



Build “PENNYWHISTLE” The Hobbyist’s Modem

*Under-\$100 interface for digital data transmission/reception
over channels such as telephone or cassette tape.*

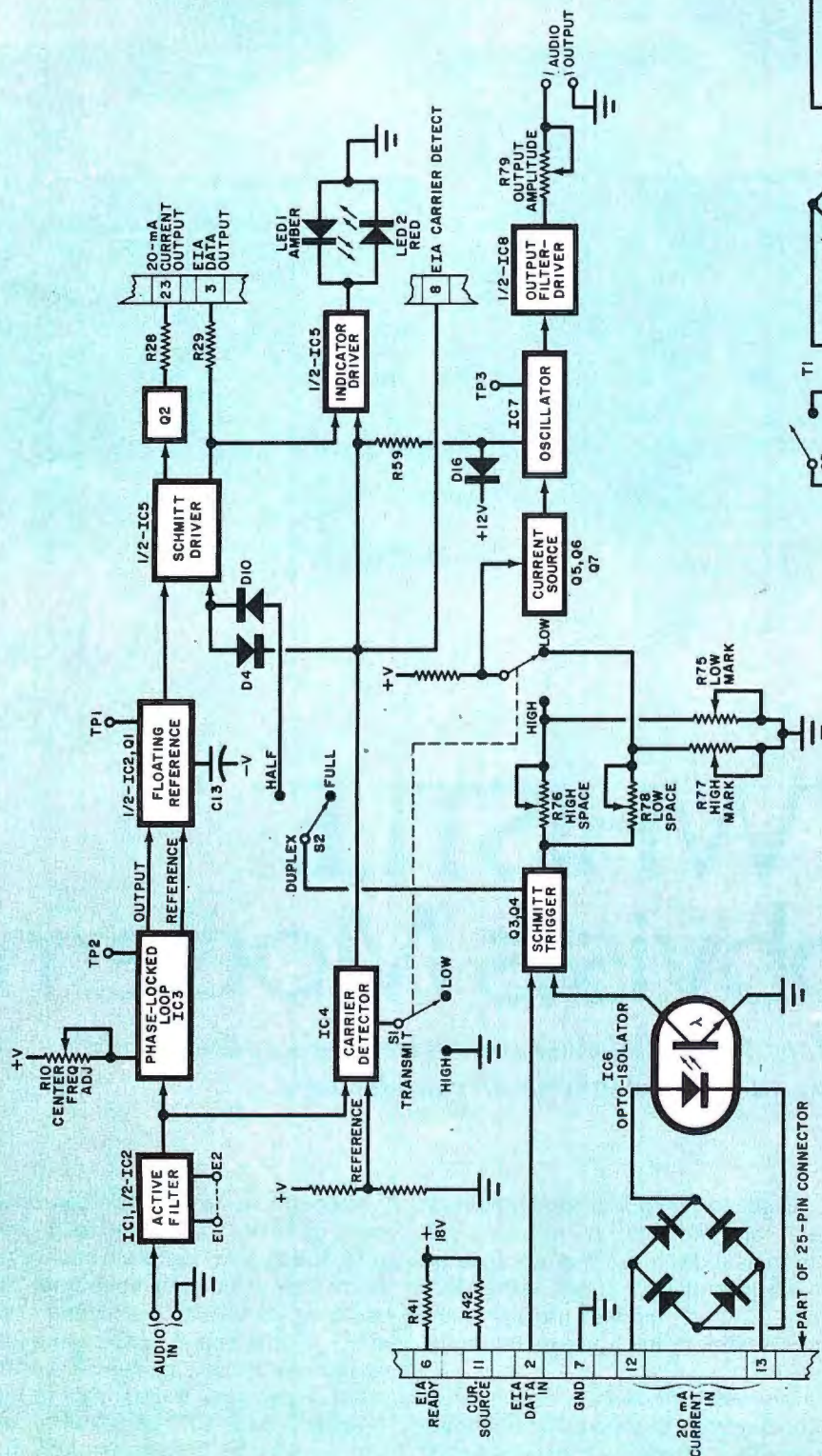
TO TRANSMIT and/or receive digital data—as between two computers, between terminal and computer, etc.—over telephone lines and other limited-bandwidth channels, you need a modem (an acronym for *modulator/demodulator*). Most such channels cannot cope with the steep-sided, flat-topped digital pulse without distorting it, much less pass the high baud rate (bits per second) used in computers. The modem translates the pulses into a usable form.

Digital pulses going into a modem at one end emerge as different frequency audio tones that are fed into the transmitting channel. At the other end, another modem translates the tones back to the appropriate digital pulses.

Modems can operate in one direction only (half duplex) or in both directions (full duplex). The under-\$100 Pennywhistle modem project presented here offers the user both modes with the flip of a switch.

Although some modems can operate at up to 9600 baud over telephone lines, full-duplex operation usually restricts the maximum speed to 300 baud, or 30 characters/second. Modems in this speed range generally operate with frequency-shift keying (FSK), using four frequencies in two “bands.” The 1070-to-1270-Hz low band is used for transmission from a terminal to a central system, while the 2025-to-2225-Hz high band is for transmission in the opposite direc-

Fig. 1. The modem receiver uses noise-reducing active filtering before its PLL detector and delivers both 20-mA and EIA-compatible outputs. Transmitter accepts either EIA or 20-mA current to modulate two-frequency, two-band oscillator. Also shown here are the power supply and active hybrid for direct telephone-line connection.



PARTS LIST

- A1,A2,A4,A5,A8—MC1458 (dual 741-type) operational amplifier IC (Motorola)
- A3—565V phase-locked loop IC
- A6—4N26 optoisolator
- A7—555 timer IC
- C1—390-pF, 5% silver-mica capacitor
- C2,C7,C10,C12,C21,C25—0.1- μ F, 10% polyester film capacitor
- C3,C4—0.0047- μ F, 10% polyester film capacitor
- C5,C14,C15,C22—0.01- μ F, 10% polyester film capacitor
- C6—0.001- μ F, 10% polyester film capacitor
- C8—0.033- μ F, 10% polyester film capacitor
- C9—620-pF, 5% silver-mica capacitor
- C11—1800-pF, 5% silver-mica capacitor
- C13—22- μ F, 25-volt electrolytic capacitor
- C16,C19,C20—1- μ F, 25-volt electrolytic capacitor
- C17,C18—470- μ F, 25-volt electrolytic capacitor
- C23,C24—270-pF, 5% silver-mica capacitor
- D1 to D4,D9,D10,D15 to D24 — IN4148 low-leakage diode

D5 to D8, D11 to D14—1N4001 rectifier diode
 F1—3AG, ½-ampere slow-blow fuse with pigtailed
 LED1, LED2—Light-emitting diode (one red, one amber)
 J1, J3—Two-conductor, closed-circuit miniature phone jack
 J2—Two-conductor, open-circuit miniature phone jack
 P1—No. DB25S connector plug
 Q1, Q2, Q4, Q5—2N2907 transistor
 Q3, Q6, Q7—2N2222 transistor
 Following resistors are ¼-watt, 5% tolerance, except as noted:
 R1, R51, R80—6800 ohms
 R2, R3, R9, R17, R18, R19, R45, R47, R54, R55, R59, R60, R61, R63—10,000 ohms
 R4, R5—150,000 ohms
 R6, R25, R26—330,000 ohms
 R7—20,000 ohms
 R8, R14—18,000 ohms
 R11, R70—2200 ohms
 R12, R13, R53—4700 ohms
 R15, R16, R22, R57, R64 to R69—1000 ohms
 R20, R21—5100 ohms
 R23, R24, R33—15,000 ohms
 R27, R40, R46, R48, R58—3300 ohms
 R28, R41, R42—1000 ohms (½-watt)
 R29, R30, R31—680 ohms (½-watt)
 R32—680 ohms
 R34—68,000 ohms
 R35, R72, R73—220,000 ohms
 R36—4300 ohms
 R37—1.5 megohms
 R38—24,000 ohms
 R39—180,000 ohms
 R43—8200 ohms
 R44, R56—100,000 ohms
 R49, R50—82 ohms (½-watt)
 R52—22,000 ohms
 R62—620 ohms
 R71—470,000 ohms
 R74—47 ohms
 R10, R77—5000-ohm trimmer potentiometer (CTS No. 360S502B or similar)
 R75—20,000-ohm trimmer potentiometer (CTS No. 360S203B or similar)
 R76, R78—100,000-ohm trimmer potentiometer (CTS No. 360S104B or similar)
 R79—1000-ohm trimmer potentiometer (CTS No. 360S102B or similar)
 S1, S2, S3—PC-type dpdt toggle switch
 T1—24-volt center-tapped, 600-mA power transformer
 Z1, Z2—12-volt, 1-watt zener diode (1N4742 or similar)
 Misc.—Printed circuit or perforated board and solder clips; sockets for IC's (optional); 2¼"-diameter, 8-ohm loudspeakers (2); suitable enclosure; three-conductor line cord with plug; line cord strain relief; metal spacers; hook-up wire; machine hardware; solder; etc.
 Note: A complete kit of all Pennywhistle modem parts, including cabinet, is available for \$97.50 from M&R Enterprises, P.O. Box 1011, Sunnyvale, CA 94088. Add \$1.50 if ordering from Canada. California residents, please add 6% sales tax. Allow 15 days for delivery after receipt of order. Send SASE to above address for free copies (8" × 11") of schematic, etching and drilling guide, and component layout guide.

tion. Modems that transmit on the low and receive on the high band are termed "originate-mode" devices, since they are usually used by a local terminal to call into a remote central computer.

In either band, digital data is translated from 1's and 0's (marks and spaces) to high and low frequencies. Don't confuse this with high and low *band* terminology. The receiving modem translates the tones back to 1's and 0's. Note that the high and low frequencies used in FSK are only 200 Hz apart.

Most originate modems, including the Pennywhistle, employ acoustic coupling to the telephone line via the telephone handset. (Some modems are, however, designed to be directly wired into the phone line.) Acoustic couplers obviate the need for the user to pay installation and rental charges for the devices the telephone company requires for direct-line hookups. The main disadvantage of the acoustic coupler is that it can cause an increase in distortion problems that can increase the error rate.

It is important that you bear in mind that modems do not process the data passed through them. They merely accept a stream of serial bits at one end and deliver the same bit information at the other end. The translation that takes place in between merely makes it possible to have remote-point communication. Also, modems do not generally have UART's built into them; they are designed to be connected to outboard UART's, such as those designed into computers.

Circuit Operation. A block diagram of the modem is shown in Fig. 1, which we will use to explain system operation. (The schematic diagram and etching and drilling and component placement guides are too large to fit on these pages. They are available FREE by sending a stamped, self-addressed 8" × 11" envelope to the source given in the Parts List.)

The audio input to the modem is first applied to a three-stage filter consisting of both parts of IC1 and half of IC2. This prevents most noise and harmonics from passing through the system. The filtered signal is then passed to the IC3 phase-locked loop, which contains a variable-frequency oscillator and comparator. The PLL always attempts to lock the frequency of its internal oscillator to the incoming signal frequency. The correction vol-

tage supplied by the comparator to the oscillator provides a measure of how far off the incoming signal frequency is from a preset center frequency.

It is difficult for a PLL to discriminate between an input signal of the proper frequency and one of its harmonics or subharmonics. Since the high-band frequencies are almost twice those of the low band, this can present a problem for some modems, which is the reason for preceding the PLL with the three-stage active filter in the Pennywhistle. Potentiometer R10 is used to set the PLL's center frequency. The PLL itself delivers two outputs: one is a fixed reference voltage from the internal voltage divider, and the other is the actual output of the stage.

One of the lesser problems associated with a loop is that voltages drift with changes in temperature. The Pennywhistle tackles this problem with the floating reference circuit made up of half of IC2 and Q1. This circuit takes advantage of the fact that in asynchronous data transmission, the serial data signal returns to the "mark" condition between every character sent. The floating reference circuit detects the mark and resets its voltage accordingly. If the data goes to and remains at a "space" condition, the circuit slowly readjusts itself and, in about 2 seconds, will claim the new level as a "mark." It readjusts much faster in the opposite direction to correct such a mistaken impression quite rapidly.

The floating reference is fed to IC5, a Schmitt trigger, while the data is fed to the other input. The output of IC5 is an EIA data output which, in turn, drives Q2 to deliver a 20-mA current output.

The IC4 circuit is used to detect the presence of an adequate signal level for reliable loop operation. The output of IC4 provides a positive EIA-type "carrier present" signal to turn on external terminals and hold the data output to the terminal at a mark condition when insufficient carrier is present. Indicators LED1 and LED2 are driven by IC5. A positive output from the IC turns on LED2, while a negative output turns on LED1. When no carrier is present, the output of IC5 is normally negative. With a carrier present, it is positive. Hence, the LED's will alternately light when data is being received, providing a useful indication of modem operation.

The carrier detect signal turns on

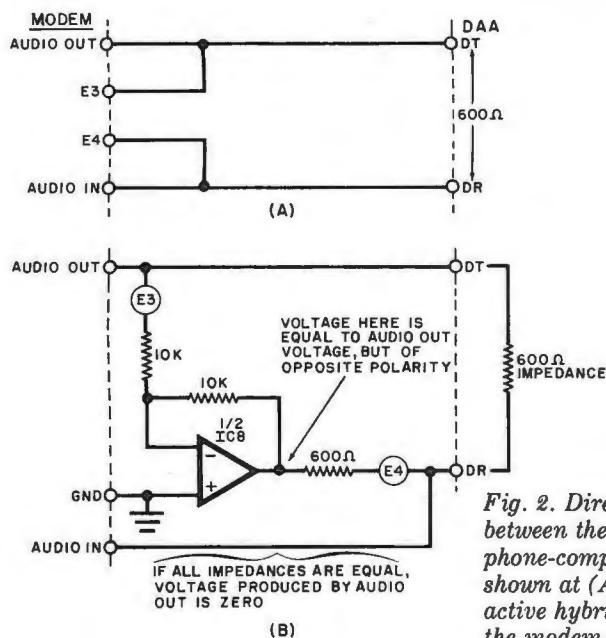


Fig. 2. Direct line connection between the modem and the phone-company supplied DAA is shown at (A). Use of the active hybrid connection between the modem and DAA is shown at (B).

transmitter oscillator IC7 via R59. The TRANSMIT switch (S1) has a section that simulates a received carrier to turn on the oscillator. Data is "looped back" from the transmitter to the receiver when DUPLEX switch S2 is in the HALF duplex position. This provides an echo of data originated at the terminal without requiring that the data travel to the other end and return. Some time-share services require half-duplex operation, which is one reason for including this feature in the Pennywhistle. Another is that it provides a self-test capability for the terminal and modem.

The transmitter is built around IC7, a 555 timer chip. The output of IC7 is fed to the output filter (half of IC8), which smooths out the waveform to reduce harmonics and provides enough power to drive a small speaker or the telephone line.

The frequency at which IC7 operates is determined by Q5, Q6, and Q7, which form a symmetrical current source that keeps the "on" and "off" periods of the oscillator equal, regardless of the operating frequency. Potentiometers R77 and R75 set the mark frequency, while R76 and R78 determine the space frequency.

The Q3-Q4 Schmitt trigger circuit accepts data from either the EIA data input (positive or negative levels) or from optoisolator IC6, which can be tied into a standard 20-mA teleprinter current loop. Mark data has a negative voltage level at the EIA input or a current of 15 mA or more at the current-loop input. Space data is a positive voltage level at the EIA data input or no

current at the current-loop input. With nothing connected to either input, the modem "sees" a space.

TRANSMIT switch S1 is used to select either the high- or the low-tone band. Normally left in the Low position, for tape recording or unit-to-unit transmission, it is switched to HIGH.

Construction. The modem lends itself equally well to either printed-circuit or perforated-board wiring. Since the design of the system provides for maximum flexibility, both current-loop and EIA circuits are provided. However, you can omit either of these circuits, depending on the needs of your system.

Capacitors C2, C7, C8, C10, C12, and C22 must operate with a relatively high degree of stability in the circuit. So, it is important that you use only Mylar, polystyrene, or other high-stability capacitors where these are called out.

Do not use wire-wound potentiometers. They can be difficult to adjust with a high enough degree of accuracy. Transistor types are not critical, but it is good policy to use only complementary pnp and npn types for Q5 and Q6. All transistors in the system must be good-quality silicon switching types.

Any 741-type operational amplifier IC will operate in the modem's circuit. The only restriction here is that the op amp you select must be able to operate with a short-circuited output indefinitely with ± 18 volts dc applied to the positive and negative pins of the IC. Not all op amps can meet this re-

quirement; check this out on the IC specifications sheet before you buy. Most quad op amps will not meet the requirement. Type 3900 op amps will not work in this circuit because of the radical design changes required.

After wiring the circuit board assembly, mount the two soft-rubber acoustic "muffs" on the cover of the enclosure. Note that all parts, except the muffs and J1, J2, and J3, mount on the pc board. The case supplied with the kit has a stepped area through which the toggles of the switches protrude and holes through which the LED's are visible. Connector P1 fits along the edge of the board and is held in place by soldering its pins to the foil pads. The connector is then secured to the metal base plate that forms the bottom of the enclosure with machine hardware through its tabs. Mount J1, J2, and J3 in holes in the base plate near P1 and wire them to the board. Secure the power cord with a strain relief after soldering its conductors to the appropriate points in the circuit.

If you buy your parts locally, you'll have to fabricate your own acoustic coupler from a pair of small loudspeakers (see Parts List) and some commonly available materials.

To do this, apply a thin bead of silicone adhesive/sealing compound around the entire front edge of one of the speakers. Make sure the bead is no more than $\frac{1}{8}$ " (3.2-mm) thick and doesn't bleed onto the cone. Place this speaker, front down, on a square of wax paper atop a flat, level surface. Gently press the speaker so that the silicone cement bead spreads out. Allow the speaker to remain like this for at least 24 hours to permit the silicone cement to cure. At the end of this time, slowly and gently peel away the wax paper. Trim the silicone cement flush with the outside perimeter of the speaker and check that the silicone provides a tight seal to the microphone of a telephone handset.

From a piece of resilient polyurethane foam, cut a "donut" to fit over the rear of this loudspeaker. Solder lengths of stranded hookup wire to the speaker's lugs. Route the wires through the hole in the plastic foam, and cement the latter to the rear of the speaker with silicone adhesive.

Two $2\frac{5}{8}$ " (6.7-cm) diameter tin cans can be used as "wells" in which to mount the speakers to make good contact with the telephone handset. The cans should be mounted $5\frac{3}{4}$ " (14.6) apart, center to center, and

should have 3/16" (5-mm) thick polyurethane foam lining their sides. Punch a hole in the bottom of each can to allow wires to pass through for connecting the speakers into the circuit. Fashion two circular wedges of polyurethane foam to fit into the bottoms of the cans, where they will hold the speakers the correct distance away from and at the proper angle to assure firm contact with the handset when the handset is placed in the cans. You may have to experiment a bit to get the right wedge shapes. Punch a hole through each wedge. Route the speaker wires through the holes in the wedges and the cans, and silicone cement the wedges in place. Then connect the wires from the speaker with the silicone "gasket" to the output and the wires from the other speaker to the input terminals of the modem.

If you prefer, you can use an inductive pickup at the receiving side of the modem. To do so, you'll have to lower the value of $R19$, (which determines the gain of the last stage of the active filter) to compensate for the lower gain of the pickup. In this way, you eliminate the possibility of external noise pickup.

Test and Adjustment. Set TRANSMIT switch $S1$ to LOW and DUPLEX switch $S2$ to FULL. Temporarily connect a jumper wire from pin 2 of the 25-pin connector to a voltage source of about -12 volts dc. This can be found at the negative side of $C2$. Connect a frequency counter to test point $TP3$ (at $IC7$) and temporarily connect a jumper across $D16$. This will turn on the transmitter. Now, adjust $R77$ for a frequency of 1270 Hz, ± 5 Hz. Remove the jumper from pin 2 of the connector and power supply, and adjust $R78$ for a frequency of 1070 Hz, ± 5 Hz.

Set the TRANSMIT switch to HIGH and replace the jumper from pin 2 of the connector to the negative voltage supply. Adjust $R75$ for a frequency of 2225 Hz, ± 10 Hz. Remove the jumper and adjust $R76$ for a frequency of 2025 Hz, ± 10 Hz.

The output of the modem must now be set for -15 dBm (0.14 V rms or 0.39 V p-p) on the telephone line when the handset is in position in the modem's acoustic coupler by adjusting $R79$. Assuming you don't have a standard modem test instrument to perform this adjustment, carefully follow the procedure below.

First, make no measurements of the voltage on your phone line until you have dialed and have a party on the other end. Next, be very careful not to short the telephone terminals, and use an ungrounded meter to make all measurements. If your meter doesn't have an OUTPUT jack, place a 0.1- μ F capacitor in series with one of its test probes.

Set the TRANSMIT and DUPLEX switches to the LOW and FULL positions, respectively. Turn on the transmitter by jumpering $D16$. Place the telephone handset into the acoustic coupler. (Make sure the handset is correctly oriented.) Then connect the meter to the telephone connector block. (Do not attempt to use a "key-set" telephone that has lighted pushbuttons.) Adjust $R79$ for -15 dBm, 0.14 V rms, or 0.39 V p-p.

Connect a 1000-ohm resistor between the audio input terminal to the active filter and ground. With a 100,000-ohm resistor connected in series with the signal or "hot" output, connect a signal generator to the audio input terminal and the generator's ground lead to the modem's common ground.

Monitoring the output with a frequency counter, set the generator's frequency for 1170 Hz. Connect the

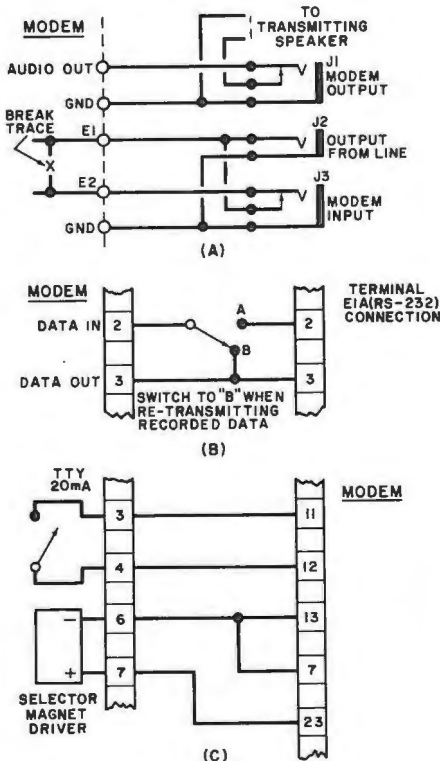


Fig. 3. Ways to connect the modem to tape recorder, an EIA terminal, or a Model 33 TTY Teleprinter.

counter between $TP3$ and ground and a dc voltmeter between $TP1$ (floating reference) and ground. Adjust $R10$ through its entire range, observing where the monitored voltage swings smoothly between positive and negative. This is the lock range of the PLL. Adjust $R10$ so that the meter indicates zero within the lock range. Perform this adjustment several times to be sure you haven't adjusted outside the lock range; false indications are possible there.

Direct-Line Hookup. To wire the modem directly to the telephone line, the telephone company requires that you use a DAA (Direct Access Arrangement) to isolate the two. The lowest-cost system available, generally renting for \$2 to \$5 a month, is the CDT (1001A) coupler. It has a switch that cuts the telephone out and the coupler in when turned on. The wiring diagram for this setup is shown in Fig. 2A.

When the CDT is used, $IC8$ is wired as an "active hybrid" circuit that can subtract the output of the transmitter from the input of the receiver, as shown in Fig. 2B. Terminal E3 is connected to the output of the modem, which is also connected to one side of the phone line. E4 goes to the input terminal of the modem and the other side of the phone line. Ideally, $R62$ should be the same resistance as the line impedance, specified by the telephone company as 600 ohms, when a DAA is used. However, this resistor's value can be trimmed if "balancing out" adjustments are needed.

Tape Recorder Connections. The phone jacks, $J1$, $J2$, and $J3$, permit the use of the modem with a tape recorder to record data from the terminal or from the phone line, and to play the data back to the terminal for the phone line, or both.

The jacks are wired into the modem as shown in Fig. 3A. Jack $J1$ then connects to the transmitting speaker and serves as the interconnect for the microphone input to the tape recorder. Jacks $J2$ and $J3$ connect between E1 and E2 and ground. (Make sure you break the foil between E1 and E2 on the circuit board if you use this mode.) Jack $J2$ goes to E1, which is the output of the first stage of the filter, and also feeds the microphone input of the tape recorder when $J2$ is used. Jack $J3$ breaks the connection between E1 and E2 and allows the tape recorder to

feed a signal into the second stage of the filter.

To record local terminal data, plug the tape recorder's microphone input into *J1* and set the TRANSMIT switch to HIGH. Run the recorder and input data from the terminal.

To record line data, plug the recorder's microphone or auxiliary input into *J2*. Run the recorder for the duration of the desired output. Record a 5-second leader of no-data carrier on the tape before the data.

To play data back to a local terminal, plug the recorder's speaker output into *J3*. Then play the tape. The modem will track with any desired speed variations from the tape. The first point of failure for speed change will occur when the timing of the signal into the terminal goes beyond the limits of its serial receiver circuit.

To play data back to the line, connect a switch between pins 2 and 3 of the 25-pin connector on the modem and pins 2 and 3 of the terminal as shown in Fig. 3B. Using the terminal, set up the proper conditions in the system to receive the data. Make sure that you start the tape in the no-data carrier leader area. Plug the recorder cable

into the tape recorder and throw the switch to connect pins 2 and 3 of the connector. Plug the other end of the recorder cable into *J3*. Data will now be feeding into the modem's receiver, looping back to the transmitter section. Simultaneously, the data will appear on the terminal.

Current-Loop Hookup. Teleprinters handle data on a current loop, where 20 mA of current represents a 1 or "mark" and no current represents a 0 or "space." The wiring between the modem and a Model 33 Teletype (TTY) are shown in Fig. 3C. If you have an older teleprinter that has bare coils, use a reed relay between pins 23 and 7 (ground) on the modem. Connect a diode between pin 23 and ground, with the cathode going to pin 23. This diode will prevent inductive "kickback" voltages from damaging current-source transistor *Q2* inside the modem.

Teleprinter keyboards consist of switches that open and close according to a set pattern to control an externally supplied current. Pin 11 of the modem is a source of 18 mA of maximum current. Connect pin 11 to

pin 12 and the teleprinter keyboard from pin 13 to pin 7.

EIA Interface. The EIA standard relevant to the modem is RS232C. Any terminal wired according to this specification will mate with the Pennywhistle modem.

EIA signals in the RS232C standard are always more than 3 volts in amplitude and always less than 25 volts open circuit (15 volts when connected). They are positive or negative, depending on the data. Negative is a data 1 (mark), positive a data 0 (space). Control lines are active with a positive signal. EIA signals are not required to drive a load of less than 3000 ohms, but they must be protected from ground and each other.

Final Remark. To communicate between two Pennywhistle modems, the TRANSMIT switch must be set to LOW for receiving, HIGH for transmitting. Keep the DUPLEX switch in the FULL position, and your receiver will come back with what you're transmitting. Bear in mind that communication can be in only one direction when using this scheme. 