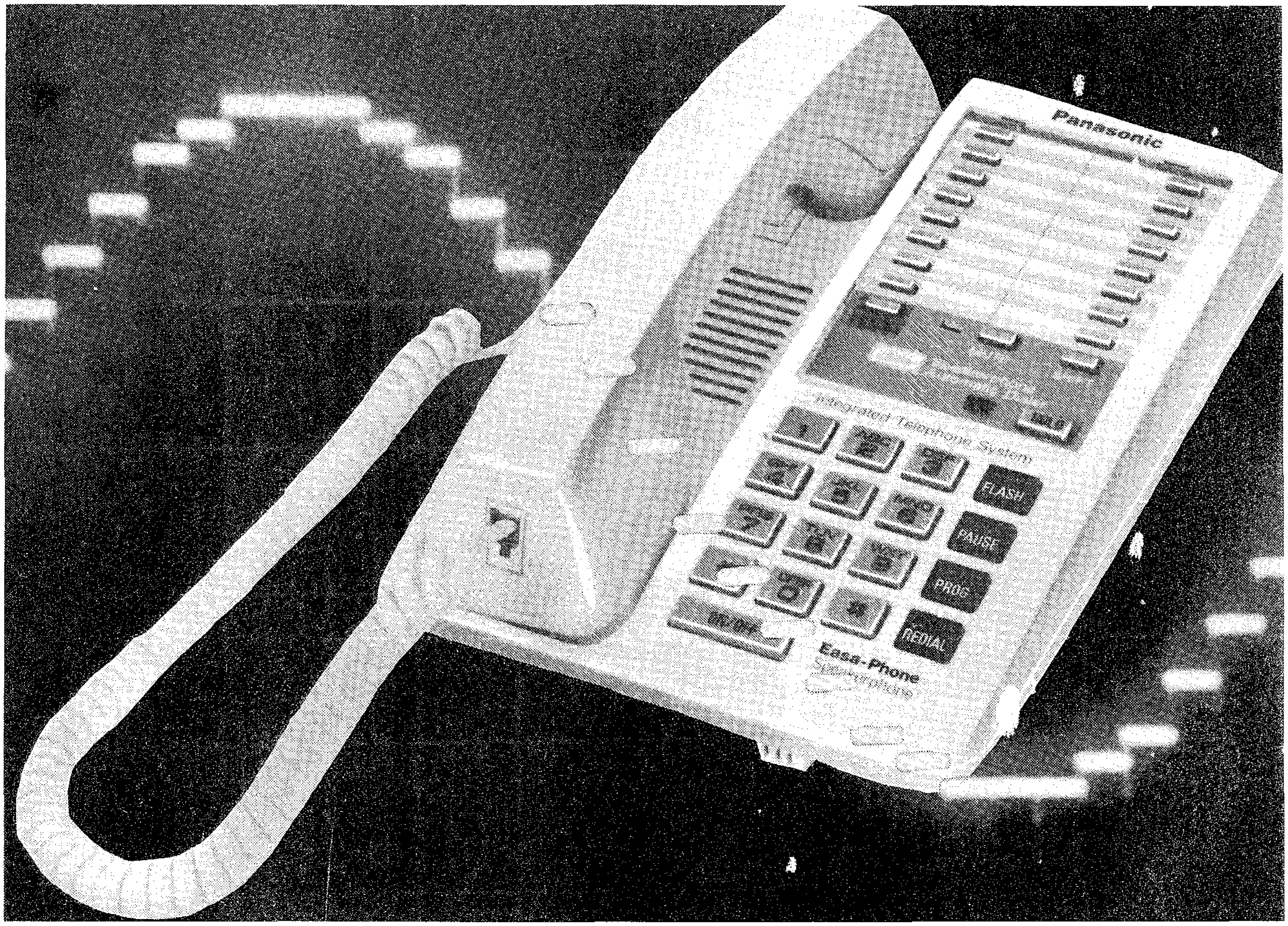

DTMF Encoding and Decoding

Thanks to new low-cost DTMF encoders and decoders, the world of DTMF signalling now is available for use in your next project.

DALE NASSAR

DTMF (*DUAL-TONE MULTI-FREQUENCY*) signalling was developed about two decades ago by Bell Labs as a faster (by a factor of about 10), more versatile, and more reliable telephone-dialing scheme than the old pulse or rotary-dialing technique. The DTMF method is often referred to as tone dialing or *Touch-Tone* (note that *Touch-Tone* is a trademark of AT&T) and is used with push-button telephones and other equipment.

A standard DTMF signal consists of a pair of audio tones chosen from a group of eight standard frequencies. Those frequencies are divided into two groups: a low-tone group of four frequencies and a high-tone group of four frequencies. A valid DTMF signal consists of the algebraic sum of one tone from the low group and one tone from the high group. There are therefore 16 (4 low × 4 high) possible DTMF signals that can be encoded with the eight frequencies. The four standard low frequencies are 697, 770, 852, and 941 Hz, and are referred to as row frequencies R1, R2, R3, and R4, respectively. The four standard high frequencies are 1209, 1336, 1477, and 1633 Hz, and are referred to as column frequencies C1, C2, C3, and C4, respectively. Any combination of DTMF tone can be generated using a 4 × 4 keypad switch matrix as shown in Fig. 1. The DTMF frequencies and the keypad layout of Fig. 1 are international standards. The frequencies produced by DTMF generators are allowed a ±1.5% deviation from the listed standards. Note that all of those tones are well within the telephone system's voice band.

The choice of the standard DTMF frequencies was by no means an arbitrary one. The designers of the DTMF system used a great deal of care in selecting the particular frequencies. Other tones that may appear on the telephone line such as dial tones and power-line noise must not fall in the DTMF frequency band. Further, the standard frequencies must have no harmonic interaction, thus the highest standard frequency (1633 Hz) is lower than the third harmonic of the lowest standard frequency (697 Hz).

Conventional telephones that use DTMF signalling are usually equipped with a standard 3 × 4 keypad matrix for representing the digits 0–9, and two spare symbols, * (star or asterisk), and # (pound or octothorpe), which can be used for various purposes. That 3 × 4 matrix represents all four row frequencies (R1–R4), and the three lowest column frequencies (C1–C3). Some special-purpose

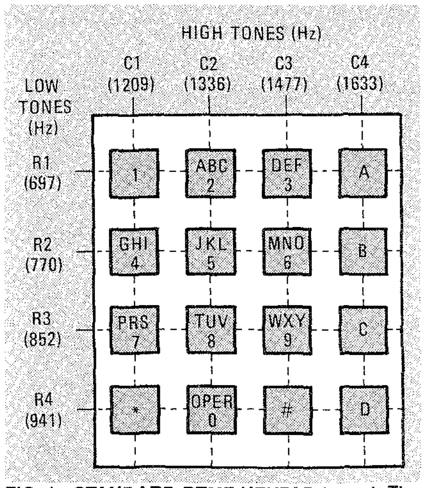

FIG. 1—STANDARD DTMF KEYPAD layout. The DTMF row and column frequencies are as shown.

telephones use the fourth column (C4) to represent four additional symbols (shown as A, B, C, and D in Fig. 1) in order to encode all of the sixteen possible DTMF signals.

If you have a tone-dial phone you can listen to a DTMF signal by simply picking up the telephone handset and pressing one of the buttons. For example, pressing the 8 key generates a 852-Hz tone (R3) and a 1336-Hz tone (C2) simultaneously. Those signals are processed and decoded by a DTMF receiver at the telephone company's central office.

The central office contains the switching equipment that provides local-exchange telephone service for a given geographical area. That area is designated by the first three digits of the telephone number. After the connection is established between the called and the calling parties, the DTMF receiver (at the central office) is no longer active and the connected parties are free to use the keypad-generated signals for station-to-station (end-to-end) signalling.

Until very recently, the DTMF encoders used by the telephone companies exclusively used large and bulky transistorized LC-tuned oscillator circuits to generate the tones. Many such LC circuits are still in use. Such rugged circuits were used by the telephone company because they were extremely dependable. They were designed to withstand the worst of operating conditions. For the hobbyist, limited parts availability makes building that type of circuit almost impractical. Fortunately it is also unnecessary, as DTMF generators are available in IC form.

Further, until just a few years ago the experimenter had to settle for a not-so-reliable IC decoding (receiving) system. The decoding circuitry had to be built up using a number of simple IC's. For instance, a separate 567 phase-locked-loop tone-detector IC was required for each frequency used, for a total of eight. Additionally, each tone detector had to be tuned by critical external timing components. Because each DTMF signal received activated two detector outputs (one for each frequency received), a logic circuit had to be added to convert those outputs into a usable format. The net result was a complex circuit that was time-consuming to build and difficult to align. Also, performance was often unsatisfactory. True, performance could be improved with the addition of pre-filtering at the inputs of each tone detector. But the active-filter circuitry required for that made an already complex circuit even more so.

Fortunately, those days are gone forever. With the new DTMF IC's available today, a complete and extremely reliable DTMF-encoding and -decoding system can be breadboarded in less than 10 minutes. Also, the built-in features of those decoding IC's usually include pre-filtering, complex processing, signal validation, etc., making possible a high degree of efficiency and reliability. In addition, no external tuning components are required, keeping the parts count minimal. DTMF IC's are manufactured by Nation-

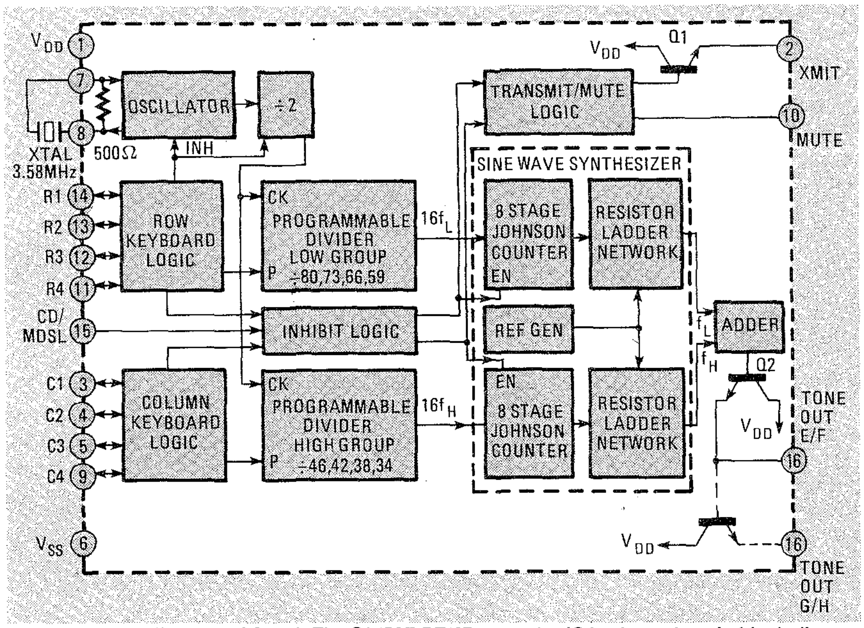

FIG. 2—INSIDE A DTMF ENCODER. The S2559E DTMF generator IC is shown here in block-diagram form.

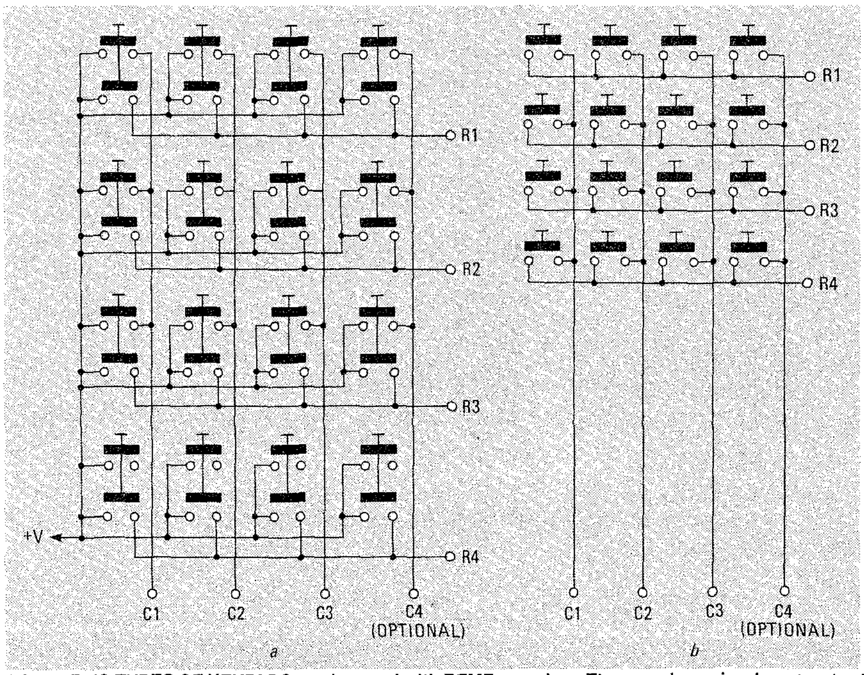

FIG. 3—TWO TYPES OF KEYPADS can be used with DTMF encoders. The one shown in *a* is a standard telephone tone-dialing keypad and uses DPST switches. The one shown in *b* is a calculator-type keypad and uses simple SPST switches, but it can not be used with all encoder IC's.

al, Silicon Systems, Mostek, Motorola, AMI, and Teltone.

Although the DTMF system was originally designed for telephone dialing, it is extremely useful as the basis for remote-control systems. In this article we'll describe some of the DTMF-encoding and -decoding IC's that are commercially available, and how they can be used in remote-control applications. After reading this article, you should have no trouble choosing and sucessfully using the DTMF IC's that best fit your needs.

DTMF encoding

The heart of a DTMF encoder is a a DTMF tone-generator IC. Those IC's are extremely easy to use and are very low in cost. Some DTMF tone generators are available for less than $2.00 in single quantities! They generate the desired DTMF signals by dividing a crystal-generated reference frequency. The oscillator is on-board the IC; the crystal is simply connected across two terminals of the IC. The most-common crystal frequency is 3.579545 MHz; that's the TV color-burst frequency, so those crystals are readily available and low in cost. However, as we will see shortly, other frequency references may be used for special purposes.

A block diagram of a typical tone-encoder IC is shown in Fig. 2. The IC illustrated there is a Gould AMI (3800 Homestead Rd., Santa Clara, CA 95051) S2559E. The desired DTMF signals are activated by a twelve-key (3 × 4) or sixteen-key (4 × 4) matrix keypad that is connected directly to the row- and column-input pins of the tone-generator IC. Two major types of keypads are used: One is the standard telephone pushbutton keypad. They are used with IC's that generate tones whenever the corresponding row and column pins are pulled high. As shown in Fig. 3-*a*, that keypad consists of a series of DPST momentary switches with a common line that simultaneously pulls the corresponding row and column outputs high when pressed. Note that some encoders are active low. For those, the keypad common line is connected to ground. Then, the appropriate row and common outputs are grounded when a key is pressed. The other, and simpler, keypad arrangement is shown in Fig. 3-*b*. Referred to as a calculator-type or X-Y keypad, it consists of SPST momentary switches and can be built easily. However, it can only be used with tone generators that use calculator-type scanning circuitry to detect switch closures. The S2559E contains such circuitry. Generally, the data sheet of a particular tone encoder will specify the type of keypad required.

A simple DTMF encoder is shown in Fig. 4. It mainly consists of a 16-key SPST keypad like the one shown in Fig. 3-*b*, and the S2559E tone-encoder IC. Power can be supplied by a small power supply or by a conventional 9-volt battery. Because the S2559E is a CMOS device, power consumption is low. Typically, the circuit shown will draw 5 mA during encoding and 7 μA when idle. Since the device is CMOS, be sure to observe all of the standard precautions when handling the IC.

TABLE 1—PIN FUNCTIONS

Pin	Function
SIGNAL IN	DTMF input. Internally biased so that the input signal may be AC coupled. SIGNAL IN also permits DC coupling as long as the input voltage does not exceed the positive supply.
12/$\overline{16}$	DTMF-signal detection control. When 12/$\overline{16}$ is at logic 1, the M-957 detects the 12 most commonly used DTMF signals (1 through #). When 12/$\overline{16}$ is at logic Ø, the M-957 detects all 16 DTMF signals (1 through D).
A, B	Binary DTMF signal-sensitivity control inputs. A and B select the sensitivity of the SIGNAL IN input to a maximum of −31 dBm.
D3, D2, D1, D0	Data outputs. When enabled by the OE input, the data outputs provide the code corresponding to the detected digit in the format programmed by the HEX pin. The data outputs become valid after a tone pair has been detected and are cleared when a valid pause is timed.
OE	Output enable. When OE is at logic 1, the data outputs are in the CMOS push/pull state and represent the contents of the output register. When OE is driven to logic Ø, the data outputs are forced to the high-impedance or "third" state.
HEX	Binary output format control. When HEX is at logic 1, the output of the M-957 is full 4-bit binary. When HEX is at logic Ø, the output is binary-coded 2-of-8.
STROBE	Valid data indication. STROBE goes to logic 1 after a valid tone pair is sensed and decoded at the data outputs. STROBE remains at logic 1 until a valid pause occurs or the CLEAR input is driven to logic 1, whichever is earlier.
CLEAR	STROBE control. Driving CLEAR to logic 1 forces the STROBE output to logic Ø. When CLEAR is at logic Ø, STROBE is forced to logic Ø only when a valid pause is detected. Tie to VNA or VND when not used.
BD	Early signal presence output. BD indicates that a possible signal has been detected and is being validated.
XIN, XOUT	Crystal connections. When an auxiliary clock is used, XIN should be tied to logic 1.
OSC/$\overline{CLK}$	Time base control. When OSC/$\overline{CLK}$ is at logic 1, the output of the M-957's internal oscillator is selected as the time base. When OSC/$\overline{CLK}$ is at logic Ø and XIN is at logic 1, the AUXCLK input is selected as the time base.
AUXCLK	Auxiliary clock input. When OSC/$\overline{CLK}$ is at logic Ø and XIN is at logic 1, the AUXCLK input is selected as the M-957's time base. The auxiliary input must be 3.58 MHz divided by 8 for the M-957 to operate to specifications. If unused, AUXCLK should be left open.
VNA, VND	Negative analog and digital power supply connections. Separated on the chip for greater system flexibility, VNA and VND should be at equal potentials.
VP	Positive power suppy connection.

Encoder output

The output of the encoder consists of two of the eight DTMF frequencies. Figure 5 shows an oscilloscope display of the row-3 signal (852 Hz) and Fig. 6 shows the column-2 signal (1336 Hz). The DTMF output is produced by adding the two signals together. The resulting signal,

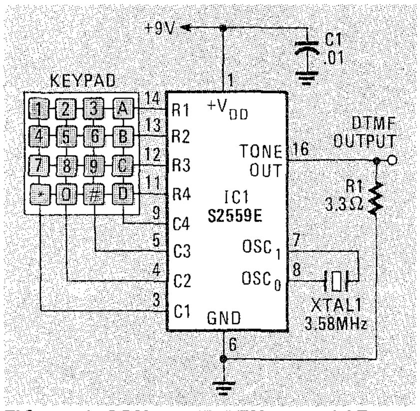

FIG. 4—A COMPLETE DTMF ENCODER requires just a keypad, an encoder IC, a crystal, and two additional components.

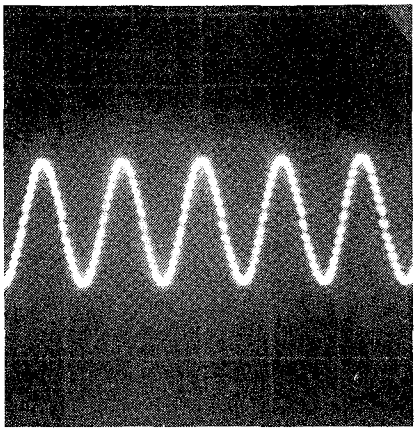

FIG. 5—A ROW 3, 852 Hz, DTMF signal.

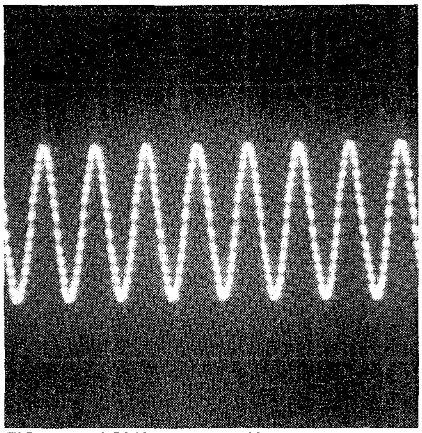

FIG. 6—A COLUMN 2, 1336 Hz DTMF signal.

which would be generated by pressing the "8" key, is shown in Fig. 7. Note that the output of the S2559E is not a pure sinewave. Instead the output is a digitally synthesized approximation, as shown in Fig. 8.

The S2559E also is capable of generating single-frequency tones. To place the IC in the single-frequency mode, pin 15, the mode-select pin (MDSL), is either tied high or left floating; for DTMF operation, that pin is grounded. Once in the single-frequency mode, a single frequency is output by pressing *two* keys in the appropriate row or column. For instance, simultaneously pressing the 4 and 5 keys (in row 2) will result in a 770-Hz output. The single-frequency mode is used primarily for testing.

The S2559E, as well as most other encoder IC's, have mute and transmit pins (MUTE and XMIT). In the S2559E, when no keys are pressed, the MUTE pin is low and the XMIT output is enabled and can

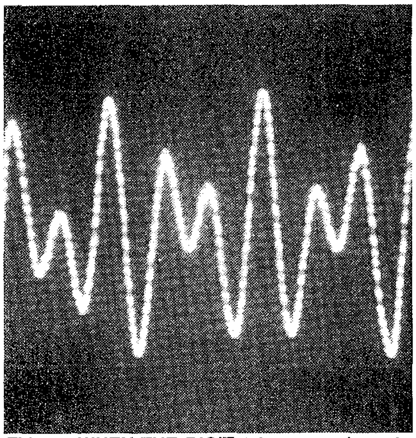

FIG. 7—WHEN THE DIGIT 8 is pressed on the keypad, the encoder generates the signal shown here. It consists of the sum of the row 3 (Fig. 5) and the column-2 (Fig. 6) signals.

source current to an external load. When a key is pressed, the XMIT output goes into a high-impedance state and the MUTE output goes high. Those pins are used in telephone applications. For instance, the MUTE pin is used to mute the telephone receiver during dialing so that the user does not hear the DTMF signals at full volume. The enterprising experimenter will doubtless find many other uses for those handy outputs.

To make the output of the encoder circuit audible, a speaker or some other transducer must be driven by the output signal. The S2559E output must be buffered to drive an 8-ohm speaker, but other high-impedance speakers can be driven by the IC directly. For example, the author has driven the earpiece from an old telephone headset by adding a 330-ohm resistor in series with the earpiece to prevent loading the encoder's output as well as to increase battery life.

We've been discussing the S2559E thus far, but there are three other members of that IC family. They are the S2559F, G, and H. Those four devices have replaced the earlier A, B, C, and D versions and feature extended operating voltage (2.5 to

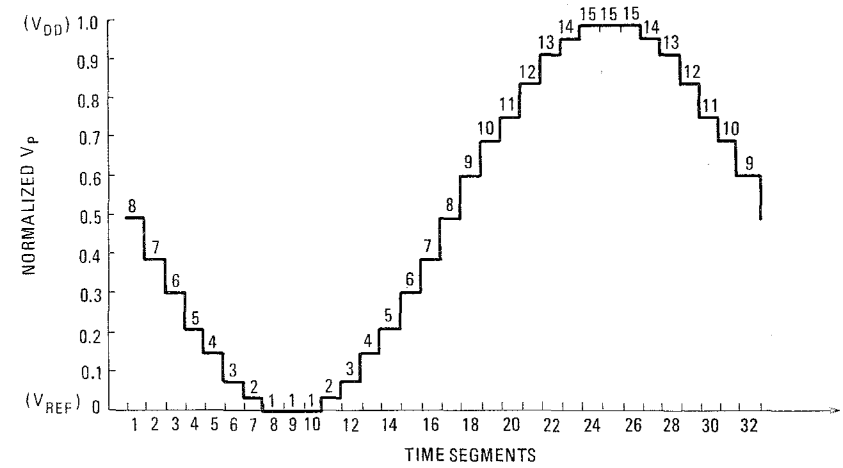

FIG. 8—THE OUTPUT OF THE S2559E is not a pure sinewave. Instead it is a digitally synthesized waveform. The stairstep-shape of such a waveform is shown here.

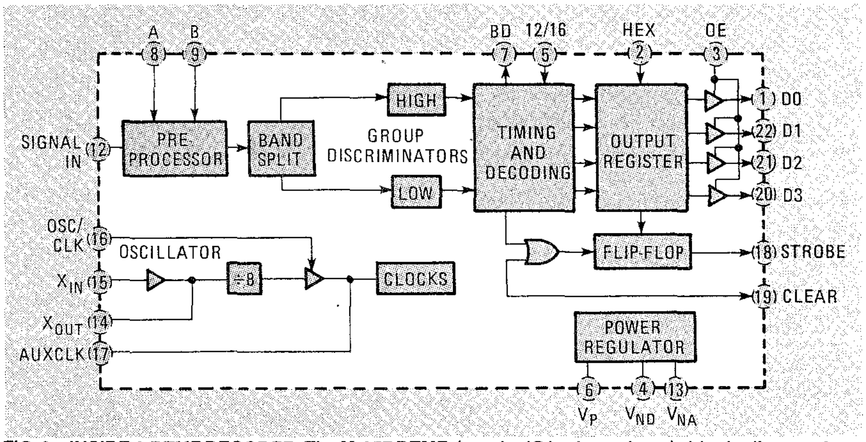

FIG. 9—INSIDE A DTMF DECODER. The M-957 DTMF decoder IC is shown here in block-diagram form.

TABLE 2—DTMF TO BINARY DECODING

Signal	Low-Frequency Component (Hz)	High-Frequency Component (Hz)	Hex Output Format 3210	2-Of-8 Output Format 3210
1	697	1209	ØØØ1	ØØØØ
2	697	1336	ØØ1Ø	ØØØ1
3	697	1477	ØØ11	ØØ1Ø
4	770	1209	Ø1ØØ	Ø1ØØ
5	770	1336	Ø1Ø1	Ø1Ø1
6	770	1477	Ø11Ø	Ø11Ø
7	852	1209	Ø111	1ØØØ
8	852	1336	1ØØØ	1ØØ1
9	852	1477	1ØØ1	1Ø1Ø
0	941	1336	1Ø1Ø	11Ø1
*	941	1209	1Ø11	11ØØ
#	941	1477	11ØØ	111Ø
A	697	1633	11Ø1	ØØ11
B	770	1633	111Ø	Ø111
C	852	1633	1111	1Ø11
D	941	1633	ØØØØ	1111

Note: The M-957 detects signals A through D only when the 12/$\overline{16}$ input is at logic Ø.

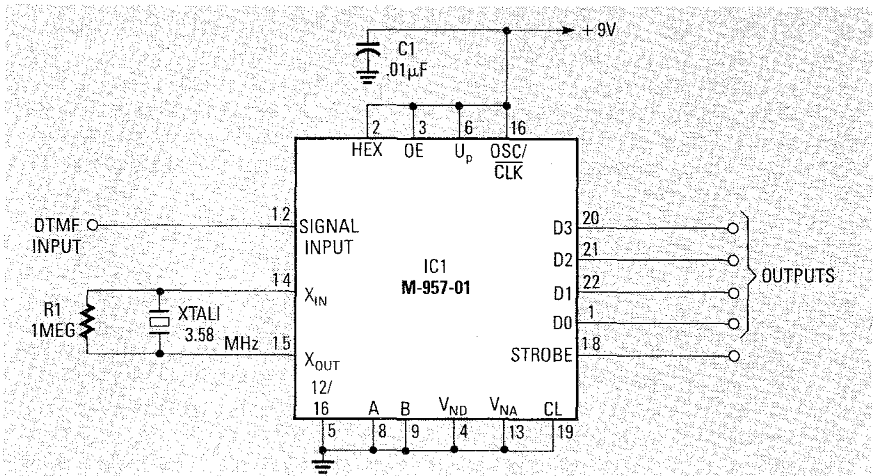

FIG. 10—USING THE M-957, building a DTMF decoder requires just the IC, a crystal, and a capacitor.

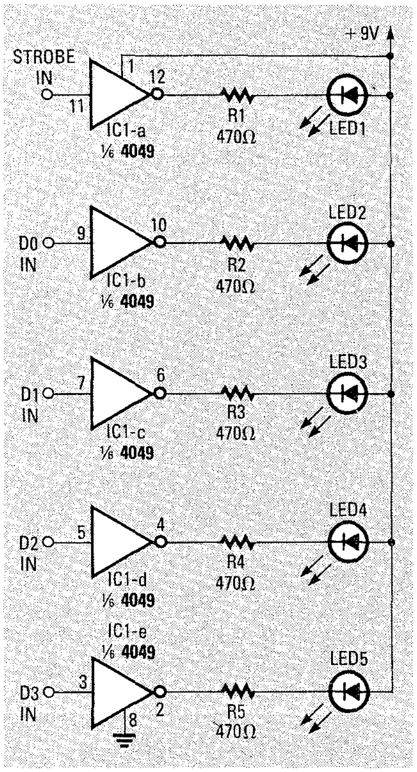

FIG. 11—USE THIS LED MONITOR CIRCUIT to verify that the encoder and decoder are operating correctly.

10 volts), improved tone fidelity, and an on-chip oscillator bias-resistor. In the S2995F, the MDSL function of pin 15 is replaced by a chip disable (CD) function that is active high. When that pin is tied high, the row and column inputs are placed in a high-impedance state, the tone output is tied to ground, the oscillator is inhibited, the MUTE pin is tied high, and the XMIT pin is enabled. Essentially, the effect is that the IC is electronically disconnected from the keypad. That allows one keypad to be shared by several different devices.

The S2559G and H are identical to the S2559E and F, respectively, except that the output transistor has been replaced by a Darlington pair. In some applications that eliminates the need for an external transistor amplifier stage in the telephone circuit.

DTMF decoding

DTMF decoding is considerably more complex than DTMF encoding. The most involved function of the detector is to determine whether a received signal within the DTMF frequency band (697–1633 Hz) is a true DTMF signal or merely noise or speech. The detector must also be capable of detecting a DTMF signal that is combined with such noise. The DTMF detector should recognize any valid DTMF signal that is within ±2% of the standard value. The detector's job is made somewhat easier by the fact that a DTMF signal must have a minimum duration of 40 ms, and that each DTMF signal must be separated from others by at least 35 ms.

Somewhat surprisingly, most of the circuitry required to decode DTMF signals is now available in IC form. Therefore, despite its greater complexity, an entire 16-digit decoder can be built as easily and as simply as a 16-digit encoder.

DTMF decoders are often referred to by manufacturers as DTMF receivers. Those devices have only recently become commonly available at affordable prices. Some can be purchased for under $15.00 in single-unit quantities. Just a few years ago, when the first IC encoders became available, those devices cost about $100, and required external filters. The IC's on the market today are extremely sophisticated signal-processing devices with switched-capacitor filtering that use digital frequency-detection techniques. They can reliably detect DTMF signals with no need for pre-filtering.

The decoder that we'll use in our circuit is the M-957 from Teltone (P.O. Box 657, 10801-120th Ave. N.E., Kirkland, WA 98033). That CMOS device can be powered by a DC power supply or batteries. There are two versions of the M-957: the M-957-01, which can accept voltages of 5 to 12, and the M-957-02, which is designed for 5-volt operation only.

A block diagram of the M-957 is shown in Fig. 9. The function of each pin is outlined in Table 1. The pre-processing stages of the M-957 filter out noise and split the received DTMF signal into its high and low-frequency-group components, and limit each component to provide automatic gain control. The individual tones are then detected. The decoded output of the M-957-01 is a 4-bit binary code appearing at the DØ–D3 output. The output code format can be selected via pin 2, HEX. When that pin is high (logic 1), the output format is 4-bit hexadecimal; when the pin is low (logic Ø), the output format is binary-coded 2-of-8.

Putting it together

It takes very little in the way of external circuitry to put the M-957 to work. Adding just a single capacitor and a crystal as shown in Fig. 10 yields a functional DTMF receiver/decoder.

Now that we have an encoder and a decoder, the next step is to verify that both work as intended. The easiest way to do that is to wire the output of the encoder (Fig. 4) to the input of the decoder. If you are using separate sources (batteries or DC power supplies) to power the circuits, be sure to tie their grounds together.

To monitor the output states of the encoder during testing you can build a simple monitor circuit like the one shown in Fig. 11. That circuit uses 5/6 of a 4049 hex inverter as a buffer to drive five indicating LED's. Those five LED's show the states of the four data outputs as well as state of the STROBE output. Table 2 shows the correspondence between the DTMF signal received and the state of the data outputs. The strobe output should be high, as indicated by a lighted LED, any time that a valid DTMF signal is received and decoded by the circuit.

Once you are sure that the decoder is operational it is time to think about adding to its usefulness and versatility. For one thing, the outputs could be further decoded to provide a 1-of-16 output. A circuit for doing that is shown in Fig. 12.

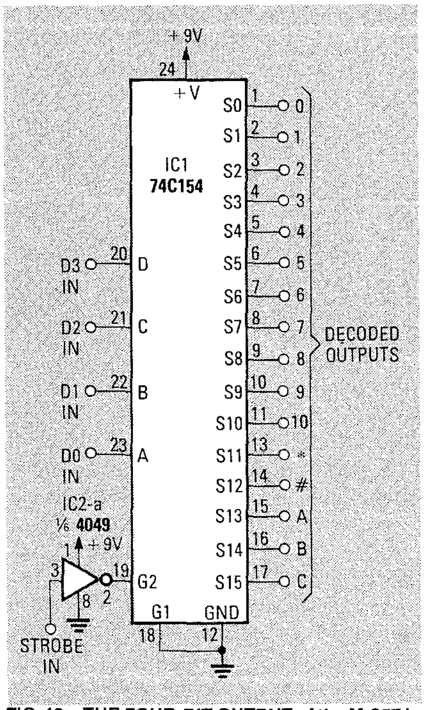

FIG. 12—THE FOUR-BIT OUTPUT of the M-957 is decoded using this circuit. With it, each DTMF code can be used to address one of the 16 outputs.

ORDERING INFORMATION

The following is available from High Technology Semiconductors, 2512 Chambers Road, Suite 204, Tustin, CA 92680, (714) 259-7733: Teltone M-957-N, $11.35; Stantel STC-5089-N (which is pin-for-pin compatible with the AMI S2559E), $2.10; 3.58-MHz crystal, $1.25. Also available is a kit of parts, TRK-957-N, which consists of the M-957, STC-5089, 3.58-MHz crystal, a 22-pin DIP socket, and a 1-megohm resistor for $14.95. Please add $2.30 shipping to all orders. MasterCard, Visa, and COD orders accepted.

Built around a 74C154 4-to-16 decoder/multiplexer, it provides 16 separate output lines. Each of the 16 DTMF signals will enable only one of the circuit's normally high outputs. For instance, if a DTMF 9 is received, only the S9 output, pin 10 of IC1, will go low. That output will remain low as long as a valid DTMF 9 is being received by the circuit.

Another useful enhancement would be to add some type of latched output. That means that once the appropriate DTMF signal is received, the output would remain either high or low until the next time the same DTMF signal is received. Such operation approximates the on/off action of a toggle or pushbutton switch.

A circuit for adding latched outputs is shown in Fig. 13. It is built around half of a 74C73 dual flip-flop that is configured to act as an edge-triggered binary divider (divide-by-2). When the circuit is used as shown, no external debounce circuitry is required. The input is shown as a DTMF D, but it could be any of the DTMF signals. Two complementary latched outputs are available. Use whichever output is appropriate for your application. Tie all of the IC's unused inputs (IC1-b) to ground to prevent oscillation and unnecessary current drain.

Switch S1 is used to clear both outputs to zero. That switch is not needed for all applications and can be eliminated if desired. Conversely, the circuit can be set up

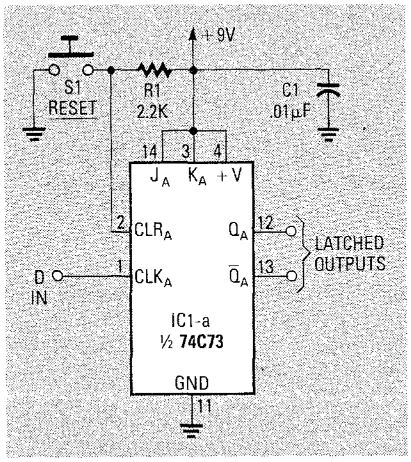

FIG. 13—LATCHED OUTPUTS can be provided using this circuit.

for remote reset. That is done by eliminating the switch and the 2.2K resistor (R1) and tying one of the momentary outputs of the 74C154 to the CLR_A pin of the 74C73. For example, if pin 17 of the 74C154 is connected to pin 2 of the 74C73, the latch will be reset anytime a DTMF C is received. If no reset function is desired, the CLR pin must be tied high.

Up to sixteen devices may be independently controlled by the outputs of the circuit in Fig. 12. If the controlled device is digital and if it is voltage-compatible with the decoder output, direct connection to that device is possible. If heavy driving currents are required, that current can be supplied by transistor switches located at the decoder outputs. If the voltages are not directly compatible, matching can be done using optocouplers or power-driver IC's. Also solid-state relays may be used to interface the digital signals with high-voltage, high-current loads, such as 117-volt AC household appliances, or even industrial devices with larger power requirements.

Going farther

If a wireless data link is desired, any simple, single-channel radio or infrared communications link may be used. For example, a toy walkie-talkie set or a low-cost FM wireless-microphone/FM radio system may be used.

Many DTMF tone generators can be driven by logic-level signals. That allows direct control of DTMF signalling by a microprocessor or ROM circuit. The S2559E requires active high logic-levels at all of its row and column inputs. That means that an 8-bit signal or some type of external driving circuitry is required for digital control of the IC. Other DTMF devices are better suited to digital control. One such device is AMI's S2579 DTMF tone generator with binary input. That device is designed so that a 4-bit digital signal can be used to encode all 16 DTMF signals.

The DTMF IC's will function with crystal frequencies other than those specified for DTMF operation. However, the frequencies that will be generated or decoded will differ from the standard DTMF ones. If a higher crystal frequency is used, all tones will be correspondingly higher in frequency; if a lower crystal frequency is used, all tones will be lower in frequency. That effect can be useful for applications such as when a private communications code is desired.

In this article we've presented some of the basics of DTMF communications. We've also presented some possible applications of that technology. For the enterprising experimenter there are countless more. Now that the cost of the required encoding and decoding IC's is so low, the only limit to their use is your own imagination. **R-E**