Dual Tone Multiple Frequency (DTMF)

National Semiconductor
Application Note 521
Verne H. Wilson
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The DTMF (Dual Tone Multiple Frequency) application is associated with digital telephony, and provides two selected output frequencies (one high band, one low band) for a duration of 100 ms. A benchmark subroutine has been written for the COP820C/840C microcontrollers, and is outlined in detail in this application note. This DTMF subroutine takes 110 bytes of COP820C/840C code, consisting of 78 bytes of program code and 32 bytes of ROM table. The timings in this DTMF subroutine are based on a 20 MHz COP820C/840C clock, giving an instruction cycle time of 1 μs.

The matrix for selecting the high and low band frequencies associated with each key is shown in *Figure 1*. Each key is uniquely referenced by selecting one of the four low band frequencies associated with the matrix rows, coupled with selecting one of the four high band frequencies associated with the matrix columns. The low band frequencies are 697, 770, 852, and 941 Hz, while the high band frequencies are 1209, 1336, 1477, and 1633 Hz. The DTMF subroutine assumes that the key decoding is supplied as a low order hex digit in the accumulator. The COP820C/840C DTMF subroutine will then generate the selected high band and low band frequencies on port G output pins G3 and G2 respectively for a duration of 100 ms.

The COP820C/840C each contain only one timer. The problem is that three different times must be generated to satisfy the DTMF application. These three times are the periods of the two selected frequencies and the 100 ms duration period. Obviously the single timer can be used to generate any one (or possibly two) of the required times, with the program having to generate the other two (or one) times.

The solution to the DTMF problem lies in dividing the 100 ms time duration by the half periods (rounded to the nearest micro second) for each of the eight frequencies, and then examining the respective high band and low band quotients and remainders. The results of these divisions are detailed in Table I. The low band frequency quotients range from 139 to 188, while the high band quotients range from 241 to 326. The observation that only the low band quotients will each fit in a single byte dictates that the high band frequency be produced by the 16 bit (2 byte) COP820C/840C timer running in PWM (Pulse Width Modulation) Mode.

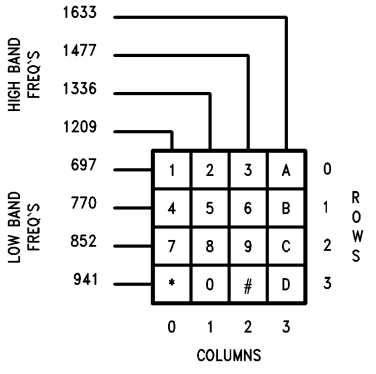

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FIGURE 1. DTMF Keyboard Matrix

The solution then is to use the program to produce the selected low band frequency as well as keep track of the 100 ms duration. This is achieved by using three programmed register counters R0, R2, and R3, with a backup register R1 to reload the counter R0. These three counters represent the half period, the 100 ms quotient, and the 100 ms remainder associated with each of the four low band frequencies.

The theory of operation in producing the selected low band frequency starts with loading the three counters with values obtained from a ROM table. The half period for the selected frequency is counted out, after which the G2 output bit is toggled. During this half period countout, the quotient counter is decremented. This procedure is repeated until the quotient counter counts out, after which the program branches to the remainder loop. During the remainder loop, the remainder counter counts out to terminate the 100 ms. Following the remainder countout, the G2 and G3 bits are both reset, after which the DTMF subroutine is exited. Great care must be taken in time balancing the half period loop for the selected low band frequency. Furthermore, the toggling of the G2 output bit (achieved with either a set or reset bit instruction) must also be exactly time balanced to maintain the half period time integrity. Local stall loops (consisting of a DRSZ instruction followed by a JP jump back to the DRSZ for a two byte, six instruction cycle loop) are embedded in both the half period and remainder loops. Consequently, the ROM table parameters for the half period and remainder counters are approximately only one sixth of what otherwise might be expected. The program for the half period loop, along with the detailed time balancing of the loop for each of the low band frequencies, is shown in *Figure 2*.

The DTMF subroutine makes use of two 16 byte ROM tables. The first ROM table contains the translation table for the input hex digit into the core vector. The encoding of the hex digit along with the hex digit ROM translation table is shown in Table II. The row and column bits (RR, CC) representing the low band and high band frequencies respectively of the keyboard matrix shown in *Figure 1*, are encoded in

TABLE I. Frequency Half Periods, Quotients, and Remainders

	Freq. Hz	Half Period 0.5P	Half Period in μs	100 ms/0.5P	
				Quotient	Remainder
Low Band Freq.'s	697	717.36	717	139	337
	770	649.35	649	154	54
	852	586.85	587	170	210
	941	531.35	531	188	172
High Band Freq.'s	1209	413.56	414 (256 + 158)	241	226
	1336	374.25	374 (256 + 118)	267	142
	1477	338.52	339 (256 + 83)	294	334
	1633	306.18	306 (256 + 50)	326	244

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the two upper and two lower bits of the hex digit respectively. Consequently, the format for the hex digit bits is RRCC, so that the input byte in the accumulator will consist of 0000RRCC. The program changes this value into 1101RRCC before using it in setting up the address for the hex digit ROM translation table.

The core vectors from the hex digit ROM translation table consist of a format of XX00TT00, where the two T (Timer) bits select one of four high band frequencies, while the two X bits select one of four low band frequencies. The core vector is transformed into four different inputs for the second ROM table. This transformation of the core vector is shown in Table III. The core vector transformation produces a timer vector 1100TT00 (T), and three programmed counter vectors for R1, R2, and R3. The formats for the three counter vectors are 1100XX11 (F), 1100XX10 (Q), and 1100XX01 (R) for R1, R2, and R3 respectively. These four vectors produced from the core vector are then used as inputs to the second ROM table. One of these four vectors (the T vector) is a function of the T bits from the core vector, while the other three vectors (F, Q, R) are a function of the X bits. This correlates to only one parameter being needed for the timer (representing the selected high band frequency), while three parameters are needed for the three counters (half period, 100 ms quotient, 100 ms remainder) associated with the low band frequency and 100 ms duration. The frequency parameter ROM translation table, accessed by the T, F, Q, and R vectors, is shown in Table IV.

Program			Bytes/Cycle	Conditional Cycles		Cycles	Total Cycles
	LD	B,#PORTGD	2/3				
	LD	X,#R1	2/3				
LUP1:	LD	A,[X−]	1/3			3	
	IFBIT	2,[B]	1/1			1	
	JP	BYP1	1/3	3	1		
	X	A,[X+]	1/3		3		
	SBIT	2,[B]	1/1		1		
	JP	BYP2	1/3		3		
BYP1:	NOP		1/1	1			
	RBIT	2,[B]	1/1	1			
	X	A,[X+]	1/3	3			
BYP2:	DRSZ	R2	1/3 DECREMENT			3	
	JP	LUP2	1/3 Q COUNT			3	
	JP	FINI	1/3				
LUP2:	DRSZ	R0	1/3 DECREMENT		3	3	
	JP	LUP2	1/3 F COUNT		3	1	
	NOP		1/1			1	
	LD	A,[X]	1/3			3	
	IFEQ	A,#104	2/2			2	
	JP	LUP1	1/3		1	3	31
	NOP		1/1		1		
	IFEQ	A,#93	2/2		2		
BACK:	JP	LUP1	1/3	1	3		35
	JP	BACK	1/3	3			
				3			39

Table IV Frequency	×	Stall Loop	+	Total Cycles	=	Half Period
((114 − 1)		x 6)		+ 39		= 717
((104 − 1)		x 6)		+ 31		= 649
((93 − 1)		x 6)		+ 35		= 587
((83 − 1)		x 6)		+ 39		= 531

FIGURE 2. Time Balancing for Half Period Loop

TABLE II. Hex Digit ROM Translation Table

	0	1	2	3
ROW	697 Hz	770 Hz	852 Hz	941 Hz
COLUMN	1209 Hz	1336 Hz	1477 Hz	1633 Hz

ADDRESS *	DATA (HEX)	KEYBOARD
0xD0	000	1
0xD1	004	2
0xD2	008	3
0xD3	00C	A
0xD4	040	4
0xD5	044	5
0xD6	048	6
0xD7	04C	B
0xD8	080	7
0xD9	084	8
0xDA	088	9
0xDB	08C	C
0xDC	0C0	*
0xDD	0C4	0
0xDE	0C8	#
0xDF	0CC	D

* HEX DIGIT IS RRCC,
WHERE R = ROW #
AND C = COLUMN #
- - - EXAMPLE: KEY 3 IS ROW #0,
COLUMN #2, SO HEX DIGIT
IS 0010 = 2
RRCC

TABLE III. Core Vector Translation

CORE VECTOR - XX00TT00 - - - - - - - - - -

*
* *
* * *

TIMER VECTOR	TIMER	T	1100TT00
HALF PERIOD VECTOR	R1	F	1100XX11
QUOTIENT VECTOR	R2	Q	1100XX10
REMAINDER VECTOR	R3	R	1100XX01

TABLE IV. Frequency Parameter ROM Translation Table

T - TIMER F - FREQUENCY Q - QUOTIENT R - REMAINDER

ADDRESS	DATA (DEC)	VECTOR
0xC0	158	T
0xC1	53	R
0xC2	140	Q
0xC3	114	F
0xC4	118	T
0xC5	6	R
0xC6	155	Q
0xC7	104	F
0xC8	83	T
0xC9	32	R
0xCA	171	Q
0xCB	93	F
0xCC	50	T
0xCD	25	R
0xCE	189	Q
0xCF	83	F

In summary, the input hex digit selects one of 16 core vectors from the first ROM table. This core vector is then transformed into four other vectors (T, F, Q, R), which in turn are used to select four parameters from the second ROM table. These four parameters are used to load the timer, and the respective half period, quotient, and remainder counters. The first ROM table (representing the hex digit matrix table) is arbitrarily placed starting at ROM location 01D0, and has a reference setup with the ADD A,#0D0 instruction. The second ROM table (representing the frequency parameter table) must be placed starting at ROM location 01C0 (or 0xC0) in order to minimize program size, and has reference setups with the OR A,#0C3 instruction for the F vector and with the OR A,#0C0 instruction for the T vector.

The three parameters associated with the two X bits of the core vector require a multi-level table lookup capability with the LAID instruction. This is achieved with the following section of code in the DTMF subroutine:

```
        LD      B,#R1
        LD      X,#R4
        X       A,[X]
LUP:    LD      A,[X]
        LAID
        X       A,[B+]
        DRSZ    R4
        IFBNE   #4
        JP      LUP
```

This program code loads the F frequency vector into R4, and then decrements the vector each time around the loop. This successive loop decrementation of the R4 vector changes the F vector into the Q vector, and then changes the Q vector into the R vector. This R4 vector is used to access the ROM table with the LAID instruction. The X pointer references the R4 vector, while the B pointer is incremented each time around the loop after it has been used to store away the three selected ROM table parameters (one per loop). These three parameters are stored in sequential RAM locations R1, R2, and R3. The IFBNE test instruction is used to skip out of the loop once the three selected ROM table parameters have been accessed and stored away.

The timer is initialized to a count of 15 so that the first timer underflow and toggling of the G3 output bit (with timer PWM mode and G3 toggle output selected) will occur at the same time as the first toggling of the G2 output bit. The half period counts for the high band frequencies range from 306 to 414, so these values minus 256 are stored in the timer section of the second ROM table. The selected value from this frequency ROM table is then stored in the lower half of the timer autoreload register, while a 1 is stored in the upper half. The timer is selected for PWM output mode and started with the instruction LD [B],#0B0 where the B pointer is selecting the CNTRL register at memory location 0EE.

The DTMF subroutine for the COP820C/840C uses 110 bytes of code, consisting of 78 bytes of program code and 32 bytes of ROM table. A program routine to sequentially call the DTMF subroutine for each of the 16 hex digit inputs is supplied with the listing for the DTMF subroutine.

```
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  1              ;DTMF PROGRAM FOR COP820C/840C          VERNE H. WILSON
  2              ;                                            5/1/89
  3              ;DTMF - DUAL TONE MULTIPLE FREQUENCY
  4              ;
  5              ;PROGRAM NAME: DTMF.MAC
  6              ;
  7                        .TITLE DTMF
  8                        .CHIP 840
  9              ;******* THE DTMF SUBROUTINE CONTAINS 110 BYTES *******
 10              ; ***** THE DTMF SUBROUTINE TIMES OUT IN 100MSEC *****
 11              ;    ** FROM THE FIRST TOGGLE OF THE G2/G3 OUTPUTS **
 12              ;       *** BASED ON A 20 MHZ COP820C/840C CLOCK ***
 13              ;
 14              ;G PORT IS USED FOR THE TWO OUTPUTS
 15              ;     -    HIGH BAND (HB) FREQUENCY OUTPUT ON G3
 16              ;     -    LOW BAND (LB) FREQUENCY OUTPUT ON G2
 17              ;
 18              ;TIMER COUNTS OUT
 19              ;     -    HB FREQUENCIES
 20              ;
 21              ;PROGRAM COUNTS OUT
 22              ;     -    LB FREQUENCIES
 23              ;     -    100 MSEC DIVIDED BY LB HALF PERIOD QUOTIENT
 24              ;     -    100 MSEC DIVIDED BY LB HALF PERIOD REMAINDER
 25              ;
 26              ;FORMAT FOR THE 16 HEX DIGIT MATRIX VECTOR IS 1101RRCC,
 27              ;    WHERE  -  RR IS ROW SELECT (LB FREQUENCIES)
 28              ;           -  CC IS COLUMN SELECT (HB FREQUENCIES)
 29              ;
 30              ;FORMAT FOR THE 16 CORE VECTORS FROM THE MATRIX SELECT
 31              ;    TABLE IS XX00TT00, WHERE  -  TT IS HB SELECT
 32              ;                                 XX IS LB SELECT
 33              ;
 34              ;FREQUENCY VECTORS (HB & LB) FOR FREQ PARAMETER TABLE
 35              ;    MADE FROM CORE VECTORS
 36              ;
 37              ;HB FREQUENCY VECTORS(4) END WITH 00 FOR TIMER COUNTS,
 38              ;    WHERE VECTOR FORMAT IS 1100TT00
 39              ;
 40              ;LB FREQUENCY VECTORS(12) END WITH:
 41              ;    11 FOR HALF PERIOD LOOP COUNTS,
 42              ;         WHERE VECTOR FORMAT IS 1100XX11
 43              ;    10 FOR 100 MSEC DIVIDED BY HALF PERIOD QUOTIENTS,
 44              ;         WHERE VECTOR FORMAT IS 1100XX10
 45              ;    01 FOR 100 MSEC DIVIDED BY HALF PERIOD REMAINDERS,
 46              ;         WHERE VECTOR FORMAT IS 1100XX01
 47              ;
 48              ;HEX DIGIT MATRIX TABLE AT HEX 01D* (OPTIONAL LOCATION,
 49              ;    DEPENDING ON  'ADD  A,#0D0' INST. IMMEDIATE VALUE)
 50              ;
 51              ;FREQ PARAMETER TABLE AT HEX 01C*  (REQUIRED LOCATION)
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  52                        .FORM
  53                  ;
  54                  ;MAGIC:       CORE VECTOR
  55                  ;               XX00TT00
  56                  ;
  57                  ;    TIMER     T    TT00
  58                  ;    R1        F    XX11
  59                  ;    R2        Q    XX10
  60                  ;    R3        R    XX01
  61                  ;
  62                  ;DECLARATIONS:
  63       00D0          PORTLD = 0D0          ; PORTL DATA REG
  64       00D1          PORTLC = 0D1          ; PORTL CONFIG REG
  65       00D4          PORTGD = 0D4          ; PORTG DATA REG
  66       00D5          PORTGC = 0D5          ; PORTG CONFIG REG
  67       00DC           PORTD = 0DC          ; PORTD REG
  68       00EA         TIMERLO = 0EA          ; TIMER LOW COUNTER
  69       00EE           CNTRL = 0EE          ; CONTROL REG
  70       00EF             PSW = 0EF          ; PROC STATUS WORD
  71       00F0              R0 = 0F0          ; LB FREQ LOOP COUNTER
  72       00F1              R1 = 0F1          ; LB FREQ LOOP COUNT
  73       00F2              R2 = 0F2          ; LB FREQ Q COUNT
  74       00F3              R3 = 0F3          ; LB FREQ R COUNT
  75       00F4              R4 = 0F4          ; LB FREQ TABLE VECTOR
  76                  ;
  77  0000 DD2F    START:     LD        SP,#02F         ; HEX DIGIT MATRIX
  78  0002 BCD1FF             LD        PORTLC,#0FF     ; 1  2  3  A
  79  0005 BCD080             LD        PORTLD,#080     ; 4  5  6  B
  80  0008 DEDC               LD        B,#PORTD        ; 7  8  9  C
  81  000A 9E00               LD        [B],#0          ; *  0  #  D
  82  000C AE      LOOP:      LD        A,[B]           ; DTMF TEST LOOP
  83  000D 3160               JSR       DTMF            ; HEX MATRIX DIGIT
  84  000F DEDC               LD        B,#PORTD        ; TO SUBROUTINE IS
  85  0011 AE                 LD        A,[B]           ; OUTPUT TO PORTD
  86  0012 9405               ADD       A,#5            ; DO WILL TOGGLE
  87  0014 A6                 X         A,[B]           ; FOR EACH CALL OF
  88  0015 6C                 RBIT      4,[B]           ; DTMF SUBROUTINE
  89  0016 9DD0               LD        A,PORTLD        ; PORTL OUTPUTS
  90  0018 A1                 SC                        ; PROVIDE SYNC
  91  0019 B0                 RRC       A               ; OUTPUT ORDER IS
  92  001A 9CD0               X         A,PORTLD        ; 1,5,9,D,4,8,#,A,
  93  001C EF                 JP        LOOP            ; 7,0,3,B,*,2,6,C
  94                  ;
  96                  ;
```

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```
 97      0160              .=0160
 98                ;
 99 0160 DED5     DTMF:    LD        B,#PORTGC
100 0162 9B3F              LD        [B-],#03F
101 0164 6B                RBIT      3,[B]          ; OPTIONAL
102 0165 6A                RBIT      2,[B]          ; OPTIONAL
103               ;
104 0166 94D0              ADD       A,#0D0
105 0168 A4                LAID                     ; DIGIT MATRIX TABLE
106               ;
107 0169 5F                LD        B,#0
108 016A A6                X         A,[B]
109 016B AE                LD        A,[B]
110 017B 65                SWAP      A
111 016C 97C3              OR        A,#0C3
112 016E DEF1              LD        B,#R1
113 0170 DCF4              LD        X,#R4
114 0172 B6                X         A,[X]
115 0173 BE      LUP:      LD        A,[X]
116 0174 A4                LAID                     ; LB FREQ TABLES
117 0175 A2                X         A,[B+]         ;   (3 PARAMETERS)
118 0176 C4                DRSZ      R4
119 0177 44                IFBNE     #4
120 0178 FA                JP        LUP
121               ;
122 0179 5F                LD        B,#0
123 017A AE                LD        A,[B]
124 017C 97C0              OR        A,#0C0
125 017E A4                LAID                     ; HB FREQ TABLE
126 017F DEEA              LD        B,#TIMERLO     ;   (1 PARAMETER)
127 0181 9A0F              LD        [B+],#15
128 0183 9A00              LD        [B+],#0
129 0185 A2                X         A,[B+]
130 0186 9A01              LD        [B+],#1
131 0188 9EB0              LD        [B],#0B0       ; START TIMER PWM
132               ;
133 018A DED4              LD        B,#PORTGD
134 018C DCF1              LD        X,#R1
135               ;
136 018E BB      LUP1:     LD        A,[X-]
137 018F 72                IFBIT     2,[B]          ; TEST LB OUTPUT
138 0190 03                JP        BYP1
139 0191 B2                X         A,[X+]
140 0192 7A                SBIT      2,[B]          ; SET LB OUTPUT
141 0193 03                JP        BYP2
142 0194 B8      BYP1:     NOP
143 0195 6A                RBIT      2,[B]          ; RESET LB OUTPUT
144 0196 B2                X         A,[X+]
145 0197 C2      BYP2:     DRSZ      R2             ; DECR. QUOT. COUNT
146 0198 01                JP        LUP2
147 0199 0C                JP        FINI           ; Q COUNT FINISHED
148               ;
149 019A C0      LUP2:     DRSZ      R0             ; DECR. F COUNT
150 019B FE                JP        LUP2           ; LB (HALF PERIOD)
151               ;
152 019C B8                NOP                      ; **************
153 019D BE                LD        A,[X]          ; BALANCE
154 019E 9268              IFEQ      A,#104         ; LB FREQUENCY
155 01A0 ED                JP        LUP1           ; HALF PERIOD
156               ;                                  ; RESIDUE
157 01A1 B8                NOP                      ; DELAY FOR
158 01A2 925D              IFEQ      A,#93          ; EACH OF 4
159 01A4 E9      BACK:     JP        LUP1           ; LB FREQ'S
160 01A5 FE                JP        BACK           ; **************
161               ;
162 01A6 C3      FINI:     DRSZ      R3             ; DECR. REM. COUNT
163 01A7 FE                JP        FINI           ; R CNT NOT FINISHED
164               ;
165 01A8 BDEE6C            RBIT      4,CNTRL        ; STOP TIMER
166 01AB 6B                RBIT      3,[B]          ; CLR HB OUTPUT
167 01AC 6A                RBIT      2,[B]          ; CLR LB OUTPUT
168               ;
169 01AD 8E                RET
170               ;
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                                    .FORM
                    ;
                    ;FREQUENCY AND 100MSEC PARAMETER TABLE
          01C0                      .=01C0
                    ;
 01C0 9E                            .BYTE     158             ; T
 01C1 35                            .BYTE      53             ; R
 01C2 8C                            .BYTE     140             ; Q
 01C3 72                            .BYTE     114             ; F
 01C4 76                            .BYTE     118             ; T
 01C5 06                            .BYTE       6             ; R
 01C6 9B                            .BYTE     155             ; Q
 01C7 68                            .BYTE     104             ; F
 01C8 53                            .BYTE      83             ; T
 01C9 20                            .BYTE      32             ; R
 01CA AB                            .BYTE     171             ; Q
 01CB 5D                            .BYTE      93             ; F
 01CC 32                            .BYTE      50             ; T
 01CD 19                            .BYTE      25             ; R
 01CE BD                            .BYTE     189             ; Q
 01CF 53                            .BYTE      83             ; F
                    ;
                    ;DIGIT MATRIX TABLE
          01D0                      .=01D0
                    ;                                                   ROW  COL
 01D0 00                            .BYTE     000             ; 1       0    0
 01D1 04                            .BYTE     004             ; 2       0    1
 01D2 08                            .BYTE     008             ; 3       0    2
 01D3 0C                            .BYTE     00C             ; A       0    3
 01D4 40                            .BYTE     040             ; 4       1    0
 01D5 44                            .BYTE     044             ; 5       1    1
 01D6 48                            .BYTE     048             ; 6       1    2
 01D7 4C                            .BYTE     04C             ; B       1    3
 01D8 80                            .BYTE     080             ; 7       2    0
 01D9 84                            .BYTE     084             ; 8       2    1
 01DA 88                            .BYTE     088             ; 9       2    2
 01DB 8C                            .BYTE     08C             ; C       2    3
 01DC C0                            .BYTE     0C0             ; *       3    0
 01DD C4                            .BYTE     0C4             ; 0       3    1
 01DE C8                            .BYTE     0C8             ; #       3    2
 01DF CC                            .BYTE     0CC             ; D       3    3
                    ;
                                    .END
```

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SYMBOL TABLE

 B       00FE          BACK    01A4          BYP1    0194          BYP2    0197
 CNTRL   00EE          DTMF    0160          FINI    01A6          LOOP    000C
 LUP     0174          LUP1    018E          LUP2    019A          PORTD   00DC
 PORTGC  00D5          PORTGD  00D4          PORTLC  00D1          PORTLD  00D0
 PSW     00EF  *       R0      00F0          R1      00F1          R2      00F2
 R3      00F3          R4      00F4          SP      00FD          START   0000  *
 TIMERL  00EA          X       00FC



MACRO TABLE


   NO WARNING LINES

   NO ERROR LINES

  139  ROM BYTES USED

SOURCE CHECKSUM = 99A7
OBJECT CHECKSUM = 03E1

INPUT   FILE C:DTMF.MAC
LISTING FILE C:DTMF.PRN
OBJECT  FILE C:DTMF.LM
```

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The code listed in this App Note is available on Dial-A-Helper.

Dial-A-Helper is a service provided by the Microcontroller Applications Group. The Dial-A-Helper system provides access to an automated information storage and retrieval system that may be accessed over standard dial-up telephone lines 24 hours a day. The system capabilities include a MESSAGE SECTION (electronic mail) for communicating to and from the Microcontroller Applications Group and a FILE SECTION mode that can be used to search out and retrieve application data about NSC Microcontrollers. The minimum system requirement is a dumb terminal, 300 or 1200 baud modem, and a telephone.

With a communications package and a PC, the code detailed in this App Note can be down loaded from the FILE SECTION to disk for later use. The Dial-A-Helper telephone lines are:

Modem (408) 739-1162
Voice (408) 721-5582

For Additional Information, Please Contact Factory

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