Transceive With Transistors {Almost}

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THIS project started off innocently and unintentionally, as most projects do when a choice part or component has been acquired. In this case, it was the donation of a 455-kc. mechanical filter by W1HTK, along with his "maybe you can use this someplace" comment. Its subsequent incorporation into a transistorized (almost) transceiver evolved from some preliminary circuit experiments and then into a system concept which included the following objectives:

1. Compactness and portability for either fixed or mobile use.
2. Built-in a.c. or d.c. power supply.
3. Minimum battery drain when only receiving.
4. Operation on c.w., a.m., and s.s.b. (selectable sideband) with moderate output.
5. All-band (80 through 10) full frequency coverage.
6. Offset receiver tuning, audio-derived a.g.c., r.f. gain control, signal-strength and output-power indicator.
7. Construction with commercially available components wherever possible.
8. Stability adequate for s.s.b. and mobile use.
9. One-knob band switching.

The overall design, however, was compromised because the selection of mixing frequencies was determined by the availability of crystals already on hand. These crystals were borrowed from the home station SB-300 receiver and resulted in using higher oscillator and mixing frequencies than preferred. An inspection of the transistorized SBE-34 transceiver also indicated many desirable circuit features, which were utilized wherever adaptable.

Early in the design, serious consideration was given to a 100-percent solid-state unit. After some experimentation which indicated substantial drive requirements in order to obtain a minimum respectable power output (15 watts), tubes were chosen for the final amplifier and driver. R.f. power transistors do exhibit excellent efficiency— (up to 70 percent) but the low power gain, 15 db. or less, requires relatively high r.f. input power. In addition, the problems of band switching the extra stages and their associated input/output coil taps did not look inviting. Neither did the price of 30-Mc. r.f. power transistors.

As the design developed and stages were bread-boarded, a despairing observation became evident. Specifically, the conventional "well-stocked junk box" was almost useless. The transition of construction techniques from tubes to transistors required the use of components and parts which were not ready to hand, particularly

"Almost" transistorized, in this case, means semiconductors everywhere but in the last two transmitter stages, where the r.f. power can be obtained more economically with tubes. The overall size, 11¾ by 5 by 10½ inches, and combination d.c./a.c. power supply make the transceiver useful either in the home station or the car.

miniature low-voltage and low-wattage common components such as resistors and capacitors. Many of these items were either purchased new or removed from surplus transistorized equipment and printed circuit boards, in addition to an active advertising campaign among some W1 acquaintances.

With any new construction effort, various sizes and values of components are needed where substitution and experimentation are necessary. This added considerably to the total cost of the transceiver, since many of these components did not end up in the final unit.

Test equipment utilized included a v.o.m., v.t.v.m., audio signal generator, grid dip meter, regulated variable d.c. power supply, and a general coverage receiver. During the final alignment and performance checks, a high-frequency wide-band oscillscope, frequency meter, and r.f. signal generator were used.

General Principles

The simplified block diagram, Fig. 1, indicates signal flow and the various stages comprising the unit. The sideband-generator concept used was originally described by W6TEU[1] as a vacuum-tube exciter, and later a transistorized version was incorporated in the SBE-34. W6TEU's article provides an excellent description and alignment procedure. Basically, the 453-kc. carrier signal from Q_6 is fed into the balanced modulator, where the carrier is nulled out, and the sidebands are then fed through an amplifier

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[1] Bigler, "A Sideband Package", *QST*, June, 1958. Also in *Single Sideband for the Radio Amateur*.

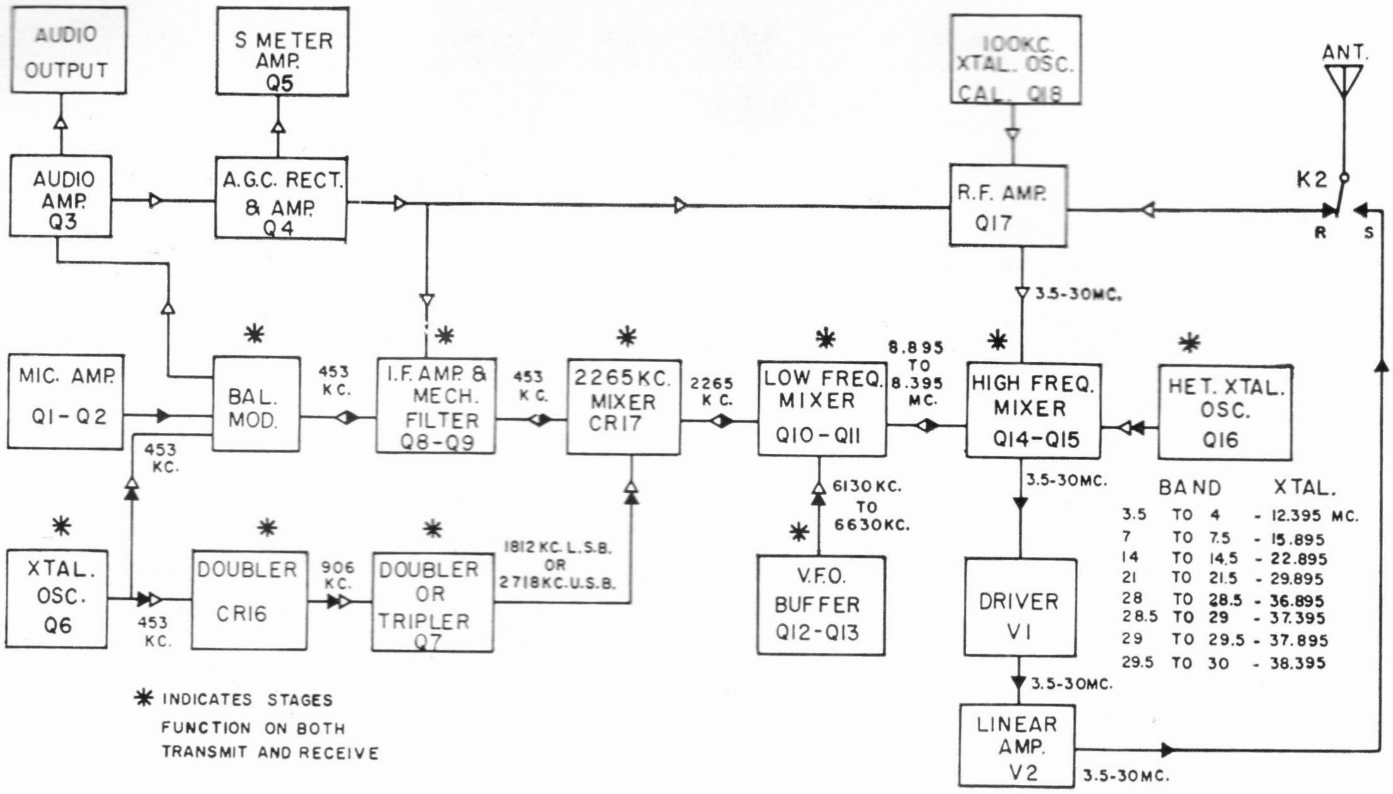


Fig. 1—Block diagram of the transceiver. Open arrowheads indicate direction of signal flow in receiving; solid arrowheads indicate direction in transmitting.

and the 455-kc. mechanical filter, which strips off the lower sideband. Sideband selection is accomplished by doubling the carrier frequency and then either doubling or tripling again (in Q_7) to arrive at 1812 kc. for lower sideband or 2718 kc. for upper sideband. The selected frequency is mixed in CR_{17}, with the 453-kc. u.s.b. signal, resulting in a sum or difference suppressed-carrier frequency at all times of 2265 kc., upper or lower sideband. The s.s.b. 2265-kc. output of the sideband generator is fed into the low-frequency mixer stage, Q_{10}, which also receives the output of the v.f.o. The v.f.o. tunes a 500-kc. band from 6130 to 6630 kc. The resultant sum output of the low-frequency mixer is tunable from 8.395 to 8.895 Mc. This signal is then converted to the desired operating band in the following high-frequency mixer stage, Q_{14}, by the associated heterodyne crystal oscillator, Q_{16}. Since the heterodyne oscillator frequency is always on the high side of the h.f. mixer input signal, a single v.f.o. dial calibration will suffice for all bands when the proper heterodyne-oscillator crystals are selected. With the v.f.o. dial calibrated from 0 to 500 kc. the operating frequency is directly read on the dial by adding the lowest frequency in megacycles, for the band in use, to the dial reading. The 10-meter band requires four 500-kc. segments to cover 28 to 29.6 Mc.

In the TRANSMIT mode the output from the high-frequency mixer, Q_{14}, is fed to the 12BY7 Class A driver and from there to the 6JB6 Class AB_1 final linear amplifier. In the RECEIVE mode the signal from the antenna is coupled into the r.f. amplifier stage, Q_{17}, and thence to the high-frequency mixer, after which it follows a reverse path back through the mixers to the diode balanced modulator, which acts as a detector. The detected signal is then amplified by the audio amplifier, Q_3, and the audio output stages. At the same time, the audio output is gain-controlled by the a.g.c. amplifier, Q_4, which controls the gain of the r.f. amplifier, Q_{17}, and the 453-kc. amplifier, Q_9.

Fig. 1 also indicates those stages which operate in either the receive or transmit modes. The amplifier/mechanical-filter, low-frequency mixer and high-frequency mixer perform bilaterally, and can be considered unidirectional in the selected mode, allowing signals to be passed in the desired direction. The injection oscillators Q_6, Q_7, Q_{12}, Q_{13}, and Q_{16} operate continuously. Other stages are biased off as required.

Microphone Amplifier

The mike preamplifier, Q_1, and amplifier, Q_2, are conventional common-emitter amplifiers. Q_1 is designed for low-impedance input, isolated and bypassed for r.f. by the *RC* combination of the 4700-ohm resistor and 470-pf. capacitor Fig. 2. The audio stages were built on a $3\frac{1}{2} \times 1\frac{1}{2}$-inch epoxy board, allowing ample room for addition of a speech compressor at a later date. The two stages of audio provide ample audio gain for this use. These two stages provide sufficient gain (in excess of one volt output) even when a high-impedance −54-dbm.-output microphone is used. With this mismatch the amplifier dynamic gain is reduced, the microphone is heavily loaded, and some low frequencies are attenuated. However, audio response is adequate since the microphone in use has a roll-off characteristic in the opposite direction. A matching input transformer (100,000 to 2000 ohms) could be used for a better match. The output would then be proportionally increased, and possibly Q_2 would not be necessary since only 0.2 to 0.3 volt of audio is needed to drive the balanced modulator. It should be noted that to reduce hum and feedback, Q_1 and Q_2 are decoupled from the 11.5-volt bus through a 150-ohm resistor and a 100-μf. bypass capacitor.

Balanced Modulator

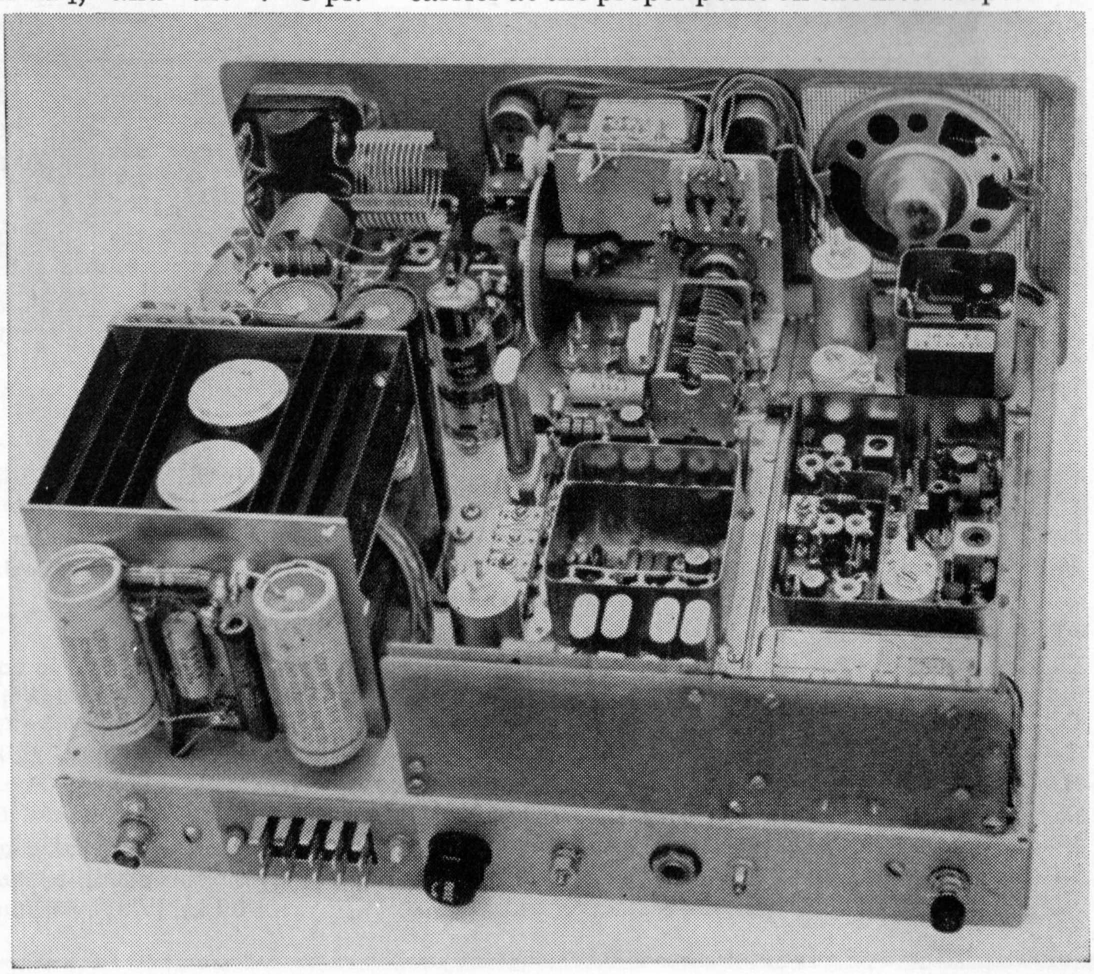
The diode ring-type balanced modulator, Fig. 2, provides approximately 35 db. of carrier suppression as measured with an r.f. probe and v.t.v.m. For TUNE/C.W. operation a small d.c. voltage is allowed to upset the balanced modulator through the CARRIER INSERT control, R_2, when the function switch, S_6, (Fig. 4), is in the TUNE or C.W. position. The amount of voltage or carrier insertion is adjusted by this rear-panel 10K control pot. For c.w. operation a key is inserted into the normally-closed jack, J_2, interrupting the d.c. path except in the key-down position. The c.w. note is remarkably smooth. This is partially attributable to the filter network composed of the 56K resistor and the two 0.1-μf. capacitors. During c.w. operation the mike gain control should, of course, be fully counterclockwise. Amplitude modulation is possible by setting the amount of carrier insertion to the safe AB_1 plate-dissipation operating point of the 6JB6 final amplifier and adjusting the mike gain for proper modulation.

As in most balanced modulators, some interaction exists between the carrier null pot, the tuning of transformer T_1, and the 7- 5-pf. trimmer capacitor, C_3. Adjustments to each alternately are necessary to obtain maximum carrier null.

Amplifier, Filter and Low-Frequency Mixer

The 453-kc. common-emitter amplifiers, Q_8 and Q_9, are controlled by the 11.5-volt d.c. or ground bus as selected by control relay, K_1, (Fig. 4), as are also the low-frequency mixers, Q_{10} and Q_{11}, and high-frequency mixers, Q_{14} and Q_{15} (Fig. 3). In the TRANSMIT mode the bias resistors for Q_8, Q_{10} and Q_{14} are grounded, completing the bias voltage-divider network path and allowing these transistors to conduct. In the RECEIVE mode the same bias resistors receive a positive voltage (base and emitter at same potential), effectively cutting these transistors off. In either case, the exact reverse biasing method is used for Q_9, Q_{11} and Q_{15}, enabling conduction of the stages in the desired transmit or receive direction. The two capacitors in series across the input to the mechanical filter resonate the filter to 455 kc. and provide a better impedance match to the base of Q_9.

The 3.1-kc. bandwidth filter has a substantial insertion loss—almost 15 db. With 2.5 volts of r.f. at the collector of Q_8, centered in the middle of the pass band, the output from the filter at the terminals is 0.5 volt. Limited information was available on the actual slope and attenuation characteristics of the filter in use. If the newer type 2.1-kc. Collins experimenters' filter is used the insertion loss should not be as severe, on the assumption that the newer filters have improved characteristics. A different carrier-oscillator crystal frequency would have to be used to place the carrier at the proper point on the filter slope.



In the top-of-chassis layout the transmitting driver and final amplifier occupy the left-hand section between the power supply and panel. Audio, i.f., and v.f.o. circuits are along the right-hand edge; the mechanical filter is visible beyond the upper edge of the circuit board mounted vertically along the rear chassis edge. In the center section, the receiving r.f. amplifier and mixer components are alongside the three-gang tuning capacitor; the heterodyne oscillator and its crystals are in the foreground.

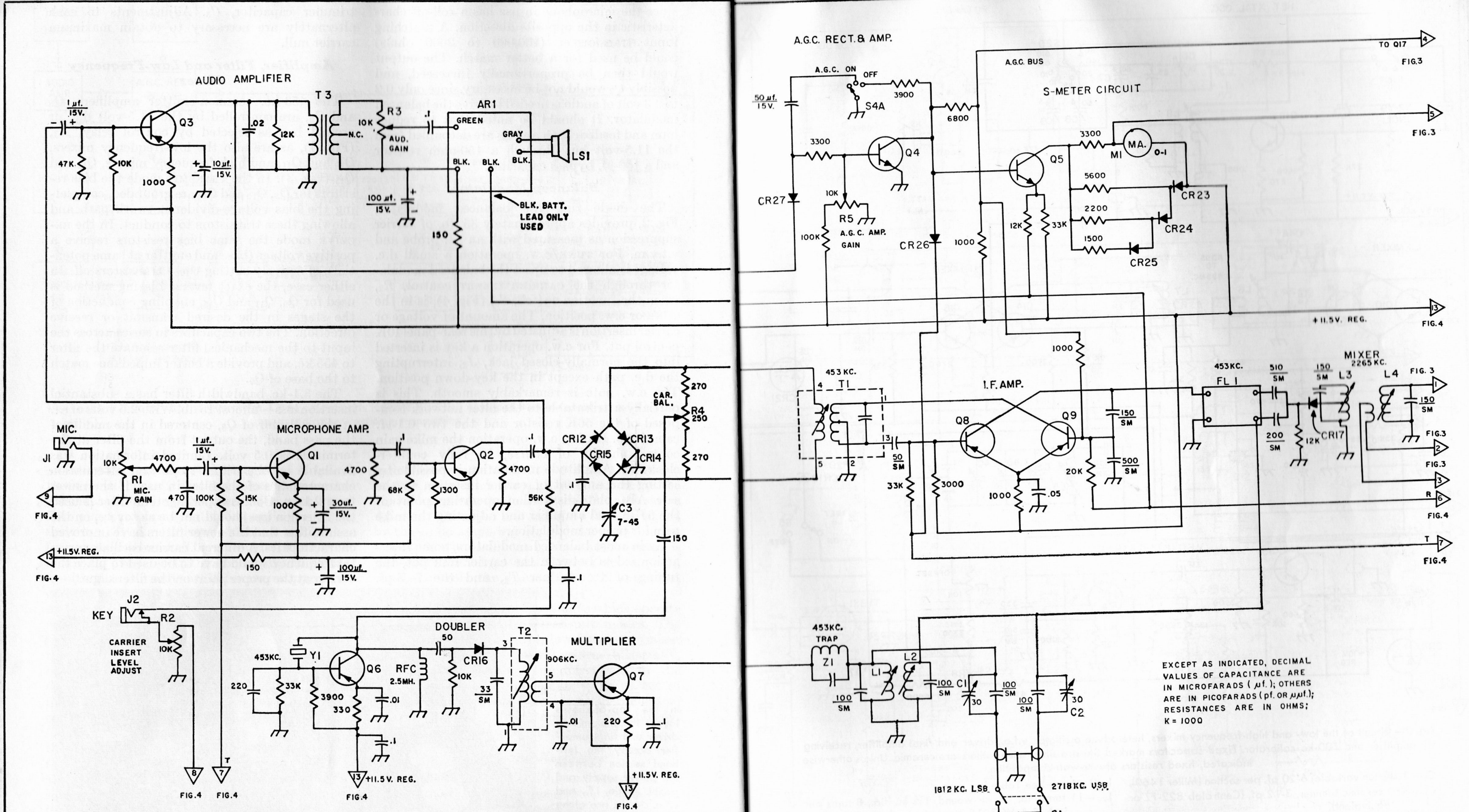


Fig. 2—Circuit of the sideband generator, audio amplifier, a.g.c. amplifier and S-meter amplifier. Unless otherwise specified, fixed resistors are ¼-watt composition; capacitors with polarity indicated are electrolytic, fixed capacitors are ceramic except those marked SM (silver mica).

AR1—100-mw. audio amplifier (Lafayette 99-9042; orange switch leads and red battery lead not used; assembly insulated from chassis.)

C_1, C_2—3-30-pf. mica trimmer (Arco 403 or equivalent).

C_3—7-45-pf. ceramic trimmer.

FL_1—455-kc. mechanical filter (Collins F455-C-31, 3.1 kc. bandwidth, used).

J_1—2-circuit phone jack.

J_2—Closed-circuit phone jack (must be insulated from chassis).

L_1-L_4, inc.—See Table I.

LS_1—3-inch speaker, 8-ohm voice coil.

M_1—0-1 milliammeter, edge mounting (Calrad EW2-S or equivalent).

R_1-R_5, inc.—Linear controls, ¼ or ½ watt composition.

S_1—D.p.s.t. slide switch.

S_4—See Fig. 4.

T_1—455-kc. transistor i.f. transformer (Miller 2042).

T_2—Transistor broadcast oscillator transformer padded to 900 kc. (Vidaire 455 OA or equivalent).

T_3—Transistor interstage audio transformer, 10,000 to 2000 ohms (Lafayette TR-96, center tap not used).

Y_1—453 kc. (Surplus FT-241A, Channel 45).

Z_1—Miniature 455-kc. i.f. transformer (see text).

DIODES AND TRANSISTORS

CR_{12}-CR_{15}, inc. CR_{27}—Germanium; 1N34A, 1N67A, 1N68, or similar, matched for forward resistance.

CR_{16}, CR_{17}—Germanium, see text

CR_{23}-CR_{26}, inc.—Silicon; 1N914, 1N484, 1N645, or similar.

Q_1, Q_3—2N508 (p-n-p).

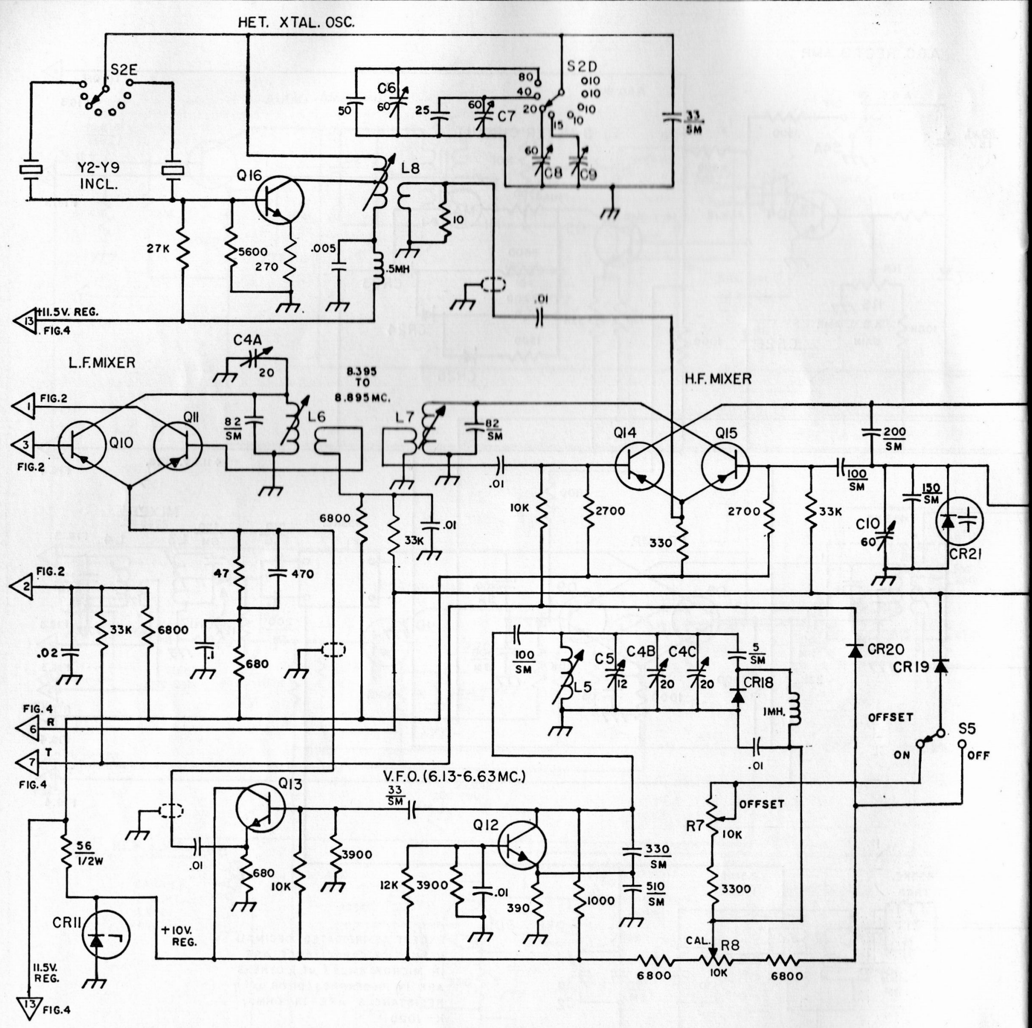
Q_2—2N396 (p-n-p).

Q_4—2N697, 2N440A, 2N1893, 2N1613, HEP-50 (n-p-n).

Q_5—2N1613, 2N697, HEP-50 (n-p-n).

Q_6—2N396A, 2N425, 2N1305 (p-n-p).

Q_7, Q_8, Q_9—2N396A, 2N425, HEP-51, 2N1305 (p-n-p).



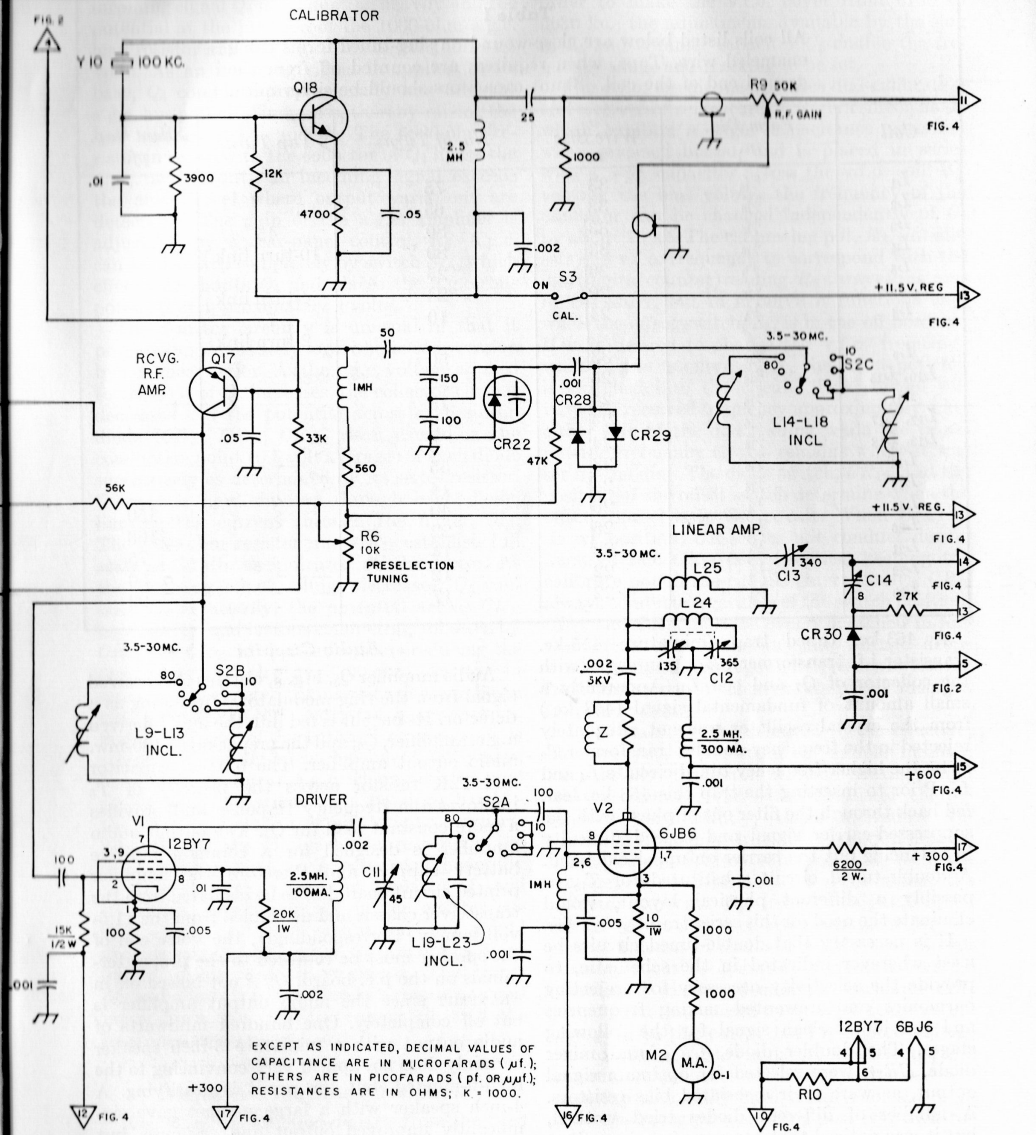


Fig. 3—Circuit of the low- and high-frequency mixers, heterodyne oscillator, v.f.o., driver and final amplifier, receiving r.f. amplifier and 100-kc. calibrator. Fixed capacitors marked SM are silver mica; others are ceramic. Unless otherwise indicated, fixed resistors are ¼-watt composition.

C_4—3-section variable; 6-20 pf. per section (Miller 1460).

C_5—NPO ceramic trimmer, 3-12 pf. (Centralab 822-FZ or equivalent).

C_6, C_7, C_8, C_{10}—8-60 pf. mica trimmer (Arco 404 or equivalent).

C_9—2-20 pf. mica trimmer (Arco 402 or equivalent).

C_{11}—5-45 pf. air padder with rear shaft extension, ganged with R_6.

C_{12}—2-section superhet-type variable, 365 and 135 pf. (Lafayette 32G1101 or equivalent).

C_{13}—65-340 pf. mica trimmer (Arco 303 or equivalent) modified by adding ⅛-inch shaft for panel control.

C_{14}—1-8 pf. piston trimmer, plastic (Erie 532-000-8R or equivalent).

L_5-L_{23}, inc.—See Table I.

L_{24}—11 turns No. 16, air-wound, 1¼ in. dia., 8 turns per inch (B & W 3018 or equivalent).

L_{25}—14 turns No. 20, air-wound, 1 in. dia., 16 turns per inch, tapped 4th turn from ground end (B & W 3015 or equivalent).

M_2—0-1 milliammeter (Calrad EW-2 or equivalent); indicates 200 ma. full-scale in circuit shown.

R_6-R_9, inc.—Linear-taper control, ¼ or ½ watt.

R_{10}—7.5 ohms, 10 watts, (TV ballast type, Hamilton-Hall FR-7.5).

S_2—Ceramic rotary, 5 sections, 1 pole per section, 11 positions (8 used) (Centralab PS-21 sections with indexes; see text).

S_3—S.p.s.t. slide switch.

S_5—S.p.d.t. slide switch.

Y_2-Y_9, inc.—See Fig. 1 for frequencies.

Y_{10}—100 kc.

Z—4 turns No. 16 spaced to occupy length of 100-ohm 2-watt composition resistor.

DIODES AND TRANSISTORS

CR_{11}—10-volt zener, ½ watt (1N758 or similar).

CR_{18}, CR_{28}-CR_{30}, inc.—Silicon (1N484, 1N645, or similar).

CR_{19}, CR_{20}—Silicon, matched forward resistances (1N434B, 1N484, 1N645 or similar).

CR_{21}, CR_{22}—Voltage-variable capacitor (1N955, TRW V47 or V947, or similar).

Q_{10}, Q_{11}, Q_{14}, Q_{15}, Q_{17}—PNP r.f. type (2N2905A, 2N2672, 2N1132, 2N711, HEP-51* or similar).

Q_{12}, Q_{13}—NPN, r.f. type (2N706, 2N708, 2N918 or similar).

Q_{16}, Q_{18}—NPN, r.f. type (2N708, 2N918, HEP-50 or similar).

* HEP-51 not optimum for Q_{17}.

Table I

All coils listed below are close-wound on slug-tuned forms using enameled wire. Taps, when required, are counted off from the ground end of the coil. Shunt capacitors should be silver mica.

Coil	*Form Dia. in.*	*Wire Size*	*No. of Turns*	*Tap Turns*	*Shunt Cap. pf.*
L_1	3/16	33	75		
L_2	3/16	33	65		
L_3	3/16	33	80	45	
L_4	3/16	33	80	10-turn link	
L_5	3/8	26	25		
L_6, L_7	3/16	20	24	4-turn link	
L_8	1/4	24	10	7	
L_9	3/16	33	50	2-turn link	
L_{10}, L_{15}	3/16	26	26		
L_{11}	3/16	24	13		
L_{12}, L_{17}	3/16	24	8		
L_{13}, L_{18}	3/16	24	5		
L_{14}	3/16	33	55		
L_{16}	3/16	24	14		
L_{19}	1/4	26	40		150
L_{20}	1/4	26	22		100
L_{21}	1/4	22	14		75
L_{22}	1/4	22	12		50
L_{23}	1/4	22	17		22

A 453-kc. tuned trap (miniature 455-kc. transistor i.f. transformer), Z_1, is in series with the collector of Q_7 and coil L_1. Apparently a small amount of fundamental signal (453 kc.) from the crystal oscillator was not adequately rejected in the frequency-doubler transformer T_2 or by the higher-frequency tuned circuits L_1 and L_2. Prior to inserting the trap this 453-kc. leak fed back through the filter out of phase with the suppressed-carrier signal and caused difficulty in balancing out the carrier on upper sideband. A double-tuned circuit substituted for T_2, or possibly a different physical layout, would eliminate the need for this series trap.

It is necessary that double-tuned circuits be used wherever indicated in the schematic, to provide the selectivity necessary for rejecting harmonics and unwanted mixing frequencies and provide a clean signal for the following stages. The doubler diode, CR_{16}, and mixer diode, CR_{17}, were selected for optimum signal output, as were their associated bias resistors. A number of different diodes tried worked, but it was noticed that because of various characteristics a particular diode performed better. Both types finally used were unmarked gemanium surplus.

The output (or input as may be the case) coil, L_6 (Fig. 3), of the low-frequency mixer stage is tuned and tracks with one section of the three-gang v.f.o. tuning capacitor. This provides uniform frequency response, along with rejection of unwanted frequencies, to its associated coil, L_7. The mica trimmer of the variable-capacitor section is adjusted to obtain the padding necessary to tune L_6 through a 500-kc. range.

Audio Circuits

Audio amplifier Q_3, Fig. 2, obtains the received signal from the ring modulator, now acting as a detector. Its output is fed into the audio-derived a.g.c. amplifier, Q_4, and the prepackaged 100-mw. audio output amplifier. The 0.02-μf. capacitor and 12K resistor across the primary of T_3 improves the frequency response and provides a more constant load for Q_3. The output audio amplifier is designed for a common positive battery supply, and therefore the amplifier printed circuit board has to be insulated from the transceiver chassis and decoupled from the 11.5-volt supply. Correspondingly, the voice coil of the speaker must be returned to the proper terminals on the p.c. board. Q_3 is not biased off in TRANSMIT since the audio output amplifier is cut off completely. One hundred milliwatts of audio output with a miniature 3-inch speaker certainly does not appear very convincing to the high-fi-minded, but the result is gratifying. A 4-inch speaker with a large magnet gave significantly improved output and response, but space limitations dictated the use of the smaller speaker.

A.g.c./Meter

The audio signal to the a.g.c. amplifier, Q_4, is rectified by CR_{27} and applied as a negative-going voltage to Q_4's base. A fast attack and slow release characteristic is obtained by the combination of the base bias resistors and the 50-μf. capacitor. A.g.c. action reduces the gain of the r.f. amplifier, Q_{17}, and the 453-kc. amplifier, Q_9, by decreasing their base-to-emitter voltage, which in turn reduces collector current. With no incoming signal Q_4 is conducting heavily and the potential at the junction of the 1000-ohm a.g.c. load resistor and the a.g.c. bus is less than 11.5 volts. As an incoming signal is applied to its base, Q_4 conducts proportionally less and the a.g.c. bus potential increases, thereby raising the base voltage of Q_{17} and Q_9. The 6800-ohm resistor in series with the collector of Q_4 limits the a.g.c. action until an incoming signal exceeds the audio lovel where output variations are detectable. The gain of the a.g.c. amplifier is adjustable by a rear-panel control, R_5. A.g.c. can be defeated completely by switch S_{4A}, which effectively shunts Q_4 and places the a.g.c. bus potential at approximately 9 volts.

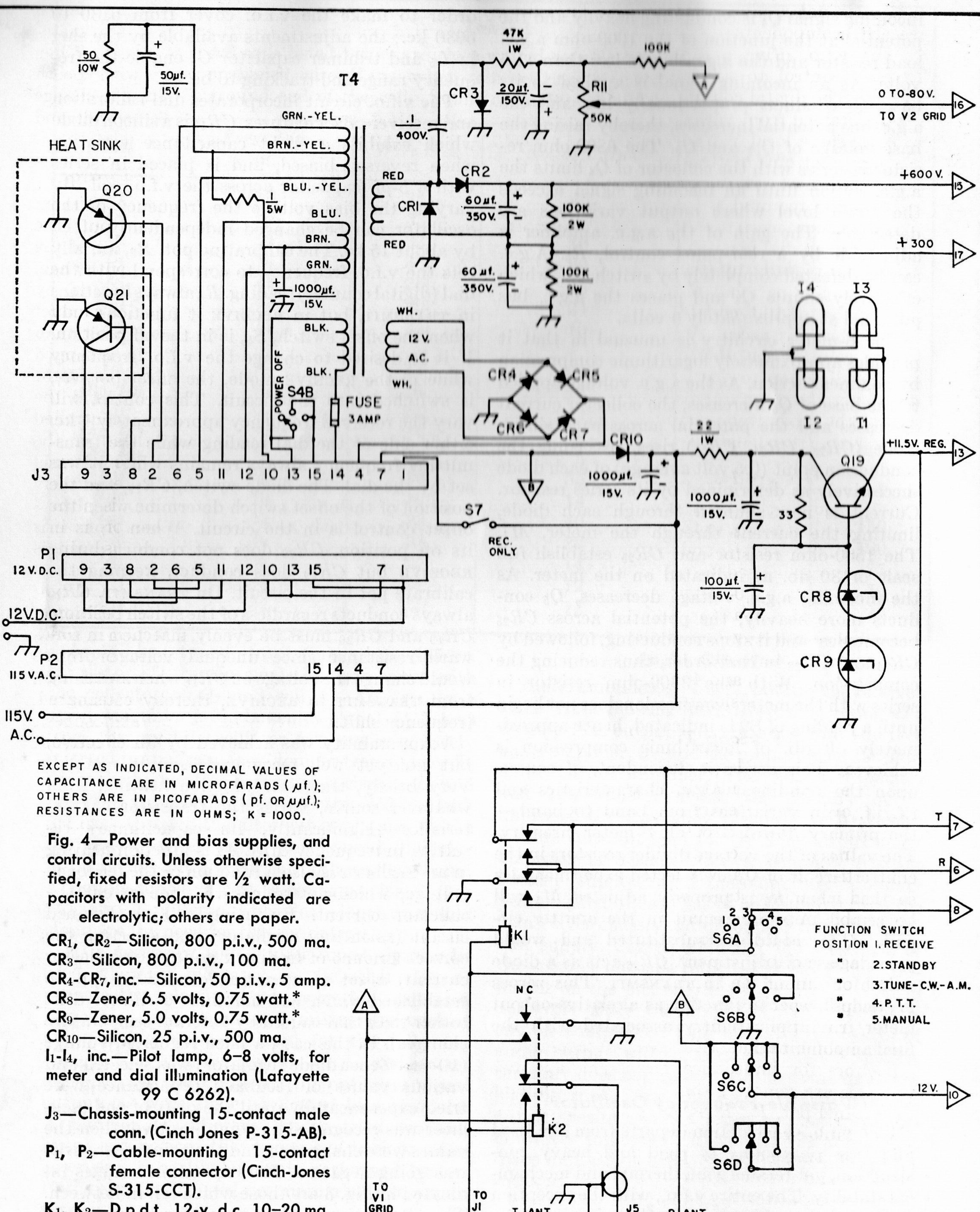
The S-meter circuitry is unusual in that it provides approximately logarithmic compression by nonlinear action. As the a.g.c. voltage applied to the base of Q_5 increases, the collector current decreases and the potential across each silicon diode (CR_{23}, CR_{24}, CR_{25}) rises, exceeding the conduction point (0.5 volt average) of each diode successively as determined by its series resistor. Current is now shunted through each diode, limiting the current through the meter, M_1. The 1500-ohm resistor and CR_{25} establish full scale or 30 db. as indicated on the meter. As the incoming a.g.c. voltage decreases, Q_5 conducts more heavily, the potential across CR_{25} becomes less and it stops conducting, followed by CR_{24} and CR_{23} in that order, thus reducing the compression. With the 3300-ohm resistor in series with the meter, compression does not begin until a reading of S9 is indicated, hence approximately 30 db. of logarithmic compression is achieved. This action is dependent, of course, upon the non-linear a.g.c. characteristics and r.f./i.f. gain variations from band to band — the primary downfall of all S-meter circuitry. The values of the voltage divider resistors in the emitter circuit of Q_5 are selected experimentally so that when R_5 is properly adjusted M_1 will be zeroed. A separate pot in the emitter circuit of Q_5 could be substituted and would provide ease of adjustment. CR_{26} acts as a diode switch to cut off Q_5 in TRANSMIT. This zeroes M_1 and allows it to function as a relative-output meter from the circuitry associated with the final amplifier tank.

Variable-Frequency Oscillator

The v.f.o. construction departs from the tried and true philosophy of rigid and heavy construction, yet retains good thermal and mechanical stability. The entire v.f.o., with the exception of C_4 and the calibrate and offset circuitry, was mounted on a copper-clad 1¾ by 3-inch epoxy board. Q_{12}, Q_{13} and L_5 are contained in a shielded enclosure. The oscillator, Q_{12}, is in a common-emitter Colpitts configuration, with an associated emitter follower, Q_{13}, used for isolation. The collector voltage for Q_{12} and Q_{13} is regulated by a Zener diode, CR_{11}. One volt of r.f. output is available at the emitter of Q_{13}. Two sections of the variable capacitor, C_4, are parallelled in order to make the v.f.o. cover from 6130 to 6630 kc.; the adjustments available by the slug in L_5 and trimmer capacitor C_5 enable the frequency range and tracking to be set.

The v.f.o. circuit incorporates dial-calibration and receiver-offset features. CR_{18} is a silicon diode which exhibits a slight capacitance variation when reversed biased, and is placed in series with a 5-pf. capacitor across the v.f.o. coil. By varying the bias voltage the frequency of the oscillator can be changed independently of C_4 by about 15 kc. The calibrating pot, R_8, initially sets the v.f.o. frequency to correspond with the dial (digital counter) reading. R_8 always functions in TRANSMIT, but in RFCEIVE it functions only when the offset switch, S_5, is in the off position. If it is desired to change the v.f.o. frequency while in the RECEIVE mode, the offset pot, R_7, is switched into the circuit. This control will vary the received frequency approximately 4 kc. either side of the dial reading while the transmitting frequency always remains where it was set by the dial. The diode switch, CR_{19}, and the position of the offset switch determine when the offset control is in the circuit. When S_7 is in its off position, CR_{20} does not conduct during RECEIVE but CR_{19} does conduct, keeping the calibrate pot in the circuit. On TRANSMIT, CR_{20} always conducts regardless of the switch position. CR_{19} and CR_{20} must be evenly matched in forward resistance since unequal voltage drops would change the voltage on CR_{18} when switching from TRANSMIT to RECEIVE, thereby causing a frequency shift.

V.f.o. stability was achieved by an effective, but not yet well recognized, simple method. Very briefly, transistor junction heating, from whatever source, varies the transistor characteristics — significantly, its capacitance — resulting in frequency drift. This junction heating in an oscillator is also a function of the feedback voltage, which determines to some extent the collector current. By using a high-Q tuned circuit (as in any oscillator) and selecting the correct amount of feedback voltage or collector current, a set of operating conditions can be established which will minimize oscillator drift (other than that caused by external temperature changes). In this case, a fixed regulated voltage (10-volt Zener diode regulator) was selected and various values of feedback capacitance were tried experimentally until the drift of the oscillator was recognized as going positive; then the values were changed to find the point where drift was going negative. The capacitance values indicated in Fig. 3 are those which fell in between. The alternative method would be to select the optimum value of the feedback capacitor to maintain maximum Q and then adjust the collector voltage in varying increments (noting voltage values) until the drift rate changes from negative to positive. At the zero-drift point a Zener diode (or combination of them) can be substituted to maintain the collector voltage at that point. It should be noted that this is not temperature compensation in the normal sense —



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µf.); OTHERS ARE IN PICOFARADS (pf. OR µµf.); RESISTANCES ARE IN OHMS; K = 1000.

Fig. 4—Power and bias supplies, and control circuits. Unless otherwise specified, fixed resistors are ½ watt. Capacitors with polarity indicated are electrolytic; others are paper.

CR_1, CR_2—Silicon, 800 p.i.v., 500 ma.
CR_3—Silicon, 800 p.i.v., 100 ma.
CR_4-CR_7, inc.—Silicon, 50 p.i.v., 5 amp.
CR_8—Zener, 6.5 volts, 0.75 watt.*
CR_9—Zener, 5.0 volts, 0.75 watt.*
CR_{10}—Silicon, 25 p.i.v., 500 ma.
I_1-I_4, inc.—Pilot lamp, 6–8 volts, for meter and dial illumination (Lafayette 99 C 6262).
J_3—Chassis-mounting 15-contact male conn. (Cinch Jones P-315-AB).
P_1, P_2—Cable-mounting 15-contact female connector (Cinch-Jones S-315-CCT).
K_1, K_2—D.p.d.t., 12-v. d.c., 10–20 ma.
Q_{19}—2N697, 2N1613, 2N1893, or equivalent (n-p-n).
Q_{20}, Q_{21}—2N441, 2N442, HEP231, or equivalent (p-n-p).
R_{11}—50,000-ohm linear control, ½ watt.
S_4—2-pole, 3-position rotary, 5-amp. contact rating (one section, S_{4a}, Fig. 2, is used for a.g.c. switching; S_{4b} is used for power switching. These functions are combined to conserve panel space.)
S_6—Miniature ceramic rotary, 2 sections, 2 poles per section, 5 positions, non-shorting (Centralab PS-111).
S_7—S.p.s.t. toggle (on R_3).
T_4—Transistor converter/a.c.; primaries, 12.6 volts d.c. and 115 volts a.c.; secondaries 280 volts d.c., at 150 ma., 12.6 volts a.c., 3 amp. (Thordarson TR-294 or Stancor P-8195).

Note: Heat sink is Motorola type MS-15 modified to take two TO-36 transistors.

*** CR_8 and CR_9 in series for 11.5-volt output.**

i.e., it is not applicable to thermal changes in external components.

The v.f.o. drive uses a Jackson dual-ratio vernier control to allow either fast or slow tuning. The digital counter and associated gears were obtained from various surplus sources, including some local W1's who dug real deep to the very bottoms of their junk boxes. A lucky combination of ratios was made up to obtain exactly the required 0 to 500 counter reading from minimum mesh to full mesh of C_4. A circular direct-driven dial is much simpler and of course would not require any gearing. For information, with the gearing available the last gear ended up at the digital counter with a one-to-one ratio. This was necessary in order to have the digital counter read correctly by turning in the reverse direction to the tuning capacitor; with the heterodyne crystal oscillator on the high side of the mixer frequency, the v.f.o. frequency decreases as the signal frequency increases.

Heterodyne Oscillator

Link coupling is used from the heterodyne crystal oscillator, Q_{16}, to the emitters of the high-frequency mixers, Q_{14} and Q_{15}. Although a different crystal is used to cover each of the four segments of the 10-meter band, L_8 with the parallel 33-pf. capacitor allows oscillation to take place with any one of the four. Trimmer capacitors resonate the coils for each of the lower bands. On 80 and 40 meters, an additional fixed capacitance is shunted across the trimmer.

Varicap Tuning

Among the problems of tunable circuit design are those of matching to the input of transistors and the extra switching required to connect each tuned circuit's low-impedance tap to the transistor. A compromise was reached by eliminating the extra switching in the r.f. amplifier and h.f. mixer stages while still retaining an acceptable impedance match. Both the r.f. amplifier, Q_{17}, and high-frequency mixer, Q_{15}, utilize a voltage-variable capacitor diode (CR_{21} and CR_{22}) for tuning the band in use. These diodes (Varicaps), specifically designed for relatively high-Q r.f. applications, are used in a series-parallel combination with fixed voltage-divider capacitors for impedance matching. The two Varicaps are remotely controlled by a common front-panel pot, R_6. R_6 is ganged to the 12BY7 driver tank-circuit capacitor, C_{11}, and thus is used for single-control preselector tuning in RECEIVE and driver output tuning in TRANSMIT. Trimmer capacitor C_{10} in the base of Q_{15} is a padding adjustment for CR_{21} to keep the capacitance range consistent with the frequency band it covers. In circuits of this type where r.f. voltage is applied, the d.c. bias across the Varicap must be greater than the developed r.f. voltage since it is possible that the capacitance of the Varicap can be changed by the r.f. voltage if it exceeds the d.c. bias level. This normally undesirable situation is put to good use, when Q_{14} is conducting, to provide some degree of low-level a.l.c. action. The d.c. bias is reduced slightly, with the L/C ratios adjusted to maintain resonance at the desired frequency. When the r.f. voltage amplitude increases with speech and exceeds the threshold d.c. bias, the change in Varicap capacitance detunes the circuit and the output proportionally levels off.

Rf. Amplifier and 100-kc. Calibrator

Q_{17} is a common-base amplifier for maximum voltage gain and high-impedance output; the latter is desirable for minimizing loading of the high-frequency mixer and driver input stage. Protection is provided from transmitted r.f. by two silicon diodes, CR_{28} and CR_{29}, which conduct to ground when the r.f. voltage is greater than 0.5 volt at the front end. The antenna is tapped down for impedance matching by the capacitor voltage divider mentioned previously, and the circuit is tuned by CR_{22}. R.f. gain is controlled right at the receiver front end, ahead of the amplifier, and a strong signal at the antenna that could cause overloading can be effectively attentuated by this control. As Q_{17} is always operating at maximum gain, no compromise is made on a.g.c. characteristics, as usually is necessary in normal r.f. gain control circuits.

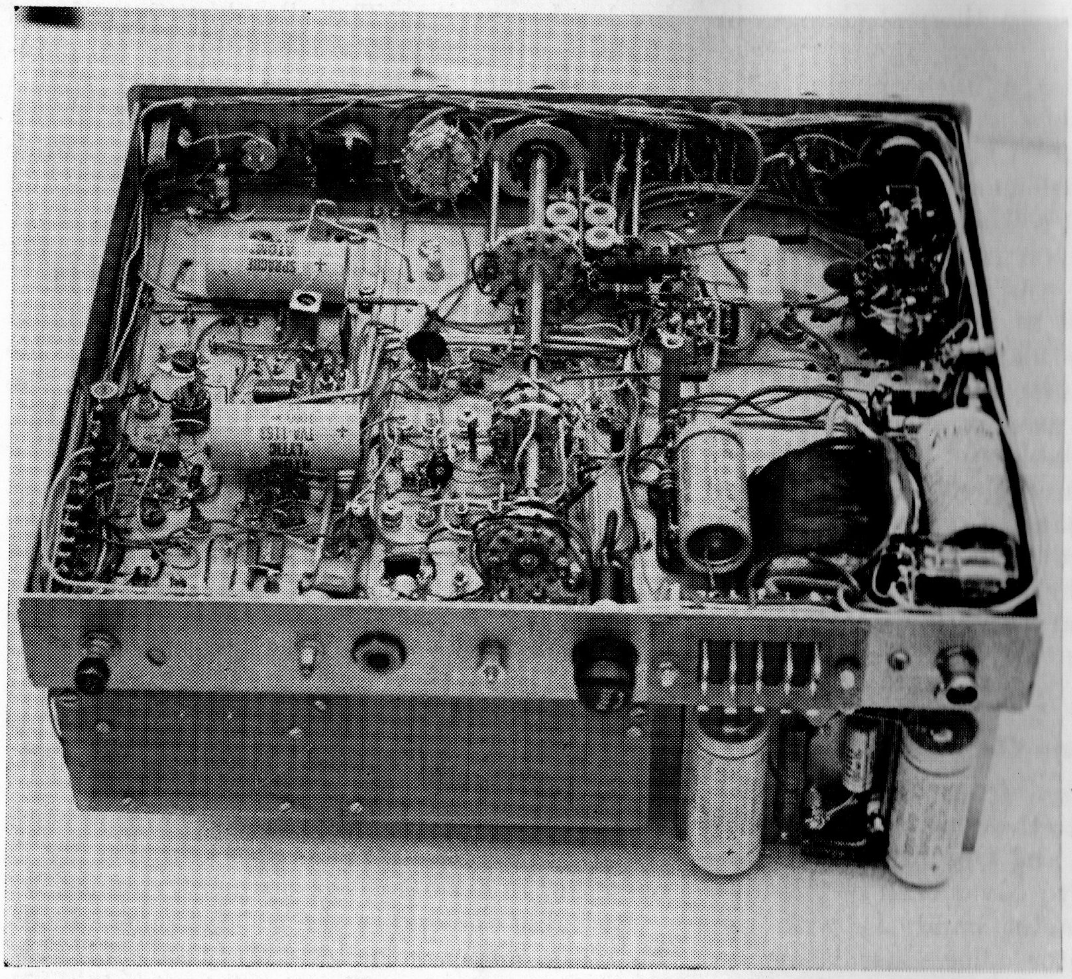
By tying one end of the r.f. gain-control pot, R_9, to the output of the 100-kc. crystal calibrator, variable-amplitude calibration injection is available. When the calibrator is turned on by S_3 and R_9 is rotated toward the calibrator end, signals coming from the antenna are attenuated. Eliminating incoming signals and atmospheric background noise makes the 100-kc. markers easily identifiable across any band.

Driver and Final Amplifier

The 12BY7 class A driver is completely cut off in RECEIVE by applying − 80 volts through K_2 (Fig. 4) and the grid resistor. In TRANSMIT the grid resistor is allowed to complete its normal path to ground. Up to 3.5 volts peak r.f. is available at the grid of this stage on 10 meters. All the driver output coils, L_{19} to L_{23}, are swamped with resistors (not shown in the schematic) to provide a constant load and to prevent self-oscillation. The values of these resistors were not critical, and they were experimentally selected to allow sufficient drive to the final amplifier, yet maintain stability. There is more than enough drive on all bands and heavy swamping was necessary, particularly across the 80-and 40-meter coils, to prevent grid current flow in the final amplifier. As information, the values used were: L_{19} and L_{20}, 4700 ohms; L_{21}, 6800 ohms; L_{22} and L_{23}, 10,000 ohms; all ½ watt. Optimum values should be determined experimentally.

A multiband tuner is used in the final tank circuit. It resonates in 80-, 20-, 40-, 15-, 10-meter sequence from maximum to minimum capacitance.

C_{13}, the output loading capacitor, is adjusted conventionally for loading the amplifier into the antenna.



The band switch extends along the center of the underside of the chassis. Wiring here is principally between the circuit boards that make up individual sections of the transceiver.

Relative power-output indication is obtained by rectifying a portion of the r.f. output by CR_{30} and applying it to the combination output/S-meter. Relative reading on the meter can be adjusted by C_{14}. Since the meter circuitry is at a positive potential the diode rectifier path for this circuit must be returned to the 11.5-volt bus rather than to ground. The 0–1 milliammeter M_2, is connected as a voltmeter to indicate 200 ma. full scale. Final-amplifier resting plate current is adjusted to 25 ma. on TRANSMIT by the bias pot, R_{11} (Fig. 4); on RECEIVE the resting current decreases to 15 ma. because the 100K resistor in the grid circuit of the 12BY7 is lifted from ground and increases the bias voltage. Plate current in the TUNE/C.W. position with the amplifier loaded is 150 ma.

Power Supply and Regulator

High voltage is obtained from a dual-purpose power supply. The power supply transformer, T_4, is a readily available item and is especially designed for either 115 volts a.c. or 12 volts d.c. input. The secondary, which is rated at 280 volts, 150 ma., is used with a voltage-doubling rectifier-filter which raises the B+ voltage to 600 volts, and also supplies a 300-volt output for the driver B+ and the screen of the final. The supply has been loaded to a full 200 ma. continuously without any evidence of excessive heat. Negative voltage for the final amplifier and the driver grids is obtained by a shunt rectifier directly off the secondary a.c. winding.

In a.c. operation full-wave bridge rectification is used from the 12-volt a.c. winding to provide d.c. voltage for the transistors. This voltage is filtered and then regulated to 11.5 volts by Q_{19}. CR_8 and CR_9 are Zener diodes which establish the reference level for the 11.5 volt regulated bus. This figure was chosen in order to allow for possible voltage drop in supply leads from a 12-volt battery when d.c. power supply is used. A 10- or 11-volt Zener probably could be substituted with no change in overall operation, but in that case the optimum values for bias resistors for the various stages might be different from those given and should be determined experimentally.

With 12 volts d.c. input, CR_{10} acts as a one way current valve, preventing 12 volts d.c. from being applied back through the d.c.-to-d.c. converter. This is necessary in order to allow the receiver to be turned on by switch S_7, on R_3, and yet not allow the filaments or other circuits to draw current when the "receiver only" mode is selected. Total current drain in the "receiver only" mode is 140 ma. Half of this current is used by the four illuminating lamps for the dial and meters.

The d.c.-to-d.c. converter portion of the power supply circuitry is that recommended by the transformer manufacturer, with the exception that higher-power transistors (Q_{20} and Q_{21}) are used. Both transistors are mounted on a finned heat sink attached to the top of T_4. The end bells of T_4 were removed to save space and enable T_4 to be mounted horizontally on the chassis.

Construction Notes

The balanced modulator, its associated crystal oscillator and doubler/tripler, the mechanical filter/453-k.c. amplifiers, and low-frequency mixers were constructed on a 6½ by 3-inch copper-clad epoxy board. Another copper-clad board, 8½ by 3½ inches, was utilized for the heterodyne oscillator, r.f. amplifier, high-frequency mixer, and the v.f.o. tuning capacitor. The a.g.c. amplifier, S-meter amplifier, d.c. regulator, and 100-kc. calibrator were located on the two boards where it was found convenient, since their associated circuitry was not critical with placement. Each stage was constructed and tested individually before going on to the next stage. The v.f.o. used the same construction, and likewise was tested and corrected for stability as previously described.

Most of the components were mounted above the boards and their leads interconnected either by direct wiring or through terminals beneath the board. For most components the copper-clad board was drilled to accept the wire size of each lead, and then countersunk by hand with a larger size drill just deep enough to remove the copper foil around the hole, to prevent shorting. Ground connections were soldered directly to the copper surface. The boards were mounted to the 11 by 9-inch cutout chassis after most of the individual stage construction and testing had been finished.

The metal boxes and shields (other than for the v.f.o.) visible in the photographs were used as a precautionary measure rather than from necessity. However, it was considered good practice, and no doubt has contributed to good stability. With the close spacing of components and wiring, care was taken in placement of the various r.f. stages to minimize undesired coupling.

The band switch, S_2, is actually three separate ceramic rotary assemblies ganged together. The first section, using a single wafer, is mounted on a bracket placing the wafer 2 inches behind the panel. A two-wafer assembly, for the preselector, is similarly mounted in line with the first so that its front wafer is 4 inches away from the single wafer; the shafts of the two switches are ganged with metal tubing and set screws. The third assembly also has two wafers, separated 3 inches from the second section; this assembly (in the heterodyne oscillator circuit) is similarly ganged to the second switch.

Only those transistor types that were available for use and were either directly substituted or found suitable for operation, after appropriate base-bias adjustments were made, are indicated in the diagrams. The variety of transistors used indicates that many other types of small-signal high-frequency transistors can be effectively used. Whatever the types chosen, the base-bias resistors should be adjusted individually for best performance, even for transistors nominally of the same type, since the operating characteristics do vary somewhat from one unit to another. The utilization of transistor sockets greatly simplified circuit testing. For mobile operation, soldered-in transistors would probably be desirable, but good-quality sockets have proven most reliable under severe vibration.

Conventional precautions were taken concerning transistor handling, heat, applying voltages, polarity, and so on, during the construction and testing. Even with these normal precautions 8 transistors were destroyed by sheer negligence, because of a variety of circumstances — including accidentally applying the full r.f. output of the linear directly to the emitter of the receiving r.f. amplifier.

As a side note, after all of the transistor circuitry was completed and working it was noticed that the copper-clad boards had begun to tarnish heavily. An attempt was made to remove the tarnish with alcohol and a detergent. This proved catastrophic. Whatever the chemical reaction that took place, within days corrosion crept over the boards and under components until it appeared that the entire transceiver would have to be scrapped. As a last resort, the entire transceiver was immersed in a tub of soap and water, carefully washed, scrubbed and then rinsed. Then the chassis was placed in a 250-degree oven to bake out. The copper-clad boards with the components were later sprayed with clear Krylon. Corrosion is no longer evident, and the equipment has been very reliable since.

Overall performance of the transceiver has been very good. It has been operated on all bands and modes, with gratifying reports. Single-tone power output into a Byrd wattmeter indicates 52 watts minimum output on 80 through 15 meters and 45 watts on 10 meters. Receiver sensitivity, while not accurately measured, compares favorably with that of the home-station receiver, and the set has been used as a "second receiver" for DX chasing. A few birdies are evident in the receiver, but only two of these are bothersome, falling in the phone portion of the 15- and 10-meter bands. All others are of very low amplitude and barely discernible. An exceptionally strong adjacent-channel local station will produce cross-modulation, but this can be controlled to a certain degree by the r.f. gain control, and the effect is not serious unless the desired station is very weak. No doubt an FET r.f. amplifier would solve this situation, and it is planned eventually to replace the existing r.f. amplifier. The low current drain in the "receive only" mode is a decided advantage, since automobile battery drain can be considered negligible. There was no need for any special noise suppression for mobile operation, thanks to the substantial amount of filtering used in the d.c. regulator input circuit.

The significant problem of acquiring miniature components that were suitable for use requires acknowledgement to those who materially assisted both in searching and in donating to me many items. Therefore, my thanks to W1EEE, W1VBI, W1MOJ, and W1HTK. Extra thanks go to W1MOJ for his efforts in fabrication of the aluminum chassis, front panel and cabinet. QST