LINE) n1 n2 --- addr count PRIMITIVE

Converts the line number n1 and the screen number n2 to the disk buffer address containing the data. A count of 64 indicates the full line text length. See .LINE .

(LOOP) PRIMITIVE

The run-time procedure, compiled by LOOP, which increments the loop index and tests for loop completion. See LOOP .

(NUMBER) d1 addr1 --- d2 addr2 PRIMITIVE

Converts the ASCII text beginning at addr1+1 with regard to BASE . The new value is accumulated into d1, being left as d2. addr2 is the address of the first unconvertable digit. See NUMBER .

* n1 n2 --- n3 ARITHMETIC

"times"
Multiples n1 by n2 and leaves the product n3.

*/ n1 n2 n3 --- n4 ARITHMETIC

"times-divide"
Multiplies n1 by n2, divides the result by n3 and leaves the quotient n4. n4 is rounded toward zero. The product of n1 times n2 is maintained as an intermediate 32-bit value for a greater precision than the otherwise equivalent sequence:

```
n1  n2  *  n3  /
```

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

*/MOD n1 n2 n3 --- n4 n5 ARITHMETIC
"times-divide-mod"
Multiplies n1 by n2, divides the result by n3 and leaves the remainder n4 and quotient n5. A 32-bit intermediate product is used as for */ . The remainder has the same sign as n1.

+ n1 n2 --- n3 ARITHMETIC
"plus"
Adds n1 to n2 and leaves the arithmetic sum n3.

+! n addr --- MEMORY
"plus store"
Adds n to the 16-bit value at the address, by the convention given for +.

+- n1 n2 --- n3 ARITHMETIC
"plus-minus"
Applies the sign of n2 to n1, which is left as n3.

+BUF addr1 --- addr2 flag MASS
"plus-buf"
Advances the virtual storage buffer address (addr1) to the next buffer address (addr2). Boolean flag is false when addr2 is the buffer presently pointed to by variable PREV .

+LOOP n1 --- (run-time) CONTROL IC
addr n2 --- (compile-time)
"plus-loop"
Used in a colon-definition in the form:

```
DO ... n1 +LOOP
```

At run-time, +LOOP selectively controls branching back to the corresponding DO based on n1, the loop index and the loop limit. The signed increment n1 is added to the index and the total compared to the limit. The branch back to DO occurs until the new index is equal to or greater than the limit (n1 > 0), or until the new index is equal to or less than the limit (n1 < 0). Upon exiting the loop, the parameters are discarded and execution continues. Index and limit are signed integers in the range <-32,768..32,767>.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

+LOOP (Cont.)

At compile-time, +LOOP compiles the run-time word (+LOOP) and computes the branch offset from HERE to the address left on the stack by DO . n2 is used for compile time error checking.

,

n --- DICTIONARY

"comma"

Stores n into the next available dictionary memory cell, advancing the dictionary pointer.

,/

n --- DICTIONARY

"comma slash"

Stores n into the next available heads dictionary memory cell, advancing the dictionary pointer, DP/.

-

n1 n2 --- n3 ARITHMETIC

"minus"

Substracts n2 from n1 and leaves the difference n3.

-->

MASS I

"next-screen"

Continues interpretation with the next virtual storage screen.

-BCD

u1 --- u2

"b-c-d"

Converts a number to its binary coded decimal (BCD) equivalent.

-DUP

n1 --- n1 (if zero) STACK
n1 --- n1 n1 (non-zero)

"minus-dup"

Reproduces n1 only if it is non-zero. This is usually used to copy a value just before IF , to eliminate the need for an ELSE clause to drop it.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

-FIND --- pfa b tf (found) DICTIONARY
--- ff (not found)
"dash-find"
Accepts the next text word (delimited by blanks) in the input stream to HERE , and searches the CONTEXT and then CURRENT vocabularies for a matching entry. If found, the dictionary entry's parameter field address, its length byte, and a boolean true is left. Otherwise, only a Boolean false is left.

-TRAILING addr n1 --- addr n2 FORMAT
"dash-trailing"
Adjusts the character count n1 of a text string beginning address to suppress the output of trailing blanks. The characters at addr+n1 to addr+n2 are blanks. An error condition exists if n1 is negative.

. n --- INPUT/OUTPUT
"dot"
Displays the number on the top of a stack. The number is converted from a signed 16-bit two's complement value according to the numeric BASE . The sign is displayed only if the value is negative. A trailing blank is displayed after the number. Also see D. .

." INPUT/OUTPUT I
"dot-quote"
Used in the form:

." cccc"

Accepts the following text from the input stream, terminated by " (double-quote). If executing, transmits this text to the selected output device. If compiling, compiles so that later execution will transmit the text to the selected output device. At least 127 characters are allowed in the text. If the input stream is exhausted before the terminating double-quote, an error condition exists.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR
.LINE	nl n2 ---	FORMAT

"dot-line"
Displays a line of text from mass storage by its line number nl and screen number n2. Trailing blanks are suppressed.

.R nl n2 --- FORMAT

"dot-R"
Displays number nl right justified n2 places. No trailing blank is printed.

.S STACK

"dot-S"
Displays the contents of the stack without altering the stack. This word is very useful in determining the stack contents during debugging programs and learning FORTH.

/ nl n2 --- n3 ARITHMETIC

"divide"
Divides nl by n2 and leave the quotient n3. n3 is rounded toward zero. The remainder is lost.

/MOD nl n2 --- n3 n4 ARITHMETIC

"divide-mod"
Divides nl by n2 and leaves the quotient n4 and remainder n3. n3 has the same sign as nl.

0 --- 0 NUMERIC

"zero"
The number zero is placed on top of the stack.

0< n --- flag COMPARISON

"zero-less"
Leaves a true flag (1) if the number is less than zero (negative), otherwise leaves a false flag (0). The number is lost.

0= n --- flag COMPARISON

"zero-equals"
Leaves a true flag (1) if the number is equal to zero, otherwise leaves a false flag (0). The number is lost.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR
OBRANCH	flag ---	PRIMITIVE

"zero-branch"
The run-time procedure to conditionally branch. If the flag is false (zero), the following in-line parameter is added to the interpretive pointer to branch ahead or back. Compiled by IF , UNTIL , and WHILE .

1	--- 1	NUMERIC

"one"
The number one is placed on top of the stack.

1+	n --- n+1	ARITHMETIC

"one-plus"
Increments n by one according to the operation of + .

1-	n --- n-1	ARITHMETIC

"one-minus"
Decrements n by one according to the operation of - .

2	--- 2	NUMERIC

"two"
The number two is placed on top of the stack.

2+	n --- n+2	ARITHMETIC

"two-plus"
Increments n by two according to the operation of + .

2-	n --- n-2	ARITHMETIC

"two-minus"
Decrements n by two, according to the operation of - .

2DROP	d ---	STACK

or n1 n2 ---
"two-drop"
Drops the top double number on the stack.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
2DUP	d --- d d or n1 n2 --- n1 n2 n1 n2 "two-dup" Duplicates the top double number on the stack.	STACK	
3	--- 3 "three" The number three is placed on top of the stack.	NUMERIC	
4	--- 4 "four" The number four is placed on top of the stack.	NUMERIC	
:	"colon" A defining word used in the form: : <name> ... ; Selects the CONTEXT vocabulary to be identical to CURRENT . Creates a dictionary entry for <name> in CURRENT , and sets the compile mode. Words thus defined are called 'colon-definitions'. The compilation addresses of subsequent words from the input stream which are not immediate words are stored into the dictionary to be executed when <name> is later executed. IMMEDIATE words are executed as encountered. If a word is not found after a search of the CONTEXT and FORTH vocabularies conversion and compilation of a literal number is attempted, with regard to the current BASE ; that failing, an error condition exists.	DEFINING	E
;	"semi-colon" Terminates a colon-definition and stops further compilation. If compiling from mass storage and the input stream is exhausted before encountering ; an error condition exists.	DEFINING	I,C

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

;CODE DEFINING

"semi-colon-code"
Used in the form:

```
: <name> .... ;CODE <assembly code>
END-CODE
```

Stops compilation and terminates a new defining word <name> by compiling (;CODE) . Sets the CONTEXT vocabulary to ASSEMBLER , assembling to machine code the following mnemonics.

When <name> is later executed in the form:

```
<name> <namex>
```

to define the new <namex>, the code field address of <namex> will contain the address of the code sequence following the ;CODE in <name>. Execution of any <namex> will cause this machine code sequence to be executed.

;DUMP addr n --- I/O

"semicolon dump"
Dumps n bytes starting at addr in ASCII format in one semicolon record.

;S COMPILER

"semi-colon-S"
Stops interpretation of a screen. ;S is also the run-time word compiled at the end of a colon-definition which returns execution to the calling procedure.

< n1 n2 --- flag COMPARISON

"less-than"
Leaves a true flag (1) if n1 is less than n2; otherwise leaves a false flag (0).

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

<# d --- d FORMAT

"less-than-sharp"

Initializes the pictured numeric output format using the words:

```
<#  #  #S HOLD SIGN  #>
```

specifies the conversion of a double-precision number into an ASCII character string stored in right-to-left order, producing text at PAD .

<BUILDS DEFINING I,C

Used within a colon-definition:

```
: <name> <BUILDS ... DOES> ... ;
```

each time <name> is executed, <BUILDS defines a new word with a high-level execution procedure. Executing <name> in the form:

```
<name> <namex>
```

uses <BUILDS to create a dictionary entry for <namex> with a call to the DOES> part for <namex>. When nnnn is later executed, it has the address of its parameter area on the stack and executes the words after DOES> in <name>. <BUILDS and DOES> allow run-time procedures to written in high-level rather than in assembler code (as required by ;CODE).

= n1 n2 --- flag COMPARISON

"equals"

Leaves a true flag (1) if n1 is equal to n2; otherwise leaves a false flag (0).

> n1 n2 --- flag COMPARISON

"greater-than"

Leaves a true flag (1) if n1 is greater than n2; otherwise a false flag (0).

>LINE n --- <text> MASS E

"to-line"

Place the following text on line n of the current screen as designated by SCR.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

>R n --- STACK

"to-R"

Removes a number from the computation stack and places it as the most accessible number on the return stack. Use should be balanced with R> in the same definition.

? addr -- MEMORY

"question-mark"

Displays the value contained at the address on the top of the stack in free format according to the current BASE. Uses the format of . .

?COMP SECURITY

Issues error message if not compiling.

?CSP SECURITY

Issues error message if stack position differs from value saved in CSP .

?ERROR SECURITY

Issues error message #1 (STACK EMPTY), if the Boolean flag is true.

?EXEC SECURITY

Issues an error message if not executing.

?KERNEL --- DICTIONARY

"question kernel"

Tests name following an input stream for code being inside or outside the RSC-FORTH kernel. "IN" or "OUT" is displayed accordingly.

?PAIRS n1 n2 --- SECURITY

Issues error message #19 (CONDITIONALS NOT PAIRED) if n1 does not equal n2. The message indicates that compiled conditionals do not match.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

?STACK — SECURITY

Issues error message #7 (FULL STACK) if the stack is out of bounds.

?TERMINAL — --- flag — INPUT/OUTPUT

Tests the terminal keyboard for actuation of any key. Generates a Boolean value. A true flag (1) indicates actuation, whereas a false flag (0) indicates non-actuation.

@ — addr --- n — MEMORY

"fetch"
Leaves the 16-bit contents of the address on top of the stack.

ABORT — SECURITY

"abort"
Clears the stacks and enters the execution state. Returns control to the AIM 65/40 keyboard.

ABS — n --- u — ARITHMETIC

"absolute"
Leaves the absolute value of n as u.

ADMP — addr1 addr2 --- — I/O

Dumps bytes from addr1 to addr2 in ASCII format in as many semicolon records as necessary. Also sends closing record.

AGAIN — addr n --- (compile-time) — CONTROL

"again"
Used in a colon-definition in the form:

```
BEGIN ... AGAIN
```

At run-time, AGAIN forces execution to return to the corresponding BEGIN . There is no effect on the stack. Execution cannot leave this loop (unless R> DROP is executed one level below).

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

AGAIN (Cont.) At compile-time, AGAIN compiles BRANCH with an offset from HERE to addr. n is used for compile-time error checking.

ALLOT n --- DICTIONARY
"allot"
Adds the signed number to the dictionary pointer DP . May be used to reserve dictionary space or re-origin memory. n is the number of bytes.

ALLOT/ n --- DICTIONARY
"allot slash"
Adds the signed number to the dictionary pointer DP/ . May be used to reserve space in the heads dictionary or re-origin memroy.

AND n1 n2 --- n3 ARITHMETIC
"and"
Leaves the bit-wise logical AND of n1 and n2 as n3.

ASSEMBLER VOCABULARY I
"assembler"
Sets the vocabulary to ASSEMBLER .

AUTOSTART addr --- DICTIONARY
"autostart"
Establishes autostart pattern of memory location addr. Bit pattern A55A is put at addr. Parameter Field Address (CFA+2) is placed at addr+2.

B/BUF --- n MASS
"bytes-per-buffer"
Leaves the number of bytes (value = 1024) per data buffer, the byte count read from mass storage by BLOCK . The actual buffer size is four bytes larger than this value.

B/SIDE --- addr MASS
"blocks per side"
User variable containing number of 1K-byte blocks per side per disk drive.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

B/SCR --- n MASS

"blocks per screen"

Leaves the number of blocks (value = 1) per FORTH screen. By convention, an editing screen is 1024 bytes organized as 16 lines of 64 characters each.

BANKC@ addr n --- b MEMORY

"bank c fetch"

Fetches data b of bank n, address addr.

BANKC! b addr n --- MEMORY

"bank c store"

Stores data b in bank n, address addr.

BANKEEC! b addr n1 n2 --- MEMORY

"bank e e c store"

Stores data b in bank n1, address addr for n2 cycles. Used in programming EEROM's and EPROM's.

BANKEXECUTE addr n --- CONTROL

"bank execute"

Execute FORTH word with CFA of addr in bank n. Restore to current bank upon return.

BASE --- addr NUMERIC U

"base"

Leaves the address of the variable containing the current number base used for input and output conversion. The range of BASE is 2 through 70.

BEGIN --- addr n (compile-time) CONTROL C

"begin"

Occurs in a colon-definition in form:

```
BEGIN ... flag UNTIL
BEGIN ... AGAIN
BEGIN ... flag WHILE ... REPEAT
```

At run-time, BEGIN marks the start of a word sequence for repetitive execution.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

BEGIN (Cont.)

A BEGIN-UNTIL loop will be repeated until flag is true. A BEGIN-WHILE-REPEAT loop will be repeated until flag is false. The words after UNTIL or REPEAT will be executed when either loop is finished. flag is always dropped after being tested. The BEGIN-AGAIN loop executes indefinitely.

At compile-time, BEGIN leaves its return address and n for compiler error checking.

BL --- char INPUT/OUTPUT

"blank"

A constant that leaves the ASCII character value for "blank", i.e., $20.

BLANKS addr n --- MEMORY

"blanks"

Fills an area of memory beginning at addr with the ASCII value for "blank", the number of bytes specified by count n will be blanked.

BLK --- addr MASS U

"b-l-k"

Leaves the address of a user variable containing the number of the mass storage block being interpreted as the input stream. If the content is zero, the input stream is taken from the terminal.

BLOCK n --- addr MASS

"block"

Leaves the first address of the block buffer containing block n. If the block is not already in memory, it is transferred from mass storage to whichever buffer was least recently accessed. If the block occupying that buffer has been marked as updated, it is rewritten onto mass storage before block n is read into the buffer. If correct mass storage read or write is not possible, an error condition exists. Only data within the latest block referenced by BLOCK is valid by byte address, due to sharing of the block buffers. n is an unsigned number. Also see BUFFER , R/W , UPDATE and FLUSH .

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

BOUNDS addr n --- add +n addr ARITHMETIC

"bounds"

Bounds is equivalent to OVER + SWAP . It is used to convert addr and count to a start and stop address for a loop.

BRANCH PRIMITIVE

"branch"

The run-time procedure to unconditionally branch. An in-line offset is added to the interpretive pointer IP to branch ahead or back. BRANCH is compiled by ELSE , AGAIN , and REPEAT .

BUFFER n --- addr MASS

"buffer"

Obtains the next block buffer, assigning it to block n. The block is not read from mass storage. If the previous contents of the buffer is marked as UPDATED, it is written to the mass storage. If correct writing to mass storage is not possible, an error condition exists. The address left is the first byte within the buffer for data storage.

C! n addr --- MEMORY

"c-store"

Stores the least significant 8-bits of n into the byte at the address.

C, n --- DICTIONARY

"c-comma"

Stores 8 bits of n into the next available dictionary byte, advancing the dictionary pointer.

C,CON b --- <name>(compile time) DEFINING P

<name> --- b (run time)

"c comma constant"

A defining word used in the form:

```
b C,CON <name>
```

to create a dictionary entry for <name>, leaving b in its parameter field. When <name> is executed later in command mode b will be pushed on the stack, when in compile mode the CFA of CLIT followed by b will be compiled into the definition.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

C/L --- n INPUT/OUTPUT

"characters/line"

Leaves the number of characters (default value = 80) per input line.

C@ addr --- byte MEMORY

"c-fetch"

Leaves the 8-bit contents of the byte at the address on the top of the stack in the low order byte. The high order byte is zero.

CASE: --- <name> DEFINING E

"case colon"

A defining word used in the form

CASE: <name> ... ;

Creates a dictionary entry for <name> in CURRENT , and sets the compile mode. Words thus defined are called "case statements". The compilation addresses of subsequent words from the input stream are stored into the dictionary. (Intended for non-immediate words only.)

CFA pfa --- cfa MISC

"c-f-a"

Converts the parameter field address (pfa) of a definition to its code field address (cfa).

CLD/WRM --- addr MONITOR U

"cold warm"

User variable containing the COLD/WARM flag. When equal to A55A, reset does a warm start. When not equal to A55A reset does cold start. Checked by the kernel; set by the user or development ROM.

CLIT --- b PRIMITIVE

"c-lit"

Compiled within system object code to indicate that the next byte is a single character literal (i.e., in range 0-255). Used only in system code (not by application program, i.e. user). Application programs use LITERAL , which uses CLIT or LIT as appropriate.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

CMOVE addr1 addr2 n --- MEMORY

"c-move"
Moves n bytes from memory area beginning at address addr1 to memory area starting at addr2. The contents of addr1 is moved first proceeding toward high memory. If n is zero or negative, nothing is moved.

CODE DEFINING

"code"
A defining word used in the form:

CODE <name> ... <assembly code> ... END-CODE

To set CONTEXT to the ASSEMBLER vocabulary and to create a dictionary entry for <name>. When <name> is later executed the machine code in this parameter field will execute.

COLD MONITOR

"cold"
The cold start procedure to adjust the dictionary pointer to the minimum standard and restart via ABORT . May be called from the terminal to remove application programs and restart.

COMPILE COMPILER

"compile"
When the word containing COMPILE executes, the compilation address of the next non-immediate word following COMPILE is copied (compiled) into the dictionary. This allows specific compilation situations to be handled in addition to simply compiling an execution address (which the interpreter already does).

CONSTANT n --- <name> (compile-time) DEFINING
<name> --- n (run-time)

"constant"
A defining word used in the form:

n CONSTANT <name>

to create a dictionary entry for <name>, leaving n in its parameter field. When <name> is later executed, it will push the value of n to the stack.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

CONTEXT --- addr VOCABULARY

"context"
Leaves the address of a user variable pointing to the vocabulary in which dictionary searches are to be made, during interpretation of the input stream.

COUNT addr --- addr+1 n FORMAT

"count"
Leaves the address addr+1 and the character count n of text beginning at addr. The first byte at addr must contain the character count n. The actual text starts with the second byte. The range of n is 0-255. Typically COUNT is followed by TYPE .

CR INPUT/OUTPUT

"carriage-return"
Transmits a carriage return (CR) and line feed (LF) to the active output device.

CREATE DICTIONARY

"create"
A defining word used in the form:

CREATE <name>

Creates a dictionary entry for <name> without allocating any parameter field memory. When <name> is subsequently executed, the address of the first byte of <name>'s parameter field is left on the stack. The code field contains the address of the word's parameter field. The new word is created in the CURRENT vocabulary.

CSP ---- addr SECURITY U

"c-s-p"
Leaves the address of a user variable temporarily storing the check stack pointer (CSP) position, for compilation error checking.

CURRENT --- addr VOCABULARY

"current"
Leaves the address of a user variable pointing to the vocabulary into which new word definitions are to be entered.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

CYLINDER --- addr MASS
"cylinder"
User variable, four bytes long, used as an array. Each byte contains the track number of corresponding disk.

D+ d1 d2 --- d3 ARITHMETIC
"d-plus"
Adds double precision numbers d1 and d2 and leaves the double precision number sum d3.

D+- d1 n --- d2 ARITHMETIC

Applies the sign of n to the double precision number d1 and leaves it as double precision number d2.

D. d --- FORMAT
"d-dot"
Displays a signed double-precision number from a 32-bit two's complement value. The high-order 16 bits are most accessible on the stack. Conversion is performed according to the current BASE . A blank follows.

D.R d n --- FORMAT
"d-dot-r"
Displays a signed double-precision number d right aligned in a field n characters wide.

DABS d --- ud ARITHMETIC
"d-abs"
Leaves the absolute value ud of a double number.

DECIMAL NUMERIC
"decimal"
Sets the numeric conversion BASE to decimal (base 10) for input-output.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

DEFINITIONS VOCABULARY

"definitions"
Used in the form:

```
cccc  DEFINITIONS
```

Sets CURRENT to the CONTEXT vocabulary so that subsequent definitions will be created in the vocabulary previously selected at CONTEXT .

DIGIT NUMERIC

```
char n1 --- n2  tf (Valid conversion)
char n1 --- ff     (Invalid conversion)
```

"digit"
Converts the ASCII character (using base n1) to its binary equivalent n2, accompanied by a true flag (1). If the conversion is invalid, leaves only a false flag Ø).

DISK `addr n f ---` MASS

"disk"
Single point entry to kernel disk handlers. Perform disk operation, read if f=1, write if f=0, write disk block n and memory location addr.

DISKNO `--- addr` MASS U

User variable containing the currently selected disk drive number 0 through 3.

DLITERAL `d --- d` (executing) COMPILER
`d ---` (compiling)

"d-literal"
If compiling, compiles a stack double number into a literal. Later execution of the definition containing the literal will push it to the stack.

If executing, the number will remain on the stack.

DNEGATE `d1 --- -d1` ARITHMETIC

"d-negate"
Leaves the two's complement of a double precision number.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
DO	n1 n2 --- (run-time) addr n --- (compile-time)	CONTROL	C

Occurs in a colon-definition in form:

```
DO  ...  LOOP
DO  ...  +LOOP
```

DO (Cont.)

At run-time, DO begins a sequence with repetitive execution controlled by a loop limit n1 and an index with initial value n2. DO removes these from the stack. Upon reaching LOOP the index is incremented by one. At the +LOOP the index is modified by a positive or negative value. Until the new index equals or exceeds the limit, execution loops back to just after DO ; otherwise the loop parameters are discarded and execution continues ahead. Both n1 and n2 are determined at run-time and may be the resuult of other operations.

Loops may be nested. Within a loop I will copy the current value of the index to the stack. See I , LOOP , +LOOP , LEAVE .

At compile-time within the colon-definition, DO compiles (DO) and leaves the following addr and n for later error checking.

DOES> DEFINING

"does"
Defines the run-time action within a high-level defining word.
Used in the form:

```
: <name>  ...  (BUILDS  ...
     DOES>  ...  ;
and then  <name>  <namex>.
```

Marks the termination of the defining part of the defining word <name> and begins the definition of the run-time action for words that will later be defined by <name>.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

DOES> (Cont.)

DOES> alters the code field and first parameter of the new word to execute the sequence of compiled word addresses following DOES> . Used in combination with <BUILDS . The execution of the DOES> part begins with the address of the first parameter of the new word <namex> on the stack. Upon execution of <name> the sequence of words between DOES> and ; will be executed, with the address of <namex>'s parameter field on the stack. This allows interpretation using this area or its contents.

Typical uses include the FORTH assembler, multi-dimensional arrays, and compiler generation.

DP ---- addr PARAMETER U

"d-p"

Leaves the address of user variable, the dictionary pointer, which points to address the next free memory address above the dictionary. The value may be read by HERE and altered by ALLOT .

DP/ --- addr PARAMETER

"d-p-slash"

Accesses user variable. Addr is dictionary pointer for heads portion of definitions. When normal code DP/ equals DP. When headerless DP/ equals DP plus two.

DPL ---- addr FORMAT U

"d-p-l"

Leaves the address of user variable containing the number of digits to the right of the decimal on double integer input. It may also be used hold output column location of a decimal point in user generated formatting. The default value on single number input is -1.

DREAD addr n --- m MASS

"d read"

Reads from disk sector 4n +1 to memory location adder in 1K-byte records and leaves the disk error byte on the stack (see E.4).

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

DROP n --- STACK

"drop"

Drops the number on top of the stack from the stack.

DUMP addr n --- INPUT/OUTPUT

"dump"

Displays the contents of n memory locations beginning at addr. Both addresses and contents are shown in the current numeric base. DUMP outputs 8 bytes on a line.

DUP n --- n n STACK

"dup"

Duplicates the value on the stack.

DWRITE addr n --- MASS

"d-write"

Writes to disk sector 4n + 1 from memory location addr in 1K-byte records and leaves the disk error byte on the stack (see E.4).

EEC! b addr n --- MEMORY

" e-e-c store"

Stores data b in addr for n clock cycles. Used for EEROM or EPROM programming.

ELSE CONTROL I,C

addr1 n1 --- addr2 n2 (compiling)

"else"

Occurs within a colon-definition in the form:

IF ... ELSE ... THEN

At run-time, ELSE executes after the true part following IF . ELSE forces execution to skip over the following false part and resumes execution after the THEN . It has no stack effect.

At compile-time, ELSE emplaces BRANCH reserving a branch offset, leaves the address addr2 and n2 for error testing. ELSE also resolves the pending forward branch from IF by calculating the offset from addr1 to HERE and storing at addr1. See IF and THEN .

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

EMIT char --- INPUT/OUTPUT

"emit"
Transmits an ASCII character to the selected output device. See KEY .

EMPTY-BUFFERS MASS

"empty-buffers"
Marks all block-buffers as empty, not necessarily affecting the contents. Updated blocks are not written to the mass storage. This is also the required initialization procedure before first use of the mass storage.

ENCLOSE PRIMITIVE

addr char --- addr n1 n2 n3

"enclose"
The text scanning primitive used by WORD. From the text address addr and an ASCII delimiting character, is determined the byte offset to the first non-delimiter character n1, the offset to the first delimiter after the text n2, and the offset to the first character not included n3. This procedure will not process past an ASCII 'null', treating it as an unconditional delimiter.

END CONTROL I,C

"end"
This is an 'alias' or duplicate definition for UNTIL .

ENDIF addr n --- (compile) CONTROL I,C

"end-if"
An alias for THEN . See THEN .

ERASE addr n --- MEMORY

"erase"
Clears a region of memory to zero from addr over n addresses.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

ERROR line --- in blk SECURITY

"error"

Executes error notification and restart of system. WARNING is first examined. If WARNING = 1, the text of line n, relative to screen 4 of drive 0 is printed. This line number may be positive or negative, and beyond just screen 4. If WARNING = 0, n is just printed as a message number (non-disk installation). If WARNING = -1, the definition (ABORT) is executed, which executes the system ABORT . The user may cautiously modify this execution by altering (ABORT) . RSC-FORTH saves the contents of IN and BLK to assist in determining the location of the error. Final action is execution of QUIT .

EXECUTE addr -- COMPILER

"execute"

Executes the definition whose code field address is on the stack. The code field address is also called the compilation address.

EXPECT addr count --- INPUT/OUTPUT

"expect"

Transfers characters from the terminal beginning at addr, upwards until a "return" or the count of n characters has been received. Takes no action for n = zero or less. One or more nulls are added at the end of the text.

FENCE --- addr SECURITY U

"fence"

Leaves the address of a user variable containing an address below which FORGETting is trapped. To forget below this point the user must alter the contents of FENCE .

FILL addr n b --- MEMORY

"fill"

Fills n bytes, beginning at addr, with the byte pattern b.

FINIS MONITOR

"finis"

Marks the end of the input data stream into the compiler.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

FIRST --- n MASS

"first"

Leaves the first (lowest) address of the data (or mass storage buffer.

FLUSH MASS

"flush"

Writes all blocks to mass storage that have been flagged as UPDATEd . An error condition results if writing to mass storage is not completed.

FORGET DICTIONARY

"forget"

Executes in the form:

FORGET <name>

Delete from the dictionary <name> (which is in the CURRENT vocabulary) and all words added to the dictionary after <name>, regardless of their vocabulary. An error message will occur if the CURRENT and CONTEXT vocabularies are not currently the same. Failure to find <name> in CURRENT or FORTH is an error condition.

FORMAT n1 n2 --- MASS

"format"

Format n1 tracks on disk number n2.

FORTH VOCABULARY I

"forth"

The name of the primary vocabulary. Execution makes FORTH the CONTEXT vocabulary.

New definitions become a part of FORTH until a differing CURRENT vocabulary is established.

User vocabularies conclude by "chaining" to FORTH, so it should be considered that FORTH is 'contained' within each user's vocabulary.

FMTRK n1 n2 --- MASS

"format track"

Format track n1 on side n2 of the selected disk.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

H/C addr --- DICTIONARY
"h-slash-C"
Separates heads and codes dictionary. Heads are set to generate at addr. DP/ is assigned this addr. Codes are set to generate at value of DP prior to execution. HEADERLESS is set to 1. Results are displayed for verification.

HEADERLESS --- addr DICTIONARY
"headerless"
User variable containing boolean flag indicating state of target compilation. When equal to 0, normal code is compiled. When equal to 1 headerless code is compiled.

HERE --- addr DICTIONARY
"here"
Leaves the address of the next available codes dictionary location.

HERE/ --- addr DICTIONARY
"here-slash"
Leaves the address of the next available dictionary in the heads dictionary.

HEX NUMERIC
"hex"
Sets the numeric conversion BASE to sixteen (hexadecimal).

HLD --- addr FORMAT
"hold"
Leaves the address of user variable which holds the address of the latest character of text during numeric output conversion.

HOLD char FORMAT
"hold"
Used between <# and #> to insert an ASCII character into a pictured numeric output string.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

HWORD --- DICTIONARY

"h-word"
Latest defined word's code section is lifted from codes dictionary, relinked and placed in the heads dictionary. Dictionary pointers are re-adjusted accordingly.

I --- n CONTROL

"i"
Used within a DO-LOOP to copy the loop index from the return stack to the stack.

ID. nfa --- INPUT/OUTPUT

"i-d-dot"
Prints a definition's name from its name field address. See NFA.

IER --- addr MISC P

"interrupt-enable-register"
System address constant for addr of Interrupt Enable Register.

IF flag --- (run-time) CONTROL
--- addr n (compile)

"if"
Used in a colon-definition in form:

```
IF ... THEN
IF ... ELSE ... THEN
```

At run-time, IF selects execution based on a Boolean flag. If flag is true, the words following IF are executed and the words following ELSE are skipped. The ELSE part is optional.

If flag is false, the words between IF and ELSE , or between IF and THEN (when no ELSE is used), are skipped. IF-ELSE-THEN conditionals may be nested.

At compile-time, IF compiles OBRANCH and reserves space for an offset at addr . Addr and n are used later for resolution of the offset and error testing.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

IFR --- addr MISC P
"interrupt-flag-register"
System address constant for addr of Interrupt Flag Register.

IMMEDIATE COMPILER
"immediate"
Marks the most recently made dictionary entry as a word which will be executed when encountered rather than being compiled.

IN --- addr INPUT/OUTPUT U
"in"
Leaves the address of user variable containing the byte offset within the current input text buffer (terminal or disk) from which the next text will be accepted. WORD uses and moves the value of IN .

INDEX n1 n2 --- MASS
"index"
Lists the first lines of screens n1 to n2.
Terminates indexing if a key is typed.

INIT --- MASS
"init"
Sets all locations in CYLINDER to $FF, in effect forcing the next access to that drive to recalibrate from track 0.

INTFLG --- addr MISC P
"interrupt-flag"
System address constant for addr of High Level Interrupt Flag.

INTVEC --- addr MISC P
"interrupt-vector"
System address constant for addr of High Level Interrupt Vector.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

INTERPRET — COMPILER

"interpret"
The outer text interpreter which sequentially executes or compiles text from the input stream (terminal or mass storage) depending on STATE . If the word name cannot be found after a search of CONTEXT and then CURRENT it is converted to a number according to the current BASE . That also failing, an error message echoing the <name> with a "?" will be given.

Text input will be taken according to the convention for WORD . If a decimal point is found as part of a number, a double number value will be left. The decimal point has no other purpose than to force this action. See NUMBER .

IRQVEC — --- addr — MISC — P

" I-R-Q vector"
System address constant for addr of Low Level IRQ vector.

KEY — --- char — INPUT/OUTPUT

"key"
Leaves the ASCII value of the next available character from the active input device.

KHZ — --- addr — PARAMETER — U

"kilo-hertz"
A user variable that specifies the speed of the processor clock. Currently unused and uninitialized.

LATEST — ---- addr — DICTIONARY

"latest"
Leaves the name field address of the top-most word in the CURRENT vocabulary.

LEAVE — CONTROL

"leave"
Forces termination of a DO-LOOP at the next opportunity by setting the loop limit equal to the current value of the index. The index itself remains unchanged, and execution proceeds normally until LOOP or +LOOP is encountered.

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

LFA pfa --- lfa DICTIONARY

"l-f-a"

Converts the parameter field address (pfa) of a dictionary definition to its link field address (lfa).

LIMIT --- n MASS

Leaves the highest address plus one available in the data (or mass storage) buffer. Usually this is the highest system memory.

LIST n --- MASS

"list"

Lists screen n to the current output device.

LIT --- n PRIMITIVE

"lit"

Within a colon-definition, LIT is automatically compiled before each 16-bit literal number encountered in input text. Later execution of LIT causes the contents of the next dictionary address to be pushed to the stack.

LITERAL n --- (compiling) COMPILER

"literal"

If compiling, then compile the stack value n as a 16-bit literal, which when later executed, will leave n on the stack. This definition is immediate so that it will execute during a colon definition. The intended use is:

```
: xxx [ calculate ] LITERAL ;
```

Compilation is suspended for the compile time calculation of a value. Compilation is then resumed and LITERAL compiles this value into the definition.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

LOAD n --- MASS

"load"

Begins interpretation of screen n by making it the input stream; preserves the locators of the present input stream (from IN and BLK).

If interpretation is not terminated explicitly it will be terminated when the input stream is exhausted. Control then returns to the input stream containing LOAD , determined by the input stream locators IN and BLK .

LOOP addr n --- (compiling) CONTROL I,C

"loop"

Occurs in a colon-definition in form:

```
DO ... LOOP
```

At run-time, LOOP selectively controls branching back to the corresponding DO based on the loop index and limit. The loop index is incremented by one and compared to the limit. The branch back to DO occurs until the index equals or exceeds the limit; at that time, the parameters are discarded and execution continues ahead.

At compile-time, LOOP compiles (LOOP) and uses addr to calculate an offset to DO . n is used for error testing.

M* n1 n2 --- d ARITHMETIC

"m-times"

A mixed magnitude math operation which leaves the double number signed product of two signed number.

M/ d n1 --- n2 n3 ARITHMETIC

"m-divides"

A mixed magnitude math operator which leaves the signed remainder n2 and signed quotient n3, from a double number dividend d and divisor n1. The remainder takes its sign from the dividend.

M/MOD ud1 u2 --- u3 ud4 ARITHMETIC

"m-divide-mod"

An unsigned mixed magnitude math operation which leaves a double quotient ud4 and remainder u3, from a double dividend ud1 and single divisor u2.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
MAX	n1 n2 --- max	ARITHMETIC	
	"max" Leaves the greater of two numbers.		
MCR	--- addr	MISC	P
	"mode control register" System address constant for addr of Mode Control Register.		
MEMTOP	addr ---	MASS	
	"memory top" Initializes ULIMIT to addr and UFIRST to addr-$C0C. Clears disk buffers.		
MESSAGE	n ---	SECURITY	
	"message" Displays on the selected active device the text of line n relative to screen 4 of drive 0. n may be positive or negative. MESSAGE may be used to print incidental text such as report headers. If WARNING is zero, the message will simply be displayed as a number (no mass storage).		
MIN	n1 n2 --- n3	ARITHMETIC	
	"min" Leaves the smaller number n3 of two numbers, n1 and n2.		
MOD	n1 n2 --- n3	ARITHMETIC	
	"mod" Leaves the remainder n3 of n1 divided by n2, with the same sign as n1.		
MODE	--- addr	PARAMETER	U
	"mode" A variable used by the assembler.		
MON		MONITOR	
	"mon" Exits to the micro Monitor, leaving a re-entry to FORTH.		

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

NEGATE n --- -n ARITHMETIC
"negate"
Leaves the two's complement of a number, i.e. the difference of 0 less n.

NFA pfa --- nfa DICTIONARY
"n-f-a"
Converts the parameter field address (pfa) of a definition to its name field address (nfa).

NMIVEC --- addr MISC P
"N-M-I vector"
System address constant for addr of Low Level NMI vector.

NOT flag --- COMPARISON
"not"
Leaves a true flag (1) if the number is equal to zero, otherwise leaves a false flag. Same as 0 = .

NUMBER addr --- d FORMAT
"number"
Converts a character string left at addr with a preceeding count, to a signed double precision number, using the current number BASE . If a decimal point is encountered in the text, its position will be given in DPL , but no other effect occurs. If numeric conversion is not possible, an error message will be given.

OFFSET --- addr MASS U
"offset"
Leaves the address of user variable which contains a block offset to mass storage. The content of OFFSET is added to the stack number by BLOCK . Messages by MESSAGE are independent of OFFSET . See BLOCK and MESSAGE .

OR n1 n2 --- n3 ARITHMETIC
"or"
Leaves the bit-wise logical or of two 16 bit values.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
OVER	n1 n2 --- n1 n2 n1	STACK	
	"over" Copies the second stack value, placing it as the new top of stack.		
PA	--- addr	MISC	P
	"port-a" System address constant for addr of Port A.		
PAD	--- addr	DICTIONARY	
	Leaves the address of a scratch area used to hold character strings for intermediate processing. The maximum capacity is 64 characters.		
PB	--- addr	MISC	P
	"port-b" System address constant for addr of Port B.		
PC	--- addr	MISC	P
	"port-c" System address constant for addr of Port C.		
PD	--- addr	MISC	P
	"port-d" System address constant for addr of Port D.		
PE	--- addr	MISC	P
	"port-e" System address constant for addr of Port E.		
PF	--- addr	MISC	P
	"port-f" System address constant for addr of Port F.		
PFAPTR	nfa --- pfaptr	DICTIONARY	
	"p-f-a-pointer" Converts the name field address (nfa) of a pointer dictionary definition to its parameter field address (pfaptr).		

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

PG --- addr MISC P
"port-g"
System address constant for addr of Port Port G.

PICK n --- nth STACK
"pick"
Returns the contents of the nth stack value, not counting n itself. An error conditions results for n less than one. 2 PICK is equivalent to OVER .

PREV --- addr MASS U
"prev"
Leaves the address of a user variable containing the address of the disk buffer most recently referenced. The UPDATE command marks this buffer to be later written to mass storage.

QUERY INPUT/OUTPUT
"query"
Accepts input of up to 80 characters of text, (or until a "return") from the keyboard into the terminal input buffer (TIB) . WORD may be used to accept text from this buffeer as the input stream, by setting IN and BLK to zero.

QUIT MISC
"quit"
Clears the return stack, stops compilation, and returns control to the keyboard. No message is given.

R --- n STACK
"r"
Copies the top of the return stack to the computation stack.

R/W addr blk flag --- MASS
"r-slash-w)
The mass storage read-write linkage. addr specifies the source or destination block buffer, blk is the sequential number of the referenced block; and flag specified read or write (flag = 0 is write and flag = 1 is read). R/W determines the location on

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

R/W (Cont.) storage, performs the read-write and performs any error checking. R/W executes the cfa found in UR/W . On cold start this is the address of (ABORT) .

R> --- n STACK
"r-from"
Removes the top value from the return stack and leaves it on the computation stack. See >R and R .

R0 --- addr PRIMITIVE U
"r-zero"
Leaves the address of user variable containing the initial value of the return stack pointer. See RP! .

REPEAT addr n --- (compiling) CONTROL I,C
"repeat"
Used within a colon-definition in the form:

BEGIN ... WHILE ... REPEAT

At run-time, REPEAT forces an unconditional branch back to just after the corresponding BEGIN .

At compile-time, REPEAT compiles BRANCH and the offset from HERE to addr. n is used for error testing.

ROT n1 n2 n3 --- n2 n3 n1 STACK
"rote"
Rotates the top three values on the stack, bringing the third to the top.

RP! --- PRIMITIVE
"r-p-store"

Initializes the return stack pointer from user variable R0 .

RP@ --- addr STACK
"r-p-fetch"
Leaves the address of a variable containing the return stack pointer.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR
S->D	n --- d	ARITHMETIC	
	"s-to-d"		
	Extends the sign of single number n to form double number d.		
S0	--- addr	PRIMITIVE	U
	"s-zero"		
	Leaves the address user variable that contains the initial value for the parameter stack pointer. See SP!		
SCCR	--- addr	MISC	P
	"serial channel control register"		
	System address constant for addr of Serial Channel Control Register.		
SCDR	--- addr	MISC	P
	"serial channel data register"		
	System address constant for addr of Serial Channel Data Register.		
SCSR	--- addr	MISC	P
	"serial channel status register"		
	System address constant for addr of Serial Channel Status Register.		
SCR	--- addr	MASS	P
	"s-c-r"		
	Leaves the address of user variable containing the screen number most recently referenced by LIST .		
SEEK	n ---	MASS	
	"seek"		
	Causes drive selected to seek track n.		
SELECT	n ---	MASS	
	"select"		
	Selects and activates disk drive number n.		

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

SIGN n d --- d FORMAT

"sign"

Inserts the ASCII "-" (minus sign) into the pictured numeric output string if n is negative. n is discarded, but double number d is maintained. Must be used between <# and #> .

SMUDGE --- DICTIONARY

"smudge"

Used during word definition to toggle the "smudge bit" in a definitions name field. This prevents an uncompleted definition from being found during dictionary searches, until compiling is completed without error.

SOURCE --- MONITOR

"source"

A procedure which allows batch compilation from the serial channel or an alternate input.

Compilation continues until FINIS is encountered. FINIS alters serial input back to serial channel.

SP! --- STACK

"s-p-store"

Initializes the stack pointer from S0 .

SP@ --- addr STACK

"s-p-fetch"

Returns the address of the top of the stack as it was before SP@ was executed. (e.g., 1 2 SP@ @ . . . would type 2 2 1)

SPACE INPUT/OUTPUT

Transmits an ASCII blank to the active output device.

SPACES n ---

"spaces"

Transmit n ASCII blanks to the active output device.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

STATE --- addr COMPILER U

"state"

Leaves the address of user variable containing the compilation state. A non-zero value indicates compilation.

SWAP n1 n2 --- n2 n1 STACK

"swap"

Exchanges the top two values on the stack.

TASK --- DICTIONARY

"task"

A no-operation word which can mark the boundary between applications. By forgetting TASK and re-compiling, an application can be discarded in its entirety. Its definition is : TASK ; .

THEN CONTROL I,C

"then"

Used within a colon-definition, in the form:

```
IF . . . ELSE . . . THEN or
IF . . . THEN
```

THEN is the point where execution resumes after ELSE or IF (when no ELSE is present).

TIB --- addr INPUT/OUTPUT U

"t-i-b"

Leaves the address of user variable containing the starting address of the terminal input buffer.

TOGGLE addr b --- MEMORY

"toggle"

Complements the contents of addr by the 8-bit pattern byte.

TRAVERSE addr n --- addr DICTIONARY

"traverse"

Adjust the addr in a negative or positive direction, depending on the sign of n, until the contents of addr is greater than $7F. n must be either 1 or -1.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

TYPE addr n --- INPUT/OUTPUT
"type"
Transmits n characters beginning at addr to the active output device. No action takes place for n less than one.

U* unl un2 --- ud ARITHMETIC
"u-times"
Performs an unsigned multiplication of unl by un2, leaving the unsigned double number product of two unsigned numbers.

U/ ud ul --- u2 u3 ARITHMETIC
"u-divide"
Performs the unsigned division of double number ud by ul, leaving the unsigned remainder u2 and unsigned quotient n3 from the unsigned double dividend ud and unsigned divisor ul.

U< unl un2 --- flag COMPARATIVE
"u-less-than"
Leaves the flag representing the magnitude comparison of unl < un2 where unl and un2 are treated as 16-bit unsigned integers.

UABORT --- addr PARAMETER U
"u-abort"
Leaves the address of the user variable containing the code field address of the ABORT word.

UC/L --- addr PARAMETER U
"u-characters-per-line"
Leaves the address of the user variable containing the number of characters per line.

UFIRST --- addr PARAMETER U
"u-first"
Leaves the address of the user variable containing the first address of the data (or mass storage) buffer.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

ULIMIT --- addr PARAMETER U

"u-limit"
Leaves the address of the user variable containing the last address plus one of the data (or mass storage) buffer.

UNTIL flag --- (run-time) CONTROL I,C
addr n --- (compile-time)

"until"
Occurs within a colon-definition in the form:

BEGIN ... UNTIL

At run-time, if flag is true, the loop is terminated. If flag is false, execution returns to the first word after BEGIN . BEGIN - UNTIL structures may be nested.

At compile-time, UNTIL compiles OBRANCH and an offset from HERE to addr. n is used for error tests.

UPAD --- addr PARAMETER U

"u-pad"
Leaves address of the user variable containing the address of the temporary storage area PAD .

UPDATE MASS

"update"
Marks the most recently referenced block (pointed to by PREV) as altered. The block will subsequently be transferred automatically to mass storage, should its buffer be required for storage of a different block.

UR/W --- addr PARAMETER

"u-read-write"
Leaves the address of the user variable containing the code field address of the mass storage I/O word. Initialized to (ABORT) on a cold start.

USE --- addr MASS U

"use"
Leaves the address of user variable containing the address of the block buffer to use next, as the least recently written.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

USER n --- DEFINING

"user"
A defining word used in the form:

n USER <name>

which creates a user variable <name>. The parameter field of <name> contains n as a fixed offset relative to the user pointer register UP for this user variable. When <name> is later executed, it places the sum of its offset and the user area base address on the stack as the storage address of that particular variable. Offsets of $60 to $7F are available. See Appendix G.

VARIABLE n --- <name> (compute-time) DEFINING
<name> --- (run-time)

"variable"
A defining word executed in the form:

n VARIABLE <name>

to create a dictionary entry for <name> and allot two bytes for storage in the parameter field. When <name> is later executed, it will place the storage address on the stack.

VOC-LINK ---- addr VOCABULARY U

"voc-link"
Leaves the address of user variable containing the address of a field in the definition of the most recently created vocabulary. All vocabulary names are linked by these fields to allow control for FORGETting through multiple vocabularies.

VOCABULARY VOCABULARY

"vocabulary"
A defining word used in the form:

VOCABULARY <name>

to create (in the CURRENT vocabulary) a dictionary entry for <name>, which specifies a new ordered list of word definitions. Subsequent execution of <name> will make it the CONTEXT vocabulary. When <name> becomes the CURRENT vocabulary (see DEFINITIONS), new definitions will be created in that list.

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

VOCABULARY (Cont.) New vocabularies 'chain' to FORTH. This is, when a all of dictionary search through a vocabulary is exhausted, FORTH will be searched.

VLIST — VOCABULARY

"v-list"
Lists the names of the definitions in the CONTEXT vocabulary. Depression of any key will terminate the listing.

WARNING --- addr — SECURITY — U

"warning"
Leaves the address of user variable containing a value controlling messages. If value = 1 mass storage is present and screen 4 of drive 0 is the base location for messages. If value = 0, no disk is present and messages will be presented by number. If value = -1, execute (ABORT) for a user specified procedure. See MESSAGE and ERROR .

WHILE flag --- (run-time) — CONTROL — I,C
addr1 n1 -> addr1 n1 addr2 n2

"while"
Occurs in a colon-definition in the form:

```
BEGIN ... WHILE (tp) ... REPEAT
```

At run-time, WHILE selects conditional execution based on Boolean flag. If flag is true (non-zero), WHILE continues execution of the true part through to REPEAT , which then branches back to BEGIN . If flag is false (zero), execution skips to just after REPEAT , exiting the structure.

At compile-time, WHILE emplaces (OBRANCH) and leaves addr2 of the reserved offset. The stack values will be resolved by REPEAT .

WORD	STACK NOTATION/DEFINITION	GROUP ATTR

WIDTH --- addr SECURITY U
"width"
Leaves the address of user variable containing the maximum number of letters saved in the compilation of a definitions name. It must be 1 through 31, with a default value of 31. The name character count and its natural characters are saved, up to the value in WIDTH . The value may be changed at any time within the above limits.

WORD char --- COMPILER
"word"
Receives characters from the input stream until the non-zero delimiting character in the stack is encountered or the input stream is exhausted, ignoring leading delimiters. The characters are stored as a packed string with the character count in the first character position. The actual delimiter encountered (char or null) is stored at the end of the text but not included in the count. If the input stream was exhausted as WORD is called, then a zero length will result.

XOFF --- MONITOR
"x-off"
Sends XOFF ($13) character to system terminal.

XON --- MONITOR
"x-on"
Sends XON ($11) character to system terminal.

XOR n1 n2 --- n3 ARITHMETIC
"x-or"
Leaves the bit-wise logical exclusive or of two values.

[COMPILER I
"left-bracket"
Ends the compilation mode. The text from the input stream is subsequently executed. See] .

WORD	STACK NOTATION/DEFINITION	GROUP	ATTR

[COMPILE] COMPILER I

"bracket compile"
Used in a colon-definition in form:

[COMPILE] <name>

Forces compilation of the following word. This allows compilation of an IMMEDIATE word when it would otherwise be executed.

] COMPILER

"right bracket"
Sets the compilation mode. The text from the input stream is subsequently compiled. See [.

" " (NULL) --- INPUT/OUTPUT

"null"
Null is executed at the end of each line of input or screen of input. It is not called directly by the user.

APPENDIX C

RSC-FORTH ASSEMBLER FUNCTIONAL SUMMARY

This appendix contains a summary of the RSC-FORTH Assembler word definitions grouped by area of primary function. Consult appendix D for the detail definition of each word.

Stack Notation

The stack operation is denoted in parenthesis. The symbols on the left indicate the order in which input parameters must be placed on the stack prior to FORTH word execution. Three dashes (---) indicate the FORTH word execution point. Any parameters left on the stack after execution are listed on the right. The top of the stack is to the right.

Symbol Definition

A/T	Assembly-time
R/T	Run-time
H/B	High-byte
L/B	Low-byte
addr, addrl,...	Address

C.1 OP-CODES

ADC,	DEC,	LSR,	SEC,
AND,	DEX,	NOP,	SED,
ASL,	DEY,	ORA,	SEI,
BIT,	EOR,	PHA,	SMB,
BRK,	INC,	PHP,	STA,
CLC,	INX,	PLA,	STX,
CLD,	INY,	PLP,	STY,
CLI,	JMP,	ROL,	TAX,
CLV,	JSR,	ROR,	TAY,
CMP,	LDA,	RMB,	TSX,
CPX,	LDX,	RTI,	TXA,
CPY,	LDY,	RTS,	TXS,
		SBC,	TYA,

C.2 ADDRESS MODES

.A	---	Accumulator address mode.
#	---	Immediate address mode.
,X	---	Indexed X address mode.
,Y	---	Indexed Y address mode.
X)	---	Indexed Indirect X address mode.
)Y	---	Indirect Indexed Y address mode.
)	---	Indirect Absolute address mode.

C.3 CONDITIONAL SPECIFIERS

0<	A/T:	---	cc		Branch on negative (N=1).
0=	A/T:	---	cc		Branch on zero (Z=1).
VS	A/T:	---	cc		Branch on overflow (V=1).
CS	A/T:	---	cc		Branch on carry (C=1).
NOT	A/T:	cc1	---	cc2	Reverse the condition code.
BITCLR	A/T:n	addr	---	cc	Branch on bit n of zero page address addr clear.
BITSET	A/T:n	addr	---	cc	Branch on bit n of zero page address addr set.

C.4 CONTROL

BEGIN, pointer	A/T:	--- addr 1	At A/T, leaves the dictionary address and the value 1 for later testing of conditional pairing.
	R/T:	---	At R/T, marks the beginning of a repeatedly executed assembly sequence.
UNTIL,	A/T:	addr 1 cc --	At A/T, assembles a conditional branch instruction to addrB (BEGIN, point based on condition code cc.
	R/T:	---	At R/T, conditionally branches to the BEGIN, point (if cc is false) or continues ahead (if cc is true).
AGAIN,	A/T:	addr 1 ---	At A/T, assembles a JMP instruction to addrB (BEGIN, point).
	R/T:	---	At R/T, jumps to the BEGIN, point.

C4 CONTROL (Continued

REPEAT,	A/T:	addr 1 addrW 3 ---	At A/T, assembles a JMP instruction to the BEGIN, point.
	R/T:	---	At R/T, jumps to the BEGIN, point.
WHILE,	A/T:	addr 1 --- addr 1 addrW 3	At A/T, assembles a conditional branch instruction to the instruction following REPEAT, based on the condition code cc.
	R/T:	---	At R/T, conditional branches to the point following REPEAT, is cc is false, or continues ahead if cc is true.
IF,	A/T:	--- addr 2	At A/T, creates an unresolved forward conditional branch based on cc and leaves addr for resolution by ELSE, or THEN,.
	R/T:	cc --- addr 2	At R/T, conditionally branches to the ELSE, point (or THEN, point if ELSE is not present) if cc is false, or continues ahead if cc is true.
ELSE,	A/T:	addr1 2 --- addr2 2	At A/T, assembles a forward JMP instruction to THEN, and resolves the forward conditional branch from IF, .
	R/T:	---	At R/T, marks the start of an assembly sequence conditionally branched to from IF, if cc is false.
THEN,	A/T:	addr 2 ---	At A/T, marks the conclusion of a conditional structure started by IF, and resolves the forward conditional branch from IF, (if ELSE, is not present).
	R/T:	---	At R/T, marks the conclusion of a conditional structure started by 'IF, .

C.4 CONTROL (Continued)

ENDIF,	A/T:	addr 2 ---	Alias for THEN, .
	R/T:	---	

C.5 RETURN

BINARY	A/T:	--- addr	At A/T, leaves the address of a return point which, at R/T, will pull two 16-bit values from the stack and push the accumulator (H/B) and the top machine stack byte (L/B) to the data stack.
	R/T:	n1 n2 --- (n)	
PUSH	A/T:	--- addr	At A/T, leaves the address of the R/T return point which will add the accumulator (H/B) and the top machine stack byte (L/B) to the data stack.
	R/T:	--- n	
PUT	A/T:	--- addr	At A/T, leaves the address of the R/T return point which will write the accumulator (H/B) and the top machine stack byte (L/B) to replace the existing top data stack 16-bit value (n1).
	R/T:	n1 --- n2	
POP	A/T:	--- addr	At A/T, leaves the address of the R/T return point which will pull a 16-bit value from the data stack and continue interpretation.
	R/T:	n ---	
PUSHOA	A/T:	--- addr	At A/T, leaves the address of the R/T return point which will push a zero (H/B) and the accumulator (L/B) onto the data stack.
	R/T:	--- n	
PUTOA	A/T:	--- addr	At A/T, leaves the address of the R/T return point which will write a zero (H/B) and the accumulator (L/B) to replace the existing data stack 16-bit Value (n1).
	R/T:	n1 --- n2	

C.5 RETURN (Continued)

POPTWO	A/T:	--- addr	At assembly-time, leaves the address of the run-time return
	R/T:	n1 n2 ---	return which will pull two 16-bit values from the data stack and continue interpretation.
NEXT	A/T:	--- addr	At assembly-time, leaves the address of the FORTH inner-interpreter.

C.6 STACK

RP)	A/T:	--- 101 (hex)	At A/T, used to address the bottom of the Return Stack.
TOP	A/T:	--- 0	At A/T, used to address the top item on the data stack.
SEC	A/T:	--- 2	At A/T, used to address the second item on the data stack.
SETUP	A/T:	--- addr	Leaves the address of a utility routine to move items from the stack to the N area on z-page.

C.7 REGISTERS

N	A/T:	--- addr	Leaves the address of a nine-byte work space in page zero.
IP	A/T:	--- addr	Leaves the address of the pointer to the next FORTH execution address in a colon-definition to be interpreted.
UP	A/T:	--- addr	Leaves the address of the pointer to the base of the user area.
W	A/T:	--- addr	Leaves the address of the pointer to the code field of the FORTH word being executed.
XSAVE	A/T:	--- addr	Leaves the address of a temporary buffer for saving the X register.

C.8 MISCELLANEOUS

END-CODE	A/T:	---	Marks the end of a CODE-definition.
MEM	A/T:	---	Sets MODE to direct memory addressing on z-page.

APPENDIX D

RSC-FORTH ASSEMBLER GLOSSARY

This glossary contains the definitions of all words in the RSC-FORTH ASSEMBLER vocabulary with exception of the op-codes. The definitions are presented in ASCII sort order.

Stack Notation

The first line of each entry shows a symbolic description of the action of the procedure on the parameter stack. The symbols on the left indicate the order in which input parameters have been placed on the stack. Three dashes "---" indicate the execution point; any parameters left on the stack after execution are listed on the right. In this notation, the top of the stack is to the right.

Symbol Definition

addr,addrl,...	memory address
cc,ccl,...	condition code
n,nl,...	16-bit signed number

Pronunciation

The natural language pronunciation of FORTH names is given in double quotes (").

Capitalization

Word names as used within the glossary are conventionally written in upper-case characters. Lower case is used when reference is made to the run-time machine codes (not directly accessible), e.g., VARIABLE is the user word to create a variable. Each use of that variable makes use of a code sequence 'variable' which executes the function of the particular variable.

Group Key Words (GROUP)

ADDRESS	Addressing Mode
OP-CODE	Operation Code
CONTROL	Control Structures
STACK	Stack Addressing
REGISTER	Assembly Register
CONDITION	Conditional Specifiers
RETURN	Return of Control

WORD	STACK NOTATION/DEFINITION	GROUP
#	--- "immediate" Specifies 'immediate' addressing mode for the next op-code generated.	ADDRESS
)	--- "indirect" Specifies 'indirect absolute' addressing mode for the next op-code generated.	ADDRESS
)Y	--- "indirect indexed Y" Specifies 'indirect indexed Y' addressing mode for the next op-code generated.	ADDRESS
,X	--- "indexed x" Specifies 'indexed X' addressing mode for the next op-code generated.	ADDRESS
,Y	--- "indexed Y" Specifies 'indexed Y' addressing mode for the next op-code generated.	ADDRESS
.A	--- "accumulator" , Specifies accumulator addressing mode for the next op-code generated.	ADDRESS
0<	--- cc (assembly-time) "zero-less" Specifies that the immediately following conditional will branch based on the processor negative flag status bit being negative (N=1), i.e., less than zero. The flag cc is left at assembly-time; there is no run-time effect on the stack.	CONDITION
0=	--- cc (assembly-time) "zero-equals" Specifies that the immediately following conditional will branch based on the processor zero flag status bit being equal to one (Z=1); i.e. equal to zero. The flag cc is left at assembly-time; there is no run-time effect on the stack.	CONDITION

WORD	STACK NOTATION/DEFINITION	GROUP
AGAIN,	addr 1 --- (assembly-time) --- (run-time) "again" Occurs in a CODE-definition in the form: BEGIN, . . . AGAIN, At assembly-time, AGAIN, assembles a JMP instruction to addr. The number 1 is issued for error checking. At run-time, AGAIN, branches unconditionally to its matching BEGIN, .	CONTROL
BEGIN,	--- addr 1 (assembly-time) --- (run-time) Occurs in a CODE-definition in the form: BEGIN, . . . cc UNTIL, At assembly time, BEGIN , leaves the dictionary pointer address addr and the value 1 for later testing of conditional pairing by UNTIL, or AGAIN, . At run-time, BEGIN, marks the start of an assembly sequence repeatedly executed. It serves as the return point for the corresponding UNTIL, . When reaching UNTIL, a branch to BEGIN, will occur if the processor status bit given by cc is false; otherwise execution continues ahead.	CONTROL
BINARY,	--- addr (assembly-time) n1 n2 --- (n) (run-time) "binary" At assembly-time constant which leaves the machine address of a return point which, at run-time, will pull two 16-bit values from the stack and push the accumulator (high-byte) and the top machine stack byte (as low-byte) to the data stack.	RETURN
BITCLR	n addr --- cc (assembly time)	CONDITION
BITSET	n addr --- cc (assembly time)	CONDITION

WORD	STACK NOTATION/DEFINITION	GROUP
CS	--- cc (assembly-time) "carry-set" Specifies that the immediately following conditional will branch based on the processor carry status flag being set (C=1). The flag cc is left at assembly-time; there is no run-time effect on the stack.	CONDITION
ELSE,	addr1 2 --- addr2 2 2 (assembly-time) --- (run-time) "else" Occurs within a CODE-definition in the form: cc IF, <true part> ELSE, <false part> THEN, At assembly-time, ELSE, assembles a forward jump to just after THEN, and resolves a pending forward conditional branch from IF, . The value 2 is used for error checking of conditional pairing. At run-time, if the condition code specified by cc is false, execution will skip to the machine code following ELSE, .	CONTROL
END-CODE	--- "end-code" An error check word marking the end of a CODE-definition. Successful execution to and including END-CODE will unsmudge the most recent CURRENT vocabulary definition, making it available for execution. END-CODE also exits the ASSEMBLER making CONTEXT the same as CURRENT .	MISC
ENDIF,	addr 2 --- (assembly-time) --- (run-time) "end-if" Another name for THEN, .	CONTROL
IF,	--- addr 2 (assembly-time) cc --- addr 2 (run-time) "if" Occurs within a code definition in the form: cc IF, <true part> ELSE, <false part> THEN,	CONTROL

WORD	STACK NOTATION/DEFINITION	GROUP

IF, (Cont.)

At assembly-time IF, creates an unresolved forward branch based on the condition code cc, and leaves addr and 2 for resolution of the branch by the corresponding ELSE, or THEN, . Conditionals may be nested.

At run-time, IF, branches based on the condition code cc (0< or 0= or CS). If the specified processor status is true, execution continues ahead, otherwise branching occurs to just after ELSE, (or THEN, when ELSE, is not present). At ELSE, execution resumes at the corresponding THEN, .

IP --- addr (assembly-time) REGISTER

"i-p"

Used in a CODE-definition in the form:

IP STA, or IP)Y LDA,

At assembly-time, a constant which leaves the address of the pointer to the next FORTH execution address in a colon-definition to be interpreted.

At run-time, NEXT moves IP ahead within a colon-definition. Therefore, IP points just after the execution address being interpreted. If an in-line data structure has been compiled (i.e., a character string), indexing ahead by IP can access this data:

IP STA, or IP)Y LDA,

loads the third byte ahead in the colon-definition being interpreted.

MEM --- MISC

"memory"

Used within the assembler to set MODE to the default value for direct memory addressing on z-page.

WORD	STACK NOTATION/DEFINITION	GROUP

N --- addr (assembly-time) REGISTER

"n"

Used in a CODE-definition in the form:

```
N 1 - STA,  or  N 2+ )Y ADC,
```

A constant which leaves the address of a 9 byte workspace in z-page. Within a single CODE-definition, free use may be made over the range N-1 thru N+7. See SETUP .

NEXT --- addr (assembly-time) RETURN

"next"

A constant which leaves the machine address of the FORTH address interpreter. All CODE-definitions must return execution to NEXT, or include code that returns to NEXT (i.e., PUSH , PUT , PUSHOA , PUTOA , BINARY , POP , POPTWO).

NOT cc1 --- cc2 (assembly-time) CONDITION

"not"

When assembling, reverse the condition code for the following conditional. For example:

```
0= NOT IF,  <true part>  THEN,
```

will branch based on "not equal to zero".
NOT is not valid for BITCLR or BITSET reversal.

POP --- addr (assembly-time) RETURN

n --- (run-time)

"pop"

A constant which leaves (during assembly) the machine address of the return point which, at run-time, will pull a 16-bit value from the data stack and continue interpretation.

POPTWO --- addr (assembly-time) RETURN

n1 n2 --- (run-time)

"pop-two"

At assembly time, constant which leaves machine address of the return point which, at run-time, will pull two 16-bit values from the data stack and continue interpretation.

WORD	STACK NOTATION/DEFINITION	GROUP
PUSH	--- addr (assembly-time) --- n (run-time) "push" At assembly-time, constant which leaves the machine address of the return point which, at run-time, will add the accumulator (as high-byte) and the top machine stack byte (as low-byte) to the data stack.	RETURN
PUSH0A	--- addr (assembly-time) --- n (run-time) "push-0-a" At assembly-time, constant which leaves the machine address of the return point which, at run-time, will add a zero (as high byte) and the accumulator (as low byte) to the data stack.	RETURN
PUT	--- addr (assembly-time) n1 --- n2 (run-time) "put" At assembly time, constant which leaves the machine address of the return point which, at run-time, will write the accumulator (as high-byte) and the top machine stack byte (as low-byte) over the existing data stack 16-bit value (n1).	RETURN
PUT0A	--- addr (assembly-time) n1 --- n2 (run-time) "put-zero-a" At assembly-time, constant which leaves the machine address of the return point which, at run-time, will write a zero (as high-byte) and the accumulator as low-byte) over the existing data stack 16-bit value (n1).	RETURN
REPEAT,	addrB 1 addrW 3 --- (assembly-time) --- (run-time) "repeat" Occurs in a code definition in the form: BEGIN, ... cc WHILE, ... REPEAT,	CONTROL

WORD	STACK NOTATION/DEFINITION	GROUP

REPEAT, (Cont.)

At assembly-time, REPEAT, assembles as JMP instruction to the instruction immediately following the BEGIN, word.

At run-time REPEAT, unconditionally branches back to its matching BEGIN, .

RP)

--- 101 (assembly-time) STACK
"return-pointer"
Used in a CODE-definition in the form:

RP) LDA, or RP) 3+ STA,

Addresses the top byte of the return stack (containing the low byte) by selecting the ,X mode and leaving n=$0001. n may be modified to another byte offset. Before operating on the return stack the X register must be saved in XSAVE and TSX, executed. Before returning to NEXT, the X register must be restored.

SEC

--- 2 (assembly-time) STACK
"second"
Used in a CODE-definition in the form:

SEC LDA, or SEC 1+ STA,

Addresses the second 16-bit item on the data stack by selecting the , X,X address mode and leaving 2 on the stack.

SETUP

--- addr (assembly-time) STACK
"setup"
A constant whose value is the address of a utility routine to move items from the stack to the N area of zero page. The number of items to move (1, 2, 3 or 4 only) is in the A register.

THEN,

addr 2 --- (assembly-time) CONTROL
--- (run-time)
"then"
Occurs in a CODE-definition in the form:

cc IF, <true part> ELSE, <false part> THEN,

WORD	STACK NOTATION/DEFINITION	GROUP

THEN, (Cont.)

At assembly-time, THEN, marks the conclusion of a conditional structure. The conditional branch instructions generated by IF, and the JMP instruction generated ELSE, point to the instruction immediately following THEN, . When assembling, addr and 2 are used to resolve the pending forward branch to THEN, .

At run-time THEN, marks the conclusion of a conditional structure. Execution of either the true part or false part resumes following THEN, .

TOP

--- 0 (assembly-time) STACK

"top"

Used during code assembly in the form:

TOP LDA, or TOP 1+ X) STA,

Addresses the top of the data stack (containing the low byte) by selecting the ,X mode and leaving n=0, at assembly-time. This value of n may be modified to another byte offset into the data stack. Must be followed by a multi-mode op-code mnemonic.

UNTIL,

addr 1 cc --- (assembly-time) CONTROL

--- (run-time)

"until"

Occurs in a CODE-definition in the form:

BEGIN, ... cc UNTIL,

At assembly-time, UNTIL, assembles a conditional relative branch to addr based on the condition code cc. The number 1 is used for error checking.

At run-time, UNTIL, controls the conditional branching back to BEGIN, . If the processor status bit specified by cc is false, execution returns to BEGIN, ; otherwise execution continues ahead.

WORD	STACK NOTATION/DEFINITION	GROUP

UP --- addr (assembly-time) REGISTER

"user pointer"
Used in a CODE-definition in the form:

```
UP LDA,  or  UP )Y STA,
```

A constant which leaves the address of the pointer to the base of the user area. The instructions

```
HEX  12 # LDY,  UP )Y LDA,
```

will load the low byte of the sixth user variable, DP.

VS --- cc (assembly-time) CONDITION

"overflow set"
Specifies that the immediately following conditional will branch based on the processor status overflow flag being on (V=1). The flag cc is left at assembly-time; there is no run-time effect on the stack.

W --- addr (assembly-time) REGISTER

Used in a CODE-definition in the form:

```
W 1+ STA,  or  W 1 - JMP,  or  W )Y ADC,
```

At assembly-time constant which leaves at assembly-time the address of the pointer to the code field (execution address) of the FORTH dictionary word being executed. Indexing

relative to W can yield any byte in the definitions parameter field. For example, the instructions

```
2 # LDY,  W )Y LDA,
```

will fetch the first byte of the parameter field.

WORD	STACK NOTATION/DEFINITION	GROUP

WHILE, addrB 1 --- addrB 1 addrW 3 CONTROL
(assembly-time) --- (run-time)
"while"
Occurs in a CODE-definition in the form:

```
BEGIN, ... cc WHILE, ... REPEAT,
```

At assembly-time, WHILE, assembles a conditional relative branch instruction to the instruction immediately following the REPEAT, based on the condition code cc.

At run-time WHILE, controls the conditional branching to just past REPEAT, . If the processor status bit specified by cc is true, WHILE, continues execution through to REPEAT, which then branches back to BEGIN, . If cc is false a jump is made to just after REPEAT, and execution continues.

X) "indexed indirect X" ADDRESS
Specifies "indexed indirect X" addressing mode for the next op-code generated.

XSAVE --- addr (assembly-time) REGISTER
"x-save"
Used in a CODE-definition in the form:

```
XSAVE STX, or XSAVE LDX,
```

A constant which leaves the address at assembly time of a temporary buffer for saving the X register. Since the X register indexes to the data stack in z-page, it must be saved and restored when used for other purposes.

APPENDIX E

ERROR MESSAGES AND RECOVERY

E.1 STANDARD ERROR MESSAGE

The standard FORTH error message is "?" . This question mark is output along with the most recently interpreted word when that word can not be found in the dictionary and will not convert into a number in the current BASE . For example:

```
 RSC-FORTH V1.5

QUERTY
QUERTY ?

ABC
ABC ?

HEX OK

ABC OK
DECIMAL . <RETURN> 2748 OK
```

Upon initialization, QUERTY and ABC were not in the dictionary, therefore, the ? error message was displayed when they were entered. After the number base of the I/O was changed to HEX , however, ABC became a valid number. ABC was then accepted as a valid number upon the record entry attempt, converted to internal two's complement binary format, and stored on the stack. The number was then removed from the stack and displayed in decimal.

E.2 STANDARD ERROR MESSAGE WORD

RSC-FORTH has a standard error message word

?ERROR

which takes two items from the stack:

t n ?ERROR

where t is Boolean and n is the desired error number.

If the Boolean is false, nothing happens; but if it is true, one of three things happen depending on the value of the user variable WARNING . If WARNING is zero, the number n is printed as an error message. If WARNING is greater than zero, a disk is assumed to be in use. Then n becomes the line number relative to line 0, screen 4 of drive 0 and that line number is displayed in ASCII. The line number may be negative, zero or positive and greater than fifteen. The line number is simply an offset from line 0 screen 4. If WARNING is less than zero, the word ABORT is executed.

E.3 RSC-FORTH ERROR DEFINITIONS

The error conditions detected by RSC-FORTH are listed in Table E-1. For increased utility the two most common errors are given in English. These are error message 1, STACK EMPTY , and warning message 4, NOT UNIQUE .

The last action of error messages processing is to clear the stacks and execute QUIT . However, the warning message 'NOT UNIQUE' is simply output, it has no effect on the stacks and execution continues normally.

Error message number 3 is slightly different in that it prints the name of the code word being defined, the name of the assembler op-code word being interpreted, and the message number or message.

Table E-1. RSC-FORTH Error Message

Number	Message	Definition	Action
0	?	Echoed word was the last one interpreted. Name is not in the dictionary and is not a number.	Define the named item. Check number conversion base.
1	STACK EMPTY	Parameter stack	Don't pull more is empty items off the stack than are there.
2	DICTIONARY FULL	The dictionary space is used up. FIRST HERE - is less than $A0.	Increase space for dictionary by FORGETing entries or moving FIRST .
3	HAS INCORRECT ADDRESS MODE	The address mode for that assembler op-code is incorrect.	Use a correct address mode. See R6500 Programming Manual.
4	NOT UNIQUE	The dictionary entry <name> just created is not unique.	Be aware that the new definition of <name> obscures the old one and all future references to <name> will be to the new entry (often an advantage).

Table E-1. RSC-FORTH Error Message (Continued)

Number	Message	Definition	Action
5	--	Not assigned	--
6	DISC RANGE?	The disk block asked for is out of range.	This is available for the user to put in his definition of R/W.
7	FULL STACK	The parameter stack is full (more than 50 items).	Remove some stack item. DROP or output.
8	DISC ERROR!	There has been a disk error.	This is available for the user's R/W definition.
9-16	--	Not assigned	--
17	COMPILATION ONLY	The word just interpreted must be used in a definition.	Don't use compilation words interpretively.
18	EXECUTION ONLY	The word just interpreted must be used outside of a definition.	Don't use interpretive words in a definition.
19	CONDITIONALS NOT PAIRED	Omitted word or incorrect nesting of conditionals.	Pair conditionals correctly.
20	DEFINITION NOT FINISHED	The current definition is not yet finished.	Finish definition.
21	IN PROTECTED DICTIONARY	The word in question is below the FENCE	Cease trying to FORGET a protected word or move FENCE.
22	USE ONLY WHEN LOADING	Incorrect use of the word -->	Use the word --> only while loading.

E.4 DISK ERRORS

Floppy disk operation errors are reported in the error byte left on the stack after DREAD or DWRITE is executed. The individual meanings of each bit in this status byte is defined in Table E-2.

Table E-2. Disk Error Byte Description

Bit No.	Description
7	- - -
6	Disk is write protected
5	Read Record Type error (1 = Deleted Data Mark) Write error
4	Record not found (Seek error in Format)
3	CRC error in ID Field
2	Lost Data error
1	- - -
Ø	FDC device is busy.

APPENDIX F

PAGE ZERO and ONE MEMORY MAP

Hex Address	No. Bytes	Cold Start Hex Value	Warm Start Hex Value	Parameter Name	Parameter Description
000-00F	16	- -	- -	-	Internal ports
010-01F	16	- -	- -	-	Internal registers
020-03F	32	- -	- -	-	Reserved
040-041	2	(COLD)	- -	IRQVEC	
042-043	2	(COLD)	- -	NMIVEC	
044-045	2	(INK)	(INK)	UKEY	
046-047	2	(OUT)	(OUT)	UEMIT	
048-049	2	00 03	00 03	UP	
04A	1	00	00	INTFLG	
04B	1	6C	6C	(W-1)	
04C-040	2	- -	- -	W	
04E-04F	2	- -	- -	IP	
050	1	-	-	(N-1)	
051-058	8	- -	- -	N	
059-05A	2	- -	- -	XSAVE	
05B-05C	2	(COLD)	- -	INTVEC	High level interrupt vector
05D	-	-	-	TOS	Last free memory in data stack
05D-0C1	100	- -	- -	-	Parameter (data) stack
0C2-0FF	60	- -	- -	-	Return stack
100	1	-	-	-	Floppy Disk Status/ Command Register
101	1	-	-	-	Floppy Disk Track Register
102	1	-	-	-	Floppy Disk Sector Register
103	1	-	-	-	Floppy Disk Data Register
106	1	-	-	-	Floppy Disk Control Register

APPENDIX G

USER VARIABLES RAM MAP

Hex Address	No. Bytes	Cold Start Value	Warm Start Value	Parameter Name	Parameter Description
300-301	2	80 03	80 03	TIB	Terminal Input Buffer address.
302-303	2	FF 00	FF 00	R0	Return Stack base address.
304-305	2	C2 00	C2 00	50	Parameter Stack base address.
306-307	2	50 00	- -	UC/L	No. of characters/line.
308-309	2	7E 03	- -	UPAD	Location of PAD in memory.
30A-30B	2	(DISK)	- -	UR/W	CFA of UR/W orphan word.
30C-30D	2	10 00	- -	BASE	Current I/O base number.
30E-30F	2	- -	- -	CLD/WRM	Cold/warm reset flag.
310-311	2	- -	- -	IN	Byte offset in current input stream.
312-313	2	- -	- -	DPL	Number of decimals in double-precision input.
314-315	2	- -	- -	HLD	Address of current output.
316-317	2	- -	- -	DISKNO	Number of selected disk drive.
318-31B	4	FF FF FF FF	-	CYLINDER	Track of eack disk.
31C-31D*	2	80 -	- -	B/SIDE	Blocks per side per disk.
31E-31F	2	F8 17	- -	UFIRST	Start of mass storage buffer.
320-321	2	00 20	- -	ULIMIT	End of mass storage buffer.
322-323	2	00 00	- -	OFFSET	BLock offset to disk drives.
324-325	2	31 00	- -	WIDTH	Number of letters in name.
326-327	2	00 00	- -	WARNING	Error message action switch.
328-329	2	04 04	- -	FENCE	Forget protection point
32A-32B	2	- -	- -	DP	Dictionary pointer
32C-32D	2	00 00	- -	DP/	Dictionary pointer for heads when headerless
32E-32F	2	00 00	- -	HEADERLESS	Headerless code flag.
330-331	2	3C 03	- -	VOC-LINK	Last VOC field.
332-333	2	81 A0	- -		FORTH chain head.
334-335	2	04 04	- -		FORTH vocabulary pointer.
336-337	2	00 00	- -		FORTH vocabulary link.
338-339	2	81 A0	- -		ASSEMBLER chain head.
33A-33B	2	36 03	- -		ASSEMBLER vocabulary pointer.
33C-33D	2	00 00	- -		ASSEMBLER vocabulary link.
33E-33F	2	5C 3C	- -	UABORT	CFA of UABORT orphan word.
340-341	2	- -	- -	USE	Mass storage buffer to use
342-343	2	- -	- -	PREV	Mass storage buffer just used.
344-345	2	- -	- -	BLK	Number of current blk.
346-347	2	- -	- -	SCR	Most recently listed screen.
348-349	2	- -	- -	CONTEXT	CONTEXT vocabulary pointer.

*Last address referred to by kernel - following variables used in R65FR1 Development ROM.

Hex Address	No. Bytes	Cold Start Value	Warm Start Value	Parameter Name	Parameter Description
34A-34B	2	- -	- -	CURRENT	CURRENT vocabulary pointer.
34C-34D	2	- -	- -	STATE	Contains state of computation.
34E-34F	2	- -	- -	CSP	Check Stack Pointer.
350-351	2	- -	- -	MODE	Assembler addressing mode.
352-353	2	- -	- -	KHZ	Space for system clock frequency.
354-37E	43	- -	- -		User available (less room for PAD).
380-3FF	128	- -	- -		Terminal Input Buffer.

APPENDIX H

ASCII CHARACTER SET

HEX	DEC	ASCII	HEX	DEC	ASCII	HEX	DEC	ASCII	HEX	DEC	ASCII
00	0	NUL	20	32	SP	40	64	@	60	96	
01	1	SOH	21	33	!	41	65	A	61	97	a
02	2	STX	22	34	"	42	66	B	62	98	b
03	3	ETX	23	35	#	43	67	C	63	99	c
04	4	EOT	24	36	$	44	68	D	64	100	d
05	5	ENQ	25	37	%	45	69	E	65	101	e
06	6	ACK	26	38	&	46	70	F	66	102	f
07	7	BEL	27	39	'	47	71	G	67	103	g
08	8	BS	28	40	(	48	72	H	68	104	h
09	9	HT	29	41	)	49	73	I	69	105	i
0A	10	LF	2A	42	*	4A	74	J	6A	106	j
0B	11	VT	2B	43	+	4B	75	K	6B	107	k
0C	12	FF	2C	44	,	4C	76	L	6C	108	l
0D	13	CR	2D	45	-	4D	77	M	6D	109	m
0E	14	SO	2E	46	.	4E	78	N	6E	110	n
0F	15	SI	2F	47	/	4F	79	O	6F	111	o
10	16	DLE	30	48	0	50	80	P	70	112	p
11	17	DC1	31	49	1	51	81	Q	71	113	q
12	18	DC2	32	50	2	52	82	R	72	114	r
13	19	DC3	33	51	3	53	83	S	73	115	s
14	20	DC4	34	52	4	54	84	T	74	116	t
15	21	NAK	35	53	5	55	85	U	75	117	u
16	22	SYN	36	54	6	56	86	V	76	118	v
17	23	ETB	37	55	7	57	87	W	77	119	w
18	24	CAN	38	56	8	58	88	X	78	120	x
19	25	EM	39	57	9	59	89	Y	79	121	y
1A	26	SUB	3A	58	:	5A	90	Z	7A	122	z
1B	27	ESC	3B	59	;	5B	91	[	7B	123	{
1C	28	FS	3C	60	<	5C	92	\	7C	124	|
1D	29	GS	3D	61	=	5D	93	]	7D	125	}
1E	30	RS	3E	62	>	5E	94	↑	7E	126	~
1F	31	VS	3F	63	?	5F	95	←	7F	127	DEL

NUL - Null
SOH - Start of Heading
STX - Start of Text
ETX - End of Text
EOT - End of Transmission
ENQ - Enquiry
ACK - Acknowledge
BEL - Bell
BS - Backspace
HT - Horizontal Tabulation
LF - Line Feed
VT - Vertical Tabulation
FF - Form Feed
CR - Carriage Return
SO - Shift Out
SI - Shift In

DLE - Data Link Escape
DC - Device Control
NAK - Negative Acknowledge
SYN - Synchronous Idle
ETB - End of Transmission Block
CAN - Cancel
EM - End of Medium
SUB - Substitute
FSC - Escape
FS - File Separator
GS - Group Separator
RS - Record Separator
US - Unit Separator
SP - Space (Blank)
DEL - Delete

APPENDIX I

FORTH STRING WORDS

This appendix defines FORTH words that can be created to handle character string data. The defined words are based on, and extend, functions described by Ralph Deane in an article entitled "A Proposal On Strings for FORTH," published in Dr. Dobbs Journal of Computer Calisthenics & Orthodonia, November/December 1980 (See Appendix N).

1.1 WORD COLON DEFINITIONS

The following string handling words can be implemented using the colon-definitions listed in Table I-1:

FORTH Word	Function
STRING	Define a string
"	Enter text
S!	Store entire string
SUB	Substitute part of string
MID$	Get m characters of string
LEFT$	Get left-most n characters of string
RIGHT$	Get right-most n characters of string
VAL	Convert string to numeric value
STR$	Convert numeric to string
LEN	Get current length of string
MLEN	Get maximum length of string
S+	Add strings
S=	Compare strings

Table I-1. FORTH String Words

```
: SRCH
  DUP BEGIN DUP
  C@ SWAP 1+ SWAP
  0= END SWAP - 1- ;


: STRING
  <BUILDS ABS
  255 MIN 1 MAX DUP
  C,
  0 DO 32 C, LOOP 0 C,
  DOES> 1+ DUP SRCH ;


  0 VARIABLE IB
  254 ALLOT
```

Table I-1. FORTH String Words (Continued)

```
: (")
  R COUNT DUP 1+
  R> + >R ;


: "
  34 STATE @ IF
  COMPILE (") WORD
  HERE C@ 1+ ALLOT
  ELSE WORD HERE COUNT
  IB SWAP ROT OVER IB
  SWAP 1+ CMOVE 2DUP
  + 0 SWAP C! THEN ;
  IMMEDIATE


: VAL
  OVER + BL SWAP
  C! 1- NUMBER ;


: STR$
  SWAP OVER DABS
  <# #S SIGN #> ;


: MLEN
  DROP 1- C@ ;


: S!
  DROP DUP 1- C@
  ROT MIN 1 MAX 2DUP
  + 0 SWAP C! CMOVE ;


: LEN
  SWAP DROP ;


: MID$
  SWAP >R ROT
  MIN 1 MAX SWAP OVER
  MAX OVER - 1+ SWAP
  R> + 1- SWAP OVER
  SRCH MIN ;


: LEFT$
  >R >R 1 SWAP
  R> R> MID$ ;
```

Table I-1. FORTH String Words (Continued)

```
: RIGHT$
  >R >R 256
  R> R> MID$ ;


: S+
  ROT >R ROT R>
  SWAP OVER IB SWAP
  CMOVE SWAP OVER +
  255 MIN DUP >R OVER
  - SWAP IB + SWAP
  CMOVE R> 0 OVER IB
  + C! IB SWAP ;


: SUB
  ROT MIN 1 MAX
  CMOVE ;


: S=
  ROT OVER
  = IF 1 SWAP 0 DO
  DROP OVER
  C@ OVER C@ = IF 1+
  SWAP 1+ SWAP 1 ELSE
  0 LEAVE THEN LOOP
  ELSE DROP 0 THEN
  SWAP
  DROP SWAP DROP ;
```

I.2 WORD DESCRIPTIONS

Each of the string words are described below. Note that there are two words, SRCH and (") , and a variable area, IB , that are used internally by the string functions and are not described.

STRING

STRING creates a word in the dictionary up to 255 characters. The string is initialized to all spaces with a zero at the end and the maximum length at the beginning. For example,

```
30 STRING A$
```

Creates a string named A$ which has room for 30 characters. When the name A$ is executed, the current length and the address of the text is put on the stack in the order required for the word TYPE .

" enters text into an intermediate buffer called IB , if used in the immediate mode. In the compile mode, the text is put into the dictionary. In either case the length and text address is left on the stack. Text is terminated by another " .

S!

S! moves the entire string text from one string to another, for example,

```
" COWS EAT CORN" A$ S!
```

puts the text "COWS EAT CORN" into the string A$.

Also as an example, define another string BEST and move A$ into it

```
40  STRING BEST
A$  BEST  S!
```

MID$

MID$ gets the m characters of a string starting at the nth character position, for example,

```
6  3  A$  MID$  TYPE
```

will print the word EAT .

LEFT$

LEFT$ gets the left-most n characters of a string, for example,

```
3  BEST  LEFT$  TYPE
```

will print the word COW .

RIGHT$

In like manner RIGHT$ gets the right-most n characters of a string. The sequence

```
10  A$  RIGHT$  BEST  S!
```

makes the string BEST now contain the word CORN verified by

```
BEST  TYPE
```

VAL

VAL converts a string to a double-precision number, for example,

```
" 128"  VAL  D.
```

gives

```
128
```

STR$

Conversely, STR$ converts a double-precision number into text. The sequence

```
567.  STR$  A$  S!
```

makes the string A$ equal to "567.".

LEN

LEN returns the current length of a string, such as

```
A$  LEN  .  <return> 3
```

MLEN

MLEN returns the maximum length of a string, such as

```
A$  MLEN  . <RETURN>  30
```

SUB

SUB allows substitution of characters in a string, for example,

```
" COWS EAT CORN" A$ S!
" ATE" 6 3 A$ MID$ SUB
```

replaces EAT with ATE in string A$.

S+

S+ adds strings together and puts the result in IB , for example,

```
" AND HAY"  BEST  S!
A$  BEST  S+  BEST  S!
```

adds BEST to A$. Verify by

```
BEST  TYPE
```

and get

```
COWS EAT CORN AND HAY
```

S=

S= compares strings to see if they are equal in length and text. If so, a 1 is returned on the stack, else a 0.

APPENDIX J

USER 24-HOUR CLOCK PROGRAM IN FORTH

This appendix describes a 24-hour clock program written in FORTH using either machine level (see Figure J-1) or interpretive interrupt (see Figure J-2) handling. The 24-hour clock is maintained under interrupt control, using Timer 3 of the R65F11 or R65F12. The program allows you to initialize the clock, enter a message that will be displayed with the time, and display the time just once or continuously.

J.1 HOW TO OPERATE THE PROGRAM

The 24-hour clock program is compiled into FORTH words as described in the next section. Once compiled you must be in FORTH to command the 24-hour clock functions. Once initiated, however, the clock will continue to run as long as it is not reset, Timer 3 operating mode is not altered, or the processor interrupt enable bit and the Interrupt Enable Register (IER) are not altered to inhibit the $\overline{IRQ}$ interrupt.

The 24-hour clock functions are entered from FORTH using any of four keys. These four keys are defined as FORTH words and are entered into the FORTH vocabulary. The keys, their functions and the associated operating procedure is:

M Key — Allows a message of up to 32 characters to be displayed preceding the time value. Enter the message as follows

(1) Type M.
(2) Press <RETURN>.
(3) Type a message up to 30 characters long.
(4) Press <RETURN> (do not press <RETURN> if exactly 30 characters are entered)). An example is:

```
M <RETURN> RSC-FORTH TIME
<RETURN> OK
```

T Key — Allows the initial time value to be entered. Enter it as follows:

(1) Type in the time in the format HH.MM.SS (not HH:MM:SS).
(2) Press <SPACE>.
(3) Type T.
(4) Press <RETURN>.

For example:

```
16.05.00 <SPACE> T <RETURN> OK
```

D Key

Causes the message and time to be displayed once each time D is typed. The display format is:

```
<MESSAGE>HH:MM:SS
```

The time is displayed immediately after the message, for example,

```
D<RETURN>
RSC-FORTH TIME 16:05:10
```

The system remains in the FORTH command mode.

C Key

Causes the message and time to be continuously displayed. For example,

```
C<RETURN>
RSC-FORTH TIME 16:05:30
```

Press a key to terminate the display (although the clock will continue to run). The key will also be interpreted as a FORTH command or data character.

```
( 24-HOUR CLOCK USING IRQ INTERRUPTS )
HEX
1C CONSTANT TBL
1E CONSTANT TBH
4F CONSTANT PERIODL
C3 CONSTANT PERIODH

0 VARIABLE DAY# ( 2 BYTES)
0 VARIABLE TICKS ( 4 BYTES) 0 ,

CODE DISABLE ( DISABLE USER VIA INT)
00 # LDA,
IER STA,
NEXT JMP,
END-CODE
DISABLE

ASSEMBLER HERE ( SAVE IRQ VECTOR)
PHA,
CLC,
5 # LDA, ( 50 MS)
TICKS 3 + ADC,
TICKS 3 + STA,
64 # CMP, ( AT 100?)
 CS IF, ( >= 100)
 0 # LDA,
 TICKS 3+ STA,
 TICKS 2+ INC,
 TICKS 2+ LDA,
 3C # CMP,
  CS IF, ( >= 60)
  0 # LDA,
  TICKS 2+ STA,
  TICKS 1+ INC,
  TICKS 1+ LDA,
   3C # CMP,
   CS IF, ( >= 60)
   0 # LDA,
   TICKS 1+ STA,
   TICKS INC,
   TICKS LDA,
   18 # CMP,
    CS IF, ( >= 24)
    0 # LDA,
    TICKS STA,
    DAY# INC,
     0= IF,
     DAY# 1+ INC,
     THEN,
    THEN,
   THEN,
  THEN,
THEN,

TBL LDA, ( CLEAR TIMER IRQ)
  PLA,
  RTI, ( RETURN)
```

Figure J-1. 24-Hour Clock Program
Using a Machine Level Interrupt Handler

```
0040 ! ( SET IRQ VECTOR)

FORTH
: INIT ( INITIALIZE THE TIMER)
 E0 MCR C! ( SET TB FREE-RUN MODE)
 PERIODL TBL C! , ( LOAD TB VALUE = 1/100 SEC)
 PERIODH TBH C! , ( ENABLE TIMER B INT)
 20 IER C!

DECIMAL
: :DD ( TYPE M OR S)
 S->D <# # # 58 ( :) HOLD #> TYPE ;

: .T ( PRINT TIME)
 TICKS C@ ( HRS) 2 .R TICKS 1+ C@ ( M)
 :DD (SAVE & PRINT SEC )
 TICKS 2+ C@ DUP :DD
 BEGIN ( WAITING)
 TICKS 2+ C@
 OVER = NOT UNTIL DROP ;

: M ( ENTER 30 CHAR MESSAGE)
 601 DUP 30 EXPECT 600
 BEGIN
   1+ DUP C@ 0=
 UNTIL ( NULL FOUND)
 601 - ( # OF CHARACTERS)
 600 C! ( FOR TYPE) ;

: .M (PRINT MESSAGE)
 600 COUNT 30 MIN TYPE ;

: D
 DECIMAL .M .T ;

: T! ( SET TIME)
 100 U/ ( GET SEC)
 100 /MOD ( MIN HRS)
 TICKS C! ( LOAD HRS)
 TICKS 1+ C! ( MIN)
 TICKS 2+ C! ( & SEC)
 0 TICKS 3 + C! ( ZERO 100THS) ;

: T ( SET TIME & GO)
 T! INIT ;

: C ( CONTINUOUSLY DISPLAY MST & TIME)
 BEGIN 24 EMIT ( BLANK CURSOR )
   13 EMIT ( STAY ON LINE) D ?TERMINAL
 UNTIL 23 EMIT ( RESTORE CURSOR ) QUIT ;

: D ( DISPLAY MSG & TIME ONCE)
 CR D QUIT ;
```

Figure J-1. 24-Hour Clock Program
Using a Machine Interrupt Handler (Cont'd)

```
( 24-HOUR CLOCK USING FORTH INTERRUPTS )
HEX
1C CONSTANT TBL
1E CONSTANT TBH
4F CONSTANT PERIODL
C3 CONSTANT PERIODH

0 VARIABLE DAY# ( 2 BYTES)
0 VARIABLE TICKS ( 4 BYTES) 0 ,

CODE DISABLE ( DISABLE INT)
00 # LDA,
IER STA,
NEXT JMP,
END-CODE
DISABLE

( MACHINE CODE INTERRUPT SERVICE )
ASSEMBLER HERE ( SAVE IRQ VECTOR)
PHA,
80 # LDA, ( SET INT REQUEST)
INTFLG ORA,
INTFLG STA,
TBL LDA, ( CLEAR USER VIA IRQ)
PLA,
IRQRTN JMP, ( RETURN TO I/O ROM)

CODE ARM ( RETURN FROM FORTH INTERRUPTS)
BF # LDA, ( RESET INT REQUEST BIT )
INTFLG AND,
INTFLG STA,
~~! ;S JMP,~~ ( RESTORE INTERRUPTED IP )   PLA, IP STA, PLA, IP 1+ STA,
END-CODE                                                    NEXT JMP,

IRQVEC ! ( SET IRQ VECTOR)

FORTH
: INIT ( INITIALIZE THE USER VIA)
 E0 UACR C! ( SET TB FREE-RUN MODE)
 PERIODL TBL C! ( LOAD TB VALUE = 1/100 SEC)
 PERIODH TBH C!
 20 IER C! ; ( ENABLE TIMER B INT)

DECIMAL
: +!L ( INCREMENT / STORE / LIMIT CHECK)
 OVER +! ( ADD INC.)
 SWAP OVER C@ < DUP
IF 0 ROT C!
  ELSE SWAP DROP
THEN ;

: T+ ( FORTH LEVEL INTERRUPT SERVICE )
 99 TICKS 3 + 5 +!L ( 1/100 SEC COUNT)
 IF 59 TICKS 2+ 1 +!L ( SECONDS )
   IF 59 TICKS 1+ 1 +!L ( MINUTES)
     IF 23 TICKS 1 +!L ( HOURS)
     THEN
```

Figure J-2. 24-Hour Clock Program
Using an Interpretive Interrupt Handler

```
   THEN
 THEN
 ARM [ SMUDGE ( SIMILAR TO ; )

' T+ CFA ( PUT ADDRESS ON STACK )
ASSEMBLER INTVEC ! ( SAVE INT VECTOR)

FORTH
: :DD ( TYPE M OR S)
 S->D <# # # 58 ( :) HOLD #> TYPE ;

: .T ( PRINT TIME)
 TICKS C@ ( HRS) 2 .R
 TICKS 1+ C@ :DD ( MIN)
 TICKS 2+ C@ DUP :DD ( SAVE & DISP SEC)
 BEGIN ( WAITING FOR A SECOND CHANGE)
   TICKS 2+ C@
   OVER = NOT
 UNTIL DROP ;

: M ( ENTER 30 CHAR MESSAGE)
 601 DUP 30 EXPECT 600
 BEGIN
   1+ DUP C@ 0 =
 UNTIL ( NULL FOUND)
 601 - ( # OF CHARACTERS)
 600 C! ( FOR TYPE) ;

: .M ( PRINT MESSAGE)
 600 COUNT 30 MIN TYPE ;

: D
 DECIMAL .M .T ;

: T! ( SET TIME)
 100 U/ ( GET SEC)
 100 /MOD ( MIN HRS)
 TICKS C! ( LOAD HRS)
 TICKS 1+ C! ( LOAD MIN)
 TICKS 2+ C! ( LOAD SEC)
 0 TICKS 3 + C! ; ( ZERO 100TH SEC)

: C ( CONTINUOUSLY DISPLAY MSG & TIME)
 BEGIN 24 EMIT ( BLANK CURSOR )
   13 EMIT ( STAY ON SAME LINE) D ?TERMINAL
 UNTIL 23 EMIT ( RESTORE CURSOR ) QUIT ;

: D ( DISPLAY MSG & TIME ONCE)
 CR D QUIT ;
```

Figure J-2. 24-Hour Clock Program
Using an Interpretive Interrupt Handler (Cont'd)

APPENDIX K

UTILITY EXAMPLES

K.1 MEASURING FORTH WORD EXECUTION TIME

It is often desired to know how long it takes for a FORTH word to execute, especially in time critical applications. The following words measure such execution time in R65F11 or R65F12 clock cycles, i.e., microseconds.

```
HEX
: ON FF FF 1C C! 1E C! ;
: OFF 001C @ 12B + CR
     FFFF SWAP - 0 D.;
```

The word ON initializes and starts Timer B. The word OFF displays the number of cycles elapsed from the start of the timer minus ON and OFF word overhead. Use these words as shown in the following colon-definition example to measure the execution time of a FORTH word, in this case DUP .

```
DECIMAL OK
: TDUP ON DUP OFF ;
OK
TDUP
68 OK
```

Using this technique, the execution time of most FORTH words defined using colon- or CODE-definitions can be measured. Set up and run similar colon-definition words as needed for your application.

Many problems can be programmed in FORTH using different combinations of FORTH words with differing resultant execution speed. If speed is important, measure the execution time of each approach to decide which solution to use.

If the execution time of a FORTH word defined in high level, i.e., colon-definitions, is too long, redefine portions, or all, of the word in assembly code, i.e., colon-definitions, then remeasure. Comparing the execution time of the word defined in assembly code versus FORTH will show the performance improvement. For cases where the execution time exceeds the 16-bit counter capacity, other timing words can easily be defined to accumulate the time.

APPENDIX L

RSC-FORTH VERSUS FIG-FORTH

This table is a comparison of RSC-FORTH V1.5 and the FIG-FORTH model from which it is derived.

a. Words in RSC-FORTH V1.5 that are not in FIG-FORTH 1.0:

Word Name	
,/	HEADERLESS
.S	HERE/
;DUMP	HWORD
>LINE	IER
1-	IFR
2-	INIT
2DROP	INTFLG
2DUP	INTVEC
4	IRQVEC
?KERNEL	KHZ
ADMP	MCR
ALLOT/	MEMTOP
ASSEMBLER	NEGATE
AUTOSTART	NMIVEC
B/SIDE	NOT
BANKEEC!	PA
BANKC!	PB
BANKC@	PC
BANKEXECUTE	PD
BOUNDS	PE
C,CON	PF
C/L	PFAPTR
CASE:	PG
CLD/WRM	PICK
CLIT	PR@
CODE	SCCR
CURRENT	SCDR
CYLINDER	SCSR
DISK	SEEK
DISKNO	SELECT
DNEGATE	SOURCE
DP/	U<
DREAD	UABORT
DWRITE	UC/L
EEC!	UFIRST
FINIS	ULIMIT
FLUSH	UPAD
FORMAT	UR/W
FMTRK	XOFF
H/C	XON

b. The following words are in FIG-FORTH 1.0 but are not in RSC-FORTH V1.5 (however, some of the words are in the RSC-FORTH Assembler vocabulary):

Word Name	Where Used	Comment
+ORIGIN	system	
?LOADING	system	
BACK	system	
BLOCK-READ	user disk word	(DREAD)
BLOCK-WRITE	user disk word	(DWRITE)
DLIST	duplicate name	(VLIST)
DMINUS	new name	(DNEGATE)
DR0	disk	
DR1	disk	
FLD	not used	
MINUS	new name	(NEGATE)
MOVE	N/A	(word addressing computers)
NEXT	RSC-FORTH Assembler	
OUT	not used	
POP	RSC-FORTH Assembler	
PUSH	RSC-FORTH Assembler	
PUT	RSC-FORTH Assembler	
R#	system	
TRAVERSE	system	
TRIAD	disk	
X	system	(null)

APPENDIX M

FLOPPY DISK INTERFACE

The R65F11/R65F12 hardware interface is configured to directly interface with a 1793 type Floppy Disk Controller (FDC) device with minimal support circuitry required. Figure M-1 shows the minimum external circuitry (excluding chip decode) required to connect the R65F11/R65F12 to the 1793 and support circuits.

In addition, the RSC-FORTH operating system provides the complementary software interface. Figure M-2 shows the memory map of words (bytes) assigned to transfer data and command/status between the R65F11/R65F12 and the 1793 FDC device. The 1793 Data, 1793 Sector, 1793 Track and 1793 Status/Command bytes all conform to the standard 1793 interface definitions. The bit definitions for the DRIVE STAT (read, R/$\overline{W}$=1) and DRIVE CTL (write, R/$\overline{W}$=0) are shown in Figure M-3.

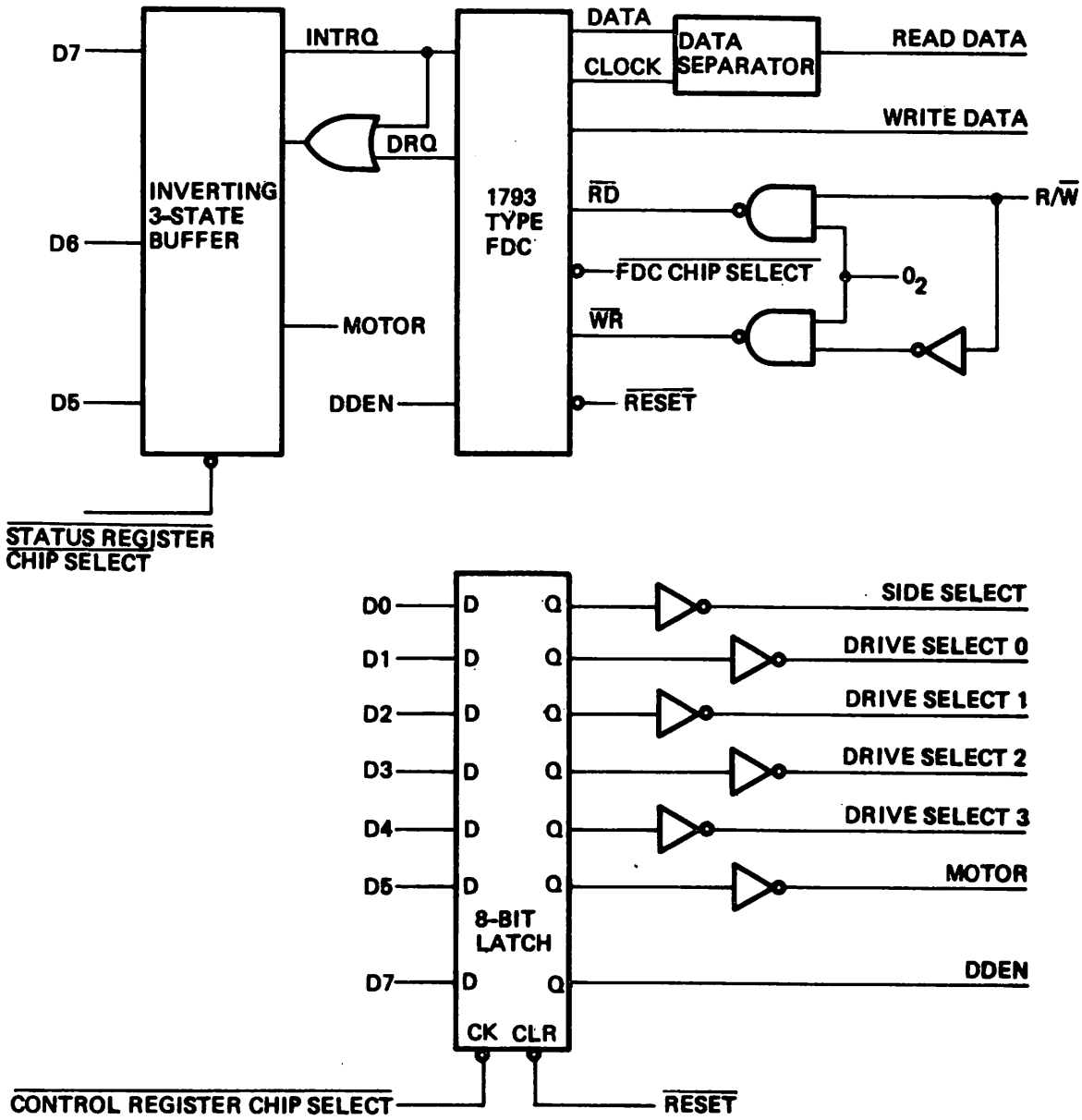


Figure M-1. R65F11/R65F12 Floppy Disk Controller Interface

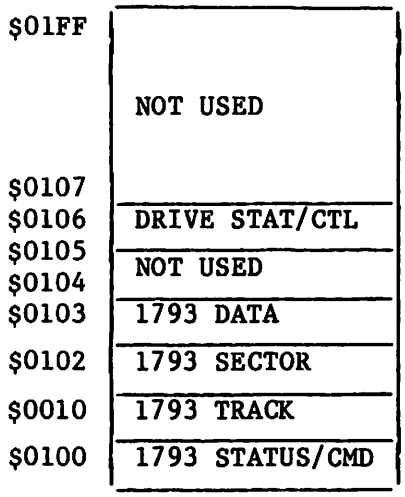


Figure M-2. Floppy Disk Controller Memory Map

BIT	DRIVE STAT (R/$\overline{W}$=1)	DRIVE CTL (R/$\overline{W}$=0)
7	$\overline{INTRQ}$ FROM 1793	DENSITY 0 = Double 1 = Single
6	$\overline{INTRQ+DRQ}$ FROM 1793	NOT USED
5	MOTOR ON STATUS 0 = ON 1 = OFF	MOTOR ON CONTROL 0 = OFF 1 = ON
4	NOT USED	DRIVE SELECT 3
3	NOT USED	DRIVE SELECT 2
2	NOT USED	DRIVE SELECT 1
1	NOT USED	DRIVE SELECT 0
0	NOT USED	SIDE SELECT 0 = Side 0 1 = Side 1

Figure M-3. DRIVE STAT/DRIVE CTL Bit Definitions

APPENDIX N

RSC-FORTH SCREEN NUMBERS VERSUS TRACK NUMBERS

The RSC-FORTH disk operating system is designed to operate with up to four double-sided, quad-density 5 1/2-inch disk drives (80-track). This provides the capability for over 2.5 MB of on-line storage. Smaller disk drives may still be used, however. The FORTH "SCREEN" numbering scheme must be considered for different size drives. When using smaller drives, there will appear to be "holes" in the "screen" numbers. For example, drive 1 normally contains "screens" 640 through 1279. If a 40-track double-sided drive is substituted, the "screens" will now range from 640 to 799 on side 0 and from 960 to 1119 on side 1. Figure N-1 shows the boundary starting screen numbers for 40- and 80-track disk drives.

Track No.	First Screen No.			
	Disk 0		Disk 1	
	Side 0	Side 1	Side 0	Side 1
1	0	320	640	960
2	4	324	644	964
↓	↓	↓	↓	↓
40	156	476	796	1116
41	160	480	800	1120
42	164	484	804	1124
↓	↓	↓	↓	↓
80	316	636	956	1276

Track No.	First Screen No.			
	Disk 2		Disk 3	
	Side 0	Side 1	Side 0	Side 1
1	1280	1600	1920	2240
2	1284	1604	1924	2244
↓	↓	↓	↓	↓
40	1436	1756	2076	2396
41	1440	1760	2080	2400
42	1444	1764	2084	2404
↓	↓	↓	↓	↓
80	1596	1916	2236	2556

Figure N-1. First Screen No. Versus Track No.

APPENDIX O

RSC-FORTH EDITOR

This appendix lists a FORTH Editor that will operate with RSC-FORTH.

```
                                SCR #  60
 0 ( leoFORTH Editor: Load Block              24 FEB 83 MWR )          *
 1 ( public domain editor compatible with 'Starting Forth' )           *
 2 ( written by Sam Daniels. )                                         *
 3 ( modified & extraneous garbage removed by Dave Boulton )           *
 4 ( modified to RSC Forth compatibility by MWR )                      *
 5 VOCABULARY EDITOR  IMMEDIATE                                        *
 6  77 LOAD   74  75 THRU     ( compatibility )                        *
 7 EDITOR DEFINITIONS                                                  *
 8       71 LOAD     ( Match )                                         *
 9  61   68 THRU     ( Editor words )                                  *
10  70      LOAD     ( New )                                           *
11  72      LOAD     ( Bulkclear, wipe )                               *
12  73 LOAD                                                           *
13  76 LOAD           ( Copying stuff )                               *
14 FORTH DEFINITIONS                                                  *
15                                                                    *


                                SCR #  61
 0 ( leoFORTH Editor: Line, Text, .Cursor, Use  24 FEB 83 MWR )        *
 1 : LINE     ( line# -- addr )                                        *
 2       SCR @ (LINE) DROP    ;                                       *
 3                                                                     *
 4 : TEXT     ( c --- )  ( put text till 'c' to PAD )                  *
 5       HERE 65 BLANKS    WORD    HERE PAD 65 CMOVE    ;             *
 6                                                                     *
 7        0 VARIABLE R#        ( cursor position )                     *
 8 94 CONSTANT DELIM    ( for text delimiter )                         *
 9                                                                     *
10 : .CURSOR    DELIM EMIT     ;                                      *
11                                                                     *
12                                                                     *
13                                                                     *
14                                                                     *
15                                                                     *


                                SCR #  62
 0 ( leoFORTH Editor: #Lead, #Lag, -Move          24 FEB 83 MWR )      *
 1 : #LOCATE         ( -- # line#  |  give cursor position )           *
 2       R#  @     C/L /MOD    ;                                       *
 3 : #LEAD           ( -- addr #  |  string before cursor posn )       *
 4       #LOCATE  LINE SWAP ;                                          *
 5 : #LAG            ( -- addr #  | string after cursor posn )         *
 6       #LEAD  DUP >R +  C/L R> -   ;                                 *
 7 : -MOVE           ( addr line# --   | fill line from addr )         *
 8       LINE C/L  CMOVE UPDATE    ;                                   *
 9 : BUF-MOVE        ( addr --   | move PAD to addr, if non-null )     *
10       PAD 1+ C@  IF    PAD SWAP C/L 1+ CMOVE    ELSE DROP  THEN   ; *
11 : >LINE#         ( -- line#  | give line # of cursor posn )         *
12       #LOCATE SWAP DROP    ;                                       *
13 : FIND-BUF PAD 80 + ;                                              *
14 : INSERT-BUF PAD 160 + ;                                           *
15 ;S                                                                 *
```

Figure 0-1. RSC-FORTH Editor

```
                                SCR #  63
 0 ( leoFORTH Editor: (Hold), (Kill), etc.        24 FEB 83 MWR )    *
 1 : (HOLD)          ( line# --  | move line to insert buffer)       *
 2       LINE  INSERT-BUF  1+ C/L DUP  INSERT-BUF C!  CMOVE  ;       *
 3 : (KILL)          ( line# --  | erase line to blanks )            *
 4       LINE C/L BLANKS  UPDATE   ;                                 *
 5 : (SPREAD)        ( --  | spread block at cursor line )           *
 6       >LINE#  DUP 1-  14                                          *
 7       DO  I LINE   I 1+ -MOVE  -1 +LOOP     (KILL)  ;            *
 8 : ?               ( --  | print cursor line )                     *
 9       CR SPACE  #LEAD TYPE  .CURSOR   #LAG TYPE  >LINE# 3 .R  ;   *
10 : (DELETE)        ( # --  | zap '#' chars before cursor )         *
11       >R  #LAG  +   R -     #LAG R NEGATE R# +!                   *
12       #LEAD + SWAP CMOVE   R> BLANKS  UPDATE   ;                  *
13 : >>              ( # --  | move cursor '#' characters )          *
14       R# +!  ?   ;                                                *
15 ;S                                                                *


                                SCR #  64
 0 ( leoForth editor: X, T, L, N, B, TOP, R, P   24 FEB 83 MWR )    *
 1 : X               ( --  | delete cursor line, save in i-buf )     *
 2       >LINE# DUP (HOLD)   15 DUP ROT                              *
 3       DO  I 1+ 15 MIN LINE  I -MOVE  LOOP  (KILL)   ;             *
 4 : T               ( line# --  | type a line, move cursor)         *
 5       C/L * R# !   ?  ;                                           *
 6 : L               ( --  |  list current screen )                  *
 7       SCR @ LIST   ;                                              *
 8 : TOP     0 R# !         ;       ( --  | reset cursor to home )   *
 9 : N       1 SCR +! TOP   ;       ( --  |  move to next block )    *
10 : B      -1 SCR +! TOP   ;       ( --  |  move to prev block )    *
11 : (PUT)        ( --  |  replace cursor line w/ i-buf )           *
12       >LINE#  INSERT-BUF  1+ SWAP  -MOVE   ;                     *
13 : P              ( -- <text>  |  put text to cur-line, i-buf)     *
14       DELIM   TEXT  INSERT-BUF BUF-MOVE  (PUT)   ;               *
15                                                                   *


                                SCR #  65
 0 ( leoForth editor: searching                   24 FEB 83 MWR )    *
 1 : SEEK-ERROR     ( --  | error handler for failed search )       *
 2       TOP   FIND-BUF  COUNT TYPE  ." ?"  QUIT  ;                  *
 3 : 1LINE           ( -- f  |  scan for find buf, give success, )   *
 4       #LAG OVER >R  FIND-BUF COUNT  MATCH  R> - R# +!  0=   ;     *
 5 : (SEEK)          ( --  |  find buf over whole block, or err )    *
 6       BEGIN   1023 R# @ <   IF  SEEK-ERROR  THEN                  *
 7          1LINE  UNTIL  ;                                          *
 8 : (F)             ( -- <text>  | find 'text' )                    *
 9     DELIM TEXT   FIND-BUF  BUF-MOVE (SEEK)    ;                  *
10 : F              ( -- <text>  | find & display )                 *
11       (F)  ?  ;                                                   *
12 ;S                                                                *
13                                                                   *
14                                                                   *
15                                                                   *
```

Figure O-1. RSC-FORTH Editor (Continued)

```
                                SCR #  66
 0 ( leoForth editor: D, Till, U                    24 FEB 83 MWR )   *
 1 : TILL            ( -- <text> | delete from cursor, to match )   *
 2       #LEAD +   DELIM   TEXT   FIND-BUF BUF-MOVE                 *
 3       1LINE   0= IF  SEEK-ERROR  THEN   #LEAD + SWAP - (DELETE)  *
 4       ?  ;                                                       *
 5 : U               ( -- <text>  | put text under cursor line )    *
 6       C/L R# +!  (SPREAD)  P  ;                                  *
 7                                                                  *
 8 : E               ( --  | erase backwards from cursor )          *
 9       FIND-BUF  C@ (DELETE)  ?  ;                                *
10 : D               ( -- <text> |  find it, kill it, show result ) *
11       (F)  E  ;                                                  *
12                                                                  *
13 : K               ( --  | swap find/insert buffers )             *
14       FIND-BUF PAD 65 CMOVE   INSERT-BUF FIND-BUF 65 CMOVE       *
15       INSERT-BUF  BUF-MOVE   ;                          ;S       *


                                SCR #  67
 0 ( leoFORTH Editor: Bump, S                       24 FEB 83 MWR )   *
 1 0 VARIABLE COUNTER                                               *
 2 : BUMP            ( --  |  bump line#, handle paging )           *
 3       1 COUNTER +!   COUNTER @                                   *
 4       56 > IF   0 COUNTER !   CR CR  15 MESSAGE  12 EMIT  THEN ; *
 5                                                                  *
 6 : S               ( end --  |  global search, print hits )       *
 7       12 EMIT   DELIM   TEXT    0 COUNTER !   FIND-BUF BUF-MOVE  *
 8       SCR @  DUP >R  DO   I SCR !   TOP                          *
 9       BEGIN   1LINE                                              *
10          IF  ?  SCR @ 4 .R  BUMP  THEN                          *
11          1023 R# @ <                                            *
12       UNTIL   ?TERMINAL IF LEAVE THEN LOOP   R>  SCR !   ;       *
13 ;S                                                               *
14                                                                  *
15                                                                  *


                                SCR #  68
 0 ( leoFORTH Editor: I, R, M                       24 FEB 83 MWR )   *
 1 : I               ( -- <text>  | insert within line )            *
 2        DELIM  TEXT   INSERT-BUF  BUF-MOVE                        *
 3       INSERT-BUF COUNT  #LAG ROT  OVER  MIN >R                   *
 4       R  R# +!   R - >R                                          *
 5       DUP HERE  R CMOVE    HERE #LEAD +  R> CMOVE                *
 6       R> CMOVE  UPDATE    ?   ;                                  *
 7                                                                  *
 8 : R               ( -- <text>  | replace matched w/ insert )     *
 9       E  I   ;                                                   *
10 ;S                                                               *
11                                                                  *
12                                                                  *
13                                                                  *
14                                                                  *
15                                                                  *
```

Figure O-1. RSC-FORTH Editor (Continued)

SCR # 69

SCR # 70

```
 0 ( leoeditor -- NEW: WFR's hyperhack version   24 FEB 83 MWR )    *
 1 : NEW       ( line# -- )                                         *
 2 FORTH    16 0  DO                                                *
 3          CR I 3 .R SPACE                                         *
 4          I OVER = IF  [ DROP ]                                   *
 5          TIB @ C/L EXPECT   0 IN !                               *
 6          1 WORD   HERE 1+ C@                                     *
 7             IF  I                                                *
 8 [ CURRENT @ CONTEXT ! ]    C/L *  R# !   #LAG BLANKS             *
 9                HERE COUNT  #LAG DROP SWAP  CMOVE                 *
10 FORTH          UPDATE   1+                                       *
11             ELSE  8 EMIT  [ ROT 2 ]                              *
12             THEN   I SCR @                                       *
13 [ CURRENT @ CONTEXT ! ]        .LINE                             *
14       THEN  LOOP    DROP    ;                                    *
15 ;S                                                               *
```

SCR # 71

```
 0 ( high level pseudo -TEXT and MATCH          24 FEB 83 MWR )    *
 1 : -TEXT          ( a1 # a2  -- f  ! f's SIGN INCORRECT )         *
 2       SWAP -DUP IF   >R  0 ROT ROT R>                            *
 3       BOUNDS DO  DUP C@  I C@ -                                  *
 4          DUP IF  ROT DROP SWAP  LEAVE                            *
 5               ELSE DROP 1+ THEN    LOOP  DROP                    *
 6       ELSE  DROP  0= THEN   ;                                    *
 7                                                                  *
 8 : MATCH          ( a1 #1 a2 #2 -- f a3 ! scan for a string )     *
 9       >R >R  2DUP  R> R>  2SWAP   BOUNDS                         *
10       DO  2DUP FORTH I  -TEXT 0=                                 *
11          IF  I + >R  2DROP DROP   0 R> 0 0 LEAVE  THEN  LOOP     *
12       2DROP  OVER +  ;                                           *
13 ;S                                                               *
14                                                                  *
15                                                                  *
```

Figure 0-1. RSC-FORTH Editor (Continued)

```
                                SCR #  72
 0 ( EDITOR  12  bulkclear wipe                    24 FEB 83 MWR )   *
 1  BASE @ HEX                                                      *
 2 : WIPE      ( screen# ---  | wipe screen  )                      *
 3         OFFSET @ + FLUSH PAD 1024 BLANKS 0 PAD ! PAD SWAP 0 R/W ;*
 4                                                                 *
 5 : BULKCLEAR                          ( from scr-2 to scr-1  --- )   *
 6       CR 1+ SWAP DO                                             *
 7       FORTH I EDITOR WIPE LOOP ;                                *
 8      BASE !         ;S                                         *
 9                                                                 *
10                                                                 *
11                                                                 *
12                                                                 *
13                                                                 *
14                                                                 *
15                                                                 *


                                SCR #  73
 0 ( EDITOR  13         day year month             24 FEB 83 MWR )   *
 1  BASE  @ HEX                                                     *
 2 : DAY    R# @    2E R# ! 2 (DELETE) I R# ! ? ;                  *
 3                                                                 *
 4 : YEAR   R# @    35 R# ! 2 (DELETE) I R# ! ? ;                  *
 5                                                                 *
 6 : MONTH  R# @    32 R# ! 3 (DELETE) I R# ! ? ;                  *
 7                                                                 *
 8 : D  SCR @ SWAP SCR ! L ;                                       *
 9     BASE !         ;S                                          *
10                                                                 *
11                                                                 *
12                                                                 *
13                                                                 *
14                                                                 *
15                                                                 *


                                SCR #  74
 0 ( LeoFORTH editor compatibility to rdcFORTH   24 FEB 83 MWR )   *
 1 BASE @ HEX                                                      *
 2 : ASCII    BL WORD  HERE 1+ C@  [COMPILE] LITERAL  ;  IMMEDIATE  *
 3                                                                 *
 4 CODE 1=    TYA, TOP 1+ CMP, 0= IF, INY, TYA, TOP CMP, 0= NOT IF, *
 5       DEY, THEN, THEN, TYA, PUT0A JMP, END-CODE                 *
 6                                                                 *
 7 : BEEP 7 EMIT ;                                                 *
 8                                                                 *
 9 : TRIAD 3 / 3 * 3 OVER + SWAP DO CR I LIST LOOP CR 0F MESSAGE   *
10 CR 00C EMIT ;                                                   *
11                                                                 *
12                                                                 *
13                                                                 *
14                                                                 *
15 BASE ! ;S                                                       *
```

Figure O-1. RSC-FORTH Editor (Continued)

```
                                SCR #  75
 0 ( DOCUMENTATION SCREEN                          24 FEB 83 MWR )      *
 1    BASE @ HEX                                                       *
 2 : SHOW  3 / 1+ 3 * SWAP  DO I TRIAD ?TERMINAL IF LEAVE              *
 3      THEN   3 +LOOP ;                                               *
 4    BASE !        ;S                                                *
 5                                                                     *
 6                                                                     *
 7                                                                     *
 8                                                                     *
 9                                                                     *
10                                                                     *
11                                                                     *
12                                                                     *
13                                                                     *
14                                                                     *
15                                                                     *


                                SCR #  76
 0 ( EDITOR  08  -- rep backup                     24 FEB 83 MWR )      *
 1  BASE @ DECIMAL                                                     *
 2 : COPY   ( DUPLICATE SCREEN-2 ONTO SCREEN-1 1024 byte buffers )    *
 3      SWAP BLOCK 2 - !    UPDATE   ;                                 *
 4                                                                     *
 5 : REP  ( Replicate screen-1 to blck# on 2 drive )                   *
 6    DUP 640  + COPY  ;                                               *
 7                                                                     *
 8 : BACKING   ( part of a disk )  0 FLUSH  CR DO  FORTH I DUP REP     *
 9    [ LIMIT FIRST - B/BUF 4 + / ]   ( number of buffers )            *
10    LITERAL  MOD 0= IF FLUSH ." ." THEN LOOP FLUSH BEEP ;            *
11                                                                     *
12 : BACKUP    ( all of a disk ) 640  BACKING ;                       *
13                                                                     *
14 : SYSTEM.BACKUP    ( the system code only) 378  BACKING ;           *
15     BASE !        ;S                                                *


                                SCR #  77
 0 ( COMPATIBILITY WORDS FOR RSC-FORTH )                               *
 1 : 2SWAP ROT >R ROT R> ;                                             *
 2 : LOAD DUP BASE @ SWAP DECIMAL 5 .R BASE ! LOAD ." ." ;             *
 3 : THRU 1+ SWAP DO I  LOAD LOOP ;                                    *
 4 : B/BUF 1024 ; 64 UC/L ! : PAD HERE 68 + ;                          *
 5                                                                     *
 6                                                                     *
 7                                                                     *
 8                                                                     *
 9                                                                     *
10                                                                     *
11                                                                     *
12                                                                     *
13                                                                     *
14                                                                     *
15                                                                     *
```

Figure O-1. RSC-FORTH Editor (Continued)

APPENDIX P

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