

CHAPTER IV

TRANSMITTER : CIRCUIT COMPONENTS

General

Radio waves present a very convenient agency for transmitting aural and visual intelligence over considerable distances and areas without the need of any interconnecting wires. Radio systems are in common use for sending and receiving ;

1. Code signals (radio telegraphy.)
2. Aural (sound) intelligence in the form of speech and musical tones.
3. Fixed graphic material (facsimile and teletype.)
4. Transient visual images (television programs.)

Radio systems can be divided into two classes: communications systems and broadcast system.

In communications systems, intelligence is transmitted between two or more definite desired points, and the intelligence is generally intended only for the particular receiving station(s) to which it is transmitted.

In broadcasting systems, the intelligence transmitted is intended for reception by any person, within the service range of the transmitter, which possesses the necessary receiving equipment.

Broadcast transmitters represent the highest development of radio-telephone transmitters with respect to stability of carrier frequency, bandwidth, low distortion and voice, etc. Such transmitters normally consist

of a crystal oscillator followed by several buffer-amplifier stages, a modulated amplifier, audio-frequency modulating system, etc., plus accessories such as protection equipment, monitoring facilities, etc.

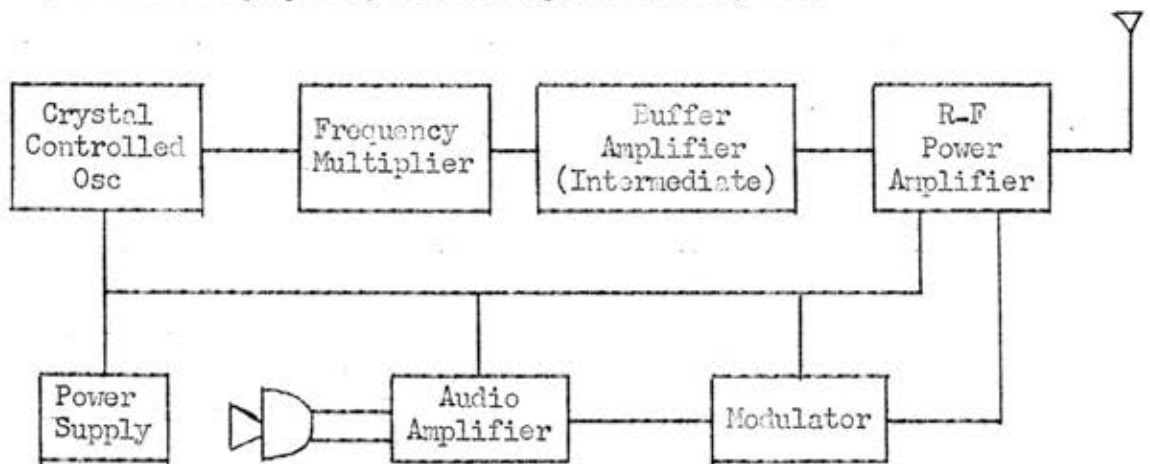


Fig. 33 — A block diagram of a complete transmitter.

The R-F portion of a transmitter consists of a crystal-controlled oscillator, a frequency multiplier, a buffer amplifier, and a R-F power amplifier. The crystal-controlled oscillator produces an alternating current of the required carrier frequency value. For high frequency of the carrier, the output from the oscillator is fed into the frequency multiplier in one or more stages. In addition, to produce a multiple of its input frequency, the frequency multiplier also serves as an R-F amplifier. The power output of the frequency multiplier is increased by the buffer amplifier to the value required to drive the power amplifier. The R-F power amplifier produces the desired power output.

The A-F portion of the transmitter consists of a microphone, a speech or audio amplifier, and a modulator. The low voltage output of the microphone

is increased by the A-F amplifier to a value that is high enough to drive the modulator. The modulator is the last stage of the A-F amplifier and produces the A-F output required to obtain 100 per cent modulation. The output of the modulator is fed into the R-F power amplifier, which also serves as a modulating amplifier.

Fig. 34 shows the simplified circuit diagram of Western Electric 443A-1 transmitter which is a type of transmitters according to the FCC Rules and Regulations which is mostly used in broadcasting services.

In this chapter, the circuit components of the radio broadcast transmitters which generally cause the interferences, and the method to reduce these interferences are mentioned.

Interference Generated by an Oscillator

The frequency of the varying currents or voltages associated with radio and electronic circuits may vary from a few cycles per second to millions of cycles per second. A vacuum tube, when used in conjunction with the proper combination of circuit elements, may be made to produce an alternating current having almost any value of frequency. The vacuum tube does not create any electrical energy; it merely changes one kind of current to another. The electrical circuit associated with a vacuum tube when used to produce an alternating current is called an oscillator circuit.

The waves sent out by a radio transmitter consist of electromagnetic and electrostatic fields. As these fields are caused by an alternating

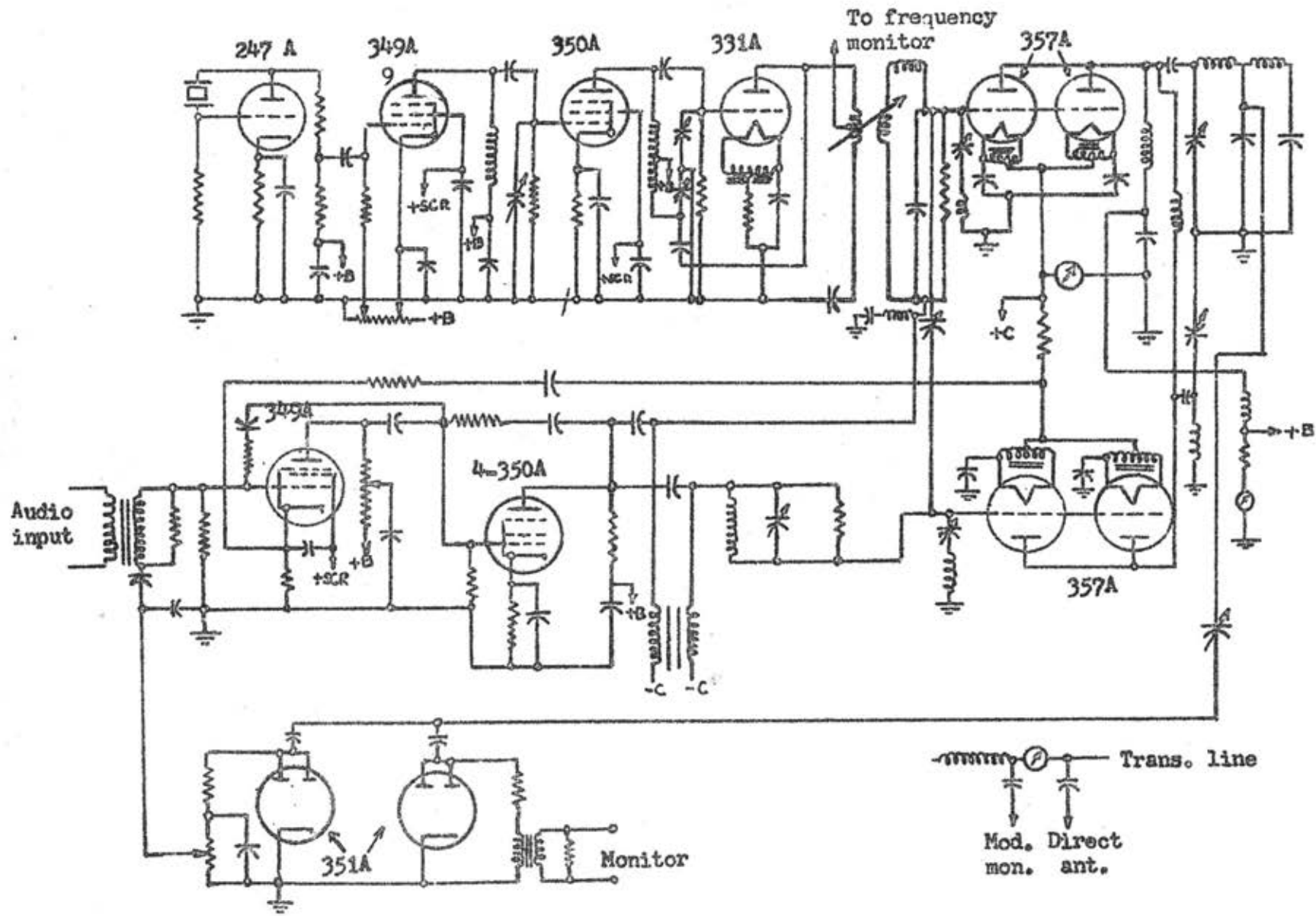


Fig. 34 Simplified circuit of Western Electric 443A-1 transmitter.

current, their frequencies are the same as that of the alternating current producing them. The frequency of the alternating currents used in communications ranges from hundreds of thousands of cycles per second to millions of cycles per second. Radio transmitters depend on vacuum-tube oscillators to produce their high-frequency carrier currents.

Oscillators can be divided into two general classes:- self-controlled oscillators and crystal-controlled oscillators.

The frequency of the transmitter depends, of course, on the oscillator. The frequency of the oscillator, in turn, closely approximates that of the resonant circuit associated with the tube. If the circuit constants could stay fixed, the frequency would never change. In practice, this is not the case.

As afore-mentioned, if the radio broadcast transmitters transmit the carrier frequency outside the assigned frequency and its tolerance it will cause a mutual interference with the adjacent operating channels. The frequency of the transmitter depends, of course, on the oscillator. Thus, the oscillator should have a good frequency stability in order to avoid the shift in carrier frequency.

The term, frequency stability, refers to the ability of the oscillators to maintain constant frequency under operating conditions. It is evident that the carrier frequency of these stations must be held to a very close tolerance. At present the allowable variation in frequency for broadcasting stations is ± 20 cycles.

The factors affecting the frequency stability of an oscillator are (1) operating voltage, (2) output load, (3) temperature, and (4) mechanical vibration of the circuit elements.

Operating Voltage. Any variation in the operating voltages applied to the tube affect the frequency by influencing the alternating currents that flow between the tank circuit and the grid and plate electrodes of the tube. The operating voltages can be stabilized by the use of a regulated power supply.

Output Load. Any variation in the plate resistance and the effective load resistance will affect the frequency of an oscillator in a similar manner as changes in plate voltage. Thus, frequency stability may be obtained by supplying the tube with a dc power supply having good regulation, and by maintaining a constant load on the tube,⁸ or by the use of (1) a tank circuit having a high effective Q, (2) a buffer amplifier, and (3) electron coupling.

Frequency stability obtained by using a tuned circuit having a high effective Q and a low L/C ratio. The tube input capacitances are in parallel with the tank capacitance and if the tank capacitance is made sufficiently large, variations of tube input capacitances will have less effect on oscillator frequency.

⁸ Transmitters, CAA Aeronautical Center Training Series Manual 137, (Air Navigation Facilities Branch), p. 5.

One method of providing a constant load to an oscillator is to use the oscillator to drive a class C amplifier with the load coupled to the plate circuit of this amplifier. For maximum stability, the grid of the Class C amplifier should not be driven positive. The type of amplifier is usually called a "buffer amplifier". The buffer is normally of low power output and is used to drive a regular Class C power amplifier.

Multigrid tubes may serve as both oscillator and buffer as shown in Fig. 35. This circuit is called an electron coupled oscillator. In oscillator of this type, the cathode, control grid and screen grid of the tube are operated as a triode oscillator, with the screen grid serving as the oscillator plate. The electron stream within the tube is the coupling medium to the plate circuit of the tube. The suppressor grid, operated at RF ground potential, reduces the capacitive coupling between the screen grid and plate, effectively eliminating frequency instability resulting from changes in the oscillator load. The use of a tank circuit in the plate section of the tube makes frequency multiplication possible, by tuning the plate tank circuit to a harmonic of the oscillator frequency.

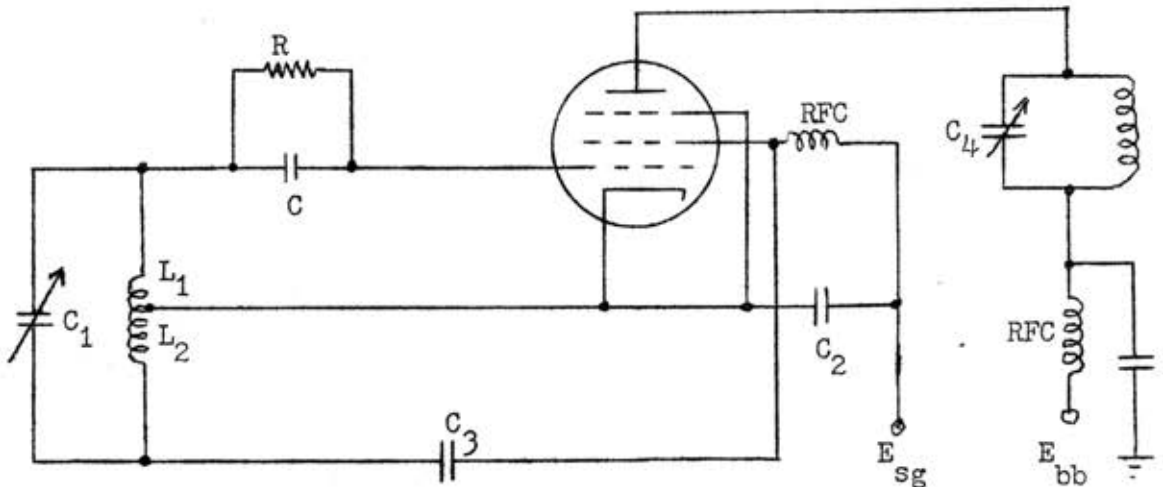


Fig. 35 — Electron Coupled Oscillator.

Temperature. Temperature is also a factor in frequency stability. Temperature changes cause tube elements to expand or contract slightly which change the interelectrode capacitances. As these capacitances are part of the tuned circuit, the frequency of oscillator will be affected. Temperature changes will also slightly affect the values of the tank coil and capacitor which change the inductance and capacitance slightly, and this too causes a shift in the resonant frequency. The method of minimizing the instability are by the use of (1) adequate ventilation, (2) a coil wound with large wire, (3) a low direct input voltage, and (4) thermo-compensating capacitors. Use of any of these methods will reduce the temperature of the oscillator unit, thus increasing the amount of stability.

Thermo-compensating capacitors⁹ are small capacitors on which temperature changes have an opposite effect than they have on ordinary components. These capacitors are so connected in the circuit that the effect temperature changes have on them offsets the effect temperature changes have on the inductance or capacitance of the circuit. The result is that the frequency stays constant.

Mechanical Vibration. Mechanical vibration of the circuit elements such as tubes, capacitors, and inductors also causes their values to vary. These changes in the values of inductance and capacitance will cause the resonant

⁹_____, "Radio Transmitters," AF Manual 100-6, (Washington, D.C.: U.S. Government Printing, 1960), p. 22.

frequency to vary with the mechanical vibration. Instability due to mechanical vibration can be minimized by isolating the oscillator from the source of mechanical vibration.

When the frequency of a transmitter must be held within close limits, a crystal-controlled oscillator is used. This is an oscillator in which a specially cut crystal controls the frequency.

Certain types of naturally occurring crystals, such as quartz, Rochelle salt, or Tourmaline, have piezo-electric properties. When certain crystalline materials are placed under a mechanical strain, such as compression or expansion, an electrical difference of potential will be developed across opposite faces of the crystal. This action is called the piezo-electric effect. Conversely, when a voltage is impressed across opposite faces of this type of crystal, it will cause the crystal to expand or contract. If the voltage applied is alternating, the crystal will get into vibration. The frequency of vibration will be equal to the resonant frequency of the crystal as determined by its structural characteristics. When the frequency of the applied voltage is equal to the resonant frequency of the crystal, the amplitude of vibration will be maximum. Because of its piezo-electric effect, a high-quality crystal can maintain the frequency of oscillation so that the variation in frequency will be less than one part in a million.

The frequency stability of crystal controlled oscillators depend on the Q^* of the crystal and its temperature coefficient. The Q of a crystal

$$* Q = X_L/R = \frac{\text{energy stored in the magnetic field}}{\text{energy dissipated as heat in the resistance}}$$

is very high. It may be more than 100 times that is obtainable in an equivalent electrical circuit. The Q of a crystal is determined by the cut, the type of holder, and the accuracy of grinding. Commercially produced crystals range in Q from 6,000 to 30,000, while some laboratory experimental crystals range in Q up to 400,000.¹⁰

Transmitters which require a very high degree of frequency stability, such as broadcast transmitters, use temperature-controlled ovens to maintain a constant crystal temperature. These ovens are thermostatically controlled containers in which the crystals are placed. Of course, crystals with special cuts are used with a temperature coefficient as close to zero as possible.

The type of cut also determines the activity of the crystal. Some crystals vibrate at more than one frequency and thus will operate at harmonic frequencies. These crystals are commonly called crystals with multiple peaks. Crystals which are not of uniform thickness may have two or more resonant frequencies. Usually one resonant frequency is more pronounced than the others, and the others are called spurious frequencies.

The amount of current that can safely pass through a crystal ranges from 50 to 200 milliamperes. When the rated current is exceeded, the amplitude of mechanical vibration becomes too great, and the crystal may crack.

¹⁰ _____, "Radio Transmitters," AF Manual 100-6, p. 33.

Over loading the crystal affects the frequency of vibration because the power dissipation and crystal temperature increase with the amount of load current.

Frequency Multipliers

To prevent interference to other radio services, radiation at harmonic frequencies must be kept at a minimum. To keep harmonic radiation down, many transmitters use crystal oscillators. At higher frequencies, it becomes increasingly difficult to keep an oscillator stable. Therefore, it is common practice to operate the oscillator at a low frequency and use stages of frequency multiplication to reach the desired output frequency. Such a stage is called a frequency multiplier.

The output wave form from an amplifier may consist of the fundamental frequency plus a mixture of even and odd harmonics. By proper circuit adjustments, it is possible to pass on one of these harmonics to the following stage and eliminate the others. In other words, it is possible to make an amplifier into a frequency multiplier.¹¹

A frequency multiplier that gives an output twice the input frequency is called a doubler. One which multiplies the input frequency by three is called a tripler. It is usual practice to keep the multiplication in a single stage down to a factor of two or three because the efficiency of a multiplier

¹¹Ibid. p. 105.

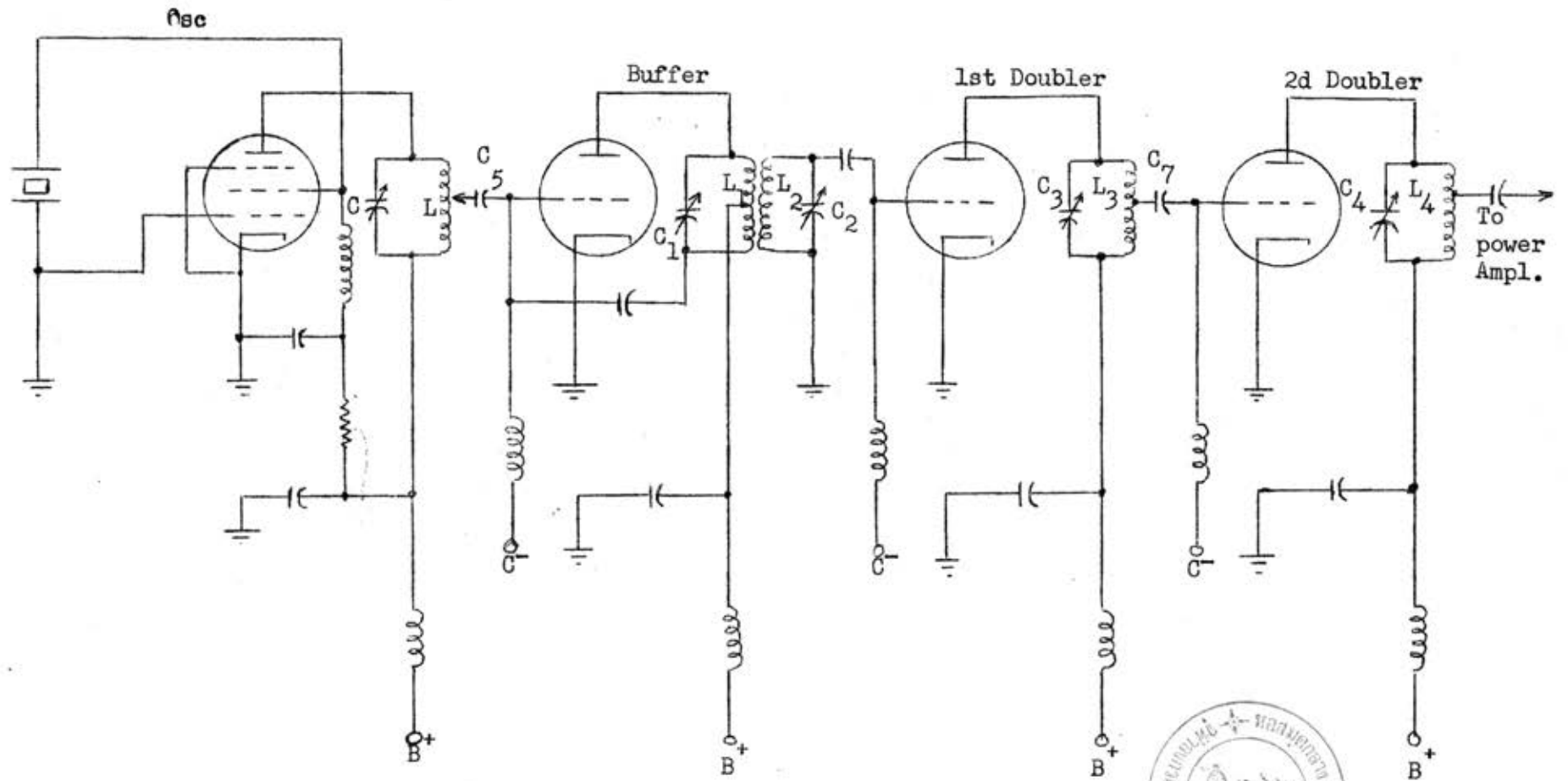


Fig. 36 — Frequency Multiplier.

decreases as the multiplication increases.¹² In any case, a multiplier usually feeds its output to a power amplifier.

Buffer Amplifier

To prevent interference to other radio services, radiation at harmonic frequencies must be kept at a minimum. To keep harmonic radiation down, many transmitters use crystal oscillators, which have relatively low power. With the oscillation occurring at low power, there is relatively little danger of interference. To raise the power output, these crystal oscillators drive buffer amplifiers. When the function of such an amplifier is to isolate the oscillator from the other stages of the transmitter it is called a buffer amplifier.¹³

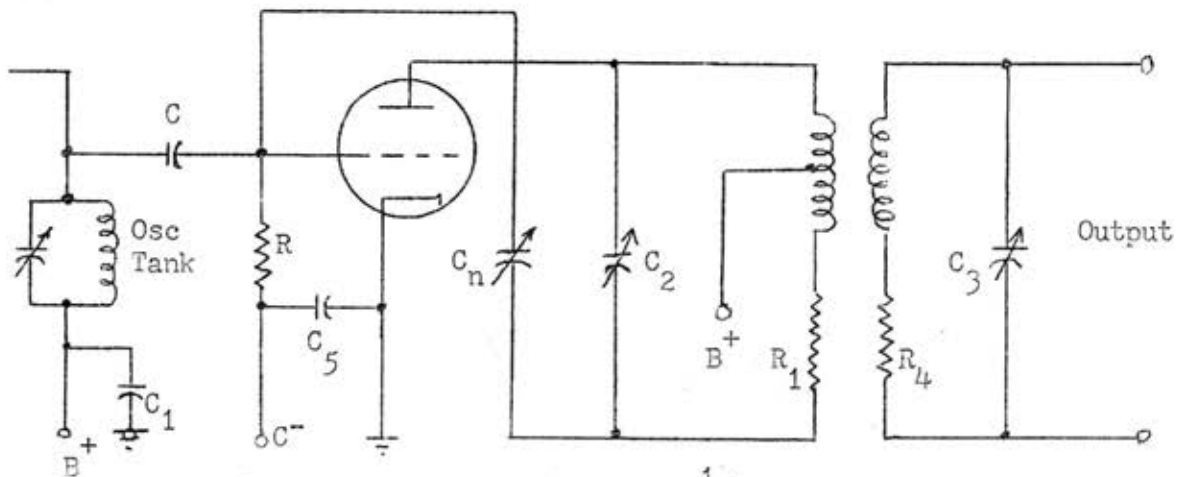


Fig. 37 — Buffer Amplifier.¹⁴

¹² Ibid. p. 106.

¹³ Ibid. p. 105.

¹⁴ Ibid.

In the case where the power amplifier is coupled directly to the oscillator, the latter is subject to a changing load. The input to the amplifier represents the load on the oscillator. This changing load causes the oscillator to become unstable. So a buffer amplifier is used. The purpose of the buffer is to act as an amplifier while isolating the oscillator from the power amplifier.

In the buffer amplifier circuit, Fig. 37, the buffer operates like any other voltage amplifier.¹⁵ The RF voltage developed across the oscillator tank is applied between grid and cathode of the buffer tube through coupling capacitor C. Capacitor C_5 is included to by pass the RF voltage around the bias supply. Resistor R furnishes grid leak bias for the buffer.

The buffer plate load may be a tuned circuit, or it may be the primary of an air-core transformer. The tuned circuit offers a fairly constant load impedance and good response over a band of frequencies. Once the circuit is adjusted with the values of capacitors C_2 and C_3 fixed, the load remains unchanged.

Interference Generated by the Amplifiers

Most amplifiers require some care and consideration in design and construction to prevent spurious oscillations from occurring in the ampli-

¹⁵Electronics Training Staff of the Cruft Laboratory, Electronic Circuits and Tubes, (New York:McGraw-Hill Book Company, Inc., 1947), p. 494.

fier and associated circuitry.

The first form of oscillation is that which may occur at approximately the same frequency as the amplifier operating frequency. This is due to either or both of two possible reasons. The first is feedback through the coupling capacitance of the amplifier tube. This results in the amplifier acting like a TPTG oscillator. The cure for this oscillation is to cancel the feedback capacitance by means of a centralizing circuit, or to use a tetrode, or both. The second cause of oscillation at the amplifier operating frequency is through direct external feedback between the tuned input circuit of the amplifier and the output circuit. This can take place through the inductive field of the coils that are part of the input and output networks, or capacitively through the placement of other components associated with the input and output circuits.

The second form of oscillation is due to stray capacitances and inductances in the grid and plate circuits resonating and forming an oscillator in the VHF region.

The third form of oscillation that may occur is a low frequency one due to the R-F choke in the grid and plate resonating with the stray capacitances present in the circuit and forming a TPTG oscillator.

In communication engineering, periodic oscillations occur that are not harmonic. The microphone current when a steady sound is sung or spoken, the output of detector on which a harmonic voltage is impressed, the scanning voltage on a cathode-ray tube, are important examples of periodic non-harmonic oscillations. Analysis of periodic functions shows that a nonhar-

monic wave (periodic function of time) consists of harmonic components, (see APPENDIX I), of which the component of lowest frequency, or fundamental, has the same period T as the nonharmonic wave. The other components have periods of $T/2$, $T/3$, etc. A nonharmonic wave consists of a number of harmonic waves of frequencies $f = 1/T$, $2f$, $3f$, The wave of frequency f is called the fundamental; the waves of frequencies $2f$, $3f$, are called the second harmonic, third harmonic,

If the amplitude of the output of an oscillator is unstable the wave form will be distorted thus producing undesirable harmonics. An oscillator tube generally operates as a Class C amplifier delivering power during less than one-half of the input cycle. Under this condition, the plate current variation will not produce a sine wave, and a tank circuit is added in order to obtain an approximate sine-wave output. In order to have an output of approximately sine-wave form, it is necessary that the tank circuit store energy during the portion of the cycle in which the tube is delivering power and to deliver this stored energy to the load during the portion of the cycle in which no power is being delivered by the tube. The greater the amount of energy transferred to the succeeding stage, the higher the efficiency of the tank circuit. The ideal condition would be to have the tank circuit deliver to the coupled load all the energy it receives from the tube, This is impossible, of course, for the tank circuit does consume some energy. The amount it consumes depends on its Q . If the circuit were unloaded, it would be desirable to have the Q of the unloaded circuit very high. The higher the Q , the lesser the amount of energy consumed in the circuit by the resistance of the tank. With the circuit loaded, through, and

with energy being transferred to the load, the Q of the loaded circuit should be as low as possible, to provide the highest possible effective Q . Under these conditions, very little energy is consumed in the tank circuit itself, and practically all of the power is consumed by the load. However, there is a minimum value of Q below which it is not practical to reduce the effective Q of the circuit. If the value of Q is much lower, considerable distortion appears in the RF wave form, because the harmonic components of the plate current pulses produce harmonic voltage drops across the tuned tank. Harmonic output from the amplifier is undesirable as it represents wasted power. In addition, it may lead to radiation of energy at harmonic frequencies which may interfere with other radio services. A high Q circuit discriminates against these harmonic components but causes a loss in the efficiency of the tank circuit.

A-F Amplifiers

The A-F amplifier systems is used for modulation of radio telephone transmitters. Because ~~the~~ a very low distortion, low driving power, and low power output are wanted, the A-F amplifier may be operated under Class A and with special connections, under Class AB or Class B conditions. The performance of a single tube Class A amplifier is limited to a certain from the output by using two tubes in a push-pull circuit.

In the push-pull amplifier two tubes are arranged with the grids excited by equal voltages 180° out of phase and the outputs combined by means of a transformer having a center-tapped primary. With this arrangement even harmonics and even order combination frequencies cancel in the

output.

The push-pull amplifier has several advantages over single-sided circuits for power-output stages. Probably the most important of these is the reduction of nonlinear distortion, which makes it possible to obtain increased power output for a specified maximum distortion. Other advantages is to reduce magnetization of the output transformer core.

Push-pull Class A Audio Amplifiers.

Fig. 38 is the schematic diagram of the Push-pull Class A amplifier. The even harmonics of the individual tubes are in phase, whereas the fundamental output currents are 180° out of phase. By connecting to the load through a properly designed output transformer, the even harmonics will not be transferred. The principal distortion remaining is then the third harmonic.

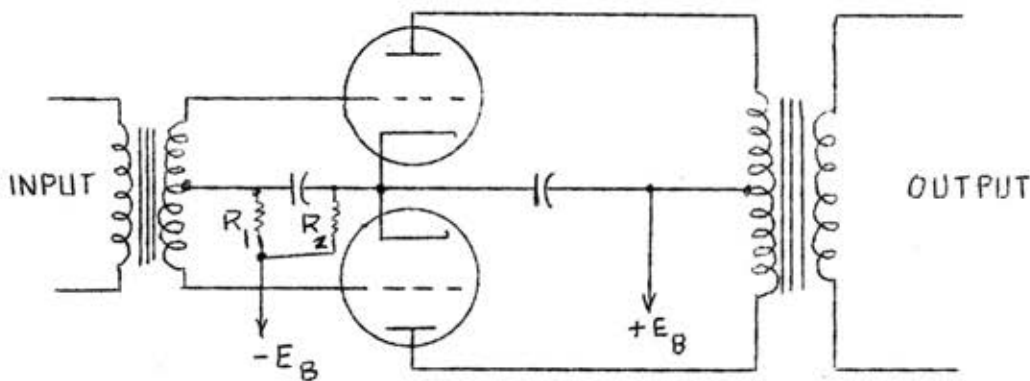


Fig. 38 — Push-pull Class A amplifier, R_1 = De-coupling resistor, R_2 = cathode resistor for bias.¹⁶

¹⁶ Sterling and Monroe, The Radio Manual, p. 95.

Push-pull Class A audio amplifiers do possess three very important advantages:

(1) The d-c plate currents of the two tubes flow through the output transformer windings in opposite directions, thereby producing no steady magnetization of the transformer core. This is important, since the core need only be large enough to handle the magnetic flux caused by the a-c output current. This makes the unit more compact, less expensive and more efficient.

(2) There is no tendency for the output current to flow through the power supply unless the tubes are unmatched. This greatly simplifies the bypassing and isolating necessary for stable operation.

(3) When the filaments are operated from alternating current, the resulting hum is reduced by the push-pull action.¹⁷

R-F Amplifiers

One job of an R-F amplifier is to isolate the oscillator from the antenna. Another job is to increase the transmitters' power output up to the desired power level. This is particularly important when a crystal oscillator is used. This amplifier may feed the amplified RF oscillations right into the antenna system, or it may feed into another amplifier, which feeds into the antenna system.

¹⁷ Ibid.

Naturally, R-F amplifiers are designed to develop moderately to very high power across the load in the plate circuit. It is a natural course to choose Class C operation, due to its power capabilities, and high plate circuit efficiency.

A modulated R-F wave has a frequency spectrum which extends over a band of frequencies that is usually small when compared with the magnitude of the carrier frequency. It is necessary to design R-F amplifiers which have large voltage amplification for frequencies in the neighborhood of the carrier frequency and which can be adjusted easily, within given limits, for various carrier frequencies. It is equally essential that R-F amplifiers have low voltage amplification for all frequencies outside the given band in order that a given station may be selected to the exclusion of all other stations which might be transmitting at that time. This selectivity is accomplished by use of tuned parallel circuits in which the tuning capacitance is composed of the interstage wiring capacitance, the input and output capacitances of the tubes used, and whatever added capacitance may be required.

Suppression of Harmonic Radiation

In Class C and linear amplifiers generate harmonics, provision must be made to prevent these harmonic voltages from being radiated. This is especially important in radio broadcast transmitters which radiated harmonic in a very small fraction of the desired radiation but will still have sufficient strength to produce interference with other communications up to a reasonable distance.

Harmonic energy may be directly radiated from the circuits of the transmitter or from miscellaneous wires that are coupled to the transmitter circuits. This direct radiation is usually small and can be prevented by completely shielding the entire transmitter.

Harmonic energy may also be delivered directly to the antenna by the R-F output amplifier of the transmitter. This harmonic radiation can be kept small by use of: (1) a high Q tank circuit; (2) coupling systems from the final tank circuit to antenna that discriminate against harmonics; and (3) R-F filters between final tank circuit and the antenna.

Monitoring of Radio Transmitters

Provision is always made in all except very small radio transmitters for monitoring the transmitter behavior and protecting against faults. Monitoring equipment normally includes meters to read the plate and grid currents of the various stages and the transmitter output. Frequency monitors and modulation monitors are also employed in all broadcast transmitters.

Frequency Monitor. The FCC Rules and Regulations under Section 3.59 states that the operating frequency of each amplitude-modulation broadcasting station shall be maintained within 20 cycles of its assigned value. Under Section 3.60 of the FCC states that the frequency monitor is subject to FCC approval and must have a stability and accuracy within 5 ppm.

Fig. 39 indicates the simplified circuit diagram of the General Radio Type 1181A Frequency Monitor which is an approved type operating within the specified limits.

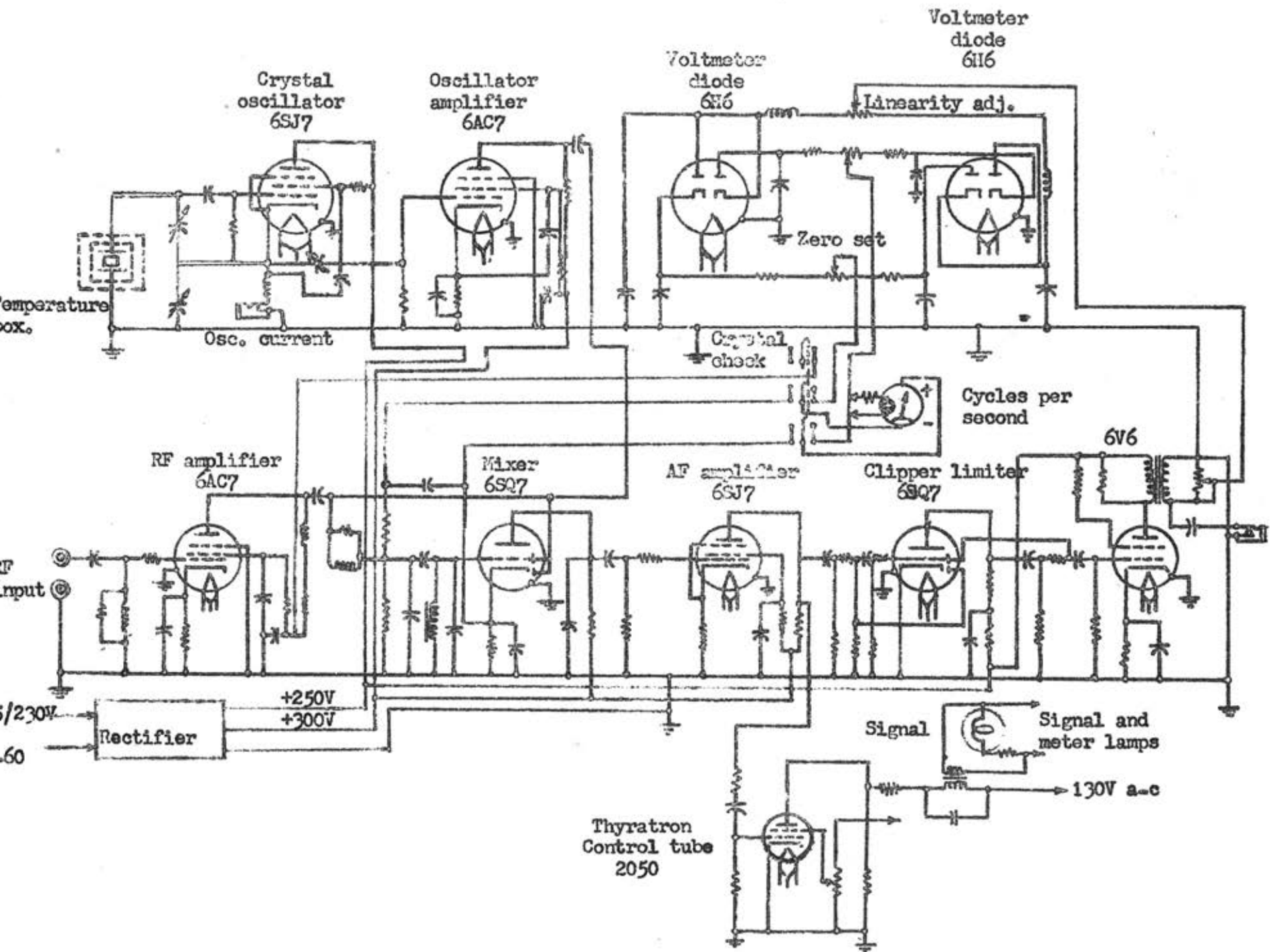


Fig. 39 - Schematic of General Radio type 1181A frequency deviation monitor.

Modulation Monitor. The FCC Rules and Regulations under Section 3.56 requires that each broadcasting station shall have an approved modulation monitor in operation at the transmitter to measure the degree of modulation of the transmitter and for furnishing instant warning when the degree of modulation of the transmitter **exceeds** a selected specified value.

Fig. 40 indicates the simplified circuit diagram of RCA 66A Modulation Monitor, which is a type of modulation monitor according to the FCC Rules and Regulations which is mostly used in broadcasting services.

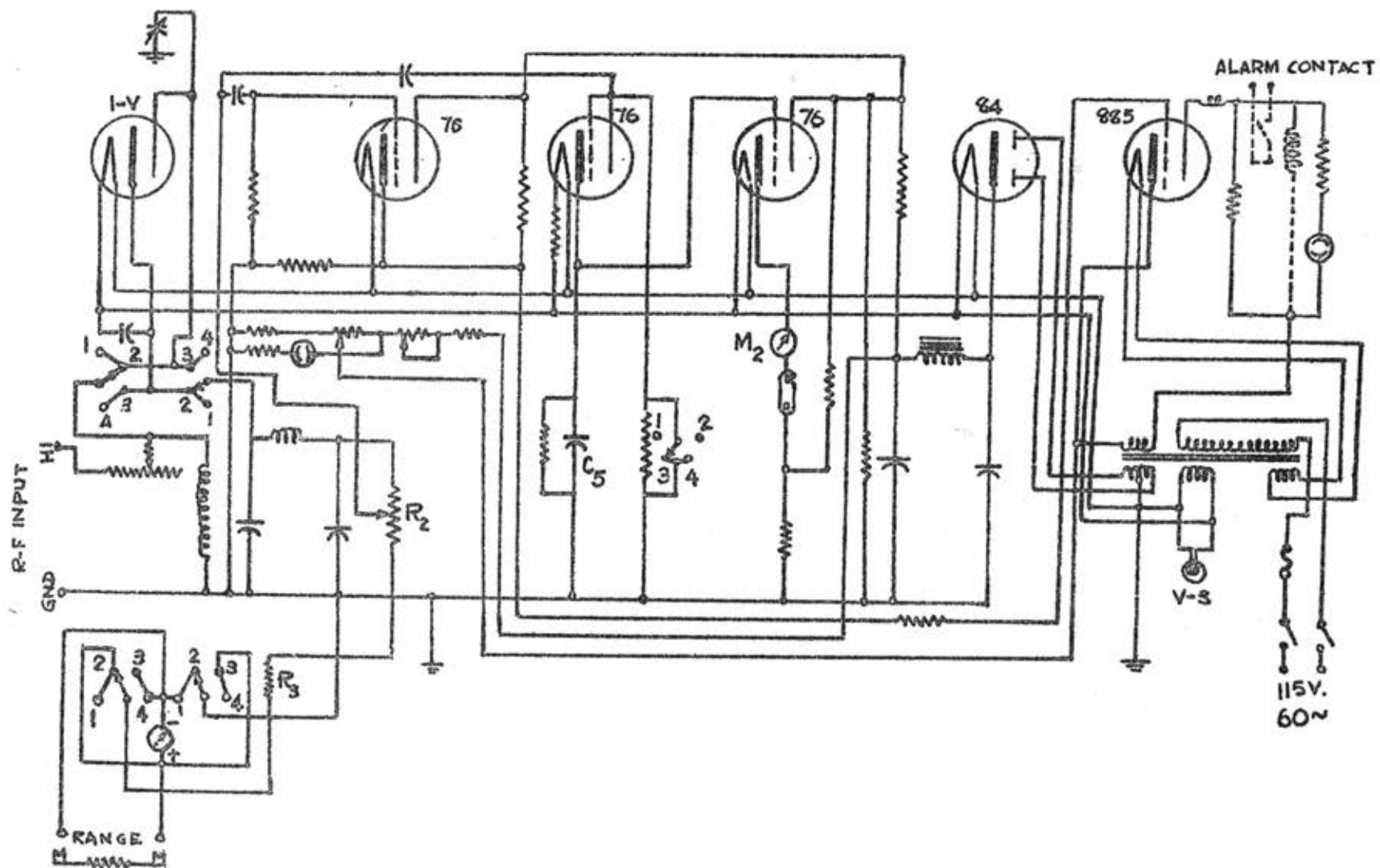


Fig. 40 - RCA 66A Modulation Monitor.