AUDIO SCRAMBLING SYSTEM

Prevent eavesdropping by scrambling and descrambling your telephone conversations.

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THERE ARE MANY INSTANCES where some form of speech encryption is needed for privacy or security. Complex and costly voice-scrambling systems are common in covert military operations, but simpler and less-expensive systems are adequate for discouraging the casual eavesdropper. The voice-encryption system described here inverts the frequency spectrum of the speech about a reference frequency to scramble the audio, and reinverts it to descramble the speech. Although the system is intended primarily to scramble telephone conversations, it is not limited to that. The device can also scramble tape recordings, which will be made intelligible only with the correct descrambler.

This method of speech scrambling is accomplished by mixing the audio input to be scrambled with a carrier tone as shown in Fig. 1. The mixing process is carried out with a balanced modulator, which results in a double-sideband suppressed-carrier signal. The two resulting sidebands are the lower-sideband audio frequencies in the voice range (about 150–3000 Hz) and upper-sideband frequencies (about 3000–7000 Hz).

Since most voice circuits are designed for frequencies in the lower sideband range, the upper sideband is filtered out. The lower sideband contains frequencies that are similar to the original voice frequencies, but it has an inverted spectrum. Assuming a 3000-Hz carrier signal, an input signal of 500 Hz will produce a 2500-Hz output, and a 1-kHz signal will produce a 2-kHz output. The spectral energy of a human voice is more concentrated at the ends of the voice spectrum, mainly the 300–1000 Hz range, and somewhat less in the 2000–2500 Hz range. The resulting output will therefore have a very high-pitched sound, and be unintelligible. It can, however, be carried over normal telephone lines without being understood by eavesdroppers.

A digital voice-scrambling method is used in the circuit because it requires fewer parts than an analog system, needs no adjustment, and requires no switching. Because the descrambling process is the inverse of the scrambling process, the same circuit can be used for both functions. The encryption system has two channels for full-duplex operation, which allows easy two-way communication. Note that two complete systems—one at each end of a phone line—are required for two people to carry on a scrambled conversation.

The system operates as follows: An audio input is first fil-

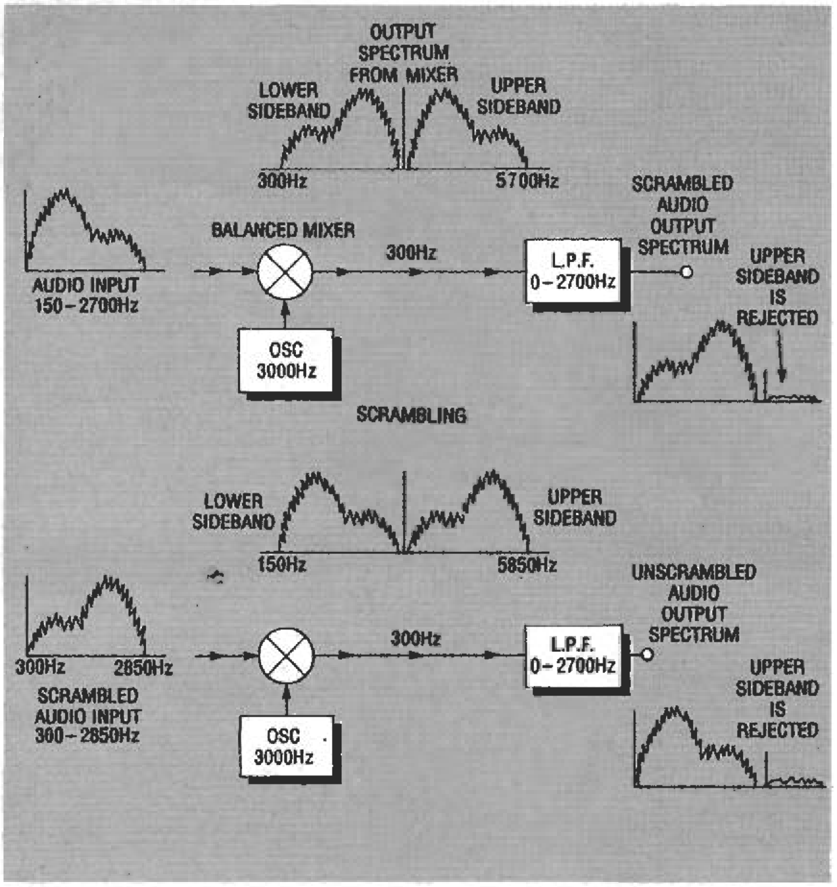


FIG. 1—AUDIO IS SCRAMBLED by mixing the audio input with a carrier tone. The two resulting sidebands are the lower sideband audio frequencies in the voice range (about 150–3000 Hz) and upper sideband frequencies (about 3000–7000 Hz).

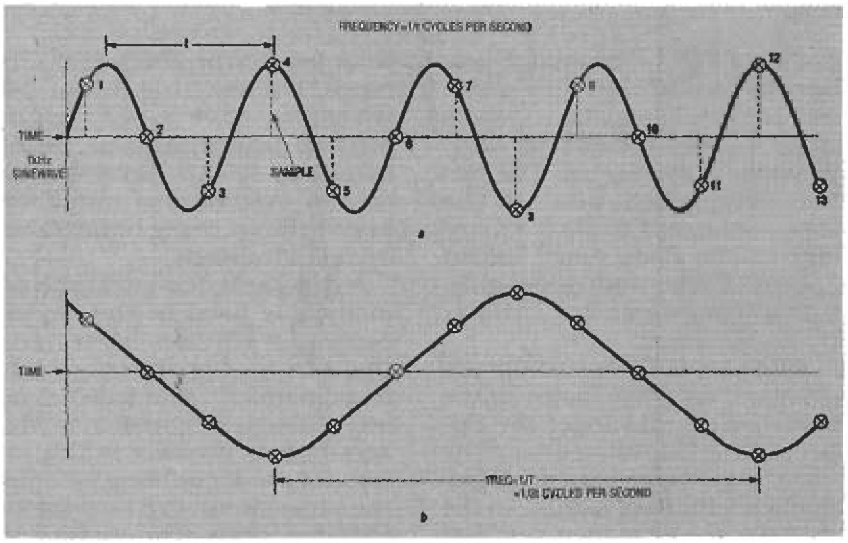


FIG. 2—A 1-KHZ SINEWAVE IS SAMPLED (*a*), and even-numbered samples are inverted, resulting in a lower-frequency sinewave (*b*).

tered with an active switched-capacitor bandpass filter to limit the frequency range to between 150 Hz and 2700 Hz. The signal is then digitized with a sampling rate of 5.86 kHz, which is more than double the highest audio frequency (2700 Hz). Every second eight-bit digitized audio sample has its sign bit inverted while being fed to a digital-to-analog converter. That has the effect of inverting the spectrum of the analog output signal after conversion from the digitized audio. The signal is then fed to a bandpass filter to remove switching components, leaving the final audio signal as one that corresponds to the input signal, except that its spectrum is folded around one-fourth of the sampling frequency, or 1465 Hz.

In Fig. 2-*a* it can be seen that

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—2.2 megohms
R2, R3—470 ohms
R4, R5—100 ohms
R6, R7—22,000 ohms
R8, R10, R14, R15, R17—1000 ohms
R9, R11—6800 ohms
R12—8200 ohms
R13—1000 ohms, potentiometer
R16—10,000 ohms, potentiometer
R18–R20—10,000 ohms
R21—33,000 ohms
Capacitors
C1—22 pF, NPO
C2, C3—82 pF, NPO
C4, C5, C11, C14, C16—0.01 µF, disc
C6, C9, C10—1 µF, 35 volts, electrolytic
C7, C8—10 µF, 16 volts, electrolytic
C12—470 pF, disc
C13, C15—470 µF, 16 volts, electrolytic
Semiconductors
IC1—74HC86 quad 2-input exclusive-or gate
IC2, IC7—74HC74 dual D-type flip-flop
IC3, IC4—74HC161 synchronous 4-bit binary counter
IC5, IC6—TP3054N Codec (National Semiconductor)
IC8—LM7905 – 5-volt regulator
IC9—LM7805 5-volt regulator
D1, D2—1N4002 diode
Q1—2N3565 or 2N3904 NPN transistor
Other components
S1, S2—DPDT slide switch
J1, J2—RJ-11 4-conductor modular telephone jack
J3—⅛-inch power connector jack
XTAL1—3 MHz crystal (2.5 to 4 MHz usable)
Miscellaneous: PC board, ⅛-inch rubber grommets, insulated standoffs, case, hardware, 6–14 VAC, 100 mA transformer, IC sockets (optional), wire, solder.
Note: A kit of parts for one voice scrambler (two complete units are necessary) including a PC board and all parts that mount on it (does not include a telephone, case, phone cords, or wall transformer) is available from North Country Radio, P.O. Box 53, Wykagyl Station, New Rochelle, NY 10804 for $59.00 + $3.50 shipping and handling. A wall transformer is available for $9.50. A North Country Radio catalog is $1. New York State residents must add appropriate sales tax.

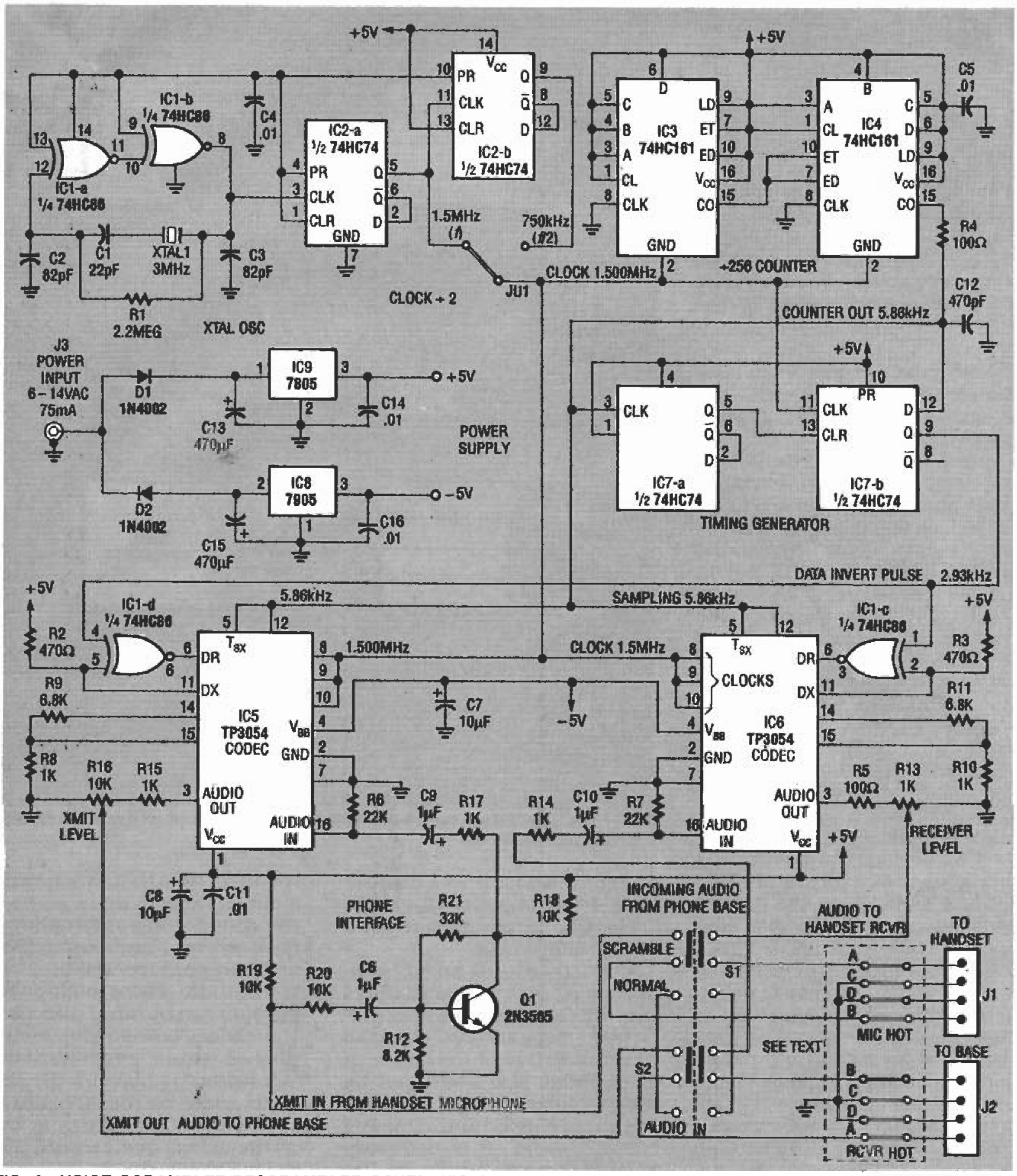


FIG. 3—VOICE SCRAMBLER/DESCRAMBLER SCHEMATIC. The clock and control circuitry supports the two Codecs, IC5 and IC6 (one for each channel).

a 1-kHz sinewave sampled as shown, with even-numbered samples inverted, results in a lower-frequency sinewave (*b*). The process also works in reverse; if the lower-frequency waveform (2-*b*) is sampled at the same points, and alternate samples inverted, the original waveform can be regenerated.

Circuitry

Figure 3 is the schematic of the voice scrambler/descrambler. Two chips—each a National Semiconductor TP3054 coder/decoder, or codec—form the heart of the circuit. The two integrated circuits, IC5 and IC6, contain all of the necessary A/D and D/A converters, switched-capacitor filters, and associated tuning and control circuitry.

The scrambler's "ground" must be isolated with respect to true earth ground. Therefore the PC board of the scrambler should be mounted on insulated standoffs and fed about 75 milliamperes of isolated, low voltage AC from a wall-mounted

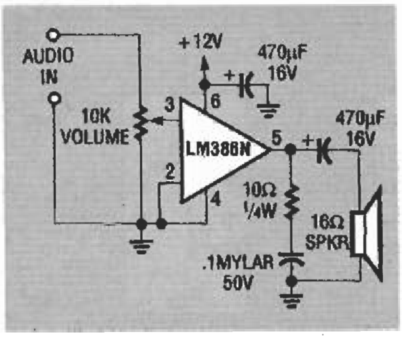


FIG. 4—FOR LOUDSPEAKER APPLICATIONS, a small audio amplifier like this one will generally be needed.

transformer. Do not connect the unit to the AC line without such a suitable isolating transformer.

Most of the rest of the circuit is clock and control circuitry that supports the two codecs. The clock signal is generated by an oscillator made up of 3-MHz crystal XTAL1 and IC1-a and -b. The 3-MHz signal is divided in half by IC2-a to produce the main 1.5-MHz clock signal, and IC2-b again divides by 2 to produce an optional clock frequency of 750 kHz. That signal is further divided down by IC3 and IC4 to produce 5.86- and 2.93-kHz signals. D-type flip-flop IC4 produces a 2.93-kHz pulse train that's used for bit-sign inversion.

The 5.86-kHz pulse shifts a serial data stream, eight clock pulses wide, from the codec's A/D converter to the D/A converter. Data from an A/D converter (pin 11 of IC5 or IC6) is fed to IC1-d or -c, respectively. Those EXCLUSIVE OR gates act as inverters if one input is held high, or as straight-through non-inverting buffers if the other input is held low. By applying a 2.93 kHz pulse on one input, alternate data-stream sign bits (which occur at a 5.86-kHz rate) are inverted. Therefore, the data from pin 11 of IC5 (or IC6) that is fed back to the D/A converter section (pin 6) has every other sample reversed in sign. That has the aforementioned effect of inverting the frequency spectrum of the reconstructed analog signal.

The circuitry required to interface the voice-encryption system to a telephone is contained in Fig. 3. Resistor R17 couples audio from amplifier Q1 to IC5. Transistor Q1 provides about a 10 dB voltage gain.

Modular jacks J1 and J2 connect to S1 and S2 via jumpers that are configured for your particular telephone set. Because direct insertion of the device in a telephone line would not be feasible without a lot of switching due to ringing and signaling considerations, it is necessary to install this device in the handset line. This way only the microphone and earphone have to be considered.

The TP3054 can drive a 600-ohm load (the impedance of a telephone line) directly. If telephones are not being used, simply use the input and output pins directly of each codec. To have the chip drive a loudspeaker, a small audio amplifier, such as that shown in Fig. 4 is required. Note that, when using a microphone to input audio to the codec, some microphones have internal audio amplifiers and can produce well over one volt of audio. Those microphone outputs can be input directly to the codec. Low-output microphones require amplification.

A switching network (S1 and S2) is added on the PC board to switch the scrambler in or out of the telephone circuit. Resistor R13 sets the sound level at the telephone receiver, and R16 is set for optimum reception at the other end of the telephone line.

Figure 5 shows two more applications; 5-*a* shows how the system can be used to make scrambled audio recordings, and 5-*b* shows how a radio transceiver can be fitted with this device. (Bear in mind that in services such as amateur ra-

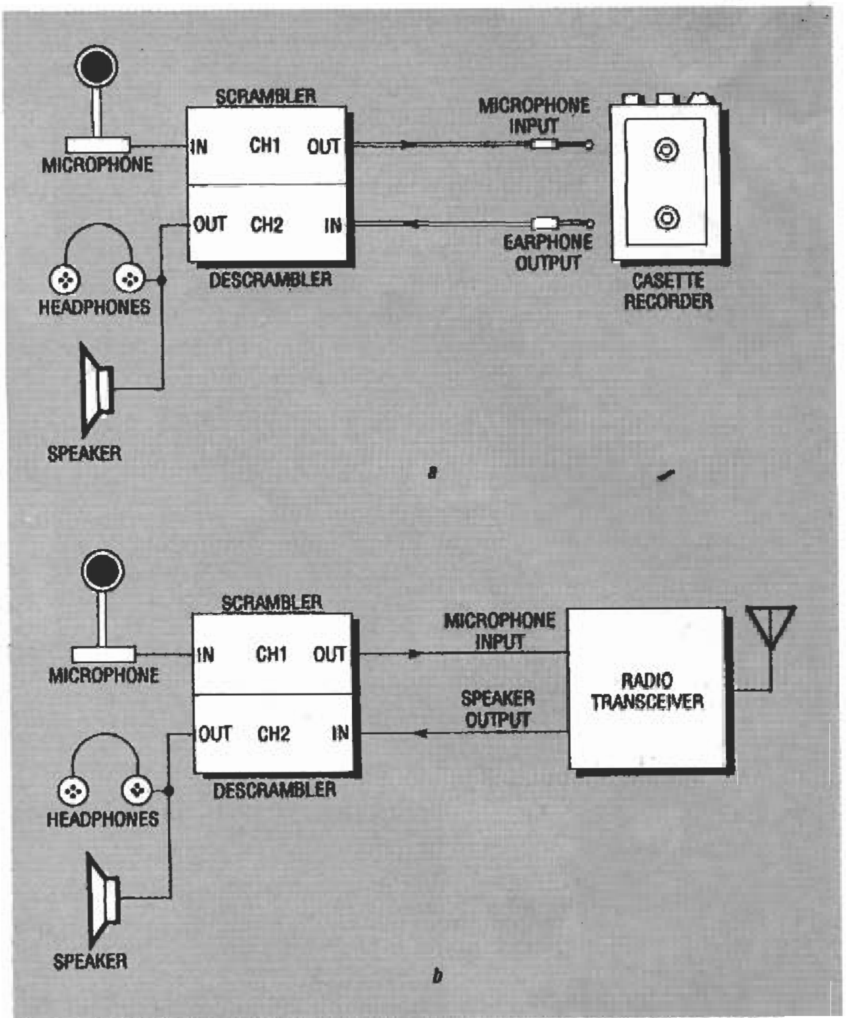


FIG. 5—THE SYSTEM can make scrambled audio recordings (*a*), or it can also be fitted to a radio transceiver (*b*).

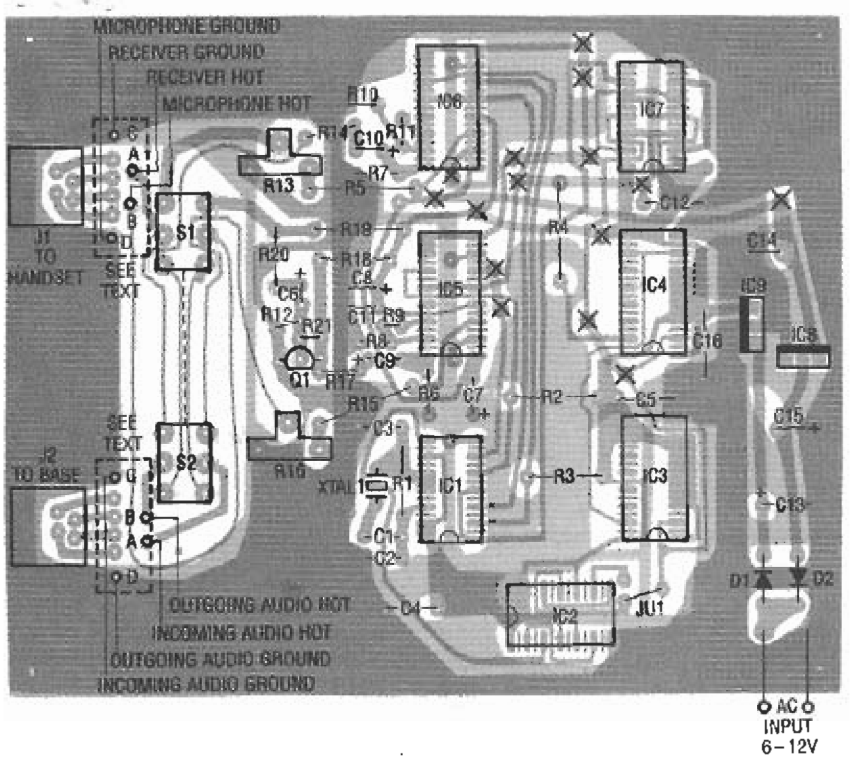
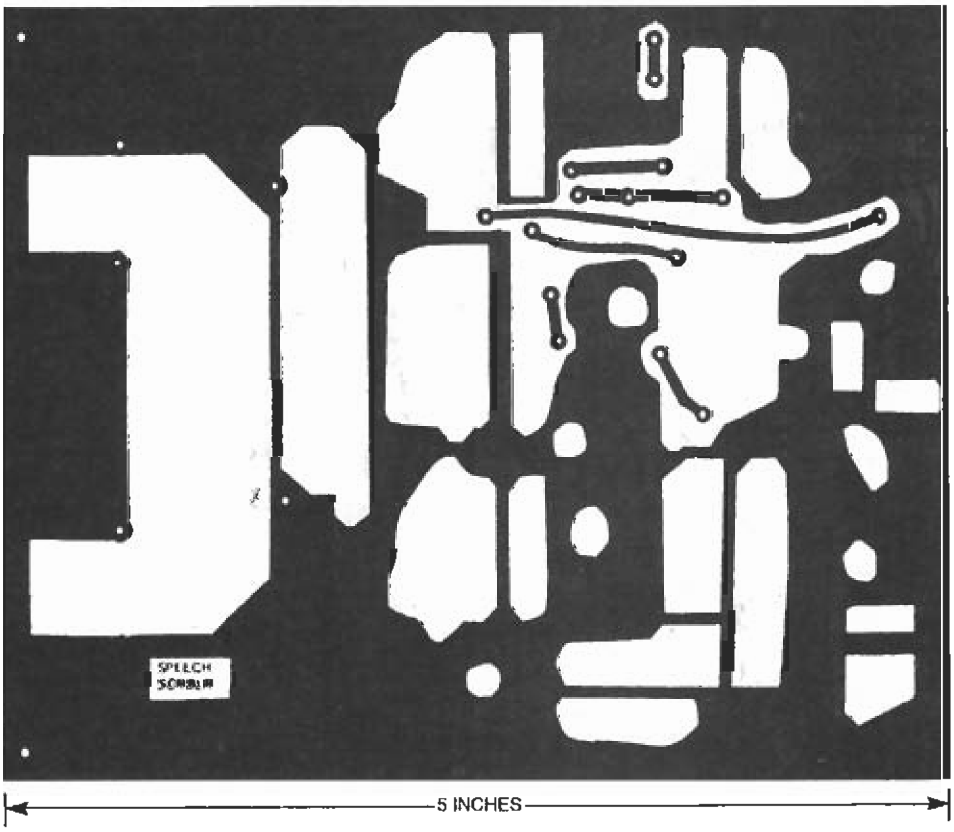


FIG. 6—PARTS-PLACEMENT DIAGRAM. Install through-board jumpers in all locations marked with an "X" and solder them on both sides of the board. All component leads that pass through a hole copper clad on both sides must also be soldered on both sides.



COMPONENT-SIDE FOIL PATTERN for the voice scrambler.

dio, it is illegal to use encryption, so check FCC rules to verify the legality for any intended application.)

Construction

The circuit can be point-to-point wired by hand or made on the double-sided PC board for which foil patterns are provided in this article. Figure 6 is the parts-placement diagram. Because the PC board does not have plated-through holes, first install through-board jumpers in all locations marked with an "X," and solder them on both sides of the board. All component leads that pass through a hole with copper on both sides must also be soldered on both sides.

Install all passive components such as resistors, capacitors, jumpers, and switches on the PC board. Then install voltage regulators IC8 and IC9. Also install the sockets for the rest of the ICs, if you are using them (they are recommended). Before the ICs are inserted in their sockets, apply 6 to 12 volts AC to the junction of D1 and D2 and ground. Check for 5 volts at pin 4 of IC5 and IC6, and pin 16 of IC2, IC3, and IC4, and pin 14 of IC1. Next, verify −5 volts at pin 1 of IC5 and IC6. If these voltages check out, insert the ICs in their sockets. Figure 7 shows how to gang switches S1 and S2 together mechanically, and Fig. 8 shows the finished board, with the ganged switches, mounted in a case.

Testing

Verify that a 5-volt peak-to-peak, 1.5-MHz signal exists at pin 2 of IC3. Check for a 5.86-kHz pulse train at pin 15 of IC4, pins 5 and 12 of IC5, and IC6. Check for 2.93-kHz pulse train at pin 1 of IC1-c and pin 4 of IC1-d. Due to the short pulse width (250 nanoseconds), it might be difficult to see these pulses with an economy model oscilloscope.

If all checks out, apply a 0.5-volt peak-to-peak, 1-kHz tone to the junction of R17 and C9; a 2-kHz tone should be pro-

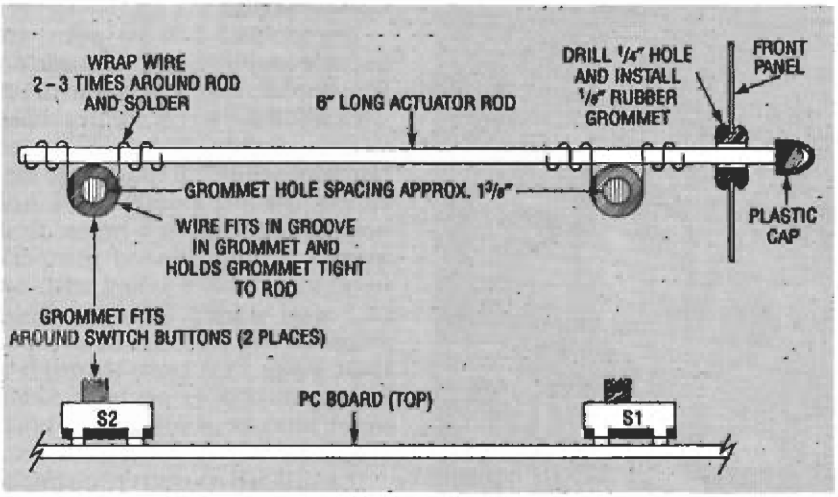


FIG. 7—SWITCHES S1 AND S2 must work in conjunction with one another, so they must be ganged together as shown here.

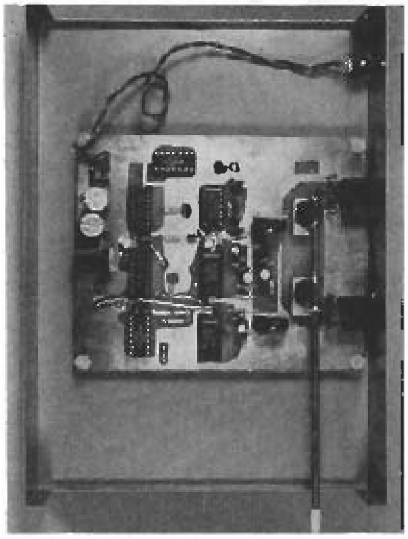


FIG. 8—HERE'S WHAT THE FINISHED board looks like mounted in the case. Notice how S1 and S2 are ganged together.

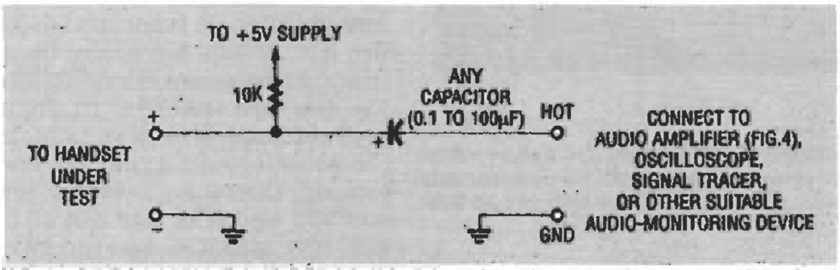
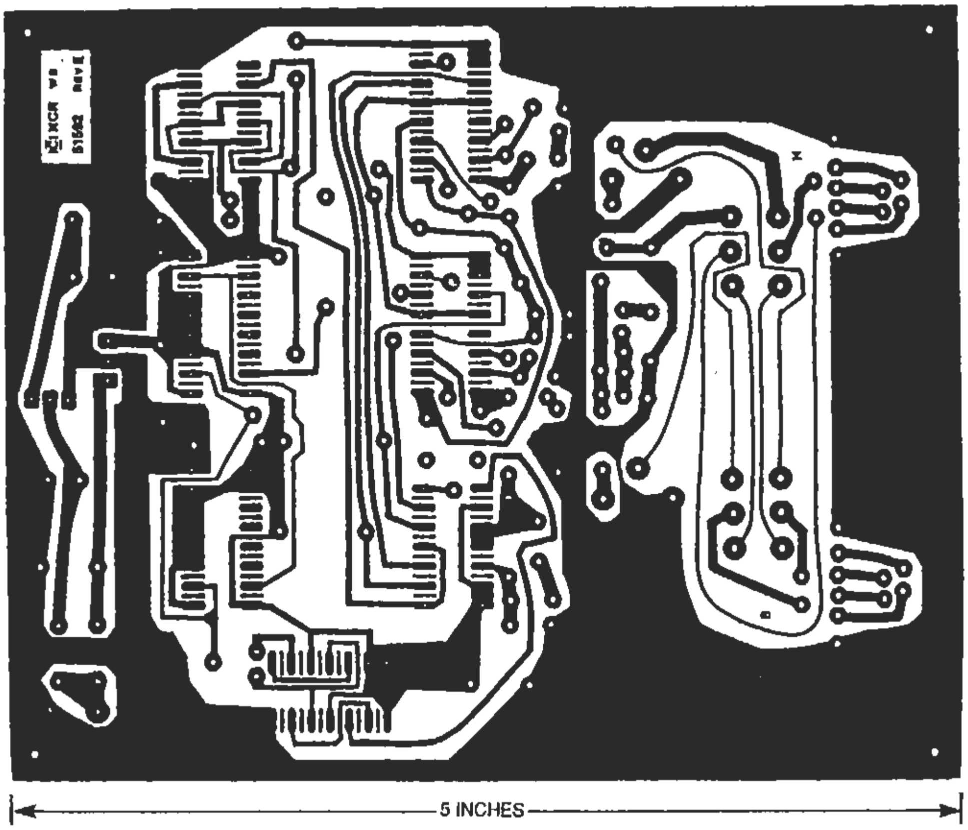


FIG. 9—TO DETERMINE THE POLARITY of the microphone leads, connect the microphone pair to this test circuit and see if the microphone works; if not, reverse the connections.



SOLDER-SIDE FOIL PATTERN for the voice scrambler.

duced by IC5. Now temporarily connect pin 3 of IC5 to the junction of C10 and R14 using a 100K resistor. Pin 3 of IC6 should produce the original 1-kHz tone.

Next, apply an audio signal (from a tape deck or radio) with about 2 volts peak-to-peak to the junction of R17 and C9. Listen to the output at pin 3 of IC5; it should sound "scrambled." Now listen to the output of channel 2. It should be normal, but note that the high and low frequencies might sound somewhat attenuated due to the narrow bandwidth of the system.

Adapting a phone

Note that this unit cannot be connected directly to the phone lines. It will handle speech audio only, and will not pass ringing signals or rotary dialing pulses. It will also distort dialing tones. You must use only a phone whose handset has accessible microphone and receiver connections. You cannot use a unified telephone (where the dial or pad is built into

Continued on page 46

AUDIO SCRAMBLING

continued from page 42

the handset). The handset should preferably have an electret microphone. However, carbon microphones (found in older phones) can be used, if necessary, but R19 should be changed to about 1K, and R20 might have to be increased if excessive audio from a carbon microphone overdrives Q1, causing distortion.

Depending on the phone you have, you must make the proper jumper connections on the PC board near J1 and J2. A Radio Shack telephone model No. ET-171 (cat No. 43-374) was used in the author's prototype.

You must identify the following things on your phone(s):

1. The handset microphone and earpiece connections
2. The type of microphone (electret, dynamic, or carbon)
3. Microphone polarity (if it's the electret type)
4. The base connections

There are usually four wires that connect a telephone handset to its base. If you can't visually identify the wires after disassembling the handset, try connecting a 1.5-volt battery to alternate pairs of wires on the handset until you hear a click in the earpiece. Mark these as the receiver leads; there should be between 50 and 1000 ohms between them. The other two leads are for the microphone.

Check for short circuits between both of the receiver leads and the microphone leads with an ohmmeter on a high resistance range. A low resistance or a short between any two leads indicates that they are the ground leads for the microphone and receiver. If you find no continuity between the two sets of leads, connect the microphone pair to the test circuit shown in Fig. 9, and see if the microphone works; if not, reverse the connections. This will identify the microphone's hot and ground leads. Once you've identified all of the handset leads, note their positions on the modular connector. The telephone base connections can now be determined from the positions of the handset leads at the modular connector.

When you have all of the telephone connections identified, install the jumpers on the PC board near jacks J1 and J2. In Fig. 6 there are four jumper pads labeled A–D near each modular jack; the pads are also labeled by function. Once you know the signal positions at jacks J1 and J2 for your phone, install four jumpers per jack to properly route the signals.

The finished board can be mounted in a case like the one pictured in Fig. 8, or in any other suitable case. The case pictured allows the telephone to be placed on top of the scrambler without taking up any extra space.

With a pair of scrambler phones in hand, you're ready to start talking. All you need now is someone to talk to and a confidential topic to discuss. Ω