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P A S C A L / 4 8

R E F E R E N C E M A N U A L

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# PASCAL/48 Reference Manual

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1 INTRODUCTION AND OVERVIEW

Pascal/48 is a programming language for the Intel MCS-48 series of microcomputers. In particular, it can be used with the Intel 8748. It is designed to allow the programmer to control most of the instructions being generated and the allocation of storage. The language has sufficient expressive power that it can be used instead of assembly language in most applications while allowing the user to exercise the necessary degree of control over hardware resources.

A thorough knowledge of the MCS-48 hardware (Microcontroller Handbook, Intel Corporation, May 1983) is assumed in this manual. Some knowledge of Pascal would be useful.

Although it is called Pascal/48, the language differs in many ways from Pascal. The program structure and statements of the two languages are similar. The major differences are in the expression mechanism and the data types.

The syntax diagrams in this manual precisely describe the syntax of the Pascal/48 language. Upper case quantities and special symbols indicate items which are actually written in a Pascal/48 program and lower case quantities are names of other diagrams. They must be located and used to generate valid instances of the named diagram. Below is the diagram for 'program' (see also section 4) and it indicates that a Pascal/48 program consists of the word PROGRAM followed by an ident, followed by a semicolon, followed by a block, followed by a period. Ident and block are names of other diagrams because they are in lower case. Starting with the diagram named 'program', any path through the diagram defines a syntactically correct program.

\[
<<< \text{program} >>>
\]

\[
\rightarrow \text{PROGRAM} \rightarrow \text{ident} \rightarrow ; \rightarrow \text{block} \rightarrow . \rightarrow
\]

For reference purposes, all of the syntax diagrams are repeated in Appendix C.
Pascal/48 is a free format language. Column numbers have no meaning except that the compiler only reads columns 1 to 72 inclusive of the input records (usually card images). The number of columns read can be changed with a compiler option (see section 10). Blanks may not be used inside identifiers, reserved words, constants or multi-character operators but otherwise can be used freely to improve program readability. Blank lines are specifically allowed. A blank character is assumed between input records and so a single word cannot be continued across two input records.

Identifiers are defined by the following syntax diagram:

```
<<< ident >>>
```

--- letter -----------
    ↑
    ← letter ←
    ← digit ←
    ← ← ←

letter means a letter of the alphabet,
digit means 0,1,2,3,4,5,6,7,8, or 9.

Example:

```
COUNTER MY_PROGRAM DIGIT3
```

are valid identifiers.

Identifiers can be of any length but only the first ten characters are used by the compiler. Thus identifiers must be unique in the first ten characters.

Certain words called reserved words are used to build statements and other constructs and may not be used as variable names.

Example:

```
The identifiers IF, THEN, and ELSE are reserved.
```
The list of reserved words is:

AND ARRAY BEGIN CASE
CONST DOWNTO DO ELSE
END FOR GOTO IF
LABEL NOT OF OR
PROCEDURE PROGRAM REPEAT THEN
TO UNTIL VALUE VAR
WHILE

Comments are any sequence of characters beginning with the special symbol (* and ending with the special symbol *). Comments may appear anywhere that a blank may appear.

Example:

(* THIS IS A COMMENT *)

Comments may extend over several lines. It is important to correctly terminate a comment with the *) characters. If they are not present or extend past the last column the compiler reads (usually 72), the rest of the program will be taken as comment.
3 CONSTANTS AND VARIABLES

Variables may be scalars or arrays. Scalar variables can be of type integer, character or Boolean. Integer variables occupy one word (eight-bit byte) and can take on values in the range 0 to 255 inclusive. The syntax of integer constants is:

```plaintext
<<< int const >>>
```

- digit
- letter

Example:

8748  Decimal representation.
16_222C  Hexadecimal representation of 8748.
8_21054  Octal representation of 8748.

If the first integer and underscore are present they designate the base of the constant. The second integer is then a constant in that base. The base is specified in decimal. Letters are used in the conventional way for constants with bases larger than 10. The base may be any integer between 2 and 36 inclusive but a warning is issued for any base other than 2, 8 or 16. If there is only one integer in the constant (i.e., no base is specified) then it is assumed to be a decimal constant.

Boolean variables occupy one word and can take on the values TRUE and FALSE. TRUE and FALSE are the Boolean constants. The internal representation of TRUE is any eight bits with the least significant bit one. The internal representation of FALSE is any eight bits with the least significant bit zero. A special provision to specify a Boolean as a bit reference is provided (see section 4.3) to permit packing several Boolean variables in one word. In this case all eight bits are considered significant so the compiler will generate extra code to preserve the bit pattern of the word.

Character variables occupy one word and take on values defined by the 128 character ASCII subset. Character constants which are printable on standard CYBER computers are represented as a single character.
contained within quotes, except for the quote character which is represented as two quotes within quotes. A single character is used for upper case letters, digits and special characters. Lower case letters are represented by the string LC_ followed by the corresponding upper case letter.

Example:

<table>
<thead>
<tr>
<th>ASCII</th>
<th>Hex Code</th>
<th>Name</th>
<th>ASCII</th>
<th>Hex Code</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td></td>
<td>NUL</td>
<td>10</td>
<td></td>
<td>DLE</td>
</tr>
<tr>
<td>01</td>
<td></td>
<td>SOH</td>
<td>11</td>
<td></td>
<td>DC1</td>
</tr>
<tr>
<td>02</td>
<td></td>
<td>STX</td>
<td>12</td>
<td></td>
<td>DC2</td>
</tr>
<tr>
<td>03</td>
<td></td>
<td>ETX</td>
<td>13</td>
<td></td>
<td>DC3</td>
</tr>
<tr>
<td>04</td>
<td></td>
<td>EOT</td>
<td>14</td>
<td></td>
<td>DC4</td>
</tr>
<tr>
<td>05</td>
<td></td>
<td>ENQ</td>
<td>15</td>
<td></td>
<td>NAK</td>
</tr>
<tr>
<td>06</td>
<td></td>
<td>ACK</td>
<td>16</td>
<td></td>
<td>SYN</td>
</tr>
<tr>
<td>07</td>
<td></td>
<td>BEL</td>
<td>17</td>
<td></td>
<td>ETB</td>
</tr>
<tr>
<td>08</td>
<td></td>
<td>BS</td>
<td>18</td>
<td></td>
<td>CAN</td>
</tr>
<tr>
<td>09</td>
<td></td>
<td>HT</td>
<td>19</td>
<td></td>
<td>EM</td>
</tr>
<tr>
<td>0A</td>
<td></td>
<td>LF</td>
<td>1A</td>
<td></td>
<td>SUB</td>
</tr>
<tr>
<td>0B</td>
<td></td>
<td>VT</td>
<td>1B</td>
<td></td>
<td>ESC</td>
</tr>
<tr>
<td>0C</td>
<td></td>
<td>FF</td>
<td>1C</td>
<td></td>
<td>FS</td>
</tr>
<tr>
<td>0D</td>
<td></td>
<td>CR</td>
<td>1D</td>
<td></td>
<td>GS</td>
</tr>
<tr>
<td>0E</td>
<td></td>
<td>SO</td>
<td>1E</td>
<td></td>
<td>RS</td>
</tr>
<tr>
<td>0F</td>
<td></td>
<td>SI</td>
<td>1F</td>
<td></td>
<td>US</td>
</tr>
<tr>
<td>7B</td>
<td></td>
<td>L_BRACE</td>
<td></td>
<td>7E</td>
<td>TILDE</td>
</tr>
<tr>
<td>7C</td>
<td></td>
<td>B_AR</td>
<td>7F</td>
<td></td>
<td>DEL</td>
</tr>
<tr>
<td>7D</td>
<td></td>
<td>R_BRACE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other non-printable character constants are represented by the corresponding ASCII name. These names are:

Arrays are limited to one dimension. They can be of any size within the limits of the machine. Array elements can be any scalar type except for a bit specified Boolean. Arrays must be indexed when referenced and the resulting element used anywhere that a scalar of the element type can be used. The notation for indexing is the array name followed by either a scalar variable or an integer constant surrounded by brackets. There are no array constants. However, strings of characters can be used in the VALUE part of a program (see section 4.4) to initialize an array of characters.

Example:

Suppose A is an array.
A[I] - the Ith element of A.
For the rules governing the use of arrays in expressions see section 6. The declaration of arrays is covered in section 4.3.
The syntax of a Pascal/48 program is:

```plaintext
<<< program >>>

---> PROGRAM --> ident --> ; --> block --> . -->

<<< block >>>

--- lab_part ---- con_part ---- var_part ---

--- val_part ---- proc_part ---- cmpnd_stmt ----
```

A program describes a set of instructions which can be placed in an 
MCS-48 computer and executed. As with an MCS-48 assembly language 
program there is no operating system or other software to support a 
Pascal/48 program. It is the user's responsibility to ensure that a 
program is totally self-contained.

The following is a very simple Pascal/48 program:

Example:

```pascal
(* ECHO BUS TO PORT2 *)

PROGRAM DEMO;

BEGIN
    WHILE TRUE DO
        PORT2 := BUS;
END.
```

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This program reads BUS and outputs the value to PORT2. It continues to do this forever. The compiler will generate an unconditional branch to the program instructions at location 0. When the computer is reset, this will branch past the memory locations reserved in the hardware for interrupt processing. For this example, the program instructions will be placed in memory beginning at address 9.

At the end of a Pascal/48 program, an unconditional branch to itself instruction is generated. This helps to prevent an incorrect program from executing data or uninitialized ROM.

Each of the subsections of the remainder of section 4 will conclude with expanded versions of this program. The expanded versions are merely examples of the syntax and may not be meaningful.
4.1 LABEL DECLARATION PART

The syntax of the label declaration part is:

<<< lab_part >>>

--- > LABEL -- int_const -- > ; --- >

Example:

LABEL 1,100,1000;

The purpose of the label declaration part is to declare integer constants which will be used as statement labels. The labels can then be used in GOTO statements. All the labels used in a program must be declared. The use of labels and GOTO statements is discouraged because other control statements (WHILE, IF etc) are provided and their use is preferred.

No code is generated for a label declaration part and labels bear no relation whatsoever to machine addresses.

Example:

(* USE GOTO AND LABEL *)

PROGRAM DEMO;

LABEL 100;

BEGIN
  100: PORT2 := BUS;
  GOTO 100;
END.

This program generates the same machine instructions as the previous version of the program which used a WHILE statement. Efficient programs do not need to use GOTO statements.
4.2  CONSTANT DEFINITION PART

The syntax of the constant definition part is:

```<< con_part >>>

--- > CONST --- > ident --- > = --- > constant --- > ; --- >
```

Example:

```CONST  MASK = 2_01111111;
  COUNT  Reg = 5;
  LOOP  COUNT = 100;
  ESC_CHAR = ' ';```

The meaning of a constant definition is the association of an identifier with a constant value. Subsequent references to the identifier are equivalent to references to the constant. This is a similar capability to an assembly language EQUATE. No code is generated for a constant definition part.

Example:

```(* OUTPUT THE 7 LEAST SIGNIF. BITS OF BUS TO PORT2 *)

PROGRAM DEMO;

  CONST MASK = 2_01111111;

  BEGIN
     WHILE TRUE DO
       PORT2 := BUS AND MASK;
  END.```
4.3 VARIABLE DECLARATION PART

The syntax of the variable declaration part is:

```
<<< var_part >>>

--- VAR --- ident --- addr_spec --- : --- type_spec ; ---

<<< addr_spec >>>

--- [ --- int_const --- , --- RAM --- ] ---

--- type_spec ---

--- array_spec --- OF --- scl_type ---

<<< array_spec >>>

--- ARRAY --- [ --- int_const --- .. --- int_const --- ] ---
```
The variable declaration part of a program declares variables which a program can use. The address specification is required for each variable and indicates the address to be used for the variable and the type of memory it will occupy; random access - RAM, read only - ROM, external random access - XRAM. The memory type is optional and RAM is assumed if no type is specified. RAM addresses are in the range 0 to 63 inclusive, but may be expanded by the data RAM option (see section 10). XRAM address must be in the range 0 to 255 inclusive. ROM addresses must be in the range 0 to 255 inclusive. Variables which are declared in the main part of a program are called global variables. Global ROM variables are allocated space in page 3 and their address is a displacement into page 3. An address must be specified for global variables. They are accessible throughout the entire program. Variables may also be declared inside procedures (see section 4.5). They are called local variables. Local ROM variables are allocated space in the page in which the procedure resides. Their address specification is required but the actual integer constant specifying the address may be omitted. If present, it is a displacement into that page. If absent, the ROM variable will be allocated space automatically, ahead of the instructions for the procedure. It is the programmer's responsibility to relocate instructions and place variables in ROM so that the required access is possible. Relocation can be achieved with the origin option (see section 10). Booleans may be defined as a bit within a word. The value of the integer constant following the scalar type BOOLEAN specifies the bit of the word and is limited to the range 0 to 7. The array specification is not allowed with the bit specification of Boolean variables.

Example:

```pascal
VAR X[4], Y[5] : INTEGER;
 S[7] : BOOLEAN[0];
 T[7] : BOOLEAN[1];
 A[0,ROM] : ARRAY[1..10] OF INTEGER;
 CH[20,XRAM] : CHAR;
```
In the above example, X and Y are one word integer variables which will occupy words 4 and 5 of RAM. Z is a Boolean variable which will occupy word 6 of RAM. S and T are Boolean variables which will occupy bits 0 and 1 of word 7 of RAM. A is an array with ten elements each of which is an integer. Assuming it is global, it will occupy ten words of ROM beginning at word 300(hex), i.e., the first word of the third page. CH is a character variable which will occupy word 20 of external RAM.

Since the hardware defines RAM addresses 0 to 7 inclusive as registers, the address specification allows the programmer control of the registers. Registers 0 and 1 should not be used by the programmer. They are reserved for use by the compiler and if used explicitly may produce unpredictable results. If register bank one (see section 8.9) is selected, RAM addresses 24 and 25(dec) will become registers 0 and 1 respectively. Note that RAM addresses 8 through 23(dec) are used by the hardware for a stack of procedure call return addresses and other data. The programmer should not use these addresses unless explicit modification of the stack is required. Warning messages are issued for variables defined at RAM addresses 0, 1 and 8 thru 23 but not for register bank one RAM addresses 24 and 25.

No code is generated for a variable declaration part.

Example:

(* ADD 7 LEAST SIGNIF. BITS OF BUS TO REG 4 *)
(* STORE RESULT IN REG 4 AND OUTPUT TO PORT 2 *)

PROGRAM DEMO;

CONST MASK = 2_0111111;

VAR X[4] : INTEGER;

BEGIN
  X := 0;
  WHILE TRUE DO
    BEGIN
      X := BUS AND MASK + X;
      PORT2 := X;
      END;
  END.

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4.4 VALUE PART

The syntax of the value part is:

\[
\langle\langle\text{val_part}\rangle\rangle
\]

\[
\rightarrow \text{VALUE} \rightarrow \text{ident} \rightarrow = \rightarrow \text{val_con} \rightarrow ; \rightarrow
\]

The value part associates a constant with a previously declared variable which is in ROM. The value is placed into ROM with the program thereby defining the variable. This is the only way to assign a value to a variable in ROM. No executable code is generated for a value part.

The identifier preceding the equals sign is the variable to be initialized. The value is either a single quantity (for a scalar) or a list contained in parentheses (for an array). A replication factor can be used to generate many copies of a value in a list. It precedes the value and is separated from it by the reserved word OF. It indicates the number of copies of the value that are required.

A special case is provided for the initialization of arrays of characters where all the characters required are printable. Instead of writing each character within quotes and separating each pair in the list with a comma, the characters may be written as a string within a single pair of quotes. Note that non-printable characters may not appear in the string and must be listed individually if required.
Example:

```
VAR MESSAGE[0,ROM] : ARRAY[1..11] OF CHAR;
VALUE MESSAGE = ('ENTER DATA',CR);
```

Example:

```
VAR X[0,ROM] : INTEGER;
  Y[1,ROM] : ARRAY[1..10] OF INTEGER;
VALUE X = 5;
  Y = (3 OF 1, 4 OF 2, 5, 8, 11);
(* X IS THE FIRST WORD OF PAGE 3. IT IS PRESET TO 5 *)
(* Y IS NEXT TEN WORDS. IT IS SET TO *)
(* 1, 1, 1, 2, 2, 2, 5, 8, 11 *)
```

Example:

```
(* SIMULATION OF A 7447 BCD TO 7 SEGMENT DECODER *)
(* BCD INPUT IS ON LEAST SIGNIF. NIBBLE OF PORT 1*)
(* GENERATES 7 SEGMENT DRIVER SIGNS ON PORT 2 *)
```

PROGRAM BCD_TO_7SEG;

```
CONST MASK = 16_OF;

VAR TABLE [0,ROM] : ARRAY [1..16] OF INTEGER;
  DIGIT[2] : INTEGER;

VALUE TABLE = (2_000000001, 2_01001111, 2_01101101,
               2_000000110, 2_01001100, 2_00100100,
               2_01100000, 2_00001111, 2_00000000,
               2_01110010, 6 OF 2_11111111);

BEGIN
  WHILE TRUE DO
    BEGIN
      DIGIT := PORT1 AND MASK;
      PORT2 := TABLE[DIGIT];
    END;
  END.
```
4.5 **PROCEDURE DECLARATION PART**

The syntax of the *procedure declaration part* is:

\[
<<< \text{proc\_part} >>>
\]

\[
\text{proc\_hdr} \rightarrow \text{proc\_body} \rightarrow ; \rightarrow
\]

\[
<<< \text{proc\_hdr} >>>
\]

\[
\rightarrow \text{PROCEDURE} \rightarrow \text{ident} \rightarrow ; \rightarrow
\]

\[
<<< \text{proc\_body} >>>
\]

\[
\rightarrow \text{EXTERNAL} \rightarrow [ \rightarrow \text{int\_const} \rightarrow ] \rightarrow
\]

Procedures are merely subroutines. They may be called from the main program or other procedures.

The machine code for a procedure will be generated following the previous procedure or at location 9 if it is the first procedure. The origin option (see section 10) can be used to change the location counter at any point in a program but an important special use is to relocate procedures. This facility must be used to relocate procedures appropriately in the various pages of ROM. Many MCS-48 instructions are only able to generate "within page" addresses. The boundary (default) option will ensure that no problems will occur with page boundaries, however, the machine code generated will not be optimal. If the boundary problems are nested redundant code will probably be generated.
It is the programmer's responsibility to adjust the location counter to ensure optimal code at the page boundaries. If the boundary option is not selected and the compiler encounters difficulty with a page boundary, a diagnostic will be issued and it will be necessary for the programmer to explicitly relocate the code as necessary.

The body of a procedure may take one of three forms. If it is the word `FORWARD` then it indicates that the procedure will be defined lower down in the program but it informs the compiler of its existence. This allows forward references to procedures. If a `FORWARD` declaration is not present, a procedure must be defined before it can be called.

If the body of a procedure is the word `EXTERNAL` followed by an integer inside brackets, it indicates that the procedure will be produced separately from this program (an assembly language subroutine for example) but will occupy this location at execution time. The integer following the word `EXTERNAL` indicates the size of the procedure in bytes and this amount of space is left empty by the compiler.

The third form a procedure body may take is a block and so all of the components of a program may appear inside a procedure (see section 4). Any identifier declared inside a procedure is only known (i.e., can only be used) inside that procedure or others nested inside it. Pascal/48 uses the same scope rules for identifiers as Pascal (Pascal User Manual and Report, Second Edition: Jensen, Kathleen; Wirth, I. Niklas; 1974; Springer-Verlag Berlin Heidelberg New York).

Example:

```pascal
PROCEDURE CONVERT;

CONST ASCII_ZERO = 16_30;

VAR DIGIT[10] : INTEGER;

BEGIN
  DIGIT := DATA ASCII - ASCII_ZERO;
  IF DIGIT > 10 THEN
    DIGIT := DIGIT - 7;
  DATA HEX := DIGIT;
END;
```

In this example, the constant ASCII ZERO and the variable DIGIT can only be used inside procedure CONVERT. The procedure CONVERT takes a character in a variable called DATA ASCII which is assumed to be the character representation of a hex digit and converts it to the corresponding binary integer, e.g., character 1 (ASCII hex code 31) is converted to binary 1. The result is placed in the variable DATA HEX. The variable DIGIT is not required but is used as an example. Variables declared in procedures must still have an address specified for them and storage will be allocated statically.
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The Pascal/48 compiler will generate machine code for each procedure in order and place it into ROM beginning at address 9 if the origin option is not used. A program may contain any number of procedures within the memory limits of the machine. It is not necessary (nor is it possible) to write an RET instruction at the end of a procedure. The compiler will automatically generate the RET instruction when the END statement of a procedure body is encountered.

Example:

PROGRAM ECHO;

PROCEDURE COPY;

    CONST MASK = 2_1011110;

    VAR X[2] : INTEGER;

    BEGIN
        X := PORT1 AND MASK;
        PORT2 := X;
        END (* COPY *);

    BEGIN
        WHILE TRUE DO
            COPY;
        END.

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4.6 COMPOUND STATEMENT

The syntax of a compound statement is:

```
<<< cmpnd_stmt >>>
```

```
--- BEGIN ---- statement ---- END ------
```

This is just a sequence of statements (see section 8) separated by semicolons. In the case of a program, this compound statement constitutes the body of the program. The sequence of statements will be compiled into machine code and placed into ROM following the machine code for the last procedure. A branch instruction to the beginning of the code for this compound statement is placed into ROM location 0.

For a procedure, the compound statement constitutes the body of the procedure and it is the sequence of statements which will be executed when the procedure is called. The BEGIN-END pairs contained in examples in other sections of this manual are examples of compound statements.
Operators are used to build expressions and they give access to many of the MCS-48 instructions. Operators are either monadic or dyadic. Monadic operators have one operand and dyadic operators have two operands.

Each monadic operator may be used in two different ways in expressions (see section 6) but the operator actually generates either zero or one instruction. A monadic operator can only be used with an operand of the correct type and the appropriate instruction is applied with the operand in the accumulator. The compiler generates the instructions necessary to evaluate the operand (if it is an expression) or load the operand into the accumulator (if it is a variable) prior to generating the instruction for the monadic operator. The monadic operators and their meanings are given by the following table:

<table>
<thead>
<tr>
<th>OPERATOR</th>
<th>OPERAND TYPE</th>
<th>RESULT TYPE</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC_ADJ</td>
<td>Integer</td>
<td>Integer</td>
<td>Decimal adjust.</td>
</tr>
<tr>
<td>NOT</td>
<td>Int/Bool</td>
<td>Int/Bool</td>
<td>Invert each bit.</td>
</tr>
<tr>
<td>CHR</td>
<td>Integer</td>
<td>Character</td>
<td>Character representation of integer.</td>
</tr>
<tr>
<td>ORD</td>
<td>Any scl.</td>
<td>Integer</td>
<td>Integer representation of any scalar type (in particular character).</td>
</tr>
<tr>
<td>ADDR_PAGE</td>
<td>Program label</td>
<td>Integer</td>
<td>Page number in which a program label occurs.</td>
</tr>
<tr>
<td>ADDR_WORD</td>
<td>Program label</td>
<td>Integer</td>
<td>Word offset in which a program label occurs.</td>
</tr>
</tbody>
</table>

DEC_ADJ performs the normal decimal adjustment algorithm necessary to generate a BCD result after binary arithmetic with BCD quantities. NOT merely performs a bit by bit inversion. CHR and ORD are for switching types between type INTEGER and CHARACTER. They allow programmers to indicate explicitly that arithmetic on scalar, non-integer quantities is required. In particular, ORD(FALSE) is 0 and ORD(TRUE) is 1. ADDR_PAGE and ADDR_WORD take a programmer defined label as their operand and return the page number and within-page word offset respectively of that label. The labels must be between 0 and 255. The results of these operators are the actual machine address corresponding to the label. These operators do not generate any code. They give access to machine addresses so that in the few necessary cases, machine addresses can be used in a Pascal/48 program. A possible use would be the explicit modification of the hardware stack to provide a non-standard return from an interrupt (see section 9).
Example:
Y := DEC_ADJ(X+1);
Z := ORD CH + 1;
C := CHR Z;

In the above example, one is added to X, the result is decimal adjusted, and assigned to Y. The numeric representation of the character CH is made available, one is added to it, and the result assigned to Z. The character corresponding to the integer in Z is assigned to the character variable C.

The rules governing the use of monadic operators in expressions are given in section 6.

Dyadic operators are either one or two special characters, or a meaningful sequence of letters. In either case they are written between their operands (infix) in the usual way. Each operator generates either one or a small number of MCS-48 machine instructions. The dyadic operators and their meanings are given by the following table:

<table>
<thead>
<tr>
<th>OPERATOR</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Eight-bit addition.</td>
</tr>
<tr>
<td>-</td>
<td>Eight-bit subtraction (see below).</td>
</tr>
<tr>
<td>++</td>
<td>Eight-bit addition with carry (see below).</td>
</tr>
<tr>
<td>--</td>
<td>Eight-bit subtraction with borrow (see below).</td>
</tr>
<tr>
<td>&lt;</td>
<td>Test for less than.</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Test for less than or equals.</td>
</tr>
<tr>
<td>=</td>
<td>Test for equality.</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Test for greater than or equals.</td>
</tr>
<tr>
<td>&gt;</td>
<td>Test for greater than.</td>
</tr>
<tr>
<td>&lt;&gt;</td>
<td>Test for inequality.</td>
</tr>
<tr>
<td>AND</td>
<td>Logical and.</td>
</tr>
<tr>
<td>OR</td>
<td>Logical or.</td>
</tr>
<tr>
<td>XOR</td>
<td>Logical exclusive or.</td>
</tr>
<tr>
<td>ROTL</td>
<td>Rotate left without carry (carry not affected).</td>
</tr>
<tr>
<td>ROTR</td>
<td>Rotate right without carry (carry not affected).</td>
</tr>
<tr>
<td>ROTLC</td>
<td>Rotate left through carry.</td>
</tr>
<tr>
<td>ROTr</td>
<td>Rotate right through carry.</td>
</tr>
<tr>
<td>SHL</td>
<td>Shift left, insert zeros (carry affected).</td>
</tr>
<tr>
<td>SHR</td>
<td>Shift right, insert zeros (carry affected).</td>
</tr>
<tr>
<td>BIT</td>
<td>Select bit.</td>
</tr>
</tbody>
</table>

For the operator -, subtraction means negate the right operand and add. Negate means complement each bit and add one (two's compliment). The operators add with carry (++) and subtract with borrow (--) should only be used in a double precision context with the eight-bit addition and subtraction. To insure the setting of the carry bit, the expression should be simple.
Example:

\[
\begin{align*}
(* \text{DOUBLE PRECISION ADDITION} *) \\
(* \text{DOUBLE PRECISION SUBTRACTION} *)
\end{align*}
\]

For the rotate and shift operators, the left operand is the operand to be acted on and the right operand gives the rotate or shift count. These operators are implemented with some special case analysis. For example, a rotate without carry by four is implemented as a SWAP NIBBLES instruction. The rules governing the use of dyadic operators in expressions are given in section 6.

The operands for the dyadic operators must be of type integer, except the logical operators which take either Boolean or integer operands. The result type is integer for all of the dyadic operators except the BIT and relational operators which produce Boolean results and the logical operators which produce Boolean results if their operands were Boolean.

The dyadic operator BIT is used for bit selection. Its left operand must be an integer and its right operand must be an integer constant in the range 0 to 7. It is particularly useful in testing individual bits of the I/O ports.

Example:

\[
\begin{align*}
\text{IF PORT1 BIT 7 THEN } \ldots \\
\text{WHILE PORT1 BIT 2 DO } \ldots
\end{align*}
\]
6 EXPRESSIONS

The syntax of an expression is:

<<< expression >>>

--- monadic_op --- ( --- expression --- ) ---

--- monadic_op --- constant ---

--- variable ---

--- dyadic_op ---

<<< variable >>>

--- ident --- [ --- int_const --- ] ---

--- ident ---

Expressions define sequences of MCS-48 instructions for operating on data. The rules which govern expressions are designed to allow flexibility in these expressions but allow the programmer to retain control of machine resources.

Recall that any path through the syntax diagram labelled <<< expression >>> yields a valid expression. A variable is either an identifier (i.e., a scalar variable) or an array element. An array element can have either a constant or a variable index.

There is no operator hierarchy and dyadic operators in an expression are executed strictly in order from left to right. Note that
parentheses cannot be used to force a priority on dyadic operator evaluation. For a monadic operator whose operand is in parentheses (and can therefore be an expression), the operand is evaluated first and then the monadic operator is applied. For a monadic operator whose operand is not in parentheses (and must therefore be a constant or variable) the monadic operator is applied directly to the operand. The result may then become an operand of a dyadic operator.

Example:

```
DEC ADJ(X+1)
```

Valid expression. Add X and 1 and decimal adjust the result.

```
DEC_ADJ X+1
```

Valid expression. Decimal adjust X and add 1 to the result.

```
DEC_ADJ(X+1) AND Y
```

Valid expression. Add X and 1, decimal adjust the result, and mask Y with the ensuing result.

```
DEC_ADJ(ORD CH1 + ORD CH2)
```

Valid expression. Decimal adjust the sum of the ordinals of the character variables CH1 and CH2.

```
DATA[I] + DATA[I+1]
```

Invalid expression. Array index must be a constant or a variable. This expression would have to be broken into two parts—first I+1 would have to stored in a variable; second DATA would have to indexed by that variable and then added to DATA[I].

```
```

Valid expression. Add A and the first element of B, subtract C, rotate left two, add the third element of array TABLE with carry.
PORT1 + PORT2 + TABLE[4] XOR 16_82

Valid expression. Read PORT1 and PORT2 and add, add fourth element of array TABLE, exclusive or the result with the hexadecimal constant 82.
Access to many parts of the MCS-48 computer is provided by a set of predeclared variables. These are variables which can be used in programs without being declared by the programmer. They represent data items or similar which are not part of the machine's memory. Use of a predeclared variable in an expression causes the data item to be referenced and assignment to the variable causes the data item to be set.

Example:

CARRY is a predeclared variable.

CARRY := TRUE; (* THIS TURNS THE CARRY BIT ON *)

IF CARRY THEN X := X + 1
ELSE X := 0;
(* THIS INCREMENTS X IF THE CARRY BIT IS ON *)
(* OTHERWISE IT SETS X TO ZERO *)

Example:

TIMER is a predeclared variable.

TIMER := 100;
(* THIS SETS THE MACHINE'S TIMER TO 100 *)

The table below shows all of the predeclared variables, their type and meaning.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>TYPE</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCUMULATOR</td>
<td>Typeless</td>
<td>The accumulator.</td>
</tr>
<tr>
<td>BUS</td>
<td>INTEGER</td>
<td>The bus.</td>
</tr>
<tr>
<td>CARRY</td>
<td>BOOLEAN</td>
<td>The accumulator carry bit.</td>
</tr>
<tr>
<td>COUNTER</td>
<td>INTEGER</td>
<td>The built-in counter.</td>
</tr>
<tr>
<td>FLAG0</td>
<td>BOOLEAN</td>
<td>Flag 0.</td>
</tr>
<tr>
<td>FLAG1</td>
<td>&quot;</td>
<td>Flag 1.</td>
</tr>
<tr>
<td>INT</td>
<td>&quot;</td>
<td>Interrupt pin.</td>
</tr>
<tr>
<td>PORT1</td>
<td>INTEGER</td>
<td>I/O port 1.</td>
</tr>
<tr>
<td>PORT2</td>
<td>&quot;</td>
<td>I/O port 2.</td>
</tr>
<tr>
<td>PORT4</td>
<td>&quot;</td>
<td>I/O port 4.</td>
</tr>
<tr>
<td>PORT5</td>
<td>&quot;</td>
<td>I/O port 5.</td>
</tr>
<tr>
<td>PORT6</td>
<td>&quot;</td>
<td>I/O port 6.</td>
</tr>
<tr>
<td>PORT7</td>
<td>&quot;</td>
<td>I/O port 7.</td>
</tr>
<tr>
<td>PSW</td>
<td>&quot;</td>
<td>Program status word.</td>
</tr>
<tr>
<td>TIMER</td>
<td>&quot;</td>
<td>The built-in timer.</td>
</tr>
<tr>
<td>TIMER FLAG</td>
<td>BOOLEAN</td>
<td>Timer flag.</td>
</tr>
<tr>
<td>TO</td>
<td>&quot;</td>
<td>Pin TO.</td>
</tr>
<tr>
<td>T1</td>
<td>&quot;</td>
<td>Pin T1.</td>
</tr>
</tbody>
</table>
The predeclared variable ACCUMULATOR is typeless and can be assigned to any scalar variable and can have any scalar value assigned to it. It is used when the accumulator must be stored or initialized (in handling interrupts for example — see section 9). Great care must be exercised in dealing with the accumulator and carry since the compiler will generate instructions which will affect these variables for almost every statement.

The predeclared variables PORT1 through PORT7 and BUS are particularly important because they give access to most of the machine’s input/output features. Assignment to them causes data to be output and reference to them causes data to be read.

Example:

```
DATA := PORT1;
PORT2 := 2_10101100;
```

Single bits can be set on a port or the BUS by referencing and assigning the appropriate predeclared variable in the same statement.

Example:

```
PORT1 := PORT1 AND 2_00000001;
```

(* THIS WILL GENERATE     ANL P1,#1 *)
The syntax of a statement is:

```plaintext
<<< statement >>>
```

- `int const` ----> : assignment stmt
- `if stmt`
- `while stmt`
- `rept_stmt`
- `for_stmt`
- `case stmt`
- `call stmt`
- `goto stmt`
- `cmpnd_stmt`

Note that a statement may be labelled only once and that a statement can be empty. Empty statements are used in many examples in this manual. Also, since a compound statement is defined to be a statement, anywhere that a statement can appear a compound statement can appear. Each of the statements is explained in the following sections.
8.1 ASSIGNMENT STATEMENT

The syntax of the assignment statement is:

<<< assign_stmt >>>

--- variable --- := --- expression ---

The expression is evaluated and the variable is given that value. If the variable is an array element, the array index is evaluated before the expression. The type of the expression must match the type of the variable. Note that Boolean expressions and assignment are specifically allowed. Assignments to bit specified Boolean variables will generate code to preserve the bit pattern of the word and modify only the bit referenced. For the definitions of variables and expressions, and the rules governing the construction of expressions see section 6.

Example:

TIMER := 100; (* SET TIMER TO 100 *)
X := A + B SHL 1; (* ADD A AND B, SHIFT LEFT 1 *)
V[I] := V[I] + C; (* ADD C TO V[I] *)
8.2 IF STATEMENT

The syntax of the IF statement is:

```pascal
<<< if_stmt >>>

--- IF --- expression --- THEN --- statement ---

--- ELSE --- statement ---
```

The expression must be of type Boolean. It is evaluated and if it is true, the statement following the THEN is executed. If it is false, the statement following the ELSE is executed if an ELSE is present, otherwise nothing is executed.

Example:

```pascal
IF A[I] > MAX THEN MAX := A[I];
```

Example:

```pascal
IF RESET THEN PORT1 := 0 ELSE PORT1 := DATA;
(* RESET IS A BOOLEAN - ITS VALUE IS TESTED *)
```

Example:

```pascal
IF COUNT > LIMIT THEN
BEGIN
  COUNT := 1;
  PORT1 := NEWDATA;
END
ELSE
BEGIN
  COUNT := COUNT + 1;
  PORT1 := OLDDATA;
END
(* NOTE THE USE OF COMPOUND STATEMENTS. *)
```
Example:

```pascal
IF A < B THEN
  IF B < C THEN
    PORT1 := C
  ELSE PORT1 := B
ELSE
  IF A < C THEN
    PORT1 := C
  ELSE PORT1 := A
(* THIS EXAMPLE OUTPUTS THE LARGEST *)
(* OF THREE INTEGERS A, B, AND C *)
```

Care should be taken with nested if-then-else constructs in avoiding the problem of the "dangling else." An else clause is associated with the nearest if. Consequently, in the following example, the variable C would be undefined if A is false even though the indenting might lead the reader to infer that C should be assigned 1 when A is false.

Example:

```pascal
IF A THEN
  IF B THEN
    C := 0
  ELSE
    C := 1
(* THIS EXAMPLE DEMONSTRATES THE POSSIBILITY *)
(* OF A DANGLING ELSE CLAUSE *)
```

To prevent the problem of the "dangling else" a compound statement (BEGIN-END pair) is necessary.

Example:

```pascal
IF A THEN
  BEGIN
    IF B THEN
      C := 0
  END
ELSE
  C := 1
(* THIS EXAMPLE DEMONSTRATES THE METHOD *)
(* OF PREVENTING A DANGLING ELSE CLAUSE *)
```
8.3 **WHILE STATEMENT**

The syntax of the `WHILE statement` is:

```pascal
<<< while_stmt >>>
```

```pascal
---< WHILE ---< expression ---< DO ---< statement ----->
```

The expression is evaluated. It must be of type Boolean. The statement is repeatedly executed until the expression becomes false. If its value is false at the beginning, the statement is not executed at all.

Example:

```pascal
(* INTEGER DIVISION BY REPEATED SUBTRACTION *)
DIV := 0;
WHILE NUMERATOR > DENOMINATOR DO
  BEGIN
    DIV := DIV + 1;
    NUMERATOR := NUMERATOR - DENOMINATOR;
  END;
REMAINDER := NUMERATOR;
```

A useful special case of the `WHILE statement` involves using the Boolean constant `TRUE` as the expression. Since `TRUE` is always true (by definition) this generates an infinite loop. This construct is used in the example program in section 4.

Another useful special case is the use of one of the I/O ports (or the BUS) as part of the expression, provided the port is being used for input. Evaluation of the expression causes the port to be read and, since its value changes independently of the microcomputer, the `WHILE` statement can be used to wait for changes in the port. The statement part of the `WHILE statement` can be empty and so the effect is continuous looping until a certain input occurs.

Example:

```pascal
WHILE PORT1 > 0 DO;
(* LOOP UNTIL PORT1 CHANGES TO ALL ZEROS *)
```

---

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Example:

```pascal
WHILE PORT2 BIT 7 DO;
(* LOOP UNTIL PORT2 BIT 7 GOES LOW *)
```

Example:

```pascal
CONST STATUS = 7;
```

```pascal
WHILE NOT(PORT1 BIT STATUS) DO;
(* LOOP UNTIL PORT1 BIT 7 GOES HIGH *)
```
8.4 REPEAT STATEMENT

The syntax of the REPEAT statement is:

```
<<< rept_stmt >>>
```

```
----> REPEAT ----> statement ----> UNTIL ----> expression ---->

; ----
```

The expression is evaluated. It must be of type Boolean. The sequence of statements between the symbols REPEAT and UNTIL is executed repeatedly (and at least once) until the expression becomes true.

Example:

```
I := 0;
REPEAT
  I := I + 1;
  R := R - S;
UNTIL R < S;

(* INTEGER DIVIDE BY REPEATED SUBTRACTION *)
(* ASSUMES R > S INITIALLY *)
```

A useful special case of the REPEAT statement has an empty statement between the REPEAT and UNTIL (i.e., no text). In this case, the condition is repeatedly tested until it is true. As with the WHILE statement, if the expression involves the I/O ports or the BUS, this allows a loop to be written which will continue to execute until an outside event occurs.

Example:

```
REPEAT
  UNTIL PORT1 = 0;
```

In this example, PORT1 will be read and compared with zero and this will be repeated until PORT1 becomes zero.
8.5 FOR STATEMENT

The syntax of the FOR statement is:

```
<<< for_stmt >>>

---&gt; FOR ---&gt; for_list ---&gt; DO ---&gt; statement ---&gt;

<<< for_list >>>

---&gt; ident ---&gt; := ---&gt; con_var ---&gt; TO ---&gt; con_var ---&gt;

---&gt; DOWNTO
```

The FOR statement indicates that a statement called the controlled statement is to be executed zero or more times. The identifier is called the control variable. The first con_var in the definition of for_list is called the initial value and the second is called the final value. These values must be of type integer.

The initial value expression and the final value expression are evaluated. The control variable is given the initial value. If the initial value is greater than (less than) the final value in the TO (DOWNTO) case, the controlled statement is not executed. Otherwise, the control variable is given a progression of values up to (down to) the final value and the controlled statement is executed for each one.

Example:

```
FOR I := 1 TO 100 DO
  PORT1 := I;

(* OUTPUT THE INTEGERS 1 THROUGH 100 IN SEQUENCE ON PORT1 *)
```

Example:

```
SUM := 0;
FOR I := 1 TO 10 DO
  SUM := A[I] + SUM;

(* ADD UP THE ELEMENTS OF AN ARRAY *)
```
PASCAL/48

Example:

```
FOR I := 10 DOWNTO 1 DO
BEGIN
A[I] := 0;
B[I] := 0;
C[I] := 0;
END;
(* INITIALIZE ARRAYS *)
```

Example:

```
FOR I := 200 DOWNTO 1 DO
FOR J := 200 DOWNTO 1 DO;
```

The last example generates two nested Decrement and Jump on Non-Zero instructions (DJNZ) if I and J are registers. Nothing will be executed by these loops but they constitute a convenient form of 'busy wait', i.e., a delay (see also the predeclared procedure DELAY in section 8.9).

The FOR statement is implemented with a DJNZ instruction if the DOWNTO case is used, the final value is the constant 1, and the control variable is a register. This is the most efficient form of counting loop on the MCS-48 computers. Other forms of the FOR statement are implemented with explicit incrementation for the arithmetic and explicit comparison for the loop control.

The value of the control variable is undefined after the FOR statement completes execution, i.e., the programmer cannot assume it will have any particular value.
8.6 CASE STATEMENT

The syntax of the **CASE statement** is:

```
<<< case_stat >>>
```

```
----> CASE ---> expression ---> OF ---> case_list_elt ---> END ------>
```

```
<<< case_list_elt >>>
```

```
----> constant ----> : ---> statement ------>
```

The expression (called the **selector**) is evaluated. The statement labelled with a constant (called a **case label**) equal to the selector value is executed. Upon completion of the selected statement, control is transferred to the end of the case statement, provided no GOTO statement was executed. If the selector value is not within the limits of the case labels, the results are undefined. It is the programmer's responsibility to ensure that this does not occur. The case statement is implemented with a table of the addresses of the statements in the case list elements. This table is indexed with the expression. The size of the table is determined by the range of constant values used as case labels but not their absolute values. Thus the smaller the range of values, the smaller the size of the table generated. Case labels must have ordinal values in the range 0 to 255. A case statement **must not cross a page boundary**. When the compiler corrects for a page boundary problem the whole case statement is shifted to the beginning of the next page.

It is important to realize that the case labels are **not** statement labels. They cannot be used as the targets of GOTO statements and their scope is limited to the case statement in which they appear.

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Example:

```
CASE I OF
  1: PORT1 := X; (* EXECUTE THIS IF I = 1 *)
  2: PORT2 := Y; (* EXECUTE THIS IF I = 2 *)
  3,4: BEGIN
    .
    . (* EXECUTE THIS IF I = 3 OR 4 *)
    .
   END;
  5: PORT1 := 2; (* EXECUTE IF I = 5 *)
END
```

Example:

```
CH := CHR(PORT1);
(* READ A CHARACTER FROM PORT1 *)
CASE CH OF
  'D': PORT2 := DATA[I];
  'C': DATA[I] := PORT2;
  'M': IF DATA[J] > 128 THEN
    BEGIN
      DATA[I] := PORT2;
      DATA[K] := BUS;
    END;
END
(* NOTE THE TABLE RANGE IS II. *)
(* 'E'..'L' TRANSFER CONTROL TO THE END *)
(* OF THE CASE. 'A', 'B', 'N'..'Z' *)
(* PRODUCE UNDEFINED RESULTS. *)
```
8.7 GOTO STATEMENT

The syntax of the GOTO statement is:

\[
\text{<<< goto\_stmt >>>}
\]

\[
\longrightarrow \text{GOTO} \longrightarrow \text{int\_const} \longrightarrow
\]

Execution of a GOTO statement causes control to be transferred to the statement labelled with the integer constant. This constant has to have been declared in a LABEL part.

It is possible to branch to any label defined on any statement. This means that it is possible to jump into or out of a procedure. If this is done, the Pascal/48 compiler will generate the necessary unconditional branch only. The stack will remain unchanged. It is the programmer’s responsibility to modify the stack and PSW as necessary in these special cases. The use of labels and GOTO statements is discouraged because other control statements (WHILE, IF etc) are provided and their use is preferred.

Example:

\[
\text{GOTO 1;}
\]

(* BRANCHES TO STATEMENT LABELLED WITH 1 *)
8.8 PROCEDURE CALL STATEMENT

The syntax of a PROCEDURE CALL statement is:

```
<< call_stmt >>>
--- ident ------
```

A procedure call statement causes the named procedure to be executed and then control returns to the statement following the call. The call is effected with an MCS-48 CALL instruction which places the return address on the hardware stack. As in assembly language programming, the programmer must take care not to overflow the stack since it wraps around and will overwrite previous stack frames. Recall that the stack has a capacity of eight frames.
8.9 PREDECLARED PROCEDURES

Certain procedures are predeclared (i.e., do not have to be declared by the programmer in order to be used) and they provide access to some of the MCS-48 instruction set. They may be called anywhere that a procedure call can occur and the effect is to generate a either one or a small number of MCS-48 instructions. Each takes a variable number of parameters (i.e., one or more as the user chooses) but the parameters are of a special type in some cases.

The procedures are:

ENABLE
Use: Enable interrupts, timer or clock output.
Parameters: COUNT_INT, TIMER_INT, EXTERN_INT, CLOCK_OUT.
Example: ENABLE(COUNT_INT, EXTERN_INT);
          (* ENABLE COUNTER AND EXTERNAL INTERRUPTS *)

DISABLE
Use: Disable interrupts.
Parameters: COUNT_INT, TIMER_INT, EXTERN_INT.
Example: DISABLE(COUNT_INT, EXTERN_INT);
          (* DISABLE COUNTER AND EXTERNAL INTERRUPTS *)

DELAY
Use: Generate a delay loop. Since this depends on crystal frequency, see the M option in section 10.
Parameters: Integer expression(s) (delay(s) in milliseconds).
Example: ($M3.6 SET XTAL FREQUENCY *)
          .
          .
          . DELAY(100);
          (* GENERATE 100 MILLISEC DELAY *)

START
Use: Start the timer or counter.
Parameters: TIMER, COUNTER.
Example: START(TIMER);
          (* TURN ON TIMER *)

STOP
Use: Stop the timer or counter.
Parameters: TIMER, COUNTER.
Example: STOP(TIMER);
          (* TURN OFF TIMER *)
INCREMENT
Use: Increment the value of variable(s).
Parameters: Any integer variable(s).
Example: INCREMENT(I, PORT1);
(* INCREMENT I AND PORT1 *)

DECREMENT
Use: Decrement the value of variable(s).
Parameters: Any integer variable(s).
Example: DECREMENT(I, PORT1);
(* DECREMENT I AND PORT1 *)

SELECT
Use: Select register banks.
Parameters: REG BANK0, REG BANK1.
Example: SELECT(REG BANK1);
(* SELECT REGISTER BANK 1 *)

COMPLEMENT
Use: Complement the value of variable(s).
Parameters: Any Boolean variable(s).
Example: COMPLEMENT(F0, CARRY, B);
(* COMPLEMENT F0, CARRY AND B *)

INLINE
Use: Inline insertion of code into the object file.
Parameters: Any integer constant(s).
Example: INLINE(16_27, 16_97);
(* INSERT INSTRUCTION TO CLEAR THE *)
(* ACCUMULATOR AND CARRY BIT *)

Note that the DELAY procedure generates loops to cause the machine to perform a 'busy wait'. The maximum value for any one operand is 255 so the maximum delay is 255 milliseconds. The delay is determined by the computers operating frequency and to implement DELAY correctly the compiler needs to know the crystal frequency (see the M option in section 10). Since the DELAY capability depends on the execution time of the machine instructions generated, the compiler will not correct any page boundary problems (see section 4.5) and will issue an error message. The programmer must then relocate the code as necessary. The INCREMENT, DECREMENT and COMPLEMENT procedures are implemented using the corresponding instructions of the machine where possible. This means that INCREMENT(I) is considerably more efficient than the assignment statement I := I + 1 and does not affect the carry bit. Similarly the efficiency of COMPLEMENT(B) for a bit specified Boolean is considerable compared to B := NOT B. The INLINE procedure allows the programmer to enter machine instructions directly into the object file. This facility is provided as a precaution in the event that the required instructions cannot be generated from other features of Pascal/48. The INLINE procedure should seldom be needed.
9 INTERRUPTS

Interrupt handlers are written as procedures with special names. The names are TIMER_INT or COUNT_INT for timer and counter interrupts EXTERN_INT for external interrupts. If procedures by these names are present, they should not be called anywhere in the program. If they are, the compiler will issue a warning but will generate the required instructions for the call. The compiler will generate machine code for these procedures and place branch instructions to them at address 3 (external) and address 7 (timer or counter). When an interrupt occurs, the effect is an automatic call to the appropriate procedure. When the procedure completes, control returns to the instruction following the one which preceded the interrupt. This return is done by an RETR instruction which the compiler generates. If no interrupt handler is provided, the compiler will generate an unconditional branch to location 3 at location 3 and to location 7 at location 7. Thus, if an interrupt occurs and no handler was provided, the machine will enter an infinite loop at the appropriate address.

Interrupts are enabled and disabled by calling Pascal/48 predeclared procedures (see section 8.9). The compiler will not generate any instructions in the interrupt handling procedure to switch register banks or save and restore the accumulator. These actions are not always required and are left to the programmer. Register banks can be switched with the SELECT predeclared procedure and the accumulator can be saved and restored using the predeclared variable ACCUMULATOR. The interrupt handlers will reset the register bank when the control is returned to the appropriate code.

Example:

```
PROCEDURE TIMER_INT;

VAR SAVE_ACC[60] : INTEGER;

BEGIN
    SELECT(REG_BANK1);
    SAVE_ACC := ACCUMULATOR;

    (* REGISTER BANK IS RESET AUTOMATICALLY *)
    ACCUMULATOR := SAVE_ACC;

    END (* TIMER_INT *);
```

It is not always appropriate to return to the point of interruption following an interrupt. For example, the external interrupt may be used to perform some sort of partial reset of the computer. In such cases, it may be preferable to return to a statement in the program which is labelled. One way to achieve this is to modify the hardware stack within the interrupt handler and the allow the RETR instruction at the
end of the interrupt handling procedure to transfer control to the labeled statement. The following example shows how this can be done.

Example:

```
PROGRAM EXAMPLE;

LABEL 100;

PROCEDURE EXTERN_INT;

VAR I[3], J[4] : INTEGER;

STACK[8] : ARRAY[0..15] OF INTEGER;

BEGIN

I := PSW - 1 AND 16_07 SHL 1;
(* DECREMENT THE PROGRAM STATUS WORD. *)
(* MASK THE STACK POINTER BITS WHICH *)
(* POINT TO THE STACK PAIRS. SHIFT *)
(* FOR THE INDEX IN THE STACK ARRAY. *)

STACK[I] := ADDR_WORD 100;
(* THE FIRST STACK ENTRY CONTAINS THE *)
(* LOCATION WITHIN THE PAGE. *)

INCREMENT(I);

J := STACK[I] AND 16_F8 + ADDR_PAGE 100;
STACK[I] := J;
(* THE SECOND STACK ENTRY CONTAINS *)
(* THE PAGE NUMBER IN THE LOWER THREE *)
(* BITS. *)

END (* EXTERN_INT *);

BEGIN

.
.
100:
.
.
END.
```
The Pascal/48 cross compiler is an indirect access file on the Langley CYBER/NOS complex and is called PAS48 on the user number MICRO. It uses a single input file which contains the program to be compiled. It produces three output files which contain the listing, the object file, and an assembly language program equivalent to the machine instructions which the compiler generated. This last file could be assembled to produce the same object file as the compiler produced. The necessary NOS control cards are:

GET,PAS48/UN=MICRO.
PAS48,input,output,object,assembl.

The lower case names are the default files which the Pascal/48 compiler will use if no file is specified by the user. All files are rewound before a compilation.

The listing that the compiler generates shows the source program annotated with the corresponding line numbers and the approximate value of the location counter as it was at the beginning of each printed line. The value is approximate because of the non-uniform mapping between the source text and the generated instructions. If the compiler corrects for a page boundary problem the location counter will be further affected, since the listing is generated before the machine code is modified. The location counter values are useful in determining the points in programs where page boundaries are crossed.

Following the source program listing is the cross reference of identifiers and a map of the variables of RAM by their location. The RAM map provides an indication of the overloading of variables. Following this is the pseudo-assembly listing of the instructions that the compiler generated. Each instruction has a line number in its comment field and once again, these line numbers are only approximate.

Several options are available to control the Pascal/48 compiler's output. Options may be included in source programs inside comments or they may appear on the execute line. If they are used inside comments, a dollar sign must follow the opening (*) and the options follow the dollar sign. Many options may appear in which case they are separated by commas.

Example:

(*$A+,I+ TURN ON ASSEMBLY LIST AND ROM IMAGE *)

Options may follow the last file name on the execute line and are separated from it by a slash.

Example:

PAS48,MYPROG,LISTING,MYOBJ/A+,X-,I+.

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The options and their meaning are given in the following table:

- **A+** Turn assembly listing on (default).
- **A-** Turn assembly listing off.
- **B+** Code is modified for conditional jumps cross page boundaries (default).
- **B-** Code is not modified and errors emitted.
- **B=** Restore previous setting.
- **C+** Read 80 columns of the input records.
- **C-** Read 72 columns (default).
- **Cn** Read ‘n’ columns (10 < n < 120).
- **C=** Restore previous setting.
- **Dn** Number of internal data RAM-64 byte blocks (1 <= n <= 4). Default is 1.
- **H+** Turn on complete page headings (default).
- **H-** Turn page headings off.
- **H** Turn on partial headings (page ejects).
- **H=** Restore previous setting.
- **I+** Generate ROM image listing.
- **I-** No ROM image listing (default).
- **L+** Turn listing on (default).
- **L-** Turn listing off, error messages listed.
- **L** Page eject.
- **L=** Restore previous setting.
- **L’s** cs is a character string used as a title.
- **Mn** Crystal frequency of ‘n’ hertz (if an integer) or megahertz (if n contains a decimal point). Default is 5.9904 MHz.
- **O+** Origin at next page boundary.
- **On** Origin at address ‘n’.
- **P+** Print 52 lines per page.
- **P-** Print 40 lines per page (default).
- **P=** Restore previous setting.
- **Pn** ‘n’ lines per page (11 < n < 1000).
- **R+** ROM size is eight 256-byte pages.
- **R-** ROM size is four pages (default).
- **T+** Equivalent to A-,H-,L+,X- (suitable for terminals).
- **T-** Restore previous listing option settings.
- **T=** Restore previous T option setting.
- **W+** Print warning messages (default).
W- Suppress warning messages.
W= Restore previous setting.
X+ Turn on cross reference listing (default).
X- Turn off cross reference listing.

The assembly listing is a pseudo-assembly listing of the instructions that the compiler generated. The ROM image listing shows the contents of the ROM as it would look if the object program were loaded into an MCS-48 computer. The page heading and line count options are designed to allow the terminal user to disable the headings and page control because they are of most use when the listing is sent to a line printer. Since options can be specified on the execute line, the listing format can be changed temporarily when a compilation is being done at a terminal and the results displayed on the terminal. The cross reference is a cross reference of the identifiers used in the program. Extended program memory addressing has not been implemented in the Pascal/48 language, so the ROM size is limited to eight 256-byte pages. The crystal frequency option should only be included in the source program inside a comment and not on the execute line. The CYBER Control Language limits fields to seven characters so defining of the frequency in hertz is impossible. The decimal point in the megahertz notation terminates the the execution line and therefore the option list is also terminated.
Four programs are included here as examples of the use of Pascal/48. The first takes ASCII characters from a keyboard and translates them into Morse code. The remaining examples are different methods of turning the MCS-48 microcomputer into a simple stopwatch. These programs are examples and are intended to be used for reference purposes. None of the programs is written to be particularly functional or efficient.

The Morse code example reads an ASCII character on PORT1 and outputs Morse code on pin seven of PORT2. The BUS is not used. The seven least significant bits of PORT1 contain the character and the most significant bit is on while a key is pushed. The keyboard is assumed to generate both upper and lower case letters and the program takes account of this. The Morse code corresponding to the letters is contained in an array in ROM and the end of the code for each letter is indicated by a one followed by all zeros. A one in the code indicates a DAH and a zero a DIT. For example, the letter A is coded as the bit string 01100000 which gives a DIT then a DAH and then the end code.

The first stopwatch program assumes that a control switch is connected to bit seven of the BUS. Pushing the switch changes this bit from zero to one. The output is presented on PORT1 and PORT2 as BCD digits. The upper half of PORT1 is a minute count, the lower half and the upper half of PORT2 is a second count, and the lower half of PORT2 is a tenths of a second count. Upon initialization the display is all zeros. Pushing the switch once causes the watch to start counting in minutes, seconds and tenths of a second. Pushing the switch a second time causes the watch to stop counting and pushing it a third time resets the watch. The second stopwatch program uses the decimal adjust capability for a BCD counter, and outputs the minute count on PORT1 and the second count on PORT2. The third program uses an INTERSIL ICM 7218 LED driver for output displays.
--- Example Program 1 ---

(* THIS PROGRAM CONVERTS ASCII KEYBOARD INPUT TO MORSE CODE OUTPUT *)

PROGRAM MORSE_CODE;

CONST
  FIFTY_MILLISECONDS = 50;

VAR
  CH[4] : INTEGER;

PROCEDURE GET_KEY;

VAR
  CODETABLE[,.ROM] : ARRAY [0 .. 63] OF INTEGER;

VALUE
  CODETABLE =
    (2_00000000, 7 OF 2_10000000,
     2_10110110, 2_10110110, 2_10000000, 2_10000000,
     2_11011110, 2_10000000, 2_11100010, 2_11100010,
     2_11111110, 2_01111110, 2_00111110, 2_00111110,
     2_00001100, 2_01000000, 2_10000000, 2_11000000,
     2_11001000, 2_11111000, 2_11100010, 2_11100010,
     2_10000000, 2_10000000, 2_10000000, 2_10000000,
     2_00000100, 2_00100000, 2_00100000, 2_00100000,
     2_00001000, 2_00001000, 2_01111110, 2_01111110,
     2_01001000, 2_11100010, 2_10100000, 2_10100000,
     2_01010000, 2_00100000, 2_00100000, 2_00100000,
     2_10000000, 2_10000000, 2_10000000, 2_10000000);

BEGIN (* GET_KEY *)
  REPEAT
    UNTIL PORT1 BIT 7; (* PIN 7 HIGH MEANS KEY PUSHED *)

    CH := PORT1 AND 2_01111111;

  REPEAT
    UNTIL NOT PORT1 BIT 7; (* WAIT FOR PIN 7 LOW *)

  (* CONVERT LOWER CASE LETTERS TO UPPER CASE *)
  IF CH > 16_60 THEN CH := CH - 16_40
  ELSE CH := CH - 16_20;

  CH := CODETABLE[CH] (* LOOK UP MORSE CODE *)
END; (* GET_KEY * )
PROCEDURE SEND;

VAR
  I[2] : INTEGER;

PROCEDURE DIT;

BEGIN
  PORT2 := PORT2 AND 2_11111110;
  DELAY(FIFTY_MILLISECONDS);
  PORT2 := PORT2 OR 2_00000001;
  DELAY(FIFTY_MILLISECONDS)
END; (* DIT *)

PROCEDURE DAH;

BEGIN
  PORT2 := PORT2 AND 2_11111110;
  DELAY(150); (* 150 MILLISEC DELAY *)
  PORT2 := PORT2 OR 2_00000001;
  DELAY(FIFTY_MILLISECONDS)
END; (* DAH *)

BEGIN (* SEND *)
  IF CH = 0 THEN (* MEANS ILLEGAL CHARACTER *)
    FOR I := 8 DOWNTO 1 DO
      DIT
  ELSE WHILE CH <> 2_10000000 DO
    BEGIN
      IF NOT CH BIT 7 THEN
        DIT
      ELSE DAH;
      CH := CH SHL 1
    END (* WHILE *)
  END; (* SEND *)

BEGIN (* THE MAIN PROGRAM: MORSE_CODE *)
  PORT2 := PORT2 AND 2_11111110;
  PORT1 := PORT1 OR 2_00000001;
  WHILE TRUE DO
    BEGIN
      GET_KEY;
      SEND
    END (* WHILE *)
END. (* THE MAIN PROGRAM *)
--- Example Program 2 ---

PROGRAM STOP_WATCH;

(* MAKE MCS-48 INTO A SIMPLE STOP WATCH *)
(* INPUT - BIT 7 OF THE BUS *)
(* OUTPUT - UPPER HALF PORT 1 MINUTES *)
(* LOWER HALF PORT 1 TENS OF SECS *)
(* UPPER HALF PORT 2 UNITS OF SECS *)
(* LOWER HALF PORT 2 TENTHS OF SECS *)

CONST
  TEN_MILLISEC = 128;

VAR
  DIGITS[60] : ARRAY[1..4] OF INTEGER;
  SWITCH_COUNT[2], INT_COUNT[3], I[4] : INTEGER;
  PROCEDURE DISPLAY;

  (* DISPLAY TO 9:59.9 ON PORT 1 AND PORT 2 *)

BEGIN
  PORT1 := DIGITS[1] SHL 4 + DIGITS[2];
  PORT2 := DIGITS[3] SHL 4 + DIGITS[4];
END (* DISPLAY *);
PROCEDURE TIMER_INT;

VAR
    SAVE_ACC[7] : INTEGER;

    BEGIN
        SAVE_ACC := ACCUMULATOR;
        TIMER := TEN_MILLISEC;
        START(TIMER);

        IF INT_COUNT = 9 THEN
            BEGIN
                INT_COUNT := 0;

                IF DIGITS[4] = 9 THEN
                    BEGIN
                        DIGITS[4] := 0;
                        IF DIGITS[3] = 9 THEN
                            BEGIN
                                DIGITS[3] := 0;
                                IF DIGITS[2] = 5 THEN
                                    BEGIN
                                        DIGITS[2] := 0;
                                        IF DIGITS[1] = 9 THEN
                                            DIGITS[1] := 0
                                        ELSE
                                            INCREMENT(DIGITS[1])
                                        END
                                    ELSE
                                        INCREMENT(DIGITS[2])
                                    END
                                ELSE
                                    INCREMENT(DIGITS[3])
                                END
                            ELSE
                                INCREMENT(DIGITS[4])
                            END
                        ELSE
                            INCREMENT(INT_COUNT);
                    END
                ELSE
                    INCREMENT(DIGITS[4])
                END
            ELSE
                INCREMENT(INT_COUNT);
        END

        DISPLAY;
        ACCUMULATOR := SAVE_ACC;
    END (* TIMER_INT *);
BEGIN
  SWITCH_COUNT := 0;

  WHILE TRUE DO
    BEGIN
      CASE SWITCH_COUNT OF
        0 : BEGIN
            FOR I := 4 DOWNTO 1 DO
              DIGITS[I] := 0;
              DISPLAY;
              END (* 0 *);
        1 : BEGIN
            INT_COUNT := 0;
            TIMER := TEN_MILLISEC;
            START(TIMER);
            ENABLE(TIMER_INT);
            END (* 1 *);
        2 : BEGIN
            STOP(TIMER);
            DISABLE(TIMER_INT);
            END (* 2 *);
      END (* CASE *);
    END (* CASE SWITCH_COUNT *);

    WHILE BUS BIT 7 DO;

    WHILE NOT(BUS BIT 7) DO;

      INCREMENT(SWITCH_COUNT);
      IF SWITCH_COUNT = 3 THEN SWITCH_COUNT := 0;
      END (* WHILE *);

  END (* STOP_WATCH *).
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-- Example Program 3 --

PROGRAM STOP_WATCH;

(* MAKE MCS-48 INTO A SIMPLE STOP WATCH *)
(* INPUT - BIT 7 OF THE BUS *)
(* OUTPUT - PORT 1 CONTAINS MINUTES *)
(* PORT 2 CONTAINS SECONDS *)

CONST
   TEN_MILLISEC = 128;

VAR
   SWITCH_COUNT[2] : INTEGER;

PROCEDURE DISPLAY;

(* DISPLAY BCD TO 99:59 ON PORTS 1 AND 2 *)

BEGIN
   PORT1 := MIN;
   PORT2 := SEC;
END (* DISPLAY *);
PROCEDURE TIMER_INT;

(* WHEN THE TIMER FLAG IS SET, THEN THE INT_COUNT *)
(* REGISTER IS INCREMENTED ONE. IF INT_COUNT IS *)
(* FILLED THIS PROCEDURE INCREMENTS THE SECONDS *)
(* AND DISPLAYS THEM. *)

VAR
SAVE_ACC[7] : INTEGER;

BEGIN
SAVE_ACC := ACCUMULATOR;
TIMER := TEN_MILLISEC;
START(TIMER);

IF INT_COUNT = 99 THEN
BEGIN
INT_COUNT := 0;
IF SEC = 16_59 THEN
BEGIN
SEC := 0;
MIN := DEC_ADJ(MIN + 1)
END
ELSE
SEC := DEC_ADJ(SEC + 1)
END
ELSE
INCREMENT(INT_COUNT);

DISPLAY;
ACCUMULATOR := SAVE_ACC;
END (* TIMER_INT *);
BEGIN

SWITCH_COUNT := 0;

WHILE TRUE DO
BEGIN

CASE SWITCH_COUNT OF

0 : BEGIN

SEC := 0;
MIN := 0;
DISPLAY;
END (* 0 *);

1 : BEGIN

INT_COUNT := 0;
TIMER := TEN_MILLISEC;
START(TIMER);
ENABLE(TIMER_INT);
END (* 1 *);

2 : BEGIN

STOP(TIMER);
DISABLE(TIMER_INT);
END (* 2 *);

END (* CASE *);

WHILE BUS BIT 7 DO;

WHILE NOT(BUS BIT 7) DO;

INCREMENT(SWITCH_COUNT);
IF SWITCH_COUNT = 3 THEN SWITCH_COUNT := 0;
END (* WHILE *)
END (* STOP_WATCH *).
-- Example Program 4 --

PROGRAM STOP_WATCH;

(* THIS PROGRAM IS THE SAME AS THE PREVIOUS EXAMPLE *)
(* EXCEPT IT USES AN INTERSIL ICM 7218 LED DRIVER *)
(* TO OUTPUT TO 7-SEGMENT DISPLAYS, AND IT ALSO *)
(* DISPLAYS .01 SECOND. THE OUTPUT IN THIS EXAMPLE *)
(* USES THE BUS AND BIT 0 OF PORT 1 TO CONTROL THE *)
(* 7218. INPUT IS ON BIT 7 OF PORT 2. *)

CONST
  TEN_MILLISEC = 128;

VAR
  SWITCH_COUNT[2] : INTEGER;
  INT_COUNT[3] : INTEGER;
  MIN[5] : INTEGER;

PROCEDURE DISPLAY;

(* DISPLAY WITH THE INTERSIL ICM 7218 LED DRIVER *)
(* DISPLAY TO 99:59.99 *)

VAR
  DSPL[46] : ARRAY[1..8] OF INTEGER;

BEGIN
  DSPL[1] := MIN ROTR 4 AND 16F; (* TENS OF MIN *)
  DSPL[2] := MIN AND 16F; (* UNITS OF MIN *)
  DSPL[3] := 15; (* NOT USED *)
  DSPL[6] := 15; (* NOT USED *)
  DSPL[7] := INT_COUNT ROTR 4 AND 16F; (* 0.1 SEC *)
  DSPL[8] := INT_COUNT AND 16F; (* 0.01 SEC *)
  PORT1 := 16_01; (* MODE LINE OF 7218 TO PORT1 BIT 0 *)
  BUS := 16_90; (* MODE WORD FOR B CODE *)
  PORT1 := 16_00; (* MODE LINE LOW TO START DATA *)
  FOR I := 8 DOWNTO 1 DO (* LOAD ALL 8 DISPLAY BITS *)
    BUS := DSPL[I] OR 16_80
END (* DISPLAY *);
PROCEDURE TIMER_INT;

(* WHEN THE TIMER FLAG IS SET, THEN THE INT_COUNT *)
(* REGISTER IS INCREMENTED ONE. IF INT_COUNT IS *)
(* FILLED THIS PROCEDURE INCREMENTS THE SECONDS *)
(* AND DISPLAYS THEM. *)

VAR
  SAVE_ACC[7] : INTEGER;

BEGIN
  SAVE_ACC := ACCUMULATOR;
  TIMER := TEN_MILLISEC;
  START(TIMER);

  (* DECIMAL ADJUST WILL SET THE CARRY *)
  (* BIT IF OVERFLOW IS DETECTED. *)
  INT_COUNT := DEC_ADJ(INT_COUNT + 1);
  IF CARRY THEN
    IF SEC = 16_59 THEN
      BEGIN
        SEC := 0;
        MIN := DEC_ADJ(MIN + 1)
      END
    ELSE
      SEC := DEC_ADJ(SEC + 1);
  DISPLAY;
  ACCUMULATOR := SAVE_ACC;
END (* TIMER_INT *);
BEGIN

SWITCH_COUNT := 0;

WHILE TRUE DO
BEGIN
CASE SWITCH_COUNT OF
  0 : BEGIN
           INT_COUNT := 0;
           SEC := 0;
           MIN := 0;
           DISPLAY;
           END (*) 0 *);
  1 : BEGIN
           TIMER := TEN_MILLISEC;
           START(TIMER);
           ENABLE(TIMER_INT);
           END (*) 1 *);
  2 : BEGIN
           STOP(TIMER);
           DISABLE(TIMER_INT);
           END (*) 2 *);
END (*) CASE *);

WHILE PORT2 BIT 7 DO;

WHILE NOT(PORT2 BIT 7) DO;

INCREMENT(SWITCH_COUNT);
IF SWITCH_COUNT = 3 THEN SWITCH_COUNT := 0;
END (*) WHILE *)
END (*) STOP_WATCH *).
The fourth program of Appendix A is included here as an example of the output listing and object file generated by the Pascal/48 cross compiler. The Langley CYBER/NOS control cards used to generate the files from the input source STOPWAT are:

GET,STOPWAT.
GET,PAS48/UN=MICRO.
PAS48,STOPWAT,LISTING,OBJECT/I+,P48.

The file OBJECT is the object code of the stopwatch program. The appropriate record format, which is generated for the object file, includes the record mark, byte count, address, and type, the program memory, and the record checksum. All records of program memory are 16 bytes long starting at an even 16-byte address. The object code of the stopwatch program is:

```
:1000000004700004030000044DF47530FB82EA0F8
:1001000230F5DB82FA0B83B00FFC47530FB83195
:1002200A0230F5CB832A0B833B00FFB47530FB812
:100330034A0230F5BB835A0230139239002273960
:1004400BE08FE032DA8F0438002EE4283AF23805A
:1005500625523016B57ABE66C2359DC966727ACDE
:100600023016D57AD046C23016C57AC1409FF9349
:100700027D727AAPA038DB327AB27AC27AD1409DE
:10080000490238062352504906535049078828918
:10090000A37F29604900AF29B04961A2303DA9622
:100A000A327AA047404A5000000000000000BB
:00000001FF
```

The file LISTING is the output listing of the compiler. The compiler options, I+ and P48, are selected to include the image of the object code and 48 lines per page for documentation purposes.
PROGRAM STOP_WATCH;

(* THIS PROGRAM IS THE SAME AS THE PREVIOUS EXAMPLE *)
(* EXCEPT IT USES AN INTERSIL ICM 7218 LED DRIVER *)
(* TO OUTPUT TO 7-SEGMENT DISPLAYS, AND IT ALSO *)
(* DISPLAYS .01 SECOND. THE OUTPUT IN THIS EXAMPLE *)
(* USES THE BUS AND BIT 0 OF PORT 1 TO CONTROL THE *)
(* 7218. INPUT IS ON BIT 7 OF PORT 2. *)

CONST
  TEN_MILLISEC = 128;

VAR
  SWITCH COUNT[2] : INTEGER;
  INT_COUNT[3] : INTEGER;
  MIN[5] : INTEGER;

PROCEDURE DISPLAY;

(* DISPLAY WITH THE INTERSIL ICM 7218 LED DRIVER *)
(* DISPLAY TO 99:59.99 *)

VAR
  DSPL[46] : ARRAY[1..8] OF INTEGER;

BEGIN
  DSPL[1] := MIN ROTR 4 AND 16_F; (* TENS OF MIN *)
  DSPL[2] := MIN AND 16_F; (* UNITS OF MIN*)
  DSPL[3] := 15; (* NOT USED *)
  DSPL[4] := SEC ROTR 4 AND 16_F; (* TENS OF SEC *)
  DSPL[6] := 15; (* NOT USED *)
  DSPL[7] := INT_COUNT ROTR 4 AND 16_F; (* 0.1 SEC *)
  DSPL[8] := INT_COUNT AND 16_F; (* 0.01 SEC *)
  PORT1 := 16_01; (* MODE LINE OF 7218 TO PORT1 BIT 0*)
  BUS := 16_90; (* MODE WORD FOR B CODE *)
  PORT1 := 16_00; (* MODE LINE LOW TO START DATA *)
  FOR I := 8 DOWNTO 1 DO (* LOAD ALL 8 DISPLAY BITS *)
    BUS := DSPL[I] OR 16_80
END (* DISPLAY *);
PROCEDURE TIMER_INT;

(* WHEN THE TIMER FLAG IS SET, THEN THE INT_COUNT *)
(* REGISTER IS INCREMENTED ONE. IF INT_COUNT IS *)
(* FILLED THIS PROCEDURE INCREASES THE SECONDS *)
(* AND DISPLAYS THEM. *)

VAR

SAVE_ACC[7] : INTEGER;

BEGIN

SAVE_ACC := ACCUMULATOR;
TIMER := TEN_MILLISEC;
START(TIMER);

(* DECIMAL ADJUST WILL SET THE CARRY *)
(* BIT IF OVERFLOW IS DETECTED. *)
INT_COUNT := DEC_ADJ(INT_COUNT + 1);

IF CARRY THEN

IF SEC = 16_59 THEN
BEGIN
SEC := 0;
MIN := DEC_ADJ(MIN + 1)
END
ELSE
SEC := DEC_ADJ(SEC + 1);

DISPLAY;

ACCUMULATOR := SAVE_ACC;
END (* TIMER_INT *);

BEGIN

SWITCH_COUNT := 0;

WHILE TRUE DO
BEGIN
CASE SWITCH_COUNT OF

0 : BEGIN
INT_COUNT := 0;
SEC := 0;
MIN := 0;
DISPLAY;
END (* 0 *);

1 : BEGIN
TIMER := TEN_MILLISEC;
START(TIMER);
```pascal
086 97        ENABLE(TIMER_INT);
087 98        END (* 1 *);
089 99        2 : BEGIN
089 100       STOP(TIMER);
08A 101       DISABLE(TIMER_INT);
08B 102       END (* 2 *);
08D 103       END (* CASE *);
090 104
090 105       WHILE PORT2 BIT 7 DO;
096 106
096 107       WHILE NOT(PORT2 BIT 7) DO;
09B 108
09B 109       INCREMENT(SWITCH_COUNT);
09C 110       IF SWITCH_COUNT = 3 THEN SWITCH_COUNT := 0;
0A3 111       END (* WHILE *)
0A5 112       END (* STOP_WATCH *).
```
MODULE DEC REFERENCES
STOP_WATCH 1

VARIABLE TYPE-LENGTH DEC REFERENCES
ACCUMULATO T(PRE, 1) 60 77
BUS I(PRE, 1) 40 43
CARRY B(PRE, 1) 67
PORT1 I(PRE, 1) 39 41
PORT2 I(PRE, 1) 105 107
TIMER I(PRE, 1) 61 62 95 96 100
TRUE B(LIT, 1) 85

VARIABLE TYPE-LENGTH DEC REFERENCES
INT_COUNT I(REG, 1) 15 37 38 66 66 89
MIN I(REG, 1) 17 31 32 71 71 91
SEC I(REG, 1) 16 34 35 68 70 74 74 90
SWITCH COU I(REG, 1) 14 83 87 109 110 110
TEN_MILLIS I(LIT, 1) 11 61 95

MODULE DEC REFERENCES
DISPLAY 21 76 92

VARIABLE TYPE-LENGTH DEC REFERENCES
DSPL I(RAM, 8) 27 31 32 33 34 35 36 37 38 43
I I(REG, 1) 28 42 43

MODULE DEC REFERENCES
TIMER_INT 49

VARIABLE TYPE-LENGTH DEC REFERENCES
SAVE_ACC I(REG, 1) 57 60 77

PROCEDURE LIST - INDENTATION INDICATES LEVEL OF NEST

STOP_WATCH  
   DISPLAY
   TIMER_INT

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043 03 2D ADD A,#2DH ; LINE 45
045 A8 MOV R0,A ; LINE 45
046 F0 MOV A,@R0 ; LINE 45
047 43 80 ORL A,#80H ; LINE 45
049 02 OUTL BUS,A ; LINE 45
04A EE 42 DJNZ R6,L042 ; LINE 45
04C 83 RET ; LINE 45

; PROCEUDRE TIMER_INT
L04D: MOV _RT,A ; LINE 49
04E 23 80 MOV A,#80H ; LINE 61
050 62 MOV T,A ; LINE 61
051 55 STRT T ; LINE 62
052 23 01 MOV A,#01H ; LINE 63
054 6B ADD A,R3 ; LINE 66
055 57 DA A ; LINE 66
056 AB MOV R3,A ; LINE 66
057 E6 6C JNC L06C ; LINE 67
059 23 59 MOV A,#59H ; LINE 68
05B DC XRL A,R4 ; LINE 68
05C 96 67 JNE L067 ; LINE 68
05E 27 CLR A ; LINE 69
05F AC MOV R4,A ; LINE 70
060 23 01 MOV A,#01H ; LINE 71
062 6D ADD A,R5 ; LINE 72
063 57 DA A ; LINE 72
064 AD MOV R5,A ; LINE 72
065 04 6C JMP L06C ; LINE 72
067 23 01 MOV A,#01H ; LINE 73
069 6C ADD A,R4 ; LINE 74
06A 57 DA A ; LINE 74
06B AC MOV R4,A ; LINE 74
06C 14 09 CALL L009 ; LINE 75
06E FF MOV A,R7 ; LINE 77
06F 93 RETR ; LINE 78

; PROGRAM STOP_WATCH
L070: CLR A ; LINE 79
071 D7 MOV PSW,A ; LINE 82
072 27 CLR A ; LINE 83
073 AA MOV R2,A ; LINE 83
074 FA JMP @A ; LINE 84
075 03 8D ADD A,#8DH ; LINE 87
077 B3 JMPP @A ; LINE 87
078 27 CLR A ; LINE 88
079 AB MOV R3,A ; LINE 90
07A 27 CLR A ; LINE 91
07B AC MOV R4,A ; LINE 91

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<table>
<thead>
<tr>
<th>LOC</th>
<th>OBJ CODE</th>
<th>SOURCE STATEMENT</th>
</tr>
</thead>
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<td>07C</td>
<td>27</td>
<td>CLR A</td>
</tr>
<tr>
<td>07D</td>
<td>AD</td>
<td>MOV R5,A</td>
</tr>
<tr>
<td>07E</td>
<td>14 09</td>
<td>CALL L099</td>
</tr>
<tr>
<td>080</td>
<td>04 90</td>
<td>JMP L090</td>
</tr>
<tr>
<td>082</td>
<td>23 80</td>
<td>MOV A,#80H</td>
</tr>
<tr>
<td>084</td>
<td>62</td>
<td>MOV T,A</td>
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<tr>
<td>085</td>
<td>55</td>
<td>STRT T</td>
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<tr>
<td>086</td>
<td>25</td>
<td>EN TCNTI</td>
</tr>
<tr>
<td>087</td>
<td>04 90</td>
<td>JMP L090</td>
</tr>
<tr>
<td>089</td>
<td>65</td>
<td>STOP TCNT</td>
</tr>
<tr>
<td>08A</td>
<td>35</td>
<td>DIS TCNTI</td>
</tr>
<tr>
<td>08D</td>
<td>04 90</td>
<td>JMP L090</td>
</tr>
<tr>
<td>08E</td>
<td>78</td>
<td>DB 78H</td>
</tr>
<tr>
<td>08F</td>
<td>82</td>
<td>DB 82H</td>
</tr>
<tr>
<td>090</td>
<td>89</td>
<td>DB 89H</td>
</tr>
<tr>
<td>090</td>
<td>0A</td>
<td>IN A,P2</td>
</tr>
<tr>
<td>091</td>
<td>37</td>
<td>CPL A</td>
</tr>
<tr>
<td>092</td>
<td>F2 96</td>
<td>JB7 L096</td>
</tr>
<tr>
<td>094</td>
<td>04 90</td>
<td>JMP L090</td>
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<tr>
<td>096</td>
<td>0A</td>
<td>IN A,P2</td>
</tr>
<tr>
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<td>F2 9B</td>
<td>JB7 L096</td>
</tr>
<tr>
<td>099</td>
<td>04 96</td>
<td>JMP L096</td>
</tr>
<tr>
<td>09B</td>
<td>1A</td>
<td>INC R2</td>
</tr>
<tr>
<td>09C</td>
<td>23 03</td>
<td>MOV A,#03H</td>
</tr>
<tr>
<td>09E</td>
<td>DA</td>
<td>XRL A,R2</td>
</tr>
<tr>
<td>09F</td>
<td>96 A3</td>
<td>JNZ L0A3</td>
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<td>0A1</td>
<td>27</td>
<td>CLR A</td>
</tr>
<tr>
<td>0A2</td>
<td>AA</td>
<td>MOV R2,A</td>
</tr>
<tr>
<td>0A3</td>
<td>04 74</td>
<td>JMP L074</td>
</tr>
<tr>
<td>0A5</td>
<td>04 A5</td>
<td>JMP L0A5</td>
</tr>
</tbody>
</table>

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13  APPENDIX C - SYNTAX DIAGRAMS

<<< program >>>

----> PROGRAM ---> ident ---> ; ---> block ---> . ----->

<<< ident >>>

----> letter --->
     ^
    |  <- letter <-
    |  <- digit <-
    |  _ <-

<<< int_const >>>

----> digit ---+----+-----+ digit ----->
     ^             ^             ^
    |             |             |-> letter
    |             |

<<< block >>>

----> lab_part ---> con_part ----> var_part ----->
     ^             ^
    |             |

----> val_part ---> proc_part ---> cmpnd_stmt ----->
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<<< type_spec >>>

→ array_spec → OF → scl_type ---->

<<< array_spec >>>

→ ARRAY → [ → int_const → .. → int_const → ] ---->

<<< scl_type >>>

----> INTEGER

→ BOOLEAN

→ [ → int_const → ]

→ CHAR

<<< val_part >>>

→ VALUE → ident → = → val_con ; ---->

<<< val_con >>>

→ ( → int_const → OF → constant → ) ---->
<<< proc_part >>>

→→ proc_hdr →→ proc_body →→ ; →→

<<< proc_hdr >>>

→→ PROCEDURE →→ ident →→ ; →→

<<< proc_body >>>

→→ EXTERNAL →→ [ →→ int_const →→ ] →→

--------------- FORWARD ---------------

--------------- block ---------------

<<< cmpnd_stmt >>>

→→ BEGIN →→ statement →→ END →→

-------------------- ; --------------------

<<< expression >>>

→→ monadic_op →→ ( →→ expression →→ ) →→

→→ monadic_op →→ constant →→

→→ monadic_op ←→ constant ←→ variable

-------------------- dyadic_op ←→-----------------------
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<<< variable >>>

--- ident --- [ --- int_const --- ] --->

<<< statement >>>

--- int_const --- : --- assignStmt ---

--- ifStmt ---

--- whileStmt ---

--- reptStmt ---

--- forStmt ---

--- caseStmt ---

--- callStmt ---

--- gotoStmt ---

--- cmpndStmt ---

<<< assignStmt >>>

--- variable --- := --- expression ---
<<< if_stmt >>>

--- > IF --- > expression --- > THEN --- > statement --- >

--- > ELSE --- > statement --- >

<<< while_stmt >>>

--- > WHILE --- > expression --- > DO --- > statement --- >

<<< rept_stmt >>>

--- > REPEAT --- > statement --- > UNTIL --- > expression --- >

<<< for_stmt >>>

--- > FOR --- > for_list --- > DO --- > statement --- >

<<< for_list >>>

--- > ident --- > := --- > con_var --- > TO --- > con_var --- >

--- > DOWNTO --- >
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<<< case_stmt >>>

---> CASE --> expression --> OF
     --> case_list_elt --> END -->
     ; ←---

<<< case_list_elt >>>

---> constant : --> statement -->
     , ←---

<<< goto_stmt >>>

---> GOTO --> int_const -->

<<< call_stmt >>>

---> ident -->
APPENDIX D - ERROR MESSAGES

Four classes of error messages are provided to aid the Pascal/48 programmer in generating correct programs. The lower case notation in the messages are compiler derived from the Pascal/48 program source.

- **ch**: A single character.
- **id**: The significant characters of an identifier.
- **sym**: An internal Pascal/48 symbol.
- **num**: A decimal number.
- **hex**: A hexadecimal number.

The internal symbols are the reserved words, special symbols, and terminals of the language grammar. The terminals include the special notation of `<CONST>` for a constant and `<IDENT>` for an identifier.

**WARNING AT LINE** num
The rules of the language are not violated, however, the code generated may not be what the user intended. The assembly listing should be checked for correctness.

**BASE** num IS NOT 2, 8 OR 16
The base specified is non-standard and may detract from the meaning of the program.

**CASE STATEMENT** CODE IS SHIFTED hex LOCATIONS TO NEXT PAGE
A page boundary was crossed during a CASE statement. The complete CASE statement is moved to the next page boundary.

**GOTO** num IN id POSSIBLE PSW ERROR
A GOTO out of a procedure has occurred but the compiler will not modify the program status word or the program stack.

**id** INTERRUPT HANDLER REFERENCED
Interrupt routines should be referenced through the hardware interrupt mechanism and not with software references.

**INTERCEPT REDEFINED BY** id
The hardware locations for the timer interrupt and counter interrupt interface are the same. Either the timer or counter interrupt can be defined in one program.

**LINES FOLLOWING** END OF PROGRAM IGNORED
Non-comments follow the program terminating period.

**id** LOCATED WITHIN COMPILER TEMPORARIES
Registers 0 and 1 are used by the compiler and should not be used by the programmer.
id LOCATED WITHIN PROGRAM STACK
   RAM locations 8 through 24 contain the program stack and
redefinition of the stack will affect the procedure
communication.

MAXIMUM STRING LENGTH num EXCEEDED
   A character string has exceeded the compiler limits and will
be truncated.

ORIGIN OF hex LESS THAN LOCATION hex
   The current location counter is greater than the specified
origin option value.

id REDEFINED BY PROGRAM
   A predeclared variable has been redefined by the program for
the current scope.

ROM VARIABLE id NOT INITIALIZED
   A ROM variable has not been initialized with the VALUE
statement.

TOO FEW VALUES SPECIFIED FOR id
   An array of a ROM variable is not completely initialized with
the VALUE statement.

UNREFERENCED LABEL : num
   A label has been defined but has not been referenced within
the scoping limits.

UNREFERENCED PROCEDURE id
   A procedure has been defined but has not been referenced
within the scoping limits.
SEMANTIC ERROR AT LINE num
The rules of the language are violated and the code generation is terminated. The program semantics and syntax will be continually checked.

ADDRESS SPECIFICATION REQUIRED FOR id
Declarations of variables must include an address specification.

ARRAY REFERENCE EXPECTED FOR id
The variable has been declared as an array and all references to the variable must be indexed.

CONSTANT num EXCEEDS RANGE FOR id
The range of a hardware memory device has been exceeded by the constant.

CONTROL VARIABLE id IS REDEFINED
The control variable of a FOR loop has been redefined within the loop.

DIGIT ch GREATER THAN BASE num
A digit in a constant is greater than the base specified.

EMPTY INPUT FILE
The source file specified is not local to the control point.

num ERRORS PER LINE EXCEEDED
The internal stack for errors per line is exceeded. The errors are continued for the error summary but not noted in the source listing.

FORWARD PROCEDURE id NOT DEFINED
A procedure has been declared as a forward reference but has not been defined.

GLOBAL ROM REQUIRES ADDRESS
The optional address specification for ROM variables is required for global variables.

IDENTIFIER id DECLARED TWICE
The identifier has been declared more than once within the current scope level.

IDENTIFIER id NOT DECLARED
The identifier referenced has not been declared.

ILLEGAL ADDRESS REFERENCE num
An arrayed ROM variable initialization crosses the page boundary in the VALUE statement.
ILLEGAL BASE num SPECIFIED
A base value of 0 or greater than 35 is specified.

ILLEGAL CHARACTER ch
An invalid Pascal/48 character is encountered and is ignored.

ILLEGAL MEMORY REFERENCE id
The identifier is not a valid memory reference. Variable declarations must be RAM, ROM or XRAM. The optional address specification for variables and the value initialization of variables must be ROM.

ILLEGAL STRING REFERENCE
A character string is only valid in the VALUE statement to initialize arrays of characters.

INDEX num OUT OF BOUNDS FOR id
The index exceeds the declared array limits of the variable.

INVALID ARRAY REFERENCE FOR id
The variable has been referenced as an array but has not been declared as an array.

INVALID BIT BOOLEAN REFERENCE
A bit specified Boolean has been reference in an illegal context.

INVALID BIT REFERENCE num
A bit reference can only be in the range 0-7.

INVALID EXPRESSION REFERENCE
An expression is encountered in a predeclared procedure reference.

INVALID LITERAL EXPRESSION
A forward label reference with an ADDR WORD or ADDR PAGE monadic operation is contained in a literal expression. The monadic operations are treated as literals so the compiler attempts to evaluate the literal expression and therefore would destroy the internal code for patching the forward reference.

INVALID LOOP CONTROL VARIABLE id
A loop control variable can only be a simple integer.

INVALID SCOPE REFERENCE FOR id
The Pascal scoping rules have been violated with the identifier reference.

INVALID TRANSLATE OPERATOR FOR OPERATION id
An invalid internal operator has been generated. This error should not occur and if it does it should be reported.
INVALID TYPE SPECIFICATION id
Only BOOLEAN, INTEGER and CHAR types are legal.

id IS NOT A CONSTANT
The identifier referenced has not been declared as a constant.

id IS NOT A PREDECLARED PROCEDURE
Arguments are only valid for the predeclared procedures.

LOW BOUND EXCEEDS HIGH BOUND
The array specification is in error.

MULTIDEKLARED LABEL : num
A label number is declared more than once.

MULTIDElFElD CASE LABEL : num
A case label has been assigned to more than one statement.

MULTIDEFINED LABEL : num
A label has been assigned to a statement more than once.

NULL STRING INVALID
Strings must contain one or more characters.

PAGE BOUNDARY ERROR ENCOUNTERED AT hex REFERENCED AT hex
A conditional jump cross a page boundary has been generated by the compiler. The programmer can either select the boundary compiler option or adjust the code with the origin compiler option.

PARSE TERMINATED
A compiler abort has occurred. The listing is continued but no supplement information is provided beyond this point.

READ ONLY VARIABLE id
Assignments cannot be made to ROM variables or specialized predeclared variables.

REDEFINED ROM AT LOCATION hex
ROM is redefined by overloaded variables or code is generated at a ROM variable data location.

REFERENCE MUST BE id
The identifier specifies the structure allowed in the context of the source.

RUNAWAY NESTED COMMENT
The beginning comment symbol (*) has not been matched by the terminating symbol *).
STATEMENT TOO COMPLICATED
The internal stack limits have been exceeded. This implies the nesting levels are excessive or a statement is too complex for the compiler parsing scheme.

TOO MANY VALUES SPECIFIED FOR id
The initialization list in a VALUE statement exceeds the range of the array.

id TYPE IS EXPECTED
The identifier specifies the only data type allowed in the source structure.

id TYPE IS UNEXPECTED
Mixed mode has occurred and the type specified is the first conflicting type.

UNABLE TO PATCH LABEL num ADDRESS
The compiler was unable to patch the label address for a forward reference by the ADDR WORD or ADDR PAGE monadic operators.

UNDECLARED LABEL : num
A label referenced has not been declared.

UNDEFINED LABEL : num
A label referenced has not been assigned to a statement.

UNEXPECTED IDENTIFIER id
Either an identifier is not expected in the context or a key word is expected.
SYNTAX ERROR AT LINE num
The grammar rules of the language are violated. An attempt is made to fix the syntax and the parsing is continued. Syntax errors occur in pairs. The first error points to the symbol where the error is detected. The recovery scheme scans ahead in the source and an attempt is made to fix the error with respect to the context. The second error specifies the fix to obtain the correct grammar syntax with respect to the symbol specified in the first error. The fix of the syntax error may not be what the programmer intended so the code generation and semantic checking are terminated.

<EOF> ENCOUNTERED DURING RECOVERY
While attempting a syntax error recovery an end-of-file was encountered. This error commonly occurs when the BEGIN-END pairs of compound statements do not match.

EXPECTED SYMBOL : sym
The symbol specified is necessary in the source context and to obtain exceptable syntax the symbol is inserted.

RECOVER FAILURE LIMIT EXCEEDED
More than three recovery failures has occurred in the program. It is assumed that any errors occurring beyond this point will be meaningless. The parsing is terminated but the listing is continued.

RECOVERY ATTEMPTED AT SYMBOL : sym
The symbol specified violates the syntax rules of the grammar. An attempt will be made to correct the syntax by deleting or replacing the symbol, or by inserting a symbol before the symbol specified.

RECOVERY FAILED, CONTINUE SCAN AT : sym
Usually more than one syntax error is encountered in a statement and the recovery method cannot correct the error with a simple deletion, insertion or replacement. The compiler searches forward until parsing can be resumed.

SUBSTITUTED SYMBOL : sym
The symbol specified replaces another symbol in the source to obtain exceptable syntax.

UNEXPECTED SYMBOL : sym
The symbol specified is not valid in the source context and to obtain exceptable syntax the symbol is deleted.
COMPILER ERROR AT LINE num

Compiler errors should not occur and indicate that the compiler is in error. If encountered such errors should be reported. Compiler errors are caused by semantic errors which generate erroneous internal variable values. The compiler should define exceptable internal data when an error condition is encountered. Abnormal termination of the compiler other than the compiler halt with a dayfile message should also be reported.

NUMBER num id num

Compiler information for problem evaluation.
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Pascal/48 Reference Manual

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Pascal/48 is a programming language for the Intel MCS-48 series of microcomputers. In particular, it can be used with the Intel 8748. It is designed to allow the programmer to control most of the instructions being generated and the allocation of storage. The language can be used instead of assembly language in most applications while allowing the user the necessary degree of control over hardware resources. Although it is called Pascal/48, the language differs in many ways from Pascal. The program structure and statements of the two languages are similar, but the expression mechanism and data types are different.

The Pascal/48 cross-compiler is written in Pascal and runs on the CDC CYBER NOS system. It generates object code in Intel hexadecimal format that can be used to program the MCS-48 series of microcomputers.

This reference manual defines the language, describes the predeclared procedures, lists error messages, illustrates use, and includes language syntax diagrams.

microprocessor, microcomputer, compiler, Pascal, and HOL

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