F.M. BROADCAST TRANSMITTERS

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STUDY SCHEDULE No. 47

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

This Lesson is bound differently from most of your texts to permit large diagrams to be shown better. Just follow the regular order of the pages as they are numbered at the bottom.

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F.M. BROADCAST TRANSMITTERS

Direct F.M. Transmitters with Electro-Mechanical Center Frequency Controls

WE HAVE already studied the basic circuits used in f.m. transmitters. Now let us study in more detail various commercial units used in f.m. broadcasting.

We will consider four general types of f.m. transmitters: 1, direct f.m. with electro-mechanical (motor-driven) center frequency control systems; 2, direct f.m. transmitters with electronic center frequency controls; 3, indirect f.m. transmitters using the Phasitron tube; and 4, miscellaneous types of indirect f.m. transmitters. In addition, we will study the frequency monitors and modulation meters used in f.m. stations.

WESTERN ELECTRIC F.M. TRANSMITTERS

The essential circuits and sections of the basic Western Electric f.m. transmitter are shown in Fig. 1. This is a direct f.m. transmitter that uses a balanced reactance tube circuit.

The audio signal from the pre-emphasis unit is applied to the reactance tubes (VT_1 and VT_2) through T_1. The reactance tubes are connected across L_2, which is the plate tank coil of the push-pull LC oscillator using VT_3 and VT_4. Condensers C_3 and C_4 are used to tune this oscillator, whose resting frequency is 1/16 the desired carrier frequency (for example, 6.18125 mc. for a 98.9 mc. carrier). C_1 and C_2, in parallel with C_3 and C_4, are mechanically coupled to a motor that, as we will later see, is used to correct any frequency drift from the correct resting frequency of the LC oscillator.

The r.f. output, which has a maximum deviation of 4.16 kc. at 100% modulation, is coupled through L_1 to the first r.f. buffer stage (VT_5). Part of this r.f. voltage is also applied through L_3 and C_5 and C_6 to obtain the 90° phase shift in the r.f. voltage applied to the grid of VT_1 and VT_2 that is necessary to make them act as reactances. The output of the buffer is applied to the first frequency doubler (VT_6). This output is in turn applied to three more frequency doublers (VT_7, VT_8, and VT_9), which produce the desired carrier frequency.

R.F. Power Amplifier. The power amplifier section starts with the intermediate power amplifier (VT_{10}, VT_{11}), a grounded-cathode class C amplifier with resonant lines for the tank circuit. C_7 is used for tuning this stage. To neutralize the tetrode tube screen-lead inductance (which would prevent the screens from being at r.f. ground

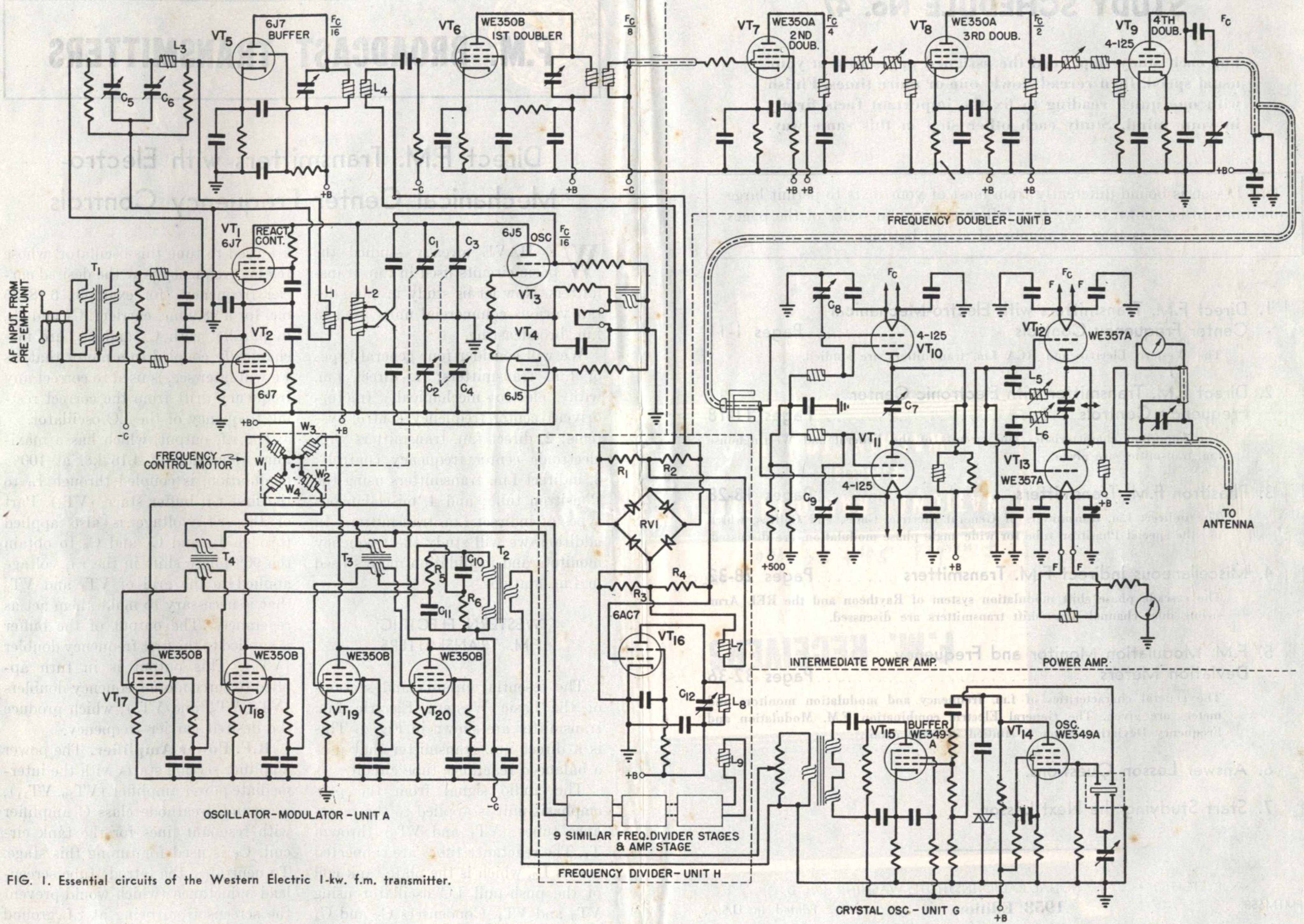


FIG. 1. Essential circuits of the Western Electric 1-kw. f.m. transmitter.

and hence cause inadequate shielding of the input r.f. from the output r.f. circuit), condensers C_8 and C_9 (called "neutralizing" condensers) are used to series-resonate these inductances.

The final r.f. power amplifier (using triodes VT_{12} and VT_{13}) has resonant lines in both the plate and grid tank circuits. Coils L_5 and L_6 form high-impedance parallel resonant circuits with the undesired C_{pg} of VT_{12} and VT_{13} and thus minimize the feedback from output to input circuits in these triodes. The output of this stage is one kilowatt, the basic power unit in the Western Electric series.

Center Frequency Control. The center resting frequency of the LC oscillator is stabilized by circuits in which its frequency of operation is compared to that of a highly stable reference oscillator. If there is any drift in the LC oscillator, the frequency-correcting circuits operate a motor that varies C_1 and C_2 to correct the drift. Let us see how this operates.

The crystal reference oscillator uses VT_{14}. A duplex crystal is used that has such a high frequency stability that no heater oven or temperature control is needed. This oscillator operates at a frequency 1/1024 that of the LC oscillator (6.03638 kc. in the example given above.) This signal is applied through buffer stage VT_{15} and transformer T_2 to the motor control circuit.

A sample of the LC oscillator output is taken from the first r.f. buffer stage by means of coil L_4 and applied to ten regenerative modulation frequency divider circuits. (We will study this circuit shortly.) Since each of these circuits divides the frequency by 2, the output will be 1/1024 that of the LC oscillator. This output is applied through T_3 and T_4 to the motor control circuit. When the crystal reference frequency and that obtained through the frequency dividers from the LC oscillator are the same, the motor will not operate; however, any drift in the LC oscillator will cause the motor to operate, tuning C_1 and C_2 to correct the drift.

Before we take up this motor control circuit, let us study the regenerative modulation frequency divider used in this circuit.

Frequency Division by Regenerative Modulation. The divider is shown in the box marked FREQUENCY DIVIDER in Fig. 1. The four rectifiers (marked RV_1) in this circuit form what is called a "ring modulator." (We will explain how a ring modulator works a little later; right now, we want you to learn how the whole circuit operates, without bothering with details.)

Let us assume, to use a numerical example, that the input frequency across R_1 and R_2 from L_4 is 6 mc. Further, let us assume that L_8 and C_{12} are tuned to a frequency of 3 mc. (exactly half the input frequency), and that this tuned circuit has been shock-excited so that a 3-mc. signal appears across L_8. This 3-mc. signal is picked up by L_7 and fed into the ring modulator along with the 6-mc. R_1-R_2 signal.

The ring modulator combines the two signals, producing a double-side-band suppressed-carrier signal across R_3 and R_4. The two side bands have frequencies of 3 mc. (6 mc. —3 mc.) and 9 mc. (6 mc. +3 mc.). These side bands are amplified by VT_{16}. The amplified 3-mc. side band sustains the

oscillations in the L_8 tuned circuit. Therefore, a 3-mc. signal continues to appear across L_8, inducing 3-mc. voltages in L_7 and L_9. The signal induced in L_9 constitutes the output of the frequency divider stage, since it is half the input (6 mc.) signal; it is fed to another divider stage. The signal induced in L_7 is fed back to the ring modulator, where it again combines with (modulates) the input signal, thus permitting the action of the stage to continue. This feedback action is the reason why the term "regenerative modulation" is used to describe the operation of this circuit.

The L_8-C_{12} circuit must be tuned to exactly half the input frequency for the frequency dividing action to occur. To see why, let's suppose it is tuned to some other frequency—to 4 mc., for example. The side bands produced by the ring modulator are now 2 mc. (6 mc. —4 mc.) and 10 mc. (6 mc. +4 mc.). Neither of these is of the same frequency as that to which L_8 and C_{12} are tuned; therefore, the oscillations in L_8 and C_{12} are not sustained, and the circuit has no output. In other words, this circuit will either halve the input frequency or not operate at all; it will not produce undesired frequencies. This is the chief advantage of a frequency divider of this sort.

Ring Modulator. The basic principle used in ring modulation for obtaining a double-side-band suppressed-carrier signal is shown in Fig. 2A. In it, a switch S, operating at the carrier frequency, alternately switches the modulating signal to the two sections in the output transformer, thereby continually reversing the polarity of the modulating signal. Let's say that the modulating signal is a sine wave, as shown in Fig. 2B, and that the carrier frequency is 5 times the modulating frequency; then the output has the form of the solid line in Fig. 2C. Notice that during one cycle of the modulating signal, the direction of its current flow through the circuit is reversed 10 times by the operation of switch S.

This method of combining the carrier frequency with the modulating signal produces an amplitude-modulated signal with the carrier suppressed. (The operation of switch S introduces the carrier frequency into

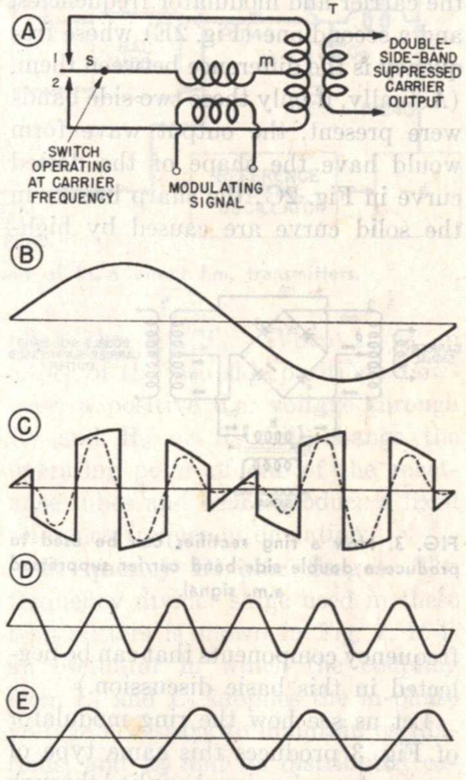


FIG. 2. A double side-band suppressed-carrier signal (C, D, and E) can be produced by a switch S, (shown in A) operating at the desired carrier frequency that changes the polarity of the modulating signal (B) at the carrier rate.

the circuit, but the carrier voltage itself is never applied to the circuit; therefore, a suppressed-carrier signal is produced.) Thus, the output shown as the solid line in Fig. 2C essentially consists of two side bands, one (Fig. 2D) whose frequency is the sum of the carrier and modulator frequencies, and a second one (Fig. 2E) whose frequency is the difference between them. (Actually, if only these two side bands were present, the output wave form would have the shape of the dotted curve in Fig. 2C; the sharp breaks in the solid curve are caused by high-

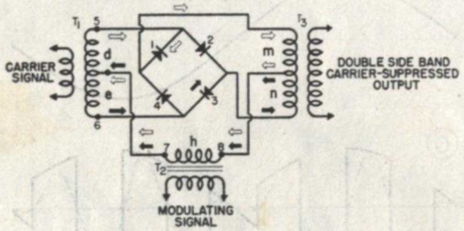


FIG. 3. How a ring rectifier can be used to produce a double side-band carrier suppressed a.m. signal.

frequency components that can be neglected in this basic discussion.)

Let us see how the ring modulator of Fig. 3 produces this same type of output. A carrier signal applied through T_1 to the rectifiers will cause them to conduct alternately in pairs and thus replace the switch S of Fig. 2A. For example, when terminal 5 is negative and 6 is positive, rectifiers 1 and 4 will conduct and rectifiers 2 and 3 will not conduct. On the next half cycle of the carrier signal, rectifiers 2 and 3 will conduct and 1 and 4 will be effectively open circuits. None of the carrier signal is applied to the output transformer T_3 on either half of the carrier frequency.

Now assume that the modulating signal applied through T_2 is so small (about 1/10 of the carrier amplitude) that it cannot cause any of the rectifiers to conduct. The direction of the modulator current flow is therefore determined by the rectifiers that are conducting because of the presence of the carrier. When terminal 8 of winding h of the modulation transformer is positive and terminal 7 is negative, electrons flow as shown by the arrows. On the half of the carrier cycle when rectifiers 2 and 3 are conducting, the electron flow (indicated by the solid black arrows) is through winding e of T_1, rectifier 3, and winding n of T_3. On the next half cycle of the carrier, (when rectifiers 1 and 4 are conducting) the outlined arrows indicate that winding m of T_3 is energized through rectifier 1 by the modulating signal. Thus, in this ring modulator, the direction of flow of the modulating signal current is reversed by the carrier, just as it was in the circuit in Fig. 2A. As a result, the output of the ring modulator is a double-sideband suppressed-carrier signal similar to that shown in Fig. 2C.

Motor Control Unit. The control circuit used to operate the frequency correcting motor is shown in Fig. 4. (This is the same circuit as that shown in Fig. 1 except that it has been redrawn for greater clarity.)

A two-phase motor is used. Its windings, W_1, W_2, W_3, and W_4, form the plate loads for tubes VT_1, VT_2, VT_3, and VT_4, respectively.

Each pair of these tubes (VT_1-VT_2 and VT_3-VT_4) is arranged in a circuit that is practically identical with the Foster-Seeley frequency discriminator you have already studied except that the tubes are used to amplify signals rather than just to rectify them. Each circuit is fed both the crystal reference frequency and the transmitter frequency; the former is fed in through phase-shifting circuits that, as Fig. 4 shows, create 45° phase shifts in it.

When the transmitter frequency and

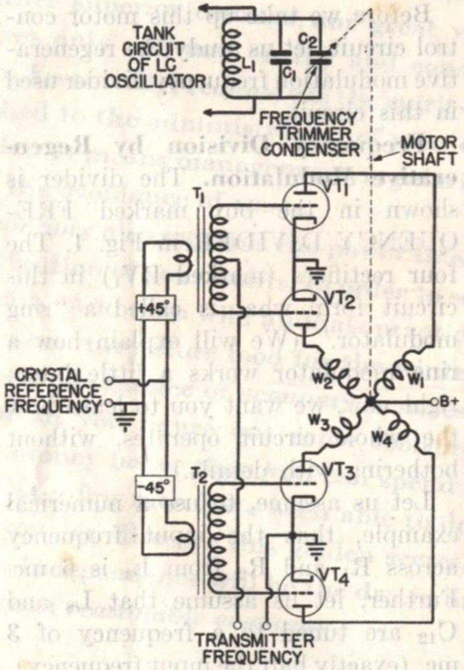


FIG. 4. Basic circuit for motor driven automatic frequency control circuit of direct f.m. transmitters. When the transmitter frequency drifts from the crystal reference frequency, the voltage and phase unbalance in the four windings of the motor (W_1, W_2, W_3, and W_4) will cause the armature to rotate. This turns the shaft of C_2 to correct the frequency drift.

the crystal reference frequency are identical, this motor control circuit is perfectly balanced, and the currents flowing through the motor windings create equal and opposite magnetic fields that cancel one another and so cause no rotation of the motor armature. If the transmitter frequency drifts even slightly, however, a considerable unbalance will occur; the magnetic fields of the motor windings will then no longer cancel, and the motor armature will rotate. The torque produced on the armature will depend on the amount of frequency drift, and the direction of rotation will depend on whether the drift is above or below the reference frequency.

The armature of the motor, acting through a reducing gear, rotates the shaft of a trimmer condenser (C_2 in Fig. 4) that is connected across the tank circuit of the LC oscillator. This adjustment will correct the original frequency drift that caused the motor to operate. If the transmitter frequency is too high, the value of C_2 will increase; if the frequency is too low, C_2 will decrease. When full correction is made, the motor will stop. Thus, the frequency of the LC oscillator is kept practically as stable as that of the crystal reference oscillator at all times.

One principal advantage of this method of frequency correction is that the d.c. operating points of the reactance modulator tubes are not affected by the amount of correction applied.

The motor control circuit of Fig. 1 is quite similar to the basic circuit shown in Fig. 4. The +45° phase shift in the crystal reference frequency is obtained by making the capacitive reactance of C_{10} equal to the resistance of R_6, and the —45° phase shift by making R_5 equal to the reactance of C_{11}.

► The frequency deviation of 4.16 kc. of the LC oscillator is also reduced by the frequency divider so that it is only 4.15 cycles. Thus, even

100% modulation of the carrier can produce only a very slight variation of the speed of the correcting motor. Actually, because of the motor inertia and viscous (oil) damping, the motor speed is independent of modulation. This damping and the gearing also prevents the motor from "overshooting" the correct frequency. There is, therefore, no "hunting," even when large values of frequency drift are corrected.

High-Power F.M. Transmitters. The 1-kw. transmitter just described is the basic unit in Western Electric f.m. transmitters. When more power is needed, this unit is used as a driver for a higher power amplifier. For example, in the 3-kw. transmitter, it drives a grounded-grid 3-kw. amplifier. If 10 kw. of power is needed, the 1-kw. transmitter drives a grounded-plate (cathode follower) r.f. amplifier. For higher powers of 25 kw. or 50 kw., the 10-kw. amplifier is used as a driver.

Performance Specifications. The specifications and performance of most standard f.m. broadcast transmitters are similar despite variations in the method used for obtaining frequency modulation.

The specifications for the Western Electric series are:

Audio-Frequency Response: ±0.25 db from 30 to 15,000 cycles.*

Harmonic Distortion for ±75-kc. swing: Less than 0.5% from 30 to 15,000 cycles.

±100-kc. swing: Less than 0.75% from 30 to 15,000 cycles.

Intermodulation for ±75-kc. swing: Less than 0.5% for 80% at 50 cycles and 20% at 1,000 cycles; less than 1.0% for 80% at 50 cycles and 20% at 7,000 cycles.

F.M. Noise Level: 65 db down at ±75-kc. swing.

A.M. Noise Level: 50 db down at 100% amplitude modulation.

Carrier-Frequency Stability: Less than 2,000 cycles deviation (no crystal heater is used).

Modulation Capability: All f.m. broadcast transmitters are capable of 100-kc. deviation, which corresponds to 133% modulation.

* The response is always given in reference to the standard 75-microsecond pre-emphasis curve.

RCA F.M. TRANSMITTERS

The 250-watt RCA f.m. transmitter is shown in block diagram form in Fig. 5. Notice that it and the Western Electric are quite similar in that each uses a balanced reactance tube modulator and a frequency stabilization system consisting of a series of frequency dividers, a piezo-electric reference oscillator, and a two-phase synchronous motor that drives the LC tuning condenser to correct for frequency drifts.

In the RCA transmitter, the LC oscillator frequency is 1/18 that of the final carrier; this is multiplied by 9 in the exciter unit and doubled in the final power amplifier stage.

The frequency - correcting system consists of a four-stage frequency divider whose output frequency is 1/240 that of the LC oscillator—in other words, between 18.75 kc. and 25 kc., depending on the station assignment in the 88-108 mc. band. Since highly stable crystals are available in the 100-kc. region, the reference crystal oscillator operates from

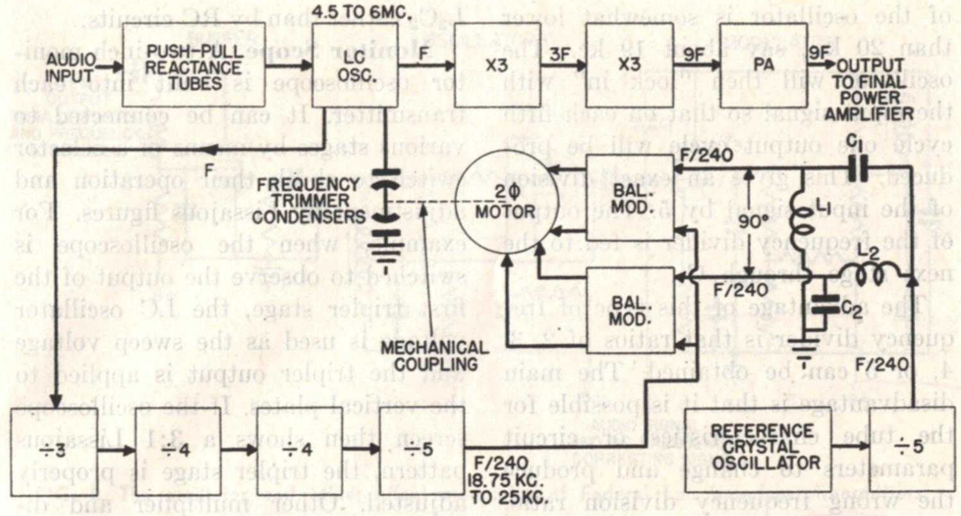


FIG. 5. Block diagram of the exciter unit of RCA direct f.m. transmitters.

90.75 to 125 kc. and is stepped down by a five to one frequency divider.

F.M. Modulator and Oscillator. Let us now study the basic circuits in the RCA f.m. transmitter. The reactance tube modulator and LC oscillator are shown in Fig. 6. The LC oscillator is a single-ended Hartley with a plate tank consisting of L_5 and C_4, C_5, and C_6; C_4 and C_5 are controlled by the frequency-correcting motor.

The 90° phase shift in r.f. voltage applied to the reactance tube grids is obtained inductively by link L_4-L_2 and tuned circuit L_1, L_3, C_1, C_2, and C_3.

This reactance tube circuit increases the linear operating range of the modulator, because many irregularities in modulation are eliminated by the balanced circuit.

Switch S_1 is used to produce a fixed frequency deviation in the transmitter. When the switch is in the center position, the circuit operates normally with the audio signal being applied through T_1. When it is in either of the two side positions, however, a positive d.c. voltage through R_1 and R_2 or R_3 will change the operating point of one of the reactance tubes and hence produce a fixed reference frequency deviation.

Frequency Divider Stages. The frequency divider stage used in these transmitters is shown in Fig. 7. It is an oscillator in which the coupling from L_1 and L_2 supplies the in-phase voltage necessary to maintain oscillations, and L_2 and its distributed capacitance C_3 determine the frequency of oscillation. R_1 is used to limit the positive grid excursions.

To produce frequency division, this circuit is adjusted to oscillate at some frequency that is slightly below a desired submultiple of the input frequency, which is fed into it from the preceding stage through C_1. For example, if the input signal is 100 kc. and a frequency division of five is desired, the values of L_2 and C_3 are chosen so that the natural frequency of the oscillator is somewhat lower than 20 kc., say about 19 kc. The oscillator will then "lock in" with the input signal so that on each fifth cycle one output cycle will be produced. This gives an exact division of the input signal by 5. The output of the frequency divider is fed to the next stage through C_2.

The advantage of this type of frequency divider is that ratios of 2, 3, 4, or 5 can be obtained. The main disadvantage is that it is possible for the tube characteristics or circuit parameters to change and produce the wrong frequency division ratio, either continuously or intermittently. The operation of such a stage must therefore be carefully and frequently checked.

Motor Control Circuits. The motor control circuit is quite similar to that shown in Fig. 4. In Fig. 5, the +45° and —45° phase shift in crystal reference voltage is produced by L_1C_1 and L_2C_2 rather than by RC circuits.

Monitor Scope. A two-inch monitor oscilloscope is built into each transmitter. It can be connected to various stages by means of a selector switch to check their operation and adjustment by Lissajous figures. For example, when the oscilloscope is switched to observe the output of the first tripler stage, the LC oscillator voltage is used as the sweep voltage and the tripler output is applied to the vertical plates. If the oscilloscope screen then shows a 3:1 Lissajous pattern, the tripler stage is properly adjusted. Other multiplier and divider stages can be checked and adjusted in a similar manner.

Higher Power. The basic unit just described is the exciter unit. To obtain a 250-watt output, a power amplifier consisting of a 4-125A frequency doubler driving a pair of 4-125A's in parallel is used. This complete unit is contained in one cab-

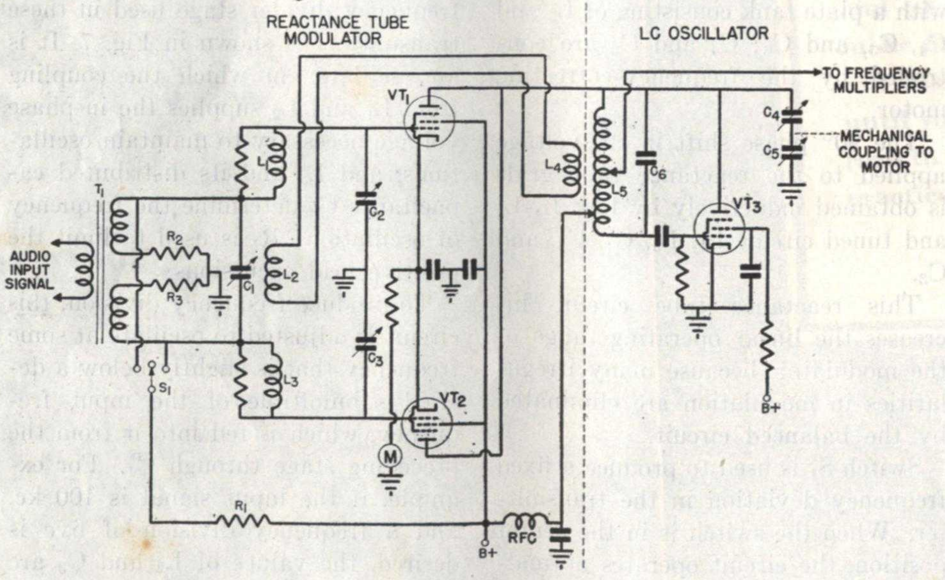


FIG. 6. The balanced reactance tube modulator and LC oscillator used in RCA f.m. transmitters.

inet. When 1-kw. output is desired, a separate grounded-grid 7C24 power amplifier is used; it is mounted in a

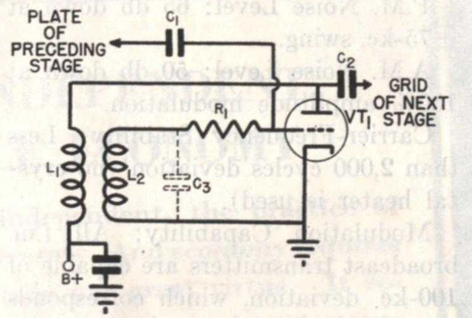


FIG. 7. The basic frequency divider stage used in RCA f.m. transmitters. It is a "free-running" oscillator that will "lock in" at some sub-multiple of the inutput frequency; frequency division of 3, 4, and 5 can be obtained by using this circuit.

cabinet that matches the 250-watt driver. For 3-kw. operation, another 7C24 grounded-grid amplifier, driven by the 1-kw. transmitter, is used; this is mounted in a third matching cabinet.

RCA power amplifier stages have variable power-supply voltages for operating at reduced input or at odd values of power. For example, the 1-kw. transmitter can be varied from 250 watts to 1 kw. in output.

Performance Specifications.

Audio-Frequency Response: ±1 db from 30 to 15,000 cycles.

Audio-Frequency Distortion: 30-100 cycles 1.5%; 100-7500 cycles 1.0%; 7500-15,000 cycles 1.5%.

F.M. Noise Level: Down 65 db.

A.M. Noise Level: Down 50 db.

Carrier Frequency Stability: Less than 2000 cycles.

Direct F.M. Transmitters with Electronic Center Frequency Controls

Some types of f.m. transmitters use a variation in the d.c. level applied to the modulator tube to correct electronically any frequency drift of the master LC oscillator. The Federal f.m. transmitters (block diagrammed in Fig. 8) are examples of this type of f.m. transmitter.

FEDERAL F.M. TRANSMITTERS

Basically, the operation of the center frequency control is as follows: The output of the buffer following the LC oscillator is fed to a frequency divider where an output 1/256 that of the input is obtained. This signal is then applied to a phase discriminator where it is compared with a submultiple of the crystal oscillator frequency. Any frequency drift of the LC oscillator will produce a d.c. voltage in the phase discriminator output, the polarity of the voltage depending on the direction of drift and the amplitude of the drift. This d.c. voltage is applied to the reactance tube, where it acts to correct the drift of the LC oscillator. We will take up this control in more detail in a moment, but let us first learn how the frequency modulator itself works.

Miller-Effect Frequency Modulator. The frequency modulator is shown in Fig. 9. The LC oscillator is a Hartley using VT_2 as the oscillator tube. The oscillator tank coil L_1 is tuned by its distributed capacitance and by the shunt capacitance from its tap to ground. This shunt capacitance is essentially the effective plate-to-grid capacitance C_1 of VT_3, because C_2 and C_3 are r.f. by-pass condensers. As you know, a d.c. change in the grid voltage of VT_3 will cause a change in the effective size of C_1 (this is called the Miller effect). Thus, frequency modulation of VT_2 can be obtained by applying an audio signal to the grid of VT_3, and any undesired frequency drift of the LC oscillator can be corrected by changing the d.c. level of the signal applied to VT_3. The r.f. voltage across L_1 is applied to VT_1, which is the buffer r.f. amplifier.

The r.f. exciter unit consists of three frequency-doubler stages using type 1614 tubes and a tripler stage using an 815 tube. In the 250-watt transmitter, another 815 is the buffer-driver for two 4-250A tetrodes used as push-pull class C r.f. output amplifiers.

Center Frequency Control. The frequency divider in the center frequency control system consists of a series of multivibrator frequency dividers. The basic multivibrator circuit used is shown in Fig. 10. When no synchronizing signal is applied to it, the frequency of operation depends essentially on the values of C_1, R_1, C_2, and R_2. If a frequency division of 5 is desired, the multivibrator is designed to operate at a frequency somewhat less than 1/5 that of the input signal. If a synchronizing signal from the preceding stage is applied

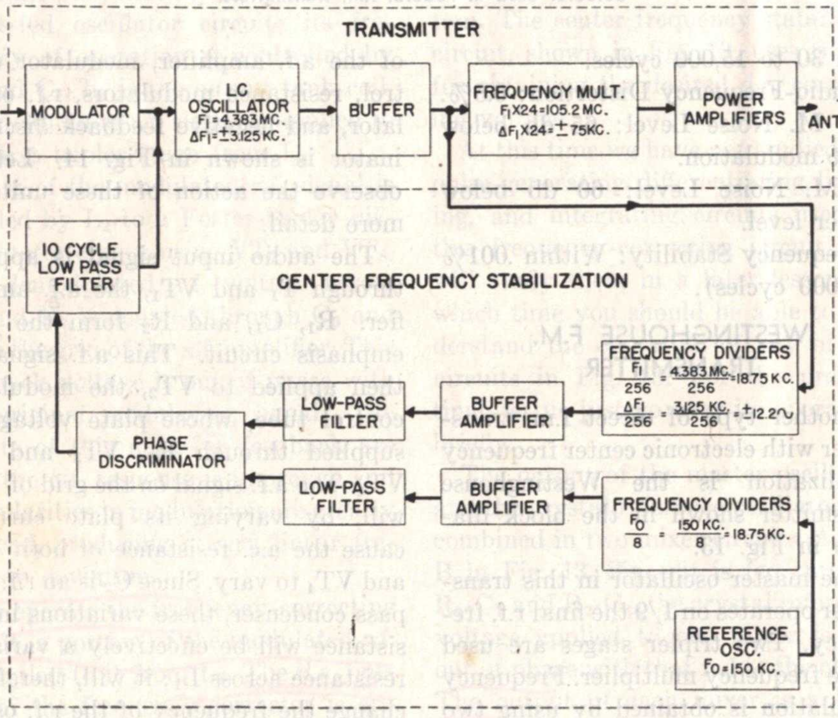


FIG. 8. Block diagram of Federal f.m. broadcast transmitters.

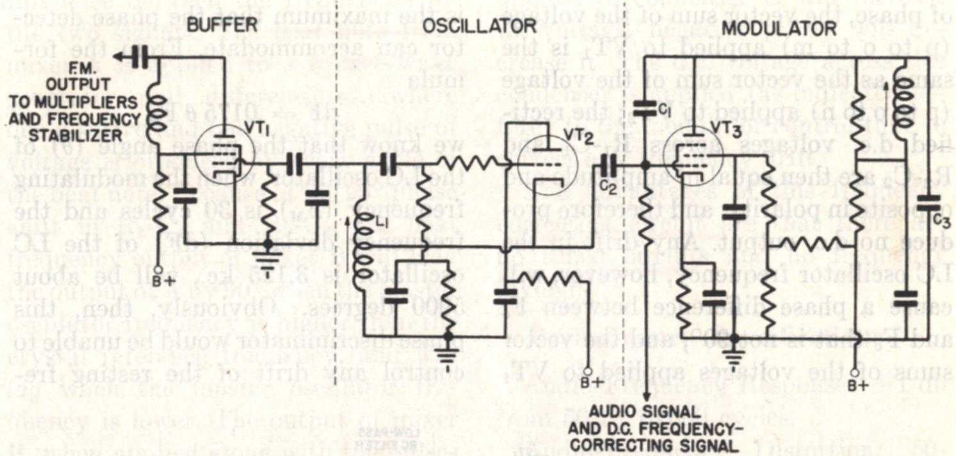


FIG. 9. The oscillator and Miller effect modulator of Federal f.m. broadcast transmitters.

across R_3, the multivibrator will "lock in" on every fifth pulse of the incoming signal and will send one pulse to the next stage. In a similar manner, frequency divisions of 3 and 4 can be obtained when desired.

Phase Discriminator. The output of a multivibrator is a rectangular wave, but the phase discriminator operates best with a sine-wave input. This is why the low pass LC filters indicated in Fig. 8 are used; they remove the higher harmonics and leave essentially the fundamental sine-wave output of the frequency dividers. As long as the crystal reference frequency and the output of the LC oscillator are equal, the phase relationship between them will remain constant; however, any slight drift in LC oscillator frequency will appear as a change in phase difference between the two signals. (Any large difference between the two signals is, of course, a "beat note" rather than a phase difference.) Thus, a phase discriminator that will detect small changes in phase angle and produce a d.c. voltage corresponding to this phase difference can be used as a sensitive oscillator-drift control, because the d.c. voltage can be applied to the modulator tube to correct the drift.

The circuit of the basic phase discriminator used in Federal f.m. transmitters is shown in Fig. 11. As you can see, it is the same as the Foster-Seeley frequency discriminator used in f.m. receivers. In our discussion of this discriminator in an earlier lesson, you learned that when F_c and F_o are the same frequency but 90° out

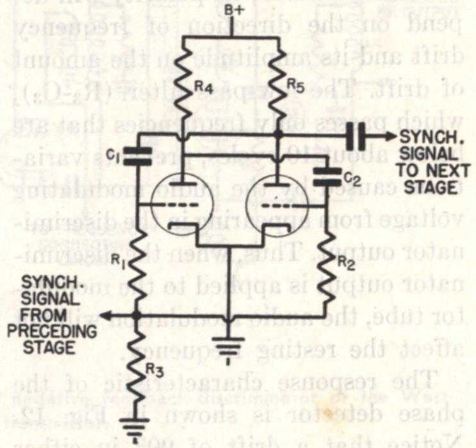


FIG. 10. The basic frequency divider multivibrator circuit used in Federal f.m. transmitters.

of phase, the vector sum of the voltage (p to o to m) applied to VT_1 is the same as the vector sum of the voltage (p to o to n) applied to VT_2; the rectified d.c. voltages across R_1-C_1 and R_2-C_2 are then equal in amplitude and opposite in polarity, and therefore produce no d.c. output. Any drift in the LC oscillator frequency, however, will cause a phase difference between F_o and F_c that is not 90°, and the vector sums of the voltages applied to VT_1

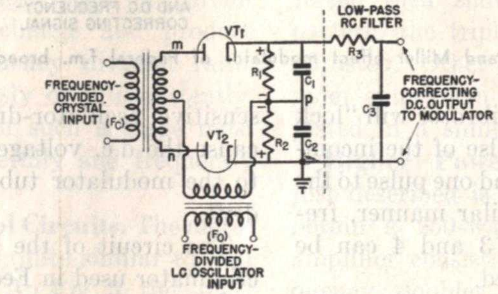


FIG. 11. The phase discriminator used in Federal f.m. transmitters. Any slight change in the LC oscillator frequency will produce a d.c. output which, when applied to the frequency modulator, will correct the original drift.

and VT_2 will no longer be equal. This will cause a d.c.voltage to appear at the discriminator; its polarity will depend on the direction of frequency drift and its amplitude on the amount of drift. The low-pass filter (R_3-C_3), which passes only frequencies that are below about 10 cycles, prevents variations caused by the audio modulating voltage from appearing in the discriminator output. Thus, when the discriminator output is applied to the modulator tube, the audio modulation will not affect the resting frequency.

The response characteristic of the phase detector is shown in Fig. 12. Notice that a drift of 90° in either direction (a total variation of 180°) is the maximum that the phase detector can accommodate. From the formula

$$dF = .0175\,\theta\,F_M$$

we know that the phase angle (θ) of the LC oscillator, when the modulating frequency (F_M) is 30 cycles and the frequency deviation (dF) of the LC oscillator is 3.125 kc., will be about 5900 degrees. Obviously, then, this phase discriminator would be unable to control any drift of the resting frequency of the LC oscillator if it operated at the same frequency as the LC oscillator, because the deviation under modulation is far more than the phase discriminator can accommodate. That is why a frequency division of 256 is used in this frequency control system. This division brings the phase difference due to modulation down to a value that can be handled by the frequency control system (23°, in the example given):

Higher Power. The basic 250-watt transmitter can be used as a driver for either a 1-kw. or a 3-kw. power amplifier. The 1 kw. amplifier is identical with the 3-kw. power amplifier except that the former uses a

plate voltage of 2000 volts, whereas the latter uses 3000 volts. Each is a conventional grounded-cathode cross-neutralized amplifier using two triode tubes. Resonant lines are used in both the plate and grid circuits.

If still higher power is desired, the 3-kw. amplifier can be used to drive a 10-kw. amplifier, which, in turn, can drive other high-power amplifiers.

Performance Specifications.

Audio-Frequency Response: ±1 db from 30 to 15,000 cycles.

Audio-Frequency Distortion: 0.5%.

F. M. Noise Level: 65 db below 100% modulation.

A.M. Noise Level: 60 db below carrier level.

Frequency Stability: Within .001% (±1000 cycles).

WESTINGHOUSE F.M. TRANSMITTER

Another type of direct f.m. transmitter with electronic center frequency stabilization is the Westinghouse transmitter shown in the block diagram in Fig. 13.

The master oscillator in this transmitter operates on 1/9 the final r.f. frequency. Two tripler stages are used in the frequency multiplier. Frequency modulation is obtained by using two duo-diodes for resistance tuning of the LC oscillator. (Using diode tubes reduces the possibility of microphonic noises in the modulator system.) Part of the frequency-modulated output of the oscillator is fed back to a frequency discriminator. The output of this stage is applied to the audio amplifier; this provides negative feedback that improves both the audio-frequency response and the linearity of frequency deviation.

Circuit Operation. The diagram of the a.f. amplifier, modulator control, resistance modulators, r.f. oscillator, and negative feedback discriminator is shown in Fig. 14. Let us observe the action of these units in more detail.

The audio input signal is applied through T_1 and VT_1, the a.f. amplifier. R_1, C_1, and R_2 form the pre-emphasis circuit. This a.f. signal is then applied to VT_2, the modulator control tube, whose plate voltage is supplied through R_5, VT_3 and R_4, VT_4. The a.f. signal on the grid of VT_2 will, by varying its plate current, cause the a.c. resistance of both VT_3 and VT_4 to vary. Since C_2 is an r.f. bypass condenser, these variations in resistance will be effectively a variable resistance across L_1; it will, therefore, change the frequency of the r.f. oscillator and thus produce the desired f.m.

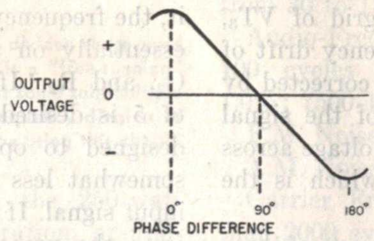


FIG. 12. Response characteristics of the phase detector used in Federal f.m. transmitters.

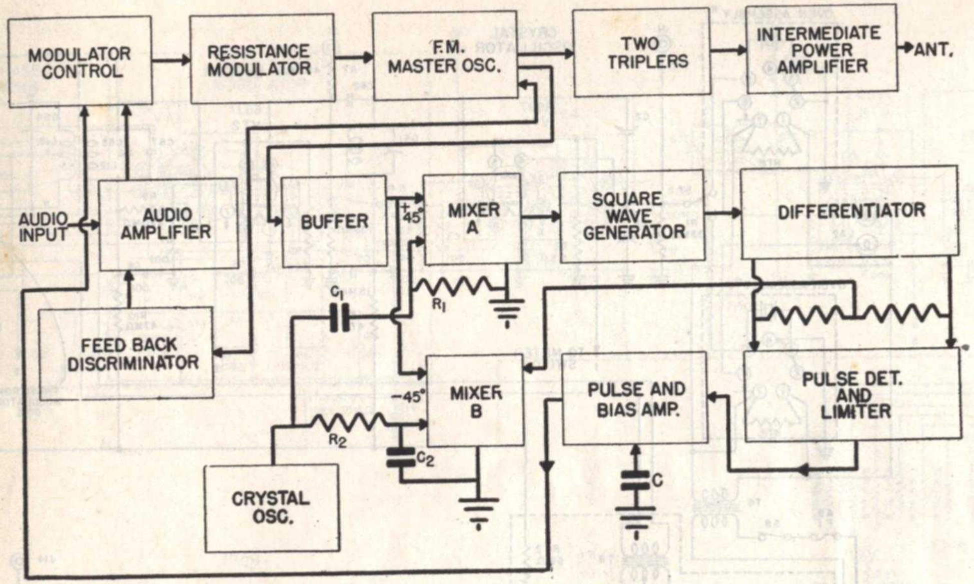


FIG. 13. Block diagram of the Westinghouse f.m. transmitter.

The r.f. oscillator uses VT_5 and VT_6 in a push-pull, tuned-grid, tuned-plate, shunt-fed oscillator circuit; its frequency of operation is controlled by C_3 and C_4. L_4 is the output tank coil. The modulated r.f. signal is applied to the first tripler stage from L_4.

Part of the modulated r.f. signal is coupled by L_2 to a Foster-Seeley discriminator circuit using VT_7 and VT_8. The demodulated a.f. voltage across R_6 and R_7 is coupled through C_5 and R_2 to the grid of the a.f. amplifier. This feedback voltage is out of phase with the original modulating signal. The results of this negative feedback are that the a.f. response is improved and irregularities in modulation are greatly reduced, producing a very linear frequency deviation.

To operate the frequency-correcting circuit, a portion of the modulated r.f. is coupled to it from L_3. The d.c. output of the frequency corrector is applied through R_3 to stabilize any drift of the LC oscillator.

Center Frequency Control System. The center frequency stabilizing circuit, shown in Fig. 13, uses pulses for obtaining the desired d.c. correcting voltage.

At this time we have not studied the pulse-generating, differentiating, limiting, and integrating circuits used in this frequency-correcting circuit. We will study them in a later lesson, at which time you should be able to understand the operation of any of the circuits in Fig. 13. For the present time, let us just go over its operation briefly.

The output of the master oscillator and the crystal reference oscillator are combined in two mixer circuits, A and B in Fig. 13. Since it is fed through R_1-C_1 and R_2-C_2, the crystal reference voltage applied to one mixer is 90° out of phase with that fed to the other. The output of each mixer is a beat note with a frequency equal to the

difference between the frequencies of the two signals. The beat note from mixer A is applied to a square wave generator and differentiator, where one positive and one negative pulse of voltage is produced by every cycle of the beat note. Because of the 90° phase shift in R_1-C_1 and R_2-C_2, the beat frequency output of mixer B will *lead* the output of A by 90° when the master oscillator frequency is higher than the crystal reference frequency, and will *lag* when the master oscillator frequency is lower. The output of mixer B, when applied along with the pulses from the differentiator to the pulse detector and limiter circuit, will cause only the positive pulses to be amplified when the frequency is too high and only the negative pulses when the frequency is too low. Positive pulses applied to condenser C will increase its voltage, negative pulses will decrease it. The d.c. voltage across this condenser is applied (as indicated before) to the modulator control tube to correct any frequency drift.

The advantages of this frequency correcting circuit are that there are no tuned circuits and no frequency dividers.

Performance Specifications.

Audio-Frequency Response: ±1 db from 50 to 15,000 cycles.

Audio-Frequency Distortion: 50-100 cycles and 7500-15,000 cycles, less than 1.5%; 100-7500 cycles, less than 1.0%.

F.M. Noise: At least 65 db down.

A.M. Noise: At least 50 db down.

Frequency Stability: ±1000 cycles.

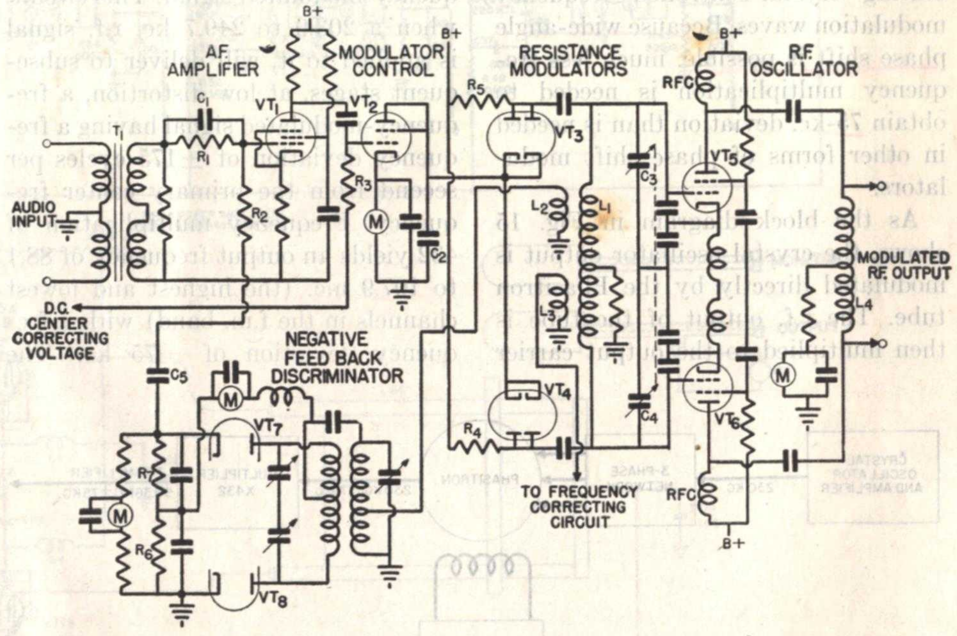


FIG. 14. The amplifier, modulator, oscillator, and negative feedback discriminator of the Westinghouse f.m. transmitter.

Phasitron F.M. Transmitters

General Electric, Gates, and Collins manufacture f.m. transmitters that use a special "Phasitron" tube to obtain wide-angle phase modulation. (By "wide-angle" we mean that large phase shifts occur—in other words, that the angle of phase shift is wide.) The block diagram of transmitters of this type is shown in Fig. 15.

A single crystal of the required frequency stability directly controls the output carrier frequency. Although the Phasitron tube is phase-modulated, the characteristics of the magnetic field controlling the modulation are such that the output is frequency-modulated. The use of the Phasitron tube results in an extremely simple, direct, and reliable method of generating crystal-controlled frequency modulation waves. Because wide-angle phase shift is possible, much less frequency multiplication is needed to obtain 75-kc. deviation than is needed in other forms of phase shift modulators.

As the block diagram in Fig. 15 shows, the crystal oscillator output is modulated directly by the Phasitron tube. The r.f. output of the tube is then multiplied to the output carrier frequency and amplified to the required power level.

THE PHASITRON MODULATOR

The 2H21 Phasitron tube is a special tube for producing wide-angle phase modulation of radio frequencies up to 500 kc. The basic phase modulator using this tube is shown in Fig. 16.

Fundamentally, the tube and circuit are designed to produce a rotating sheet of electrons in the Phasitron tube whose rate of rotation can be either increased or decreased by a varying magnetic field. When the desired modulating signal controls the magnetic field, the result is a frequency-modulated signal. This circuit, when a 203.9 to 249.7 kc. r.f. signal is applied to it, will deliver to subsequent stages, at low distortion, a frequency-modulated signal having a frequency deviation of ±175 cycles per second from the primary center frequency. Frequency multiplication of 432 yields an output frequency of 88.1 to 107.9 mc. (the highest and lowest channels in the f.m. band) with a frequency deviation of ±75 kc. The

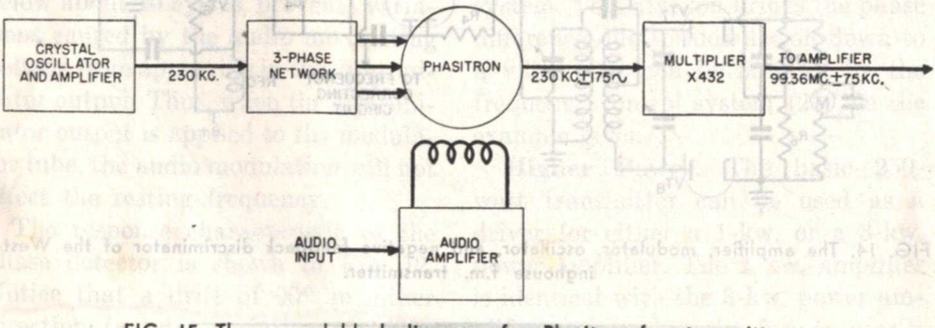


FIG. 15. The general block diagram of a Phasitron f.m. transmitter.

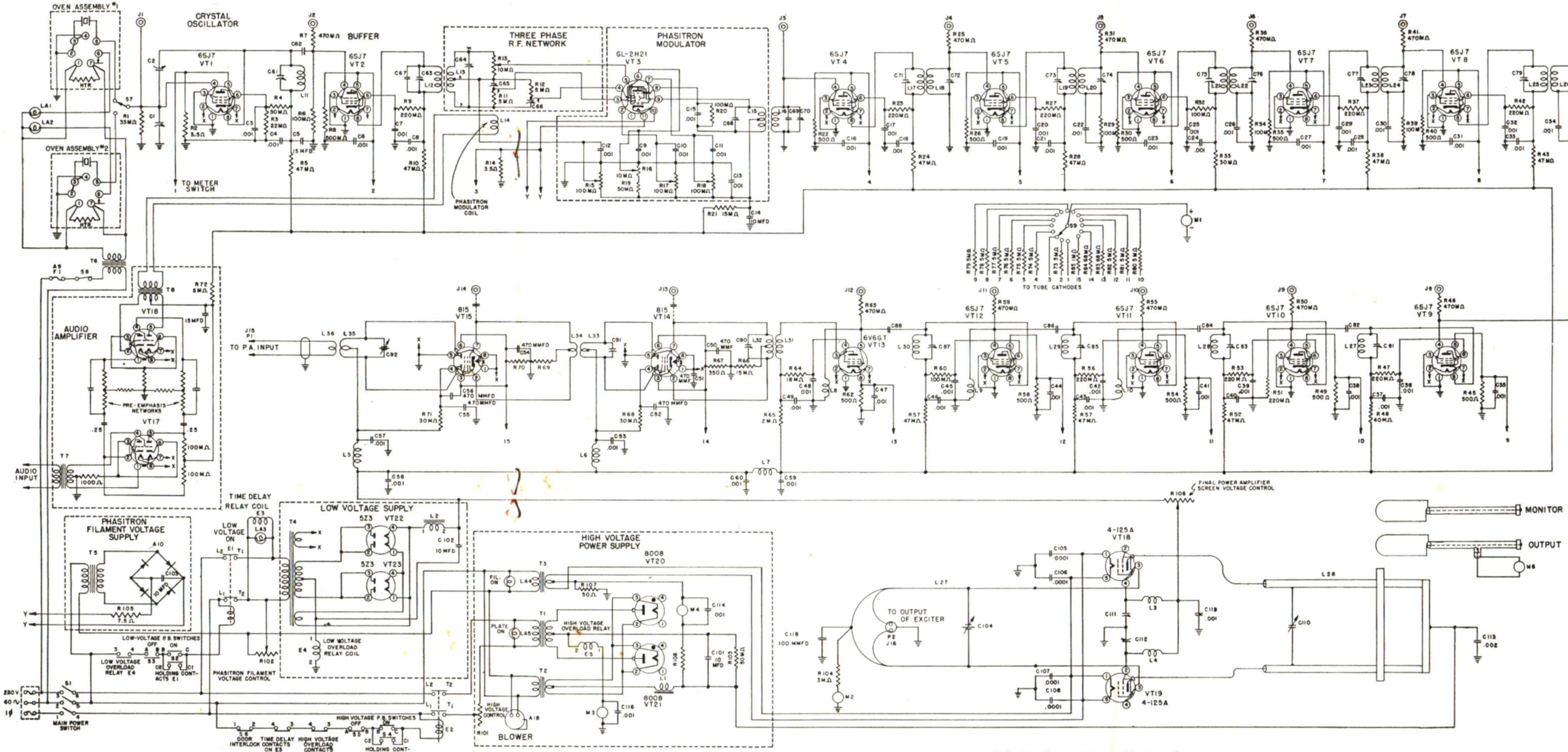


FIG. 24. Gates 250-watt Phasitron f.m. transmitter.

maximum audio-frequency power required to produce this modulation is approximately 50 milliwatts.

The operation of the tube can best be studied by referring to its construction. Fig. 17 shows the entire structure of the tube; Fig. 18 shows an enlarged cut-away view of the tube elements with each of the parts labeled.

Producing the Electron Disc. Anodes number one and two are at positive d.c. potentials and draw electrons from the cathode. The two focus electrodes form this electron stream into a thin sheet or disc. This electron disc, with the cathode as its axis, lies between the neutral plane and the deflector grid structure and strikes anode number one.

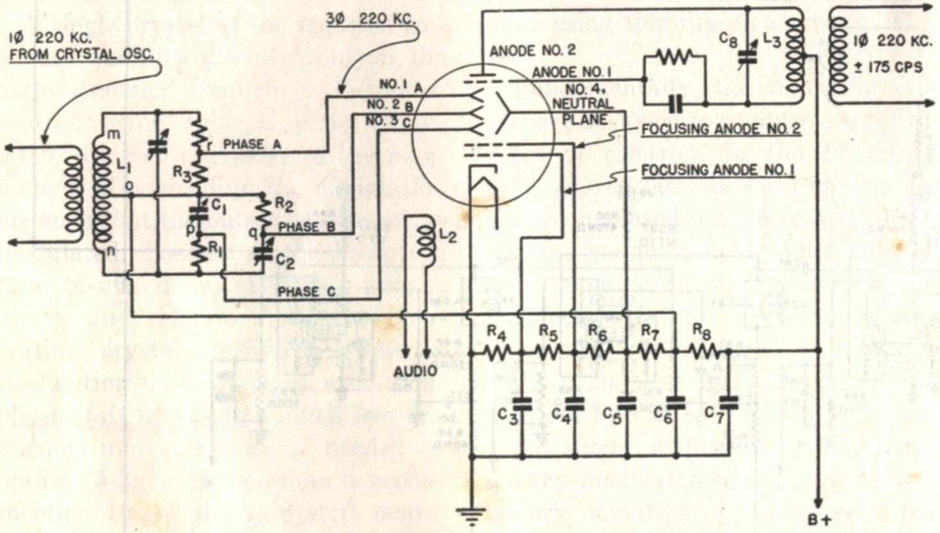


FIG. 16. Basic GL-2H21 Phasitron circuit.

Rotation of the Electron Disc. The deflectors consist of thirty-six separate wires, the active portions of which run radially out from the cathode. These wires are labeled A, B, and C in Fig. 18. All the A wires are connected together, all the B wires are connected together, and all the C wires are connected together. These three combinations of A, B, and C deflecting grids are brought out to the base of the tube and constitute the three deflectors, #1, #2, and #3. The neutral plane is connected to another pin on the base of the tube and is called deflector #4.

A three-phase, crystal-controlled voltage is applied to the deflectors, one phase to each of the first three deflectors. This is done to produce a rotation of the electron disc. The deflecting action these three-phase voltages have on the disc of electrons passing between the neutral plane and the deflector grids is shown in Fig. 19. At instant one, the grid wires A are positive with respect to the neutral plane while grid wires B and C are negative. This causes a distortion of the rim of the electron disc, making it appear, when viewed from the side, like curve D in Fig. 19. Fig. 20 shows how the disc would look in perspective if you

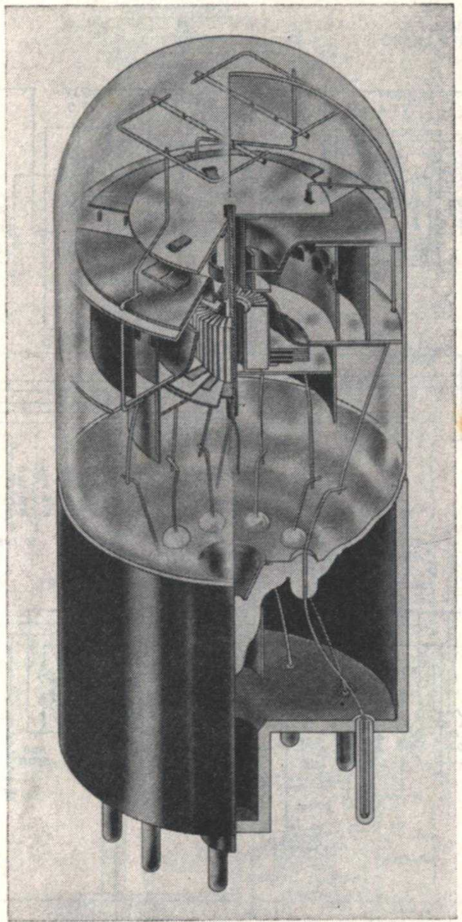

Courtesy General Electric

FIG. 17. A cut-away view of the Phasitron tube used in many phase-modulated indirect f.m. systems.

could see it. Notice that it is distorted into twelve sine waves.

At instant two, one-third of a cycle later, deflector wire B is positive and A and C are negative. This gives the disc rim the shape shown as curve E in Fig. 19, which is the same shape as curve D but has moved to the right by the space between adjacent grid wires. The disc, if it were visible, would therefore have the same appearance that it has in Fig. 20, except that it would appear to have rotated to the right a distance equal to the space between two grid wires.

Similarly, at instant 3, when deflector wire C is positive and A and B are negative, the disc would appear to have shifted to the right another grid spacing. Curve F of Fig. 19 represents the shape of the disc edge under these conditions.

Thus, a three-phase voltage applied to the deflecting grids will cause the distorted electron disc to rotate at a rate determined by the applied frequency and the number of deflector wires. (In this case, the speed of rotation is 1/12 the frequency of the r.f. voltage; for example, if the r.f. is 240 kc., the rotation is 20 kc.)

R.F. Output Circuit. A view of a portion of anode number one is shown in Fig. 21. This anode has twelve holes punched above the line where the undeflected electron disc strikes and twelve punched below. The rotating edge of the electron disc therefore meets this series of holes when the disc is deflected by the deflector grids. At an instant when the disc edge has the shape shown by the solid line, most of the electrons pass on through the holes

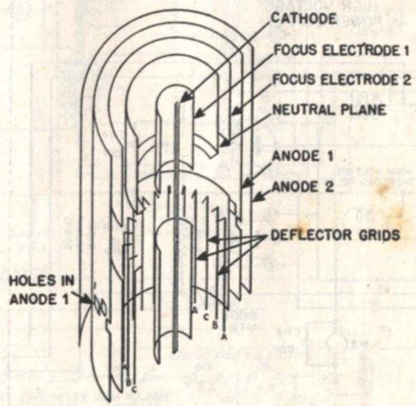


FIG. 18. Cut-away view of tube elements.

to anode number two. One half cycle later, the edge of the disc has moved on to the position shown by the dotted line. At this instant, few, if any, electrons get through to anode number two. Thus, the current flowing to anode number two varies sinusoidally at the crystal frequency, and *any variation in the angular velocity of rotation of the electron disc will result in a phase variation of this output r.f.*

the current. This displacement of the electron disc causes a phase shift in the output r.f. current while the displacement is going on.

Audio-frequency current flowing in the coil of Fig. 22 causes angular displacements that vary at the audio-frequency rate to be superimposed on the rotation of the electron disc. Thus, we obtain phase shifts varying at the audio-frequency rate in the output current.

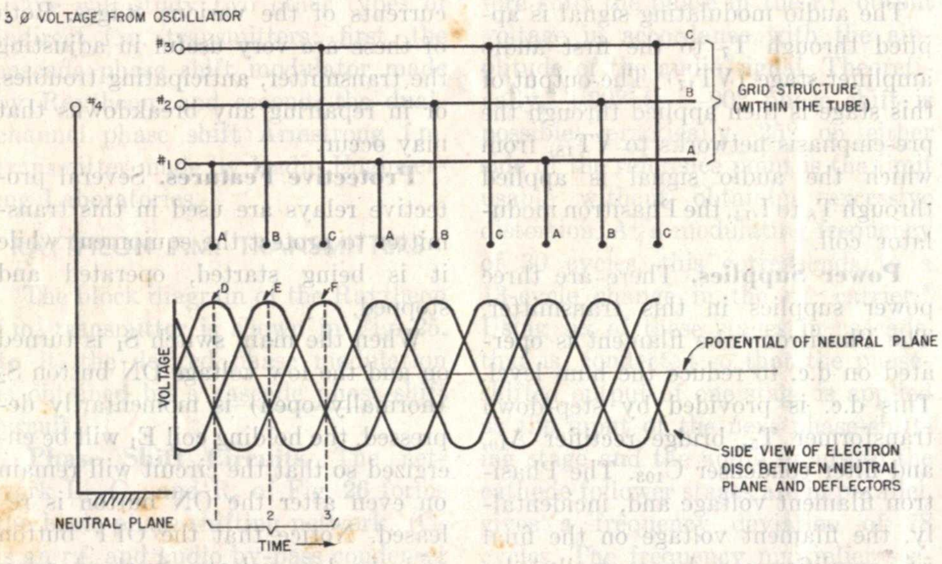


FIG. 19. Grid structure and neutral plane of a Phasitron tube.

Phase Modulation. The modulating agent is a magnetic coil or solenoid placed around the tube as shown in Fig. 22. The magnetic field resulting from current flowing in this coil is perpendicular to the plane of the electron disc. The magnetic field of the electrons in the electron disc reacts with the magnetic field of the coil; as a result, the disc undergoes an angular displacement. The direction of displacement depends on the direction of current flow in the coil, and the amount of displacement on the amplitude of the current. This current flowing through a load impedance develops a phase-modulated r.f. voltage whose average frequency is that of the crystal.

Inherent Pre-Distortion. To convert this phase modulation to frequency modulation, the amount of phase shift (as you learned in our study of pre-distorters in a previous lesson) must be inversely proportional to the frequency of the modulating signal. No special circuit is required to produce this effect in the Phasitron circuit, because the coil of Fig. 22 is essentially inductive over the entire audio range. Since the amount of current through a coil is inversely proportional to the frequency, and the amount of phase shift in the Phasitron is proportional to the current flowing, the output of a Phasitron phase modulator is a frequency-modulated signal. Effectively, the coil does the pre-distorting.

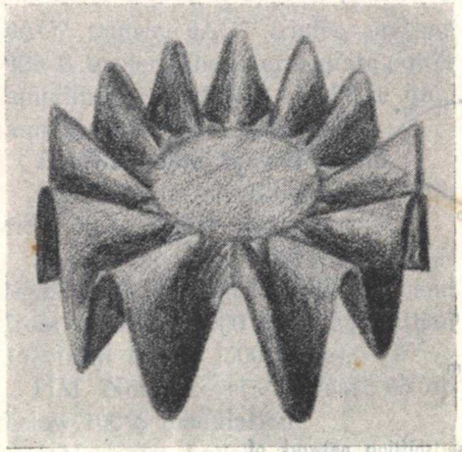


FIG. 20. Perspective view of deflecting action of 3-phase voltage on electron disc as used in Phasitrons.

Magnetic Shielding. Since the Phasitron tube is affected by magnetic fields, a magnetic shield is placed around it and the deflecting coil. Raw a.c. applied to the filament heaters would produce a varying magnetic field in the tube that would cause undesired frequency modulation that would appear as hum in the receiver output. To prevent this, Phasitron filaments are generally operated on d.c.

► Wide-angle phase deviation is possible in the Phasitron circuit. Since there are twelve r.f. cycles on the electron disc, a displacement of only 1/12 cycle of the rotating electron disc is 360° (one cycle) of the r.f. signal. This makes it possible to obtain wide phase deviation, and therefore, high frequency deviation, so that fewer frequency multiplier stages need be used

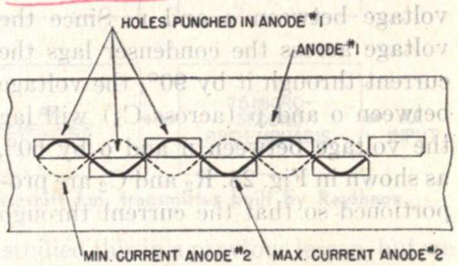


FIG. 21. A portion of anode #1. Only the current passing through the holes reaches anode #2.

than in other indirect f.m. systems.

Although deviations in excess of 360° are possible, practically, a 330° phase shift at 30 cycles is the limit used. This produces the 175-cycle frequency deviation already mentioned.

Three-Phase R.F. Voltage Source. Let us now see how the necessary

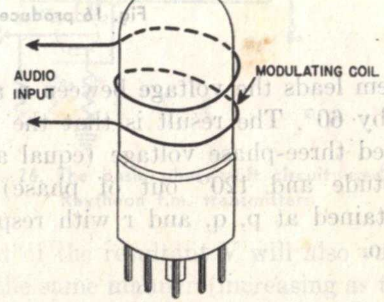


FIG. 22. Modulating coil placed around tube.

three-phase r.f. voltage for the three sets of deflection grids is obtained. The circuit is shown in Fig. 16.

As shown in the vector diagram of Fig. 23, points m and n in Fig. 16 are 180° out of phase with respect to o. A portion of the voltage between m and o is taken from R_3 to the #1 set of deflector grids. The RC combinations R_1C_1 and R_2C_2 are used to obtain the other two phases. The values of R_1 and C_1 are chosen so that the current through them leads by 30° the voltage between o and n. Since the voltage across the condenser lags the current through it by 90°, the voltage between o and p (across C_1) will lag the voltage between n and o by 60°, as shown in Fig. 23. R_2 and C_2 are proportioned so that the current through them leads the voltage beween n and o by 60°. The result is that the desired three-phase voltage (equal amplitude and 120° out of phase) is obtained at p, q, and r with respect to o.

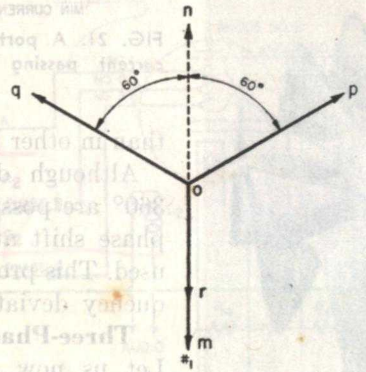


FIG. 23. How the phase shifting network of Fig. 16 produces a three-phase r.f. voltage.

GATES F.M. TRANSMITTERS

The complete circuit diagram of the Gates 250-watt Phasitron f.m. transmitter is shown in Fig. 24. (Because of its size, this diagram has been placed on pages 19-21.) Let us study it in detail.

Circuits. Two crystals and crystal ovens are used; one is a spare for emergency use. The thermostatic switch for controlling oven temperature is connected between terminals 6 and 7 in each oven assembly. Lamps LA_1 and LA_2 indicate when the two oven heaters are on. Notice that the heater voltage is supplied by T_6 and that the main power switch S_1 does not turn these heaters off; S_8 is kept closed at all times to keep both crystals at the proper operating temperature. Switch S_7 is used to switch from one crystal to another. The crystal oscillator stage (VT_1) is a form of Colpitts oscillator in which C_1 and C_2 provide a fine control of oscillator frequency.

The second stage (VT_2) is an r.f. amplifier and buffer. The single phase output of this stage is converted to a three-phase output to operate deflector grids of the Phasitron by the network L_{13}, C_{64}, R_{13}, C_{65}, R_{11}, C_{66}, and R_{12}. The action of this network is like that of the similar net in Fig. 16 that we have already studied.

R_{15}, R_{16}, R_{17}, and R_{18} are used to adjust the d.c. level of the elements in the Phasitron. R_{15} controls the d.c. voltage on the three sets of deflecting grids, and R_{17} the d.c. level on the neutral plane. R_{16} and R_{18} are used to adjust the first and second focusing anodes respectively.

The frequency-modulated output of the Phasitron is fed to five doubler stages, three tripler stages, and three amplifier stages (VT_4 through VT_{14}) and the output drives the intermediate power amplifier using VT_{15}, which is an 815. This exciter drives the two 4-125A's (VT_{18} and VT_{19}) used as the final power amplifier.

The audio modulating signal is applied through T_7 to the first audio amplifier stage (VT_{17}). The output of this stage is then applied through the pre-emphasis networks to VT_{18}, from which the audio signal is applied through T_8 to L_{14}, the Phasitron modulator coil.

Power Supplies. There are three power supplies in this transmitter. The Phasitron tube filament is operated on d.c. to reduce the hum level. This d.c. is provided by step-down transformer T_5, bridge rectifier A_{10}, and filter condenser C_{103}. The Phasitron filament voltage and, incidentally, the filament voltage on the final r.f. amplifier can be controlled by varying R_{102}.

The d.c. voltage for all other circuits except the plates of the final power amplifier is obtained from the low voltage power supply using two 5Z3's (VT_{23} and VT_{22}). A choke input filter is used. The screen voltage on the final power amplifier stage can be varied by R_{106}.

The high voltage supply for the plates of the final power amplifier employs two 8008 tubes (VT_{20}, VT_{21}). A choke input filter is also used in this supply. Meter M_4 indicates the d.c. voltage output and M_3 the current supplied by this stage. R_{101} is a fine control of the high voltage.

The three rheostats R_{101}, R_{102}, and R_{106} permit the r.f. power output of this transmitter to be varied from 50 to 320 watts.

Adjustment Indicators. A series of jacks (J_1, J_2, etc.) are used to permit observation on an oscilloscope of the voltages at various points in the circuit. Meter M_1 is used to measure cathode voltages and hence cathode currents of the various stages. Both of these are very useful in adjusting the transmitter, anticipating troubles, or in repairing any breakdowns that may occur.

Protective Features. Several protective relays are used in this transmitter to protect the equipment while it is being started, operated and stopped.

When the main switch S_1 is turned on and the low voltage ON button S_2 (normally open) is momentarily depressed, the holding coil E_1 will be energized so that the circuit will remain on even after the ON button is released. Notice that the OFF button and the low voltage overload relay contacts are normally closed. The low voltage d.c. supply, the Phasitron filament supply, the a.c. filaments to all stages (including the final), and the blower A_{18} for air-cooling the final stage are now operating and the time delay relay (E_3) is started. After the proper time delay, the normally open contacts on this relay (E_3) are closed. Since the high-voltage overload contacts are normally closed, it is now possible (presuming the door interlock switch is closed) to turn on the high-voltage supply and operate the complete transmitter.

If at any time there should be an overload on the high-voltage supply, the overload relay (E_5) contacts will open, removing the high voltage. The transmitter door may then be opened to locate the trouble. The other d.c. voltages and filaments will remain on, and all stages except the final will continue to operate. However, an overload in the low voltage source will open the contacts of relay E_4 and turn the entire transmitter off.

Miscellaneous Indirect F.M. Transmitters

We will study two other types of indirect f.m. transmitters; first, the cascade phase shift modulator made by Raytheon, and second, the dual-channel phase shift Armstrong f.m. transmitter made by Radio Engineering Laboratories.

RAYTHEON F.M. TRANSMITTERS

The block diagram of the Raytheon f.m. transmitter is shown in Fig. 25. In it, the desired phase modulation is obtained by a cascade phase-shift circuit.

Phase Shift Circuits. The network L_1, C_1, and R_c of Fig. 26 forms the basic phase-shifting network. (C_2 is an r.f. and audio by-pass condenser and R_c is the output impedance of cathode follower VT_2, which is essentially R_1 in shunt with a resistance whose value is the reciprocal of the transconductance of the tube.) The reactance of C_1 is twice that of L_1 at the operating frequency. When R_c is high, the network is essentially inductive and the voltage to VT_1 *leads* the input voltage. However, if R_c is low in value, more current flows through C_1 than L_1; the output voltage then *lags* the input voltage.

An audio voltage applied to VT_2 will vary the value of R_c and therefore shift the phase of the r.f. output voltage in accordance with the amplitude of the audio signal. Theoretically, +90° to —90° phase shift is possible; practically, 25° on either side of the reference point is the limit usable without obtaining excessive distortion. At a modulating frequency of 30 cycles, this corresponds to a 13-cycle change in the r.f. carrier.* Using six of these stages in cascade, that is, connected so that the phase-shifted output of one stage is applied as the input of the next phase-shifting stage and the audio inputs to the cathode follower stages are in parallel, gives a frequency deviation of 78 cycles. The frequency multiplier section multiplies this by a factor of 972, producing a frequency deviation of over 75 kc.

R.F. Multiplier and Amplifier. Because of the multiplier action, the crystal oscillator must be 1/972 the desired output frequency. For example, the crystal should operate at 95.5761 kc. for a 92.9-mc. carrier.

The frequency multiplier section has a 6SJ7 doubler, 6SJ7 tripler, 6SJ7 amplifier, 6SJ7 doubler, 6AC7 tripler, 6AC7 tripler, 6AC7 tripler, and an 829-B tripler. The intermediate power amplifier is an 829-B, and the final amplifier uses two 4-125-A's.

* $dF = 0.175 \times \theta \times F_m$
$= 0.175 \times 25 \times 30 = 13$ cycles.

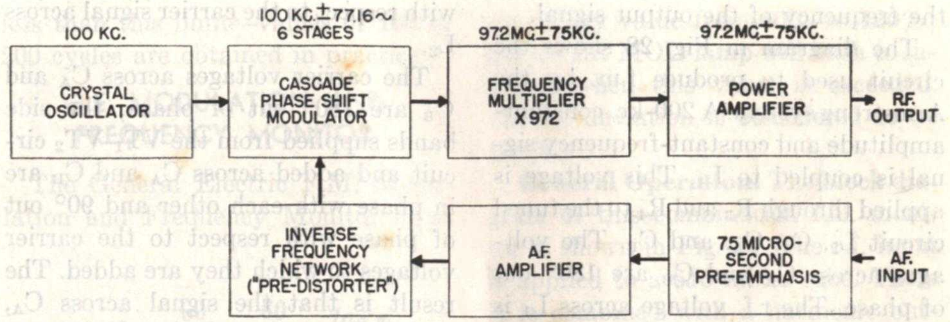


FIG. 25. A block diagram of the cascade Phaseshift f.m. transmitter built by Raytheon.

Performance Specifications.

Audio-Frequency Response: ±1 db from 50 to 15,000 cycles.

Audio-Frequency Distortion: Less than 1½% from 50 to 100 cycles and from 7500 to 15,000 cycles; less than 1% from 100 to 7500 cycles.

F.M. Noise Level: At least 65 db below 100% modulation.

A.M. Noise Level: At least 50 db below 100% modulation.

Frequency Stability: Better than ± 1000 cycles (well within the ± 2000-cycle variation allowed by the FCC).

ARMSTRONG-REL F.M. TRANSMITTER

The Armstrong dual-channel phase-shift type of f.m. transmitter is manufactured by Radio Engineering Laboratories. This type of f.m. transmitter uses a.m. to produce p.m., which in turn produces f.m. Let us see how it is done.

Using A.M. to Produce F.M. The vector diagrams in Fig. 27 illustrate the principle used to produce f.m. by the Armstrong system. You have studied this in a previous lesson, but we will review it briefly now to refresh your memory.

If we have a constant-frequency constant-amplitude r.f. carrier V_1 (Fig. 27A), and add to it an r.f. carrier V_2 that leads V_1 by 90°, then the resultant V will also lead V_1. If the amplitude of V_2 varies, the amount of

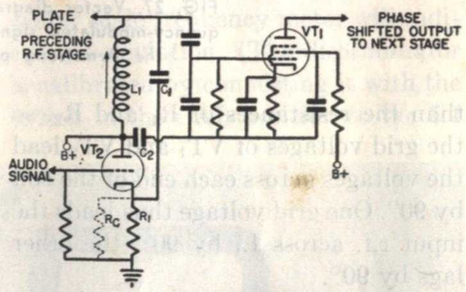


FIG. 26. The basic phase-shift circuit used in Raytheon f.m. transmitters.

lead of the resultant V will also vary in the same manner (increasing as the amplitude increases). Variations in the lead angle of the resultant appear as variations in the frequency of the output signal.

Similarly, as shown in Fig. 27B, a voltage V_2 90° behind the carrier voltage V_1 will produce a lagging resultant V. If V_2 varies in amplitude, the lag angle of resultant V will vary in the same manner, producing variations in the frequency of the output signal.

The diagram in Fig. 28 shows the circuit used to produce f.m. by the Armstrong system. A 200-kc. constant-amplitude and constant-frequency signal is coupled to L_1. This voltage is applied through R_3 and R_4 to the tuned circuit L_2, C_4, C_A, and C_B. The voltages across C_A and C_B are 180° out of phase. The r.f. voltage across L_1 is also applied through R_1C_1 and R_2C_2 to the grids of the two modulator tubes VT_1 and VT_2. The capacitive reactances of C_1 and C_2 are much higher

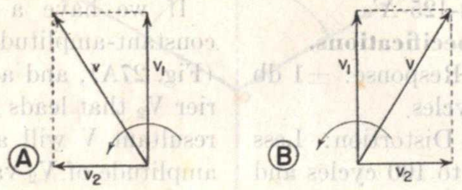


FIG. 27. Vector diagrams showing how a frequency-modulated signal can be produced by the Armstrong phase-shift method.

than the resistances of R_1 and R_2, so the grid voltages of VT_1 and VT_2 lead the voltages across each end of the coil by 90°. One grid voltage thus leads the input r.f. across L_1 by 90°, the other lags by 90°.

Since the grids are fed in push-pull and the plates of VT_1 and VT_2 are connected in parallel, the r.f. voltage outputs of VT_1 and VT_2 cancel when there is no audio modulation applied to them. However, when a push-pull audio signal is applied to the screen grids of VT_1 and VT_2, an unbalance occurs that permits part of the carrier to be applied to the output through L_3 and C_3. As a matter of fact, the output is a double-side-band suppressed-carrier a.m. signal; however, because of the phase shift in R_1C_1 and R_2C_2, these side bands are shifted 90° with respect to the carrier signal across L_2.

The carrier voltages across C_A and C_B are 180° out of phase; the side bands supplied from the VT_1-VT_2 circuit and added across C_A and C_B are in phase with each other and 90° out of phase with respect to the carrier voltages to which they are added. The result is that the signal across C_A, consisting of the resultant of the carrier and a varying-amplitude side band 90° out of phase with the carrier, is increasing in amount of phase *lag* at the same time that the phase *lead* of the resultant across C_B increases. Thus the frequency across C_A decreases at the same time that the frequency across C_B increases. On the next half cycle of the audio modulating signal, the signal frequency across C_A *increases* as that across C_B *decreases*.

Frequency Multiplication. The amount of frequency deviation produced by this method is quite small; 9.65 cycles is the maximum, which is only an 18° phase shift at 30 c.p.s. To multiply this deviation to a value of 75 kc., a dual-channel frequency multiplier chain is used.

Each chain consists of four triplers, producing a multiplication of 81. The output of each is therefore 16,200 kc. with a deviation of 781 cycles. The deviation of one chain, however, is

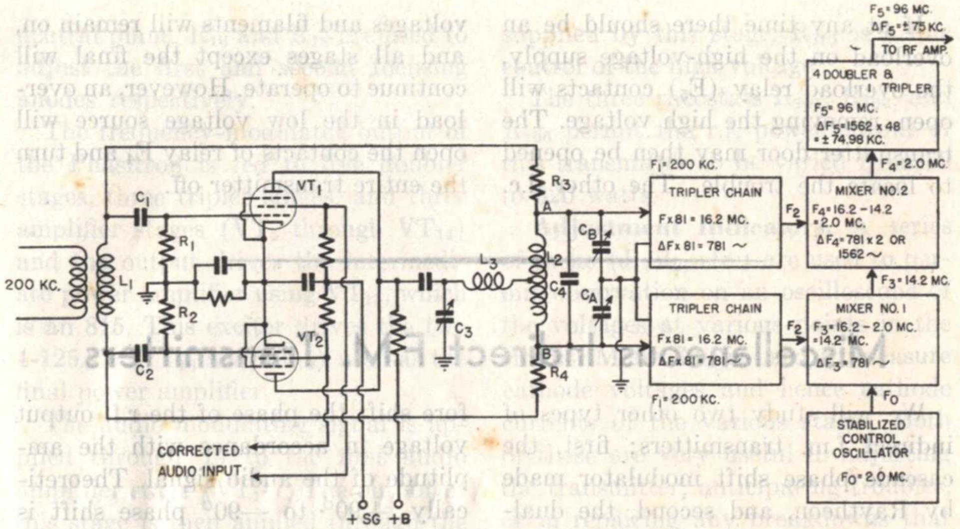


FIG. 28. REL-Armstrong modulator and multiplier chains.

781 cycles above 16,200 at the same time that the other is 781 cycles below 16,200 kc., so the total swing is 1562 cycles. A multiplication of 48 is still needed to make this into a swing of over 75 kc., but the 16,200 kc. carrier is too high to be multiplied by 48 and still be in the 88-108 mc. band. To overcome this difficulty, the frequency deviation of 1562 cycles is superimposed on a much lower carrier and the 16,200 kc. carrier is removed.

For example, if a 96-mc. output resting frequency is desired, the 1562 cycle deviation is superimposed on a 2000-kc. carrier, then the composite signal is multiplied by 48. This is done by applying a 2000-kc. crystal-stabilized signal and the output of one tripler chain to mixer No. 1 (Fig. 28). The difference frequency in the output of this mixer is 14,200 kc. with a deviation of 781 cycles. The output of mixer No. 1 is applied to mixer No. 2, where it is mixed with the output from the other tripler chain to produce a difference frequency of 2000-kc. (the original 2000-kc. signal applied to mixer No. 1) with a total frequency deviation of 1562 cycles. This signal is applied to four doublers and a tripler (multiplication factor of 48), producing the desired 96-mc. carrier with a frequency deviation of 75 kc.

A major advantage of this system of dual-channel frequency multiplication is that the frequency stability of the output carrier depends *only* on the stability of the 2000-kc. oscillator. Any drift in the original 200-kc. signal will cancel in the two mixers. Even so, the 200-kc. signal is usually crystal-controlled to prevent a large drift from causing the tripler stages to operate too far off resonance.

Higher Power. The output of the modulator stage of the REL transmitter is 30 watts; this is used to drive an amplifier using two 4-125A tubes for 250 watts output. This can in turn be used to drive either a 1-kw. grounded-grid or a 3-kw. grounded-cathode amplifier.

For still higher powers, the 1-kw

transmitter can drive a 10-kw. amplifier and that, in turn, a 50-kw. amplifier.

Performance Specifications. The system of using phase modulation to produce f.m., it is claimed, results in very low noise and distortion. The performance specifications are:

Audio-Frequency Response: ±1 db from 50 to 15,000 cycles.

Audio-Frequency Distortion: Less than 1½% between 50 and 15,000 cycles.

F.M. Noise Level: At least 70 db below 100% modulation.

A.M. Noise Level: At least 60 db below 100% modulation.

Frequency Stability: Less than 2000 cycles.

F.M. Modulation Monitor and Frequency Deviation Meters

The FCC requires that all broadcast stations be continuously monitored to indicate frequency drift and the percentage of modulation of the transmitter at all times. In f.m. broadcast stations, one combination instrument usually performs both these functions and provides an aural monitoring signal as well. Before we study this instrument, let us learn something about the general requirements of f.m. monitors.

MODULATION MONITORS

A modulation monitor must have a modulation peak indicating device that can be set to any pre-determined value from 50 to 120% modulation and that indicates either positive or negative swings.

The scale of the modulation meter is similar in appearance to a standard VU meter and has a 133% modulation mark (100-kc. deviation) indicated on it. A meter scale meeting these requirements is shown in Fig. 29. The FCC requires that the f.m. modulation meter be much quicker in action than a VU meter. It, therefore, has different dynamic characteristics from a standard VU meter and is calibrated in db rather than in VU.

Considerably more power is necessary to operate this quicker responding meter. A VU meter with a bridge rectifier has an impedance of 7500 ohms and can be connected across a 600-ohm line without excessive loading, but an f.m. meter would take considerable power if it were connected across a 600-ohm line. Generally, therefore, a rectifier and d.c. amplifier are used to operate the meter.

FREQUENCY DEVIATION MONITORS

Any frequency deviation monitor should be more stable than the source it is to measure. The FCC requirements for f.m. broadcast monitors are that they have less than 1000 cycles variation under all ordinary changes of temperature, humidity, power supply voltage, and other conditions affecting the frequency monitor's accuracy that are encountered in the United States. The frequency variation of most monitors is generally far

less than this limit—values of 100 or 200 cycles are obtained in practice.

G.E. MODULATION AND FREQUENCY MONITOR

The General Electric F.M. Modulation and Frequency Monitor is an

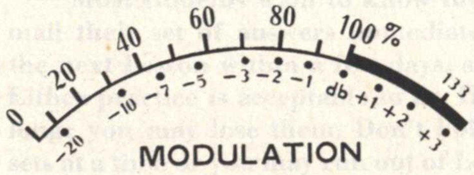
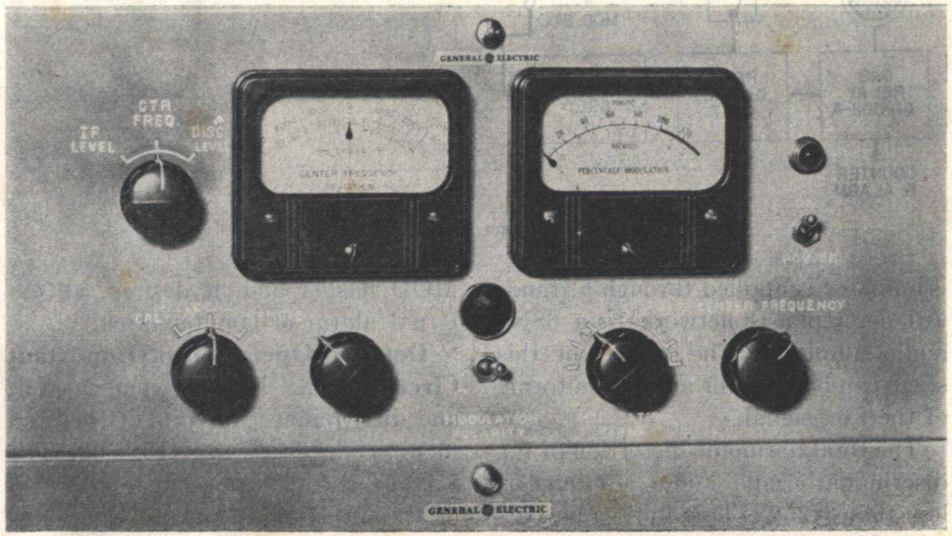


FIG. 29. The scale used on f.m. modulation monitor instruments.

example of the type of monitor used in f.m. broadcast stations. A front view of it is shown in Fig. 30. The left hand scale indicates the center frequency deviation from +3000 to —3000 cycles and the right hand scale indicates the percentage modulation. The modulation peaks control can be set to any value from 50% to 120%; the OVER MOD lamp will flash to indicate when this value is exceeded. (75-kc. deviation is considered to be 100%.)

General Operation. The block diagram of this combination f.m. monitor is shown in Fig. 31. The r.f. input is applied to a 6J6 mixer tube. There it is combined with a harmonic output of the crystal oscillator (when the switch is in the RUN position, which is its normal one) and a difference frequency of 5.4 mc. is obtained. After all amplitude variations are effectively removed in the p.a. limiter stage and the compensation circuit, this 5.4-mc. is fed to the discriminator.

When the transmitter is on frequency, the average d.c. output of this discriminator is zero, and the zero center scale frequency meter will indicate no deviation. (The discriminator is calibrated by connecting it with the switch in the CAL position to the 5.4



Courtesy General Electric

FIG. 30. This is a front view of the General Electric combination FM Modulation and Frequency Monitor. The frequency deviation meter is on the left; the modulation percentage meter is on the right.

mc. reference crystal oscillator and adjusting for zero output.)

A drift in the f.m. transmitter will cause a d.c. output; its polarity will indicate the direction of drift and its amplitude the amount of drift. This will be shown on the center frequency meter.

The audio-signal output of the discriminator is applied through a standard de-emphasis network to a 6SN7 audio amplifier. The output of this stage can be used for aural monitoring of the f.m. signal.

The total harmonic distortion of the discriminator and audio amplifier is less than 0.25%. This low value permits this output to be used in measuring the over-all distortion of the f.m. system being monitored. The output is also applied through a polarity reversing switch (MOD POL) and through an amplifier using a 6SL7 to a 6SL7 rectifier and d.c. amplifier. The output of this amplifier operates the per cent MOD meter.

The amplified d.c. can also be used to trigger a GL-502-A thyratron as a gas relay tube to operate the OVER-MOD flasher and, if desired, an external alarm or counter circuit.

Detailed Operation of Important Circuits. The limiter, compensator, and discriminator circuits of this f.m. monitor are shown in Fig. 32. The 5.4 mc. signal is applied to the grid of the 6AG7 limiter stage; the stage output is applied inductively through L_1C_2 and directly through C_3 to L_2L_3 and C_4 and thence to the discrim-

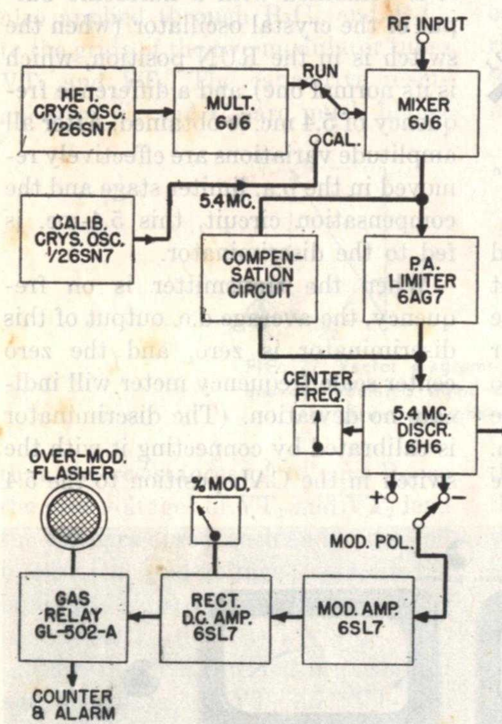


FIG. 31. Block diagram of the GE f.m. monitor.

inator using the 6H6. The voltage at point d is the vector sum of the voltage across L_2 and the r.f. voltage through C_3; the voltage at point e is the vector sum of the voltage across L_3 and the r.f. voltage through C_3. Since the L_2 and L_3 voltages are 180° out of phase with each other and 90° out of phase with the voltage through C_3 at resonance, the voltages at points d and e are equal as long as the input has a frequency of 5.4 mc. (the resonant frequency of the L_2-L_3-C_4 circuit). (The action of the circuit to this point is exactly the same as that of a Seeley discriminator.)

Since d is connected to one diode plate of the 6H6 and e connected to the cathode of the other diode, the current flow through the two diode sections is such that the voltages across C_5 and C_6 will add. These two voltages are equal as long as the voltages at d and e are equal. The common point between the two condensers is connected to ground. The frequency adjustment potentiometer R_4 is adjusted until there is no current flow through the frequency meter.

However, when the input i.f. differs from 5.4 mc., the voltage at d and e will be unequal. The d.c. voltages across C_5 and C_6 will no longer be equal—that is, the *ratio* of the two voltages will change. There will then be current flow from the arm on R_4 through the frequency meter and to ground through the polarity switch. This will cause a meter deflection that will indicate the amount of frequency deviation. This form of "ratio" detector frequency discriminator is used in this circuit because it permits the frequency deviation to be indicated directly on a meter without d.c. am-

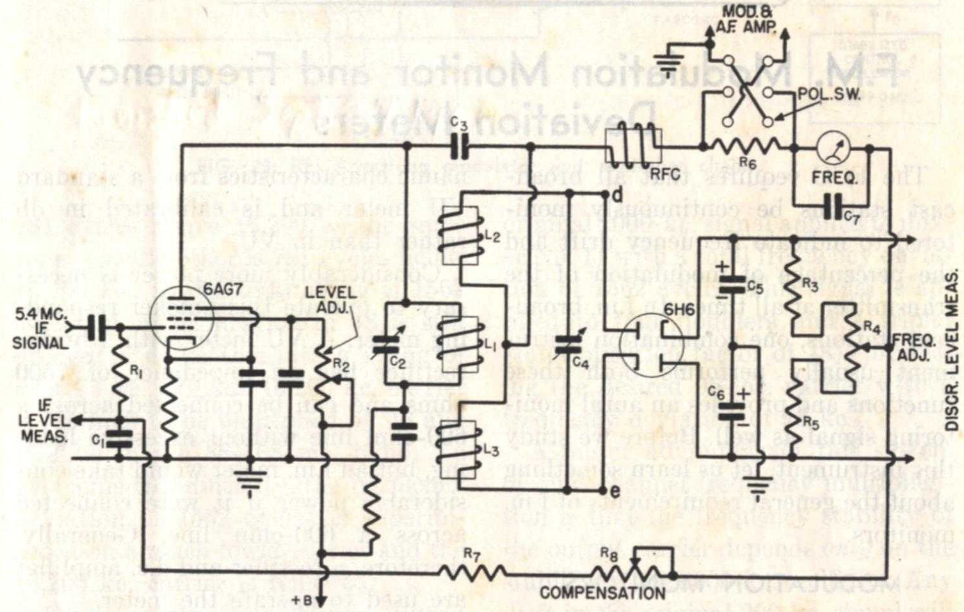


FIG. 32. The limiter, compensator, and discriminator circuits of the GE f.m. monitor.

plification. (Since the voltages across C_5, C_6, R_3, R_4, and R_5 all vary in accordance with the amplitude of the audio modulating signal, C_7 is used to by-pass audio variations around the meter so that it indicates only the *average* frequency deviation of the transmitter—that is, the drift.)

The audio signal across R_6 indicates the frequency deviation at any instant. This signal is applied to the audio amplifier and operates the modulation percentage meter as indicated before.

► The compensation circuit is used to counterbalance any amplitude variations in the input i.f. to the limiter stage. Harmonics are generated by the limiter action of the 6AG7, and their amplitude will vary when the input i.f. level changes even though the output amplitude does not vary. The discriminator output will be affected by these harmonics. It has been found that a part of the 6AG7 rectified grid voltage across C_1 can be coupled to the frequency meter to correct this slight amplitude variation. R_7 and R_8 are used to control the amount of compensation.

Lesson Questions

Be sure to number your Answer Sheet 47RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. What is the main advantage of the regenerative ring modulator used for frequency division?

2. What amount of frequency deviation corresponds to 133% modulation in standard wide band f.m. transmitters?

3. Over what range of phase differences will the ordinary phase discriminator operate?

4. What is the practical limit of phase shift per stage usable in the basic cascade phase shift modulator?

5. Why is a three-phase r.f. signal required in a Phasitron tube circuit?

6. Where does the pre-distorting occur in a Phasitron indirect f.m. transmitter?

7. What would occur if raw a.c. were applied to the filament heaters in a Phasitron tube?

8. What is the limit of the amount of phase shift used in practical Phasitron modulators?

9. Why is the f.m. modulation percentage meter calibrated in db rather than VU?

10. Why is a form of the ratio f.m. detector used, as shown in Fig. 32, instead of the conventional Foster-Seeley discriminator in f.m. frequency monitors?

TAKE TIME

Here is a quotation from the *Santa Fe Magazine* which appealed to me as containing much good, common sense. I hope you too will enjoy it—perhaps profit by it:

"Take time to live. That is what time is for. Killing time is suicide.

"Take time to work. It is the price of success.

"Take time to think. It is the source of power.

"Take time to play. It is the fountain of wisdom.

"Take time to be friendly. It is the road to happiness.

"Take time to dream. It is hitching your wagon to a star.

"Take time to look around. It is too short a day to be selfish.

"Take time to laugh. It is the music of the soul.

"Take time to play with children. It is the joy of joys.

"Take time to be courteous. It is the mark of a gentleman."

J. E. SMITH