# Easy Logarithms for COP400

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Logarithms have long been a convenient tool for the simplification of multiplication, division, and root extraction. Many assembly language programmers avoid the use of logarithms because of supposed complexity in their application to binary computers. Logarithms conjure up visions of time consuming iterations during the solution of a long series. The problem is far simpler than imagined and its solution yields, for the applications programmer, the classical benefits of logarithms:

1) Multiplication can be performed by a single addition.

2) Division can be performed by a single subtraction.

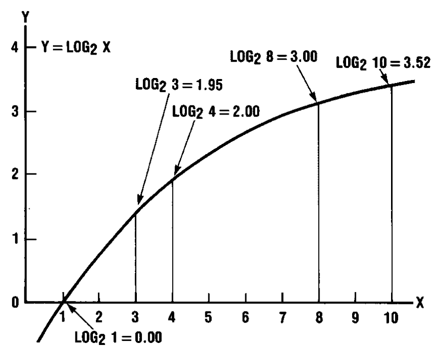
3) Raising a number to a power involves a single multiply.

4) Extracting a root involves a single divide.

When applied to binary computer operation logarithms yield two further important advantages. First, a broad range of values can be handled without resorting to floating point techniques (other than implied by the characteristic). Second, it is possible to establish the significance of an answer during the body of a calculation, again, without resorting to floating point techniques.

Implementation of $base_{10}$ logarithms in a binary system is cumbersome and unnecessary since logarithmic functions can be implemented in a number system of any base. The techniques presented here deal only with logarithms to the $base_2$.

A logarithm consists of two parts: an integer characteristic and a fractional mantissa.

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| | CHARACTERISTIC | MANTISSA |
|---|---|---|
| $LOG_2$ 3 = | 1 | 0.95 |
| $LOG_2$ 4 = | 2 | 0.00 |
| $LOG_2$ 8 = | 3 | 0.00 |
| $LOG_2$ 10 = | 3 | 0.52 |

**FIGURE 1. The Logarithmic Function and Some Example Values**

In *Figure 1* some points on the logarithmic curve are identified and evaluated to the $base_2$. Notice that the characteristic in each case represents the highest even power of 2 contained in the value of X. This is readily seen when binary notation is used.

| $X_{10}$ | $X_2$ $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $Log_2$ X Characteristic | $Log_2$ X Where X = Even Power of 2 |
|---|---|---|---|---|---|---|---|
| 3 | 0 | 0 | 0 | ↑ | 1 | 1 | |
| 4 | 0 | 0 | ↑ | 0 | 0 | 2 | 010.0000 |
| 8 | 0 | ↑ | 0 | 0 | 0 | 3 | 011.0000 |
| 10 | 0 | ↑ | 0 | 1 | 0 | 3 | |

**FIGURE 2. Identification of the Characteristic**

In *Figure 2* each point evaluated in *Figure 1* has been repeated using binary notation. An arrow subscript indicates the highest even power of 2 appearing in each value of X. Notice that in X = 3 the highest even power of 2 is $2^1$. Thus the characteristic of the $\log_2 3$ is 1. Where X = 10 the characteristic of the $\log_2 10$ is 3.

To find the $\log_2$ X is very easy where X is an even power of 2. We simply shift the value of X left until a carry bit emerges from the high order position of the register. This procedure is illustrated in *Figure 3*. This characteristic is found by counting the number of shifts required and subtracting the result from the number of bits in the register. In practice it is easier to being with the number of bits and count down once prior to each shift.

| Counter for Characteristic | Value of X in Binary | | |
|---|---|---|---|
| 1 0 0 0 | 0 0 0 0 | 1 0 0 0 | Initial |
| 0 1 1 1 | 0 0 0 1 | 0 0 0 0 | First Shift |
| 0 1 1 0 | 0 0 1 0 | 0 0 0 0 | Second Shift |
| 0 1 0 1 | 0 1 0 0 | 0 0 0 0 | Third Shift |
| 0 1 0 0 | 1 0 0 0 | 0 0 0 0 | Fourth Shift |
| 0 0 1 1 | 0 0 0 0 | 0 0 0 0 | Fifth Shift |
| **Characteristic** | **Mantissa** | | **Final** |
| 0 1 1 . 0 0 0 0 | 0 0 0 0 | | $Log_2$ X = 3.00 |

**FIGURE 3. Conversion to $Base_2$ Logarithm by Base Shift**

Examination of the final value obtained in *Figure 3* reveals no bits in the mantissa. The value 3 in the characteristic, however, indicates that a bit did exist in the $2^3$ position of the original number and would have to be restored in order to reconstruct the original value (antilog).



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The log of any even power of 2 can be found in this way:

| Decimal | Binary | $Log_2$ |
|---|---|---|
| 128 | 1 0 0 0 0 0 0 0 | 0 1 1 1 . 0 0 0 0 0 0 0 0 |
| 64 | 0 1 0 0 0 0 0 0 | 0 1 1 0 . 0 0 0 0 0 0 0 0 |
| 32 | 0 0 1 0 0 0 0 0 | 0 1 0 1 . 0 0 0 0 0 0 0 0 |
| 4 | 0 0 0 0 0 1 0 0 | 0 0 1 0 . 0 0 0 0 0 0 0 0 |
| 2 | 0 0 0 0 0 0 1 0 | 0 0 0 1 . 0 0 0 0 0 0 0 0 |
| 1 | 0 0 0 0 0 0 0 1 | 0 0 0 0 . 0 0 0 0 0 0 0 0 |

**FIGURE 4. $Base_2$ Logarithms of Even Powers of 2**

A simple flow chart, and program, can be devised for generating the values found in the table and, as will be apparent, a straight line approximation for values that are not even powers of 2. The method, as already illustrated in *Figure 3,* involves only shifting a binary number left until the most significant bit moves into the carry position. The characteristic is formed by counting. Since a carry on each successive shift will yield a decreasing power of 2, we must start the characteristic count with the number of bits in the binary value (x) and count down one each shift.

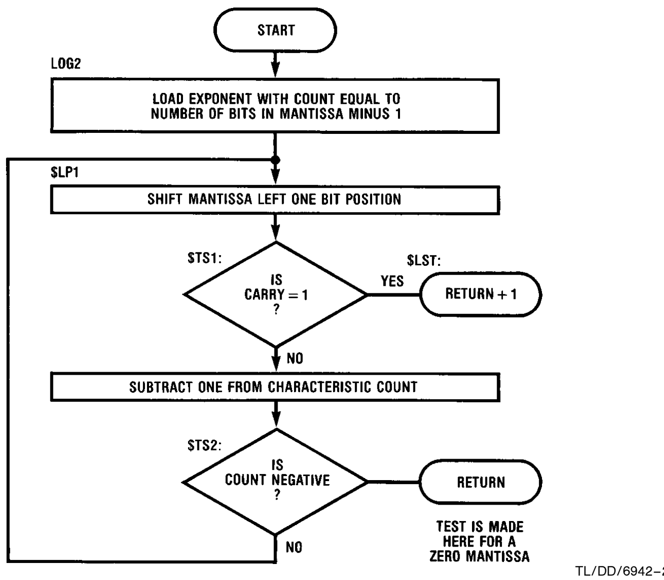


**FIGURE 5. Log Flowchart**

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LOGS

                        ; TITLE LOGS                    ; BINARY LOGARITHMS

          01A4                      . CHIP 420

                                    ; ------> CONVERT TO LOGARITHM <------;
                        ;
                        ;                               RAM ASSIGNMENT
                        ;
                        ; DIGIT:    15  14  13  12  11  10  09  08  07  06  05  04  03  02  01  00
                        ;
                        ; REG 0    |   |   |   |   |   |   |   |   |CH |HM |LM |   |   |   |  TEMP  |
                        ;
                        ; REG 1    |   |   |   |CH |HM |LM |   |   |   |   |   |   |   |   |  TEMP  |
                        ;
                        ; REG 2    |   |   |   |   |  TEMP  |   |   |   |   |   |   |   |CH |HM |LM |
                        ;
                        ; REG 3    |   |   |   |   |   |   |   |   |   |   |  TEMP  |   |CH |HM |LM |
                        ;
                        ;
                                    . LOCAL
                        ;
                        ; CH, HM, LM REPRESENT ANY THREE SEQUENTIAL MEMORY DIGITS. THEY
                        ; MAY BE DEFINED IN ANY REGISTER. THE SYMBOLIC NOTATION CH, HM,
                        ; AND LM ARE USED FOR ADDRESSING TO ALLOW USER FLEXIBILITY.
                        ; UPON ENTRY TO THE ROUTINE HM AND LM CONTAIN THE HI AND LO
                        ; OF SOME VALUE X. THE MEMORY POINTER MUST CONTAIN THE ADDRESS
                        ; OF THE CHARACTERISTIC (CH). THE CONTENTS OF THIS LOCATION ARE
                        ; IGNORED AND ARE LOST DURING EXECUTION.
                        ;
                        ; UPON EXIT CH, HM, LM CONTAIN A STRAIGHT LINE APPROXIMATION OF
                        ; THE LOG BASE 2 OF X. CH = CHARACTERISTIC  HM = HI ORDER MANTISSA
                        ; LM = LO ORDER MANTISSA. AN 8 BIT MEMORY AREA (TEMP) IS USED IN
                        ; THE REGISTER OPPOSITE DURING THE CORRECTION OF A STRAIGHT
                        LINE APPROXIMATION OF A LOG OR AN ANTILOG.
                        ;           A TEST IS MADE FOR X = 0. IF THE VALUE OF X
                        ; IS NOT ZERO AN INSTRUCTION IS SKIPPED UPON RETURN
                        ; TO THE CALLING ROUTINE.
                        ;
                        ;                                              — EXAMPLE —
                        ;
                        ; SUBROUTINE CALL                                  JSR   LOG2
                        ; RETURN HERE IF X = 0 --->                        JP    ZERO
                        ; RETURN HERE IF X>0 --->                          CONTINUE
                        ;
                        ;
                        ;
                        ;
                        ;
                        ;
     000      00        LOG2:       CLRA                                   ; SET CHARACTERISTIC.
     001      57                    AISC        07                         ; TO REG LENGTH -1.
     002      06                    X                                      ; STORE IN MEMORY.

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LOGS

     003      A4        $LP1:       JSRP        SDB2                       ; SET ADDRESS POINTER
                                                                           ; BACK 2 DIGITS.
     004      A9                    JSRP        SHLR                       ; RESET CARRY AND SHIFT
                                                                           ; REG LEFT ONE BIT.
     005      20        $TS1:       SKC                                    ; IS CARRY = 1 YET?
     006      C8                    JP          $NO                        ; NO — KEEP GOING.
     007      49        $LST:       RETSK                                  ; YES — FINISHED!!
     008      05        $NO:        LD                                     ; NO — LOAD COUNT IN ACC.
     009      5F                    AISC        -1                         ; SUBTRACT ONE.
     00A      48        $TS2:       RET                                    ; MANTISSA IS A 0! RETURN
     00B      06                    X                                      ; STORE CHARACTERISTIC.
     00C      C3                    JP          $LP1                       ; DO IT AGAIN!





                        ; 2 ROUTINES ARE CALLED FROM THE SUBROUTINE PAGE BY THIS
                        ; PROGRAM: SDB2, SHLR.

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**FIGURE 6**

The program shown develops the $\log_2$ of any even power of 2 by shifting and testing as previously described. Examine what happens to a value of X that is not an even power of 2. In *Figure 7,* the number 25 is converted to a base 2 log.

$$25_{10} = 0\,0\,0\,1\,1\,0\,0\,2_2$$

Shift left until carry = 1

| Characteristic | Carry | Mantissa | $Log_2$ |
|---|---|---|---|
| 0100 | 1 | 100100000100.10010000 | |

**Figure 7. Straight Line Approximation of $Base_2$ Log**

The resulting number when viewed as an integer characteristic and a fractional mantissa is $4.5625_{10}$. The fraction 0.5625 is a straight line approximation of the logarithmic curve between the correct values for the $base_2$ logs of $2^4$ and $2^5$. The accuracy of this approximation is sufficient for many applications. The error can be corrected, as will be seen later in this discussion, but for now let's look at the problem of exponents or the conversion to an antilog.

To reconstruct the original value of X, find the antilog, requires only restoration of the most significant bit and then its alignment with the power of 2 position indicated by the characteristic. In the example, approximation ($\log_2 25$ = 0100.1001) restoration of MSB can be accomplished by shifting the mantissa (only) one position to the right. In the process a one is shifted into the MSB position.

| **Approximation of $Log_2$ X** | **Restoration of MSB** |
|---|---|
| Char. Mantissa | Char. Mantissa |
| 0100.10010000 | 0100.11001000 |

The value of the characteristic is 4 so the mantissa must be shifted to the right until MSB is aligned with the $2^4$ position.

$2^7 \quad 2^6 \quad 2^5 \quad 2^4 \quad 2^3 \quad 2^2 \quad 2^1 \quad 2^0$

The completion of this operation restores the value of X (X = 25) and is the procedure used to find an antilog. *Figure 8* is a flow chart for finding an antilog using this procedure. Ths implementation in source code is shown in *Figure 9.*

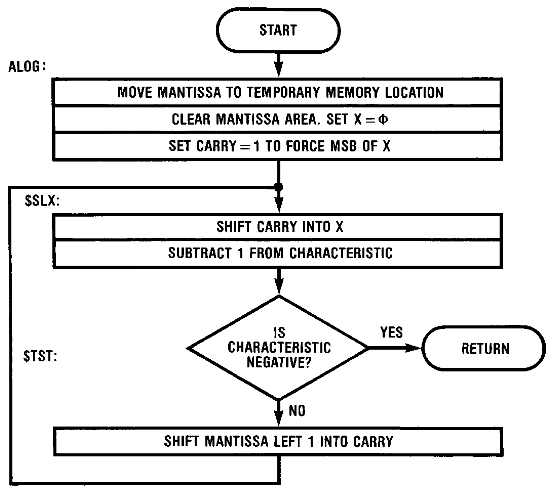


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**FIGURE 8. Flow Chart for Conversion to Antilog**

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LOGS

                    . FORM       ; ······→ CONVERT TO ANTILOG ←······ ;


                    ; THE FOLLOWING SUBROUTINE CONVERTS THE STRAIGHT LINE
                    ; THE APPROXIMATION OF A BASE 2 LOGARITHM TO ITS CORRESPONDING
                    ; ANTILOG. UPON EXIT FROM THE ROUTINE THE CONTENTS OF CH
                    ; WILL BE EQUAL TO THE HEXADECIMAL VALUE OF 'ΦF'.

                                 . LOCAL


00D   A4            ALOG:        JSRP       SDB2             ; SET ACC TO 0.
00E   00            CLRA                                     ; CLEAR MANTISSA AREA.
00F   36                         X          03               ; AND MOVE MANTISSA TO
010   34                         XIS        03               ; TEMPORARY STORAGE.
011   00                         CLRA                        ; LEAVE POINTER AT LO
012   36                         X          03               ; ORDER OF MANTISSA.
013   37                         XDS        03
014   22                         SC                          ; RESTORE MSB OF X.
015   D8                         JP         $SLX
01    A9            $SLM:        JSRP       SHLR             ; SHIFT REMAINDER
                                                             ; LEFT INTO CARRY.
017   A3                         JSRP       SDR2             ; MOVE BACK 2 DIGITS.
018   AA            $SLX:        JSRP       SHLC             ; SHIFT X LEFT 1.
019   05                         LD                          ; LOAD CHARACTERISTIC.
01A   5F            $TST:        AISC       -1               ; CHARACTERISTIC -1.
01B   48            $LST:        RET                         ; IF NO CARRY — FINIS.
01C   36                         X          03               ; STORE REMAINDER AND MOVE
                                                             ; DOWN ONE REGISTER.
01D   A4                         JSRP       SDB2             ; MOVE BACK 2 DIGITS.
01E   D6                         JP         $SLM             ; DO IT AGAIN.


                    ; 4 ROUTINES ARE CALLED FROM THE SUBROUTINE PAGE BY THIS
                    ; PROGRAM: SDB2, SDR2, SHLR, SHLC.
```

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**FIGURE 9**

Using the linear approximation technique just described, some error will result when converting any value of X that is not an even power of 2.

*Figure 10* contains a table of correct base 2 logarithms for values of X from 1 through 32 along with the error incurred for each when using linear approximation. Notice that no error results for values of X that are even powers of 2. Also notice that the error incurred for multiples of even powers of 2 of any given value of X is always the same.

| Value of X | Error |
|---|---|
| 5 | 0.12 |
| $2 \times 5 = 10$ | 0.12 |
| $4 \times 5 = 20$ | 0.12 |
| 3 | 0.15 |
| $2 \times 3 = 6$ | 0.15 |
| $4 \times 3 = 12$ | 0.15 |
| $8 \times 3 = 24$ | 0.15 |

| X | Hexadecimal Log Base | Linear Approximation of Log Base 2 | Error Hexadecimal | $E_M - 1 + \frac{EM - EM - 1}{2}$ |
|---|---|---|---|---|
| 1 | 0.00 | 0.00 | 0.00 | |
| 2 | 1.00 | 1.00 | 0.00 | |
| 3 | 1.95 | 1.80 | 0.15 | |
| 4 | 2.00 | 2.00 | 0.00 | |
| 5 | 2.52 | 2.40 | 0.12 | |
| 6 | 2.95 | 2.80 | 0.15 | |
| 7 | 2.CE | 2.C0 | 0.0E | |
| 8 | 3.00 | 3.00 | 0.00 | |
| 9 | 3.2B | 3.20 | 0.0B | |
| 10 | 3.52 | 3.40 | 0.12 | |
| 11 | 3.75 | 3.60 | 0.15 | |
| 12 | 3.95 | 3.80 | 0.15 | |
| 13 | 3.B3 | 3.A0 | 0.13 | |
| 14 | 3.CE | 3.C0 | 0.0E | |
| 15 | 3.E8 | 3.E0 | 0.08 | |
| 16 | 4.00 | 4.00 | 0.00 | |
| 17 | 4.16 | 4.10 | 0.06 | 0.03 |
| 18 | 4.2B | 4.20 | 0.0B | 0.09 |
| 19 | 4.3F | 4.30 | 0.0F | 0.0D |
| 20 | 4.52 | 4.40 | 0.12 | 0.11 |
| 21 | 4.67 | 4.50 | 0.17 | 0.15 |
| 22 | 4.75 | 4.60 | 0.15 | 0.16 |
| 23 | 4.87 | 4.70 | 0.17 | 0.16 |
| 24 | 4.95 | 4.80 | 0.15 | 0.16 |
| 25 | 4.A4 | 4.90 | 0.14 | 0.15 |
| 26 | 4.B3 | 4.IA0 | 0.13 | 0.14 |
| 27 | 4.C1 | 4.B0 | 0.11 | 0.12 |
| 28 | 4.CE; | 4.C0 | 0.0E | 0.10 |
| 29 | 4.DB | 4.D0 | 0.0B | 0.0D |
| 30 | 4.E8 | 4.E0 | 0.08 | 0.0A |
| 31 | 4.F4 | 4.F0 | 0.04 | 0.06 |
| 32 | 5.00 | 5.00 | 0.00 | 0.02 |
| 33 | | 5.1- | | |

**FIGURE 10. Error Incurred by Linear Approximation of Base 2 Logs**

An error that repeats in this way is easily corrected using a look-up table. The greatest absolute error will occur for the least value of X not an even power of 2, X = 3, is about 8%. A 4 point correction table will eliminate this error but will move the greatest uncompensated error to X = 9 where it will be about 4%. This process continues until at 16 correction points the maximum error for the absolute value of the logarithm is less than 1 percent. This can be reduced to 0.3 percent by distributing the error. Interpolated error values are listed in *Figure 10* and are repeated in *Figure 11* as a binary table.

| High Order 4 Mantissa Bits | Binary Correction Value | Hexadecimal Correction Value |
|---|---|---|
| 0 0 0 0 | 0 0 0 0 0 0 0 0 | 0 0 |
| 0 0 0 1 | 0 0 0 0 1 0 0 1 | 0 9 |
| 0 0 1 0 | 0 0 0 0 1 1 0 1 | 0 3 |
| 0 0 1 1 | 0 0 0 1 0 0 0 1 | 1 1 |
| 0 1 0 0 | 0 0 0 1 0 1 0 1 | 1 5 |
| 0 1 0 1 | 0 0 0 1 0 1 1 0 | 1 6 |
| 0 1 1 0 | 0 0 0 1 0 1 1 0 | 1 6 |
| 0 1 1 1 | 0 0 0 1 0 1 1 0 | 1 6 |
| 1 0 0 0 | 0 0 0 1 0 1 0 1 | 1 5 |
| 1 0 0 1 | 0 0 0 1 0 1 0 0 | 1 4 |
| 1 0 1 0 | 0 0 0 1 0 0 1 0 | 1 2 |
| 1 0 1 1 | 0 0 0 1 0 0 0 0 | 1 0 |
| 1 1 0 0 | 0 0 0 0 1 1 0 1 | 0 D |
| 1 1 0 1 | 0 0 0 0 1 0 1 0 | 0 A |
| 1 1 1 0 | 0 0 0 0 0 1 1 0 | 0 6 |
| 1 1 1 1 | 0 0 0 0 0 0 1 0 | 0 2 |

**FIGURE 11. Correction Table for $L_2$ X Linear Approximations**

Notice in *Figure 10* that left justification of the mantissa causes its high order four bits to form a binary sequence that always corresponds to the proper correction value. This works to advantage when combined with the COP400 LQID instruction. LQID implements a table look-up function using the contents of a memory location as the address pointer. Thus we can perform the required table look-up without disturbing the mantissa.

*Figure 12* is the flow chart for correction of a logarithm found by linear approximation. *Figure 13* is its implementation in COP400 assembly language. Notice that there are two entry points into the program. One is for correction of logs (LADJ:), the other is for correction of a value prior to its conversion to an antilog (AADJ:).

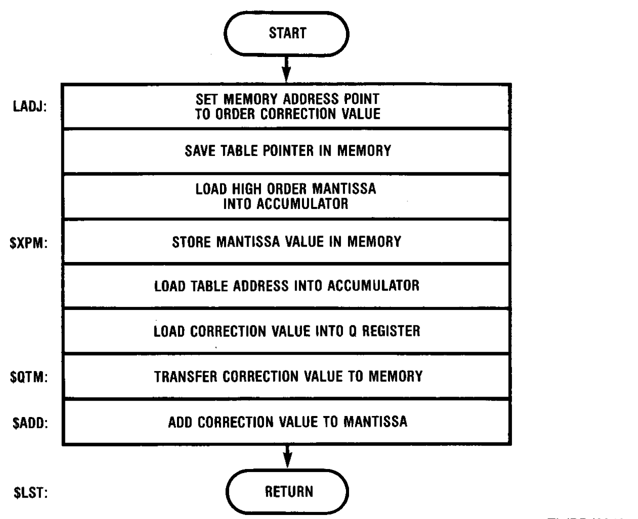


**FIGURE 12. Flow Chart for Correction of a Value Found by Straight Line Approximation**

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COP CROSS ASSEMBLER     PAGE:  4
LOGS

                        . FORM        ; ······→ ADJUST VALUE OF LOGARITHM ←······ ;

                                      . LOCAL


                        ; THE FOLLOWING TABLE IS USED DURING THE CORRECTION OF VALUES
                        ; FOUND BY STRAIGHT LINE APPROXIMATION. IT IS PLACED HERE IN
                        ; ORDER TO ALIGN ITS BEGINNING ELEMENT WITH A ZERO ADDRESS AS
                        REQUIRED BY THE LQID INSTRUCTION.

      01F     44                      NOP                                     ; REGISTER WITH ZERO ADDRESS.
      020     03        TPLS:         . WORD      03,09,0D,011
      021     09
      022     0D
      023     11
      024     15        . WORD        015,016,016,016
      025     16
      026     16
      027     16
      028     15                      . WORD      015,014,012,010
      029     14
      02A     12
      02B     10
      02C     0D                      . WORD      0D,0A,06,02
      02D     0A
      02E     06
      02F     02

                        ; THE FOLLOWING SUBROUTINE ADJUSTS THE VALUE OF A BASE 2
                        ; LOGARITHM FOUND BY STRAIGHT LINE APPROXIMATION. THE
                        ; CORRECTION TERMS ARE TAKEN FROM THE TABLE ABOVE. THE
                        ; SUBROUTINE HAS 2 ENTRY POINTS:
                        ;
                        ;             LADJ: — ADJUSTS A VALUE DURING CONVERSION TO A LOG
                        ;
                        ;             AADJ: — ADJUSTS A VALUE DURING CONVERSION TO ANTILOG
                        ;
                        ; THE CARRY FLAG IS SET UPON ENTRY TO DISTINGUISH BETWEEN LOG
                        ; (C = 1) AND ANTILOG (C = 0) CONVERSIONS. DURING A LOGARITHM
                        ; CONVERSION THE VALUE FOUND IN THE ABOVE TABLE IS ADDED TO
                        ; THE MANTISSA. DURING AN ANTILOG CONVERSION THE VALUE FOUND
                        ; IN THE ABOVE TABLE IS SUBTRACTED FROM THE MANTISSA.


      030     32        AADJ:         RC                                      ; C = 0 FOR ANTILOG
      031     F3                      JP          $LD                         ; CONVERSION.
      032     22        LADJ:         SC                                      ; C =  FOR LOG2 ADJ.
      033     05        $LD           LD                                      ; MOVE ADDRESS POINTER BACK
      034     07                      XDS                                     ; ONE LOCATION.
      035     05                      LD                                      ; LOAD CONTENTS OF HI MANTISSA
      036     37                      XDS         03                          ; AND STORE IT IN THE LO ORDER
      037     06                      X                                       ; OF THE TEMP MEMORY LOCATION.
      038     00                      CLRA                                    ; SET TABLE POINTER
      039     52                      AISC        TBL                         ; (ACC) TO TABLE ADDRESS.

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LOGS

      03A     BF                      LQID                                    ; LOAD CORRECTION VALUE TO Q.
      03B     332C      $GTM:         CQMA                                    ; TRANSFER Q REGISTER
      03D     04                      XIS                                     ; CONTENTS TO MEMORY.
      03F     07                      XDS
      03F     20                      SKC                                     ; ANTILOG?

      040     80                      JSRP        COMP                        ; YES — COMPLIMENT.
      041     98        $ADD:         JSRP        ADRO                        ; ADD CORRECTION VALUE
                                                                              ; TO MANTISSA.
      042     35                      LD          03                          ; SET POINTER TO
      043     48        $LST:         RET         ; CHARACTERISTIC AND
                                                                              ; RETURN.

                        ; 2 ROUTINES ARE CALLED FROM THE SUBROUTINE PAGE BY THIS
                        ; PROGRAM: COMP, ADRO

              0020                    V1 = TPLS&OFF
              0002                    TBL = V1/16
```

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**FIGURE 13**

## Subroutines Used by the Log and Antilog Programs

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LOGS

                              .FORM

         0080       .PAGE 02              ; ------> SUBROUTINES <------ ;

                    ; THE FOLLOWING ROUTINES RESIDE ON THE SUBROUTINE PAGE. THEY
                    ; ARE CALLED BY THE LOGS PROGRAM BUT ARE GENERAL PURPOSE IN
                    ; NATURE AND FUNCTION AS UTILITY ROUTINES.



                              ; ------> COMPLEMENT 8 BITS <------ ;

                              .LOCAL

                    ; THIS ROUTINE FORMS IN MEMORY THE 2'S COMPLEMENT OF THE TWO
                    ; ADJACENT DIGITS IDENTIFIED BY THE ADDRESS POINTER. THE
                    ; CONTENTS OF THE ADDRESS POINTER ARE NOT ALTERED.

                    ; THERE ARE TWO ENTRY POINTS:
                    ;
                    ; COP: COMPLEMENT 8 BITS.
                    ;
                    ; CMPE: EXTEND THE COMPLEMENT TO AN ADDITIONAL 8 BITS
                    ;

080      22         COMP:     SC
081      00         CMPE:     CLRA                        ; SET MINUEND=0
082      06                   X                           ; AND STORE IN MEMORY.
083      10                   CASC
084      44                   NOP                         ;
085      04                   XIS                         ;
086      00                   CLRA                        ; SET MINUEND=0
087      06                   X                           ; AND STORE IN MEMORY.
083      10                   CASC                        ;
089      44                   NOP
08A      04                   XIS                         ;
08B      44                   NOP                         ; AVOID SKIP IF DIGIT 15.
08C      A4                   JP          SDB2            ; RETURN THRU SDB2
                                                          ; TO RESTORE POINTER.



                    ; ------> ADD 8 BITS IN ADJACENT REGISTERS <------ ;

                              .LOCAL



                    ; THIS ROUTINE ADDS TWO BINARY DIGITS (8 BITS) FROM ANY REGISTER
                    ; TO THE CORRESPONDING TWO BINARY DIGITS IN EITHER REGISTER
                    ; IMMEDIATELY ADJACENT. THERE ARE THREE ENTRY POINTS:
                    ;
                    ;         LADR: — RESET CARRY AND ADD 2 DIGIT PAIRS
```

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```
                    ;          LADD: — ADD 2 DIGIT PAIRS WITH UNMODIFIED CARRY
                    ;          ADD1: — ADD 2 SINGLE DIGITS WITH UNMODIFIED CARRY




08D   32     LADR:     RC                        ; RESET CARRY PRIOR TO ADD.
08E   15     LADD:     :D         01             ; LD ADDEND AND MOVE TO ADJ REG
08F   30               ASC                       ; ADD AUGEND.
090   44               NOP                       ; AVOID CARRY!
091   14               XIS        01             ; STORE SUM AND MOVE TO ADDEND
092   15     ADD1:     LD         01             ; REPEAT PROCESS
093   30               ASC                       ; FOR
094   44               NOP                       ; HIGH ORDER
095   14               XIS        01             ; DIGIT.
096   44               NOP                       ; AVOID SKIP IF DIGIT 15.
097   48     $LST:     RET                       ; FINISHED — RETURN!!!!




                       ; ------→ ADD 8 BITS IN OPPOSITE REGISTERS ←------ ;

                       . LOCAL



             ; THIS ROUTINE ADDS TWO BINARY DIGITS (8BITS) FROM ANY REGISTER
             ; TO THE CORRESPONDING TWO BINARY DIGITS IN EITHER REGISTER
             ; DIRECTLY OPPOSITE. THERE ARE THREE ENTRY POINTS:
             ;
             ;         ADR0: — RESET CARRY AND ADD 2 DIGIT PAIRS
             ;         ADD0: — ADD 2 DIGIT PAIRS WITH UNMODIFIED CARRY
             ;         AD01: — ADD 2 SINGLE DIGITS WITH UNMODIFIED CARRY




098   32     ADR0:     RC                        ; RESET CARRY PRIOR TO ADD.
099   35     ADD0:     LD         03             ; LD ADDEND AND MOVE TO OPP REG
09A   30               ASC                       ; ADD AUGEND.
09B   44               NOP                       ; AVOID CARRY!
09C   34               XIS        03             ; STORE SUM AND MOVE TO ADDEND.
09D   15     AD01:     LD         01             ; REPEAT PROCESS
09E   30               ASC                       ; FOR
09F   44               NOP                       ; HIGH ORDER
0A0   34               XIS        03             ; DIGIT.
0A1   44               NOP                       ; AVOID SKIP IF DIGIT 15.
0A2   48     $LST:     RET                       ; FINISHED — RETURN!!!!



                       ; ------→ SET DIGIT ADDRESS BACK TWO ←------ ;

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                                       . LOCAL

                           ; THIS ROUTINE SUBTRACTS 2 FROM THE CONTENTS OF THE
                           ; DIGIT POINTER (B REGISTER). THE CONTENTS OF THE
                           ; ACCUMULATOR ARE LOST IN THE PROCESS. THE USE OF
                           ; SDB2 ALLOWS ADDRESSING WITHIN THE LOGS SUB
                           ; ROUTINE TO BE RELATIVE TO THE CONTENTS OF THE
                           ; ADDRESS POINTER (B REGISTER) UPON ENTRY.
                           ; SDB2 IS COMMONLY USED IN BYTE OPERATIONS TO RESTORE THE
                           ; DIGIT POINTER TO THE LOW ORDER POSITION.
                           ; THERE ARE TWO ENTRY POINTS:
                           ;
                           ; SDR2:        SET DIGIT ADDRESS BACK 2 AND MOVE TO OPPOSITE REGISTER.
                           ;
                           ; SDB2: SET DIGIT ADDRESS BACK 2 RETAINING PRESENT REGISTER.



   0A3      35             SDR2:       LD          03                ; MOVE TO OPPOSITE REGISTER.
   0A4      4E             SDB2:       CBA                           ; PLACE DIGIT COUNT IN ACC.
   0A5      5E                         AISC        -2                ; SUBTRACT 2.
   0A6      44                         NOP                           ; SHOULD ALWAYS SKIP.
   0A7      50                         CAB                           ; PUT DIGIT COUNT BACK.
   0A8      48                         RET                           ; FINISHED — RETURN!!


                                       ; -----→ SHIFT LEFT ←----- ;

                                       . LOCAL

                           ; THIS ROUTINE SHIFTS LEFT THE CONTENTS OF TWO MEMORY
                           ; LOCATIONS ONE BIT. THERE ARE THREE ENTRY POINTS:

                           ;                    SHLR: RESETS THE CARRY BEFORE SHIFTING
                           ;                          IN ORDER TO FILL THE LOW ORDER
                           ;                          BIT POSITION WITH A 0.
                           ;
                           ;                    SHLC: SHIFTS THE STATE OF THE CARRY INTO
                           ;                          THE LOW ORDER BIT POSITION.
                           ;
                           ;                    SHL1: SHIFTS LEFT THE CONTENTS OF ONLY
                           ;                          ONE MEMORY LOCATION. THE STATE
                           ;                          OF THE CARRY IS SHIFTED INTO THE
                           ;                          LOW ORDER POSITION OF MEMORY.



   0A9      32             SHLR:       RC                            ; CLEAR CARRY PRIOR TO SHIFT.
   0AA      05             SHLC:       LD                            ; LOAD FIRST MEM DIGIT.
   0AB      30                         ASC                           ; DOUBLE IT.
   0AC      44                         NOP                           ; AVOID SKIP.
   0AD      04                         XIS                           ; STORE SHIFTED DIGIT.
   0AE      05             SHL1:       LD                            ; LOAD NEXT MEM DIGIT.
   0AF      30                         ASC                           ; DOUBLE IT TOO.

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   0B0      44                         NOP                           ; AVOID SKIP, IF ANY
   0B1      04                         XIS                           ; STORE SHIFTED DIGIT.
   0B2      48             $LST:       RET                           ; FINISHED — RETURN!


                                       . END
```

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**LIFE SUPPORT POLICY**

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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