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# Powerline Frequency Measurement

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# POWERLINE FREQUENCY MEASUREMENT

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ABSTRACT

A microcomputer has been used to measure powerline frequency with a precision of six decimal digits (0.0001 Hz) using an averaging time of 3 to 4 min. The algorithm for frequency measurement requires no multiplication or division operations, so a very simple microprocessor can be used.

The frequency measurement is sensitive enough to permit detection of small, controlled changes in generation, hence in powerline frequency. Thus, the results of the frequency measurement can be applied to the load-management field. Methods based on these principles have the potential of providing an inexpensive communications path between the power supplier and the industrial user for purposes of shedding load during peak power usage.

## 1. INTRODUCTION

In the course of examining various methods and techniques for power systems load-management, it became apparent that a microprocessor could provide the basis for a precise yet inexpensive way to measure powerline frequency. Previous investigations[1] determined the characteristics of the powerline interconnected system frequency for potential load-management applications. In these earlier investigations, various methods were used to measure and characterize the powerline frequency to determine whether system frequency could be used as an indicator for direct load control. Even though later results showed that system frequency is not a reliable indicator for direct load-control, it was learned that a precise way to measure the system frequency is available, and this report describes its development.

## 2. HARDWARE IMPLEMENTATION

This frequency-measuring and direct load-control demonstration was implemented on an IMSAI 8048 single-board computer using the INTEL 8035 microprocessor. The computer has on-board relays under program control which allow demonstrations of load-management techniques. The load-management technique selected relies on the absolute value of the powerline frequency for determining whether to shed load. The generalization had been made that load should be shed at low values of system frequency. Provisions were made for shedding three loads at three different frequency setpoints. In principle, the first load to be shed would probably be a water heater, the next would be the washer or dryer, and the third load would be the air-conditioner. The three relays in the IMSAI 8048 computer were set to open under program control whenever the frequency dropped below the respective setpoints.

Tests of the measuring system were conducted during typical daytime, weekday, winter conditions when power usage was high. Whenever the frequency dropped below a setpoint, the proper relay would open, indicating that the local load would be removed from the line. The computer was left running for a 6-month test, and during that period,

the relay states were observed always to be correct as a function of the powerline frequency. However, the system frequency is not always a reliable indicator of the need to remove load. The interconnected power system is made up of many local systems or areas. During abnormal or emergency conditions in one area, it may be desirable and helpful to remove load in that area. The distress in one area, however, does not usually cause a significant reduction in frequency in all areas because the powerline frequency is the same throughout the interconnected system. Thus, dropping loads in all other areas would not be particularly beneficial or necessary. Only if a majority of the areas were in abnormal or emergency conditions would the frequency become a reliable indicator for dropping load. Fortunately, the probability of this condition occurring is low, and the power system procedure for handling such an emergency is complete removal of power service from selected localities. The measuring system described here would, however, provide an accurate basis for any under-frequency relaying need.

## 3. POWERLINE INTERFACE

To provide input into the computer for frequency-measuring purposes, the line voltage is stepped down to 9 V rms by a small transformer and then stepped down again through a resistor voltage-divider network to approximately a 5-V peak. This signal drives two 7404 TTL inverters in series, producing a 5-V square wave at the powerline frequency. The output of the second inverter is connected to an input of the IMSAI 8048 control computer. This input is tested by the computer program. High-frequency noise riding on the powerline voltage is always a concern because extra zero crossings may result from noise spikes. The time needed to execute a branch instruction to test the polarity of the 60-Hz square wave input provides a delay, or dead time, which effectively filters out any transients with frequency components greater than 30 kHz. The hardware series inverter stages provide sufficient gain to effectively remove the remaining noise frequencies below 30 kHz. If the system is to be used in an extremely noisy environment, a delay can be added to subroutine OVER, which will

ensure that the extra zero crossings caused by the noise will not be counted.

## 4. FREQUENCY MEASUREMENT AND APPLICATIONS

The basic frequency-measurement algorithm is implemented by first making a period measurement to improve the accuracy and reduce the variance of the frequency measurement. A set number of powerline cycles are counted while an interval timer is running. The interval time is derived from the microprocessor crystal-controlled clock frequency. Because of the lack of multiply and divide instructions on this microprocessor, the frequency cannot be computed directly from the period measurement. Instead, an approximation is made (see Appendix A) which is quite accurate over the limited frequency range of these measurements. The essence of the approximation involves the binomial expansion. The equation for the actual frequency is given by:

$$f_{actual} = \frac{k_i}{T_p} \tag{1}$$

where $k_i$ is a constant and $T_p$ is period measurement.

Using the binomial expansion and only the significant terms, Eq. (1) becomes:

$$f_{measured} = k_2 - k_3 T_p \tag{2}$$

where $k_2$ and $k_3$ are constants.

The error ($f_{measured} - f_{actual}$) is quite low over a limited range of variation for $T_p$. By using the lookup-table features of a microprocessor, Eq. (2) can be implemented very easily to yield measurements of frequency precision to six significant digits. The accuracy of the measurement is directly proportional to the accuracy of the microprocessor clock.

Appendix A includes a derivation for the frequency measurement as well as the derivation for the error in the frequency measurement.

Figure A.1 shows a plot of this error. Over the frequency range 59.94 to 60.06 Hz, the maximum error is $5.67 \times 10^{-5}$% of reading and occurs at the endpoints. For a full-scale range of 59.94 to 60.06 Hz, the error at 60 Hz is 0.21% of full scale.

Now that microcomputers on a single chip are available, a very low-cost device can be used to detect when the powerline frequency drops below a set value or to detect a coded sequence of controlled frequency changes. It can be packaged in a small box which can be inserted in the wall plug of the sheddable load, and the line cord at the load can be plugged into an outlet on the controller. The controller would contain a microprocessor, relay, line-voltage shaper, and power supply. If purchased and assembled in large quantities, the unit cost of these controllers would be quite low.

## 5. SOFTWARE IMPLEMENTATION

Structural charts (Nassi-Shneiderman diagrams) were used in the design of the software. These charts are shown in Appendix B. The original code was hand assembled because no assembler was available to the project. The structure charts made the task relatively easy by minimizing logic errors. Appendix C contains the listing of the code generated by a cross assembler. These listings are complete except for subroutines DISPRG and CLEAR, which are found in the IMSAI monitor.

## 6. CONCLUSION

A microprocessor can be used to measure powerline frequency with a precision of 0.0001 Hz when averaged over a 3- to 4-min period. This precision is much greater than necessary because the standard deviation for readings over this period is about two orders of magnitude greater than 0.0001 Hz. The measurement algorithm requires no multiplication or division, so a very simple microprocessor can perform the computations.

## REFERENCE

1. R. K. Adams, J. M. McIntyre, and F. W. Symonds, "Characteristics of the Eastern Interconnection Line Frequency," IEEE Trans.Power Apparatus and Systems, PAS-101 (12) (ISSN 0018-9510), 4542-47, December 1982.

# APPENDIX A

## METHOD FOR FREQUENCY MEASUREMENT ANALYSIS

## A.1 FREQUENCY MEASUREMENT ANALYSIS

By a judicious selection of the number of powerline cycles to be counted, an overflow of the 256-count timer register (256 additional counts in the timer register) can be made equivalent to a change in the powerline frequency of 0.01 Hz at a nominal 60 Hz. The frequency is found by:

$$f = \frac{M}{(256N + r)\ T_c} \tag{A-1}$$

where

$M$ = number of powerline cycles to be counted,

$N$ = 8-bit overflow from the timer,

$r$ = 8-bit timer value,

$T_c$ = cycle time of the clock ($134.095 \times 10^{-6}$ s).

Knowing the resolution desired (a $\Delta f$ of 0.01 Hz equals 256 additional counts in r), simultaneous equations can be set up to solve for M. When the line frequency is 60.00 Hz it is desired that r is zero and N in an integer. When the frequency changes to 60.01 Hz, one fewer overflow in the timer (i.e., N-1 counts of overflow) is desirable. Since the frequency measurement is needed over only a limited range of 59.94 to 60.06 Hz, the use of 59.96 and 60.04 Hz in the following simultaneous equations will help to minimize the error over the selected range:

$$f = 59.96 = \frac{M}{256(N + 4)(134.095 \times 10^{-6})} \quad . \tag{A-2}$$

and

$$f = 60.01 = \frac{M}{256(N + 4)(134.095 \times 10^{-6})} \quad . \tag{A-3}$$

Solving these equations simultaneously yields N = 6000 and M = 12,358.19. Since M must be an integer, it should be rounded off to the nearest integer, 12358. This rounding introduces a bias of 0.0009 Hz in the frequency measurement, which can be removed by adjusting the cycle time of the clock from 134.0950 μs to 134.09294 μs.

After 12358 powerline cycles have been counted (3 min, 26 s), the timer is stopped. The overflow accumulation of the timer addresses the location in memory containing the binary coded decimal (BCD) equivalent of the tenths and hundredths places. The timer addresses the location in memory of the thousandths and ten-thousandths places. These BCD values are shown on the eight-digit, seven-segment display of the IMSAI 8048 control computer. The binary value of the timer and overflow are compared to 2's complement values of the frequency setpoints to determine whether a control relay should be opened or closed.

## A.2 EXAMPLE OF OPERATION

If the cycle time of the clock is set to 134.09294 μs and the input frequency is very slightly over 60.01 Hz, the first task is to count out 12,358 cycles of the 60-Hz waveform. When this has been accomplished, the timer overflow register should read $176F_{16}$ ($5999_{10}$), and the timer should read $FF_{16}$. Only the two least significant digits of the timer overflow register are retained (i.e., $6F_{16}$). This number is used to look up the BCD equivalent of the frequency at location $096F_{16}$ (the address offset is $0900_{16}$). The value stored at this location is $01_{10}$ and represents the tenths and hundredths places. If the address is greater than $6F_{16}$, the two most significant digits (59) are displayed; otherwise, 60 is displayed. Since $6F_{16}$ is $\leq 6F_{16}$, 60 is displayed as the first two significant digits in this example. The timer register r is used to address memory beginning at $0A00_{16}$ to determine the BCD values for the two least significant digits (the thousandths and ten-thousandths places). Since the timer register contains $FF_{16}$, this is offset to compose the address $0AFF_{16}$ to look up the BCD value for the two least significant digits. Stored at location $0AFF_{16}$ is $00_{10}$.

Combining the values gives a display reading of 60.0000 Hz. The least significant digit table requires 256 memory locations to hold the decimal digits from 0 to $99_{10}$.

## A.3 FREQUENCY MEASUREMENT CALCULATION

Starting with Eq. (A-1) and using M = 12358 and $T_c = 134.09294 \times 10^{-6}$,

$$f = \frac{59.96 \times 6004}{N + 4/256} \quad . \tag{A-4}$$

Normalizing N for its value at a 60-Hz frequency, let:

$$N = 6000 + \Delta N \tag{A-5}$$

where

$$\Delta N = \ldots -3, -2, -1, 0, 1, 2, 3, 4 \ldots$$

and substituting:

$$f = \frac{}{6000 + \Delta N + r/256} = \frac{}{\frac{1 + \Delta N + 4/256}{6000}} \quad . \tag{A-6}$$

Applying the binomial expansion,

$$f = 59.999973 \quad 1 - \frac{\Delta N + 4/256}{6000} + \ldots \quad . \tag{A-7}$$

Equation (A-7) represents the frequency as a function of the number of overflows in excess of 6000. It is the exact relationship among the excess number of overflows, the timer magnitude, and the frequency. To adapt the solution of this equation to the limited computational capabilities of microprocessors, we must make two adjustments: first, drop the higher-order terms in the expansion and, second, round the factor 59.999973 to 60.00. The first adjustment introduces an error for large $\Delta N$. The second adjustment causes the approximation to yield the exact values of frequency with $\Delta N$ as plus and minus 4. The approximation is now:

$$f = 60 \quad 1 - \frac{\Delta N + 4/256}{6000} \quad . \tag{A-8}$$

This corresponds to Eq. (2).

## A.4 ERROR CALCULATION

The frequency error can be made zero at two points. For the parameters selected, the error should be zero at both 59.96 and 60.04 Hz. The magnitude of the error at other points can be obtained by subtracting the actual frequency, Eq. (A-7), from the measured frequency, Eq. (A-8). The result is

$$\text{Error} = 0.000027 - 0.0000016667 \ (\Delta N = r/256) \quad . \tag{A-9}$$

Since $\Delta N$ is related to frequency through the lookup table, the error can be plotted against the measured frequency as in Fig. A.1. The true error curve is zero at the points 59.96 and 60.04 Hz.

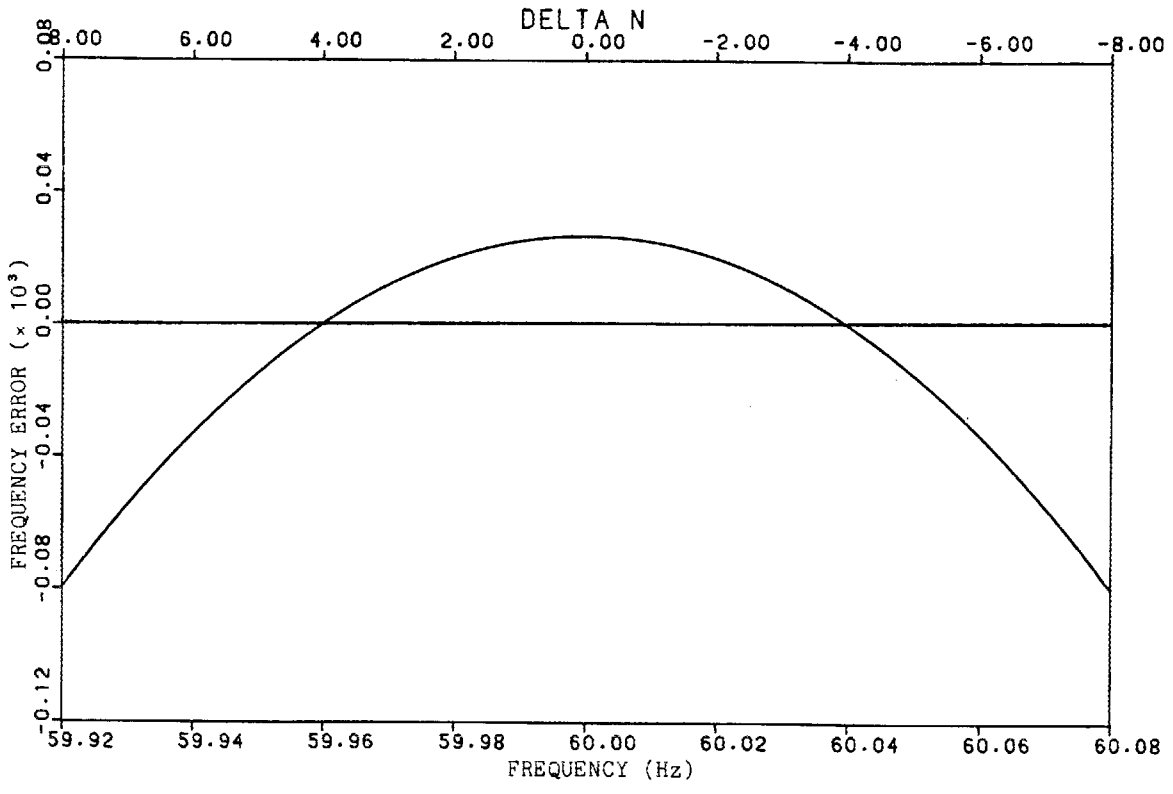


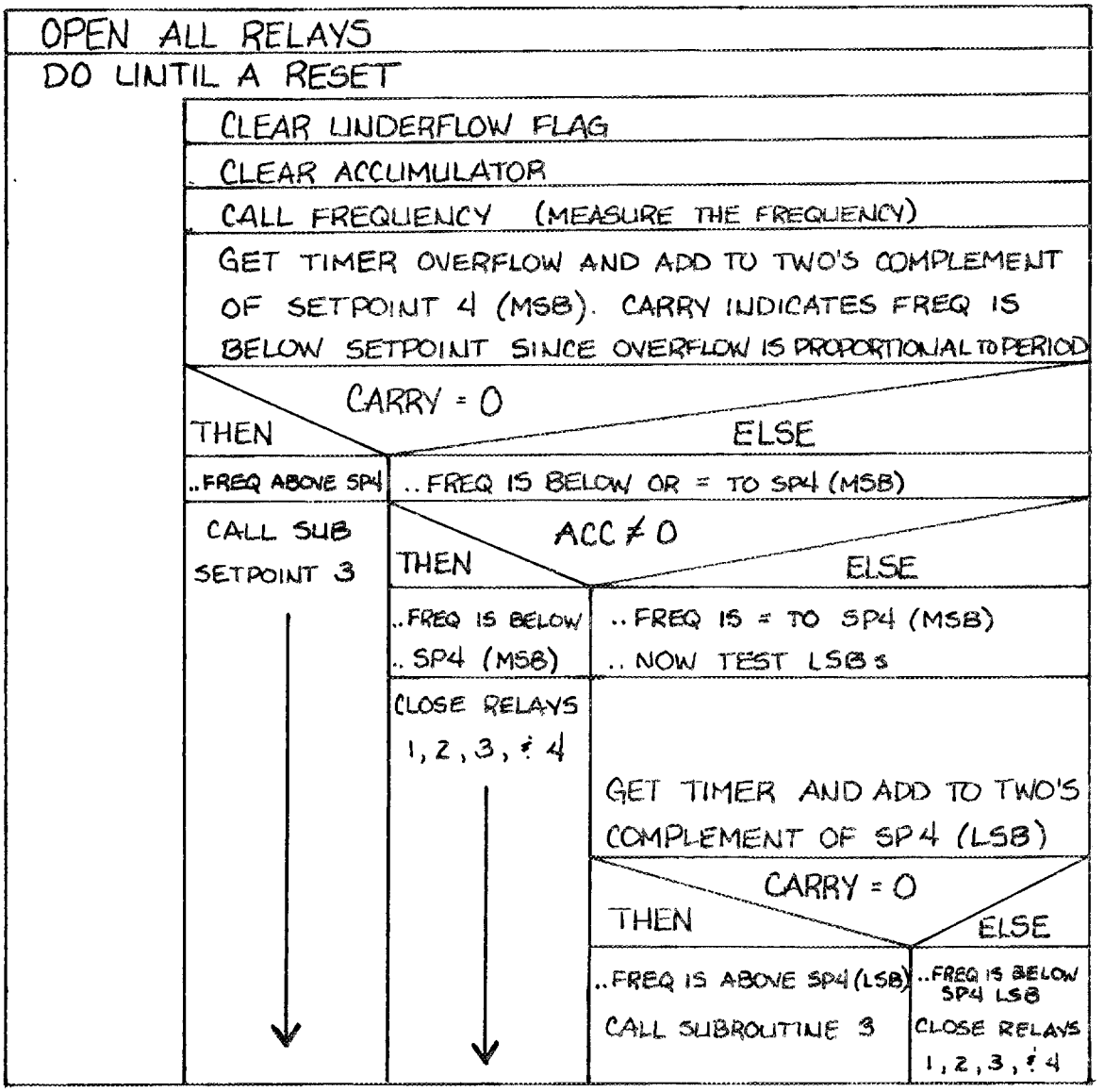

Fig. A.1. Error in frequency measurement.

# APPENDIX B

## PROGRAM STRUCTURE CHARTS

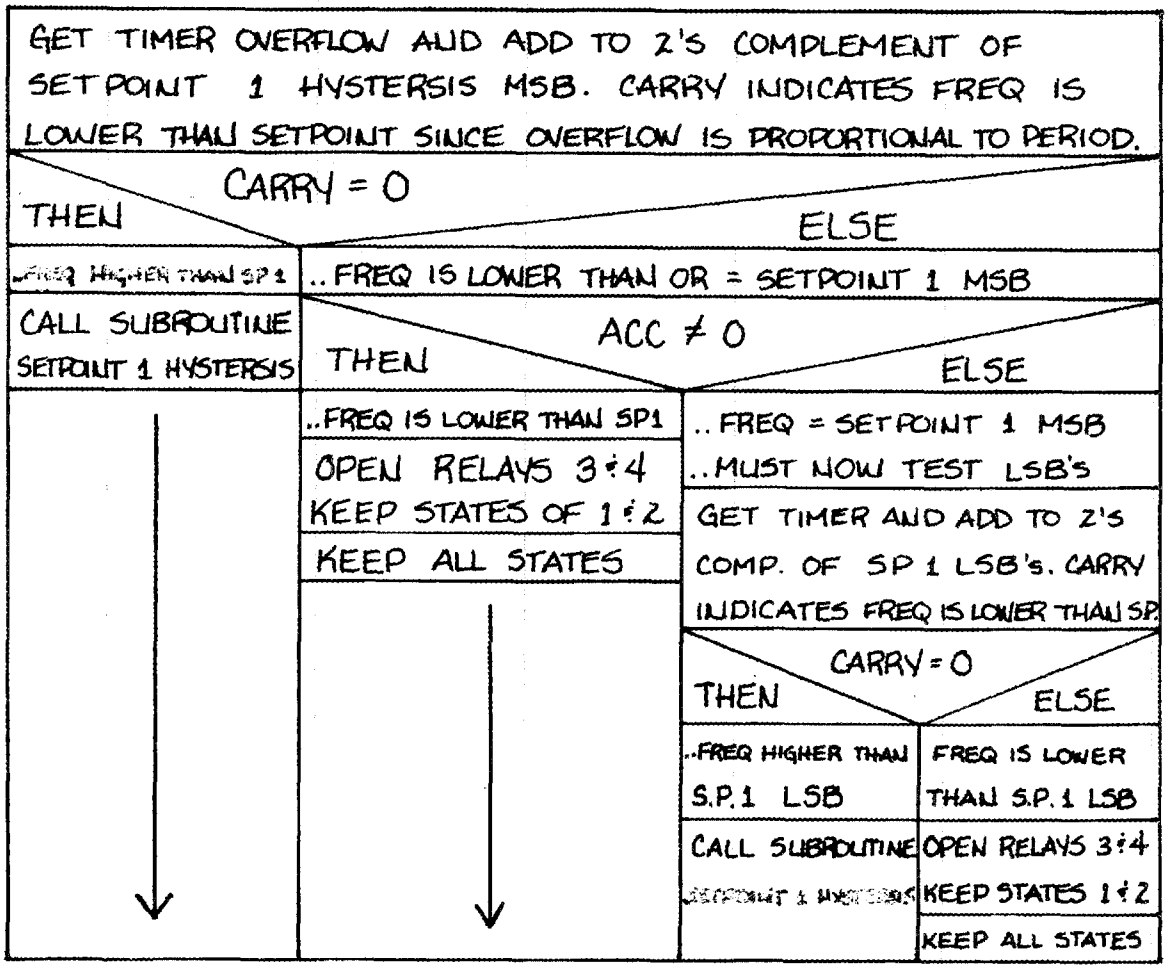
# LOAD MANAGEMENT PROGRAM

PROGRAM CALLS SUBROUTINE 3 IF FREQ IS HIGHER THAN SP4; CLOSES RELAYS 1,2,3, & 4 IF FREQ IS BELOW SETPOINT 4.



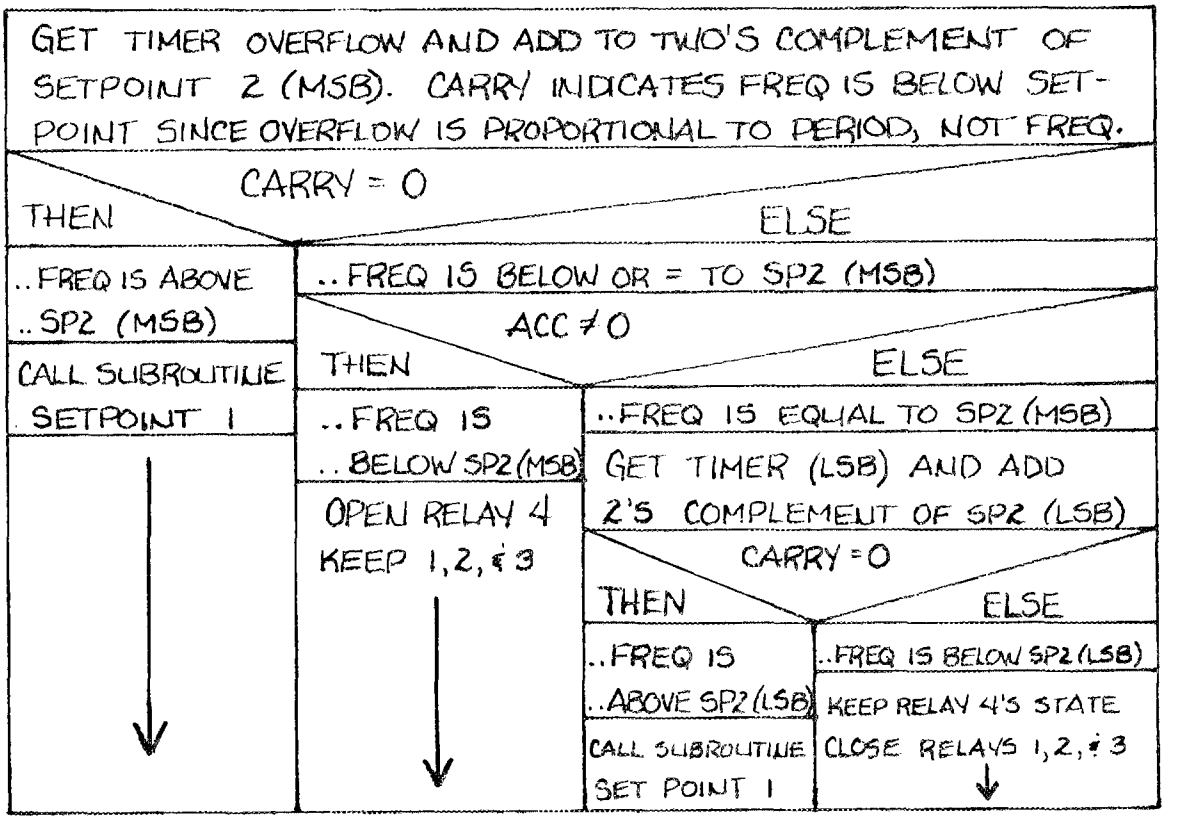
# SUBROUTINE SETPOINT 1

SUBROUTINE CALLS SUBROUTINE SETPOINT 1 HYSTERSIS IF FREQUENCY IS HIGHER THAN SET POINT 1 ; OPENS RELAYS 3 & 4 AND KEEPS THE STATES OF RELAYS 1 AND 2 IF FREQ IS BELOW SETPOINT 1.



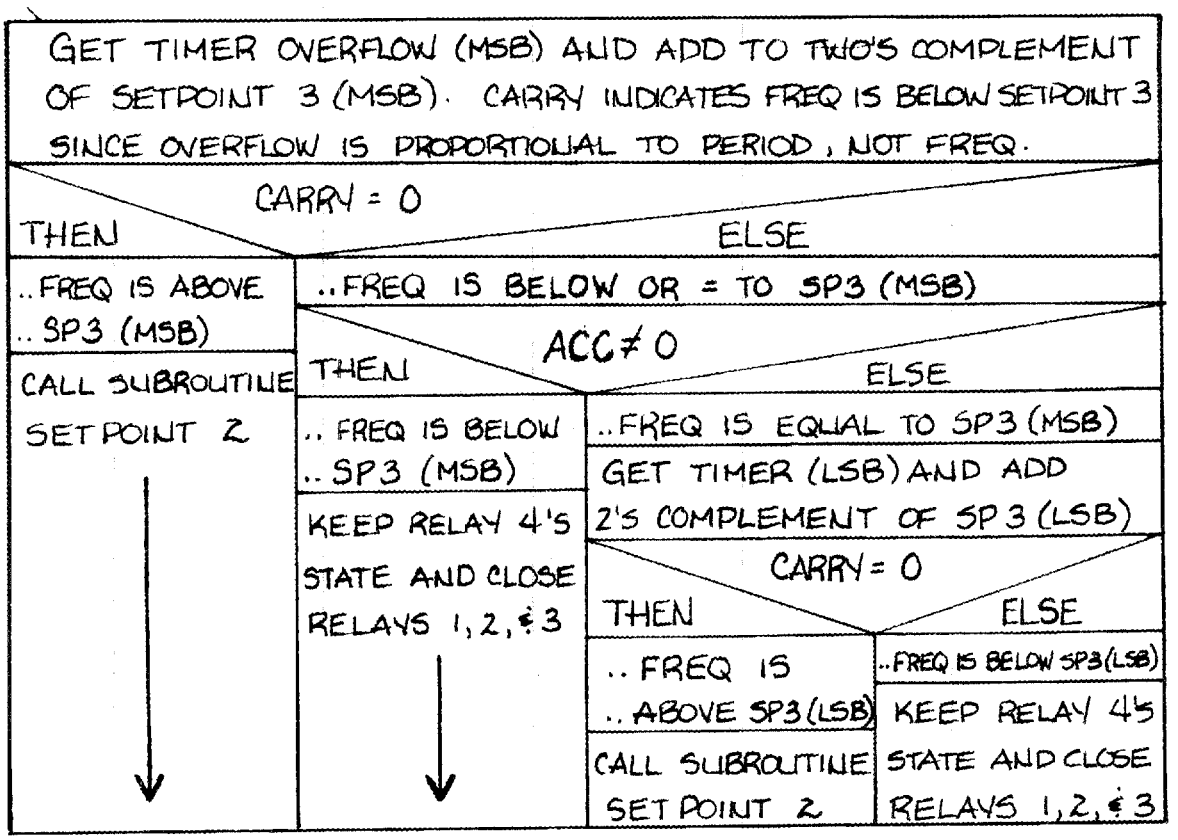
## .. SUBROUTINE SETPOINT 2

SUBROUTINE CALLS SUBROUTINE SETPOINT 1 IF FREQ IS HIGHER THAN SETPOINT 2; OPENS RELAY 4 AND KEEPS 1,2, & 3 IF FREQ IS LOWER THAN SETPOINT 2.



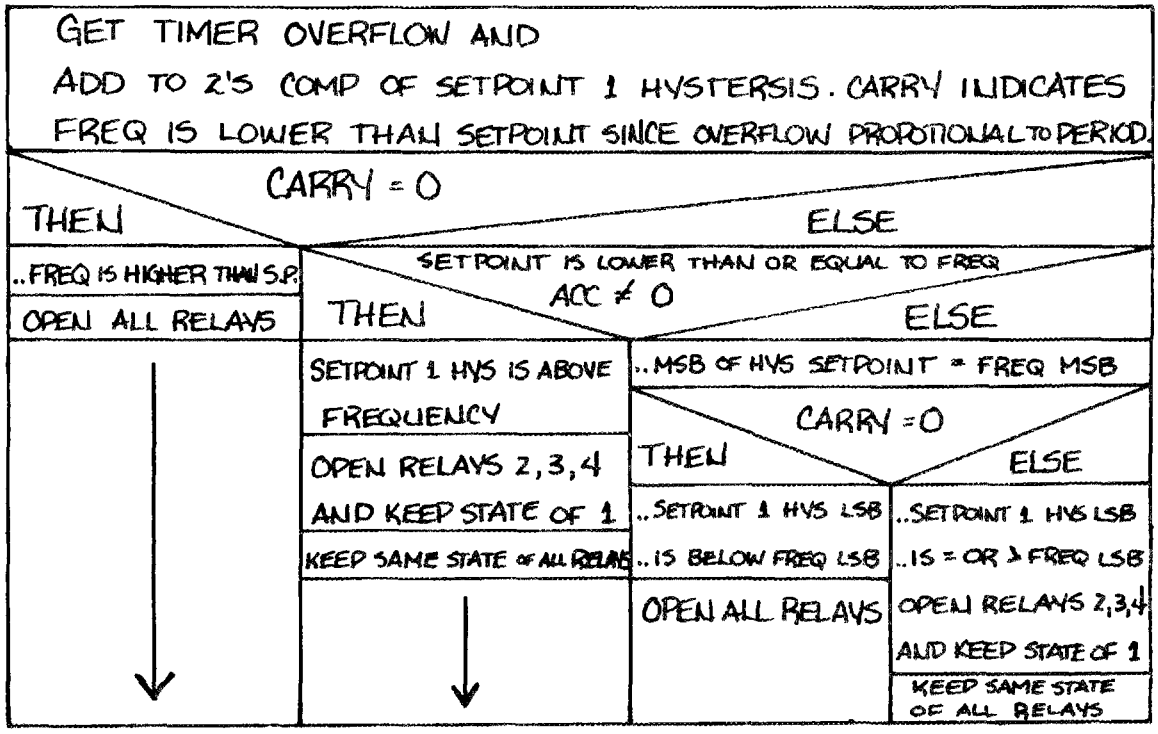
# SUBROUTINE SETPOINT 3

SUBROUTINE CALLS SUBROUTINE 2 IF FREQ IS HIGHER THAN SETPOINT 3; CLOSES RELAYS 1,2, & 3 KEEPING STATE OF 4 IF FREQ IS BELOW SETPOINT 3.



# SUBROUTINE SETPOINT 1 HYSTERSIS

SUBROUTINE OPENS ALL RELAYS IF FREQ IS HIGHER THAN SETPOINT 1 HYSTERSIS; OPENS RELAYS 2, 3, AND 4 AND KEEPS THE STATE OF RELAY 1 IF FREQ IS BELOW SETPOINT 1 HYSTERSIS.



# APPENDIX C

## 8048 CROSS-ASSEMBLER CODE LISTING

```
8048 CROSS ASSEMBLER VERSION 2A(26), FILE DSK:L.SRC  11:22:17 14-OCT-83

ADDR   OBJ CODE    SEQ  SOURCE STATEMENT

                    1   ;
                    2   ;LOAD MANAGEMENT PROGRAM
                    3   ;
                    4   ;PROGRAM ALLOWS THE IMSAI 8035 MICROPROCESSOR TO MEASURE THE
                    5   ;FREQUENCY OF THE POWER LINE.  THE FREQUENCY IS INTEGRATED
                    6   ;OVER A PERIOD OF 3.24 MINUTES.
                    7   ;
0800                8   ORG 800H
0800   F5           9   SEL MB1
0801   14C6        10   CALL OPEN  ;OPEN ALL RELAYS
0803               11   DO01:  ;DO UNTIL A RESET OCCURS
0803   85          12      CLR F0  ;CLEAR UNDERFLOW FLAG
0804   27          13      CLR A  ;CLEAR ACCUMULATOR
0805   14CA        14      CALL FREQ  ;MEASURE FREQUENCY
0807   F8          15      MOV A, R0  ;GET TIMER OVERFLOW (MSB) AND
0808   038C        16      ADD A, #8CH  ;ADD TO TWO'S COMPLEMENT OF SETPOINT 4
080A   E627        17      JNC THEN01
080C               18         ELSE01:  ;FREQ IS BELOW OR EQUAL TO SP4 (MSB)
080C   BE00        19            MOV R6, #00H   ;CONSTANTS FOR RELAY SUBROUTINE
080E   BF00        20            MOV R7, #00H
0810   9621        21            JNZ THEN02
0812               22               ELSE02:  ;FREQ IS EQUAL TO SP4 (MSB)
0812   42          23                  MOV A, T  ;GET TIMER AND ADD
0813   0303        24                  ADD A, #03H  ;2'S COMPLEMENT OF SP4 (LSB)
0815   E61B        25                  JNC THEN03
0817               26                     ELSE03:  ;FREQ IS BELOW SP4 (LSB)
0817   14C1        27                        CALL RELAY  ;CLOSE RELAYS 1,2,3,4
0819   041F        28                        JMP FI03
081B               29                     THEN03:  ;FREQ IS ABOVE SP4 (LSB)
081B   142D        30                        CALL SUB3
081D   041F        31                        JMP FI03
081F               32                  FI03:  ;END OF IF03
081F   0425        33                  JMP FI02
0821               34               THEN02:  ;FREQ IS BELOW SP4
0821   14C1        35                  CALL RELAY  ;CLOSE RELAYS 1,2,3,4
0823   0425        36                  JMP FI02
0825               37            FI02:  ;END OF FI02
0825   042B        38            JMP FI01
0827               39         THEN01:  ;FREQ IS ABOVE SP4
0827   142D        40            CALL SUB3   ;CALL SUBROUTINE SETPOINT 3
0829   042B        41            JMP FI01
082B               42      FI01:  ;END OF IF01
082B   0403        43      JMP DO01
082D               44   OD01:  ;END OF DO01
```

```
                 ;;;;;;;;;;;;;;;;;;;;;;;;;;
                 ; SUBROUTINE SETPOINT 3 ;
                 ;;;;;;;;;;;;;;;;;;;;;;;;;;
082D             SUB3:  ;START OF SUBROUTINE SETPOINT 3
082D   F8           MOV A, R0  ;GET TIMER OVERFLOW (MSB) AND ADD TO
082E   038D         ADD A, #8DH  ;TWO'S COMPLEMENT OF SETPOINT3 (MSB)
0830   E64D         JNC THEN10
0832                   ELSE10:  ;FREQ IS BELOW OR EQUAL TO SETPOINT3 (MSB)
0832   BE00               MOV R6, #00H   ;CONSTANTS FOR RELAY SUBROUTINE
0834   BF08               MOV R7, #08H
0836   9647               JNZ THEN11
0838                          ELSE11:  ;FREQ IS EQUAL TO SETPOINT 3 (MSB)
0838   42                        MOV A, T  ;GET TIMER (LSB) AND
0839   0303                      ADD A, #03H  ;ADD TO 2'S COMP. OF SP3 (MLSB)
083B   E641                      JNC THEN12
083D                                ELSE12:  ;FREQ IS BELOW SP3 (LSB)
083D   14C1                            CALL RELAY  ;KEEP RELAY 4, CLOSE 1,2,3
083F   0445                            JMP FI12
0841                                THEN12:  ;FREQ IS ABOVE SP3(LSB)
0841   1452                            CALL SUB2  ;SUBROUTINE SETPOINT 2
0843   0445                            JMP FI12
0845                             FI12:
0845   044B                      JMP FI11
0847                          THEN11:  ;FREQ IS BELOW SETPOINT 3 (LSB)
0847   14C1                      CALL RELAY  ;KEEP RELAY 4, CLOSE 1,2,3
0849   044B                      JMP FI11
084B                       FI11:
084B   0451                JMP FI10
084D                   THEN10:  ;FREQ IS ABOVE SP3 (MSB)
084D   1452               CALL SUB2  ;SUBROUTINE SETPOINT 2
084F   0451               JMP FI10
0851                 FI10:  ;END OF SUBROUTINE
0851   83         RET
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;
                  ; SUBROUTINE SETPOINT 2 ;
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;
0852              SUB2:  ;START OF SUBROUTINE SETPOINT 2
0852   F8           MOV A, R0  ;GET TIMER OVERFLOW (MSB) AND ADD TO
0853   038E         ADD A, #8EH  ;TWO'S COMPLEMENT OF SETPOINT2 (MSB)
0855   E672         JNC THEN20
0857                   ELSE20:  ;FREQ IS BELOW OR EQUAL TO SETPOINT2 (MSB)
0857   BE08               MOV R6, #08H   ;CONSTANTS FOR RELAY SUBROUTINE
0859   BF0C               MOV R7, #0CH
085B   966C               JNZ THEN21
085D                          ELSE21:  ;FREQ IS EQUAL TO SETPOINT 2 (MSB)
085D   42                        MOV A, T  ;GET TIMER (LSB) AND
085E   0303                      ADD A, #03H  ;ADD TO 2'S COMP. OF SP1 (MLSB)
0860   E666                      JNC THEN22
0862                                ELSE22:  ;FREQ IS BELOW SP1 (LSB)
0862   14C1                            CALL RELAY  ;OPEN RELAY 4, KEEP 3,
0864   046A                            JMP FI22    ;CLOSE 1,2
0866                                THEN22:  ;FREQ IS ABOVE SP1 (LSB)
0866   1477                            CALL SUB1  ;SUBROUTINE SETPOINT 1
0868   046A                            JMP FI22
086A                             FI22:
086A   0470                      JMP FI21
086C                          THEN21:  ;FREQ IS BELOW SETPOINT 2 (LSB)
086C   14C1                      CALL RELAY  ;OPEN RELAY 4, KEEP 3, CLOSE 1,2
086E   0470                      JMP FI21
0870                       FI21:
0870   0476                JMP FI20
0872                   THEN20:   ;FREQ IS ABOVE SP1 (MSB)
0872   1477               CALL SUB1  ;SUBROUTINE SETPOINT 1
0874   0476               JMP FI20
0876                 FI20:   ;END OF SUBROUTINE
0876   83         RET
```

```
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;
                  ; SUBROUTINE SETPOINT 1 ;
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;
0877              SUB1:  ;START OF SUBROUTINE SETPOINT 1
0877   F8            MOV A, R0  ;GET TIMER OVERFLOW (MSB) AND ADD TO
0878   038F          ADD A, #8FH  ;TWO'S COMPLEMENT OF SETPOINT 1 (MSB)
087A   E697          JNC THEN30
087C                    ELSE30:  ;FREQ IS BELOW OR EQUAL TO SETPOINT 1 (MSB)
087C   BE0C                MOV R6, #0CH   ;CONSTANTS FOR RELAY SUBROUTINE
087E   BF0E                MOV R7, #0EH
0880   9691                JNZ THEN31
0882                          ELSE31:  ;FREQ IS EQUAL TO SETPOINT 1 (MSB)
0882   42                        MOV A, T  ;GET TIMER (LSB) AND
0883   0303                      ADD A, #03H  ;ADD TO 2'S COMP. OF SP1 (MLSB)
0885   E68B                      JNC THEN32
0887                                ELSE32:  ;FREQ IS BELOW SP1 (LSB)
0887   14C1                            CALL RELAY  ;OPEN RELAYS 3, 4,
0889   048F                            JMP FI32    ;KEEP 2, CLOSE 1
088B                                THEN32:  ;FREQ IS ABOVE SP1 (LSB)
088B   1477                            CALL SUB1  ;SUBROUTINE SETPOINT 1
088D   048F                            JMP FI32
088F                            FI32:
088F   0495                      JMP FI31
0891                          THEN31:  ;FREQ IS BELOW SETPOINT 1 (LSB)
0891   14C1                      CALL RELAY  ;OPEN RELAY 3, 4, KEEP 2, CLOSE 1
0893   0495                      JMP FI31
0895                        FI31:
0895   049B                JMP FI30
0897                    THEN30:  ;FREQ IS ABOVE SP1 (MSB)
0897   1477                CALL SUB1  ;SUBROUTINE SETPOINT 1
0899   049B                JMP FI30
089B                  FI30:  ;END OF SUBROUTINE
089B   83          RET
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                  ; SUBROUTINE SETPOINT HYSTERSIS ;
                  ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
089C              SUBHYS:  ;START OF SUBROUTINE SETPOINT HYS
089C   F8            MOV A, R0  ;GET TIMER OVERFLOW (MSB) AND ADD TO
089D   0390          ADD A, #90H  ;TWO'S COMPLEMENT OF SETPOINT HYS (MSB)
089F   E6BC          JNC THEN40
08A1                    ELSE40:  ;FREQ IS BELOW OR EQUAL TO SETPOINT HYS (MSB)
08A1   BE0E                MOV R6, #0EH   ;CONSTANTS FOR RELAY SUBROUTINE
08A3   BF0F                MOV R7, #0FH
08A5   96B6                JNZ THEN41
08A7                          ELSE41:  ;FREQ IS EQUAL TO SETPOINT HYS (MSB)
08A7   42                        MOV A, T  ;GET TIMER (LSB) AND
08A8   0303                      ADD A, #03H  ;ADD TO 2'S COMP. OF SPHYS (MLSB)
08AA   E6B0                      JNC THEN42
08AC                                ELSE42:  ;FREQ IS BELOW SPHYS (LSB)
08AC   14C1                            CALL RELAY  ;OPEN RELAYS 2,3,4, KEEP 1
08AE   04B4                            JMP FI42
08B0                                THEN42:  ;FREQ IS ABOVE SPHYS (LSB)
08B0   14C6                            CALL OPEN   ;OPEN ALL RELAYS
08B2   04B4                            JMP FI42
08B4                            FI42:
08B4   04BA                      JMP FI41
08B6                          THEN41:  ;FREQ IS BELOW SETPOINT HYS (LSB)
08B6   14C1                      CALL RELAY  ;OPEN RELAYS 2,3,4,  KEEP 1
08B8   04BA                      JMP FI41
08BA                        FI41:
08BA   04C0                JMP FI40
08BC                    THEN40:  ;FREQ IS ABOVE SPHYS (MSB)
08BC   14C6                CALL OPEN   ;OPEN ALL RELAYS
08BE   04C0                JMP FI40
08C0                  FI40:  ;END OF SUBROUTINE
08C0   83          RET
```

```
                    ;;;;;;;;;;;;;;;;;;;;
                    ; SUBROUTINE RELAY ;
                    ;;;;;;;;;;;;;;;;;;;;
08C1                RELAY:
08C1   FE              MOV A, R6    ;ONES IN R6 OPEN RELAY
08C2   8D              ORLD P5, A    ;AND ZEROS LEAVE THE REST THE SAME
08C3   FF              MOV A, R7    ;ZEROS IN R7 CLOSE RELAY
08C4   9D              ANLD P5, A    ;AND ONES LEAVE THE REST THE SAME
08C5   83           RET
                    ;;;;;;;;;;;;;;;;;;;;
                    ; SUBROUTINE OPEN  ;
                    ;;;;;;;;;;;;;;;;;;;;
08C6                OPEN:    ;OPENS ALL RELAYS
08C6   230F            MOV A, #0FH
08C8   3D              MOVD P5, A
08C9   83           RET
                    ;;;;;;;;;;;;;;;;;;;;
                    ; SUBROUTINE FREQ  ;
                    ;;;;;;;;;;;;;;;;;;;;
                    ;SUBROUTINE FREQ IS DIVIDED INTO TWO PARTS.  THE FIRST PART
                    ;MEASURES AND RECORDS THE LINE FREQUENCY.  THE SECOND
                    ;DISPLAYS THE FREQUENCY IN SIX DIGITS.
                    ;
08CA                FREQ:  ;SUBROUTINE FREQ
08CA   A8              MOV R0, A    ;CLEAR TIMER OVERFLOW REGISTER
08CB   62              MOV T, A    ;CLEAR TIMER
08CC   BA30            MOV R2, #30H          ;INITIALIZE CYCLE COUNTER REGISTER
08CE   BB48            MOV R3, #48H          ;TO 12360 COUNTS = 3048H
08D0                   DO10:    ;DO WHILE CYCLE COUNTER<>0
08D0                      DO11:    ;DOWHILE T1=0
08D0   342D                  CALL OVER
08D2   46D0                  JNT1 DO11
08D4                      OD11:
08D4   342D                  CALL OVER
08D6                      DO12:    ;DOWHILE T1=1
08D6   56D6                  JT1 DO12
08D8                      OD12:
08D8   55                 STRT T    ;START TIMING
08D9                      DO13:    ;DO WHILE LSB'S OF CYCLE COUNTER<>0
08D9   EBDD                  DJNZ R3, DO14
08DB   04F5                  JMP OD13
08DD                         DO14:    ;DO WHILE T1=0
08DD   342D                     CALL OVER    ;CHECK FOR TIMER OVERFLOW FLAG
08DF   46DD                     JNT1 DO14
08E1                         OD14:
08E1                         DO15:    ;DO WHILE T1=1
08E1   342D                     CALL OVER    ;CHECK FOR TIMER OVERFLOW FLAG
08E3   56E1                     JT1 DO15
08E5                         OD15:
08E5   B6E9                  JF0 THEN50
08E7                            ELSE50:
08E7   04F3                        JMP FI50
08E9                            THEN50:    ;DEC R2 ONLY
08E9   EAEE                        DJNZ R2, THEN51
08EB                                  ELSE51:
08EB   85                                CLR F0    ;CLEAR UNDERFLOW FLAG
08EC   04F1                              JMP FI51
08EE                                  THEN51:
08EE   85                                CLR F0    ;CLEAR UNDERFLOW FLAG
08EF   04F1                              JMP FI51
08F1                               FI51:
08F1   04F3                        JMP FI50
08F3                         FI50:
08F3   04D9                  JMP DO13
08F5                      OD13:    ;END OF DO13
08F5   95                 CPL F0    ;SET UNDERFLOW FLAG IF IT IS ZERO
08F6   FA                 MOV A, R2
08F7                   OD10:    ;END OF DO10
08F7   65              STOP TCNT    ;STOP TIMER IF REACHED COUNT
08F8   342D            CALL OVER    ;CHECK FOR TIMER OVERFLOW
```

```
                    247     ;
                    248     ; DISPLAY OF FREQUENCY (SEQUENCE OF SUBROUTINE FREQ)
                    249     ;
08FA   E5           250     SEL MB0
08FB   3435         251     CALL CLEAR
08FD   F5           252     SEL MB1
08FE   BCFF         253     MOV R4, #0FFH   ;INITIALIZE FIRST DELAY REGISTER
0900                254     DO16:   ;DO UNTIL SECOND DELAY=0
0900                255        DO17:   ;DO UNTIL SECOND DELAY=0
0900   ED00         256           DJNZ R5, DO17
0902                257        OD17:
0902   EC00         258        DJNZ R4, DO16
0904                259     OD16:   ;END OF DOUBLE DELAY
0904   2309         260     MOV A, #09H ;SET UP ADDRESS BUS FOR
0906   3E           261     MOVD P6, A  ;LOCATION 900-9FF
0907   80           262     MOVX A, @R0  ;LOOK UP BCD EQUIV. OF TIMER
0908   53C0         263     ANL A, #0C0H   ;CHECK IF LOOKUP IS 0.40 OR GREATER
090A   C610         264     JZ THEN52
090C                265        ELSE52:   ;DISPLAY 59
090C   233B         266           MOV A, #59
090E   2414         267           JMP FI52
0910                268        THEN52:   ;DISPLAY 60
0910   233C         269           MOV A, #60
0912   2414         270           JMP FI52
0914                271     FI52:
0914   E5           272     SEL MB0
0915   3435         273     CALL DISPRG   ;DISPLAY 59 OR 60
0917   F5           274     SEL MB1
0918   2309         275     MOV A, #09H ;SET UP ADDRESS BUS
091A   3E           276     MOVD P6, A  ;  FOR TABLE LOOKUP
091B   80           277     MOVX A, @R0  ;LOOK UP BSD EQUIV. OF TIMER OVERFLOW
091C   E5           278     SEL MB0
091D   3435         279     CALL DISPRG  ;DISPLAY TENTHS AND HUNDREDTHS OF FREQ
091F   F5           280     SEL MB1
0920   00           281     NOP
0921   00           282     NOP
0922   42           283     MOV A, T   ;READ TIMER LSBS
0923   A9           284     MOV R1, A   ;STORE LSB'S OF TIMER
0924   230A         285     MOV A, #0AH ;SET-UP ADDRESS BUS FOR
0926   3E           286     MOVD P6, A  ;TABLE LOOK-UP OF 1,000TH AND 10,000THS
0927   81           287     MOVX A, @R1
0928   E5           288     SEL MB0
0929   3435         289     CALL DISPRG  ;DISPLAY THOUSANDS AND TEN-THOUSANDS
092B   F5           290     SEL MB1
092C   83           291     RET  ;END OF SUBROUTINE FREQ
                    292     ;;;;;;;;;;;;;;;;;;;;
                    293     ; SUBROUTINE OVER  ;
                    294     ;;;;;;;;;;;;;;;;;;;;
                    295     ;SUBROUTINE ACCUMULATES OVERFLOW OF 8-BIT TIMER
                    296     ;
092D                297     OVER:   ;SUBROUTINE OVER
092D   1631         298     JTF THEN60
092F                299        ELSE60:  ;NO TIMER OVERFLOW
092F   2434         300           JMP FI60
0931                301        THEN60:  ;TIMER OVERFLOW
0931   18           302           INC R0   ;INCREMENT TIMER OVERFLOW REG
0932   2434         303           JMP FI60
0934                304     FI60:
0934   83           305     RET  ;END OF SUBROUTINE OVER
0935                306     DISPRG:
0935                307     CLEAR:
0935                308     END

NO ERROR(S) DETECTED
ASSEMBLER RUNTIME 00:00:00.72
HIGHEST 8048 ADDRESS USED = 0934 (HEX)
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