from a 600-ohm speaker lead, or if the receiver has a high-impedance audio output, the Q4 amplifier stage may not be necessary.

Construction

The VOX unit, except for the controls and connection jacks, is built on a small etched circuit board. This board has a long, narrow shape, giving a modern shape factor to the VOX housing. Parts layout is not critical and it may be adjusted to suit one's individual requirements.

The case for the VOX is homemade. Two pieces of sheet aluminum, cut to size, are bent into U shapes. Small L brackets, fastened to each end of the base, are the points into which the sheet-metal screws that hold the cover are fastened. The overall size of the housing is 1 1/2 X 7 X 3 inches. Phone jacks are used for the microphone connections, and other input connections are made through phono-type jacks. The types of connectors used should mate with the other plugs and jacks used in an individual's ham shack. Unwanted rf pickup is always a potential hazard with transistor equipment. So, standard rf suppression techniques are used on the circuit board, and all connection points to the unit are bypassed.

A wide variety of npn transistors can be used; almost any of the small-signal, high-beta types are suitable. The bias resistors for the 2N2925s may have to be changed if a different type of transistor is substituted, however. When soldering connections to the etched board, care should be exercised, as excessive heat can damage transistors and diodes, as well as cause the copper foil to lift off the board. Also, correct polarity should be observed when installing the electrolytic capacitors. The unit's power supply is a 12-volt transistor-radio-battery eliminator, the Midland 18-112. Any of the 9- or 12-volt supplies sold for use with portable radios or tape recorders should do. A "stiff" supply is not necessary. The VOX does draw quite a bit of current, however, so small batteries are not suitable. Tests indicate that any voltage between 5 and 15 volts will provide satisfactory operation.

Operation

Connecting the VOX is easy. The microphone is plugged into one of the mic jacks, J1 or J2, and a patch cord is used to connect the remaining mic jack to the transmitter, as shown in Fig. 13-37A. The relay contact leads are connected to the transmitter PTT input, from J6. If a separate receiver is to be used, connect a cable from J5 to the receiver mute connections. The receiver audio can be sampled at the speaker terminals and fed to J3. The GAIN control, R19, should be advanced until even softly spoken words produce VOX operation. The DELAY time (R22) can be set to suit one's personal preference. The anti-VOX adjustment is set last. Place the microphone near the speaker, and tune in a loud signal. Then, advance the ANTIVOX control until the signal from the speaker does not operate the relay, even during periods when loud pops and static crashes are present.

A VOX adaptor can also be put to work to provide semibreak-in for cw operation. The connections for this are shown in Fig. 13-37B. Output from an audio oscillator or the audio signal from the monitor in an automatic keyer is needed to key the VOX. Only a low-level sample of the oscillator output is required; .01 volt will assure good operation. If no oscillator is available, one can be built from a commercial kit such as the RCA KC4002. Of course, both the audio oscillator and the transmitter must be keyed simultaneously.

A TRANSVERTER FOR 1.8 MHZ

Owners of five-band transceivers often get the urge to try "top band." Converting a transceiver to cover a frequency range for which the rig was not designed is difficult indeed. A far better approach is to build an outboard transverter, such as the one described here. This particular system requires one watt of drive power at either 21 or 28 MHz. Many transceivers can provide this low-level output along with the power supply voltages through an accessory socket.

The Circuit

A schematic diagram of the transverter is given in Fig. 1. Q1 operates as a crystal oscillator, to produce the local oscillator energy for the receive (Q5) and transmit (Q2) mixing stages, which runs continuously. During transmit 21.1 MHz ssb or cw energy is supplied to the emitter of Q2 through a power divider network. This signal is mixed with

Top view of transverter with cover removed. Final amplifier circuit is at the left. The rear apron has an accessory socket for an external power supply (transceiver), rf, and remote-keying connectors. The plate meter is at the lower left.

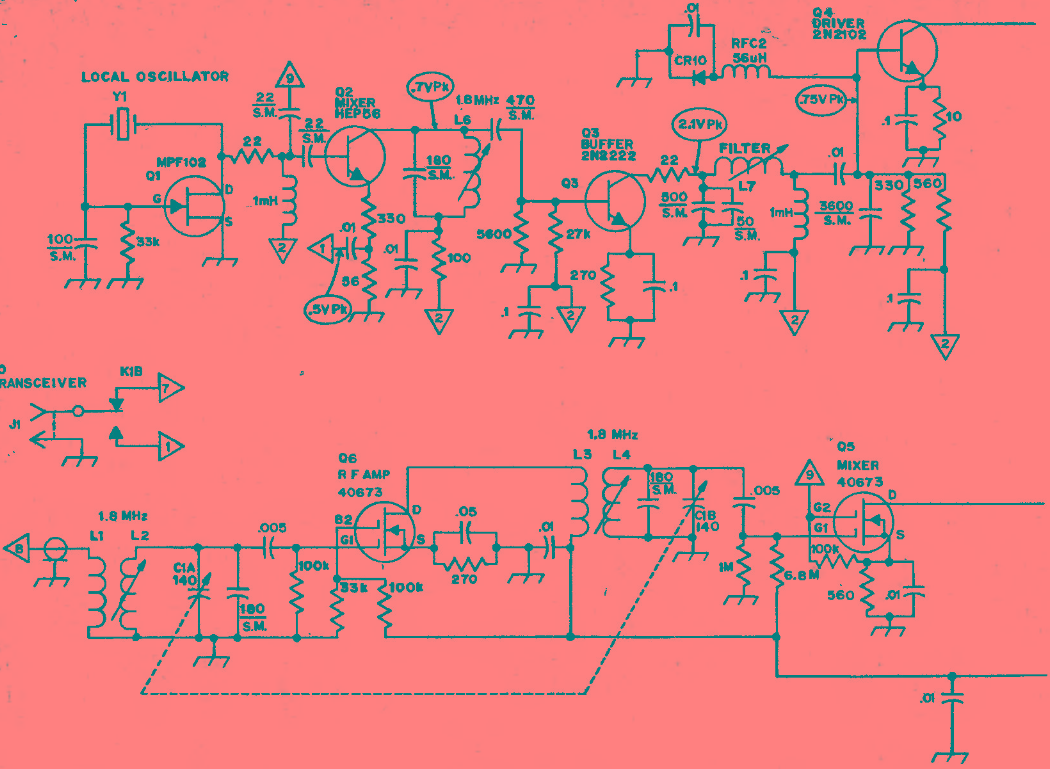


Fig. 1 — Schematic diagram for the transverter. Resistors are 1/2-watt composition and capacitors are disk ceramic, unless otherwise noted.

C1 — Dual-section air variable, 140 pF per section, or two 150 pF air variable units.

C2 — Air variable (Millen 19280).

C3 — Dual-section broadcast variable, 365 pF per section, both sections connected in parallel.

CR1 — Zener diode, 6.8-volt, 1-watt (1N4736).

CR10 — Silicon, 50 PRV, 100 mA.

J1 — Phono type, chassis mount.

J2 — Coaxial receptacle, chassis mount.

K1, K2 — 12 V dc, 2-A contacts, dpdt relay (Radio Shack 275-206).

L1 — 11 turns of No. 28 enam. wire wound over L2.

L2, L4 — 19.5-24.3 μH variable inductor (Miller 46A225CPC).

L3 — 22 turns of No. 38 enam. wire wound on L4 coil form.

L5 — 18.8-41.0 μH variable inductor (Miller 42A335CPC).

L6, L8 — 35-43.0 μH variable inductor (Miller 46A395CPC).

L7 — 13.2-16.5 μH variable inductor (Miller 46A155CPC).

L9 — 10.8-18.0 μH adjustable coil (Miller 21A155R8I).

L10 — 42 turns, No. 16 enam. wire equally spaced on a T-200 Amidon core.

M1 — 500 mA, panel mount (Simpson 17443 or similar).

Q5, Q6 — RCA MOSFET.

RFC1 — 1 mH. 500 mA rf choke (Johnson 102-572).

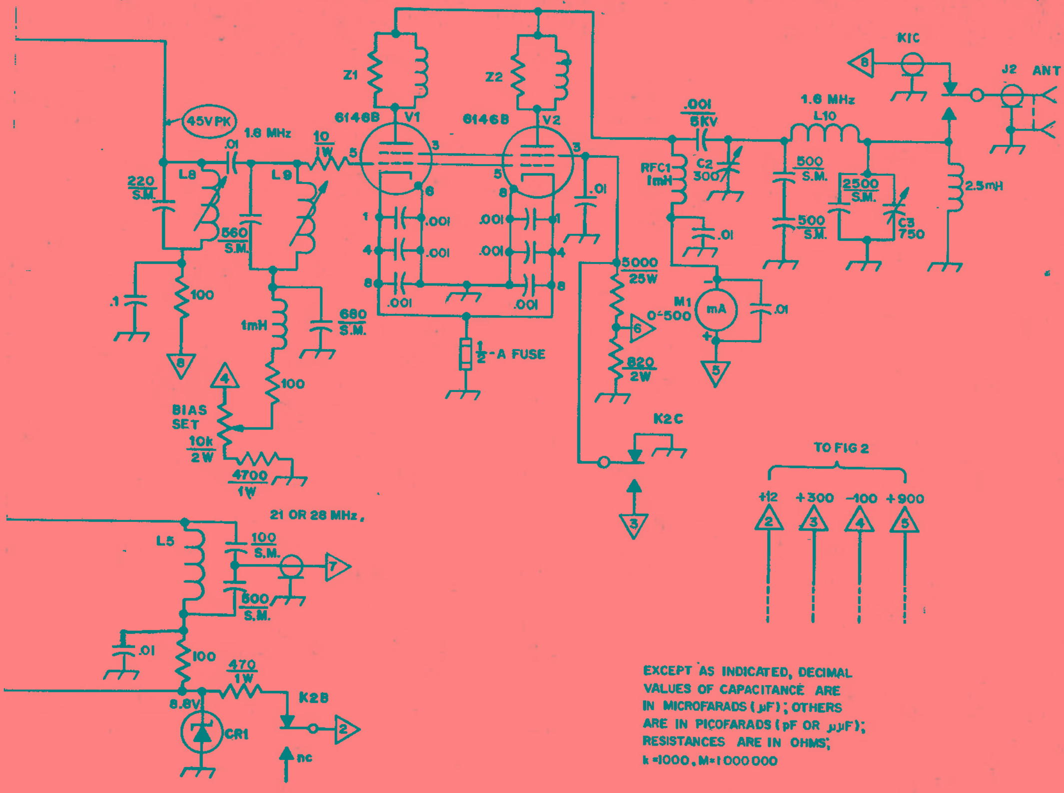
RFC2 — 56 μH rf choke (Millen J-302-56).

Y1 — 19.3-MHz crystal is used for a 21-MHz i-f, 26.5-MHz crystal for a 28-MHz i-f.

Z1, Z2 — 2 turns, No. 18 enam. wound over 47-ohm, 2-watt composition resistor.

the 19.3-MHz output from the LO producing 1.8 MHz power which is amplified by Q3, followed by a filter network. Q4 provides adequate drive to the pair of 6146Bs. The PA stage operates class AB1 which will deliver in excess of 100 watts PEP output.

During receive, an incoming signal is amplified by Q6, a dual-gate, diode-protected MOSFET. The output from the rf amplifier is mixed with local-oscillator energy at Q5 to produce a receiving i-f of 21 MHz. The frequency of the crystal is the only change required to make this system useable at 28 MHz. Changeover from transmit to receive is accomplished by K1 and K2 which are controlled by the associated transceiver. If the LO frequency is 19.3 MHz, the 1.8 to 2.0 MHz band will correspond with 21.1 to 21.3 MHz on the transceiver dial. Likewise, with a 26.5 MHz crystal in the LO circuit, the 160-meter band will appear between 28.3 and 28.5 MHz.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k=1000, M=1 000 000

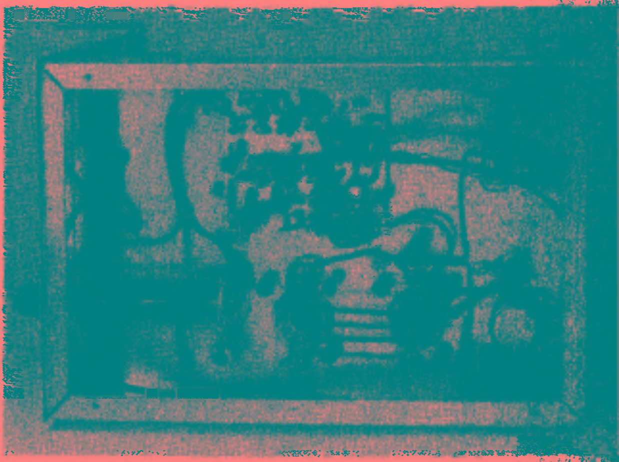
If the various supply voltages can not be obtained from the transceiver, an economy power supply shown in Fig. 2 can be used. The 6.3- and 5-volt windings of T1 are series-connected to provide 11.5 volts to power K1 and K2, the receiving converter and the predriver stages of the transmitting section. The windings must be phased properly to prevent cancellation of the voltages. If no output is obtained when the windings are connected, reverse the leads of one winding. The 11.3-volt ac is rectified by CR6.

Bias voltage is obtained for V1 and V2 by connecting a 6.3-volt filament transformer in back-to-back fashion with the 6.3-volt winding of T1. The 125-volt ac output from T2 is rectified, filtered, and then routed to the bias-adjust control, R1, to establish a PA resting plate current of 50 mA.

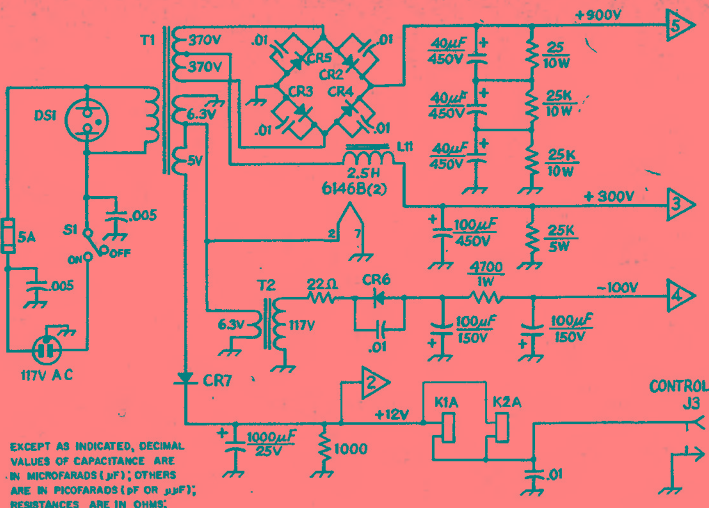
The metering circuit consists of a 500 mA meter connected in the plate voltage line. Other meters may be employed by using the proper shunts, as described in the Measurements Chapter.

Construction

An aluminum chassis which measures 7 × 11 × 2 inches is used as the base for the transverter. A homemade panel and cabinet enclose the unit. The front panel is 8 × 7-1/4 inches. The layout employed should be apparent from the photographs. All long runs of rf wiring should be made with subminiature coaxial cable (RG-174/U or similar).



The bottom view of the chassis, the sockets for the 6146B tubes are at the lower center. The etched-circuit board is above the final amplifier tube sockets and the T-R relays at the upper right. The different supply voltages are obtained from the associated transceiver.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF); OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k=1000, M=1000000

Fig. 2 — Diagram of the power-supply section. Resistors are 1/2-watt composition. Capacitors are disk ceramic, except those with polarity marked which ara electrolytic.

CR2-CR5, incl. — Silicon, 1000 PRV, 1 A.
CR6, CR7 — Silicon, 400 PRV, 1 A.
J3 — Phono type, chassis mount.
K1, K2 — see Fig. 1.
L11 — Power choke, 130 mA (Allied 6X24HF or equiv.).
S1 — Spst toggle.
T1 — Power transformer, 117-V primary; secondary windings 740 V ct at 275 mA, 6.3 V at 7 A, and 5 V at 3 A (Stancor P-6315 or equiv.).
T2 — Filament transformer, 117-V primary; 6.3-V, 1-A secondary.

The receiver section, driver stages and local oscillator are constructed on a double-sided printed-circuit board measuring 3 × 3-1/2 inches. Inductors L1 and L2 are mounted on the chassis close to C1. Short leads are used from the circuit board to the PRESELECTOR capacitor and L1-L2 which are located on the underside of the chassis. The final tank inductor is wound on an Amidon T-200 toroid core. It is supported above the chassis by a ceramic standoff insulator and two pieces of Plexiglas.

Tune Up

Provision must be made to reduce the power output of most transceivers used with the transverter since only about one watt of drive power is required. Too much rf voltage can damage the HEP 56 and will "smoke" the input resistors. Some transceivers are capable of delivering sufficient drive by removing the screen voltage from the PA stage. Or, it may be practical to disable the PA and obtain a sample of driver output by a link-coupling circuit.

Before testing the transverter, assure that the changeover relays, K1 and K2, are connected to the remote-keying terminals of the transceiver. Then connect an antenna to J2 and listen for signals. Peak the incoming signals with the PRE-

Close-up view of the printed-circuit board. This board has the local oscillator, receiver, and low-level driver stages. The crystal socket and crystal for the LO are shown at the lower left.

SELECTOR control. The slugs of L2 and L4 should be adjusted for the highest S-meter reading on the transceiver. L5 should be set for maximum output at 21 or 28 MHz. If the receiving converter is functioning properly, it will be possible to copy a 0.1 μV signal without difficulty in areas where atmospheric and man-made noise are at a minimum. If no signals can be heard, check Q1 to make certain that it is working properly. A wavemeter or general-coverage receiver can be employed to see if the crystal oscillator is operating.

Attach a 50-ohm load to J2 before testing the transmitter section. Set R1 for an indicated resting plate current of 50 mA on M1. This adjustment should be made without drive applied but with K1 and K2 energized. Next, apply about one watt of 21.1-MHz cw drive power at J1. Tune L6, L7, L8 and L9 for maximum meter reading. While monitoring the plate current, tune C2 for a dip. C3 is the **PA LOADING** control. When the PA capacitors are properly adjusted, the plate current will be about 220 mA.

A LOW-POWER SSB/CW TRANSMITTER FOR 80 OR 20 METERS

A number of QRP transmitter designs have appeared in the past, mostly for cw-only operation. The unit to be described operates in both the ssb and cw modes. Using solid-state devices throughout, the transmitter is capable of delivering up to nine watts PEP output into a 50-ohm load. A 9-MHz i-f in conjunction with a VFO that tunes 5.0 to 5.5 MHz results in single-band operation on either 80 or 20 meters. A regulated 12-volt dc supply that can furnish at least two amperes is required to power the transmitter.

Construction Details

Four separate circuit board assemblies are used. Two boards, measuring 6 by 2-3/8 inches and 5-3/4 by 2-3/4 inches, contain most of the transmitter circuitry. The VFO and power output amplifier are included on separate boards, measuring 2 by 3 inches and 2-1/2 by 4 inches respectively. Double-clad circuit board should be used for all except the VFO board. The copper plane on the component side of each board provides a good rf ground and thus enhances stability in the unit. Component leads which are soldered to ground should be soldered to both the ground plane on the component side and the ground foil on the reverse side. To prevent other leads from shorting to the ground plane, their holes on the component side are drilled out slightly with a 1/4-inch drill before mounting. As can be seen in Fig. 2, shields, made from pieces of double-clad circuit board soldered to the main circuit boards, are used to isolate stages which are susceptible to stray rf pickup.

The VFO is housed in a four-walled enclosure formed by four pieces of circuit board soldered together at their common seams. The VFO board fits snugly inside and is soldered along its edges to the walls of the enclosure. The tuning capacitor, C6, mounts firmly against the front wall from which its shaft protrudes. Dc power connection is made via a feedthrough capacitor. A short length of subminiature RG-174/U coax connects the VFO output to U2.

If the 80-meter version of the unit is being constructed, Q11 and associated components in this amplifier stage are to be omitted from the board since the stage is required only for 20-meter operation. Instead, then, a jumper connection is made from common connection 4 (as indicated in the schematic diagram) directly to the base of Q12. In the 20-meter unit this stage is included and the jumper omitted.

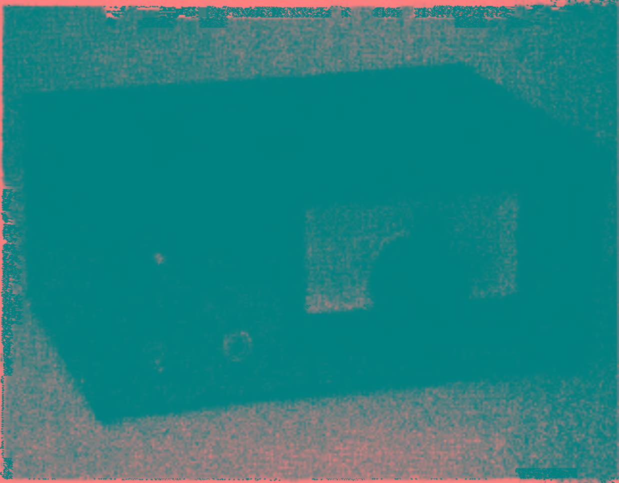
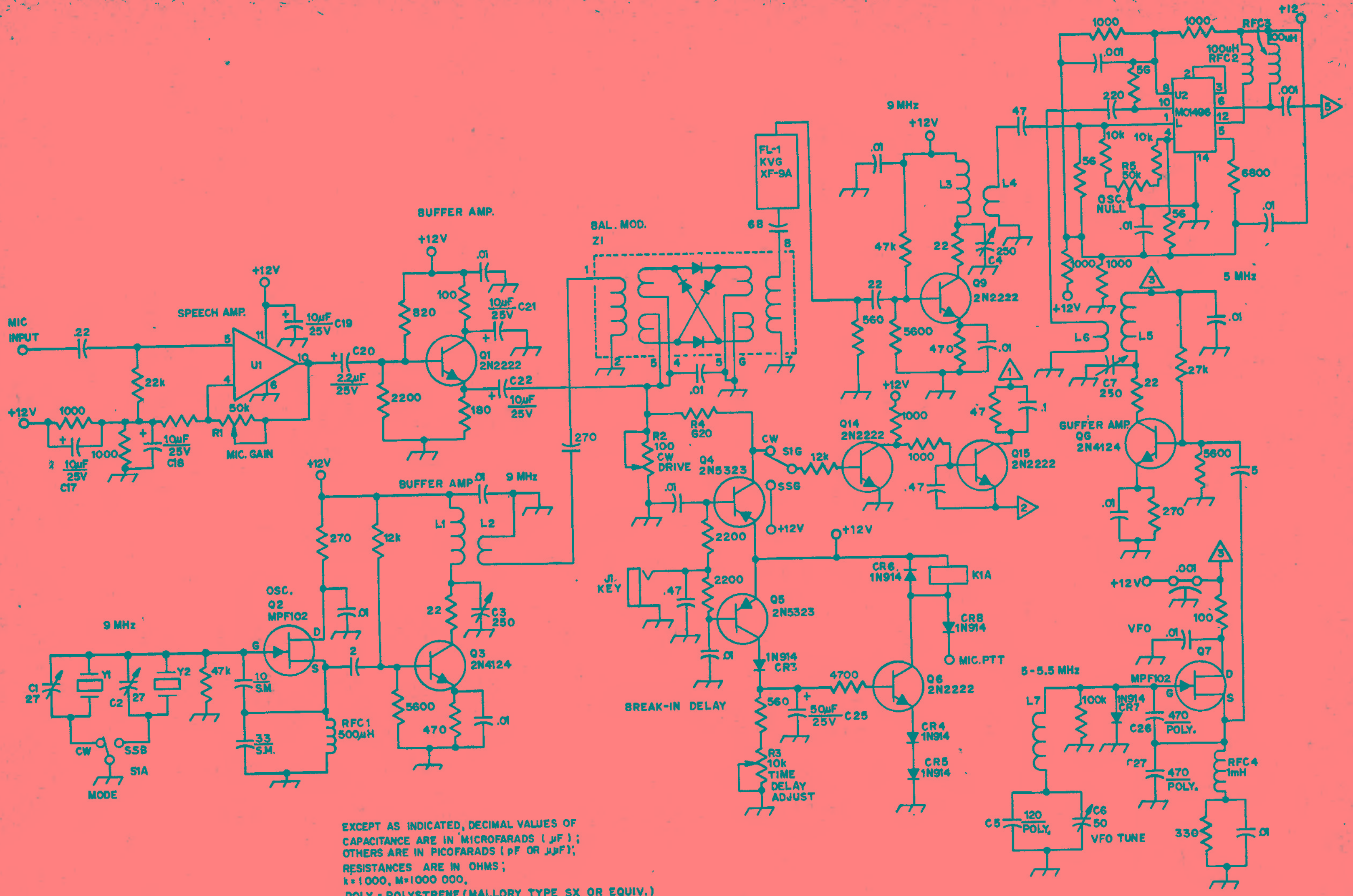


Fig. 1 — Front view of the transmitter with cover in place. The two-piece chassis is made from sheet aluminum. The front panel, which measures 9-1/2 by 4 inches, is spray-painted orange and the cover is finished in brown. White decals are used to identify the power switch, mode switch, microphone gein control, and jack. For cw operation, the key plugs into a jack at the rear of the chassis. A two-speed vernier dial is employed for VFO tuning and stick-on rubber feet are fitted on the bottom of the chassis.

The broadband power output stage employs a 2N6367 rf power transistor rated for 9 watts PEP output with a −30 dB IMD specification. All rf-carrying leads associated with the base circuit of Q13 should be absolutely as short as possible. Because of the low base input impedance – two or three ohms – even small amounts of stray reactance cannot be tolerated. Leads as short as one inch can contribute a considerable amount of inductive reactance in the base circuit.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF) ; OTHERS ARE IN PICOFARADS (pF OR µµF);
RESISTANCES ARE IN OHMS;
k = 1 000, M = 1 000 000.
POLY. = POLYSTRENE (MALLORY TYPE SX OR EQUIV.)

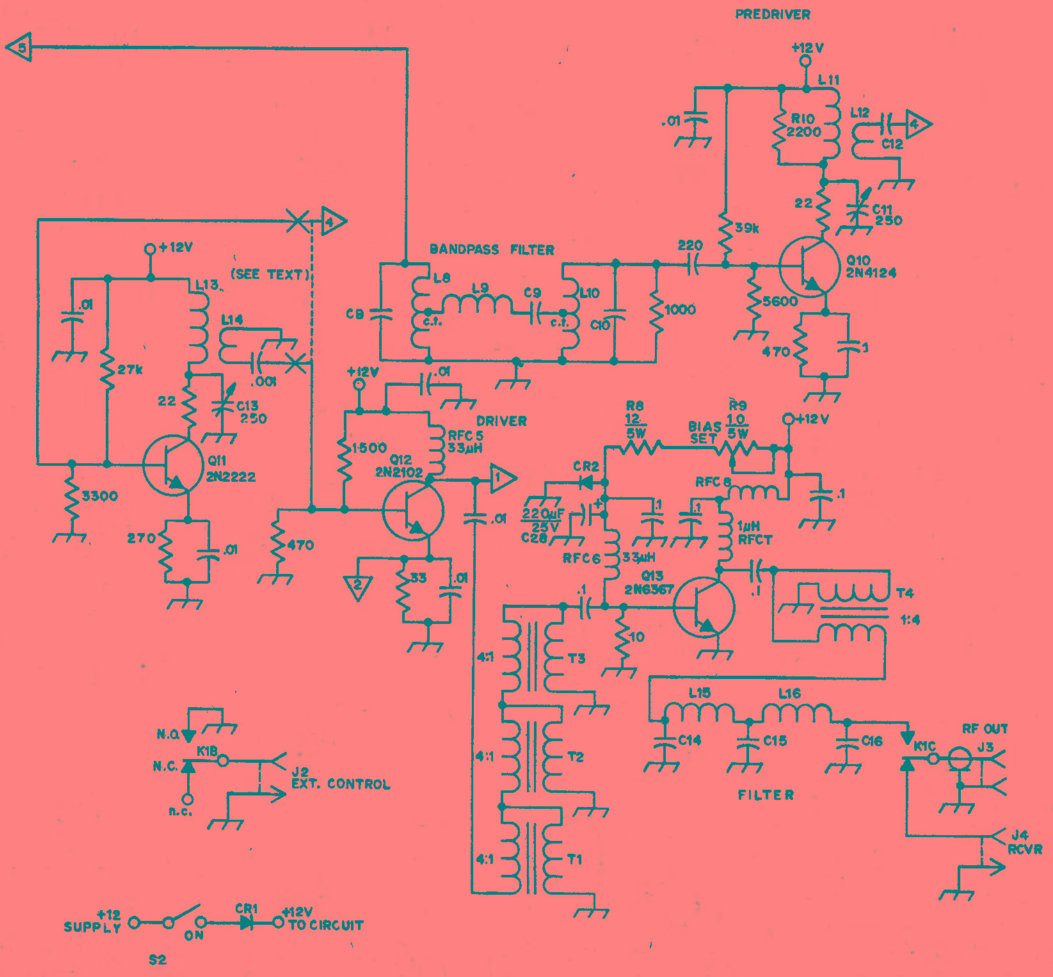


Fig. 2 — Schematic diagram of the 80- or 20-meter low-power ssb/cw transmitter. Capacitors with polarity markad are electrolytic. Fixed-value capacitors are ceramic unless otherwise noted. Resistors are 1/2-watt composition unless marked otherwise. Numbared parts not appearing below are so identified for pc-board layout purposes only.

C1, C2 — 2.0- to 27-pF printed-circuit air variable (E.F. Johnson No. 193-0008-005 or equiv.).
C3, C4, C7, C11, C13 — 250-pF max. trimmer (Arco Elmenco 426).
C6 — 50-pF air variable.
C8, C10 — 220-pF silver mica (80-meter unit); 100-pF silver mica (20-meter unit).
C9 — 68-pF silver mica (80-meter unit); 1.7- to 11-pF miniature air variable (E.F. Johnson No. 187-0106-005 or equiv. for 20-meter unit).
C12 — .001-µF (80-meter unit); 68-pF (20-meter unit).
C14 — 820-pF silver mica (80-meter unit); 680-pF silver mica (20-meter unit).
C15 — 1500-pF silver mica (80-meter unit); 470-pF silver mica (20-meter unit).
C16 — 820-pF silver mica (80-meter unit); 220-pF silver mica (20-meter unit).
CR1 — Silicon diode, 50 PRV, 1A (1N4001 or equiv.).
CR2 — Silicon diode, 50 PRV, 3A or greater, stud-mounting typa (Motorola HEP R0130 or equiv.).
FL1 — 9-MHz, 2.5-kHz bandwidth crystal filter, KVG type XF-9A.
K1 — Dpdt 12 Vdc relay, contact rating of 1 ampere or greater (Radio Shack cat. No. 275-206 or equiv.).
L1, L3 — 2.5-µH, 25 turns No. 24 enam. on Amidon T-50-6 toroid core.
L2 — 2 turns No. 24 enam. wound over L1.
L4 — 2 turns No. 24 enam. wound over L3.
L5 — 4.6-µH, 34 turns No. 24 enam. on Amidon T-50-6 core.
L6 — 3 turns No. 24 enam. wound over L5.

(Continued on next page)

L7 — 7.8- to 12.0-μH slug-tuned coil (Miller 4309).
L8, L10 — 8.9-μH, 49 turns No. 26 enam. on Amidon T-50-6 core (80-meter unit); 1.2-μH, 17 turns No. 24 enam. on Amidon T-50-6 (20-meter unit).
L9 — 26.5-μH, 68 turns No. 28 enam. on Amidon T-68-2 toroid core (80-meter unit); 17.6-μH, 55 turns No. 28 enam. on Amidon T-68-2 core (20-meter unit).
L11 — 8.1-μH, 45 turns No. 26 enam. on Amidon T-50-6 core (80-meter unit); 0.68-μH, 13 turns No. 24 enem. on Amidon T-50-6 core (20-meter unit).
L12 — 3 turns No. 24 enam. wound over L11.
L13 — 0.68-μH, 13 turns No. 24 enam. on Amidon T-50-6 core (used in the 20-meter unit only).
L14 — 1 turn No. 24 enam. wound over L13.
L15, L16 — 2.6-μH, 25 turns No. 24 enam. on Amidon T-50-6 core (80-meter unit); 0.28-μH, 8 turns No. 24 enam. on Amidon T-50-6 core (20-meter unit).
RFC8 — 6 turns No. 28 enam. using Amidon Jumbo Ferrite Bead as toroid core.
S1 — Dpdt subminiature toggle switch (Radio Shack 275-1546 or equiv.).
S2 — Spst subminiature toggle switch (Radio Shack 275-324 or equiv.).
T1, T4 — 4:1 broadband transformer; 12 turns of 1 twisted pair of No. 24 enam. wire (6 turns per inch, not critical) wound on Amidon FT-61-301 toroid core.
T2 — 4:1 broadband transformer; 6 turns of 2 twisted pairs of No. 26 enam. wire (6 turns per inch) wound on Amidon FT-61-301 toroid core. In twisting the wires, a single turn consists of a full twist of all wires. The two wires at the ends of each pair are soldered together and each pair then comprises one winding of the transformer.
T3 — 4:1 broadband transformer; 4 turns of 4 twisted pairs of No. 26 enam. wire (6 turns per inch) wound on Amidon FT-61-301 toroid core. A single turn consists of a full twist of all wires. The two wires at the ends of each pair are soldered together, the ends of two pairs are soldered together, resulting in two 4-conductor wires. Each 4-conductor wire comprises one winding of the transformer.
U1 — 741 oparational amplifier (Motorola MC1741, National Semiconductor LM741, Fairchild μA741 or equiv.), 14-pin DIP used here.
U2 — Balanced modulator IC (Motorola MC1496L or National Semiconductor LM1496L, Signetics 5596). 14-pin DIP used here.
Y1 — 8999.0-kHz crystal (KVG type XF 903).
Y2 — 8998.5-kHz crystal (KVG typa XF 901).
Z1 — Double balanced mixer, model SRA-1 manufactured by Mini-Circuits Laboratory, 2913 Quentin Rd., Brooklyn, NY 11229.

Some care must be taken in mounting Q13. The power amplifier board is drilled out to allow the flange for heat-sink mounting to pass through the board. The transistor leads, which are short straps, then lie flush with the top surface of the board and the flange lies beneath the board. The leads are soldered to the board as close to the body of the transistor as possible and should not be bent. The heat sink consists of a 1/16-inch thick rectangular piece of sheet aluminum cut to the same size as the circuit board. The transistor requires two bolts for mounting to the heat sink. The use of silicone grease to improve thermal conductivity between the transistor and heat sink is recommended. CR2, a stud-mounting type diode, also mounts on the heat sink near the power transistor since good thermal contact with Q13 is necessary for CR2 to provide thermal compensation for the output transistor. Note also that in the driver stage, Q12 requires a heat sink.

The chassis is formed from a piece of sheet aluminum bent into a U-shape. The front panel measures 9-1/2 by 4 inches and the chassis is 7 inches deep. Except for the VFO enclosure, the circuit boards mount vertically on the chassis by means of spade bolts. An aluminum cover is formed to fit over the chassis. A Jackson Bros. No. 4103 dial mechanism is used for VFO tuning. Any similar mechanism with a slow tuning rate should be satisfactory. Front-panel controls are the microphone-gain control, VFO tuning, mode switch, and on-off switch. The key jack, rf-output connector, and dc-power connector are mounted at the rear of the chassis. The transmit-receive relay socket mounts inside the chassis and the spare set of contacts are brought out to a connector at the back of the unit.

Initial Adjustments and Operation

A well-calibrated general-coverage receiver, a VOM, and a VTVM with an rf probe (or better yet, a good rf oscilloscope) are required for making the initial adjustments on the transmitter. Connect a 12-volt dc supply to the transmitter (except the final power amplifier stage). With power turned on, check to see that the unit draws no more than about 200 mA from the supply. Any reading well in excess of this value indicates a wiring error or defective components.

Tune the receiver to 9 MHz to locate the heterodyne oscillator signal. A few feet of hookup wire placed near the circuit board should suffice for a receiving antenna. Switching the mode switch to change the oscillator crystals Y1 and Y2 should shift the oscillator frequency accordingly. Adjust C3 for maximum signal at the collector of Q3 as displayed on an oscilloscope or VTVM with rf probe.

Plug a key into the key jack and set cw drive control, R2, for minimum resistance. Place the mode switch in the cw position. Depress the key while monitoring the collector of Q9 for rf output with the oscilloscope or rf probe. Slowly increase the cw drive level until a 9-MHz signal appears at Q9. Adjust C4 for maximum signal at the collector. Tuning C1 allows a small variation of the cw frequency. Adjustment is not critical but it should be tuned to place the cw signal inside the passband of FL1. If the signal is too close to the edge of the passband, keying may cause the filter to "ring," producing key clicks at the output.

Tune the receiver between 5.0 and 5.5 MHz and vary the VFO tuning capacitor, C6, until the VFO signal is located. Slug-tuned coil L7, which resonates with C6, should then be adjusted so that an entire sweep of C6 covers the range of 5.0 to 5.5 MHz or slightly greater. While monitoring the collector of Q8 with the rf probe or the oscilloscope, adjust C7 for maximum signal.

At this point, an 80- or 20-meter signal should be generated when the transmitter is keyed. By tuning the monitor receiver to the appropriate amateur band, it should be possible to hear this signal. Tune C6 to place the signal in the center of the amateur band. If an oscilloscope is being used, adjust C11 for maximum signal at the base of Q11. Be careful not to peak this capacitor to a harmonic of the 80- or 20-meter signal or to another undesired frequency output from the mixer. If the 20-meter system is being tested, it is also necessary to peak the band-pass filter at the balanced mixer output for optimum frequency response. With the VFO set to the center of the 20-meter band, adjust C9 for maximum response, using an insulated tool so as not to introduce stray capacitance which could upset the filter tuning. Place the oscilloscope probe at the base of Q12. Next tune C13 for maximum signal amplitude. If an oscilloscope is not available, the above steps may be performed by listening to the radiated signal in a general-coverage receiver and using the receiver's S meter as a peak indicator.

The carrier null pot, R5, is adjusted to minimize any 5-MHz VFO signal appearing at the output of the balanced mixer. First disable the 9-MHz heterodyne oscillator by removing Y1 or Y2 from the socket. With the oscilloscope attached to the mixer output at pin 6 of the MC1496L, adjust R5 for minimum 5-MHz output. If an oscilloscope is not available R5 should be set to the middle of its range. Good suppression of the 5-MHz signal will result at the transmitter output in conjunction with the filtering in the following stages. It is difficult to perform this step with just a receiver alone since direct pickup from the VFO will obscure any null indication. Y1 or Y2 should be replaced in its socket.

A check should be made with the VOM or VTVM to assure that the dc voltage drop across R6 is approximately 4.4 volts. This indicates proper quiescent collector current at Q12 for linear operation.

Connect the power amplifier stage to the 12-volt supply but do not key the transmitter. R9 should temporarily be set at maximum resistance first. The VOM is temporarily inserted in series with the collector lead of Q13 to measure collector current. R9 should slowly be decreased to the point where the static collector current (no rf signal input) reaches 35 mA. The VOM is removed, the collector lead reconnected, and R9 left at this setting. If a silicon diode other than an HEP R0130 is used for CR2, it may be necessary to change the values of R8 and R9 to achieve the proper quiescent collector current. Some experimentation will determine the correct values, keeping in mind the resistor power dissipation requirements.

Finally, connect a 50-ohm dummy load to the antenna connector and a high-impedance microphone to the microphone jack. The gain control is adjusted in the same manner as with any conventional ssb transmitter. The setting is best determined with the aid of a Monitorscope at the transmitter output. R1 should never be advanced beyond the point where rf peak flattening begins. A slight readjustment of C2 may be necessary to center the ssb signal properly in the passband of the crystal filter. Improper centering will impair the audio frequency response. This adjustment can be made by listening to oneself in a receiver and tweaking C2 for proper response. Note that the ssb frequency will shift, too, as the setting of C2 is changed. The audio should be clean and free from distortion.

In cw operation, the cw drive control R2 should be brought up to the point where no further increase in rf output results. The break-in delay circuit provides semibreak-in operation for cw and push-to-talk operation for ssb. The setting of time delay adjustment R3 determines the length of time the transmit-receive relay K1 remains closed after the key is released. Adjust R3 for a delay time suitable for the keying speed being used. The spare set of contacts of K1 may be used for muting a receiver during transmit or for switching an outboard power amplifier. The transmitter should never be operated without a proper load at the output.

A set of templates for the four circuit boards is available from ARRL Headquarters, Newington, Conn. 06111 for $1.

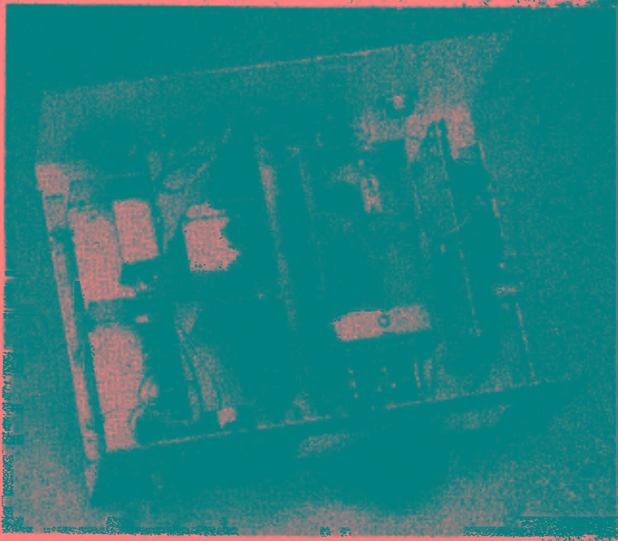
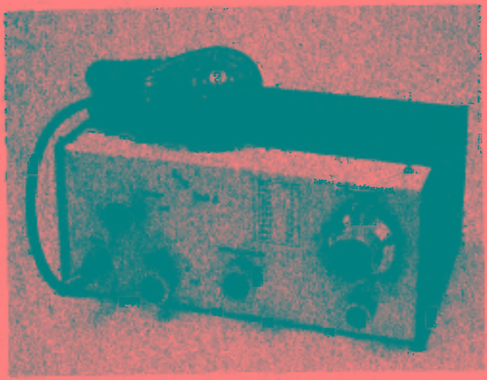


Fig. 3 — View of the inside of the transmitter. The two main circuit boards are mounted vertically on the left side. Note the use of shields (made from double-clad circuit board) to provide isolation between stages on the boards. The VFO, the third circuit board assembly from the left, is housed in a four-sided enclosure fashioned from four pieces of circuit board. The power output amplifier board mounts over the sheet aluminum heat sink which is also mounted vertically on the chassis. Transmit-receive relay K1 is just visible behind the VFO.

A SOLID-STATE TRANSCEIVER FOR 160 METERS



This ssb transceiver is suitable for QRP operation from batteries or as a main frame for fixed-station use. Its circuitry is simple enough to permit easy duplication (or substitution of components where necessary) by proficient builders with only limited experience in solid-state design.

Some 160 Notes

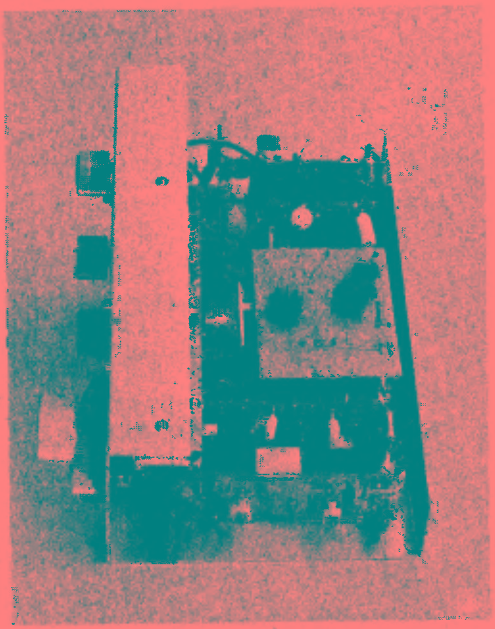
Technically speaking, 160 meters is interesting since it is the only amateur band in the mf range. Phone operation is similar to that encountered on the hf bands but the use of cw is somewhat different. Split-frequency operation is common and one should avoid transmitting within the DX "window" from 1825 to 1830 kHz when the band is open. While cw operation is possible with a transceiver, the above precaution should be noted. Because of the LORAN (Long Range Navigation) service, the band is split up according to geographical area and one should observe the frequency range and power limit for his region (See Chapter 1).

LORAN, proximity to the broadcast band, QRN, and interference from TV sets often imposes severe requirements on receiving devices for this band. While little can be done with sky-wave signals, experimentation with various antenna systems can reduce local interference to a great extent. Proximity and orientation of the antenna to the interfering source are the prime factors here. Because of latter consideration, separate transmitting and receiving antennas may be necessary. Hf-band dipoles, even though they may be electrically short on 160 meters, can still make excellent receiving antennas if a balancing network is used. The balancing transformer (T1) shown in Fig. 1 can be used for both transmitting and receiving, thus reducing ground-loop currents. A simple loading coil in one side of the feed line can be used to tune out the antenna capacitive reactance.

Adequate front-end selectivity is also necessary to assure that unwanted rf energy is rejected *before* it reaches the active elements in the receiving section of the transceiver. The preselector shown in Fig. 1 may be built from readily available parts. Some experimentation with the number of turns on L1 in receive-only applications may be necessary. Use the minimum number of turns that give sufficient sensitivity without signs of overloading. This preselector could also be used with existing receivers with inadequate front-end selectivity on 160.

Circuit Details

The circuit diagram of the transceiver is shown in Fig. 1 and Figs. 3 through 8 incl. The block diagram and switching logic of the transceiver are shown in Fig. 2. This arrangement eliminates the need for relays and provides excellent isolation around the 9-MHz filter board. The full capabilities of a good receiving filter may be reduced considerably by undesirable stray paths. Rf energy rejected by the filter goes around it through the unwanted paths. In the receive position, signals from 1.8 to 2 MHz are mixed with the LO (10.8 to 11 MHz) to give a 9-MHz i-f. Greater bandspread can be achieved by using a smaller value for C10 and increasing L5 or C11. This would reduce the band coverage, however. In the transmit position,



Interior view of the transceiver.

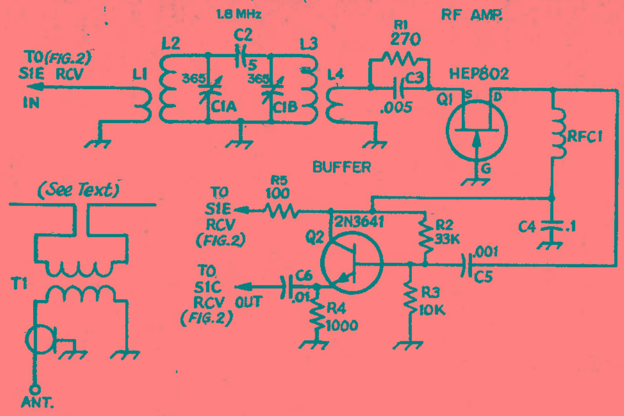


Fig. 1 — Schematic diagram of the rf amplifier and preselector. In this and succeeding diagrams, component designations not mentioned in the captions are for text and layout references only. Unlass otherwise noted, rasistors are 1/4- or 1/2-watt composition and capacitors are disk ceramic.

C1 — Air variable, 365 pF per section (J.W. Miller 2112 or equiv.).

L1, L4 — 2 turns of plastic-coated wire over cold ends of L2 and L3 respectively.

L2, L3 — Modified Ferri-Tenna Coil (Radio Shack No. 270-1430). Remove coupling coil and all but 35 turns of fine wire on core (see text).

RFC1 — 2.5 mH rf choke pc-board mounting type (Millen J302-2500).

T1 — 40 tums over Amidon T-68-3 toroid (gray core) of bifilar-wound No. 26 enamel wire.

the same mixer is used but rf energy from the balanced modulator and filter board at 9-MHz is converted to the 1.8-MHz band.

Because of the relationship between the LO and the i-f, a sideband inversion occurs. This means that the carrier oscillator crystals will be opposite that usually marked on the filter package. Cw operation is in the usb mode and both carrier-oscillator and VFO offset is used. The carrier-oscillator offset pulls the crystal frequency into the passband of the filter slightly, while the VFO offset can be adjusted for the desired tone on receiving. Keying is accomplished by unbalancing the 1496 IC balanced modulator. Waveshape is determined by the time constant of R62 and C59 in Fig. 7.

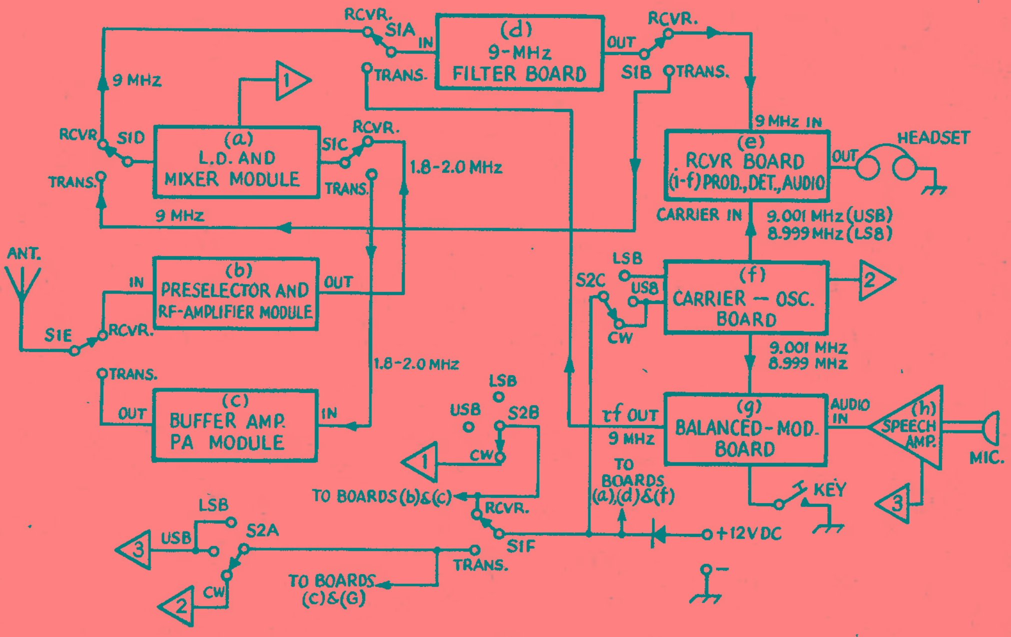


Fig. 2 — Block diagram & switching logic of the transceiver.

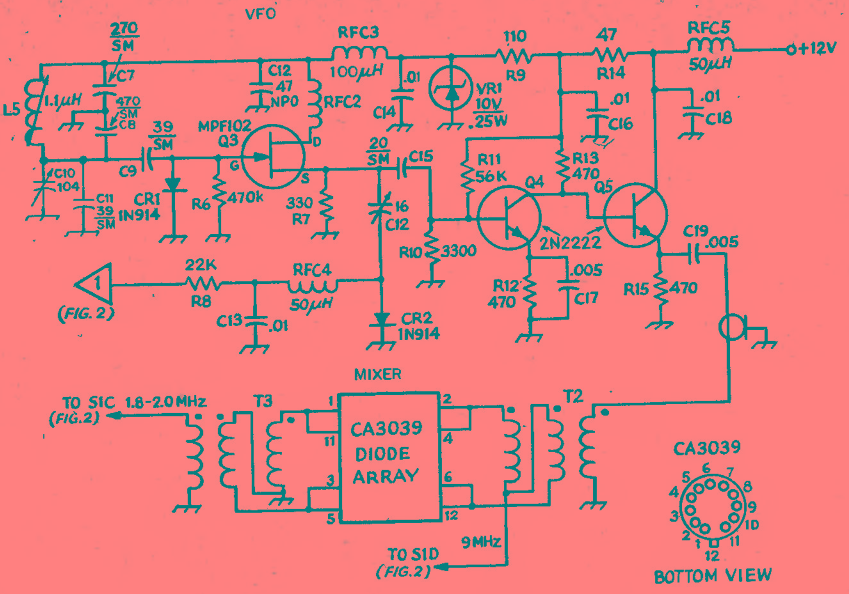


Fig. 3 — Schematic diagram of LO and mixer module. If greater bandspread is desired, a smaller value capacitor could be substituted for C10 with C11 increased by an appropriate amount to set the low-frequency end of the tuning range to 10.8 MHz.

C10 — Air variable, 104 pF maximum (J.W. Miller 2101 or equiv.).

L5 — 1.1-µH slug tuned (Millen 69054-0.91 or equiv.).

RFC2 — Three Amidon ferrite beads at drain terminal of Q3. Install on 1/2-inch length of No. 24 bare wire.

RFC3, RFC4, RFC5 — Miniature 50-µH choke (Millen Co. J300-50).

T2, T3 — 25 turns No. 28 (trifilar wound) on Amidon T-50-3 toroid core.

The low-pass filter shown in Fig. 8 is used to eliminate unwanted rf energy (LO, carrier oscillator, and other products) above 2 MHz before going to the buffer transistor Q11. While various transistors are suitable for cw service in the hf range, many will not perform well as linear power amplifiers. The variation in transistor current gain over a large dynamic range is too great. This results in distortion or imposes severe biasing problems. Generally speaking, uhf types are the best ones to use. The amplifier used with the transceiver is capable of approximately one-watt output with good IMD characteristics.

Construction

A modular-type layout was used that allows the builder to pretest various sections of the transceiver *before* installation in the cabinet. Single-sided pc board or Vectorbord construction should be avoided since unwanted capacitive and inductive coupling may cause spurious oscillations. Use double-sided pc board, or, as in the case of the unit shown, isolated-pad construction. The latter is highly recommended. The individual boards are then mounted in the cabinet with small "L" brackets or in the case of the VFO module, with screws.

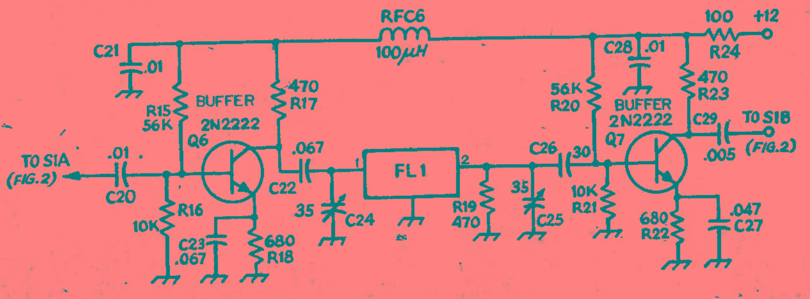


Fig. 4 — The 9-MHz filter board. Physical layout should keep input and output leads separated.

C22, C25 — 3- to 35- pF mica compression trimmer.

RFC6 — Miniature 100-µH choke (Millen Co. J300-100).

FL1 — 9-MHz crystal filter, 2.1-kHz bandwidth (KVG XF-9B Spectrum International, Box 87, Topsfield, MA 01983).

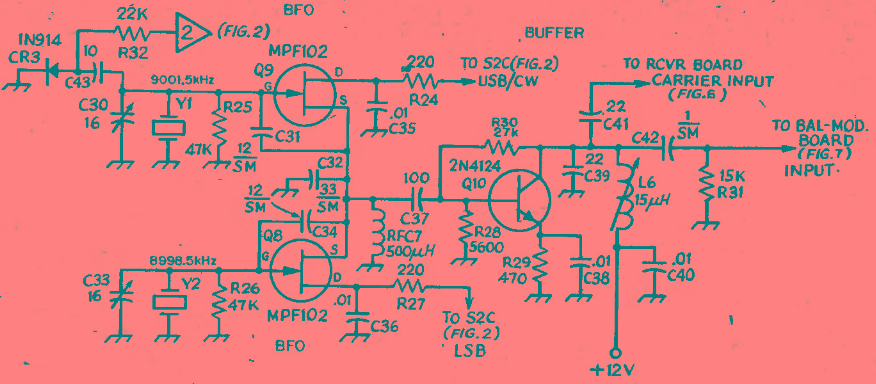


Fig. 5 — Carrier oscillator board.

C30, C33 — Miniature pc-mount air variable (Johnson 189-506-5, Allied Electronics 828-1219).

L6 — 15 µH nominal (Miller 4506 or equiv.).

RFC7 — 500-µH rf choke (Millen J300-500).

Y1, Y2 — KVG matching crystals for FL1.

Where interconnecting shielded cables are used (such as the connections on S1 and other rf leads), small coaxial cable is ideal. RG-174/U was used in the unit shown and it is good practice to tie the ground leads to one point where two or more cables come together. An example would be the switch connections at S1. Regular hook-up wire can be used for the power-supply leads going to each board.

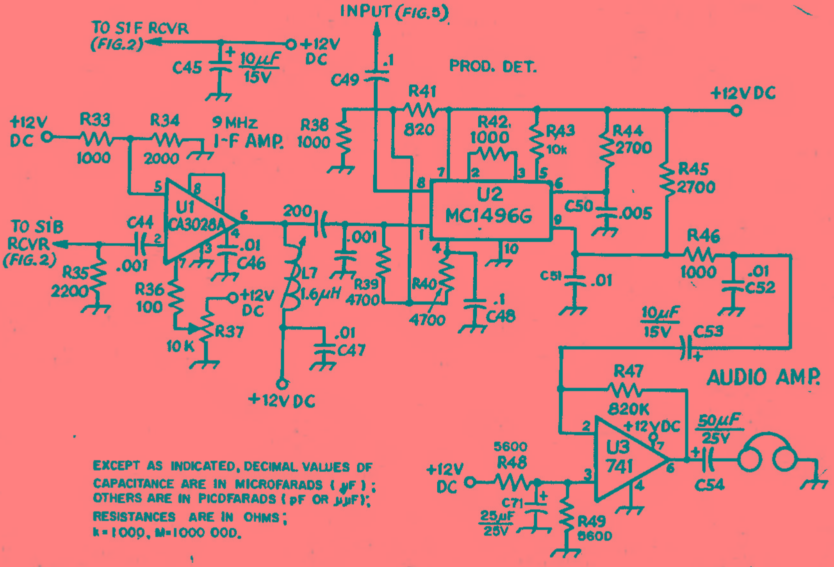
While the general layout should not be critical, the one shown in the photograph is suggested. The cabinet is a Ten-Tec MW-10 and the dial assembly can be obtained from Allied/Radio Shack. The rootary switches for S1 and S2 are surplus miniature types with glass-epoxy insulation. The size of the various components available will determine the final layout but care should be taken to keep all leads as short as possible.

It is a good idea to start with the receiver portion of the transceiver (the rf amplifier and preselector is the simplest module to build). Carefully unwind (and save) the wire from the two ferrite-loop antenna coils.

Wind a one-layer coil (35 turns) back on each form and solder it in place. Paint each coil with *Q* dope to keep the turns from unwinding. Mount the completed coils (L2 and L3) using heavy wire leads on the 365-pF capacitor as shown in the photograph. L1 and L4 consist of 2 turns of hook up wire wound on the cold end of L2 and L3 respectively. Next, lay out the circuit board for the

Fig. 6 — Receiver board. This includes the i-f amplifier, product detector, and audio amplifier. Audio power is sufficient for high-impedance earphones.

L7 — Slug-tuned inductor, 1.6 µH nominal, 13 turns No. 26 enam. on 1/4-inch form.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF); OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k=1000, M=1000 000.

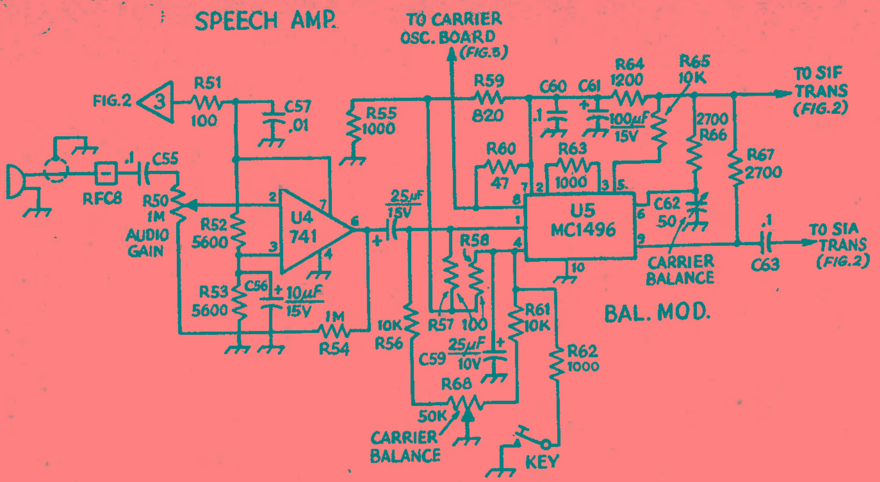


Fig. 7 — Schematic diagram of the speech amplifier and the balanced modulator boards.
C62 — Mica Compression trimmer, 50 pF.
R52, R68 — Control, pc-mounting type.
RFC8 — 3 ferrite beads over microphone-input lead.

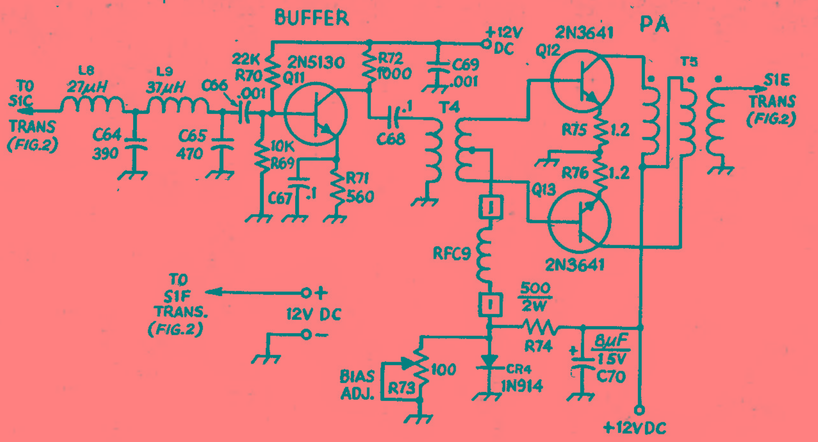
rf amplifier, making it small enough to mount on the back of the capacitor with spacers and screws. Layout for this board (and the remaining ones) will be successful if the following rules are observed. First, keep all component leads as short as possible (especially IC leads) and second, lay out the stages in a straight line as shown in the photograph. Also assure that input and output leads are kept as far away from each other as is practical. If the isolated-pad construction technique is used, a drill press (bench style) is handy. However, either a hand-held electric drill or a crank-type hand drill may be used. Once the preselector module is completed, perform the alignment procedure before going on to the next board. Complete and test the remaining boards before mounting them permanently in the cabinet.

Alignment

While the transceiver could be tested after it is completed, the procedure outlined here will assure each module is working before the next one is mounted in the cabinet. Necessary test equipment includes a signal source and receiver covering 1.8 to 2.0 MHz, and 9 to 11 MHz. The receiver should be capable of receiving ssb signals. Other suggested equipment would be a VTVM, a monitor scope which can be used with the receiver to check modulation, and a frequency counter.

The preselector module should be aligned first. Connect a signal source to the general-coverage receiver and tune in the signal. Next, connect the preselector between the generator and the receiver and adjust the slugs until the signals peak. For correct alignment, C1 should be fully meshed at the low end (1.8 MHz) of the band. The VFO should be adjusted by setting its range for 10.8 to 11 MHz as indicated on either a general-coverage receiver or a frequency counter. The preselector and LO/mixer modules may be mounted inside the cabinet and interconnected. See blocks (a) and (b) in Fig. 2. The external receiver should be connected to the output of T2. When power is applied to the transceiver and S1 is set for RCV, signals and noise should be heard at 9 MHz as the VFO and preselector are tuned. The 9-MHz filter board should be installed and the receiver connection moved from T2 to the output of the filter. See block (d) in Fig. 2. Peak C24 and C25 for maximum signal. The carrier-oscillator board may be checked by listening with the general-coverage receiver to the two crystal frequencies (8.999 and 9.001). Mount the carrier-oscillator and receiver boards, connect a headphone set and adjust L7 for maximum receiver sensitivity. This completes the alignment of the receiver. See block (c) in Fig. 2 for details.

Refer to block (h) in Fig. 2 and mount the speech amplifier. Install the appropriate power, input and output connections. Couple a headset to the output of this circuit through a 0.5-μF capacitor and speak into the microphone. Speech should be heard. Install and connect the balanced-modulator board. Refer to block (g) in Fig. 2. Ssb signals should be detected at the output terminal of T3. Adjust R68 and C62 for minimum carrier. Interconnect the buffer and PA modules, and connect a dummy load (with an output indicator) to the antenna jack. A small pilot light (No. 47) will suffice if the PA shown in Fig. 8 is used. R73 should be set for minimum collector current. A short whistle into the microphone should produce



an output signal. Clear-sounding ssb signals should be heard when listening to the general-coverage receiver. This completes the ssb alignment.

Place a jumper from either the USB or LSB position of S2A to the CW position of S2A. Set the general-coverage receiver to the USB position. Turn the transceiver to the CW position and tune until a readable ssb signal is heard. Key the transceiver and depending upon the settings of C12 and C30, a tone should be heard. C30 will determine the amount of output. Adjust C12 until the desired sidetone is obtained. This will require retuning the receiver for readable usb after each adjustment. When the adjustment is correct, a proper-sounding ssb signal can be heard in the CW position and the desired note will also be heard when the transmitter is keyed. Remove the jumper from S2A. This completes alignment of the transceiver.

Fig. 8 — Schematic diagram of buffer and PA. If a broad-band amplifier or antenna circuit is to follow T5, a low-pass filter may be necessary to reduce unwanted harmonic energy.

L8 — 27 μH, 66 turns of No. 30 enam. wire on Amidon T-50-3 (gray) toroid core.

L9 — 37 μH, 76 turns No. 30 enam. on T-50-3 core.

R73 — Control, pc-mounting type.

RFC9 — 2.7 μH minimum. Slip a ferrite bead over each end of a small rf choke (Millen 34300).

T4 — Stack two Amidon Husky (7 mm) beads and wind a 5-turn primary and a 3 turn secondary through both cores. Use No. 26 enam. wire. Make a second transformer similar to the first one. Parallel the primaries, and series connect the secondaries observing the polarities shown on the diagram.

T5 — 24 turns No. 26 enam. wire (trifilar wound) on Amidon T-68-3 core.

Chapter 14

Frequency Modulation and Repeaters

Methods of radiotelphone communication by frequency modulation were developed in the 1930s by Major Edwin Armstrong in an attempt to reduce the problems of static and noise associated with receiving a-m broadcast transmissions. The primary advantage of fm, the ability to produce a high signal-to-noise ratio when receiving a signal of only moderate strength, has made fm the mode chosen for mobile communications services and quality broadcasting. The disadvantages, the wide bandwidth required and the poor results obtained when an fm signal is propagated via the ionosphere (because of phase distortion), has limited the use of frequency modulation to the 10-meter band and the vhf/uhf section of the spectrum.

Fm has some impressive advantages for vhf operation, especially when compared to a-m. With fm the modulation process takes place in a low-level stage. The modulation equipment required is the same, regardless of transmitter power. The signal may be frequency multiplied after modulation, and the PA stage can be operated Class C for best efficiency, as the "final" need not be linear.

In recent years there has been increasing use of fm by amateurs operating around 29.6 MHz in the 10-meter band. The vhf spectrum now in popular use includes 52 to 53 MHz, 146 to 147.5 MHz, 222 to 225 MHz, and 440 to 450 MHz.

FREQUENCY AND PHASE MODULATION

It is possible to convey intelligence by modulating any property of a carrier, including its frequency and phase. When the frequency of the carrier is varied in accordance with the variations in a modulating signal, the result is frequency modulation (fm). Similarly, varying the phase of the carrier current is called phase modulation (pm).

Frequency and phase modulation are not independent, since the frequency cannot be varied without also varying the phase, and vice versa.

The effectiveness of fm and pm for communication purposes depends almost entirely on the receiving methods. If the receiver will respond to frequency and phase changes but is insensitive to amplitude changes, it will discriminate against most forms of noise, particularly impulse noise such as is set up by ignition systems and other sparking devices. Special methods of detection are required to accomplish this result.

Modulation methods for fm and pm are simple and require practically no audio power. There is also the advantage that, since there is no amplitude variation in the signal, interference to broadcast reception resulting from rectification of the transmitted signal in the audio circuits of the bc receiver is substantially eliminated.

Frequency Modulation

Fig. 14-2 is a representation of frequency modulation. When a modulating signal is applied, the carrier frequency is increased during one half cycle of the modulating signal and decreased during the half cycle of opposite polarity. This is indicated in the drawing by the fact that the rf cycles occupy less time (higher frequency) when the modulating signal is positive, and more time (lower frequency) when the modulating signal is negative. The change in the carrier frequency (frequency deviation) is proportional to the instantaneous amplitude of the modulating signal, so the deviation is small when the instantaneous amplitude of the modulating signal is small, and is greatest when the modulating signal reaches its peak, either positive or negative.

As shown by the drawing, the amplitude of the signal does not change during modulation.

Phase Modulation

If the phase of the current in a circuit is changed there is an instantaneous frequency change during the time that the phase is being shifted. The amount of frequency change, or deviation, depends on how rapidly the phase shift is accomplished. It is also dependent upon the total amount of the phase shift. In a properly operating

Fig. 14-1 — The use of vhf fm mobile rigs in conjunction with repeaters has improved the communications of many amateur emergency groups. Here F2BQ relays traffic being received via 2-meter fm on a 40-meter ssb link.

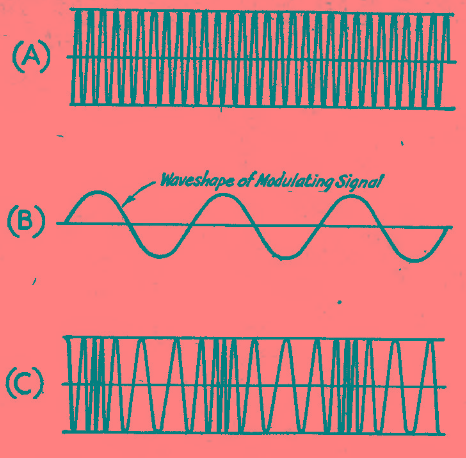


Fig. 14-2 — Graphical representation of frequency modulation. In the unmodulated carrier at A, each rf cycla occupies the same amount of time. When the modulating signal, B, is applied, the radio frequency is increased and decreased according to the amplitude and polarity of the modulating signal.

pm system the amount of phase shift is proportional to the instantaneous amplitude of the modulating signal. The rapidity of the phase shift is directly proportional to the frequency of the modulating signal. Consequently, the frequency deviation in pm is proportional to both the amplitude and frequency of the modulating signal. The latter represents the outstanding difference between fm and pm, since in fm the frequency deviation is proportional only to the amplitude of the modulating signal.

FM and PM Sidebands

The sidebands set up by fm and pm differ from those resulting from a-m in that they occur at integral multiples of the modulating frequency on either side of the carrier rather than, as in a-m, consisting of a single set of side frequencies for each modulating frequency. An fm or pm signal therefore inherently occupies a wider channel than a-m.

The number of "extra" sidebands that occur in fm and pm depends on the relationship between the modulating frequency and the frequency deviation. The ratio between the frequency deviation, in Hertz, and the modulating frequency, also in Hertz, is called the **modulating index.** That is,

$$\textit{Modulation index} = \frac{\underline{\textit{Carrier frequency deviation}}}{\textit{Modulating frequency}}$$

Example: The maximum frequency deviation in an f.m. transmitter is 3000 Hz. either side of the carrier frequency. The modulation index when the modulating frequency is 1000 Hz. is

$$\text{Modulation index} = \frac{3000}{1000} = 3$$

At the same deviation with 3000-Hz. modulation the index would be 1; at 100 Hz. it would be 30, and so on.

In pm the modulation index is constant regardless of the modulating frequency; in fm it varies with the modulating frequency, as shown in the above example. In an fm system the ratio of the *maximum* carrier-frequency deviation to the *highest* modulating frequency used is called the deviation ratio.

Fig. 14-3 shows how the amplitudes of the carrier and the various sidebands vary with the modulation index. This is for single-tone modulation; the first sideband (actually a pair, one above and one below the carrier) is displaced from the carrier by an amount equal to the modulating frequency, the second is twice the modulating frequency away from the carrier, and so on. For example, if the modulating frequency is 2000 Hz and the carrier frequency is 29,500 kHz, the first sideband pair is at 29,498 kHz and 29,502 kHz, the second pair is at 29,496 kHz and 29,504 kHz, the third at 29,494 kHz and 29,506 kHz, etc. The amplitudes of these sidebands depend on the modulation index, not on the frequency deviation.

Note that as shown by Fig. 14-3, the carrier strength varies with the modulation index. (In amplitude modulation the carrier strength is constant; only the sideband amplitude varies.) At a modulation index of approximately 2.4 the carrier disappears entirely. It then becomes "negative" at a higher index, meaning that its phase is reversed as compared to the phase without modulation. In fm and pm the energy that goes into the sidebands is taken from the carrier, the *total* power remaining the same regardless of the modulation index.

Since there is no change in amplitude with modulation, an fm or pm signal can be amplified without distortion by an ordinary Class C amplifier. The modulation can take place in a very low-level stage and the signal can then be amplified by either frequency multipliers or straight-through amplifiers.

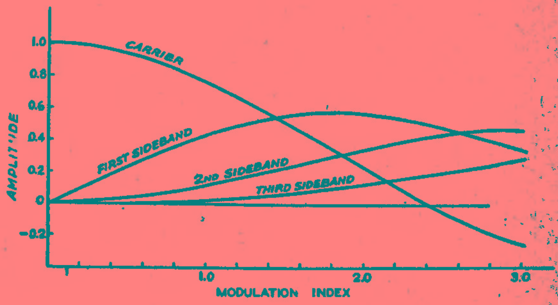


Fig. 14-3 — How the amplitude of tha pairs of sidebands varies with the modulation index in an fm or pm signal. If the curves wera extended for greater values of modulation index it would be seen that the carrier amplitude goes through zero at several points. The same statement also applies to the sidebands.

If the modulated signal is passed through one or more frequency multipliers, the modulation index is multiplied by the same factor that the carrier frequency is multiplied. For example, if modulation is applied on 3.5 MHz and the final output is on 28 MHz, the total frequency multiplication is 8 times, so if the frequency deviation is 500 Hz at 3.5 MHz it will be 4000 Hz at 28 MHz. Frequency multiplication offers a means for obtaining practically any desired amount of frequency deviation, whether or not the modulator itself is capable of giving that much deviation without distortion.

Bandwidth

FCC amateur regulations (Part 97.61) limit the bandwidth of F3 (frequency and phase modulation) to that of an a-m transmission having the same audio characteristics below 29.0 MHz and in the 50.1- to 52.5-MHz frequency segment. Greater bandwidths are allowed from 29.0 to 29.7 MHz and above 52.5 MHz.

If the modulation index (with single-tone modulation) does not exceed 0.6 or 0.7, the most important extra sideband, the second, will be at least 20 dB below the unmodulated carrier level, and this should represent an effective channel width about equivalent to that of an a-m signal. In the case of speech, a somewhat higher modulation index can be used. This is because the energy distribution in a complex wave is such that the modulation index for any one frequency component is reduced as compared to the index with a sine wave having the same peak amplitude as the voice wave.

The chief advantage of fm or pm for frequencies below 30 MHz is that it eliminates or reduces certain types of interference to broadcast reception. Also, the modulating equipment is relatively simple and inexpensive. However, assuming the same unmodulated carrier power in all cases, narrow-band fm or pm is not as effective as a-m *with the methods of reception used by many amateurs.* To obtain the benefits of the fm mode, a good fm receiver is required. As shown in Fig. 14-3, at an index of 0.6 the amplitude of the first sideband is about 25 percent of the unmodulated-carrier amplitude; this compares with a sideband amplitude of 50 percent in the case of a 100 percent modulated a-m transmitter. When copied on an a-m receiver, a narrow-band fm or pm transmitter is about equivalent to a 100-percent modulated a-m transmitter operating at one-fourth the carrier power. On a suitable (fm) receiver, fm is as good or better than a-m, watt for watt.

Three deviation amounts are now standard practice: 15, 5 and 2.5 kHz, which in the current vernacular of fm users, are known as wide band, narrow band, and sliver band, respectively. (See box above.) The 2.5-3 kHz deviation (called nbfm by OTs) was popular for a time on the vhf bands and 10 meters after World War II. Deviation figures are given for the frequency swing in one direction. The rule-of-thumb for determination of bandwidth requirements for an fm system is:

$$2\,(\triangle F) + F_{\text{Amax}}$$

where $\triangle F$ is one half of the total frequency deviation, and F_{Amax} is the maximum audio frequency (3 kHz for communications purposes). Thus, for narrow-band fm, the bandwidth equals (2) 5 + 3 or 13 kHz. Wide-band systems need a 33-kHz receiver bandwidth.

Comparison of FM and PM

Frequency modulation cannot be applied to an amplifier stage, but phase modulation can; pm is therefore readily adaptable to transmitters employing oscillators of high stability such as the crystal-controlled type. The amount of phase shift that can be obtained with good linearity is such that the maximum practicable modulation index is about 0.5. Because the phase shift is proportional to the modulating frequency, this index can be used only at the highest frequency present in the modulating signal, assuming that all frequencies will at one time or another have equal amplitudes. Taking 3000 Hz as a suitable upper limit for voice work, and setting the modulation index at 0.5 for 3000 Hz, the frequency response of the speech-amplifier system above 3000 Hz must be sharply attenuated, to prevent excess splatter. (See Fig. 14-4.) Also, if the "tinny" quality of pm as received on an fm receiver is to be avoided, the pm must be changed to fm, in which the modulation index decreases in inverse proportion to the modulating frequency. This requires shaping the speech-amplifier frequency-response curve in such a way that the output voltage is inversely proportional to frequency over most of the voice range. When this is done the maximum modulation index can only be used to some relatively low audio frequency, perhaps 300 to 400 Hz in voice transmission, and must decrease in proportion to the increase in frequency. The result is that the maximum linear frequency deviation is only one or two hundred Hz, when pm is changed to fm. To increase the deviation for narrow band requires a frequency multiplication of 8 times or more.

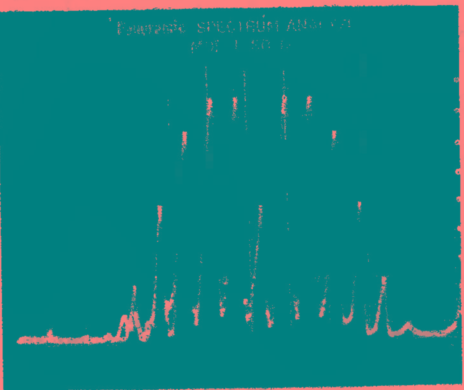


Fig. 14-4 — Output frequency spectrum of a narrow-band fm transmitter modulated by a 1-kHz tone.

It is relatively easy to secure a fairly large frequency deviation when a self-controlled oscillator is frequency-modulated directly. (True frequency modulation of a crystal-controlled oscillator results in only very small deviations and so requires a great deal of frequency multiplication.) The chief problem is to maintain a satisfactory degree of carrier stability, since the greater the inherent stability of the oscillator the more difficult it is to secure a wide frequency swing with linearity.

METHODS OF FREQUENCY MODULATION

Direct FM

A simple and satisfactory device for producing fm in the amateur transmitter is the reactance modulator. This is a vacuum tube or transistor connected to the rf tank circuit of an oscillator in such a way as to act as a variable inductance or capacitance.

Fig. 14-5A is a representative circuit. Gate 1 of the modulator MOSFET is connected across the oscillator tank circuit, C1L1, through resistor R1 and blocking capacitor C2. C3 represents the input capacitance of the modulator transistor. The resistance of R1 is made large compared to the reactance of C3, so the rf current through R1C3 will be practically in phase with the rf voltage appearing at the terminals of the tank circuit. However, the voltage across C3 will lag the current by 90 degrees. The rf current in the drain circuit of the modulator will be in phase with the grid voltage, and consequently is 90 degrees behind the current through C3, or 90 degrees behind the rf tank voltage. This lagging current is drawn through the oscillator tank, giving the same effect as though an inductance were connected across the tank. The frequency increases in proportion to the amplitude of the lagging plate current of the modulator. The audio voltage, introduced through a radio-frequency choke, varies the transconductance of the transistor and thereby varies the rf drain current.

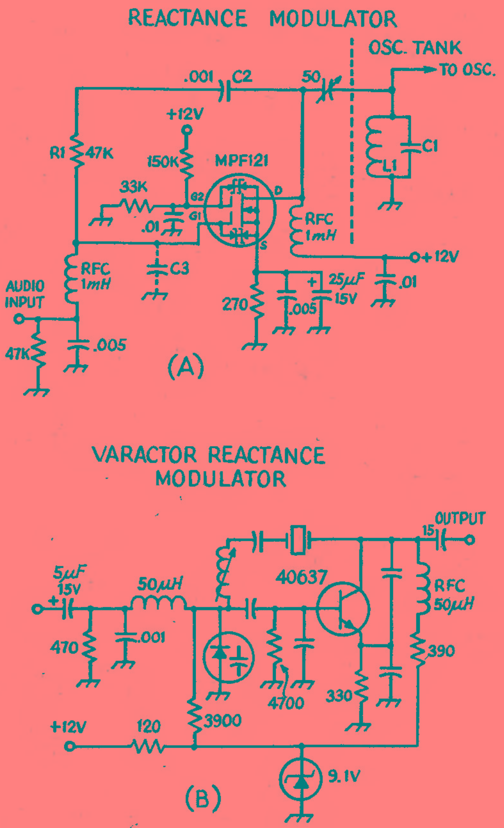


Fig. 14-5 — Reactance modulators using (A) a high-transconductance MOSFET and (B) a varactor diode.

The modulated oscillator usually is operated on a relatively low frequency, so that a high order of carrier stability can be secured. Frequency multipliers are used to raise the frequency to the final frequency desired.

A reactance modulator can be connected to a crystal oscillator as well as to the self-controlled type as shown in Fig. 14-5B. However, the resulting signal can be more phase-modulated than it is frequency-modulated, for the reason that the frequency deviation that can be secured by varying the frequency of a crystal oscillator is quite small.

The sensitivity of the modulator (frequency change per unit change in grid voltage) depends on the transconductance of the modulator transistor. It increases when R1 is made smaller in comparison with C3. It also increases with an increase in L/C ratio in the oscillator tank circuit. However, for highest carrier stability it is desirable to use the largest tank capacitance that will permit the desired deviation to be secured while keeping within the limits of linear operation.

A change in *any* of the voltages on the modulator transistor will cause a change in rf drain current, and consequently a frequency change. Therefore it is advisable to use a regulated power supply for both modulator and oscillator.

Indirect FM

The same type of reactance-tube circuit that is used to vary the tuning of the oscillator tank in fm can be used to vary the tuning of an amplifier tank and thus vary the phase of the tank current for pm. Hence the modulator circuit of Fig. 14-5A or 14-6A can be used for pm if the reactance transistor or tube works on an amplifier tank instead of directly on a self-controlled oscillator. If audio shaping is used in the speech amplifier, as described above, fm instead of pm will be generated by the phase modulator.

The phase shift that occurs when a circuit is detuned from resonance depends on the amount of detuning and the *Q* of the circuit. The higher the

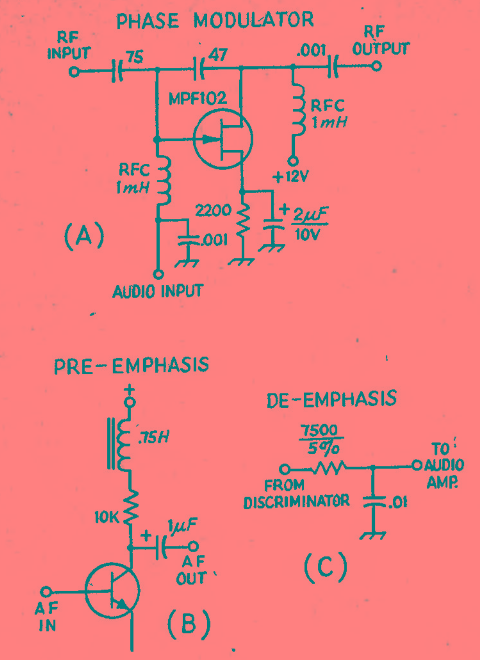


Fig. 14-6 — (A) The phase-shifter type of phase modulator. (B) Pre-emphasis and (C) de-emphasis circuits.

Q, the smaller the amount of detuning needed to secure a given number of degrees of phase shift. If the *Q* is at least 10, the relationship between phase shift and detuning (in kHz either side of the resonant frequency) will be substantially linear over a phase-shift range of about 25 degrees. From the standpoint of modulator sensitivity, the *Q* of the tuned circuit on which the modulator operates should be as high as possible. On the other hand, the effective *Q* of the circuit will not be very high if the amplifier is delivering power to a load since the load resistance reduces the *Q*. There must therefore be a compromise between modulator sensitivity and rf power output from the modulated amplifier. An optimum figure for *Q* appears to be about 20; this allows reasonable loading of the modulated amplifier and the necessary tuning variation can be secured from a reactance modulator without difficulty. It is advisable to modulate at a low power level.

Reactance modulation of an amplifier stage usually results in simultaneous amplitude modulation because the modulated stage is detuned from resonance as the phase is shifted. This must be eliminated by feeding the modulated signal through an amplitude limiter or one or more "saturating" stages – that is, amplifiers that are operated Class C and driven hard enough so that variations in the amplitude of the input excitation produce no appreciable variations in the output amplitude.

For the same type of reactance modulator, the speech-amplifier gain required is the same for pm as for fm. However, as pointed out earlier, the fact that the actual frequency deviation increases with the modulating audio frequency in pm makes it necessary to cut off the frequencies above about 3000 Hz before modulation takes place. If this is not done, unnecessary sidebands will be generated at frequencies considerably away from the carrier.

SPEECH PROCESSING FOR FM

The speech amplifier preceding the modulator follows ordinary design, except that no power is taken from it and the af voltage required by the modulator grid usually is small – not more than 10 or 15 volts, even with large modulator tubes, and only a volt or two for transistors. Because of these modest requirements, only a few speech stages are needed; a two-stage amplifier consisting of two bipolar transistors, both resistance-coupled, will more than suffice for crystal ceramic or hi-Z dynamic microphones. For more information on speech amplifiers see Chapter 13.

Several forms of speech processing produce worthwhile improvements in fm system performance. It is desirable to limit the peak amplitude of the audio signal applied to an fm or pm modulator, so that the deviation of the fm transmitter will not exceed a preset value. This peak limiting is usually accomplished with a simple audio clipper which is placed between the speech amplifier and modulator. The clipping process produces high-order harmonics which, if allowed to pass through to the modulator stage, would create unwanted sidebands. Therefore, an audio low-pass filter with a cut-off frequency between 2.5 and 3 kHz is needed at the output of the clipper. Excess clipping can cause severe distortion of the voice signal. An audio processor consisting of a compressor and a clipper, such as described in Chapter 13, has been found to produce audio with a better sound (i.e., less distortion) than a clipper alone.

To reduce the amount of noise in some fm communications systems, an audio shaping network called pre-emphasis is added at the transmitter to proportionally attenuate the lower audio frequencies, giving an even spread to the energy in the audio band. This results in an fm signal of nearly constant energy distribution. The reverse is done at the receiver, called de-emphasis, to restore the audio to its original relative proportions. Sample circuits are shown in Fig. 14-6.

FM EXCITERS

Fm exciters and transmitters take two general forms. One, shown at Fig. 14-7A, consists of a reactance modulator which shifts the frequency of an oscillator to generate an fm signal directly. Successive multiplier stages provide output on the desired frequency, which is amplified by a PA stage. This system has a disadvantage in that, if the oscillator is free running, it is difficult to achieve sufficient stability for vhf use. If a crystal-controlled oscillator is employed, unless the amount that the crystal frequency is changed is kept small, it is difficult to achieve equal amounts of frequency swing.

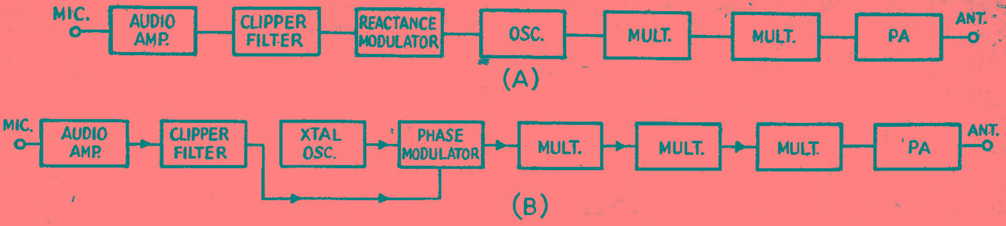


Fig. 14-7 — Block diagrams of typical fm exciters.

The indirect method of generating fm shown in Fig. 14-7B is currently popular. Shaped audio is applied to a phase modulator to generate fm. As the amount of deviation produced is very small, then a large number of multiplier stages is needed to achieve wide-band deviation at the operating frequency. In general, the system shown at A will require a less complex circuit than that at B, but the indirect method (B) often produces superior results.

TESTING AN FM TRANSMITTER

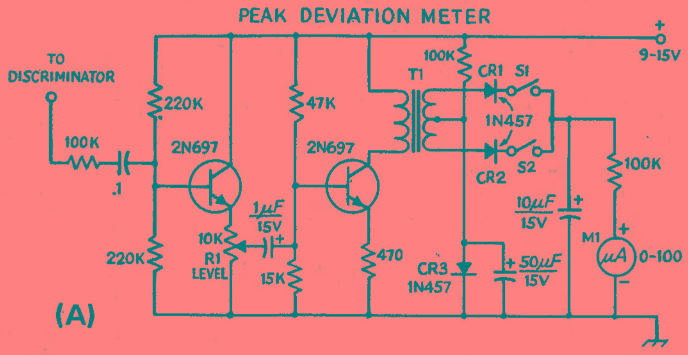
Accurate checking of the operation of an fm or pm transmitter requires different methods than the corresponding checks on an a-m or ssb set. This is because the common forms of measuring devices either indicate amplitude variations only (a milliammeter, for example), or because their indications are most easily interpreted in terms of amplitude.

The quantities to be checked in an fm transmitter are the linearity and frequency deviation and the output frequency, if the unit uses crystal control. The methods of checking differ in detail.

Frequency Checking

The crystal-controlled, channelized operation that is now popular with amateur fm users requires that a transmitter be held close to the desired channel, at least within a few hundred Hertz, even in a wide-band system. Having the transmitter on the proper frequency is particularly important when operating through a repeater. The rigors of mobile and portable operation make a frequency check of a channelized transceiver a good idea at three-month intervals.

Frequency meters generally fall in two categories, the hererodyne type and the digital counter. For amateur use, the vhf/uhf counterparts of the



(B)

Audio Frequency	Deviation Produced 1st Null	2nd Null	3rd Null
905.8 Hz	±2.18 kHz	± 5.00 kHz	± 7.84 kHz
1000.0 Hz	±2.40 kHz	± 5.52 kHz	± 8.65 kHz
1500.0 Hz	±3.61 kHz	± 8.28 kHz	±12.98 kHz
1811.0 Hz	±4.35 kHz	±10.00 kHz	±15.67 kHz
2000.0 Hz	±4.81 kHz	±11.04 kHz	±17.31 kHz
2079.2 Hz	±5.00 kHz	±11.48 kHz	±17.99 kHz
2805.0 Hz	±6.75 kHz	±15.48 kHz	±24.27 kHz

Fig. 14-8 — (A) Schematic diagram of the deviation meter. Resistors are 1/2-watt composition and capacitors are ceramic, except those with polarity marked, which are electrolytic. CR1-CR3, incl. are high-speed silicon switching diodes. R1 is a linear-taper composition control, and S1, S2 are spst toggle switches. T1 is e miniature audio transformer with a 10,000-ohm primary and 20,000-ohm center-tapped secondary (Triad A31X). (B) Chart of audio frequencies which will produce a carrier null when the devietion of an fm transmitter is set for the values given.

popular BC-221 frequency meter, the TS-174 and TS-175, will provide sufficient accuracy. Frequency counters that will work directly up to 500 MHz and higher are available, but their cost is high. The less expensive low-frequency counters can be employed using a scaler, a device which divides an input frequency by a preset ratio, usually 10 or 100. The Heathkit IB-102 scaler may be used up to 175 MHz, using a counter with a 2-MHz (or more) upper frequency limit. If the counting system does not have a sufficient upper frequency limit to measure the output of an fm transmitter directly, one of the frequency-multiplier stages can be sampled to provide a signal in the range of the measurement device. Alternatively, a crystal-controlled converter feeding an hf receiver which has accurate frequency readout can be employed, if a secondary standard is available to calibrate the receiving system.

Deviation and Deviation Linearity

A simple deviation meter can be assembled following the diagram of Fig. 14-8A. This circuit was designed by K6VKZ. The output of a wide-band receiver discriminator (before any de-emphasis) is fed to two amplifier transistors. The output of the amplifier section is transformer coupled to a pair of rectifier diodes to develop a dc voltage for the meter, M1. There will be an indication on the meter with no signal input because of detected noise, so the accuracy of the instrument will be poor on weak signals.

To calibrate the unit, signals of known deviation will be required. If the meter is to be set to read 0-15 kHz, then a 7.5-kHz deviation test signal should be employed. R1 is then adjusted until M1 reads half scale, 50 μA. To check the peak deviation of an incoming signal, close both S1 and S2. Then, read the meter. Opening first one switch and then the other will indicate the amount of positive and negative deviation of the signal, a check of deviation linearity.

Measurement of Deviation Using Bessel Functions

Using a math. relationship known as the Bessel Function it is possible to predict the points at which, with certain audio-input frequencies and predetermined deviation settings, the carrier output of an fm transmitter will disappear completely. Thus, by monitoring the carrier frequency with a receiver, it will be possible by ear to identify the deviation at which the carrier is nulled. A heterodyne signal at either the input or receiver i-f is required so that the carrier will produce a beat note which can easily be identified. Other tones will be produced in the modulation process, so some concentration is required by the operator when making the test. With an audio tone selected from the chart (Fig. 14-8B), advance the deviation control slowly until the first null is heard. If a higher-order null is desired, continue advancing the control further until the second, and then the third, null is heard. Using a carrier null beyond the third is generally not practical.

For example, if a 905.8-Hz tone is used, the transmitter will be set for 5-kHz deviation when the second null is reached. The second null achieved with a 2805-Hz audio input will set the transmitter deviation at 15.48 kHz. The Bessel-function approach can be used to calibrate a deviation meter, such as the unit shown in Fig. 14-8A

RECEPTION OF FM SIGNALS

Receivers for fm signals differ from others principally in two features – there is no need for linearity preceding detection (it is, in fact, advantageous if amplitude variations in signal and background noise can be "washed out") and the detector must be capable of converting frequency variations in the incoming signal into amplitude variations.

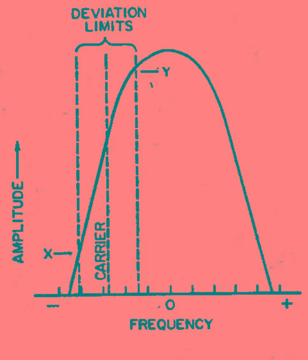


Fig. 14-9 — Fm detector characteristics. Slope detection, using the sloping side of the receivers selectivity curve to convert fm to a-m for subsequent detection.

Frequency-modulated signals can be received after a fashion on any ordinary receiver. The receiver is tuned to put the carrier frequency partway down on one side of the selectivity curve. When the frequency of the signal varies with modulation it swings as indicated in Fig. 14-9, resulting in an a-m output varying between X and Y. This is then rectified as an a-m signal.

With receivers having steep-sided selectivity curves, the method is not very satisfactory because the distortion is quite severe unless the frequency deviation is small, since the frequency deviation and output amplitude is linear over only a small part of the selectivity curve.

The FM Receiver

Block diagrams of an a-m/ssb and an fm receiver are shown in Fig. 14-10. Fundamentally, to achieve a sensitivity of less than one microvolt, an fm receiver requires a gain of several million – too much total gain to be accomplished with stability on a single frequency. Thus, the use of the

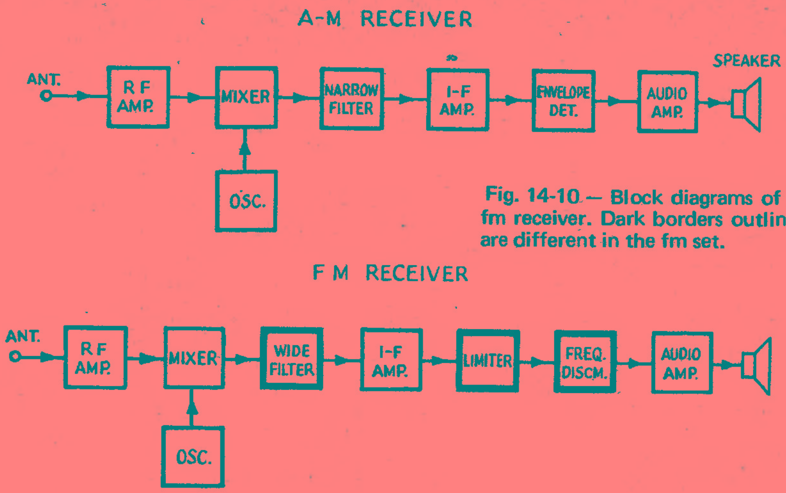


Fig. 14-10 — Block diagrams of (A) an a-m (B) an fm receiver. Dark borders outline the sections that are different in the fm set.

superheterodyne circuit has become standard practice. Three major differences will be apparent from a comparison of the two block diagrams. The fm receiver employs a wider-bandwidth filter, a different detector, and has a limiter stage added between the i-f amplifier and the detector. Otherwise the functions, and often the circuits, of the rf, oscillator, mixer and audio stages will be the same in either receiver.

In operation, the noticeable difference between the two receivers is the effect of noise and interference on an incoming signal. From the time of the first spark transmitters, "rotten QRM" has been a major problem for amateurs. The limiter and discriminator stages in an fm set can eliminate a good deal of impulse noise, except that noise which manages to acquire a frequency-modulation characteristic. Accurate alignment of the receiver i-f system and phase tuning of the detector are required to achieve good noise suppression. Fm receivers perform in an unusual manner when QRM is present, exhibiting a characteristic known as the *capture effect.* The loudest signal received, even if it is only two or three times stronger than other stations on the same frequency, will be the only transmission demodulated. By comparison, an S9 a-m or cw signal can suffer noticeable interference from an S2 carrier.

Bandwidth

Most fm sets that use tubes achieve i-f selectivity by using a number of overcoupled transformers. The wide bandwidth and phase-response characterisitic needed in the i-f system dictate careful design and alignment of all interstage transformers.

F M FILTERS

		Center	*Nonimal*	*Ultimate*	*Impedance (r)*		*Insertion*	*Crystal*
Manufacturer	*Model*	*Frequency*	*Bandwidth*	*Rejection*	*In*	*Out*	*Loss*	*Discriminator*
KVG (1)	XF-9E	9.0 MHz	12 kHz	90 dB	1200	1200	3 dB	XD9-02
KVG (1)	XF-107A	10.7 MHz	12 kHz	90 dB	820	820	3.5 dB	XD107-01
KVG (1)	XF-107B	10.7 MHz	15 kHz	90 dB	910	910	3.5 dB	XD107-01
KVG (1)	XF-107C	10.7 MHz	30 kHz	90 dB	2000	2000	4.5 dB	XD107-01
Heath Dynamics (2)	–	21.5 MHz	15 kHz	90 dB	550	550	3 dB	–
Heath Dynamics (2)	–	21.5 MHz	30 kHz	90 dB	1100	1100	2 dB	–
E.S. (3)	FB-6D	10.7 MHz	15 kHz	80 dB	950	950	2 dB	AB-1C
E.S. (3)	10-MA	10.7 MHz	30 kHz	80 dB	2000	2000	4 dB	AB-1C
E.S. (3)	EL-3A	11.5 MHz	36 kHz	70 dB	50	50	4 dB	AL-1
E.S. (3)	DR-9	21.4 MHz	20 kHz	40 dB	750	750	5 dB	AR-10
Clevite (4)	TCF4-12D3CA	455 kHz	12 kHz	60 dB	40k	2200	6 dB	–
Clevite (4)	TCF4-18G45A	455 kHz	18 kHz	50 dB	40k	2200	6 dB	–
Clevite (4)	TCF6-30D55A	455 kHz	30 kHz	60 dB	20k	1000	5 dB	–

Fig. 14-11 — A list of fm-bandwidth filters that are available to amateurs. Manufacturer's addresses are as follows:

1) Spectrum International, P. O. Box 87, Topsfield, MA 01983.
2) Heath Dynamics, Inc., 6050 N. 52nd Avenue, Glendale, AZ 85301.
3) E. S. Electronic Labs, 301 Augustus, Excelsior Springs, MO 64024.
4) Semiconductor Specialists, Inc., P. O. Box 66125, O'Hare International Airport, Chicago, IL 60666. (Minimum order $5.00.)

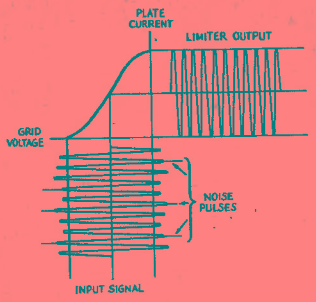


Fig. 14-12 – Representation of limiter action. Amplitude variations on the signal are removed by the diode action of the grid- and plate-current saturation.

For the average ham, the use of a high-selectivity filter in a homemade receiver offers some simplification of the alignment task. Following the techniques used in ssb receivers, a crystal or ceramic filter should be placed in the circuit as close as possible to the antenna connector – at the output of the first mixer, in most cases. Fig. 14-11 lists a number of suitable filters that are available to amateurs. Prices for these filters are in the range of $10 to $30. Experimenters who wish to "roll their own" can use surplus hf crystals, as outlined in ARRL's *Single Sideband for the Radio Amateur*, or ceramic resonators.

One item of concern to every amateur fm user is the choice of i-f bandwidth for his receiver, as both 15- and 5-kHz deviation are now in common use on the amateur bands. A wide-band receiver can receive narrow-band signals, suffering only some loss of audio in the detection process. However, a wideband signal will be badly distorted when received on a narrow-band rig. At this point it seems reasonable to assume that increasing fm activity and continued production of commercial narrow-band transceivers may gradually shift amateur operation to a 5-kHz deviation standard. But, as with the a-m operators, the wide-band enthusiasts will be around for some time to come, lured by inexpensive surplus wide-band gear.

Limiters

When fm was first introduced, the main selling point used for the new mode was the noise-free reception possibilities. The circuit in the fm receiver that has the task of chopping off noise and amplitude modulation from an incoming signal is the *limiter*. Most types of fm detectors respond to both frequency and amplitude variations of the signal. Thus, the limiter stages preceding the detector are included to "cleanse" the signal so that only the desired frequency modulation will be demodulated. This action can be seen in Fig. 14-13.

Limiter stages can be designed using tubes, transistors, or ICs. For a tube to act as a limiter, the applied B voltages are chosen so that the stage will overload easily, even with a small amount of signal input. A sharp-cutoff pentode such as the 6BH6 is usually employed with little or no bias applied. As shown in Fig. 14-12, the input signal limits when it is of sufficient amplitude so that diode action of the grid and plate-current saturation clip both sides of the input signal, producing a constant-amplitude output voltage.

Obviously, a signal of considerable strength is required at the input of the limiter to assure full clipping, typically several volts for tubes, one volt for transistors, and several hundred microvolts for ICs. Limiting action should start with an rf input of 0.2 μV or less, so a large amount of gain is required between the antenna terminal and the limiter stages. For example, the Motorola 80D has eight tubes before the limiter, and the solid-state MOTRAC receivers use nine transistor stages to get sufficient gain before the first limiter. The new ICs offer some simplification of the i-f system as they pack a lot of gain into a single package.

When sufficient signal arrives at the receiver to start limiting action, the set *quiets* – that is, the background noise disappears. The sensitivity of an fm receiver is rated in terms of the amount of input signal required to produce a given amount of quieting, usually 20 dB. Current practice using the new solid-state devices can produce receivers which achieve 20 dB quieting with 0.15 to 0.5 μV of input signal.

A single tube or transistor stage will not provide good limiting over a wide range of input signals. Two stages, with different input time constants, are a minimum requirement. The first stage is set to handle impulse noise satisfactorily while the second is designed to limit the range of signals passed on by the first. At frequencies below 1 MHz it is useful to employ untuned *RC*-coupled limiters which provide sufficient gain without a tendency toward oscillation.

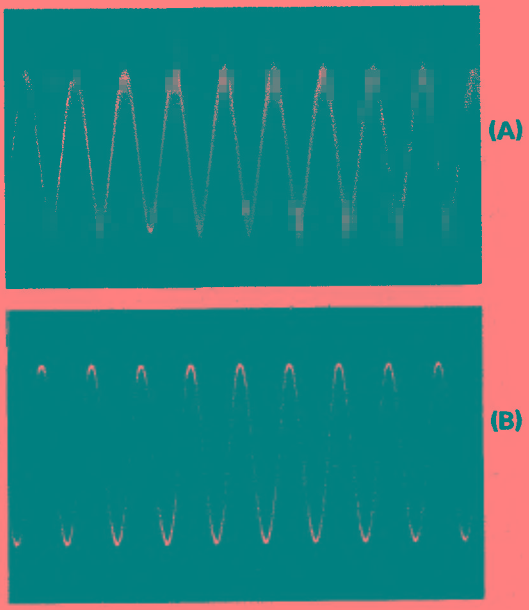


Fig. 14-13 – (A) Input wave form to a limiter stage shows a-m and noise. (B) The same signal, after passing through two limiter stages, is devoid of a-m components.

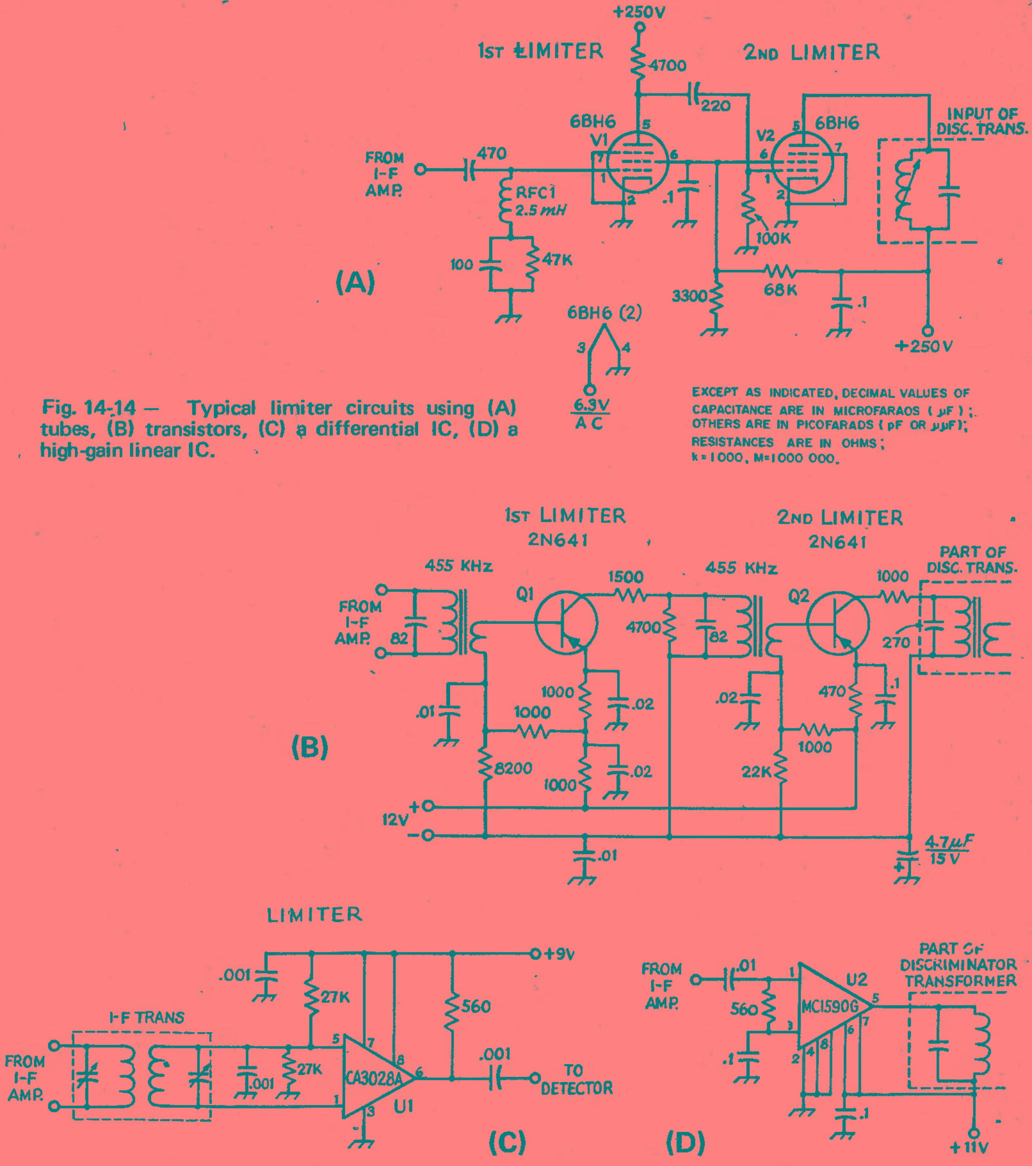


Fig. 14-14 — Typical limiter circuits using (A) tubes, (B) transistors, (C) a differential IC, (D) a high-gain linear IC.

EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF) ; OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS ; k = 1000, M = 1000 000.

Fig. 14-14A shows a two-stage limiter using sharp-cutoff tubes, while 14-14B has transistors in two stages biased for limiter service. The base bias on either transistor may be varied to provide limiting at a desired level. The input-signal voltage required to start limiting action is called the *limiting knee*, referring to the point at which collector (or plate) current ceases to rise with increased input signal. Modern ICs have limiting knees of 100 mV for the circuit shown in Fig. 14-14C, using the CA3028A or MC1550G, or 200 µV for the Motorola MC1590G of Fig. 14-14D. Because the high-gain ICs such as the CA3076 and MC1590G contain as many as six or eight active stages which will saturate with sufficient input, one of these devices provides superior limiter performance compared to a pair of tubes or transistors.

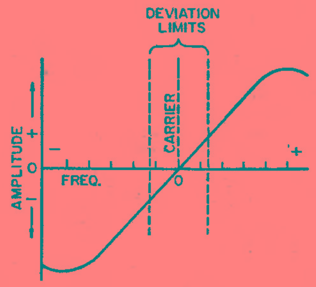
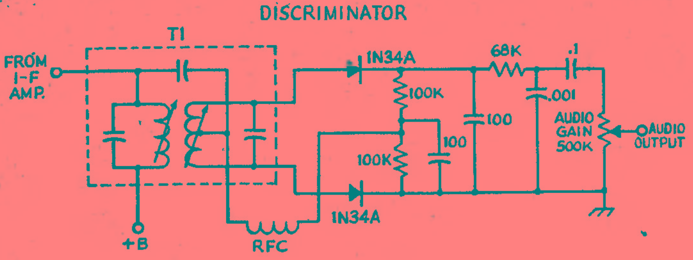


Fig. 14-15 — The characteristic of an fm discriminator.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k=1000, M=1 000 000

Fig. 14-16 – Typical frequency-discriminator circuit used for fm detection. T1 is a Miller 12-C45.

Detectors

The first type of fm detector to gain popularity was the frequency discriminator. The characteristic of such a detector is shown in Fig. 14-15. When the fm signal has no modulation, and the carrier is at point O, the detector has no output. When audio input to the fm transmitter swings the signal higher in frequency, the rectified output increases in the positive direction. When the frequency swings lower the output amplitude increases in the negative direction. Over a range where the discriminator is linear (shown as the straight portion of the line), the conversion of fm to a-m which is taking place will be linear.

A practical discriminator circuit is shown in Fig. 14-16. The fm signal is converted to a-m by transformer T1. The voltage induced in the T1 secondary is 90 degrees out of phase with the current in the primary. The primary signal is introduced through a center tap on the secondary, coupled through a capacitor. The secondary voltages combine on each side of the center tap so that the voltage on one side leads the primary signal while the other side lags by the same amount. When rectified, these two voltages are equal and of opposite polarity, resulting in zero-voltage output. A shift in input frequency causes a shift in the phase of the voltage components that results in an increase of output amplitude on one side of the secondary, and a corresponding decrease on the other side. The differences in the two changing voltages, after rectification, constitute the audio output.

In the search for a simplified fm detector, RCA developed a circuit that has now become standard in entertainment radios which eliminated the need for a preceding limiter stage. Known as the *ratio detector*, this circuit is based on the idea of dividing a dc voltage into a ratio which is equal to the ratio of the amplitudes from either side of a discriminator-transformer secondary. With a detector that responds only to ratios, the input signal may vary in strength over a wide range without causing a change in the level of output voltage – fm can be detected, but not a-m. In an actual ratio detector, Fig. 14-17, the dc voltage required is developed across two load resistors, shunted by an electrolytic capacitor. Other differences include the two diodes, which are wired in series aiding rather than series opposing, as in the standard discriminator circuit. The recovered audio is taken from a tertiary winding which is tightly coupled to the primary of the transformer. Diode-load resistor values are selected to be lower (5000 ohms or less) than for the discriminator.

The sensitivity of the ratio detector is one half that of the discriminator. In general, however, the transformer design values for *Q*, primary-secondary coupling, and load will vary greatly, so the actual performance differences between these two types of fm detectors are usually not significant. Either circuit can provide excellent results. In operation, the ratio detector will not provide sufficient limiting for communications service, so this detector also is usually preceded by at least a single limiting stage.

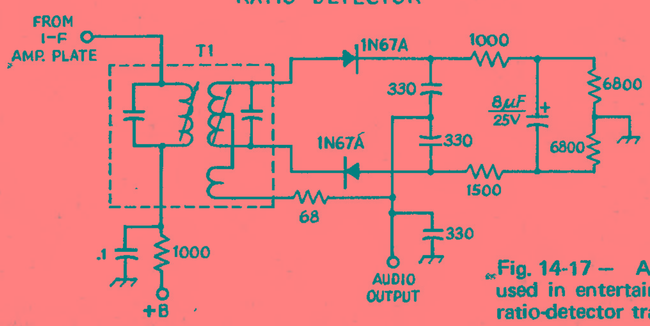


Fig. 14-17 – A ratio detector of the type often used in entertainment redio and TV sets. T1 is a ratio-detector transformer such as the Miller 1606.

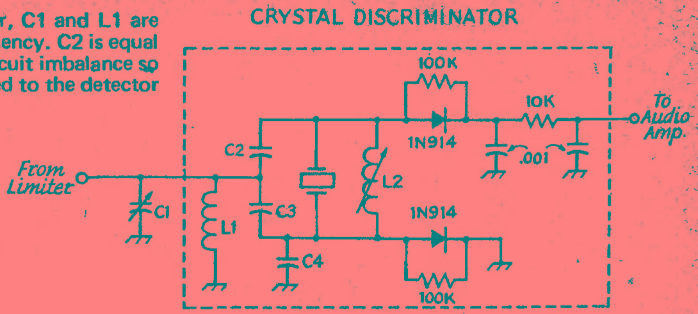


Fig. 14-18 – Crystal discriminator, C1 and L1 are resonant at the intermediate frequency. C2 is equal in value to C3. C4 corrects any circuit imbalance so that equal amounts of signal are fed to the detector diodes.

New Detector Designs

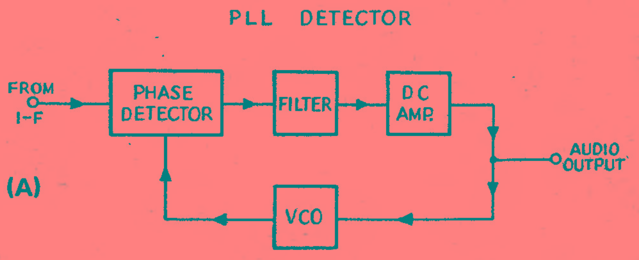
The difficulties often encountered in building and aligning *LC* discriminators have inspired research that has resulted in a number of adjustment-free fm detector designs. The *crystal discriminator* utilizes a quartz resonator, shunted by an inductor, in place of the tuned-circuit secondary used in a discriminator transformer. A typical circuit is shown in Fig. 14-18. Some commercially-made crystal discriminators have the input-circuit inductor, L1, built in (C1 must be added) while in other types both L1 and C1 must be supplied by the builder. Fig. 14-18 shows typical component values; unmarked parts are chosen to give the desired bandwidth. Sources for crystal discriminators are listed in Fig. 14-11.

The PLL

Now that the phase-locked loop (PLL) has been reduced to a single IC package, this circuit is destined to revolutionize some facets of receiver design. Introduction by Signetics of a PLL in a single flat-pack IC, followed by Motorola and Fairchild (who are making the PLL in separate building-block ICs), allows a builder to get to work with a minimum of bother.

A basic phase-locked loop (Fig. 14-19A) consists of a phase detector, a filter, a dc amplifier, and a voltage-controlled oscillator (VCO). The VCO runs at a frequency close to that of an incoming signal. The phase detector produces an error voltage if any difference in frequency exists between the VCO and the i-f signal. This error voltage is applied to the VCO. Any changes in the frequency of the incoming signal are sensed at the detector and the error voltage readjusts the VCO frequency so that it remains locked to the intermediate frequency. The bandwidth of the system is determined by a filter on the error-voltage line.

Because the error voltage is a copy of the audio variations originally used to shift the frequency of the transmitter, the PLL functions directly as an fm detector. The sensitivity achieved with the Signetics NE565 PLL is good – about 1 mV for the circuit shown in Fig. 14-19B. No transformers or tuned circuits are required. The PLL bandwidth is usually two to ten percent of the i-f for fm detection. Components R1-C1 set the VCO to near the desired frequency. C2 is the loop-filter capacitor which determines the capture range – that range of frequencies over which the loop will acquire lock with an input signal, initially starting



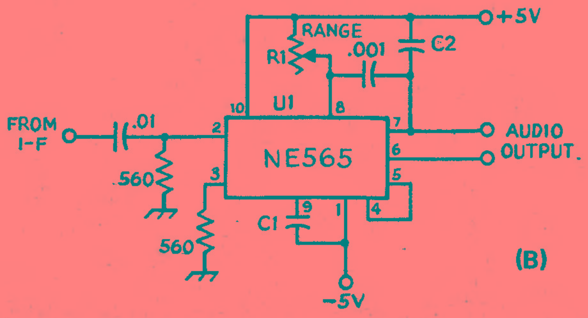


Fig. 14-19 – (A) Block diagram of a PLL demodulator. (B) Complete PLL circuit.

out of lock. The NE565 has an upper frequency limit of 500 kHz; for higher frequencies, the NE561, which is usable up to 30 MHz, can be employed.

FM RECEIVING ADAPTERS

To put the older tube receivers such as the 75A, HRO and Super Pro models into fm service, the receiving adapter shown in Fig. 14-21 was designed. Filament and plus B voltages are taken from the companion receiver. Obviously, the better the basic receiver, the better will be the performance of the fm receiving system. For this application sets with high-gain i-f amplifier sections and a broad-band selectivity position (such as the SP-400, SP-600, SX-73, and R-390) are excellent choices. Receivers that have only a 6-kHz or narrower bandwidth may need an extra i-f amplifier stage in the fm adapter in order to tap the receiver i-f at the output of the second mixer. Of course, a converter will also be required with the basic receiver if copy of vhf fm signals is desired.

A sample of the receiver i-f signal is passed to T1, a 455-kHz i-f transformer, which feeds amplifier/limiter V1. A low screen voltage and signal bias enhance the limiting characteristic of the tube. Further "hard" limiting action is provided by the two sections of V2, a 12AT7. A sample of the grid current of V2A is available at TP1, a test point used during alignment. A commercially made discriminator transformer converts the fm signal to a-m; the a-m is detected by CR1 and CR2. An *RC* de-emphasis network is included to match the standard pre-emphasis used on fm transmitters. Audio amplification is provided by V3 – in some receivers with high-gain audio systems this stage may not be necessary.

The adapter is constructed on an aluminum channel which is 11 inches long, 2 inches wide, and 1 3/4 inches high. A 1/4-inch lip is included on one side as a mounting foot. A Minibox or a standard chassis is also suitable as a base. The layout of the stages should be kept in a straight line so that rf feedback paths can be avoided. Point-to-point wiring is used throughout.

Fig. 14-20 – The fm adapter, wired for connection to a Collins 75A2.

Alignment

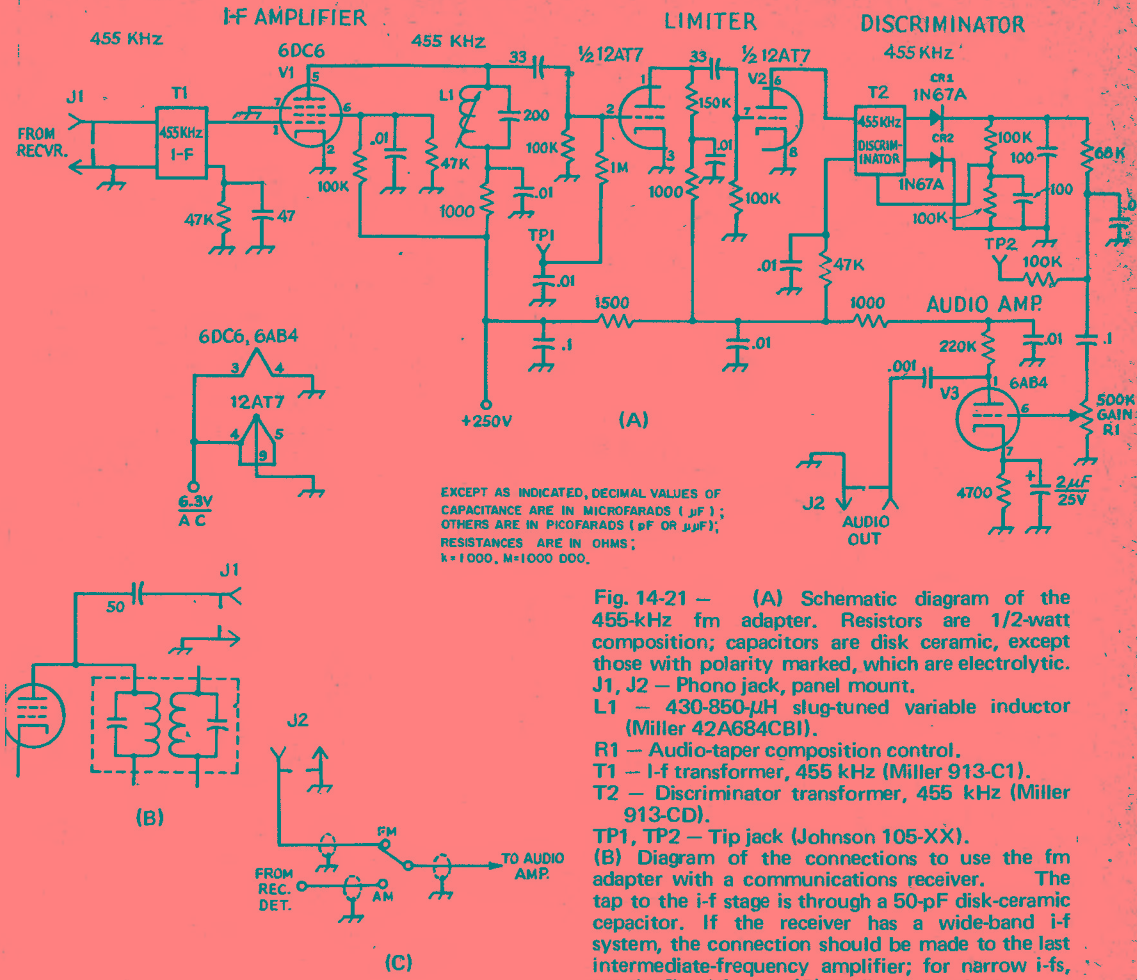
"Lining up" the adapter takes time and test equipment. A VTVM or microammeter plus a signal generator are required. Good alignment cannot be accomplished by ear; if the necessary test instruments aren't available, they should be borrowed.

To start, check the alignment of the communications receiver, following the manufacturer's instructions, to be sure that the rf and i-f stages are "peaked" before the fm adapter is installed. Two simple internal modifications are required in the receiver, as shown in Fig. 14-21 B and C. If the receiver has a wide i-f bandwidth, a sample of the i-f signal can be taken from the plate of the last i-f stage. Otherwise, the tap should be made at the plate of the first i-f amplifier, and an extra stage, a duplicate of V1, included in the adapter. Short lengths of shielded cable are used to carry the i-f signal to the adapter and to return audio to the receiver – see Fig. 14-21C. Some units (75A2, HRO-50) which have provision for fm adapters already have a front-panel switch wired for this purpose.

Connect the signal generator to the receiver, and set the generator to produce an S9 reading on the receiver signal-strength meter. The receiver crystal filter should be switched to its most selective position to insure that the incoming signal is being heterodyned to exactly 455 kHz. Then, with a voltmeter or microammeter connected to TP1, adjust both sections of T1, and L1, for maximum limiter current. The receiver i-f stage being "tapped" should also be realigned to compensate for the capacitance of the adapter cable.

To align the discriminator, set the receiver selectivity at the broad position, and connect the voltmeter to TP2. Voltage at this test point will swing both plus and minus, so a zero-center meter or VTVM with a lead-reversing switch should be employed. Set the secondary of the discriminator transformer for a zero-voltage indication on the meter. Then vary the signal-generator frequency plus or minus 15 kHz. Going off center frequency in one direction will produce positive voltage at TP2, while going in the other direction generates negative voltage. The primary of the transformer must be set so that, for example, if a shift down in frequency by 5 kHz produces plus 2 volts, then a change of 5 kHz in the other direction should produce minus 2 volts. Unfortunately, the two adjustments on the discriminator transformer are interlocking, so considerable experimentation is required. Also, the tuning of the preceding stages, if not centered on 455 kHz, will affect the discriminator linearity. The first time around, a half hour or more of alignment and realignment is usually required to achieve *equal* swings in output voltage for *equal* swings in frequency – a linear response.

One further check of the discriminator is required. An impulse-generating device, such as an electric shaver, should be switched on, and the receiver, set for a-m detection, tuned to a point in the spectrum where the noise is strong. Then,



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF); OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k = 1 000, M = 1 000 000.

Fig. 14-21 — (A) Schematic diagram of the 455-kHz fm adapter. Resistors are 1/2-watt composition; capacitors are disk ceramic, except those with polarity marked, which are electrolytic.

J1, J2 — Phono jack, panel mount.

L1 — 430-850-µH slug-tuned variable inductor (Miller 42A684CBI).

R1 — Audio-taper composition control.

T1 — I-f transformer, 455 kHz (Miller 913-C1).

T2 — Discriminator transformer, 455 kHz (Miller 913-CD).

TP1, TP2 — Tip jack (Johnson 105-XX).

(B) Diagram of the connections to use the fm adapter with a communications receiver. The tap to the i-f stage is through a 50-pF disk-ceramic cepacitor. If the receiver has a wide-band i-f system, the connection should be made to the last intermediate-frequency amplifier; for narrow i-fs, tap the first i-f stage. (C) Audio connections.

switch to the fm adapter and adjust the discriminator transformer for best suppression of the noise pulses. If the alignment with the signal generator has been completed properly, only a half a turn or so of the slugs will be needed to complete the phase tuning of the discriminator.

A SOLID-STATE ADAPTER

Tubes are seldom used in current designs. For those builders who prefer to be "up with the times," a solid-state version of the 455-kHz adapter was constructed. Using IC limiter/amplifier, and miniature i-f transformers, the unit requires only 25 mA at 12 V for power. See Fig. 14-24A. The Motorola MC1590G provides 70 dB gain, and hard limiting action superior to that obtained with the tube version.

The unit is built on a 2 X 6 1/2-inch circuit board; a template is given in Fig. 14-24B. Because of the high gain of the IC stage, a shield is required across pins 4 and 6 to isolate the input from the output. Alignment and installation are the same as for the tube version. The bandwidth of the miniature transformers restricts this adapter to narrow-band reception. However, builders wishing a wideband version can use the J. W. Miller 8811 miniature coils which are combined with a 12-pF coupling capacitor to form a wide-band transformer.

FM COMMUNICATIONS

Although information on fm theory and construction has been available to the amateur for a number of years, this mode has been largely neglected. But now large quantities of used commercial fm mobile equipment have become available for amateur use, creating new interest. Originally designed to cover frequency ranges adjacent to amateur bands, this equipment is easily retuned for amateur use.

One feature of fm is its noise-suppression capability. For signals above the receiver threshold, wideband fm has a signal-to-noise ratio advantage over a-m as a result of its greater "intelligence bandwidth." This same increased bandwidth, however, results in a much more abrupt signal threshold effect, causing weak signals to suddenly disappear. The generality can be made that a-m has

Fig. 14-22 – In this bottom view, the input transformer is to the left, followed by the i-f amplifier, limiter and detector. On the far right are the audio amplifier stage and gain control.

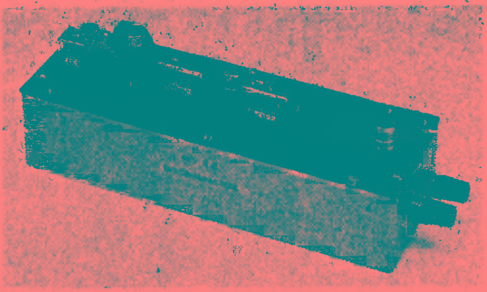


Fig. 14-23 – The solid-state fm adapter is constructed on a 6 X 2-inch etched-circuit board, mounted on a homemade chassis.

a greater range in weak signal work but that wideband fm will provide greater noise suppression in local work. However, in practice, vhf fm mobiles experience greater range than previously found on a-m due to the output powers employed which are considerably higher than those common on a-m.

Operating Practices

Amateur fm practice has been to retain the fixed-frequency channelized capability of the commercial equipment. VFOs and tunable receivers have not proven satisfactory because of the requirement for precise frequency netting. An off-frequency signal will be received with distortion and will not have full noise rejection. Channelized operation with squelched receivers permits continuous monitoring of the active frequencies. Long, time-consuming calls and CQs are not necessary (or appreciated) to establish communications, as all receivers on the channel "come alive" with the operator's first word. Natural, short transmissions are usually encour-

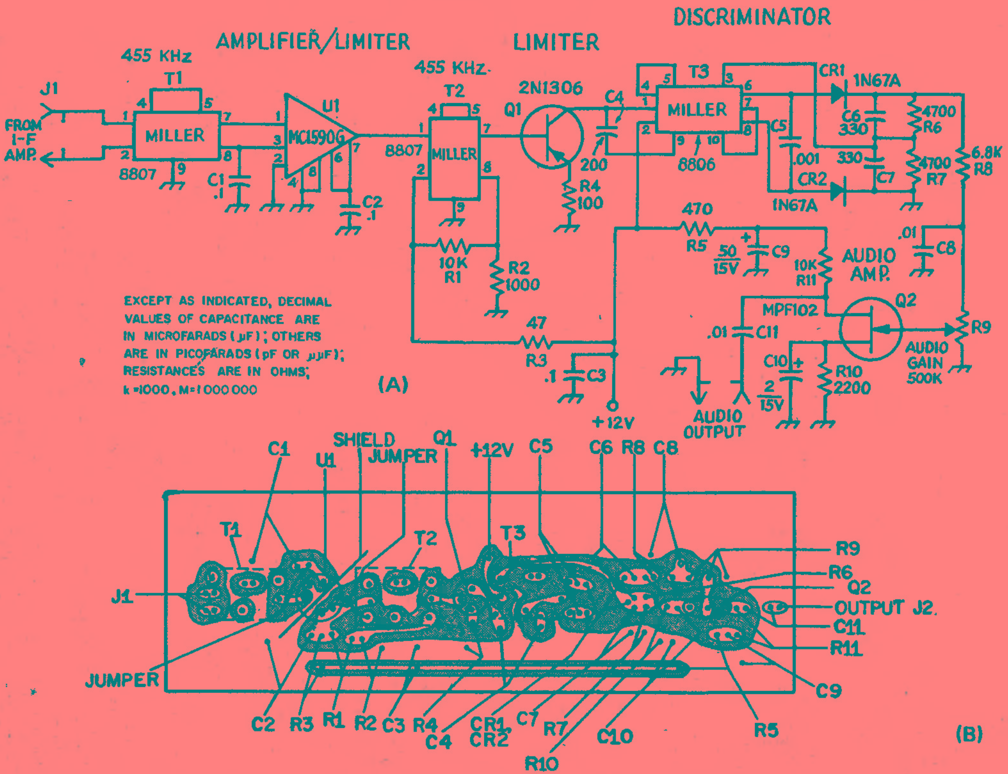


Fig. 14-24 – (A) Diagram of the 455-kHz narrow-band adapter. Resistors are 1/4- or 1/2-watt composition and capacitors are disk ceramic, except those with polarity markad, which are electrolytic. Components with reference numbers that are not listed below are notad for circuit-board location.

J1, J2 – Phono receptacle, panel mount.

R1 – Miniature 1/2-watt composition control.

T1 – Miniature 455-kHz i-f transformer (Miller 8807).

T2 – Miniature discriminator transformer, 455 kHz (Miller 8806).

U1 – Motorola MC1590G.

(B) Template for the solid-state adapter (not to scale).

aged. The old monopoly switch routine, where the operator gabs to himself for 10 minutes at a time, will get him invited off a busy fm channel. Some channels are calling channels on which extended ragchewing is discouraged, whereas other channels, or the same channel in another area, may be alive with chatter. This is a matter of local determination, influenced by the amount of activity, and should be respected by the new operators and the transient mobile operator alike. Some groups have adopted the use of the "10 code" which was originated for law enforcement communications. However, plain language in most cases is as fast and requires no clarification or explanation to anyone.

Standards

Standard channel frequencies have been agreed upon to permit orderly growth and to permit communications from one area to another. On two meters, it has been agreed that any frequency used will fall on increments of 60 kHz, beginning at 146.01 MHz. 146.94 MHz (or "nine-four") is the national calling frequency. On six meters, the national calling frequency is 52.525 MHz, with other channels having a 40-kHz spacing beginning at 52.56 MHz. Ten-meter fm activity can be found on 29.6 MHz. Recommendations for 10 meters and 220 MHz are for 40 kHz channel spacing starting at 29.04 and 220.02 MHz. Usage of the 420-MHz band varies from area to area, as it is used for control channels, repeaters, and remote bases, as will be discussed later. In the absence of any other local standard, usage should begin at 449.95 MHz and proceed downward in 50-kHz increments.

Two deviation standards are commonly found. The older standard, "wide band," calls for a maximum deviation of 15 kHz. The newer standard, "narrow band," imposed on commercial users by the splitting of their assigned channels, is 5 kHz. The deviation to be employed by amateurs on frequencies where fm is permitted is not limited to a specific value by the FCC, but it is limited by the bandpass filters in the fm receivers. In general, a receiver with a filter for 5-kHz deviation will not intelligibly copy a signal with 15-kHz deviation. In some areas, a compromise deviation of 7 or 8 kHz is used with some success with both wide and narrow receivers. When necessary, receiver filters can be exchanged to change the bandpass.

REPEATERS

A repeater is a device which retransmits received signals in order to provide improved communications range and coverage. This communications enhancement is possible because the repeater can be located at an elevated site which has coverage that is superior to that obtained by most stations. A major improvement is usually found when a repeater is used between vhf mobile stations, which normally are severely limited by their low antenna heights and resulting short communications range. This is especially true where rough terrain exists.

The simplest repeater consists of a receiver with its audio output directly connected to the audio input of an associated transmitter tuned to a second frequency. In this way, everything received on the first frequency is retransmitted on the second frequency. But, certain additional features are required to produce a workable repeater. These are shown in Fig. 14-28A. The "COR" or carrier-operated relay is a device connected to the receiver squelch circuit which provides a relay contact closure to key the transmitter when an input signal of adequate strength is present. As all amateur transmissions require a licensed operator to control the emissions, a "control" switch is provided in the keying path so that the operator may exercise his duties. This repeater, as shown, is

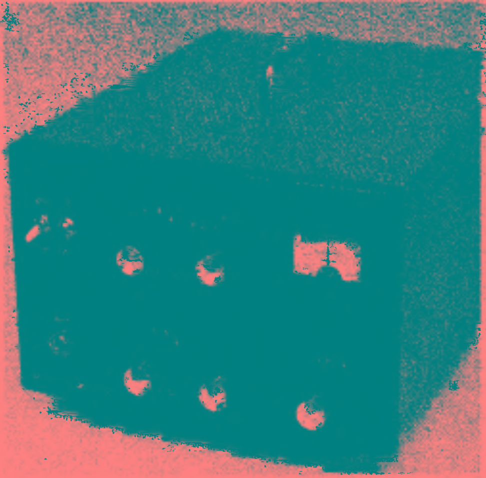


Fig. 14-25 — A homemade fm transceiver. The transmitter section uses the solid-state exciter and amplifier shown in Chapter 10.

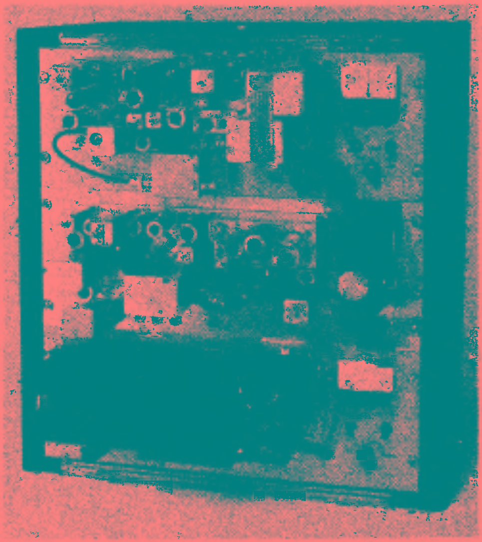


Fig. 14-26 — This typical 144-MHz amateur repeater uses GE Progress-Line transmitter and receiver decks. Power supplies and metering circuits have been added. The receiver located on the middle deck is a 440-MHz control receiver, also a surplus GE unit. A preamplifier, similar to that shown in Fig. 14-44, has been added to the 2-meter receiver to improve the sensitivity so that 0.2 μV of input signal will produce 20 dB quieting.

FM JARGON (Fig. 14-27)

Duplex – Simultaneous transmissions between two stations using two frequencies.

Simplex – Alternating transmission between two or more stations using one frequency.

Low band – 30 to 50 MHz. Also, the six-meter amateur band.

High band – 148 to 174 MHz. Also, the two-meter amateur band.

Remote base – A remotely controlled station, usually simplex (see text).

Machine – Either a repeater or a remote base. Also called a "box."

Vault – Building that houses the machine.

COR – Carrier-operated relay (see text).

CTCSS – Continuous tone-controlled squelch system. Continuous subaudible tone (250 Hz or lower) transmitted along with the audio to allow actuation of a repeater or receiver only by transmitters so equipped. More frequently referred to by various trade names such as Private Line, Channel Guard, and Quiet Channel.

Down channel – Communications circuit from the machine to the control point.

Up channel – Communications and/or control circuit from the control point to the machine.

Open repeater – A machine where transient Operators are welcome.

Closed repeater – A machine where use by non-members is not encouraged. (When heavy expenditures are involved, free-Loaders are not popular.)

suitable for installation where an operator is present, such as the home of a local amateur with a superior location, and would require no special licensing under existing rules.

In the case of a repeater located where no licensed operator is available, a special license for remote control operation must be obtained and provisions made to control the equipment over a telephone line or a radio circuit on 220 MHz or higher. The licensed operator must then be on hand at an authorized control point. Fig. 14-28B shows the simplest system of this type. The control decoder may be variously designed to respond to simple audio tones, dial pulsed tones, or even "Touch-Tone" signals. If a leased telephone line with dc continuity is used, control voltages may be sent directly, requiring no decoder. A 3-minute timer to disable the repeater transmitter is provided for fail-safe operation. This timer resets during pauses between transmissions and does not interfere with normal communications. The system just outlined is suitable where all operation is to be through the repeater and where the frequencies to be used have no other activity.

Remote Base Stations

The remote base, like the repeater, utilizes a superior location for transmission and reception, but is basically a simplex device. That is, it transmits and receives on a single frequency in order to communicate with other stations also operating on that frequency. The operator of the remote base listens to his hilltop receiver and keys his hilltop transmitter over his 220-MHz or higher control channels (or telephone line). Fig. 14-29A shows such a system. Control and keying features have been omitted for clarity. In some areas of high activity, repeaters have all but disappeared in favor of remote bases because of the interference to simplex activity caused by repeaters unable to minitor their output frequency from the transmitter location.

Complete System

Fig. 14-29B shows a repeater that combines the best features of the simple repeater and the remote base. Again, necessary control and keying features have not been shown in order to simplify the drawing, and make it easier to follow. This repeater is compatible with simplex operation on the output frequency because the operator in control monitors the output frequency from a receiver at the repeater site between transmissions. The control operator may also operate the system as a remote base. This type of system is almost mandatory for operation on one of the national calling frequencies, such as 146.94 MHz, because it minimizes interference to simplex operation and permits simplex communications through the system with passing mobiles who may not have facilities for the repeater-input frequency.

The audio interface between the repeater receivers and transmitters can, with some equipment, consist of a direct connection bridging the transmitter microphone inputs across the receiver speaker outputs. This is not recommended, however, because of the degradation of the audio quality in the receiver-output stages. A cathode

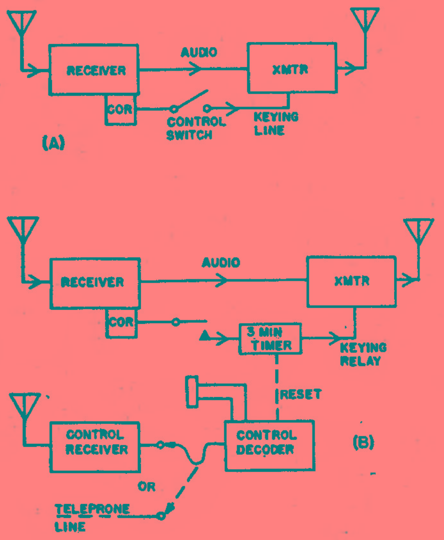


Fig. 14-28 – Simple repeaters. The system at A is for local control. Remote control is shown at B.

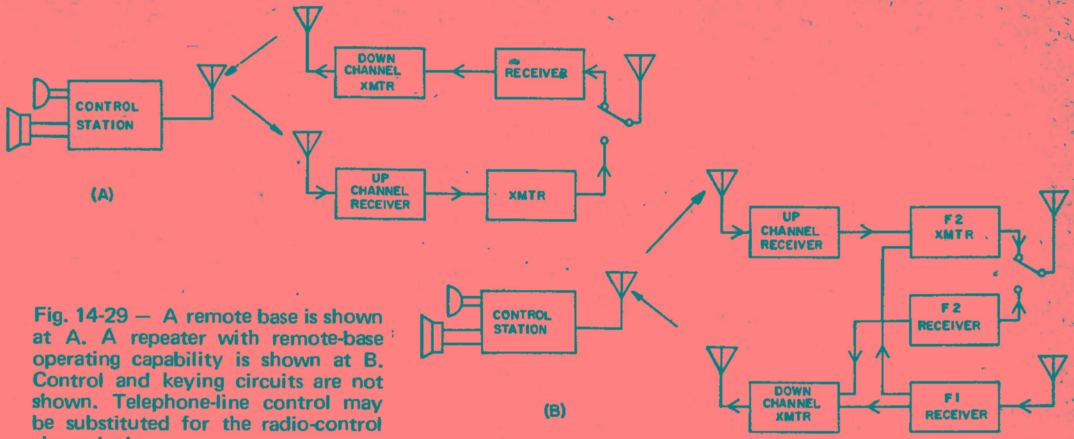


Fig. 14-29 — A remote base is shown at A. A repeater with remote-base operating capability is shown at B. Control and keying circuits are not shown. Telephone-line control may be substituted for the radio-control channels shown.

follower connected to each receiver's first squelch-controlled audio amplifier stage provides the best results. A repeater should maintain a flat response across its audio passband to maintain the repeater intelligibility at the same level as direct transmissions. There should be no noticeable difference between repeated and direct transmissions. The intelligibility of some repeaters suffers because of improper level settings which cause excessive clipping distortion. The clipper in the repeater transmitter should be set for the maximum system deviation, for example, 10 kHz. Then the receiver level driving the transmitter should be set by applying an input signal of known deviation below the maximum, such as 5 kHz, and adjusting the receiver audio gain to produce the same deviation at the repeater output. Signals will then be repeated linearly up to the maximum desired deviation. The only incoming signal that should be clipped in a properly adjusted repeater is an overdeviated signal.

The choice of repeater input and output frequencies must be carefully made. On two meters, 600-kHz spacing between the input and output frequencies is common. Closer spacing makes possible interference problems between the repeater transmitter and receiver more severe. Greater spacing is not recommended if the user's transmitters must be switched between the two frequencies, as happens when the output frequency is also used for simplex operation, either for short-range communications, or to maintain communications when the repeater is not functioning. A 5-MHz spacing is recommended on 440 MHz.

Careful consideration of other activity in the area should be made to prevent interference to or from the repeater. Many "open" or general-use repeaters have been installed on one of the national calling frequencies. On two meters, a 146.94 MHz output is usually paired with a 146.34-MHz input, and many travelers have made good use of this combination where it is found. Where 146.94-MHz simplex activity has not permitted a repeater on this frequency, 146.76 MHz has been used as an alternative. On six meters, several choices of input frequencies have been paired with 52.525 MHz. The choice and usage is a matter for local agreement.

In some cases where there is overlapping geographical coverage of repeaters using the same frequencies, special methods for selecting the desired repeater have been employed. One of the most common techniques requires the user to transmit automatically a 0.5-second burst of a specific audio tone at the start of each transmission. Different tones are used to select different repeaters. Standard tone frequencies are 1800, 1950, 2100, 2250, and 2400 Hz.

PRACTICAL REPEATER CIRCUITS

Because of their proven reliability, commercially made transmitter and receiver decks are generally used in repeater installations. Units designed for repeater or duplex service are preferred because they have the extra shielding and filtering necessary to hold mutual interference to a minimum when both the receiver and transmitter are operated simultaneously.

Wideband noise produced by the transmitter is a major factor in the design of any repeater. The use of high-Q tuned circuits between each stage of the transmitter, plus shielding and filtering throughout the repeater installation, will hold the wideband noise to approximately 80 dB below the output carrier. However, this is not sufficient to prevent desensitization – the reduction in sensitivity of the receiver caused by noise or rf overload from the nearby transmitter – if the antennas for the two units are placed physically close together.

Desensitization can easily be checked by monitoring the limiter current of the receiver with the transmitter switched off, then on. If the limiter current increases when the transmitter is turned on, then the problem is present. Only physical isolation of the antennas or the use of high-Q tuned cavities in the transmitter and receiver antenna feedline will improve the situation.

Antenna Considerations

The ultimate answer to the problem of receiver desensing is to locate the repeater transmitter a

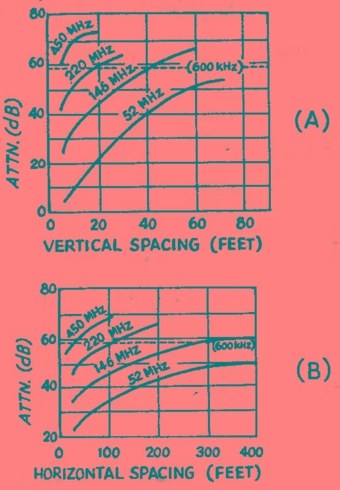


Fig. 14-30— Charts to calculate the amount of isolation achieved by (A) vertical and (B) horizontal spacing of repeater antennas. If 600-kHz separation between the transmitted and received frequencies is used, approximately 58-dB attenuation (indicated by the dotted line) will be needed.

mile or more away from the receiver. The two can be interconnected by telephone line or uhf link. Another effective approach is to use a single antenna with a **duplexer**, a device that provides up to 120 dB of isolation between the transmitter and receiver. High-*Q* cavities in the duplexer prevent transmitted signal energy and wideband noise from degrading the sensitivity of the receiver, even though the transmitter and receiver are operating on a single antenna simultaneously. A commercially made duplexer is very expensive, and constructing a unit requires extensive metal-working equipment and test facilities.

If two antennas are used at a single site, there will be a minimum spacing of the two antennas required to prevent desensing. Fig. 14-30 indicates the spacing necessary for repeaters operating in the 50-, 144-, 220-, and 420-MHz bands. An examination of 14-30 will show that vertical spacing is far more effective than is horizontal separation. The chart assumes unity-gain antennas will be used. If some type of gain antenna is employed, the pattern of the antennas will be a modifying factor. A rugged repeater antenna was described in *QST* for January, 1970.

Control

Two connections are needed between the repeater receiver and transmitter, audio and transmitter control. The audio should be fed through an impedance-matching network to insure that the receiver output circuit has a constant load while the transmitter receives the proper input impedance. Filters limiting the audio response to the 300- to 3000-Hz band are desirable, and with some gear an audio-compensation network may be required. A typical COR (carrier-operated relay) circuit is shown in Fig. 14-31A. This unit may be operated by the grid current of a tube limiter or the dc output of the noise detector in a solid-state receiver.

Normally a repeater is given a "tail"; a timer holds the repeater transmitter on for a few seconds after the input signal disappears. This delay prevents the repeater from being keyed on and off by a rapidly fading signal. Other timers keep each transmission to less than three minutes duration (an FCC requirement), turn on identification, and control logging functions. A simple timer circuit is shown in Fig. 14-31B.

Logging and Identification

Current FCC rules require that a log be kept of repeater operations showing each time the repeater is placed in (or taken out of) service. Individual transmissions, however, need not be entered. Although regulations do not require logging of individual transmissions through a repeater, some repeater committees have tape recording equipment connected to the repeater system in order to record a small portion of each transmission. The tapes provide an "unofficial" record concerning repeater usage. A two track tape recorder may have one of the tracks connected to a receiver tuned to WWV or CHU if the repeater committee is interested in having time information.

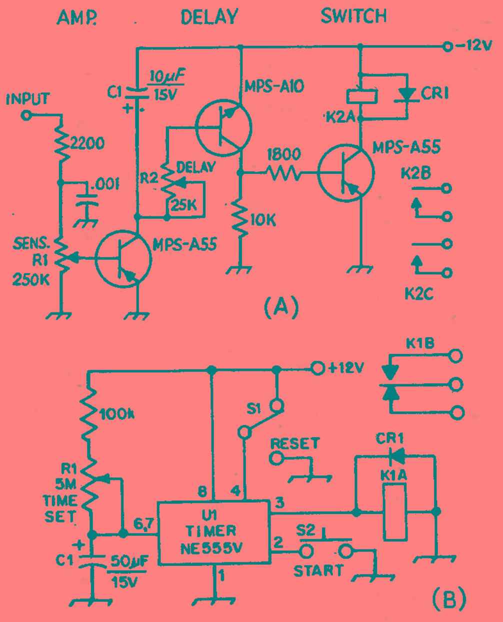


Fig. 14-31 — (A) COR circuit for repeater use. R2 sets the length of time that K1 will stay closed after the input voltage dissappears. K1 may be any relay with a 12-volt coil, although the long-life reed type is preferred. CR1 is a silicon diode. (B) Timer circuit using a Signetics NE555. R1, C1 sets the timers range. C1 should be a low-leakage type capacitor. S1, S2 could have their contacts peralleled by the receiver COR for automatic *START* and *RESET* controlled by an incoming signal.

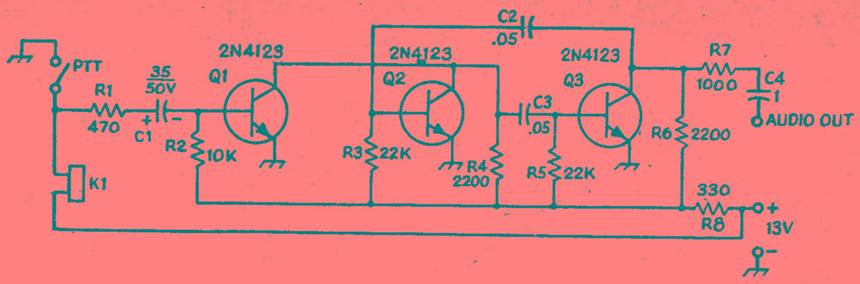
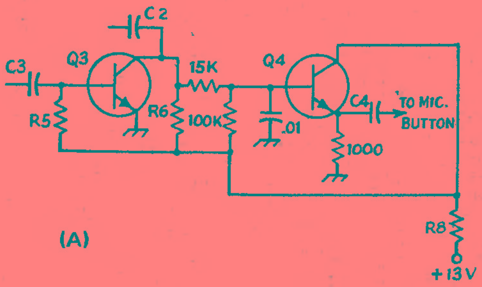


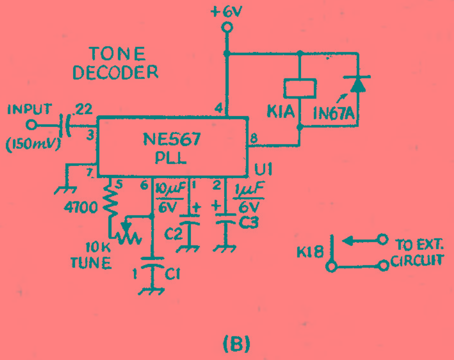
Fig. 14-32 — (A) Schematic diagram of the "electronic whistle." The main diagram is for high-impedance output. The lower portion has an emitter-follower added, for use with transmitters having low-impedance speech input circuits. All values of capacitance are in μF; polarity indicates electrolytic. (B) Tone-burst decoder. Resistors are 1/2-watt composition and capacitors are mylar. K1 is an spst reed relay with a 6-volt coil (C. P. Clare PRA-2010).



Identification of the repeater itself may be done by users, but lest a forgetful operator leave the repeater unknown, some form of automatic ID is preferred; A tape deck with a short loop tape for voice ID or a digital cw generator has proven to be effective. A suitable solid-state cw generator was described in *QST* for June, 1970.

Many repeaters use a form of tone control so that a carrier on the input frequency will not inadvertently key the transmitter. The most popular form of tone control is known as tone burst, often called whistle on because an operator with a good ear for frequency can use a short whistle instead of an electronically generated tone to key the repeater. A better approach, however, is a simple transistor tone generator, such as shown in Fig. 14-32A.

The whistle-on device was built for use with a Motorola 30-D transmitter, on a 1 1/2 X 2 1/2-inch piece of Vectorbord. It is nothing more than an astable multivibrator, triggered by a one-shot. When the push-to-talk switch is closed, actuating the transmitter relay, K1, Q1 goes from saturation to cutoff, and the multivibrator, Q2-Q3, begins oscillating with a period dependent on the values of R3, R5, C2 and C3. Values given result in a "whistle" of roughly 650 Hz.



Low Tone (Hz)	High Tone			
	1209 Hz	1336 Hz	1477 Hz	1633 Hz
697	1	2	3	cFO
770	4	5	6	F
852	7	8	9	I
941	*	0	#	P

Fig. 14-33 — Standard Touch-Tone frequencies for the 12-digit pad.

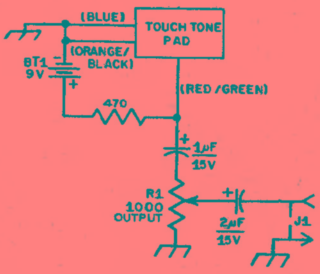


Fig. 14-34 — Typical connections to use a Touch-Tone pad for repeater control. Resistances are in ohms. R1 is a linear-taper composition control and J1 is a panel-mounted phono jack. Capacitors are electrolytic; color coding on the wira leads from the pad is shown in parentheses.

Oscillation ceases when Q1 turns on again. This is regulated by the values of R2 and C1, and is roughly 0.25 second with the values shown. The 470-ohm resistor, R1, protects the base of Q1 from current surges when the PTT is released.

The lower right portion of Fig. 14-32A shows an emitter-follower added, for use with transmitters employing carbon microphones. The value of C4 can be adjusted to give the appropriate output level.

Most of the component values are not critical, except the *RC* products which determine timing. Since the frequency is low, almost any bipolar transistors can be used. Npn types are shown, but pnp will work with opposite voltage polarity. The beta rating should be at least twice R3/R4, to insure saturation.

Most narrow-bandwidth tone decoders currently used in amateur repeater and remote-station applications employ several bulky *LC* circuits to achieve the required audio selectivity. The phase-locked loop (PLL) ICs, pioneered by Signetics, have simplified the design and reduced the size of tone decoders so that a complete Touch-Tone demodulator can be built on a 3 X 5 1/2-inch etched circuit board (about the size for a single-tone decoder using *LC* components).

A typical PLL single-tone decoder, such as might be employed for tone-burst entry control at a repeater, is shown in Fig. 14-32B. One *RC* network establishes the frequency to which the PLL is tuned, according to the relationship:

$$\mathit{frequency} = \frac{1}{\mathrm{R1C1}}$$

The PLL, a Signetics NE567, may be operated from 0.1 Hz to 500 kHz. C2 establishes the bandwidth of the decoder, which can be set between one and fourteen percent of the operating frequency. C3 smooths the output signal, and, when this capacitor is made a high value, provides a delay in the turn-on function when a tone is received. Up to 100 mA may be drawn by the '567 output circuit, enough to key a relay directly or to drive TTL logic. The PLL contains 62 transistors.

Autopatch and Touch Tone

Some repeater groups have provided an interconnection to the public telephone network through a device called an autopatch. Details on all phases of phone patching are contained in Chapter 15. Such interconnection has led to the widespread use of the telephone company's Touch Tone system of tone signaling for repeater control functions, as well as telephone dialing. Because all of the Touch Tone frequencies are within the voice band, they can be transmitted by any amateur voice transmitter.

The Touch Tone control system consists of pairs of tones (see Fig. 14-33) for each of 10 numbers and the two special functions. One tone from the high-frequency group is generated simultaneously with one tone from the low-frequency group to represent each number or function. The Touch Tone generator pad from a standard telephone instrument is usually employed. See Fig. 14-34 for connections. A simple Touch Tone decoder using ICs throughout was described in July 1971 *QST*.

A LOW-POWER TRANSMITTER FOR 29.6 MHZ FM

The transmitter shown in Fig. 14-36 has been designed to produce wide- or narrow-band fm in the 10-meter band. Power output is about 6 watts, yet only three tubes are used. The unit is suitable for fixed-station or mobile use.

Circuits

Two section, V1A and V1B, of a triple-triode Compactron tube are used as audio voltage amplifiers. The high-impedance audio input circuit is suitable for dynamic, crystal or ceramic microphones. After voltage amplification the audio signal is passed through a full-wave clipper, which consists of CR1, CR2 and associated resistors. Use of the audio clipper will insure that peak fm deviation does not exceed a preset amount. The output of the clipper is filtered in a pi-section to remove high-order audio harmonics generated during the clipping process.

The audio signal is applied to a varactor diode, CR3, producing a capacitive change. This variation in capacitance shifts the frequency of the 7.4-MHz oscillator, V2A, in a manner proportional to the modulating signal. The frequency of the fm energy thus produced is doubled in the plate circuit of the oscillator, and then doubled again by the second section of V2, delivering output in the 10-meter band. V3, a 6GK6 tube, amplifies the signal,

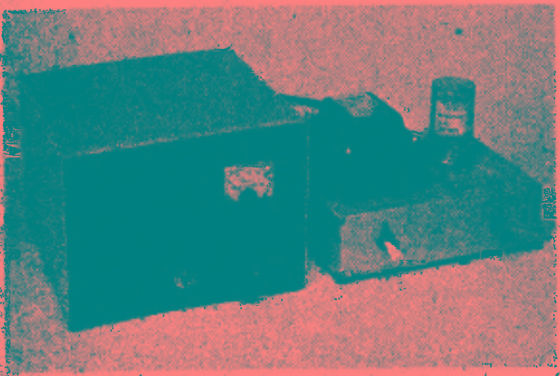


Fig. 14-35 — The front view of the 10-meter fm transmitter reveals only the plate-current meter, microphone-gain control and microphone jack.