

CROSS ASSEMBLER
FOR THE MCS-48 FAMILY

Produced by

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*      8048 CROSS ASSEMBLER      *
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Introduction

This 8048 Cross Assembler supports the the Intel MCS-48 family of single chip microcontrollers, which includes a large number of individual components. The MCS-48 family contains five basic groups, each characterized by slightly different instructions sets. This assembler will support all groups and their respective instructions with a pseudo-op to declare which set is desired. In addition, the assembler includes a large number of other pseudo-ops for symbol definition, value storage, conditional assembly, and listing control. It supports standard Intel mnemonics, and includes a full set of arithmetic, logical, and relational operators. Other features include complete expression evaluation, ten significant characters for symbols, and informative error messages.

Source for the assembler may be generated by just about any text editor which will create an ASCII file. Each line must end with a carriage return, except that a line feed may follow. The source file should not contain line numbers or any control characters other than carriage return, line feed, and tab. Source files are assembled directly from disk to an object file on disk. Several switches may be specified when invoking the assembler which affect listing, symbol table generation, and error display.

It is beyond the scope of these instructions to serve as a programming manual for MCS-48 family, but more information on these chips may be obtained in the Intel Component Data Catalog, the Intel Microcontroller User's Manual, and the Intel Microcontroller Applications Handbook, as well as data sheets on the individual components. Literature may be ordered from Intel at the following address:

Intel Corporation
Literature Department SV#-3
3065 Bowers Avenue
Santa Clara, CA 95051

The one component in the MCS-48 family that will be of most interest to the hobbyist or experimenter is probably the 8748. This is a single chip microcomputer with 1024 words of EPROM memory, 64 bytes of RAM memory, 27 I/O lines, an 8 bit timer/counter, and an internal clock oscillator in a single package. It is ideally suited to many control applications that previously would have required many separate components for the processor, program memory, RAM, I/O ports, clock, and address decode logic.

Microcontrollers in this family have found wide useage in many "smart" computer peripherals such as printers, modems, and keyboards, as well as in more mundane consumer appliances like microwave ovens and washing machines. With the availability of a disk-based cross assembler for the 8048 family that will run on the popular TRS-80 Models 1, 3, and 4, it becomes possible for the hobbyist and experimenter to use these readily available and inexpensive components in their own individual dedicated controller applications from phone dialers and print spoolers to solar energy controllers and burglar alarms. Many such projects will require little more than a five volt power supply, an 8748, and a few switches and passive components.

Section 1 - Source Format

1.1 Creation of a source file

The assembler is designed to assemble from a text file which has been previously written with a text editor. There are many word processors available for the TRS-80, and probably any of them will generate an acceptable source file. The source file should contain only ASCII characters, and program lines should not be numbered. Each source line will have four basic fields, though all fields may not be needed on each line. Fields may be separated with a single space, multiple spaces, or tabs.

1.2 The label field

The left-most field is the label field. If a label is used on a line, it must begin with the first character on that line. Labels may contain upper-case letters, lower-case letters, numbers, the underline character, a question mark, or the "at" sign (@). Lower-case letters are considered distinct and different from upper-case letters. The first character of a label may not, however, be a number. Labels may be up to ten characters in length and all characters are significant. If desired, labels may end with a colon which can also serve as a field delimiter for the label field.

1.3 The opcode field

The second field in a source line is the opcode field. A summary of legal opcodes for the various groups in the MCS-48 family is given in Appendix A. Opcodes must be entered in upper-case characters to be recognized by the assembler. Some opcodes will require an operand in the next field, and some opcodes stand alone.

1.4 The operand field

The third field in a source line is the operand field. This field includes any registers referenced by the instruction in the opcode field and any symbols, constants, or expressions required by the opcode. A complete listing of the operands required for each instruction is given in Appendix A. When the operand is an immediate numeric value, arithmetic expressions may be used. Symbols which reference labels or symbols which are equated elsewhere may also be used.

1.5 The comment field

The right-most field in the source line is the comment field. Actually, the comment field may begin anywhere in the source line, but it must always begin with a semicolon, and everything which follows the semicolon will be considered a comment and will be ignored by the assembler.

1.6 Examples

The following lines are typical source lines for the assembler:

<u>SYMBOL</u>	<u>OPCODE</u>	<u>OPERAND</u>	<u>COMMENT</u>
START	MOV	A,10	;comment
START:	DB	'This is a test'	
ABCDEF:	EQU	START+22	
	JMP	EXIT	;comment field can be anywhere to right of operand
PRTDRV:			;label with no opcode
	CALL	PRINT	
;STORAGE AREA			
	MOV	A,(VALUE1+VALUE2) AND MASK	

In general, the source file will begin with an ORG pseudo-op (see Section 4.12) followed by the body of the program, and terminate with the END statement (see Section 4.4). Once the source file has been written and saved on disk, it is called into the assembler on the "command line" when the assembler is run.

Section 2 - Running The Assembler

The name of the assembler is CASM/CMD. The command line used to run the assembler has the general form:

CASM INPUT [OUTPUT] [-LSTPE] <ENTER>

The first word, CASM, is required. It is the name of the assembler, and when the computer encounters it in the command line the assembler is loaded into memory and begins to run.

2.1 Input file specification

The second word, INPUT, represents the name of your source file. It might really be INPUT, or it might be CONTROL, or TEST/SRC:1, or any other valid filespec you have used for your source file. This is the file which CASM will read and try to assemble into an "object file". You must specify an input file so the assembler will know what to assemble. If no input file name is given, an error message will be generated.

2.2 Output file specification

The third word, OUTPUT, is in brackets because it is optional. It represents the filename you want to give the object file generated by the assembler. The object file is the assembled program created by the assembler which will be programmed into the 8748 (or any other microcontroller you are writing for). You do not have to create an object file every time you run the assembler, however. If you just want to assemble your source to check for errors, or to generate a listing, don't specify an output file name. If no output filename is given in the command line, no output file will be generated. The output filename may be any valid filespec. It might really be OUTPUT, or it might be CONTROL/OBJ, or TEST/ROM:2.

2.3 Switches

The forth expression on the command line is also in brackets because it too is optional. This expression contains the "switches" you might use to give further instructions to the assembler. Switches tell the assembler how you want it to display the assembly. There are four legal switches, and if any one of them is used it must be preceeded by a hyphen (-). If more than one switch is specified, it may be separated from the preceeding one by a space, a comma, a tab, or nothing at all. The legal switches are:

- L - Display a listing of the assembly.
- S - Display the symbol table.
- T - Truncate the object listing to one line per instruction.
- P - Route the listing, error messages, or symbol table to the line printer.
- E - Halt the listing after each error is displayed.
(Hit <ENTER> to resume)

The default values are no listing, no symbol table, don't truncate object listing, output to the video screen, and don't halt after errors. Illegal switches will generate an error message and assembly will be aborted.

2.4 Object file format

When an output file has been specified on the command line the assembler will generate a object file on disk. This object file will be a series of bytes which represent the actual object code for the microcontroller. This file is not an Intel hex file or a Radio Shack command file. It is just the bytes needed by the microcontroller to execute as a program. Once this file has been created, it is up to the user to program them into the particular chip they will be run in. Different programmers have different requirements. If your programmer needs a hex file, you will need to generate one from the binary data file created by this assembler. If you built the programmer described in the plans which are available from Mumford Micro Systems, it came with software which is ready to run on the binary file created by this assembler.

2.5 Examples

The last word in the sample command line, <ENTER>, means that you have to hit the ENTER key after typing the previous characters. The following examples will help clarify the various ways of calling up the assembler:

CASM FILE1

This command will get the input file FILE1, assemble it, and list any errors on the video screen. No source listing will be displayed and no output file will be generated.

CASM FILE1 -L

This command will get the input file FILE1, assemble it, and list it and any errors on the video screen.

CASM FILE1:1 FILE2 -P

This command will get the input file FILE1 from drive 1, assemble it, write the assembled code to the output file FILE2, and list any errors on the printer.

CASM FILE1 FILE2 -LSTPE

This command will get the input file FILE1, assemble it, list it on the printer, print the symbol table on the printer, truncate any multiple byte instructions in the source to a single line in the listing, halt the display after each error message is printed, and write the assembled object code to the output file FILE2.

Section 3 - Assembler Functions

3.1 Symbols

Symbols (or labels) in the assembler can be up to 10 characters in length and may include any upper-case letter, any lower-case letter, any number, an underline character, a question mark, or an "at" sign (@). The first character, however, must not be a number. If your computer can generate lower-case characters, they are considered as different characters than upper-case ones. The label "LOOP", therefore, is distinct and different from "Loop" and "loop", and all three are legal symbols. The following words are all legal symbols and labels:

LOOP testpoint Loop99 @HERE UH_WHAT? A8?@_Z THIS_TOO??

3.2 Numeric constants

The assembler will accept numeric constants in decimal (base 10), hexadecimal (base 16), binary (base 2), or octal (base 8). The default base, or RADIX, is decimal. All other numbers will require a "radix specifier". These specifiers are single letters which must follow any number which is not in the default base (decimal). They are "D" for decimal (yes, it is redundant and unnecessary, but it is allowed), "H" for hexadecimal, "Q" for octal, and "B" for binary. Hexadecimal numbers that begin with a letter must be preceded with a zero to tell the assembler that they are not symbols. The following numbers are examples of the possible formats:

212H	hexadecimal
234Q	octal
11110000B	binary
0FEFEH	hexadecimal
10D	decimal
1234	decimal

3.3 Character constants

Character constants are used like numeric constants except that they are specified as an ASCII character in single quotes instead of as a specific number. The assembler will take the ASCII value of the characters in quotes to use in its operations. Double characters may be used to represent 16 bit values. Since the single quote character is used as a delimiter it becomes a little awkward to use the single quote as a character itself. To get around this difficulty, the assembler will interpret two single quotes together as the single ASCII character "single quote" instead of as two delimiters. The following are examples of legal character constants:

'A'	=	41H
'AB'	=	4142H
''''	=	27H

3.4 Location counter reference

The dollar sign may be used to represent "the current location in memory" for numeric expressions. This is perhaps best explained by example. In the sample source below, the assembler has assembled object code through address 0077H when it encounters an instruction with a dollar sign in the operand field. The next available (or current) address is 0078. The dollar sign will be taken to mean the number 0078 when the expression "\$-9" is evaluated, resulting in the value 6DH.

ADDRESS	OBJECT CODE	OPCODE	OPERAND
0075	0A	IN	A,P2
0076	77	RR	A
0077	77	RR	A
0078	EF6D	DJNZ	\$-9

3.5 Arithmetic, Boolean, and logical operators

CASM has many arithmetic, logical, and relational operators which can be used in numeric expressions. The characters used to represent these operators are defined below:

Arithmetic Operators

- + --> Addition
- --> Subtraction
- * --> Multiplication
- / --> Division
- % or MOD --> Modulus (remainder of division)
- + --> Unary plus (indicates a number is positive)
- --> Unary minus (indicates a number is negative)

Boolean Operators

- | or OR --> Logical OR
- ^ or XOR --> Logical XOR
- & or AND --> Logical AND
- ~ or NOT --> Unary logical negation

Relational Operators

- > --> Greater than
- < --> Less than
- = --> Equal to
- >= --> Greater than or equal to
- <= --> Less than or equal to
- != --> Not equal to

Order of evaluations precedence

- | | | | |
|---------|---------|------|----------------------|
| Unary + | Unary - | NOT | (Highest precedence) |
| * / | MOD | | |
| + - | | | |
| < <= | > >= | = != | |
| AND | | | |
| OR XOR | | | (Lowest precedence) |

Up to 4 levels of parentheses can be used to change precedence.

Section 4 - Pseudo-Ops

Instructions which are accepted by the assembler but are not part of the instruction set of the microprocessor are called "pseudo-ops". They are instructions for the assembler as opposed to instructions for the microprocessor. Some pseudo-ops require an argument, and some stand alone. The pseudo-ops accepted by this assembler are shown below. In the examples following each pseudo-op, the left-most column represents the actual code generated by the instruction (in hexadecimal), the next column is the pseudo-op, the third column is the argument (if any), and the last column is a comment describing the meaning of each line.

4.1 DB

Define Byte. This instruction places specific numeric values in the object file. It requires an argument which can be a specific number, a string delimited by single quotes, or an arithmetic expression. Commas can be used to define several bytes on one line.

1A	DB	1AH	;SINGLE DEFINITION
41 41 41 41	DB	'AAAA'	;MULTIPLE CHARACTERS WITHIN STRING
0C 01	DB	12,5-4	;MULTIPLE ARGUMENTS WITH COMMAS
8D	DB	HIGHBIT+CR	;ARITHMETIC EXPRESSION

4.2 DS

Define Storage. This instruction reserves a number of memory locations for storage. Admittedly, in a ROM-based application like the 8048 family, a define storage pseudo-op is of questionable value. The memory locations which are reserved with this instruction are not left unaltered, however. They are filled with the current value of the "fill character", which is defined under the pseudo-op FILL (see below). This feature allows the programmer to set all unneeded bytes in the object file to the unprogrammed state for the microprocessor. This feature allows a HEX file (required by some EPROM programmers) to be generated from the object file that will define every memory location, yet not program locations that are unneeded.

The argument of the DS pseudo-op is a 16 bit expression, so it may be any number or expression that evaluates to a number in the range 0 to 65535.

00 00	DS	5	;RESERVES 5 BYTES
00 00			;CURRENT FILL CHARACTER IS 00
00			

4.3 DW

Define Word. This instruction defines two bytes to be placed in the object file. The argument of this operator can be a specific number, an arithmetic expression, or a two character string delimited with single quotes. Commas may be used to define several words on the same line. Note that bytes are not placed in reverse order in the object file, as is the case with assemblers for some microprocessors (like the 280).

```
01 02      DW      0102H      ;SPECIFIC VALUE
02 04 41 42  DW      0204H,'AB' ;NOTE THE DOUBLE CHARACTER STRING
02 33      DW      START-END   ;16 BIT ARITHMETIC EXPRESSION
```

4.4 END

The END statement tells the assembler that the end of the source file has been reached. Source files must end with this statement or a NO END FOUND error will be generated. Also, there should be no text following the END statement or the error message DATA FOUND AFTER END will be displayed. The END statement does not require an argument.

```
END      ;END OF PROGRAM
```

4.5 ENDIF

The ENDIF pseudo-op is used to terminate a conditional assembly segment. The segment is initiated with the pseudo-op IF, which is described below. All conditional assembly segments which have been initiated with the IF statement must be terminated with the ENDIF statement or the error message IF WITHOUT MATCHING ENDIF STATEMENT will be displayed. When there are multiple nested IF statements, ENDIF will terminate the last IF statement which was encountered. The ENDIF pseudo-op does not require an argument.

```
      FLAG1 EQU      1      ;DEFINE FLAG1 AS TRUE
      IF      FLAG1 = 1     ;INITIATE CONDITIONAL
96 29      JNZ      EXIT    ;CODE GENERATED IF FLAG1 IS TRUE
      ENDIF      ;END OF CONDITIONAL
```

4.6 ELSE

The ELSE pseudo-op is used to toggle conditional assembly following a IF statement (see IF pseudo-op below). IF statements do not require an ELSE, but one is allowed where it is convenient. The effect of the ELSE statement is to allow the assembler to generate code for the instructions which fall between the ELSE statement and the ENDIF statement when the argument of the original IF condition is false (equal to zero). The ELSE statement must be preceded by an IF statement or the error message ELSE WITHOUT MATCHING IF STATEMENT will be displayed. The ELSE pseudo-op does not require an argument.

```
      FLAG1 EQU      0      ;DEFINE FLAG1 AS FALSE
      IF      FLAG1
      JMP      EXIT1        ;CODE NOT GENERATED - FLAG1 IS FALSE
      ELSE
      JMP      LOOP         ;CODE IS NOW GENERATED
04 3F      ENDIF      ;TERMINATE CONDITIONAL SEGMENT
```

4.7 EQU

Equate symbol. The EQU pseudo-op creates a symbol with a defined value. The EQU statement is preceeded by the symbol you wish to create and followed by an argument which defines the value of the symbol. The value of the argument must be known on the first pass of the assembler or an error message will be displayed. The symbol may be followed by a colon, a space, or a tab.

```
CR:    EQU    13      ;DEFINE CR AS THE VALUE 13 DECIMAL
BIGNUM EQU    9080H   ;DEFINE BIGNUM AS THE VALUE 9080H
ABCDEF: EQU    13H    ;DEFINE ABCDEF AS THE VALUE 13 HEX
OD     DB     CR      ;NOW STORE THE VALUE OF CR
90 80  DW     BIGNUM  ;STORE THIS VALUE
00 13  DW     ABCDEF  ;STORE THIS VALUE
```

4.8 FILL

The FILL pseudo-op defines the character that is used as a filler for areas of memory that are not defined. FILL requires an argument which is the new value of the FILL character. The FILL character is used to pad memory between the last location used during assembly and a subsequent ORG statement, and the memory locations reserved by a DS (define storage) pseudo-op. In addition, when running the CP/M version of this assembler, any characters needed to fill out the last sector of the object file will be the current FILL character.

The default value of the FILL character is zero. The use of a fill character is convenient in that it allows you to choose a character that represents the unprogrammed condition of the ROM you are writing for. This allows you to write code that will skip over previously programmed areas, or leave areas unprogrammed which you may wish to use later. The 8048 family of microprocessors use zero as the unprogrammed condition for all ROM locations.

```
00 00    DS     4      ;DEFAULT FILL CHARACTER IS ZERO
00 00
FF FF FF FILL OFFH   ;DEFINE OFFH AS THE FILL CHARACTER
DS        3          ;DEFINE STORAGE FILLED WITH NEW VALUE
```

4.9 IF

The IF statement is used to initiate conditional assembly. It requires an argument which is evaluated as true or false. If the argument evaluates as a number which is not zero, it is considered true. If the argument evaluates to zero, it is considered false.

If the argument of an IF statement is true, the assembler will generate code for the instructions which follow, unless an ELSE statement is encountered. If an ELSE is encountered, the assembler will ignore the instructions which follow it and generate no code until an ENDIF statement is encountered.

If the argument of the initial IF statement evaluates as false, the instructions which follow it will be ignored and no code will be generated until an ELSE or ENDIF statement is encountered, at which time the assembler will once again begin to generate code.

IF statements may be nested up to 255 deep. If this limit is exceeded, the error message CAN'T NEST MORE THAN 255 IF STATEMENTS will be displayed. All IF statements must be terminated with an ENDIF statement or the error message IF WITHOUT MATCHING ENDIF will be displayed.

	FLAG	EQU	1	;DEFINE FLAG AS TRUE
		IF	FLAG=1	;BEGIN CONDITIONAL
14 69		CALL	RDRAM	;GENERATE CODE - CONDITION IS TRUE
04 0D		JMP	POLALL	;GENERATE CODE - CONDITION TRUE
		ELSE		;TOGGLE CONDITIONAL
		CALL	POLCOMP	;NO CODE GENERATED
		JMP	NOTFUL	;NO CODE GENERATED
		ENDIF		;TERMINATE CONDITIONAL

4.10 LIST

The LIST pseudo-op is used to control the assembly listing. LIST requires an argument, and if the argument evaluates as false (zero), the assembly listing will be suppressed. If another LIST statement is encountered with a true (non-zero) argument, the assembly listing will resume. The default condition for LIST is on, or true.

	ON	EQU	1	;DEFINE ON AS TRUE
	OFF	EQU	0	;DEFINE OFF AS FALSE
		LIST	ON	;LISTING IS TURNED ON (TRUE ARGUMENT)
14 69		CALL	RDRAM	;
04 0D		JMP	POLALL	;
		LIST	OFF	;LISTING IS TURNED OFF (FALSE ARGUMENT)

4.11 MICRO

This statement allows you to define which microprocessor in the MCS-48 family you are writing for. MICRO is followed by an argument which determines the instruction set that will be used by the assembler. The legal arguments, with the microprocessors they support, are shown below:

8048 - 8048, 8748, 8748H, 8749, 8049, 87P50, 8050
8041A - 8041A, 8741A, 8042, 8742
8022 - 8022
8021 - 8021

The default mode for the assembler is 8048, which includes the 8748 and is the component most likely to be used by the hobbyist or experimenter.

MICRO 8048 ;GENERATE CODE FOR AN 8048 OR 8748
MICRO 8022 ;GENERATE CODE FOR AN 8022

4.12 ORG

This statement sets the program origin. It is followed by an argument which is the address at which you want to begin assembly of the instructions which follow. If there are multiple ORG statements, each one must have an argument that is greater than the location already reached by the assembler or the error message CAN'T ORG BACKWARDS, ORG IGNORED will be displayed and the ORG will be ignored. If there are undefined memory locations between an ORG statement and the memory location reached by previously assembled instructions, the assembler will generate FILL characters (see Section 4.8) for each undetermined memory location.

ORG 0 ;BEGIN ASSEMBLY AT ADDRESS 0
04 06 JMP ENTRY ;JUMP TO LOCATION 6
00 00 ;FILL CHARACTERS GENERATED BETWEEN ORGS
00 00 ;
ORG 6 ;BEGIN ASSEMBLY AT ADDRESS 6
23 0C MOV A,12 ;PROGRAM CONTINUES HERE
3A OUTL P2,A ;

4.13 PAGE

This statement sends a formfeed character to the printer if the listing has been directed to the printer. It requires no argument, it generates no object code, and it sends one formfeed character to the printer every time it is encountered.

46 4F NOTFULL JNT1 POLCOMP
14 69 CALL RDRAM
14 57 CALL WRTPRNT
04 0D JMP POLLALL
PAGE ;FORMFEED SENT TO LINE PRINTER HERE
26 0D POLCOMP JNTO POLLALL
08 INS A,BUS
A8 MOV RO,A
14 88 CALL WRTRAM
04 0D JMP POLLALL

Appendix A - Instruction Set Summary

The list which follows contains the instructions for all members of the MCS-48 family. The list includes the opcode, the operand, a brief description of the instruction, and an indicator as to which microcontrollers each instruction will work with. Each lettered column represents a group of chips, assigned as follows:

A=8048, 8748, 8049, 8749 - B=8041A - C=8041 - D=8022 - E=8021

Opcode	Operand	Description	A	B	C	D	E
ADD	A,#data	Add immediate to A	X	X	X	X	X
ADD	A,Rr	Add register to A (r=0-7)	X	X	X	X	X
ADD	A,@Rr	Add data memory to A (r=0-1)	X	X	X	X	X
ADDC	A,#data	Add immediate with carry	X	X	X	X	X
ADDC	A,Rr	Add register with carry (r=0-7)	X	X	X	X	X
ADDC	A,@Rr	Add data memory with carry (r=0-1)	X	X	X	X	X
ANL	A,#data	And immediate to A	X	X	X	X	X
ANL	A,Rr	And register to A (r=0-7)	X	X	X	X	X
ANL	A,@Rr	And data memory to A (r=0-1)	X	X	X	X	X
ANL	BUS,#data	And immediate to BUS	X				
ANL	Pp,#data	And immediate to port (p=1-2)	X	X	X		
ANLD	Pp,A	And A to expander port (p=4-7)	X	X	X	X	X
CALL	addr	Call subroutine	X	X	X	X	X
CLR	A	Clear A	X	X	X	X	X
CLR	C	Clear carry flag	X	X	X	X	X
CLR	FO	Clear flag 0	X	X	X		
CLR	F1	Clear flag 1	X	X	X		
CPL	A	Complement A	X	X	X	X	X
CPL	C	Complement carry flag	X	X	X	X	X
CPL	FO	Complement flag 0	X	X	X		
CPL	F1	Complement flag 1	X	X	X		
DA	A	Decimal adjust A	X	X	X	X	X
DEC	A	Decrement A	X	X	X	X	X
DEC	Rr	Decrement register (r=0-7)	X	X	X		
DIS	I	Disable external interrupt	X	X	X	X	
DIS	TCNTI	Disable timer/counter interrupt	X	X	X	X	
DJNZ	Rr,addr	Decrement register and jump (r=0-7)	X	X	X	X	X
EN	DMA	Enable DMA handshaking lines		X			
EN	FLAGS	Enable master interrupts		X			
EN	I	Enable external interrupt	X	X	X	X	
EN	TCNTI	Enable timer/counter interrupt	X	X	X	X	
ENTO	CLK	Enable clock output on line T0	X				
IN	A,DBB	Input DBB to A, clear IBF		X	X		
IN	A,P0	Input port 0 to A				X	X
IN	A,Pp	Input port to A (p=1-2)	X	X	X	X	X
INC	A	Increment A	X	X	X	X	X
INC	Rr	Increment register (r=0-7)	X	X	X	X	X
INC	@Rr	Increment data memory (r=0-1)	X	X	X	X	X
INS	A,BUS	Input BUS to A	X				

Opcode	Operand	Description	A	B	C	D	E
JBB	addr	Jump on accumulator bit (b=0-7)	X	X	X		
JC	addr	Jump on carry flag = 1	X	X	X	X	X
JFO	addr	Jump on F0 flag = 1	X	X	X		
JF1	addr	Jump on F1 flag = 1	X	X	X		
JMP	addr	Jump unconditional	X	X	X	X	X
JMPP	@A	Jump indirect	X	X	X	X	X
JNC	addr	Jump on carry flag = 0	X	X	X	X	X
JNI	addr	Jump on external interrupt = 0	X				
JNIBF	addr	Jump on IBF flag = 0		X	X		
JNTO	addr	Jump on T0 = 0	X	X	X	X	
JNT1	addr	Jump on T1 = 0	X	X	X	X	
JNZ	addr	Jump on A not Zero	X	X	X	X	X
JOBF	addr	Jump on OBF flag = 1		X	X		
JTF	addr	Jump on timer flag = 1	X	X	X	X	X
JTO	addr	Jump on T0 = 1	X	X	X	X	
JT1	addr	Jump on T1 = 1	X	X	X	X	
JZ	addr	Jump on A Zero	X	X	X	X	X
MOV	A,#data	Move immediate to A	X	X	X	X	X
MOV	A,PSW	Move PSW to A	X	X	X		
MOV	A,Rr	Move register to A (r=0-7)	X	X	X	X	X
MOV	A,@Rr	Move data memory to A (r=0-1)	X	X	X	X	X
MOV	A,T	Read timer/counter	X	X	X	X	X
MOV	PSW,A	Move A to PSW	X	X	X		
MOV	Rr,A	Move A to register (r=0-7)	X	X	X	X	X
MOV	Rr,#data	Move immediate to register (r=0-7)	X	X	X	X	X
MOV	@Rr,A	Move A to data memory (r=0-1)	X	X	X	X	X
MOV	@Rr,#data	Move immediate to data memory	X	X	X	X	X
MOV	STS,A	A4-A7 to bits 4-7 of status		X			
MOV	T,A	Load timer/counter	X	X	X	X	X
MOVD	A,Pp	Input expander port to A (p=4-7)	X	X	X	X	X
MOVD	Pp,A	Output A to expander port (p=4-7)	X	X	X	X	X
MOVP	A,@A	Move to A from current page	X	X	X	X	X
MOVP3	A,@A	Move to A from page 3	X	X	X		
MOVX	A,@Rr	Move external data memory to A (r=0-1)	X				
MOVX	Rr,A	Move A to external data memory (r=0-1)	X				
NOP		No operation	X	X	X	X	X
ORL	A,#data	Or immediate to A	X	X	X	X	X
ORL	A,Rr	Or register to A (r=0-7)	X	X	X	X	X
ORL	A,@Rr	Or data memory to A (r=0-1)	X	X	X	X	X
ORL	BUS,#data	Or immediate to BUS	X				
ORL	Pp,#data	Or immediate to port (p=1-2)	X	X	X		
ORLD	Pp,A	Or A to expander port (p=4-7)	X	X	X	X	X
OUT	DBB,A	Output A to DBB, set OBF		X	X		
OUTL	BUS,A	Output A to BUS	X				
OUTL	PO,A	Output A to port 0				X	X
OUTL	Pp,A	Output A to port (p=1-2)	X	X	X	X	X

Opcode	Operand	Description	A	B	C	D	E
RAD		Move conversion result to A				X	
RET		Return from CALL	X	X	X	X	X
RETI		Return from interrupt				X	
RETR		Return and restore status	X	X	X		
RL	A	Rotate A left	X	X	X	X	X
RLC	A	Rotate A left through carry flag	X	X	X	X	X
RR	A	Rotate A right	X	X	X	X	X
RRC	A	Rotate A right through carry flag	X	X	X	X	X
SEL	ANO	Select analog input 0				X	
SEL	AN1	Select analog input 1				X	
SEL	MBO	Select memory bank 0	X				
SEL	MB1	Select memory bank 1	X				
SEL	RBO	Select register bank 0	X	X	X		
SEL	RB1	Select register bank 1	X	X	X		
STOP	TCNT	Stop timer/counter	X	X	X	X	X
STRT	CNT	Start counter	X	X	X	X	X
STRT	T	Start timer	X	X	X	X	X
SWAP	A	Swap nibbles of A	X	X	X	X	X
XCH	A,Rr	Exchange A and register (r=0-7)	X	X	X	X	X
XCH	A,@Rr	Exchange A and data memory (r=0-1)	X	X	X	X	X
XCHD	A,@Rr	Exchange nibble of A and data memory	X	X	X	X	X
XRL	A,#data	Exclusive or immediate to A	X	X	X	X	X
XRL	A,Rr	Exclusive or register to A (r=0-7)	X	X	X	X	X
XRL	A,@Rr	Exclusive or data memory to A (r=0-1)	X	X	X	X	X

Appendix B - Instruction Mnemonics and Opcodes

The following listing is an assembly of a source file which was written to test the assembler by using every instruction and all addressing modes. This printout is also an example of the listing format of the assembler. The left hand column shows the address, followed by the opcode(s). The right hand two columns are the instruction mnemonics.

```

;instructions for the 8048
      MICRO  8048
;
0000 68      ADD    A,R0
0001 69      ADD    A,R1
0002 6A      ADD    A,R2
0003 6B      ADD    A,R3
0004 6C      ADD    A,R4
0005 6D      ADD    A,R5
0006 6E      ADD    A,R6
0007 6F      ADD    A,R7
0008 60      ADD    A,@R0
0009 61      ADD    A,@R1
000A 0355    ADD    A,#55H
000C 78      ADDC   A,R0
000D 79      ADDC   A,R1
000E 7A      ADDC   A,R2
000F 7B      ADDC   A,R3
0010 7C      ADDC   A,R4
0011 7D      ADDC   A,R5
0012 7E      ADDC   A,R6
0013 7F      ADDC   A,R7
0014 70      ADDC   A,@R0
0015 71      ADDC   A,@R1
0016 1355    ADDC   A,#55H
0018 58      ANL    A,R0
0019 59      ANL    A,R1
001A 5A      ANL    A,R2
001B 5B      ANL    A,R3
001C 5C      ANL    A,R4
001D 5D      ANL    A,R5
001E 5E      ANL    A,R6
001F 5F      ANL    A,R7
0020 50      ANL    A,@R0
0021 51      ANL    A,@R1
0022 5355    ANL    A,#55H
0024 9855    ANL    BUS,#55H
0026 9955    ANL    P1,#55H
0028 9A55    ANL    P2,#55H
002A 9C      ANLD   P4,A
002B 9D      ANLD   P5,A
002C 9E      ANLD   P6,A
002D 9F      ANLD   P7,A
002E 1455    CALL   55H
0030 B455    CALL   555H

```

0032	27	CLR	A
0033	97	CLR	C
0034	A5	CLR	F1
0035	85	CLR	F0
0036	37	CPL	A
0037	A7	CPL	C
0038	95	CPL	F0
0039	B5	CPL	F1
003A	57	DA	A
003B	07	DEC	A
003C	C8	DEC	R0
003D	C9	DEC	R1
003E	CA	DEC	R2
003F	CB	DEC	R3
0040	CC	DEC	R4
0041	CD	DEC	R5
0042	CE	DEC	R6
0043	CF	DEC	R7
0044	15	DIS	I
0045	35	DIS	TCNTI
0046	E855	DJNZ	R0,55H
0048	E955	DJNZ	R1,55H
004A	EA55	DJNZ	R2,55H
004C	EB55	DJNZ	R3,55H
004E	EC55	DJNZ	R4,55H
0050	ED55	DJNZ	R5,55H
0052	EE55	DJNZ	R6,55H
0054	EF55	DJNZ	R7,55H
0056	05	EN	I
0057	25	EN	TCNTI
0058	75	ENTO	CLK
0059	09	IN	A,P1
005A	0A	IN	A,P2
005B	17	INC	A
005C	18	INC	R0
005D	19	INC	R1
005E	1A	INC	R2
005F	1B	INC	R3
0060	1C	INC	R4
0061	1D	INC	R5
0062	1E	INC	R6
0063	1F	INC	R7
0064	10	INC	@R0
0065	11	INC	@R1
0066	08	INS	A,BUS
0067	1255	JB0	55H
0069	3255	JB1	55H
006B	5255	JB2	55H
006D	7255	JB3	55H
006F	9255	JB4	55H
0071	B255	JB5	55H
0073	D255	JB6	55H
0075	F255	JB7	55H
0077	F655	JC	55H

0079	B655	JFO	55H
007B	7655	JF1	55H
007D	0455	JMP	55H
007F	A455	JMP	555H
0081	B3	JMPP	@A
0082	E655	JNC	55H
0084	8655	JNI	55H
0086	2655	JNTO	55H
0088	4655	JNT1	55H
008A	9655	JNZ	55H
008C	1655	JTF	55H
008E	3655	JTO	55H
0090	5655	JT1	55H
0092	C655	JZ	55H
0094	2355	MOV	A, #55H
0096	C7	MOV	A, PSW
0097	F8	MOV	A, R0
0098	F9	MOV	A, R1
0099	FA	MOV	A, R2
009A	FB	MOV	A, R3
009B	FC	MOV	A, R4
009C	FD	MOV	A, R5
009D	FE	MOV	A, R6
009E	FF	MOV	A, R7
009F	F0	MOV	A, @R0
00A0	F1	MOV	A, @R1
00A1	42	MOV	A, T
00A2	D7	MOV	PSW, A
00A3	A8	MOV	R0, A
00A4	A9	MOV	R1, A
00A5	AA	MOV	R2, A
00A6	AB	MOV	R3, A
00A7	AC	MOV	R4, A
00A8	AD	MOV	R5, A
00A9	AE	MOV	R6, A
00AA	AF	MOV	R7, A
00AB	B855	MOV	R0, #55H
00AD	B955	MOV	R1, #55H
00AF	BA55	MOV	R2, #55H
00B1	BB55	MOV	R3, #55H
00B3	BC55	MOV	R4, #55H
00B5	BD55	MOV	R5, #55H
00B7	BE55	MOV	R6, #55H
00B9	BF55	MOV	R7, #55H
00BB	A0	MOV	@R0, A
00BC	A1	MOV	@R1, A
00BD	B055	MOV	@R0, #55H
00BF	B155	MOV	@R1, #55H
00C1	62	MOV	T, A
00C2	0C	MOVD	A, P4
00C3	0D	MOVD	A, P5
00C4	0E	MOVD	A, P6
00C5	0F	MOVD	A, P7
00C6	3C	MOVD	P4, A

00C7	3D	MOVD	P5,A
00C8	3E	MOVD	P6,A
00C9	3F	MOVD	P7,A
00CA	A3	MOVFP	A,@A
00CB	E3	MOVFP3	A,@A
00CC	80	MOVX	A,@R0
00CD	81	MOVX	A,@R1
00CE	90	MOVX	@R0,A
00CF	91	MOVX	@R1,A
00D0	00	NOP	
00D1	48	ORL	A,R0
00D2	49	ORL	A,R1
00D3	4A	ORL	A,R2
00D4	4B	ORL	A,R3
00D5	4C	ORL	A,R4
00D6	4D	ORL	A,R5
00D7	4E	ORL	A,R6
00D8	4F	ORL	A,R7
00D9	40	ORL	A,@R0
00DA	41	ORL	A,@R1
00DB	4355	ORL	A,#55H
00DD	8855	ORL	BUS,#55H
00DF	8955	ORL	P1,#55H
00E1	8A55	ORL	P2,#55H
00E3	8C	ORLD	P4,A
00E4	8D	ORLD	P5,A
00E5	8E	ORLD	P6,A
00E6	8F	ORLD	P7,A
00E7	02	OUTL	BUS,A
00E8	39	OUTL	P1,A
00E9	3A	OUTL	P2,A
00EA	83	RET	
00EB	93	RETR	
00EC	E7	RL	A
00ED	F7	RLC	A
00EE	77	RR	A
00EF	67	RRC	A
00F0	E5	SEL	MB0
00F1	F5	SEL	MB1
00F2	C5	SEL	RB0
00F3	D5	SEL	RB1
00F4	65	STOP	TCNT
00F5	45	STRT	CNT
00F6	55	STRT	T
00F7	47	SWAP	A
00F8	28	XCH	A,R0
00F9	29	XCH	A,R1
00FA	2A	XCH	A,R2
00FB	2B	XCH	A,R3
00FC	2C	XCH	A,R4
00FD	2D	XCH	A,R5
00FE	2E	XCH	A,R6
00FF	2F	XCH	A,R7
0100	20	XCH	A,@R0

0101	21	XCH	A,@R1
0102	30	XCHD	A,@R0
0103	31	XCHD	A,@R1
0104	D8	XRL	A,R0
0105	D9	XRL	A,R1
0106	DA	XRL	A,R2
0107	DB	XRL	A,R3
0108	DC	XRL	A,R4
0109	DD	XRL	A,R5
010A	DE	XRL	A,R6
010B	DF	XRL	A,R7
010C	D0	XRL	A,@R0
010D	D1	XRL	A,@R1
010E	D355	XRL	A,#55H

;
;instructions for the 8041A

		MICRO	8041A
0110	E5	EN	DMA
0111	F5	EN	FLAGS
0112	22	IN	A,DBB
0113	D655	JNIBF	155H
0115	8655	JOBF	155H
0117	90	MOV	STS,A
0118	02	OUT	DBB,A

;
;instructions for the 8022

		MICRO	8022
		RAD	
011A	93	RETI	
011B	85	SEL	AN0
011C	95	SEL	AN1

;
;instructions for the 8021

		MICRO	8021
011D	08	IN	A,PO
011E	90	OUTL	PO,A

;
;-----
; Expressions
;-----

C33C	STAN	EQU	0C33CH
6699	FRED	EQU	6699H
0001	L1	EQU	1
0001	L2	EQU	1B
0001	L3	EQU	1D
0001	L4	EQU	1Q
0001	L5	EQU	1H
007B	L6	EQU	123D
0096	L7	EQU	10010110B
0141	L8	EQU	321D
0305	L9	EQU	773
1234	L10	EQU	1234H
011F	L11	EQU	\$
0053	L12	EQU	'S'
5352	L13	EQU	'SR'

5327	L14	EQU	'S''
2753	L15	EQU	''S'
C33C	L16	EQU	STAN
FFFE	L17	EQU	-2
FFFE	L18	EQU	- 2
FEE1	L19	EQU	-\$
3CC4	L20	EQU	-STAN
FFAD	L21	EQU	-'S'
ACAE	L22	EQU	-'SR'
FF34	L23	EQU	-11001100B
FFFD	L24	EQU	NOT 2
0002	L25	EQU	+2
E7BD	L26	EQU	STAN OR FRED
E7BD	L27	EQU	STAN FRED
A5A5	L28	EQU	STAN XOR FRED
4218	L29	EQU	STAN AND FRED
29D5	L30	EQU	STAN + FRED
5CA3	L31	EQU	STAN - FRED
8678	L32	EQU	STAN * 2
619E	L33	EQU	STAN / 2
003C	L34	EQU	STAN MOD 100H
FFFF	L35	EQU	STAN = STAN
0000	L36	EQU	STAN = FRED
FFFF	L37	EQU	STAN > FRED
0000	L38	EQU	FRED > STAN
0000	L39	EQU	STAN > STAN
0000	L40	EQU	STAN < FRED
FFFF	L41	EQU	FRED < STAN
0000	L42	EQU	STAN < STAN
FFFF	L43	EQU	STAN >= FRED
0000	L44	EQU	FRED >= STAN
FFFF	L45	EQU	STAN >= STAN
0000	L46	EQU	STAN <= FRED
FFFF	L47	EQU	FRED <= STAN
FFFF	L48	EQU	STAN <= STAN
FFFF	L49	EQU	STAN != FRED
0000	L50	EQU	STAN != STAN
C33C	L51	EQU	(STAN)
C33C	L52	EQU	(STAN)
C33C	L53	EQU	((((STAN))))
0012	L54	EQU	3 * (4 + 2)
000E	L55	EQU	(3 * 4) + 2
000E	L56	EQU	3 * 4 + 2
0000	L58	EQU	0 / STAN
0001	L59	EQU	STAN / STAN
0000	L60	EQU	1 / STAN

Appendix C - Error Messages

- Branch out of page boundary - An attempt has been made to do a conditional jump into another page.
- Byte value truncated - An attempt has been made to use a 16 bit value where an 8 bit value is required.
- Can't ORG backwards, ORG ignored - An ORG statement has been used which specifies an address lower than that which has already been reached by the assembler (see Section 4.12).
- Can't nest more than 255 IF statements - An attempt has been made to use more than 255 unterminated IF statements simultaneously (see Section 4.9).
- Can't open INPUT file - The source file does not exist or a disk I/O error has occurred.
- Can't open OUTPUT file - The disk is write protected or a disk I/O error has occurred.
- Data found after END - The END pseudo-op is not the last statement in the source file (see Section 4.4).
- Disk CLOSE error - A disk I/O error has occurred while closing the output file.
- Disk WRITE error - A disk I/O error has occurred while writing the output file.
- Division by zero - An expression has been evaluated to a condition where a number is being divided by zero.
- Doubly defined label - An attempt has been made to define the same label more than once.
- ELSE without matching IF statement - An ELSE statement has been encountered without a previously defined IF statement (see Sections 4.9 and 4.6).
- ENDIF without matching IF statement - An ENENDIF statement has been encountered without a previously defined IF statement (see Sections 4.9 and 4.5).
- IF without matching ENENDIF statement - An IF statement has not been terminated by an ENENDIF before the end of the source file was encountered (see Sections 4.9 and 4.5).
- Illegal label - An attempt has been made to use a label which does not meet the conditions defined under Section 3.1.
- Illegal number - An attempt has been made to use a number which is either too large or contains illegal characters (see section 3.2).
- Input file not specified or illegal - The command line does not contain a properly specified source file name (see Section 2.1).

Invalid opcode - The instruction is not valid for the processor defined by the MICRO pseudo-op. See Appendix A for a list of valid opcodes.

Invalid operand - The operand is either missing, illegal, or specified incorrectly for the preceding instruction (see Section 1.4 and Appendix A).

Invalid short string - A syntax error has occurred during the specification of a single or double byte character constant (see Section 3.3).

Invalid string - An uneven number of delimiters has been used when defining a string (see Section 3.3).

Invalid switch - A syntax error has occurred in the switch portion of the command line (see Section 2.3).

No END found - No END pseudo-op was found at the end of the source file (see Section 4.4).

Out of symbol table memory - There is insufficient memory to perform the assembly.

Parentheses nested too deep - An attempt has been made to have more than four levels of parentheses open simultaneously.

Parentheses uneven - An expression has been used which contains an open parenthesis without a matching closed parenthesis.

Phase error, value changed on pass 2 - The value of a symbol determined on the first pass of the assembler is not the same as the value arrived at on the second pass.

Ran out of memory during symbol table sort - There is insufficient memory to perform the assembly.

Stack overflow - An expression has been used which cannot be evaluated.

Symbol not defined on pass 1 - A symbol has been used which references a label which was not defined on the first pass of the assembler.

Undefined symbol - An instruction references a label which has not been defined elsewhere in the source.

Appendix D - Sample I/O and Math Routines

```

;
; *****
;
; Serial I/O and Math routines
;
; *****
;
RS232 EQU 00001000B ;serial output bit on port 2
;
; The delay constant for serial data rate is computed with:
; t = (400,000 / BAUD - 24) / 6
;
Bd9600 EQU ((40000 / (9600 / 100) + 5) / 10 - 24) / 6
Bd1200 EQU ((40000 / (1200 / 100) + 5) / 10 - 24) / 6
Bd300 EQU ((40000 / (300 / 100) + 5) / 10 - 24) / 6
;
;
; call to read a byte from serial port, data input on T1
; Enter: R0' = delay constant
; Exit: A = byte
; R7, R7' = undefined
SerIn MOV R7, #8 ;read in 8 bits
SerIn1 JNT1 SerIn1 ;wait till line goes high
SerIn2 JT1 SerIn2 ;wait till line goes low
;
CALL H1fDly ;wait for half a bit
JT1 SerIn ;branch if start bit missing
;
+ SerIn3 CALL BitDly2 ;delay for one bit
;
JNT1 SerIn4 ;branch if data bit low
CLR C ;clear the carry
CPL C
RRC A ;rotate the data into A
DJNZ R7, SerIn3 ;decr bit count, test for done
RET
;
SerIn4 CLR C ;set the carry bit
NOP ;keep the timing right
RRC A ;rotate the data into A
DJNZ R7, SerIn3 ;decr bit count, test for done
RET

```

```

;call SerOut to set a byte out the serial port
;   Enter:  A = byte to be sent
;           R0' = delay constant
;   Exit:   A = byte sent out
;           R7,R7' = undefined
SerOut  MOV    R7,#8           ;transmit 8 bits
;
;   ANL      P2,#~RS232       ;send the start bit
;   CALL     BitDly1          ;delay for 1 bit time
;
SerOut1 RR     A               ;rotate to get next bit
;   JB       SerOut2          ;branch if bit is a one
;
;   ANL      P2,#~RS232       ;set the bit low
;   JMP      SerOut3
;
SerOut2 ORL     P2,#RS232      ;set the bit high
;   JMP      SerOut3          ;keep the timing straight
;
SerOut3 CALL    BitDly3        ;delay one bit time
;   DJNZ     R7,SerOut1       ;go do next bit if not done
;
;   ORL      P2,#RS232        ;send the stop bit
;   CALL     BitDly1          ;delay one bit time
;   RET
;
;
;call to delay one serial bit time
;   Enter:  R0' = delay constant
;   Exit:   R7' = undefined
BitDly1 NOP                     ;delay for 8 cycles first
;   NOP
;
BitDly2 NOP                     ;delay for 6 cycles first
;   NOP
;
BitDly3 NOP                     ;delay for 4 cycles first
;   NOP
;   NOP
;   NOP
;   SEL      RB1              ;select second register bank
;   MOV      R7,A             ;save A in R7'
;   MOV      A,R0             ;get the time delay constant
BitDly4 NOP                     ;delay loop time = 6 cycles
;   NOP                      ;nops delay for 3
;   DEC      A                ;dec the loop counter
;   JNZ      BitDly4          ;loop till done
;
;   MOV      A,R7             ;restore A
;   SEL      R0               ;select first register bank
;   RET

```

```

;call to delay a half serial bit time
;   Enter:  R0' = delay constant
;   Exit:   R7' = undefined
Hlfdly  SEL    RB1          ;select second register bank
        MOV    R7,A        ;save A in R7'
        MOV    A,R0        ;get the time delay constant
;
+ Hlfdly1 DEC    A          ;dec the loop counter
        JNZ    Hlfdly1     ;loop till done
;
        MOV    A,R7        ;restore A
        SEL    RBO         ;select first register bank
        RET

```

Math Utilities

```

;call to do a double subtraction
;   Enter:  R1,R2 = Minuend, R1 = MSB
;           R3,R4 = Subtrahend, R3 = MSB
;   Exit:   R3,R4 = difference, R3 = MSB
;           R1,R2 = Minuend, R1 = MSB
Subtrct MOV    A,R2        ;subtract R4 from R2
        CPL    A
        ADD    A,R4
        CPL    A
        MOV    R4,A        ;put difference in R4
        MOV    A,R1        ;subtract R3 from R1
        CPL    A
        ADDC   A,R3        ;include carry from above
        CPL    A
        MOV    R3,A        ;put difference in R3
        RET

```

```

;call to do a 8 x 16 multiply, product 24 bits
;   Enter:  R1 = multiplicand #1
;           R2,R3 = multiplicand #2, R2 = MSB
;   Exit:   R4,R5,R6 = product, R4 = MSB
;           R2,R3 = multiplicand #2, R2 = MSB
;           R1,R7 = undefined
Multiply MOV  R4,#0           ;start with a total of 0
          MOV  R5,#0
          MOV  R6,#0           ;LSB
;
          MOV  R7,#8           ;multiply all 8 bits
Mult1    MOV  A,R6             ;double the product
          CLR  C
          RLC  A               ;rotate the low byte
          MOV  R6,A
          MOV  A,R5             ;rotate the middle byte
          RLC  A
          MOV  R5,A
          MOV  A,R4             ;rotate the high byte
          RLC  A
          MOV  R4,A
;
          MOV  A,R1             ;shift multiplicand
          CLR  C
          RLC  A
          MOV  R1,A
          JNC  Mult2           ;if high bit 0 don't add on
;
          MOV  A,R6             ;add multiplicand to product
          ADD  A,R3             ;add low bytes
          MOV  R6,A
          MOV  A,R5             ;add middle bytes
          ADDC A,R2
          MOV  R5,A
          MOV  A,R4             ;add on carry to high byte
          ADDC A,#0
          MOV  R4,A
;
Mult2    DJNZ  R7,Mult1        ;go multiply next bit
          RET                  ;all done

```

```

;call to divide a 24 bit number by a 8 bit one
;   Enter:  R4, R5, R6 = dividend, R4 = MSB
;           R3 = divisor
;   Exit:   R0, R1, R2 = quotient, R0 = MSB
;           R4, R5, R6 = remainder * 2, R4 = MSB
;           R3, R7 = undefined
Divide  MOV    R0, #0           ;start with quotient = 0
        MOV    R1, #0
        MOV    R2, #0
;
        MOV    A, R3           ;negate divisor
        CPL    A
        INC    A
        MOV    R3, A           ;R3 = -divisor
;
        MOV    R7, #16+1       ;divide 24 bit number
Div1    MOV    A, R2           ;shift quotient left once
        CLR    C               ;quotient = quotient * 2
        RLC    A               ;shift the low byte
        MOV    R2, A
        MOV    A, R1           ;shift the middle byte
        RLC    A
        MOV    R1, A
        MOV    A, R0           ;shift the high byte
        RLC    A
        MOV    R0, A
;
        MOV    A, R3           ;subtract divisor from dividend
        ADD    A, R4           ;dividend bits 23 - 16
        JNC    Div2           ;jmp dividend[23-16] < divisor
;
        MOV    R4, A           ;Div[23-16]=Div[23-16]-divisor
        INC    R2              ;set bit in quotient →
;
Div2    MOV    A, R6           ;shift dividend left once
        CLR    C               ;dividend = dividend * 2
        RLC    A               ;shift the low byte
        MOV    R6, A
        MOV    A, R5           ;shift the middle byte
        RLC    A
        MOV    R5, A
        MOV    A, R4           ;shift the high byte
        RLC    A
        MOV    R4, A
;
        DJNZ   R7, Div1       ;go divide next bit
        RET

```

```

;call to negate a 16 bit number
;   Enter:  R2,R3 = binary # to negate, R2 = MSB
;   Exit:   R2,R3 = negated number
Negate MOV    A,R3           ;get the low byte
      CPL     A             ;invert it
      ADD     A,#1          ;increment it
      MOV     R3,A          ;R3 = low byte
      MOV     A,R2          ;get high byte
      CPL     A             ;invert it
      ADDC    A,#0          ;add carry from before
      MOV     R2,A          ;R2 = high byte
      RET

;
;
;call to convert a 16 bit number to a 4 digit BCD number
;   Enter:  R3,R4 = binary # to be changed to BCD, R3 = MSB
;   Exit:   R3,R4 = number in BCD, R3 = MSB
;   R5,R6,R7 = undefined
CnvBcd MOV     R5,#0         ;zero the 4 digit BCD array
      MOV     R6,#0

;
      MOV     R7,#16        ;convert a 16 bit number
CnvBcd1 MOV     A,R4         ;shift the binary number left
      CLR     C             ;first the low byte
      RLC     A
      MOV     R4,A
      MOV     A,R3          ;then the high byte
      RLC     A
      MOV     R3,A

;
      MOV     A,R6          ;double low BCD # + carry
      ADDC    A,R6
      DA      A             ;decimal fix it
      MOV     R6,A         ;save the new BCD value
      MOV     A,R5          ;double high BCD # + carry
      ADDC    A,R5
      DA      A             ;decimal fix it
      MOV     R5,A         ;save the new BCD value
      DJNZ    R7,CnvBcd1    ;go stick on next bit of #

;
      MOV     A,R5          ;put result in R3 & R4
      MOV     R3,A
      MOV     A,R6
      MOV     R4,A
      RET

```