The COIL Forum

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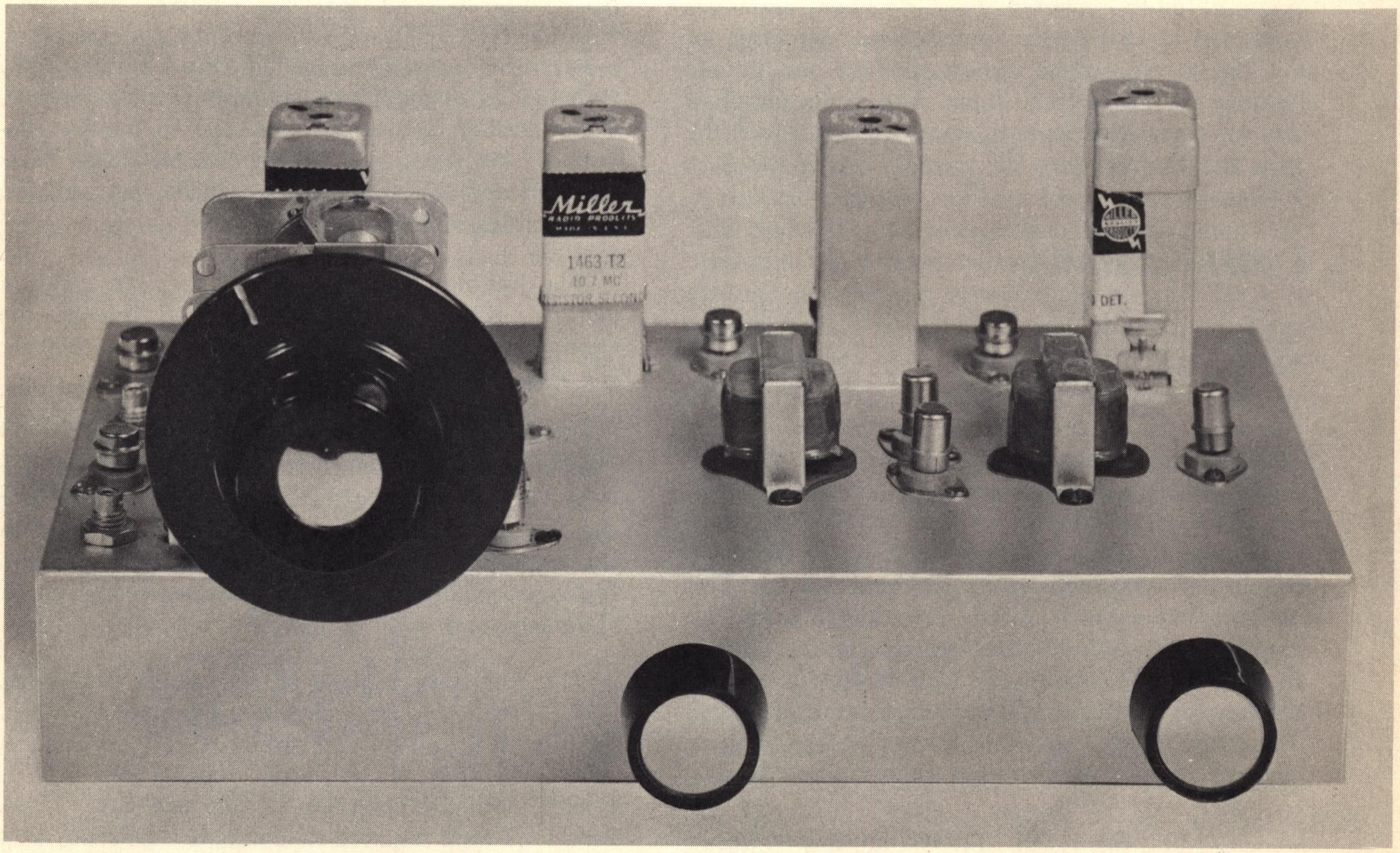
A TRANSISTOR FM RECEIVER



With this issue, the J. W. Miller Company inaugurates a new publication devoted to the experimenter. Although coils, and their associated components, are our business, we at Miller would like to supply our customers with timely information on circuits, theory to assist with your work or experiments, and data on how to select and use our coils wisely. We believe you will agree that THE COIL FORUM is indeed an appropriate name.

Recent advances in the state of the semiconductor art have made it possible to construct a transistor FM receiver which performs every bit as well as a vacuum tube version. VHF equipment places very strict demands on the transistors. They must be capable of constant amplification over the entire band being received, create a minimum of circuit drift, and provide maximum gain with a minimum of stages.

The excellent performance of the receiver to be described is an outgrowth of the work done by Philco Corporation on their transistor "Safari" television receiver. For this application it was necessary to perfect transistors that would function well above 200 mc. for the channel selector section, and have high gain at 40 mc., the intermediate frequency. In the FM receiver these same transistors are literally "loafing" at 108 and 10.7 mc. The alpha cutoff of the r.f. transistors is well above 300 mc. and the gain variation between 88 and 108 mc. is less than 6 db.

CIRCUIT DETAILS

Before delving into the construction details, let's examine the receiver circuit (Fig. 1) and see what makes it tick. The circuitry is quite similar to conventional vacuum tube designs and employs 10 transistors as r.f. amplifier, mixer, oscillator, three stage i.f. amplifier, 1st audio, push-pull Class B stage, and an automatic frequency control amplifier.

The signal, from a "whip" antenna or dipole, is coupled to the antenna jack (J1) and coil L1. This antenna coil serves to match the antenna to the r.f. amplifier transistor. It also rejects stations outside the FM band. Transistor Q1 (a T-1694) is biased by resistors R1 and R2, and R3 provides d.c. stabilization. This stage is not neutralized due to the low value of intrinsic capacitance between collector and base.

The amplified signal appears across L2 and is coupled to the mixer (Q2, a T-1696) from a low impedance tap on this coil. Bias is applied to this stage through R5 and R4, with resistor R6 providing the necessary stabilization. When fed with the proper oscillator energy, this stage converts all incoming FM stations down to 10.7 mc., the intermediate frequency.

The oscillator is a high frequency version of a self-excited common emitter circuit. Energy is fed from the collector back to the base through capacitor C12 and the stage oscillates. Coil L3, along with the tuning capacitor and circuit capacity, determines the frequency of oscillation, which is always 10.7 mc. above the incoming signal frequency. Resistors R9 and R11 provide bias and R10 is used for d.c. degeneration. Transistor Q10 and diode X1 are part of the automatic frequency control system and will be discussed later. All tuned circuits in the "front end" are tracked with a three-gang variable capacitor (C3, 3-10mmfd.)

The i.f. strip utilizes three T-1693's (Q4, Q5, and Q6) as common emitter neutralized amplifiers. In the Q4 stage resistors R7 and R8 provide forward bias, while R-17 is used for emitter stabilization. Resistors R19, R20, and R22 serve the same purposes, respectively, in the Q5 stage. The third T-1693 (Q6) functions as an amplifier and limiter at the same time. Neutralization is not required due to the low impedance load presented by the detector stage. Resistors R25 and R26 form the bias divider network and R27 stabilizes the stage.

The 100 ohm resistors in the i.f. amplifier collector circuits (R23, R43, and R44) greatly increase the strong signal handling capacity and do not attenuate the signal measurably.

Crystal diodes usually do not perform well as FM detectors. However, this circuit is as good as the tube version due to careful transformer design and the use of matched diodes (1N541's) included in the assembly. These diodes are mounted under a "swedge-cap" on top of the transformer for improved shielding.

The secondary balance of T4, which determines AM rejection to a large degree, is exceptionally good. Resistors R30 and R31 are optimized for best balance. The remainder of the ratio detector circuitry is typical, with the exception of C29 and C30. These capacitors were required to eliminate a feedback loop which occurred between the detector and mixer circuit.

The characteristic plus-zero-minus signal appears across the volume control (R32) and this voltage is used to control the "Varicap" automatic frequency diode, X1. This amazing device, manufactured by Pacific Semiconductors, exhibits a variable capacity effect when *reversed biased,* as shown in Fig. 2. A d.c. amplifier (Q10) increases the tiny ratio detector voltage to a swing of approximately 8 volts on a strong station. Resistor R14 and capacitor C16 form a low-pass filter for audio decoupling. Frequency response of the audio system is unaffected by degeneration in the a.f.c. circuit because the filter cutoff is below the frequency passed by the audio transformers. Resistor R15 provides forward bias for the d.c. amplifier (Q10) and is adjusted for a static collector potential of —4.0 volts, with the a.f.c. switch in the off position. When these conditions are established, the anode of the a.f.c. diode is approximately 7 volts more negative than the cathode. When tuning across a moderately strong FM station, the collector of Q10 swings between 0 and 8 volts, which varies the diode capacity. Due to the closed loop a.f.c. action, the oscillator locks in on the station. The "Varicap" diode is tapped at a low impedance point on the coil to prevent oscillator loading and excessive a.f.c action.

It should be pointed out that capacitor C14 and C16, in conjunction with the transistor, provide the basic elements for a blocking oscillator and capacitor C15 provides collector to base degeneration to eliminate this tendency.

The problem of receiver drift with voltage and temperature changes is eliminated with this a.f.c. system. With this correction the receiver will perform beautifully even with the varying potentials found in automobile ignition systems.

The audio circuitry is conventional. Audio appearing across the volume control is coupled to the driver (Q7, a 2N226) through a low impedance deemphasis network consisting of R42 and C37. Bias appears at the junction of R40 and R41, and R39 stabilizes the stage. Capacitor C35 prevents audio degeneration. Amplified audio, in push-pull form, is applied to the bases of Q8 and Q9. Note that the parts list specifies only one 2N224, however this number is actually a matched pair of 2N225's. The network R36 and R37 delivers bias to the Class B stage to prevent "crossover distortion." A 2.2 ohm resistor (R35) in the common emitter circuit serves to degenerate the stage. A large R/C network, consisting of R38, C33, and C34, minimizes the class B stage current variations effect on the other stages. The output transformer is tapped to match a variety of speaker impedances.

CONSTRUCTION DETAILS

The receiver is constructed on a 5 x 9 inch aluminum chassis and the dimensioned layout is shown in Fig. 3. The "front end" components are grouped close to the tuning capacitor to obtain the shortest possible lead lengths. When wiring the coils in the r.f., mixer and oscillator sections place the "hot end" nearest the chassis so that the "hot leads" will be short. The a.f.c. amplifier and associated components are located close to the oscillator section to keep the diode leads short. To aid in duplicating this circuitry, a detailed layout is shown in Fig. 4.

The i.f. system is "strung out" along the rear apron of the chassis to place the ratio detector circuitry as far from the mixer transistor as possible. Wherever possible, the bypass capacitors should lay flat against the chassis, and of course all components should have the shortest possible leads. The components associated with the ratio detector are tightly grouped on a four lug (six, counting the grounds) terminal strip. A detailed layout of this circuitry is shown in Fig. 5. The audio driver is located behind the volume control, near the detector circuit. The push-pull Class B stage is between the transformers T5 and T6. The secondary of T6 is brought out to a terminal strip to the rear of the a.f.c. switch. One end of C33 and C34 is also secured to this terminal strip.

Obviously no attempt was made to miniaturize the receiver, for this is usually folly in an initial design. It is quite likely that the chassis size could be reduced to 5 x 7 inches and the tuning capacitor set back, to reduce the size considerably.

Start the construction by drilling all holes as shown in Fig. 3. Mount the transistor sockets as follows: Q1—base towards L1, Q2—base towards L2, Q3—base away from L3, Q4—base towards T1, Q5—base towards T2, Q6—base towards T3, Q7—base away from T5, Q8— and Q9—base towards T5 and Q10—base towards front apron. Next install the four i.f. transformers with the green dots closest to the rear chassis apron. Wind coils as described in the parts list and install with all terminals pointing toward the center of the chassis. Mount a three-lug terminal strip above Q1, a four-lug strip above Q2, a four-lug strip next to Q10 (see photo), a four-lug strip near Q5, a four-lug strip behind the a.f.c. switch, a four-lug strip near Q6 (see photo) and a six-lug strip above transformer T4. Install the transformers, a.f.c. switch, volume control, jacks on the rear apron and the tuning capacitor.

Start the wiring in the r.f. and mixer sections. Next do the a.f.c. section as shown in Fig. 4, and the oscillator circuit. Next wire the i.f. amplifier and ratio detector circuitry as shown in Fig. 5. Finish the receiver by wiring the amplifier circuitry.

TESTING

To avoid damaging any of the transistors, a definite testing procedure should be followed. A variable voltage source, such as the Eico 1020, is quite useful. If a suitable supply is not available, you can install a clip lead on one battery connection and increase the voltage in 1.5 volt steps. Each stage can be brought up to operating voltage while observing the current or emitter voltage, to insure that a transistor is not drawing excessive current.

Before installing any transistors, check the resistance across J3, with the switch turned on. It should read around 1,000 ohms, after the capacitors charge. Connect a 0-20 ma. meter in series with one of the battery leads. When the receiver is first turned on (without transistors) the current will "pop-up" as the capacitors charge, then drop down to the leakage and bias divider current level (about 7 ma.). Next, insert transistors Q8 and Q9 and note an additional 3 ma. of static current (approx.). The driver transistor will account for an additional 1.6 ma. or so. Inserting the a.f.c. transistor will raise the current about one-half ma.

For testing the remaining stages, the voltage chart (Fig. 7) should be used as an approximate guide. Starting at Q6, and working towards the front end, insert one transistor at a time, and check the emitter voltage against the chart while increasing the supply to 12 volts. The emitter potential should not exceed three volts, indicating a current of less than 2 ma. per stage. Actually each stage will draw approximately 1.5 milliamperes.

Once you have established that the transistors are drawing the correct current, you should be able to receive a few FM stations, for the transformers have been preset to about 10.7 mc. However, before you start showing the unit off to your friends, let's adjust the various stages.

Turn the volume control to minimum and connect an audio oscillator (set to 1,000 cycles) across C37. Connect the tap on T6 to match the speaker impedance. Observe the waveform across the speaker with a 1 kc. tone applied. The sine wave should be pure at low levels with no "hook" near the center (crossover distortion). If you are not satisfied with the waveshape, connect a 100 ohm potentiometer in place of R36 (68 ohms). Adjust the control for the "cleanest" sine wave, measure the potentiometer value, and replace it with the closest value of fixed resistor. The speaker volume should be quite loud when peak clipping (distortion) occurs.

Next check the a.f.c. amplifier (Q10) collector voltage. It should be 4.0 volts, plus or minus 0.25 volts, with the a.f.c. switch off for optimum performance. If it is lower than this figure, remove R15 and recheck. In some transistors resistor R15 may not be required. If the collector voltage is higher than 4.0 volts with R15 out of the circuit, connect a high resistance potentiometer in its place and determine what bias resistance is required to bring the collector down to 4.0 volts. When this value has been determined, replace the potentiometer with a fixed resistor. If the collector voltage is far from the design center of 4.0 volts, you will find the a.f.c. action will be "lop-sided," that is, it will pull in and hold from one side better than the other.

ALIGNMENT

The alignment technique is relatively simple, but somewhat different than the usual technique for this transistor receiver. The ratio detector must be aligned first. Connect an oscilloscope across R32 and a sweep generator (with 52 ohm output) to pin 4 of T3, through a .01 mfd. disc. Connected in this manner, the generator swamps out all resonances in the transformer to which the generator is connected. The characteristic "S" curve should be obtained on the cathode ray tube. Adjust T4 (top and bottom) for maximum amplitude at 10.7 mc., consistent with a straight line between the positive and negative peak. In the steps to follow, the entire purpose is to keep this line as straight and linear as possible. Next move the generator lead (with the .01 capacitor) to pin 4 of T2 and adjust T3 to maintain the characteristic "S" curve. Now connect the generator and isolating capacitor to pin 4 of T1 (with short leads) and adjust T2, while maintaining the "S" curve linearity. Next connect the generator and .01 capacitor to the base of the mixer Q2 (with extremely short leads) and adjust T1 top and bottom, as before. The effects of regeneration (distortion) may be noted, but don't

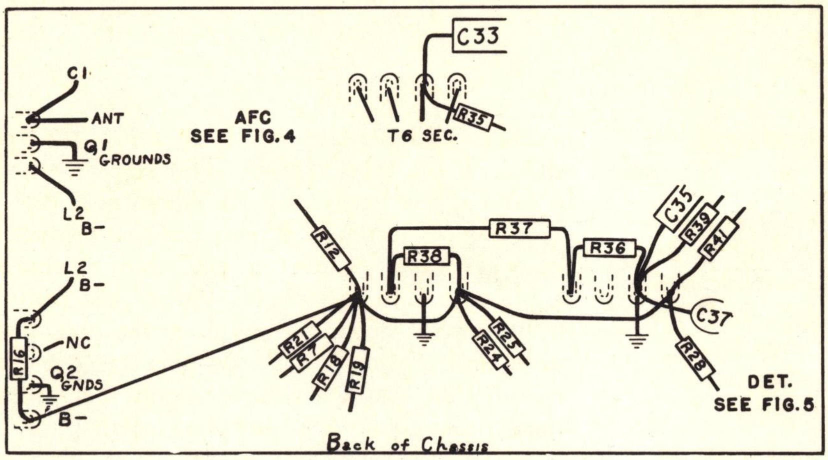


FIG. 6 LOCATION OF COMPONENTS

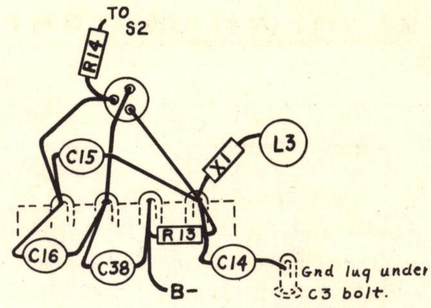


FIG. 4
AFC COMPONENTS LAYOUT

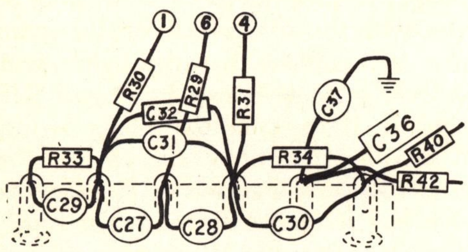


FIG. 5
RATIO DETECTOR LAYOUT

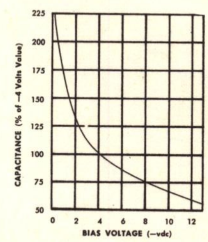
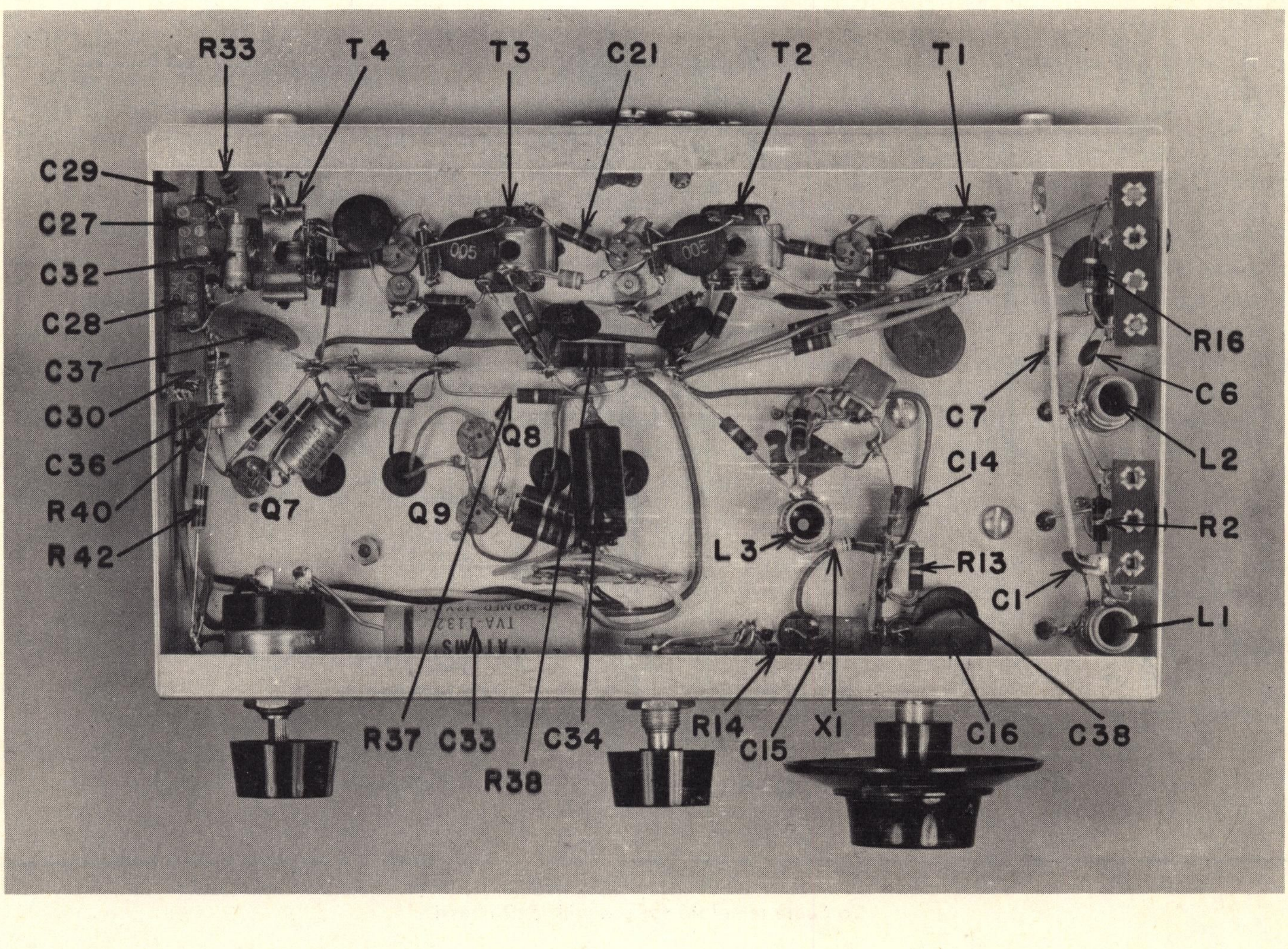


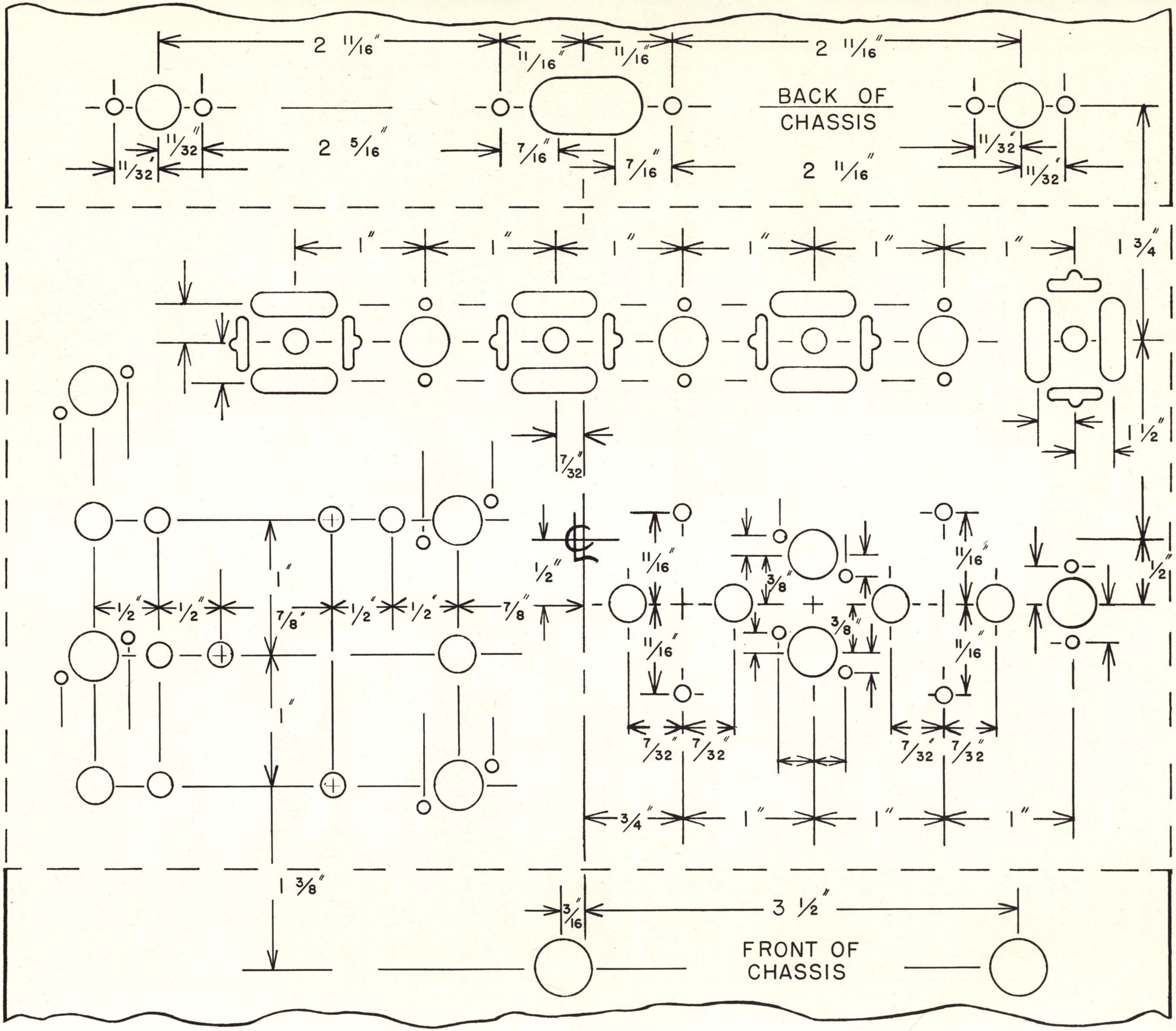
FIG. 2

A CURVE OF CAPACITY VERSUS BIAS VOLTAGE FOR THE PACIFIC SEMICONDUCTORS "VERCAP" DIODES.

NOTE THE DESIGN CENTER IS -4 VOLTS.



To Scale template for use with 5x9 chassis.



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be too concerned until you check the wave through the antenna jack at 108 mc.

Switch the generator to 108 mc. and connect it to the antenna jack, J1. You should now find the waveform much "cleaner" with no sign of regeneration, indicating a stable i.f. system. Adjust T1 again until the best "S" curve is obtained. It is permissible to "touch up" the other transformers *slightly* to obtain optimum linearity.

At this point a word about regeneration is in order. Each stage is carefully neutralized and by themselves are completely stable. However, when the full gain of the three-stage system is realized it is possible for "end-to-end" regeneration to occur. This happens when energy from the ratio detector is picked up by the mixer or 1st i.f. stage. When this occurs the i.f. system becomes very unstable or breaks into oscillation. In either case it is just about useless for amplifying signals. With the layout shown the receiver is very stable even when all i.f. windings are peaked to the same frequency. Follow the layout as closely as possible and you should have no trouble duplicating the receiver. If, however, you feel compelled to make a component or layout change, keep the above facts in mind and proceed with caution.

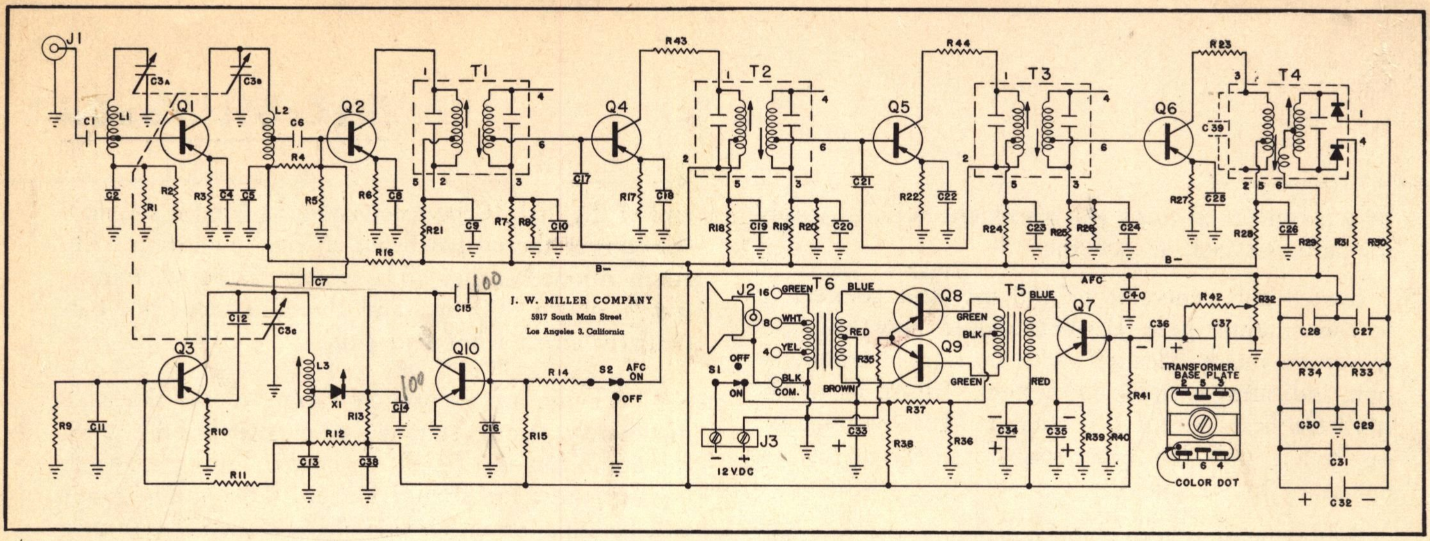
The adjustment of the transformers should be smooth and the curve should not suddenly jump to a different shape. You may note, however, that if T1 and T2 are detuned considerably the i.f. will oscillate. This is due to phase angle changes in the neutralization circuit, and does not indicate poor design.

When you are satisfied with the i.f. alignment, connect an antenna in place of the sweep generator connection. Set the oscillator trimmer (on the right side of C3, at the back) so that the dial and stations track. Reconnect the sweep generator, set the dial to 108 mc. and adjust the r.f. and mixer trimmers for maximum amplitude. Check the gain at the low end of the dial. If the receiver tracks (and it should), the gain of the unit will not change more than 6 db. As mentioned earlier alpha cutoff of the r.f. transistors is above 300 mc. and therefore does not particularly affect front end gain.

Check the a.f.c action by tuning to the side of a moderately strong station (a.f.c. switch off), until the audio can just barely be heard. Turn the switch on and the a.f.c. should lock-in. The pull-in range will be equal on either side of the station if you have carefully set the collector voltage of Q10 to 4.0 volts. If the a.f.c. action is excessive, move the "Varicap" tap towards the C17 end of the coil. If insufficient, move it towards the C3 end. If the diode is "too high" on the coil, it will load the circuit and prevent oscillation. Always grip the "Varicap" leads with needle-nose pliers when soldering to dissipate heat from the diode junction. This completes the receiver alignment.

OBTAINING THE COMPONENTS

Although the J. W. Miller Company is not in the business of selling transistors, the Philco types used in the "front end" and i.f. system are not yet available through regular channels. To expedite matters and assist experimenters in duplicating this receiver, Miller Company has arranged with Philco Corporation to supply the six r.f. transistors as part of an "FM Portable Package." We are making available the following packages to facilitate building your transistor f.m. radio. Package #777-1, which consists of 3 i.f. transformers, 1 ratio detector transformer, 6 r.f. transistors, 1 variable capacitor, 1 decal f.m. calibration scale, 3 knobs, 3 r.f. coils at a cost of $36.80. Package #777-2 consists of everything in Package #777-1 plus a punched chassis and a painted cabinet for $42.75. N.B. The chassis and cabinet, part #777-C, are also available separately at a cost of $8.00.



PARTS LIST

C1, C6- 470 mmfd. disc or mica
C2, C4, C5, C8, C9, C11, C13, C29, C30, C-31, C38,- .02 mfd, 30-50 volt disc capacitor (Centralab DA-203 or equiv)
C3- 3-10 mmfd., three-gang variable capacitor including knob (Miller)
C7- 1.0 mmfd. disc or tubular ceramic
C10, C18, C19, C20, C22, C23, C24, C25, C26- .005 mfd. disc
C12, C39- 4.7 mmfd. tubular ceramic or disc
C14, C15- .05 mfd., 30-50 volt disc (Centralab DA-503 or equiv.)
C16- 2.2 mfd., 3 volt disc (Centralab UK-225 or equiv)
C17, C21- 5.6 mmfd. tubular ceramic or disc
C27, C28- 330 mmfd. disc or mica
C-32- 2 mfd., 6 volt electrolytic (C-D NLW-2-6 or equiv)
C33, C34- 100 mfd., 15 volt electrolytic
C35, C36- 20 mfd., 6 volt electrolytic (C-D NLW 20-6 or equiv)
C37- 0.1 mfd., 3 volt disc (Centralab UK 104 or equiv)
C40- .01 mfd., 30-50 volt disc
J1, J2- Phono jacks
J3- Two-screw terminal strip
L1- 3¼ turns, #14 tinned wire, wound on 3/8" coil form, spaced 1/8" between turns. C3 end towards chassis. Remove slug. Antenna tap at 2 turns from C2 end, base tap 1 turn from C2 end.
L2- 3 turns, #14 tinned wire, wound on 3/8" coil form, spaced 1/8" between turns. Base tap 1 turn from C5 end, C3 end towards chassis, remove slug.
L3- 2 turns, #14 tinned wire, wound on 3/8" coil form, spaced 1/8" between turns. C3 end towards chassis. Diode tapped ¼ to ¾ turns from C13 end (see text)
Q1- R.f. amp., PNP type T1694 (Philco)
Q2- Mixer, PNP type T1696 (Philco)
Q3- Osc., PNP type T1695 (Philco)
Q4, Q5, Q6- I.f. amplifier, PNP type T1693 (Philco)
Q7- 1st audio, PNP type 2N226 (Philco)
Q8, Q9- Class B audio, PNP type 2N224 (matched pair of 2N225's- Philco)
Q10- AFC amplifier, PNP type 2N226 (Philco)
R1, R9- 3.9K
R2, R11- 10K
R3, R10, R17, R22, R27- 1.5K
R4- 12K
R5, R33, R34, R40- 4.7K
R6- 1.2K
R7, R19, R25, R37- 6.8K
R8, R20, R26- 2.7K
R12, R16- 1K
R13- 22K
R14- 47K
R15- 2.2 megohm
R18, R24, R28- 2.2K
R21, R42- 470 ohms
R23, R29, R43, R44- 100 ohms
R30, R31- 3.3K
R32- 25K pot., audio taper (Centralab B-29 or equiv)
R35- 2.2 ohms
R36- 68 ohms
R38- 120 ohms
R39- 220 ohms
R41- 100K
All resistors ½ watt
S1- SPST switch, part of R32 (Centralab KB or equiv)
S2- SPDT switch, rotary action (Centralab 1460 or equiv)
T1- Transistor 10.7 mc. interstage (J. W. Miller 1463-T1)
T2- Transistor 10.7 mc. interstage (J. W. Miller 1463-T2)
T3- Transistor 10.7 mc. interstage (J. W. Miller 1463-T3)
T4- Transistor 10.7 mc. ratio det. (J. W. Miller 1465-TRD)
T5- Interstage audio, 10K to 2K c.t. (Triad TY-56X or equiv)
T6- Audio output, 500 ohm c.t. to 4, 8, or 16 ohms (Triad TY-45X or equiv)
X1- "Varicap" diode Pacific Semiconductor, V-15 or International Rectifier #6.8SC20
Misc. Components- Chassis 5"x9"x1½", 10 ring mount transistor sockets (Elco 3306, 3309 or equiv), knobs, misc. hardware and terminal strips.

VOLTAGE CHART

SYMBOL	TYPE	COLLECTOR	BASE	EMITTER	CALC. CURRENT
Q1	T1694	10.1 volts	2.4 volts	2.2 volts	1.45 ma
Q2	T1696	8.8 volts	1.5 volts	1.4 volts	1.25 ma
Q3	T1695	8.6 volts	1.9 volts	2.05 volts	1.36 ma
Q4	T1693	7.4 volts	2.6 volts	2.4 volts	1.4 ma
Q5-	T1693	6.5 volts	2.6 volts	2.3 volts	1.8 ma
Q6	T1693	6.9 volts	2.6 volts	2.5 volts	1.66 ma
Q7	2N226	8.8 volts	.5 volts	.35 volts	1.6 ma
Q8, Q9	2N224	12.0 volts	.1 volts	*	1.5 ma
Q10	2N226	4.0 volts	*	0	0.6 ma

Notes:
1. * voltages too low to measure
2. No signal
3. All readings negative with respect to the chassis

Typical voltage measurements in the transistorized fm receiver.

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