EXTRACT TM 11-665

CHAPTER 1

INTRODUCTION

1. Communication by Radio

a. A good communication system is one of the prime requisites for a successful military operation. Because military aircraft and motor transport have increased the length of military lines, the importance of quick, reliable communication is vital. Tactical information must be disseminated immediately to widely separated places. The fastest, most useful, and versatile means of communication is radio. Many different types of radio equipment are used by the military services for specific purposes (fig. 1). Large fixed land radio installations providing communication over great distances include powerful radio transmitters and sensitive receivers. Small portable radio sets are used by troops in the field for short-distance communication. Specially constructed radio units are installed on aircraft to permit communication between planes or from planes to ground stations. Shipboard radio equipment enables a ship to keep in constant touch with other ships and land bases. The great advantage of a radio communication system is that no connecting wires are used between the point where the information originates and the point to which the information is sent. Instead, the connecting link takes the form of electromagnetic waves in space.

b. Modern radio has been developed by a large number of men, some of whom contributed basic ideas of theory and others practical circuits and devices. Outstanding among the early workers were such men as Faraday, Maxwell, Hertz, and Marconi. In 1896, Marconi succeeded in transmitting a signal over a distance of 2 miles with no connecting wires between the transmitting device and the receiving apparatus. *Wireless* communication was shown to be possible. Two years later, the range of the crude equipment was extended to approximately 30 miles. In the year 1899, a regular wireless telegraph service was established across the English Channel. Just 2 years later, Marconi's crude apparatus, located at Poldhu, Wales, sent out a signal which was picked up by a receiver at St. Johns, Newfoundland. The Atlantic Ocean had been spanned by a device which had been a mere laboratory curiosity. From this early equipment, modern radio communication has emerged.

2. Electrical Background

a. Electrical circuits and principles form the basis of operation of a radio system. To understand radio, it is necessary to be familiar with electrical fundamentals, which are reviewed in chapter 2.

b. Electricity may be classified as *power electricity* in which the primary concern is to transmit electrical *power* efficiently, and *communications electricity*, in which the main concern is to transmit *intelligence* efficiently. Intelligence in this sense is broadly defined as anything that conveys information. It may be in the form of telegraphic code, speech, music, or pictures. In the study of communications electricity, very small amounts of power usually are considered. Although the output power from large fixed ground transmitters can be appreciable, the actual received power at some remote location usually is measured in milliwatts, microwatts, or, frequently, even in micromicrowatts. The output power of field transmitters usually does not exceed several hundred watts, and a small portable unit may radiate only a fraction of a watt of power. The output delivered by most receivers rarely exceeds several watts and, if headphones are used, the output power is considerably less.

3. Frequencies Used

a. Speech and music fall within the a-f (audio-frequency) range. We hear audio frequencies because our ear drums vibrate at a frequency that corresponds to the frequency of the sound. The average human ear responds to frequencies from about 16 cps (cycles per second) to about 16,000 cps. Deep bass tones produced by a pipe organ, for example, may have a frequency which extends down to the lower limit of this range. The sound waves produced by a shrill high-pitched whistle may have a frequency of 15,000 cps or even higher. The most important frequencies used in human speech range from about 200 to 2,500 cps. Compared with radio frequencies, which extend from approximately 20 kc (kilocycles) to well over 3,000 mc (megacycles), these audio frequencies are low.

b. It is not possible to radiate audio-frequency power efficiently nor to span great distances with these low frequencies. Several hundred watts of audio-frequency power, radiated by large loudspeakers may span a distance of only a few miles. If this method were used to transmit audio intelligence, it would be useful for only short distances and when the level of outside noises or sounds does not obscure the information conveyed. In addition to these limitations, selectivity of information is not possible. All persons within hearing range would receive the information and the listener could not tune his *receiver* to a different band or frequency. Therefore, only one channel would be available and the utility of radio communications would be limited.

c. None of the these limitations apply when a radio-frequency signal is used to *carry* the intelligence. Tremendous distances can be covered; many channels, each carrying information, can be used; and selectivity of information is possible. Superimposing audio-frequency intelligence on a radio-frequency carrier wave involves a process called *modulation.* One type of modulation, called a-m (amplitude modulation), requires that the *amplitude* of the carrier wave be varied in accordance with the intelligence.

d. Radio frequencies extend over a wide range. In a certain radio transmitter used today the operating frequency is 22 kc. Another radio equipment produces a radio-frequency output of 28,000 mc. The characteristics and circuits used at different radio frequencies vary widely, depending on the specific frequency used. For convenience, groups or *bands* of radio frequencies have been set up. The accompanying chart shows some of these bands that are used for military purposes. The characteristics indicated are very general and the chart gives only an over-all picture.

Band	Frequency range	Distance range	
		Day	Night
vlf (very low frequency).	Below 30 kc		
lf (low frequency)	30 to 300 kc	Long	Long.
mf (medium frequency.	300 to 3,000 kc	Medium	Long.
hf (high frequency)	3 to 30 mc:		
	3 to 10 mc	Short to medium.	Medium to long.
	10 to 30 mc	Long	Long.
vhf (very high frequency).	30 to 300 mc	Short	Short.
uhf (ultrahigh frequency).	300 to 3,000 mc	Short	Short.
shf (superhigh frequency).	3,000 to 30,000 mc	Short	Short.

e. The velocity of electromagnetic radio energy in space is the same as the velocity of light—that is, 300,000,000 meters per second or 186,000 miles per second. For most practical purposes, this velocity is constant regardless of the frequency used or the conditions of transmission. The length of the radio wave is the distance traveled by the wave in the period of time required to complete 1 cycle. To find the wavelength when the frequency is known, it is necessary to divide that frequency into the velocity given above as follows:

$$\text{Wavelength (in meters)} = \frac{300{,}000{,}000 \text{ (velocity in meters per second)}}{\text{frequency (in cycles per second)}}$$

To find the frequency when the wavelength is known, it is necessary only to divide that wavelength into the velocity given above as follows:

$$\text{Frequency (in cycles per second)} = \frac{300{,}000{,}000 \text{ (velocity in meters per second)}}{\text{wavelength (in meters)}}$$

4. Components of Radio Communication System

a. In the basic radio communication system shown in block form in figure 2, a radio transmitter is used to generate the r-f (radio-frequency) waves which are to be radiated into space. This transmitter may contain only a simple oscillator stage. Usually, the output of the oscillator is applied to a power amplifier which allows greater stability to be incorporated into

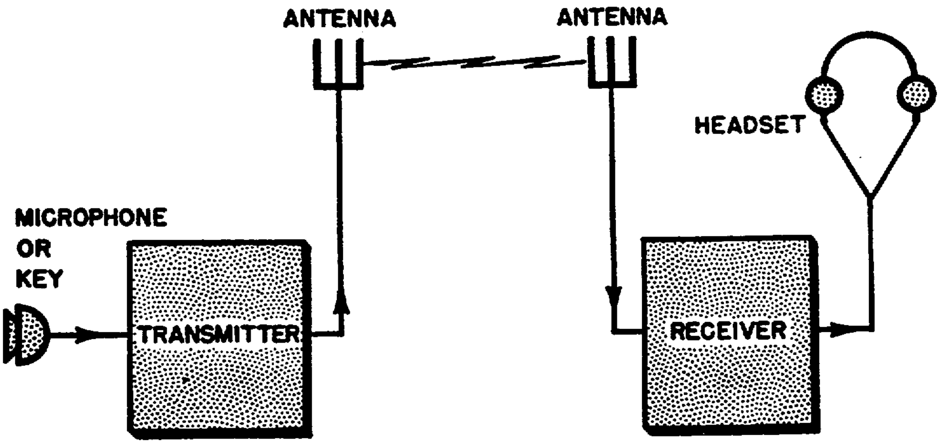

Figure 2. Block diagram of basic radio communication system.

oscillator circuity and further allows great increases in transmitter output power. Power amplifiers and coupling circuits are discussed in chapter 4.

b. A telegraph key may be used to control the energy waves produced by the transmitter. When the key is closed, the transmitter produces its maximum output. When the key is opened, no output is produced. In this way, a message in telegraphic code can be transmitted.

c. If speech intelligence is to be transmitted, a microphone is used to convert the sound energy produced by the transmitter into electrical energy. A speech amplifier and a modulator must now be included in the transmitter. The modulator superimposes the a-f speech intelligence on the r-f carrier wave.

d. The output of the transmitter is applied to the transmitting antenna, which radiates the energy into space in the form of electromagnetic waves. A small portion of the radiated energy then is picked up by a receiving antenna, and the received energy is applied to the radio receiver.

e. The receiver selects the desired transmitted signal, amplifies the received signal, and separates the audio intelligence from the radio-frequency carrier. Many different receiver circuits can be used to accomplish this. The output of the radio receiver is applied to a reproducer, usually a loudspeaker or a headset, which converts the audio-frequency electrical energy into sound energy.

5. Summary

a. The effectiveness of a communication system often determines the success or failure of a military operation.

b. In order to understand the principles of operation of radio transmitters and receivers, a background in electrical fundamentals is essential.

c. One method of superimposing a-f intelligence on an r-f carrier is to vary the amplitude of the carrier in accordance with the intelligence. This is known as amplitude modulation.

d. The velocity of electromagnetic energy in space is constant. If the frequency of radio energy is divided into the velocity, the wavelength is obtained. If the wavelength is divided into the velocity, the frequency is obtained.

e. A basic radio communication system is composed of transmitter, key or microphone, transmitting antenna, receiving antenna, receiver, and reproducer.

6. Review Questions

a. Give several advantages of a radio communication system compared with other communication systems.

b. Why is it necessary to superimpose the audio intelligence on a radio-frequency carrier wave?

c. Calculate the wavelength which corresponds to the following electrical frequencies: 60 cps, 1,000 cps, 1,000 kc, and 1,000 mc.

d. What are the main components of a basic radio communication system?

CHAPTER 4

CONTINUOUS-WAVE TRANSMISSION

52. Transmission of Information by Radio

a. Purpose of Transmitter. The purpose of the radio transmitter is to produce r-f energy, and with its associated equipment to radiate a useful signal. Any of the oscillators described in chapter 3 may be used to generate a steady flow of r-f energy. The transmitted high-frequency power is called the *carrier wave*, or simply the *carrier.*

b. Methods of Conveying Information.

(1) Since the carrier by itself does not convey any intelligence, information to be transmitted must be added to the carrier. The process of adding or superimposing information on the carrier is called *modulation.*

(2) Radiotelegraph information can be transmitted by starting and stopping the carrier by means of a switch, which is opened and closed to control the flow of power to the transmitter. A telegraph key or an automatic code machine usually is substituted for the switch. Messages can be sent by means of short and long pulses (dots and dashes) which correspond to letters and numerals of the radiotelegraph code. When the operator closes or presses the key down, the carrier wave is sent out from the antenna. When the key is raised or opened, the carrier is cut off. If the operator wishes to send the letter A in code, he closes the key for a fraction of a second, opens it for the same length of time, then closes it again for a period of time three times the length of the first. The length of a dash is three times the length of a dot. Spacing between dots or dashes within a letter or numeral is equal to the length of one dot (fig. 66). Spacing between letters in a word is equal to three dots or one dash. This process of transmitting information in the form of dots and dashes is called *radiotelegraphy.*

(3) The human voice or a wide range of sound frequencies—for example, a symphony orchestra—can be transmitted by radio. This form of transmission is called *radiotelephony.* A sensitive microphone picks up the sound and converts the sound waves into audio-frequency voltages. These voltages then are fed to a modulator which superimposes the audio-frequency signal on the carrier wave.

(4) *Facsimile* is the transmission of printed or written matter, maps, charts, and other similar data by radio. The printed mat-

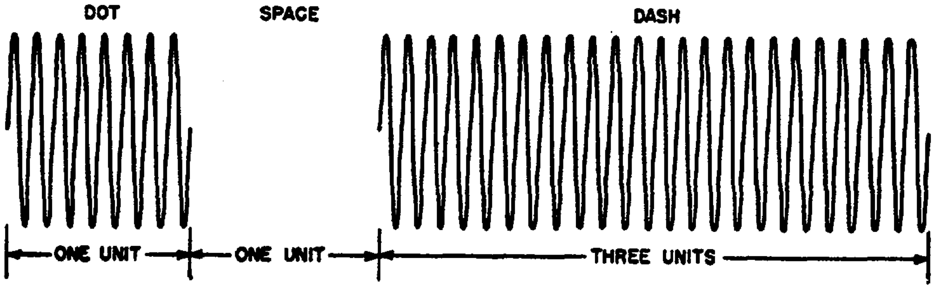

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Figure 66. Dot and dash in radiotelegraph code.

ter is placed on a rotating drum in the transmitter. Light is reflected from the light and dark areas on the copy, converted to electrical impulses, amplified, then transmitted by radio. The facsimile receiver converts the signal back to its original form. At the destination, the intensity of a tiny spot of light, controlled by the received voltages, affects a sensitized paper on a rotating drum in the receiver. After being treated with a chemical process similar to photographic developing, the paper becomes a duplicate or facsimile of the printed matter at the transmitter. This is not an instantaneous process. Some equipment requires 20 minutes to reproduce a 12- by 17½-inch photograph.

(5) *Television* is another application of radio. This is a process of transmitting and receiving over great distances continuous, instantaneous pictures of events. In addition to viewing the action, the observer hears speech and other sounds occurring at the place of action by means of a radiotelephony channel adjacent to the television picture channel.

c. Need for Carrier Wave. When any alternating current is passed through a conductor, an electromagnetic field is radiated. This principle forms the basis of a transmitting antenna. It would seem that information could be transmitted by feeding a signal, from a microphone or other pickup device, directly into the antenna. This is impractical for two reasons—The amount of electromagnetic energy radiated from an antenna for a given power input decreases with a decrease in frequency. The amount of power required for direct transmission of audio frequencies over reasonable distances is prohibitive. Even if it were practical to radiate signals at audio frequencies, all stations would interfere with each other so that only one would be able to transmit at a time. The use of a radio-frequency carrier wave excludes the limitations mentioned above. Radio-frequency carriers can be spaced every 10 kc for broadcast stations and even closer for c-w (continuous-wave) and radiotelephone communication circuits.

d. Radio-Frequency Spectrum.

(1) The assignment of a radio transmitter to a definite band of the r-f spectrum depends on many considerations. To avoid confusion, international conferences are held from time to time to assign frequencies for definite applications. Specific channels or bands are provided for marine, aeronautical, and navigational aids, standard broadcast, amateur radio, military services, international shortwave broadcasts, and miscellaneous services. Also taken into consideration are the effective transmitting range for a given transmitting power, freedom from interference by other services, and effects of seasonal changes on transmitting range and receiving conditions.

(2) Frequencies below 100 kc usually provide reliable communication for 24 hours a day without being subjected to interference by magnetic storms. Many stations engaging in international communications operate in this sector of the spectrum. Extremely large antennas are required, some of which are several miles long.

(3) Frequencies between 100 and 500 kc are allocated to marine communications, aircraft beacons, and miscellaneous services. The band is suitable for medium- and long-range communication. Antennas are usually large. The size of antennas decreases as the frequency increases.

(4) American broadcast stations are assigned frequencies between 550 and 1600 kc. The transmitting range of stations in this band varies with the time of day and usually is limited to a few hundred miles. Frequencies in this band are assigned to other services in some foreign countries.

(5) Frequencies between 1600 and 6000 kc are suitable for reliable short- and medium-range communication circuits. World-wide communication is possible but under rather unpredictable conditions. Military services, amateur, police, marine, aeronautical, and miscellaneous services have frequencies in this range. Communication circuits are fairly reliable both day and night.

(6) International shortwave broadcasts, commercial circuits, the armed forces, police, marine, and other services use

frequencies in the 6- to 30-mc range when long-range communications are desired for given periods during the day or night. As the frequency increases, the transmitting range varies sharply during different hours.

(7) Frequencies above 30 mc are used widely for short-range circuits. Variations with atmospheric conditions and time of day make long-range contacts between fixed locations unreliable. Communication circuits usually are based on line-of-sight transmission with the range limited to a few miles beyond the horizon or the most distant point that can be seen from the top of the transmitting antenna. Television, frequency modulation, radar, experimental broadcasts, the armed forces, point-to-point stations, public utilities, police and fire departments, and numerous other services operate in the frequencies above 30 mc. The radio-frequency spectrum between 10 kc and 30,000 mc together with the classification of each band is shown in figure 67.

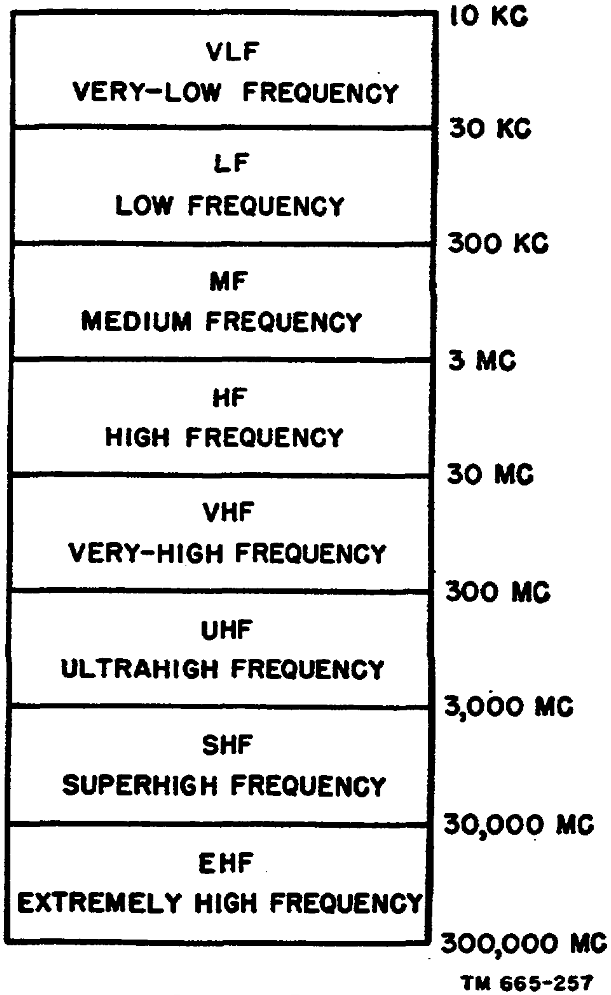

Figure 67. R-f spectrum.

e. Modulation. When a-f signals are superimposed on the r-f carrier, additional r-f signals are generated. The additional frequencies are equal to the sum and difference of the audio frequencies and the radio frequency involved. For example, assume that a 1000-kc carrier is modulated by a 1-kc audio tone. Two new radio frequencies are developed, one at 1001 kc (the sum of 1000 and 1 kc) and the other at 999 kc (the difference between 1000 and 1 kc). If a complex audio signal is used instead of a single tone, two new frequencies will be set up for each of the audio frequencies involved. The new frequencies are called sideband frequencies.

53. Classification of Emissions

a. Radio-wave emissions have been classified by international agreement depending on the type of modulation used. The ITRC (International Telecommunication and Radio Conference) which met in Cairo in 1938 devised the following classification for amplitude-modulated continuous (undamped) waves:

Designator	*Type of emission*
A0	Waves the successive oscillations of which are identical under fixed conditions.
A1	Telegraphy on pure continuous waves. A continuous wave that is keyed according to a telegraph code.
A2	Modulated telegraphy. A carrier wave modulated at one or more audible frequencies, the audible frequencies or their combination with the carrier wave being keyed according to a telegraph code.
A3	Telephony. Waves resulting from the modulation of a carrier wave by frequencies corresponding to the voice to music or to other sounds.
A4	Facsimile. Waves resulting from the modulation of a carrier wave by frequencies produced by the scanning of a fixed image with a view to its reproduction in a permanent form.
A5	Television. Waves resulting from the modulation of a carrier wave by frequencies produced at the time of the scanning of fixed or moving objects.

b. The foregoing classification of emissions is still widely used, but is inadequate since there is no provision for systems such as frequency modulation, pulse-time modulation, frequency-shift keying and multiplexing. The International Telecommunication and Radio Conference which met at Atlantic City, New Jersey, in 1947 adopted a new system which was more comprehensive and overcame the deficiencies of the previously adopted system. This system classifies emissions according to type of modulation, type of transmission, supplementary characteristics, and bandwidth as follows:

Types of modulation	*Symbol*
Amplitude	A
Frequency (or phase)	F
Pulse	P
Types of transmission	
Absence of any modulation intended to carry information	0
Telegraphy without the use of modulating audio frequency	1
Telegraphy by the keying of a modulating audio frequency or audio frequencies or by keying of the modulated emission	2
Telephony	3
Facsimile	4
Television	5
Composite transmissions and cases not covered by the foregoing	9
Supplementary characteristics	
Double side band, full carrier	None
Single side band, reduced carrier	a
Two independent side bands, reduced carrier	b
Other emissions, reduced carrier	c
Pulse, amplitude-modulated	d
Pulse, width-modulated	e
Pulse, phase- or position-modulated	f

Bandwidth

Bandwidth is indicated by a prefix giving the bandwidth in kilocycles.

c. Following are typical examples of the new ITRC designators:

Designator	*Type of emission*
0.1 A1	Telegraphy; 25 words per minute, International Morse Code, carrier modulated by keying only.
3 A3a	Amplitude-modulated telephony; 3,000 c/s maximum modulation, single-side band, reduced carrier.
46 F3	Frequency-modulated telephony; 3,000 c/s modulation frequency, 20 000 c/s deviation.

54. Simple Electron-Tube Transmitter

a. A simple one-tube c-w transmitter can be made by coupling the output of an oscillator directly to an antenna (fig. 68). The primary purpose of an oscillator is to develop an r-f voltage which has a constant frequency and is immune to outside factors which may cause its frequency to shift. The output of this simple transmitter is controlled by connecting a telegraph key at point K in series with the B-voltage supply. Since the plate supply is interrupted when the key is open, the circuit oscillates only as long as the key is closed. Although the transmitter illustrated uses a Colpitts oscillator, any of the oscillators previously described can be used.

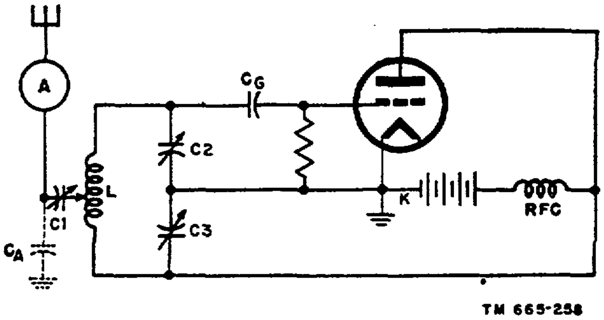

Figure 68. Simple electron-tube transmitter.

b. Capacitors *C*2 and *C*3 may be ganged together to simplify tuning. Capacitor *C*1 is used to tune (resonate) the antenna to the transmitter frequency. C_A is the effective capacitance existing between the antenna and ground. This antenna-to-ground capacitance is in parallel with the tuning capacitors, *C*2 and *C*3. Since the antenna has capacitance, any change in its length or position, such as that caused by swaying, changes the value of C_A and causes the oscillator to change frequency.

55. Multitube Transmitters

a. General.

(1) The simple one-tube transmitted shown above rarely is used in practical equipment. Most transmitters use a number of tubes or stages. The number of tubes or stages that are used depends on the frequency, power, and application of the equipment. In this chapter, c-w transmitters in the following categories are discussed: master-oscillator power-amplifier (mopa) transmitters, multistage high-power transmitters, and high-frequency and very-high frequency transmitters.

(2) The mopa is an oscillator and a power amplifier. In order to increase power and raise the frequency, it is necessary to use additional power-amplifying stages and frequency-multiplying stages. The main difference between many low- and high-power transmitters is in the number of power-amplifying stages that are used. Similarly, the main difference between many low-frequency and high-frequency transmitters is in the number of frequency-multiplying stages used.

b. Master-Oscillator Power Amplifier (fig. 69).

(1) For a transmitter to be stable, its oscillator must not be loaded down, which means that its antenna must not be connected directly to the oscillatory circuit. To obtain good frequency stability, therefore, it is necessary to send the r-f oscillations through another circuit before they are fed into the antenna. This additional circuit is an r-f power amplifier. Its purpose is to raise the level of r-f oscillations of the oscillator to the required output power level. Any transmitter consisting of an oscillator and a single amplifier stage is called a master-oscillator power-amplifier transmitter. Not shown in the block diagram is a special network, called interstage coupling, which consists of a combination of inductance, capacitance, and, sometimes, resistance, which is used to effect efficient transfer of energy from the oscillator to the power amplifier.

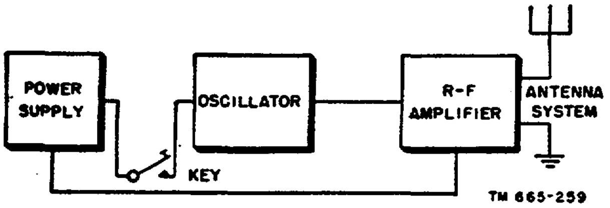

Figure 69. Block diagram of master-oscillator power-amplifier transmitter.

(2) Most mopa transmitters have only one tube in the power-amplifier stage. However, the oscillator may not produce sufficient power to drive a power-amplifier tube large enough to deliver the required power output to the antenna. In such cases, the power-amplifier stages often are designed to use two or more tubes which can be driven by the oscillator. Two or more tubes can be connected in in parallel (with similar elements of each tube connected), or in push-pull. In a push-pull amplifier, the grids are fed equal r-f voltages 180° out of phase.

(3) One advantage of a mopa transmitter is that the power-amplifier stage isolates the oscillator from the antenna and prevents changes in antenna-to-ground capacitance from affecting the frequency. A further advantage is that the r-f power amplifier is operated so that a small change in the voltage applied to its grid circuit will produce a large change in the power developed in its plate circuit.

(4) R-f power amplifiers require that a specified amount of power be fed into the grid circuit in order that the tube can deliver a given power output. Since there are limits to the amount of power that can be supplied by a stable oscillator, there is a corresponding limit to the amount of power that can be developed by a mopa transmitter. This is one of the disadvantages of the mopa transmitter. A further disadvantage is that it often is impractical for use at very-high and ultrahigh frequencies. The reason for this is that the stability of self-excited oscillators decreases rapidly as the operating frequency increases. Circuit tuning capacitances are small at high frequencies so that stray capacitances have a greater effect on the over-all frequency. Crystal-controlled oscillators are not suitable for use at very-high frequencies because such crystals are too thin and fragile to be practical.

c. Multistage High-Power Transmitters. The power amplifier of a high-power transmitter may require far more driving power than can be supplied by an oscillator. One or more low-power intermediate amplifiers may be inserted between the oscillator and the final power amplifier which feeds the antenna. In some types of equipment, a voltage amplifier, called a *buffer*, is used between the oscillator and the first intermediate amplifier. The ideal buffer is operated class A and, therefore, is biased sufficiently negative to prevent grid current flow during the excitation cycle. Therefore, it does not require driving power from the oscillator and thus does not load down the oscillator. Its purpose is to isolate the oscillator from the following stages and to minimize changes in oscillator frequency that occur with changes in loading. A buffer is essential when keying takes place in an intermediate amplifier or final amplifier operating at comparatively high power. In the block diagrams of several medium-frequency transmitters in figure 70, the input and output powers are given for each stage. It is shown that the power output rating of a transmitter can be increased by adding amplifier tubes capable of delivering the power required.

d. High-Frequency and VHF Transmitters.

(1) Oscillators are too unstable for direct frequency control in very-high frequency and ultrahigh-frequency transmitters. Therefore, these transmitters have oscillators operating at comparatively low frequencies, sometimes as low as one-hundredth of the output frequency. The oscillator frequency is raised to the required output frequency by passing it through one or more frequency multipliers. Frequency multipliers are special r-f power amplifiers which multiply the input frequency. In practice, the multiplication factor is seldom larger than five in any one stage. The block diagram of a typical vhf transmitter designed for continuous tuning between 256 and 288 mc is shown in figure 71. The stages which multiply the frequency by two are *doublers*; those which multiply by four are *quadruplers.*

(2) The oscillator is tunable from 4 to 4.5 mc. The multiplier stages increase the frequency by a factor of 64 by multiplying successively by four, four, two, and two. In high-power high-frequency transmitters, one or more intermediate amplifiers may be used between the last

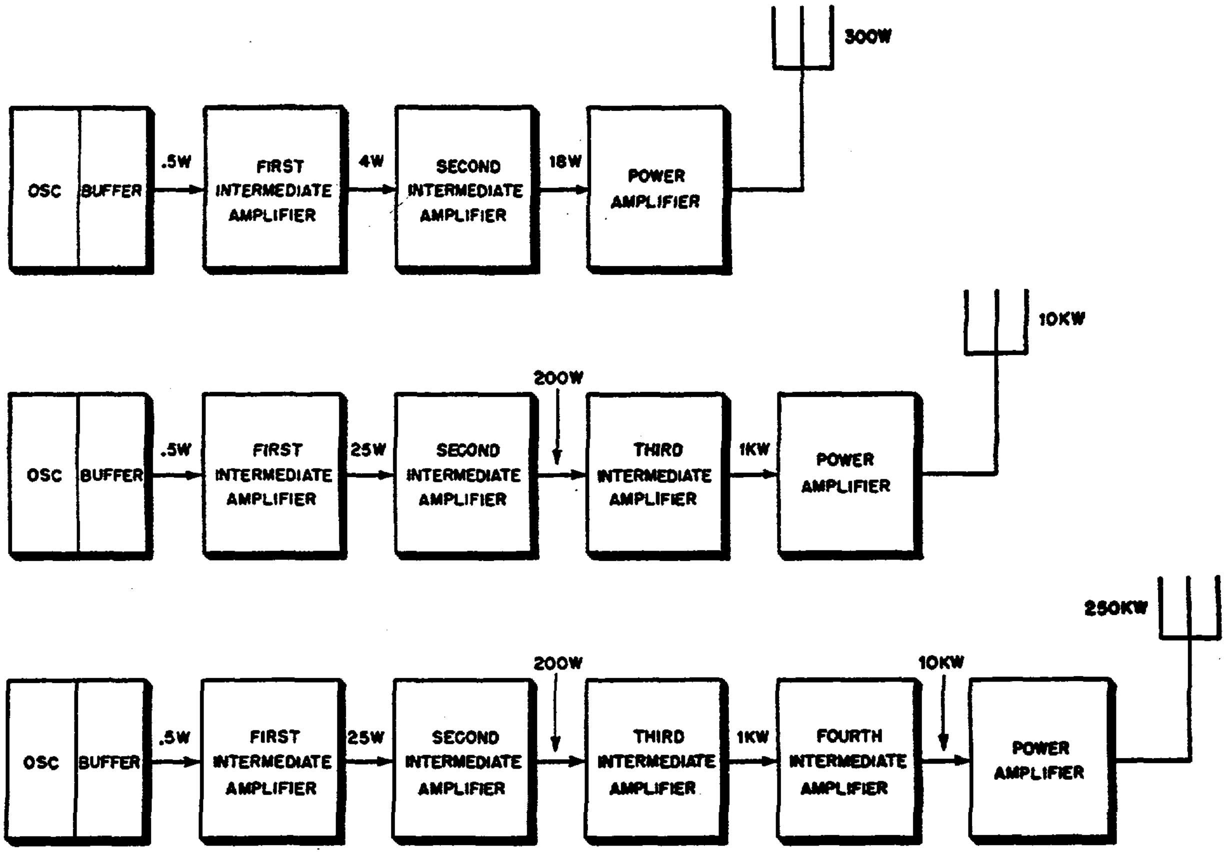

Figure 70. Block diagram of several medium-frequency transmitters.

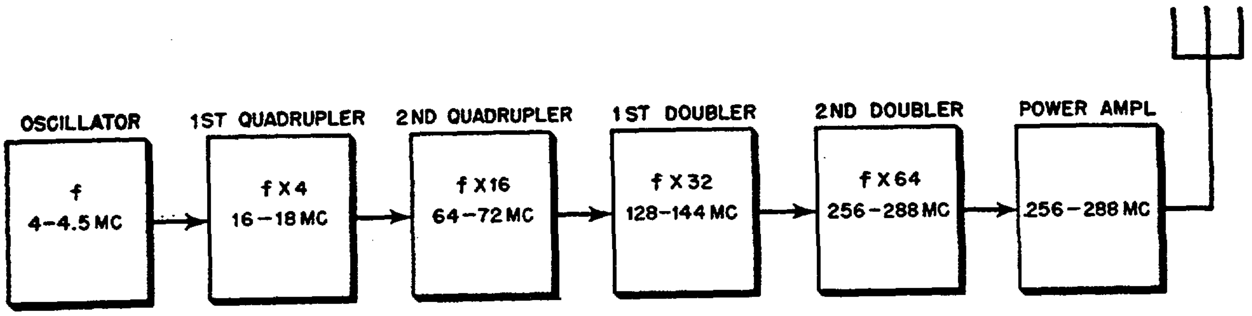

Figure 71. Block diagram of vhf transmitter.

frequency multiplier and the power amplifier. Interstage coupling networks are used between all stages within a transmitter having more than one stage.

56. Amplifiers for Radio Frequencies

a. Classes of Power Amplifiers. R-f amplifiers are divided into three classes which may be identified by the conditions under which each operates. The classifications are class A, class B, and class C. The choice of a specific type of operation is based on the circuit application. Class A operation is used for voltage amplifiers in r-f buffer stages and in audio amplifiers. Class B amplifiers sometimes are used in intermediate power amplifier applications and also for final power amplifiers when low level modulation is utilized. Class C amplifiers find widest application as frequency multipliers, intermediate amplifiers, and final power amplifiers.

b. Class A Amplifier. A class A amplifier is one in which the waveshape of the output voltage is the same as that of the signal applied to the grid of the tube. The only difference between the input and output signals is in the relative amplitudes. The operating bias is such that plate current flows for the entire excitation cycle. Since the grid is not driven positive, little or no grid current flows. Consequently, negligible driving power is required. The place circuit efficiency of the class A amplifier is approximately 25 percent.

c. Class C Power Amplifier.

(1) Class C power amplifiers are operated with grid bias two to three times greater than that required to cause plate-current cut-off. The signal applied to the grid must be large enough to overcome the bias and produce pulses of current in the plate circuit. The efficiency of the circuit increases as the duration of the plate-current flow is decreased. By making the plate-current pulse sufficiently short, circuit efficiency can be made to approach 100 percent. However, shortening the duration of plate-current flow also can reduce the input power and, consequently, the output power, even though the output is obtained at high efficiency. Therefore, as a compromise between power output and efficiency, class C amplifiers usually are operated so that the plate current flows for about 120° to 170° of the cycle. Under these conditions, the circuit efficiency is between 60 and 80 percent.

(2) When the plate-current pulse occurs, it stores energy in the plate tank circuit. As soon as the high grid bias cuts off the plate current, an oscillation starts in the tank circuit. The tank circuit may be considered shock-excited by the pulses of current and oscillating at its natural frequency between pulses. The effect of storing energy in the tank circuit is similar to the action of the flywheel on a single cylinder gasoline engine. When the gasoline is fired, the piston moves down and stores enough energy in the heavy flywheel to keep the engine turning over until the gasoline is fired on the next cycle. In amplifier circuits, the tuned-plate tank circuit corresponds to the flywheel. This action is called the flywheel effect. In addition to the fundamental, or input, frequency, many higher order harmonics are present in the pulses of current applied to the tank circuit. However, the action of the tuned tank attenuates the undesired harmonic com-

ponents and restores the sinusoidal waveform to the voltage output.

(3) For maximum output, a specified amount of driving power or excitation must be applied to the grid of a class C amplifier. Because of losses in the driver plate circuit and in the interstage coupling network, the driver stage must be capable of delivering considerably more power than required to drive the amplifier. Therefore, if a class C amplifier requires 20 watts of drive (driving power) the driver stage must deliver about 35 to 40 watts.

(4) A class C amplifier sometimes is operated as a push-pull stage. The grids of the push-pull stage are fed 180° out of phase. The signal voltage is positive on the grid of one tube at the instant that it is negative on the grid of the other. The plate tank circuit is triggered into oscillation by the plate-current pulse from the tube having the positive grid. The other tube in the push-pull circuit does not conduct at this time because the excitation voltage has driven its grid even more negative. When the signal voltage reverses, the first tube is cut off and the second tube delivers its pulse to the plate tank circuit. Therefore, the push-pull tank circuit receives a pulse during each half cycle of the excitation voltage. A push-pull circuit is used in r-f power output applications to develop a balanced voltage output waveform and to effect an increase in power output. Tubes connected in push-pull reduce the generation of the undesirable second harmonic frequency.

d. Class B Amplifiers. The essential difference between class B and class C amplifiers is in the value of the d-c bias voltage. In a class B amplifier, the grid bias is approximately equal to the cut-off value, so that the plate current is near zero when no excitation is applied. Plate current flows during the positive half of the input cycle. By careful adjustment of the driving power, the class B amplifier develops a plate-current pulse that is a replica of the positive half cycle of the input signal. The flywheel effect of the tank circuit develops a sine wave in the plate tank circuit that is an image of the input signal. The efficiency of a class B amplifier is not over 40 to 45 percent. The final power amplifier is operated as a class B amplifier when low level modulation is used.

57. Interstage Coupling Systems

a. Necessity for Interstage Coupling. Interstage coupling circuits are necessary to insure that the required amount of r-f energy is transferred from one electron tube stage to another. For maximum efficiency, the energy must be transferred with a minimum amount of power loss and a minimum amount of loading on the oscillator or driver stage. The interstage coupling system should also provide a minimum of stray coupling between stages. This stray coupling can be either electrostatic or electromagnetic. In a transmitter, the types of commonly used interstage coupling circuits are capacitive, impedance, and inductive (transformer).

b. Capacitive Coupling.

(1) A series fed plate and parallel fed grid circuit is shown in A of figure 72. The d-c supply for the plate *V*1 is in series with the tank coil and the d-c (bias) supply for the grid of *V*2 is in parallel with the tank coil. In the parallel fed plate and series fed grid circuit shown in B, the plate supply of *V*1 is in parallel with the tank circuit, which is in series with the d-c supply for the following grid.

(2) These circuits operate in a similar manner. The voltage developed across tank coil *L*1 divides across capacitors *C*1 and *C*2 in proportion to their reactances. The larger voltage is developed across the smaller capacitance. The voltage developed across *C*2 is applied to the grid of *V*2. The amount of excitation (r-f grid voltage) applied to *V*2 can be increased by decreasing the value of *C*2. Since the tank circuit is tuned by *C*1 and *C*2 in series, any change in the value of *C*2 must be counteracted by changing the value of *C*1 in the opposite direction. In each case, the r-f choke RFC provides a load for the signal.

(3) An advantage of this type of coupling is that it is possible to provide a continuous variation in the load. Furthermore, it makes it possible to vary the grid excitation voltage over a wide range. A dis-

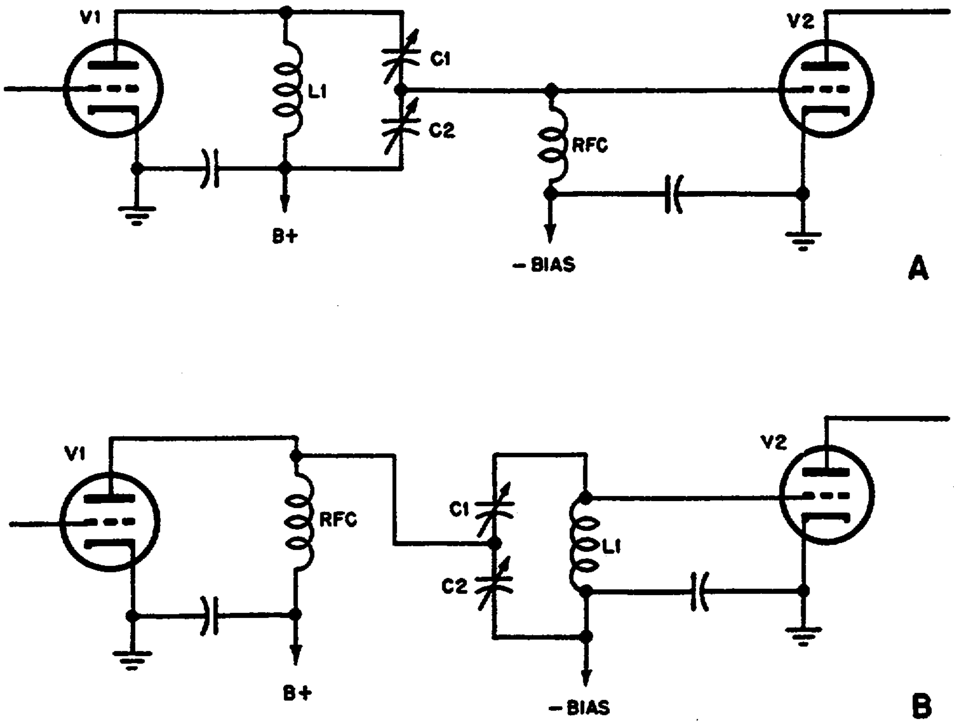

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Figure 72. Capacitive coupling circuits.

advantage is that the tuning range is limited.

c. Impedance Coupling.

(1) In the circuits shown in figure 73 as examples of impedance coupling, tank coil *L* is tapped so that the voltage applied to the grid of *V*2 can be varied. Capacitor *cc* feeds r-f voltage to the grid of *V*2 while preventing the passage of d-c. Because of the use of the coupling capacitor, this arrangement is sometimes referred to as capacitive coupling and the circuits shown can be called mutual capacitance couplings.

(2) In A of figure 73, the plate circuit of *V*1 is series fed whereas the grid circuit of *V*2 is shunt fed. In B, the plate circuit of *V*1 is shunt fed and the grid circuit of *V*2 is series fed.

(3) In another type of impedance coupling (fig. 74), untuned impedances (radio-frequency chokes) are used. The advantages of this circuit arrangement are low cost and minimum space requirements. A disadvantage is that the absence of a tuned circuit between stages makes it possible for the driver to feed unwanted harmonic frequencies into the amplifier where they are amplified along with the fundamental. Although the harmonic may be considerably weaker than the desired signal, it can be strong enough to cause serious interference to other stations. Furthermore, the indiscriminate use of r-f chokes or tapped coils can cause low-frequency parasitic oscillations at a frequency different from the frequency the stage is designed to pass.

d. Inductive Coupling (fig. 75).

(1) In these examples of inductive or transformer-coupling circuits, *L*1 and *L*2 are close together and wound in such a way that the lines of force from *L*1 cut the turns of *L*2 and induce a voltage in it. In the series fed circuit, in A, and the parallel fed circuit, in B, *L*1 and *L*2 are tuned to resonance by capacitors *C*1 and *C*2 respectively.

(2) Coupling between *L*1 and *L*2 can be varied by changing the spacing between them or by changing the angle of one coil in respect to the other. In some applica-

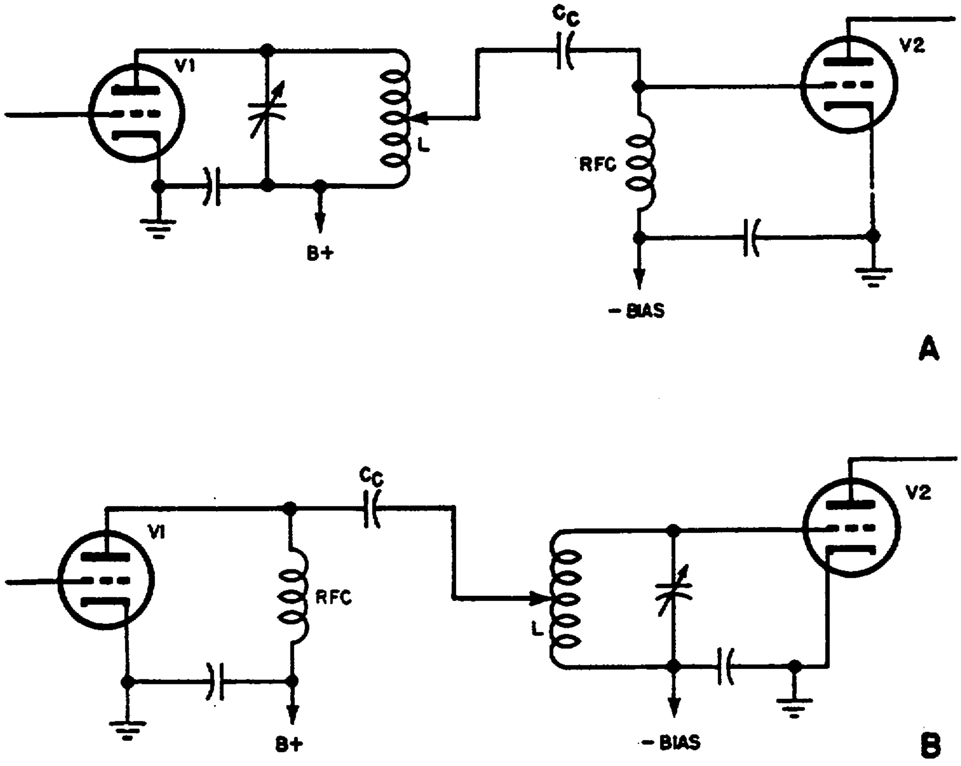

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Figure 73. Impedance-coupling circuits.

tions, the procedure is to wind the coils so that one turn of $L2$ is sandwiched between two turns of $L1$. In other circuits, $L2$ is insulated wire passed through the center of hollow copper tubing which is used for $L1$. In figure 76, the coils are wound in a unity-coupled r-f transformer. This method of interstage coupling rarely is used in military transmitters because of the mechanical difficulties encountered in adjusting the coupling to provide the proper excitation for the driven amplifier.

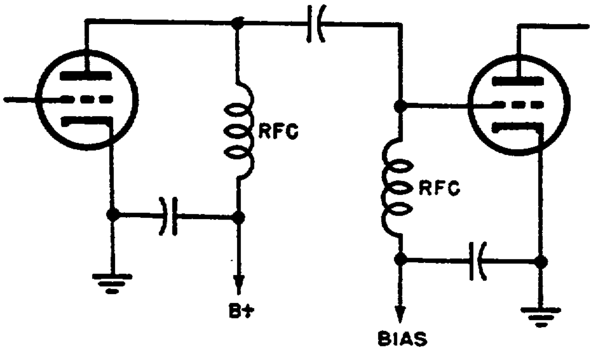

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Figure. 74. Untuned impedance coupling.

e. Link Coupling (fig. 77).

(1) Link coupling is a special form of inductive coupling. It requires the use of two tuned circuits, one in the plate circuit of the driver tube and the other in the grid circuit of the amplifier. A low impedance r-f transmission line having a coil of one or two turns at each end is used to couple the plate and grid tank circuits. The coupling links or loops are coupled to each tuned circuit at its cold end (point of zero r-f potential). Circuits which are cold near one end are called unbalanced circuits. Link coupling systems normally are used where the two stages to be coupled are separated by a considerable distance. One side of the link is grounded in cases where harmonic elimination is important or where capacitive coupling between stages must be eliminated.

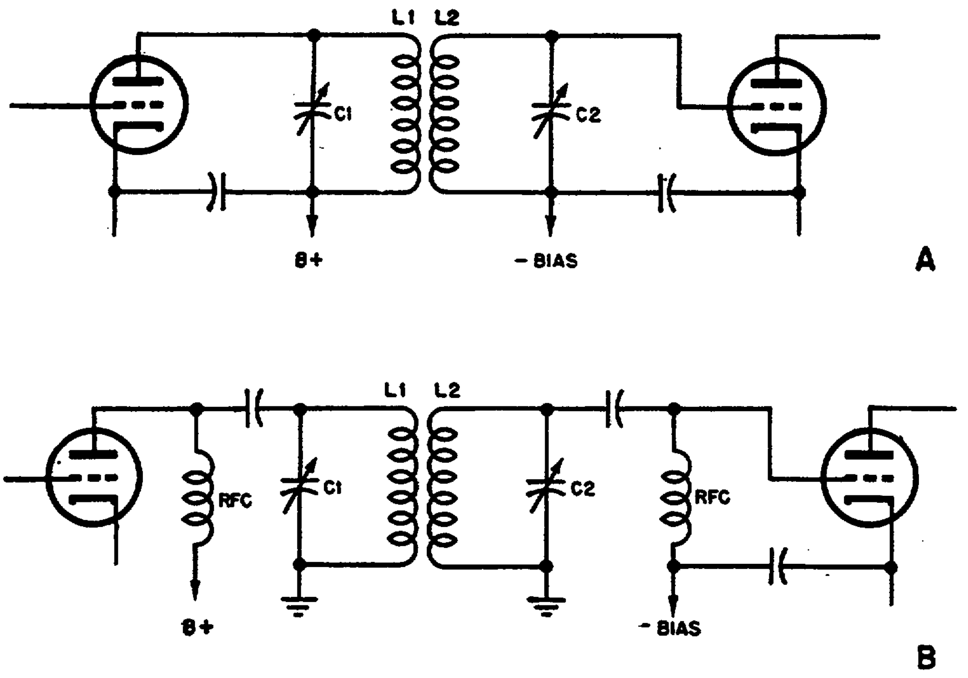

Figure 75. Inductive interstage coupling.

(2) Some types of transmitter circuits require the use of a balanced circuit. This is one in which the d-c voltage is fed to the center of the tuned coil and equal r-f voltages are developed at the ends. In this way, neither end of the circuit is at r-f ground potential. Figure 78 shows how an unbalanced circuit is link-coupled to a balanced circuit.

(3) Link coupling is a very versatile interstage coupling system. It is used in transmitters when the equipment is sufficiently large to permit the coupled coils to be so positioned that there is no stray capacitive coupling between them. Link

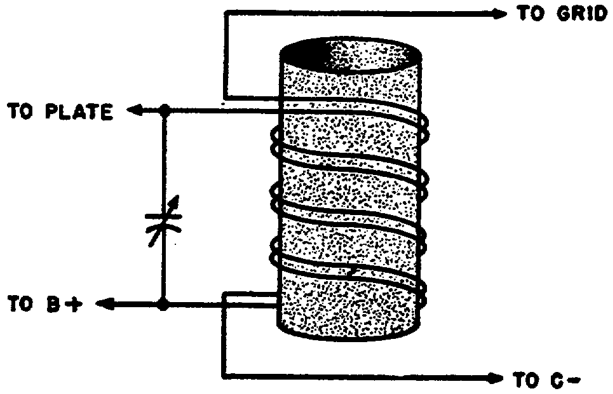

Figure 76. Unity-coupled r-f transformer.

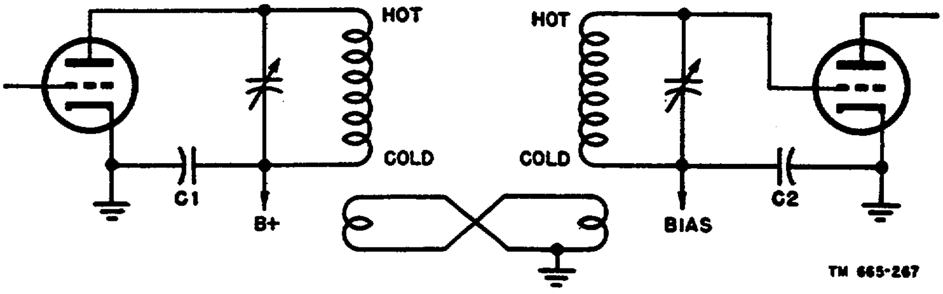

Figure 77. Link coupling.

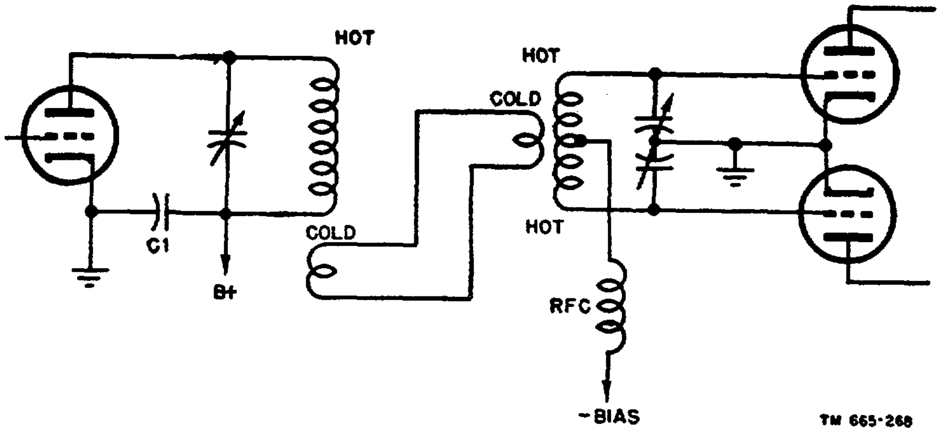

Figure 78. Balanced link coupling.

circuits are designed to have low impedance so that r-f power losses are low. Coupling between the links and their associated tuned circuits can be varied without complex mechanical problems. These adjustments provide a means of obtaining very low coupling between stages. The elimination of stray capacitive coupling makes neutralization easier and provides for reduction of harmonic transfer between stages.

58. Tuned Circuits Used for Coupling

a. Need for Tuned Circuits. The maximum amount of r-f energy is transferred from one stage to another when the interstage coupling system includes a tuned circuit which accepts r-f oscillations at the desired frequency and rejects r-f at all other frequencies. When a circuit accepts the desired frequency it is said to be tuned to resonance, and it is resonated by adjusting the capacitor or inductor.

b. Types of Tuned Circuits.

(1) There are two types of resonant circuits. The parallel tuned circuit has a high impedance at the resonant frequency, the line current is low, but the circulating tank current is high. The impedance of a series resonant circuit is minimum and equal to the circuit resistance at the resonant frequency. The reactance across the inductor and capacitor, individually, however, is large. Therefore the voltage developed across a reactance is higher than that developed across the entire circuit. The voltage drops across the reactances are found from the formulas

$$E_L = E \times \frac{X_L}{R}$$

$$E_C = E \times \frac{X_C}{R}$$

where E_L and E_C are the voltage drops across the inductor and capacitor, respectively, R is the circuit resistance, and E is the voltage delivered by the generator. Assume that the resistance of the inductor is 10 ohms, and that its reactance is 500 ohms at the resonant frequency. The generator develops 5 volts across the circuit resistance, R. The voltage across L is E times X_L/R, or 5 times 500/10, which equals 250 volts. Therefore, a series resonant circuit can be used to produce a voltage step-up.

(2) Sometimes it is difficult to determine whether a tuned circuit is a series or a parallel arrangement without a careful examination of the circuit. At first glance, tuned circuits Nos. 1 and 2 in figure 79 both appear to be parallel resonant. Circuit No. 1 is parallel resonant because it receives its voltage from the plate of the tube to which it is connected. Circuit No. 2, however, is series-resonant because of the method of applying the voltage to the circuit. Instead, the voltage is induced in $L2$ (the secondary of the r-f transformer) and is considered to be developed in series with the capacitor and inductor. In this transformer-coupled circuit, the maximum voltage is developed across

*L*1 at resonance because of the high impedance of circuit No. 1. The voltage in *L*1 induces a voltage in the secondary of the transformer. Since *L*2 is in a series-resonant circuit, the voltage on the grid of the tube will be greater than the induced voltage by the ratio of the reactance to the circuit resistance.

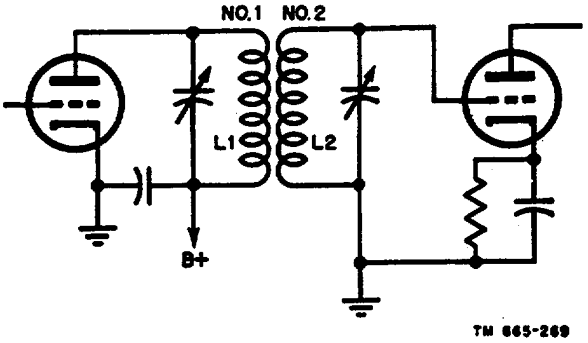

Figure 79. Transformer-coupled stages.

c. Tuning Procedure.

(1) Amplifier and oscillator circuits are tuned to the desired frequency by selecting the proper values of inductance and capacitance. The resonant frequency is continuously varied over a wide range by using a variable capacitor, a variable inductor, or a combination of both.

(2) Most tunable circuits are adjusted by using a variable capacitor in parallel or series with a suitable inductor. In modern transmitter and receiver circuits, it often is desirable to tune two or more circuits simultaneously. This usually is accomplished by using a capacitor having all rotorplate sections on a common shaft and the statorplate sections at the proper places along the stator frame. Each statorplate section is insulated from the others and from the frame. Such a capacitor is called a ganged capacitor and all circuits tuned by such a unit are said to be *ganged.*

(3) Some circuits are designed to be adjusted to one of a number of preset frequencies. Figure 80 shows an electron-coupled oscillator which is tuned to the desired frequencies by operating a switch. This circuit is adjusted to the highest desired frequency by adjusting *C*1 with the selector switch set in position 1. Lower frequencies are selected by rotating the selector switch to positions 2, 3, and 4. In positions above 1, a small variable capacitor is connected in parallel with *C*1. This increases the circuit capacitance and lowers the frequency.

(4) In some circuits, it is desirable for reasons of simplicity or design considerations to tune a circuit by varying the inductance rather than the capacitance. The most common method of varying inductance is to vary the position of a brass or powdered iron slug within the core of the coil (fig. 81). This method of tuning is called *slug tuning.* When a current is passed through the winding of an air core coil, there is a certain number of lines of magnetic force for each square inch of core area. If a core of magnetic material, powdered iron for example, is inserted in the coil, the number of magnetic lines of force will increase within the core considerably. This causes the effective inductance of the coil to increase. The increase varies directly as the permeability of the core. An increase in in-

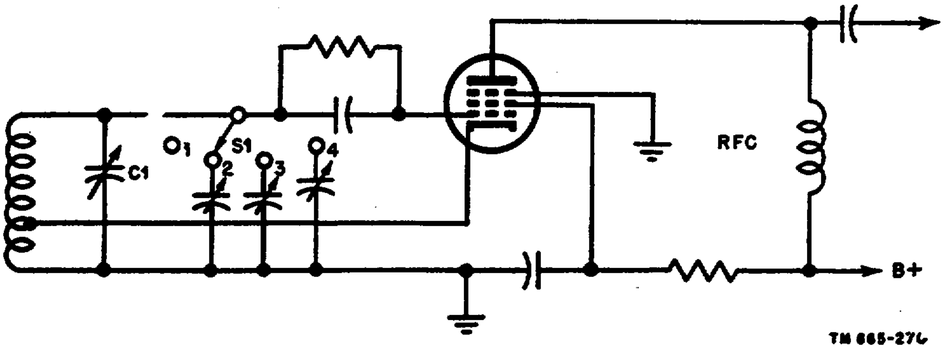

Figure 80. Electron-coupled oscillator with preset frequencies.

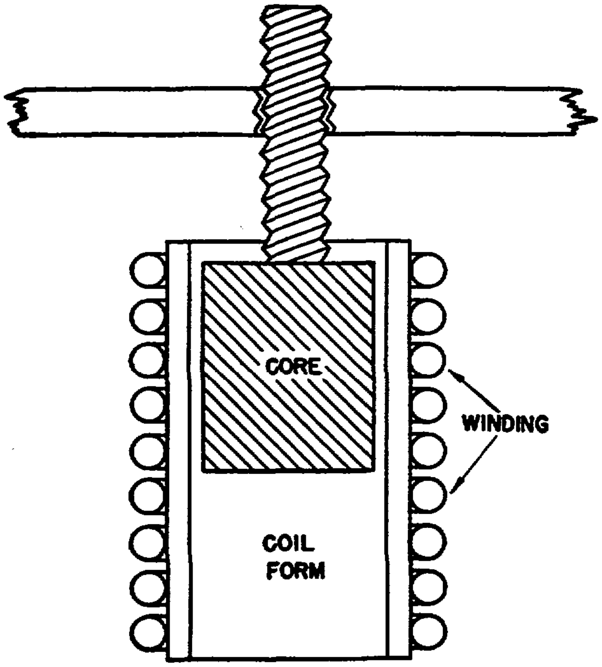

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Figure 81. Slug-tuned coil.

ductance causes a decrease in the frequency of the tuned circuit.

(5) If the tuning slug is made of brass or other conductor, the opposite effect is obtained. Inserting the slug into the coil decreases the number of magnetic lines per given area and causes a decrease in the effective inductance. By mechanical means, the slug can be moved in and out of the coil form to produce the desired change in resonant frequency.

(6) Still another method of varying the inductance of a coil, often used when one coil is used for two or more tuning ranges, is to short circuit some of the turns. This may be accomplished by a switch connected to taps on the turns (A of fig. 82). Short-circuiting turns of a coil reduces the effective number of turns and decreases the inductance. For continuous variation of inductance, the coil may be wound in a single layer. A small roller is positioned so that it rides trolley fashion along the turns and effectively short circuits all turns between the roller and one end of the coil (B of fig. 82).

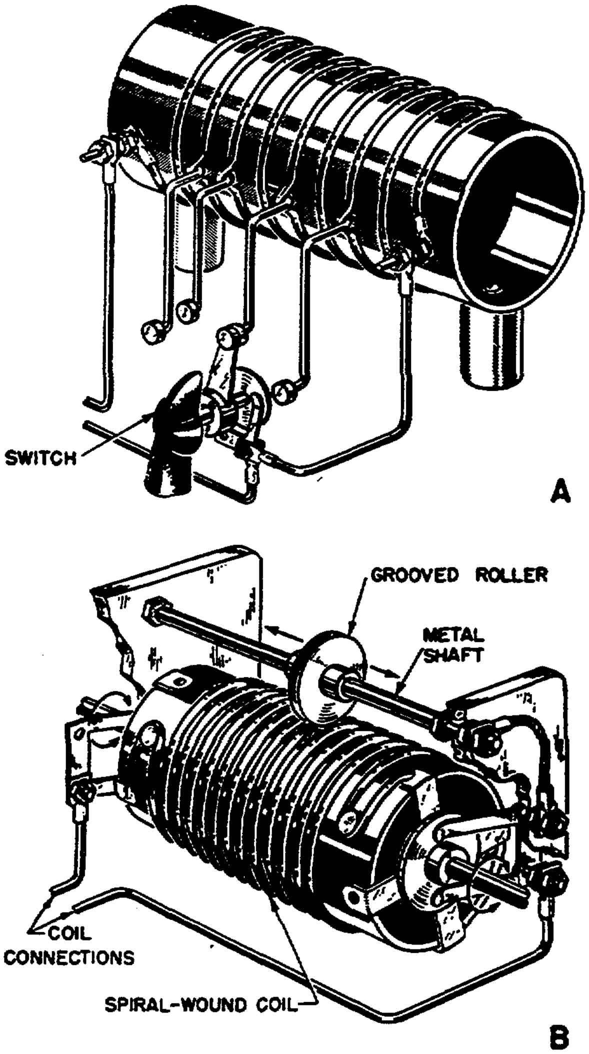

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Figure 82. Methods of short-circuiting turns of an inductor.

59. Neutralization in R-f Amplifiers

a. Need for Neutralization.

(1) In the fundamental r-f amplifier shown in figure 83 the input signal is applied to the grid circuit and the power output is taken from the tuned plate circuit. Both input and output circuits are tuned to the signal frequency. This basic amplifier circuit resembles the tuned-plate tuned-grid oscillator. Therefore, the amplifier itself can function as an oscillator. The amplifier oscillates because of the feedback of energy from plate to grid through the plate-to-grid interelec-

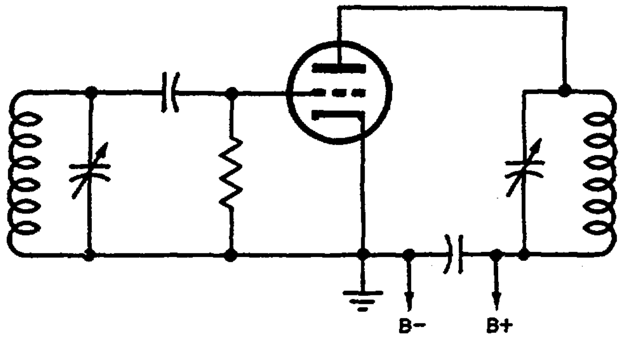

Figure 83. Triode r-f amplifier.

trode capacitance of the tube. This causes an unstable operating condition, distortion, spurious radiations, and interference to nearby radio receivers. Oscillation within the amplifier can be prevented by feeding back to the grid, through an external circuit, a voltage which is at all times equal but opposite in phase to the voltage fed back to the grid through the plate-to-grid capacitance. The voltage through the tube is canceled out by the voltage fed back through the external circuit. Since the feedback voltage through the tube is canceled, oscillation cannot take place. This process of preventing self-oscillation is called *neutralization.*

(2) Neutralization is necessary in triode amplifiers operating at approximately 500 kc or higher. Neutralization seldom is necessary in an amplifier using pentodes or beam power tubes which have a very small plate-to-grid capacitance. Transmitting-type tetrodes and pentodes are designed to operate without neutralization when simplicity is important.

b. Neutralization Systems. There are several well-known neutralization systems. Two of these, the plate or Hazeltine neutralization system, and the grid or Rice system, have the advantage or being useful over a wide frequency range. Radio-frequency amplifiers having a single tube or group of parallel tubes may use either a balanced tuned-plate or a balanced tuned-grid circuit to supply the feedback voltage in proper phase to prevent oscillation. Circuits in which out-of-phase voltages are fed back to the grid are *degenerative* and tend to decrease any change in voltages applied to the grid.

(1) *Plate neutralization* (fig. 84). Plate, or Hazeltine neutralization results when the degenerative feedback is obtained by means of a tapped plate coil. The circuits shown in A and B are suitable for use in c-w transmitters operating below approximately 6 mc. Above this frequency, minor unbalances in the inductive portion of the circuit may cause regeneration and the amplifier may be unstable. For amplifiers at higher fre-

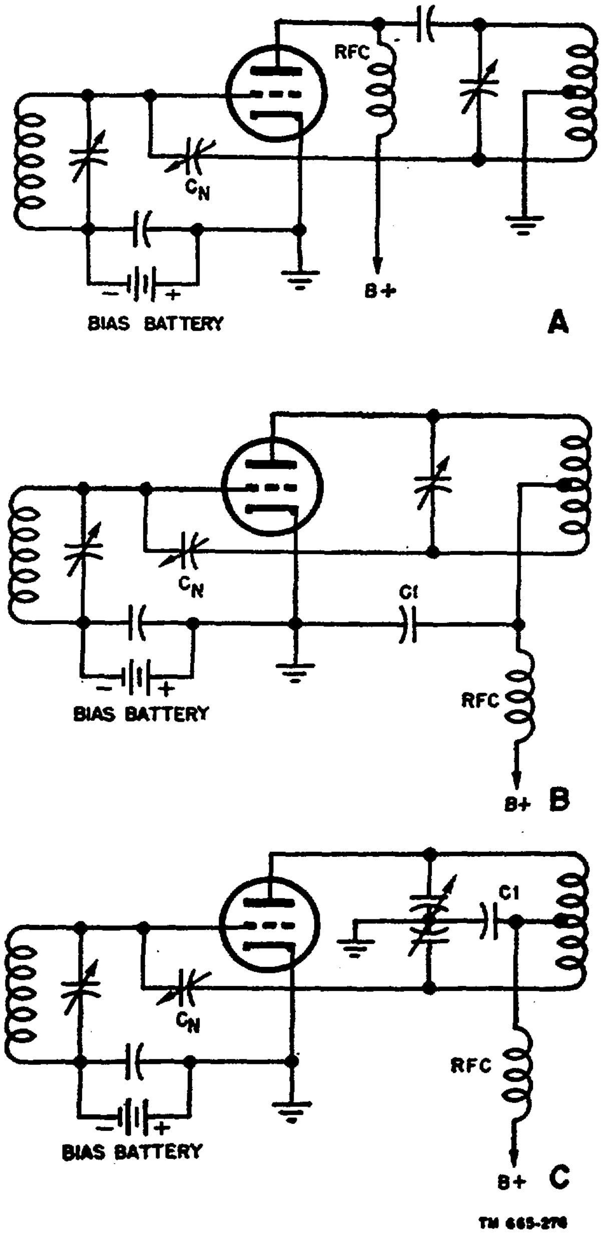

Figure 84. Plate neutralization.

quencies, the circuit in C, having a split stator capacitor, is used. This makes the circuit balanced and the division of voltage independent of mutual coupling between the halves of the coil. If the neutralization adjustment is made at the highest frequency, it will be sufficiently close to provide satisfactory operation at lower frequencies.

(2) *Grid neutralization* (fig. 85). In the grid, or Rice neutralization system, the tapped coil is in the grid circuit. A voltage is fed back through neutralizing capacitor C_N to the lower end of the tapped grid coil. The polarity of this voltage is reversed at the grid end of this coil. As a result, the feedback voltage is 180° out of phase with the voltage applied to the grid through the plate-to-grid capacitance. When the neutralizing capacitor is adjusted properly, the degenerative feedback through C_N just balances the voltage that is fed back through the tube, and proper neutralization occurs.

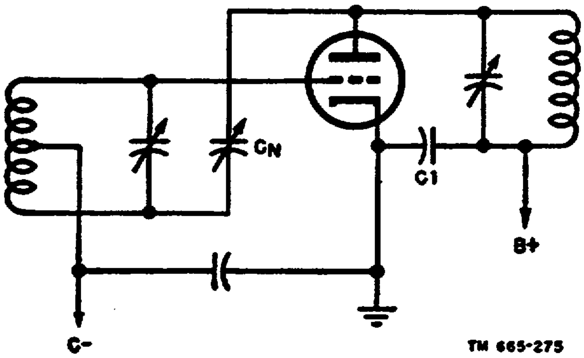

Figure 85. Grid neutralization.

(3) *Relative merits.* Plate neutralization has an advantage over grid neutralization in that one-half as much grid drive is required, but also the disadvantage that the plate tank capacitor must be rated at twice the B-plus voltage. Conversely, grid neutralization is advantageous because the tank capacitor may be rated at the value of the B-plus voltage, and disadvantageous because twice as much grid drive is required as compared with the plate system.

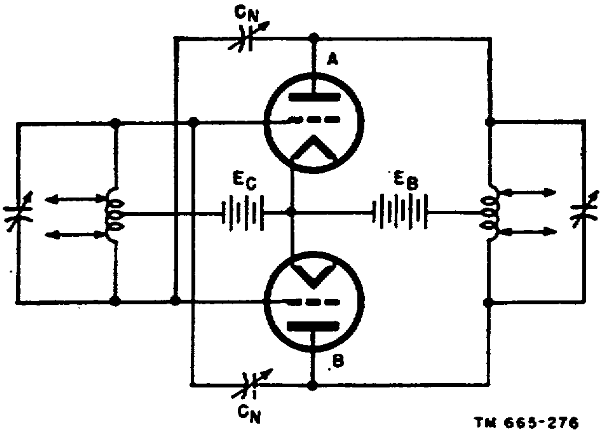

Figure 86. Cross neutralization.

(4) *Cross neutralization* (fig. 86). This type of neutralization is used in push-pull circuits. The plate voltage of tube *A* is normally 180° out of phase with the plate voltage of tube *B*. Therefore, the neutralization can be accomplished quite simply. A portion of the output voltage of tube *A* is applied through a neutralizing capacitor to the grid of tube *B*. A portion of the output voltage of tube *B* is applied through a second neutralizing capacitor to the grid of tube *A*. When the neutralizing capacitors are adjusted properly, correct neutralization occurs.

(5) *Link neutralization* (fig. 87). This system sometimes is used to stabilize pentode and tetrode amplifiers which are on the verge of oscillation because of insufficient shielding between grid and plate circuits or stray exterior coupling between input and output circuits. The feedback volt-

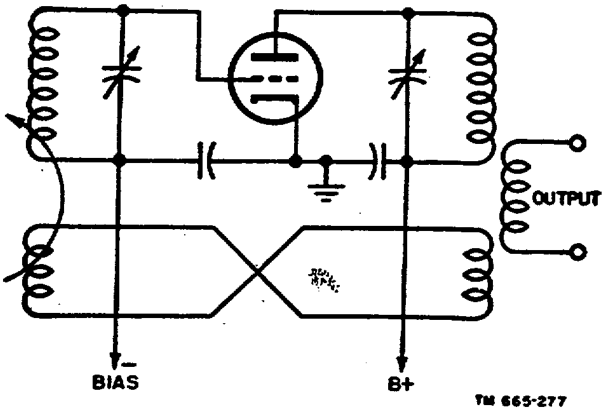

Figure 87. Link neutralization.

age is taken from the cold end of the plate coil and applied to the cold end of the grid coil through a link coupling circuit similar to that used for interstage coupling. The proper phase relationship is obtained by reversing the connections to one of the feedback loops. The voltage fed back through the link is balanced with that fed back through the tube by varying the coupling between one of the loops and the tank circuit to which it is coupled.

(6) *Inductive neutralization* (fig. 88). Inductive or shunt neutralization differs from the systems previously described. In other circuits, the voltage fed back through the plate-to-grid capacitance is canceled by an equal but opposite voltage fed back through an external path. In this circuit, we can nullify the effect of the plate-to-grid capacitance by paralleling it with an inductor having the same value of reactance. Since the two reactances are equal and opposite, we have a parallel resonant circuit between the grid and the plate. Since a parallel resonant circuit offers a very high impedance at its resonant frequency, there is no transfer of energy through the circuit from plate to grid. $C1$ is a blocking capacitor which prevents the flow of direct current. This circuit has the advantage that it can be used only for neutralization at a single frequency of operation only.

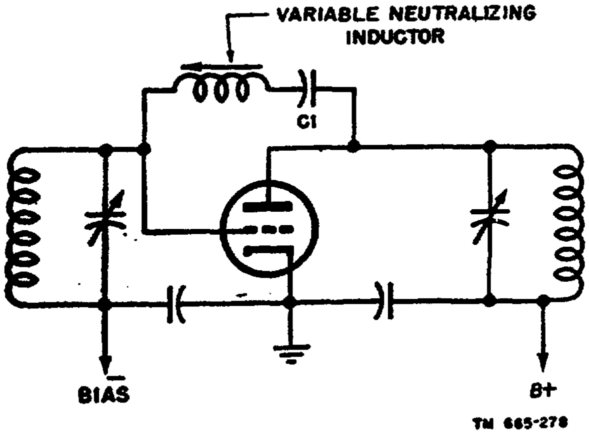

Figure 88. Inductive neutralization.

c. How Circuits are Neutralized.

(1) Several techniques can be used in neutralizing r-f amplifiers. The most common of these is performed with the plate voltage removed from the stage being neutralized. Radio-frequency excitation is applied to the grid circuit. An r-f indicator (such as a neon lamp or a dial lamp connected to the ends of a single-turn loop of wire) is coupled to the plate tank circuit. If the stage is not neutralized, the indicator glows when the plate tank is tuned to resonance with the grid circuit. The neutralizing capacitor or other neutralizing adjustment should be varied slowly until all indication of r-f disappears from the plate tank. The grid and plate circuits should be retuned after each adjustment of the neutralizing control. Push-pull amplifiers are adjusted in the same manner. The adjustment is carried out more quickly if the neutralizing capacitors are first adjusted to approximately the same capacitance. These capacitors should remain at approximately the same capacitance throughout the neutralizing procedure.

(2) A commonly used indicator is a low range d-c millimeter in the grid circuit of the stage to be neutralized. Some transmitters have amplifier grid current meters; others have provisions for switching a meter into the grid circuit. First, disconnect the plate voltage. Next, apply sufficient excitation to produce an indication on the meter, and then tune the grid circuit to resonance as indicated by maximum grid current. If the stage is not neutralized, the d-c grid current varies as the *plate tank capacitor* is tuned through resonance. The neutralizing capacitor or other neutralizing adjustment should be varied slowly until there is no change in d-c grid current as the plate tank capacitor is tuned through resonance.

(3) If the stage being neutralized is not the final amplifier, a slightly different technique can be used. A d-c grid current meter is inserted in the grid circuit of the stage following the buffer or intermediate amplifier being neutralized. The plate

voltage then is removed from the stage being neutralized and from all stages following it. The stage being neutralized is tuned to resonance, and the following stage is resonated. A small amount of grid current will be observed as long as the stage is not fully neutralized. The neutralizing adjustment is varied until there is no indication of grid current in the following stage.

60. Frequency Multiplication

a. Frequency multipliers are special class C amplifiers operated with three to ten times cut-off bias and used to generate a frequency that is a multiple of a lower frequency. Such multiple frequencies are called harmonics, and circuits designed to develop harmonic frenquencies are called harmonic generators or frequency multipliers. The signal fed to a frequency multiplier is the fundamental or first harmonic. The second harmonic is twice the fundamental, the third harmonic is three times the fundamental, and so on.

b. Frequency multipliers operate by virtue of pulses of plate current produced by a class C amplifier. The plate-current pulse usually is quite distorted. As such, it contains harmonics of the fundamental operating frequency. Although the plate current flows in pulses, the alternating plate voltage is sinusoidal because of the filter or flywheel action of the tank circuit. When the output tank circuit is tuned to the required harmonic frequency, the tank acts like a filter, accepts the desired harmonic and rejects all other harmonics, and frequency multiplication results.

c. The harmonic content and efficiency of a frequency multiplier increase as the angle of plate current flow is decreased. To reduce the angle of flow, higher grid bias is used so that the excitation voltage exceeds the cut-off voltage for a shorter period of time. The chart below shows the plate-current pulse length and power output of harmonic generators.

Harmonic	Optimum length of plate-current pulse in electrical degrees at the fundamental frequency	Percentage of output from class C first-harmonic amplifier
2	90 to 120	65
3	80 to 102	40
4	70 to 90	30
5	60 to 72	25

d. In the circuit of a typical frequency multiplier in A of figure 89, the plate tank circuit is tuned to the second harmonic. This circuit is referred to as a doubler. A tripler is a frequency multiplier whose output tank circuit is tuned to the third harmonic. A quadrupler produces an output frequency which is four times the fundamental frequency. Frequency multipliers seldom operate above the fifth harmonic because of their greatly reduced output power. Frequency multipliers need not be neutralized because the plate tank circuit is not tuned to the same frequency as the grid tank circuit.

e. Two tubes can be connected with their plates in parallel and their grids in push-pull as in B. With the grids thus fed out of phase, one pulse is produced in the common plate circuit for each half cycle of excitation. This circuit is called a push-push doubler. Not only is the excitation frequency doubled, but the circuit has the added advantage of balancing out the fundamental and all odd hormanics. A push-push doubler delivers more power output than the same two tubes operated in parallel as a doubler, using the circuit arrangement shown in A. The push-push circuit is useful also as a quadrupler when the output tank circuit is tuned to four times the input frequency.

61. Grid Biasing

Bias is used on the grid of an electron tube amplifier to insure that it operates on the proper point of the plate-current grid voltage curve. There are a number of methods of supplying the required negative biasing voltage.

a. Fixed bias is obtained from batteries (fig. 89) or from a rectifier power supply. An electron tube can be connected so that it supplies all or part of its own operating bias. Such circuits are called *self-biasing* circuits.

b. One method of self-biasing is to insert a resistor between the cathode and ground of the electron tube amplifier (fig. 90). This method is called cathode resistor bias, or simply cathode bias. Current drawn by the plate and grid (and screen grid in tetrodes and pentodes) flows through resistor *R*1 in a direction which makes the cathode end positive in respect to the lower end (ground). Omitting *R*2 for the moment, the grid of the triode is grounded through the grid tank circuit. Since bias is the voltage difference between the grid and the cathode, making the cath-

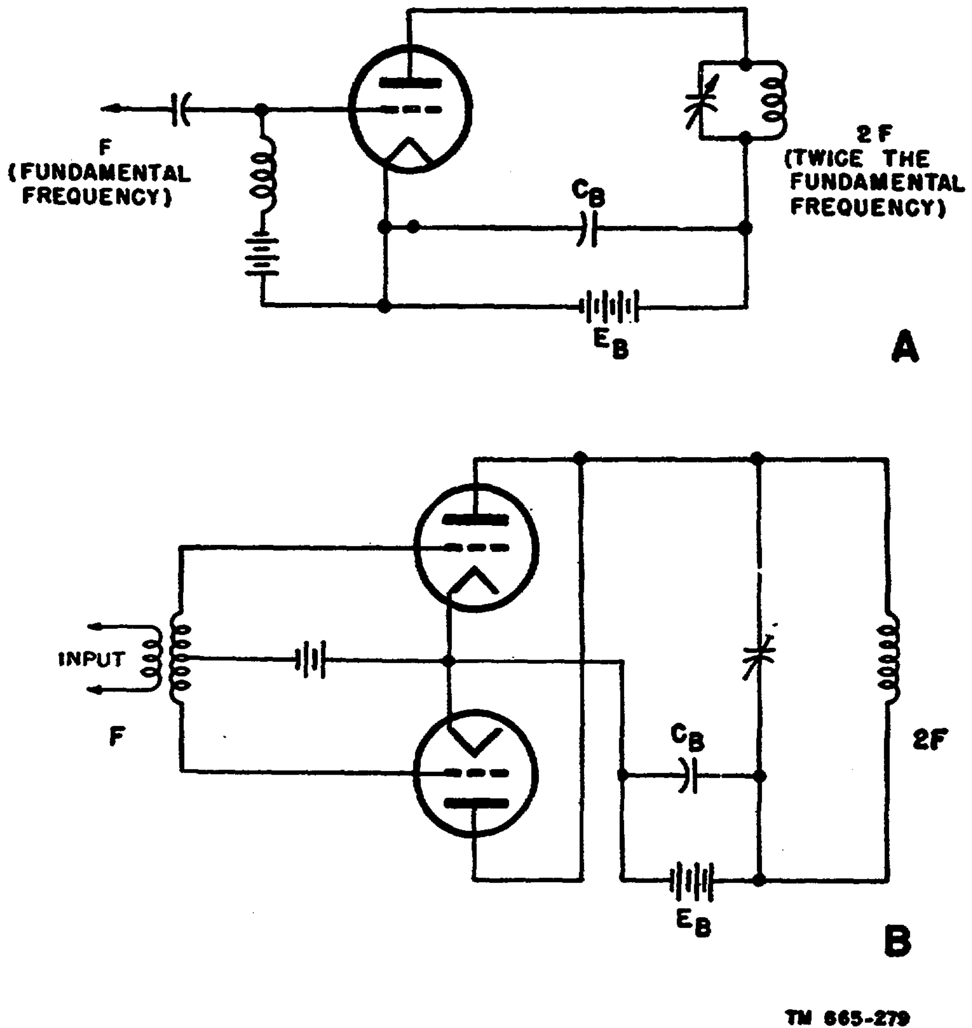

Figure 89. Frequency-doubler circuits.

ode positive in respect to the grid is equivalent to making the grid negative in respect to the cathode. Bias developed in this manner is called automatic bias. The value of the biasing resistor is chosen so that the sum of the currents flowing in the cathode circuit biases the tube for proper operation.

c. An increase in excitation causes the total cathode current to increase. The rise in cathode current causes an increased drop across resistor *R*1. This tends to hold the cathode current constant by making the grid more negative and so partially canceling the effect of increased excitation. Capacitor *C*1 presents a low reactance at the excitation frequency so that a-c pulsations in the plate circuit do not affect the operating bias. It is not feasible to use cathode bias to develop the large negative bias necessary to bias the tube be-

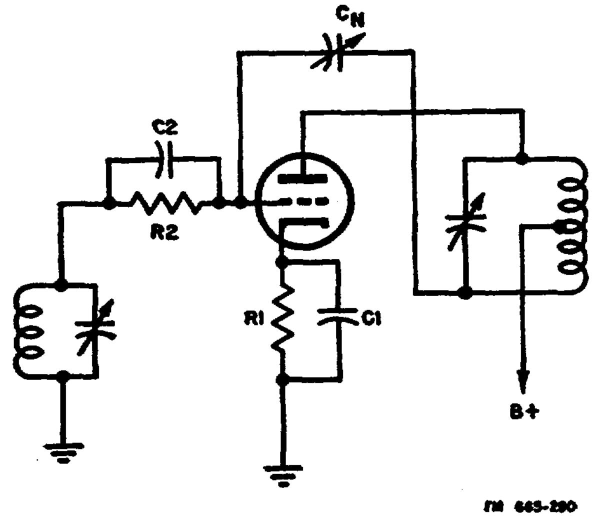

Figure 90. Cathode bias and grid-leak bias in an amplifier.

low the bend in the E_g-I_p curve, because plate current must flow in order for bias to be developed. For this reason, cathode bias is used more extensively in class A amplifiers which are biased above cut-off. Cathode bias in class C r-f amplifiers generally is used in combination with fixed bias or grid-leak bias.

d. A resistor can be connected in the grid circuit of an r-f amplifier to provide grid-leak bias. Resistor *R*2 in figure 90 is of the d-c grid return path. R-f excitation, applied to the grid of the tube causes the grid to go positive and draw grid current on the peaks of the excitation cycle. This current flows through the grid-leak resistor and produces a voltage drop. The direction of grid-current flow is such that the grid is biased negatively in respect to the cathode. Capacitor *C*2 across *R*2 bypasses any r-f energy that may be present. The value of *R*2 is selected so that the voltage drop across it develops the required amount of bias.

e. The bias voltage is the product of the grid current in amperes and the grid-leak resistance in ohms. Grid-leak bias automatically adjusts itself for fairly wide variations in excitation. Its advantage lies in the fact that very high biasing voltages can be developed without using separate voltage sources. Its main disadvantage is that the bias developed across the resistor is lost when excitation fails. To protect the tube against excessive currents when excitation is interrupted, grid-leak and cathode bias often are used in combination. The cathode bias is used to limit the flow of plate current to a safe value when the preceding stage is keyed or when excitation fails.

62. Keying

a. The carrier of a c-w transmitter is broken into short and long pulses (dots and dashes) of r-f waves in accordance with the characters of the international Morse code. A radiotelegraph key like that shown in figure 91 is used to control the output of the transmitter. When the key is closed, the transmitter radiates the r-f signal. No signal is radiated as long as the key is open.

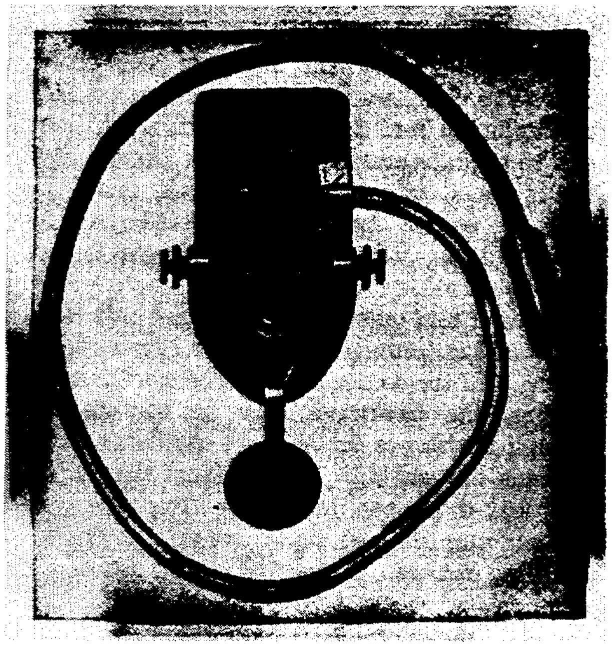

Figure 91. Radiotelegraph key.

b. In general, the keying of a transmitter is considered satisfactory if the r-f output is zero when the key is open and maximum when the key is closed. If the output does not drop to zero under key-up conditions, the signal is said to have a *backwave.* A strong backwave may reach a distant receiver and make the keying difficult to read. The effect is as though the dots and dashes were simply louder portions of a continuous carrier. In code transmissions, there are intervals between dots and dashes and between letters and words. No r-f is radiated during these brief intervals. If the receiver operates with normal sensitivity during these intervals, it is possible for the receiving operator to signal the transmitting operator by holding his key down. In this way, the receiving operator can signal the transmitting operator immediately when he has not been able to copy a part of the message because of fading, static, or interference. The ability of an operator to hear signals during key up intervals is called *break-in operation.* The oscillator may run continuously for break-in if it is inaudible in the receiver at the transmitting station.

c. Another requirement of satisfactory keying is that is should take place smoothly without key clicks which cause interference to stations receiving on other frequencies. Key clicks are caused when the output of the transmitter is changed too abruptly, and under these conditions side bands are produced. The oscillator should be absolutely stable while it is keyed. If it is not, the frequency shifts and causes a varying note (chirp) which makes the signal difficult to copy.

d. To avoid backwaves, the oscillator stage frequently is keyed directly. On the other hand, it is easier to avoid chirps by keying the transmitter in a stage between the oscillator and antenna. Since any chirp resulting from frequency shift is multiplied in each frequency multiplier, it is difficult to produce chirpless keying in a keyed oscillator operated at a frequency several times lower than the output frequency. When keying takes place in a stage other than the oscillator, the oscillator is on all the time. It must operate at very low power and must be well shielded and isolated to prevent radiation of a backwave (from the oscillator). If the oscillator does not meet these conditions, the backwave may be radiated even though the stages between the oscillator and the antenna are cut off. Energy from the oscillator may leak to the antenna through improperly neutralized amplifiers or capacitive and/or inductive coupling between the oscillator and antenna circuits.

63. Keying Circuits

A number of methods may be used for keying a transmitter. Most of them can be applied to the oscillator or amplifier stages. A transmitter can be keyed by opening and closing, simultaneously, the plate circuits of all the stages. The oscillator alone, or a stage between the oscillator and the final amplifier can be keyed. This is called *excitation keying* because excitation is applied to and removed from the input of the final amplifier while its plate voltage is applied.

a. Center-Tap or Cathode Keying. If the stage to be keyed has a directly heated cathode operated from an a-c source, the key can be inserted between the center tap on the filament transformer and the B-minus lead (fig. 92). The key opens and closes the negative side of the plate circuit. No plate current flows when the key is open. With indirectly heated tubes, the key is inserted between the cathode and the B-minus lead.

b. Simple Blocked Grid Keying. An amplifier or oscillator can be keyed by applying sufficient negative bias to the control grid to cut off the flow of plate current when the key is up. This blocking bias must be considerably higher than the normal cut-off grid bias because it must overcome the excitation voltage. It is removed by closing the key. The circuit in A of figure 93 uses cathode bias along with grid-leak bias. The addition of the cathode bias reduces the plate current and resultant output considerably. When the key is open, plate current through resistor *R* causes a voltage drop which makes the end of *R* connected to R_G negative in respect to the cathode end. If *R* is sufficiently large, the voltage drop is sufficient to reduce the plate current almost to cut-off. Closing the key short-circuits resistor R, removing the cathode bias and permitting normal plate current to flow. Resistor R_G is the usual grid-leak resistor which develops normal operating bias. Total plate-current cut-off is not possible with this system.

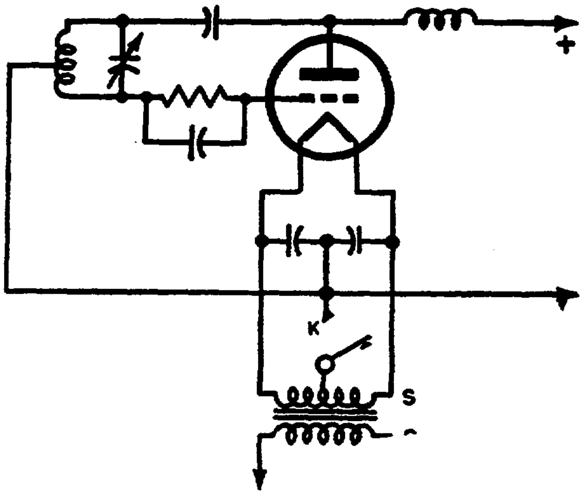

Figure 92. Center-tap or cathode keying.

c. Zero-Current Blocked Grid Keying. The circuit arrangement shown in B affords full plate-current cut-off when the key is opened. The cathode of the tube is connected to a tap on a voltage divider. When the key is open, the full 1,000 volts appears across the 100,000-ohm and the 200,000-ohm resistors in series. Since the voltage divides in direct proportion to the resistances, two-thirds (667 volts) of the supply voltage appears across the 200,000-ohm resistor between the plate and cathode and 333 volts appears across the 100,000-ohm resistor between the grid and cathode. When the key is open, the 333 volts adds to the 100 volts of fixed bias. This high negative bias cuts off the tube completely. When the key is closed, the 100,000-ohm resistor is shorted out and the full 1,000 volts appears between the plate and cathode. The grid bias is reduced to 100 volts, and the amplifier operates normally.

d. Screen Grid Keying. In some transmitters, the key is inserted in series with the screen grid of the amplifier or oscillator tube. If the key is

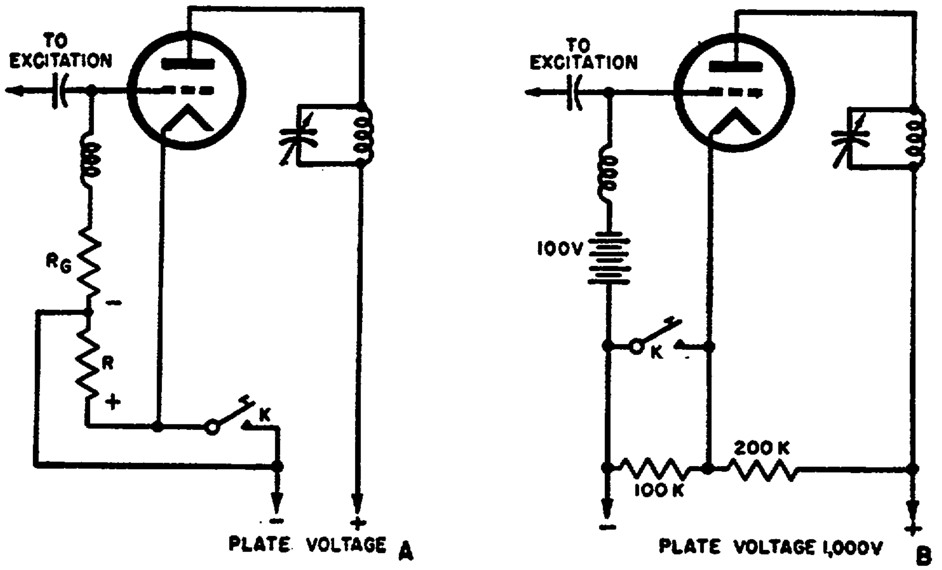

Figure 93. Blocked grid keying.

inserted in the screen grid circuit of an electron-coupled oscillator, it effectively breaks the *plate* circuit of the triode oscillating circuit and no r-f current will be developed. To prevent chirps, the voltage at the screen grid is regulated.

e. Keying Portable Sets. Most portable and mobile sets used in the field operate from batteries or from hand-driven generators. Under such conditions, it is desirable that the transmitter load on the power supply be kept as low as possible. For this reason, the transmitting key often is inserted at a point in the circuit where it opens and closes the plate circuits of all tubes in the transmitter, thus removing the entire load from the power supply when the key is open.

f. Electron Tube Keying.

(1) Large fixed station transmitters often have their output keyed at speeds of several hundred words per minute. Most of these transmitters incorporate special *keying tube* circuits. The keying tube usually is connected to a point in the circuit where the presence or absence of plate-current flow affects critical operating voltages in one or more of the stages in the transmitter and causes the transmitter to be turned on and off.

(2) A typical electron tube keying circuit consists of a triode tube connected between the cathode and ground of the r-f amplifier or oscillator to be keyed. This tube, called a *keyer* tube, operates with its grid biased to cut-off when the key is open. Since this tube is cut off, it acts as an infinitely high resistance (open circuit) between the cathode and ground of the amplifier stage. The amplifier cannot conduct as long as the keyer tube is cut off. Closing the key removes the bias so that the keyer tube becomes highly conductive. This enables normal plate current to flow in the amplifier stage. Generally, zero current blocked grid keying is used on the keyer tube to insure that it and the keyed stage are cut off completely.

(3) Elaborate circuits based on these electron tube keying systems are used on some large fixed station transmitters, particularly when the transmitter is operated from a remote point. In some cases, the biasing voltage for the keyer tube grid is sent over wire circuits to the transmitter which may be at some remote point. In such circuits, the control wires can be considered as simply extensions of the keying leads. Some remote control systems use standard telephone circuits. As an example, the output of a keyed audio oscillator can be fed into standard telephone lines at the operating point. The audio tone passes through

the telephone circuits to a receiver at the transmitter location. The tone is taken off the phone wires, amplified, and then rectified to produce the voltage necessary to control the grid of the keyer tube.

g. Primary Keying. A simple method of providing clickless keying of an a-c operated transmitter is to insert the key in series with the primary of the power transformer supplying voltages to one or more of the stages. The normal power supply filter capacitor and inductance arrangement prevents the r-f signal from building up or falling off too rapidly. It is the rapid start and stop that causes clicks. If the building up and falling off occurs at too great a rate, high keying speeds cannot be used. This is true since the code characters tend to run together with indistinct separations.

h. Keying Relay. When a transmitter is keyed in a cathode or plate circuit, high voltages sometimes exist across the key contacts or between one side of the key and ground or chassis when the key is open. A slip of the hand on the transmitting key could result in a serious shock. Furthermore, an ordinary hand key cannot handle heavy currents without arcing. For these reasons, a keying relay is used sometimes in conjunction with a low voltage source to open and close the keyed circuit (fig. 94). The hand key, *K*, is placed in some position convenient to the operator. Closing the key completes the low voltage circuit through the battery and the coil *L* of the keying relay. The current through the coil magnetizes the core and the metal armature, *A*, is attracted to it, closing contact *C*. This contact is in series with the keyed circuit of the transmitter. Spring *S* opens the contacts when the key is opened by restoring the armature to its original position.

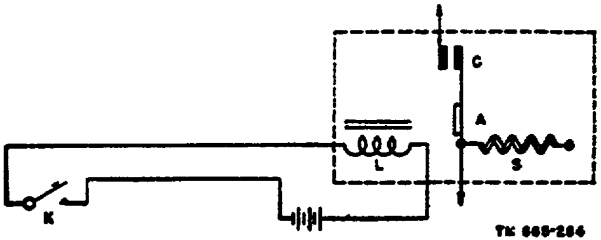

Figure 94. Keying relay.

i. Key Click Filters.

(1) Keying should produce clean cut dots and dashes which cause a minimum of interference in nearby receivers. However, keying does not instantaneously start and stop radiation of the carrier. The sudden application and removal of power causes large surges of current which result in unwanted oscillations and interference in the form of clicks which can be heard over a wide frequency range.

(2) To prevent such interference, key click filters are used in the keying systems of most transmitters. Two types of filters are shown in figure 95. The r-f chokes and bypass capacitors, in A, isolate the key from the rest of the circuit and bypass and prevent surges of r-f caused by arcing at the key contacts. A lag-circuit keying filter is shown in *B*. The inductor, *L*, causes a slight lag in the current as the key is closed. The current then builds up gradually instead of rapidly. Capacitor *C* releases its energy slowly when the key is opened. Resistor *R* controls the rate of charge and discharge of *C* when the key is opened and closed.

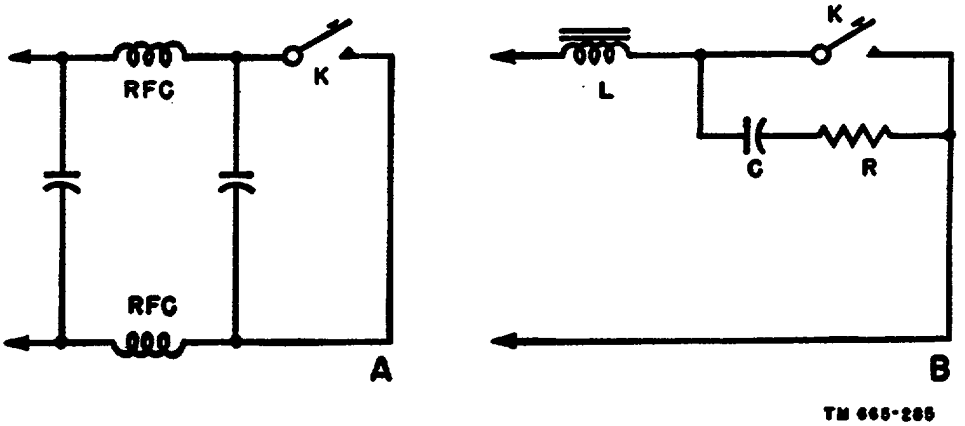

Figure 95. Key click filters.

64. Parasitics and Harmonics

a. Parasitic Suppression.

(1) Parasitic oscillations are oscillations at some frequency usually far removed from the frequency to which the transmitter is tuned. Any inductor will resonate at some frequency when associated with a capacitance. Occasionally, various transmitter components which possess both inductive and capacitive properties will cause the circuit to oscillate at their common resonant frequency. The inductance may be that of wiring, leads of capacitors, a section of a coil or r-f choke, or the element leads within a tube. The capacitance may be that of normal circuit capacitors, or the capacitance between turns of a coil or choke, or the interelectrode capacitance of the tube. Parasitics usually are eliminated in the design of the transmitter but they sometimes appear after the set has been modified or if some parts are replaced. Defective tubes are another cause of parasitics. The presence of parasitic oscillations is indicated by a rough, nonmusical note in the receiver and an indication of plate and grid current in a properly neutralized amplifier when excitation is removed. Parasitics reduce the useful power output of the transmitter by absorbing some of the power which should be useful output. They may cause excessive currents that blow fuses, trip overload relays, ruin capacitors and inductors in the oscillating circuit, and damage the tubes.

(2) High-frequency parasitics usually can be removed by inserting small r-f chokes or resistors in series with each grid and plate connection. These should be placed as close as possible to the tube terminals. Chokes for parasitic suppression have very low inductance and negligible distributed capacitance. The resistor can be approximately 50 ohms. An efficient parasitic suppressor can be made by winding a coil of wire on the body of a small carbon resistor and connecting the coil and resistor in parallel. This combination usually is most effective in grid circuits but its use may be necessary in some plate circuits. The presence of the parasitic suppressor in grid circuits makes the amplifier harder to drive at high frequencies but the decrease in the power sensitivity is compensated for by the lack of spurious oscilaltions. Low-frequency parasitics occur most often in amplifiers having r-f chokes in both grid and plate circuits. Sometimes the tube or tuning capacitor may be tapped down on a tank coil to provide proper impedance matching and to insure maximum energy transfer at the desired frequency.

b. Suppression of Harmonics.

(1) Harmonic radiation is particularly undesirable in a transmitter. It can cause severe interference to other stations authorized to operate on the harmonic frequencies. Furthermore, the generation of harmonics produces a definite power loss at the assigned frequency.

(2) Suppression or elimination of harmonic radiation can be accomplished in a number of ways. Some devices for the purpose are built into the transmitter and are beyond the control of the operator. He can do much to suppress harmonics, however, merely by tuning the transmitter properly and adjusting the operating voltages to the correct values. The harmonic content of an amplifier output increases as the bias and excitation voltages are increased. Therefore, by keeping the bias and excitation within specified limits, harmonic radiation is minimized.

(3) When r-f energy is transferred from one circuit to another by an inductive arrangement such as an r-f transformer or link coupling, the inductors have a certain amount of stray capacitance. The capacitance between the coils is small but far from negligible. Energy at the resonant frequency is transferred through magnetic coupling alone. However, harmonics are transferred between the inductors by electrostatic coupling through the capacitance. Therefore, if harmonics are to be eliminated, the coupling must be purely magnetic, and the capacitive effects must be excluded by inserting a Faraday shield between the two inductors (fig. 96). The Faraday shield (sometimes

called an electrostatic shield) consists of a group of parallel conductors, connected at one end only. This forms an effective shield against electrostatic coupling without affecting the transfer of energy through magnetic coupling.

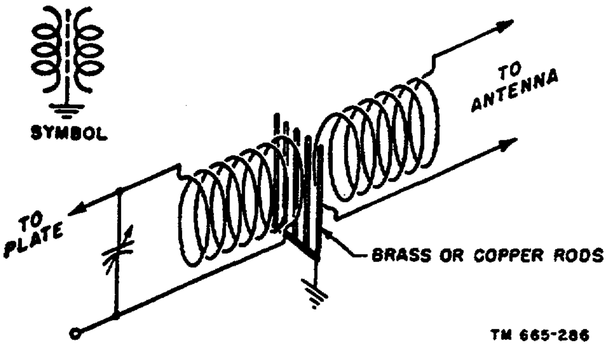

Figure 96. Faraday shield.

(4) An important factor in reducing harmonic radiation from high-frequency transmitters is the use of low-power frequency multipliers. When multiplication is at low power levels, direct radiation from the circuits involved is minimized and there is less danger of the multiplier signals and their harmonics leaking through to the antenna where they may be radiated. For this reason high-frequency transmitters often use receiving tubes as frequency multipliers. After the oscillator frequency is multiplied to the required output frequency, it is amplified to the required power levels by class C amplifiers biased only slightly beyond cut-off and supplied with the minimum of excitation required to develop sufficient power for driving the following stage. By operating the class C amplifiers with a large angle of plate-current flow, harmonic generation is minimized.

(5) Some transmitters have small auxiliary parallel tuned circuits in series with the plate lead and in series with each power line going to the power transformer. These circuits are tuned to the transmitter harmonics. They present a high impedance to the flow of harmonic currents. The tuned circuits in series with the power lines prevent harmonics from being radiated from the power lines. Radiation of harmonics can be reduced also by using an antenna which does not respond to harmonic frequencies. Special antenna coupling networks can be used to eliminate harmonics.

65. Antenna Coupling

a. Need for Antenna Coupling Networks. The primary purpose of antenna tuners or couplers is to provide the maximum transfer of power from the transmitter to the antenna. Most military transmitters are designed to operate over a wide range of frequencies under varying conditions. For example, one transmitter may be used with a whip antenna on tanks and similar land vehicles, with a long wire elevated antenna for fixed station use and another type of antenna when used in aircraft. Even in fixed station service, the type of antenna used depends on the operating frequencies and on the available space. An antenna tuning unit provides a means of reasonating any antenna that can be used and of varying the antenna-to-transmitter impedance match and coupling.

b. Antenna Coupling Circuits.

(1) The versatile antenna tuning unit shown in A of figure 97 is designed to connect a 2- to 18-mc transmitter to a whip antenna or to a long wire antenna. The circuit is shown in B when the antenna range switch is in position 1. In this position, a whip antenna is used and the frequency range covered is from 2 to 10 mc. Because the whip antenna is less than a quarter-wavelength long it presents a capacitive reactance to the transmitter, which is balanced out by the addition of a portion of inductor $L2$, the low-frequency loading coil. This inductor is varied by a movable tap which short circuits some of the turns. When the inductive reactance of $L2$ is equal to the capacitive reactance of the antenna, the load presented to the transmitter is purely resistance. Coupling coil $L1$ is link coupled to the power amplifier tank circuit. It acts in such a way that the resistance of the antenna is reflected back as an optimum load on the amplifier tank circuit. The antenna current meter is at

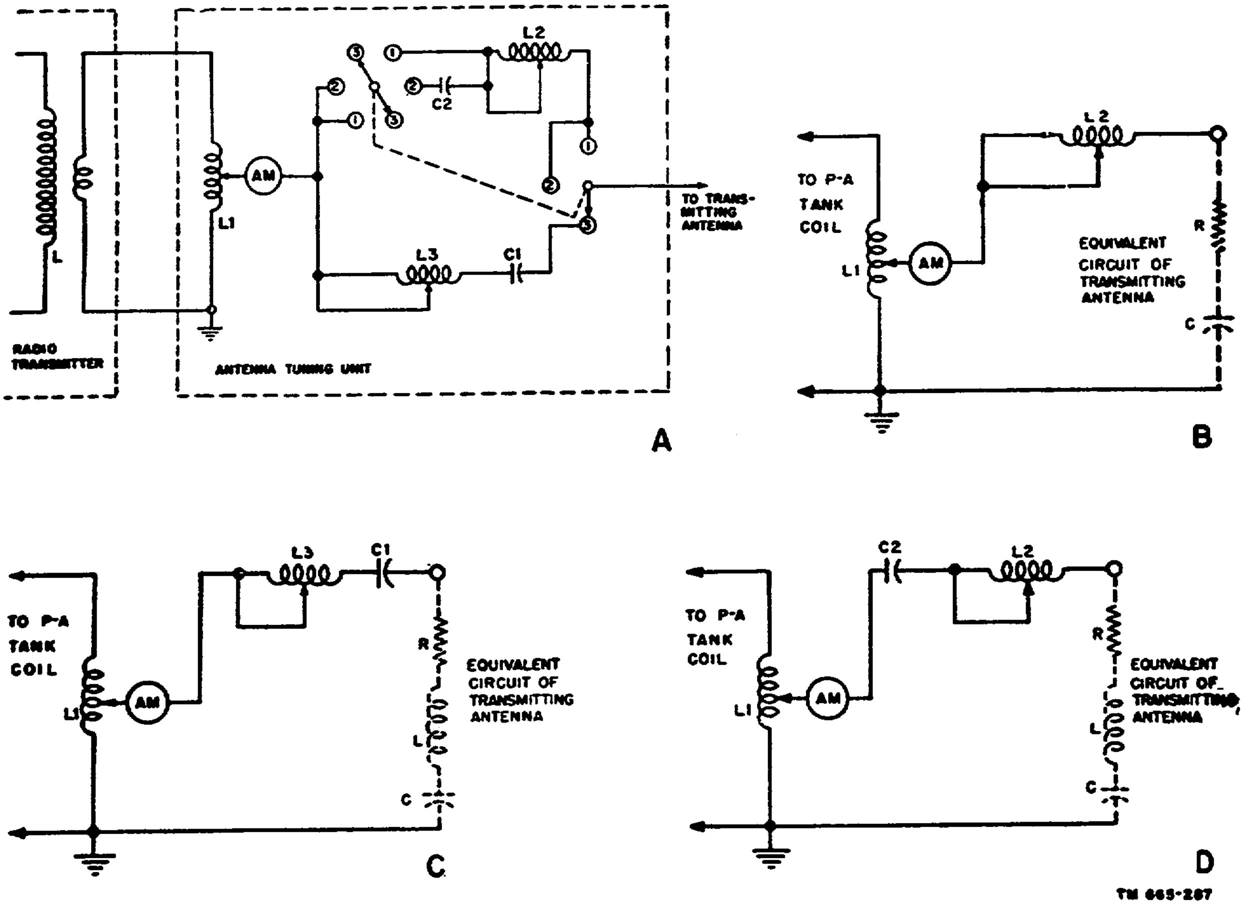

Figure 97. Antenna coupling circuits.

a maximum when the antenna is tuned properly.

(2) The circuit of the tuning unit when the range switch is set to position 3 is shown in C. Here a whip antenna is used and the frequency range covered is from 10 to 18 mc. From 10 to 12.5 mc, the reactance of the particular whip antenna used is capacitive; from 12.5 to 18 mc, the reactance is inductive. At approximately 12.5 mc, the antenna is purely resistive. The antenna is tuned to resonance by varying the inductance of the high-frequency loading coil, *L*3, which is made variable by a movable tap controlled from the front panel. Capacitor *C*1 provides the added capacitance necessary when operating at frequencies between 12.5 and 18 mc. Its effect is neutralized by using more turns in *L*3 when the transmitter is operating in the 10- to 12.5-mc range.

(3) The circuit of the tuner when adjusted for use with a long wire antenna is shown in D. The switch is now in position 2. The antenna is either capacitive or inductive depending on its length and operating frequency. As in previous adjustments, the antenna is tuned to resonance by varying the series inductance.

66. Multitube Transmitter Circuits

a. Mopa Transmitter with Hartley Oscillator (fig. 98).

(1) The oscillator develops an r-f voltage across the tank circuit comprising capacitor *C*2 and inductor *L*. Coupling capacitor *C*3 permits the r-f currents to flow to the amplifier while preventing the amplifier bias voltage supply E_c, from being short circuited by the oscillator inductor. This capacitor is tapped down on *L* to

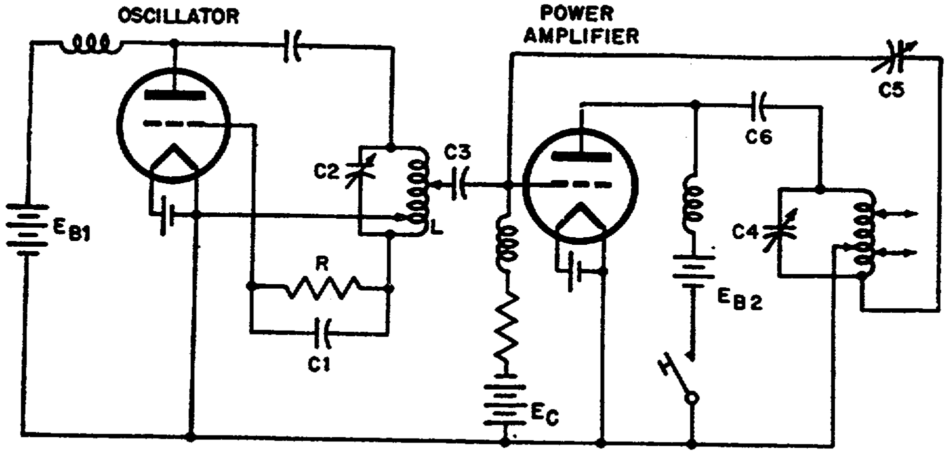

Figure 98. Schematic diagram of mopa transmitter.

provide an efficient match between the oscillator output and amplifier input and to minimize loading on the oscillator. Plate voltages for the oscillator and amplifier are taken from power supplies E_{B1} and E_{B2}, respectively.

(2) The power amplifier uses a parallel fed plate circuit. Feedback voltage required for neutralizing the amplifier is taken from the lower end of the tank coil. The voltage is fed back through neutralizing capacitor *C*5. When the stage is neutralized, the capacitance of *C*5 is approximately equal to the grid-to-plate capacitance of the amplifier tube. Plate circuit keying is used.

b. High-Power High-Frequency Transmitter. Figure 99 illustrates many of the circuits described in this chapter. The high-power high-frequency transmitter is designed for 900 watt output at frequencies between 1.5 and 30 mc. Its circuit arrangement is similar to that of many transmitters used in military applications, an example of which is shown in figure 100. A top view of the same transmitter is illustrated in figure 101.

(1) ***Exciter.*** *V*1 (fig. 99) is an electron-coupled oscillator designed to tune concontinuously from 1.5 to 3.8 mc. Its screen and plate voltages are stabilized at 210 volts by the series connected VR (voltregulator) tubes. Therefore, the oscillator is immune to frequency changes caused by changes in supply voltage. The oscillator stage is housed in a shielded, insulated compartment located within a larger shielded compartment housing the class A buffer amplifier and class C buffer amplifier or crystal oscillator.

(*a*) *V*2 is a class A buffer amplifier which is coupled to the oscillator through a modified impedance coupling. In this circuit, the usual r-f choke or tuned circuit is replaced by a resistor (100,000 ohms) in the grid circuit of *V*2. Because this tube operates class A, it presents a constant high impedance load to the oscillator. Therefore the oscillator load is constant, and its frequency is not affected by changes in loading in subsequent stages of the transmitter.

(*b*) The class A buffer, *V*2, feeds *V*3 which is used as a class C buffer amplifier or a crystal oscillator, depending on the position of switch *S*1. The plate of the class A buffer is coupled to a contact on *S*1 through a blocking capacitor. One section of the switch opens the high voltage lead to the master oscillator and buffer while the other section switches the grid of *V*3 from the plate circuit of *V*2 to one of the crystals. Therefore, *V*3 is converted from an r-f amplifier to an ordinary tetrode crystal oscillator.

(*c*) The exciter, consisting of *V*1, *V*2, and *V*3, can be used for controlling the frequency of almost any transmitter. The input power to the exciter is comparatively low and can be supplied by bat-

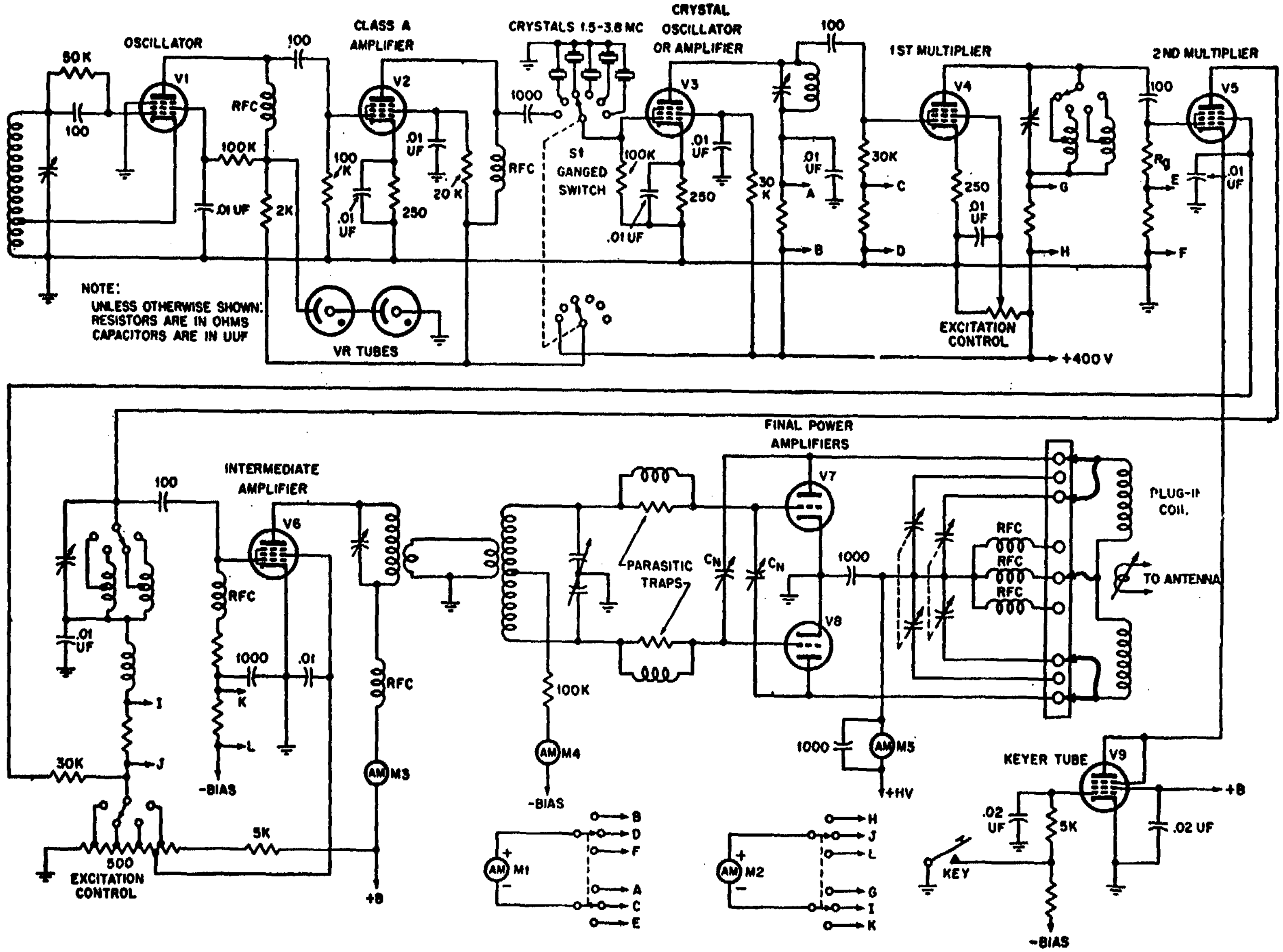

Figure 99. Schematic diagram of high-frequency high-power transmitter.

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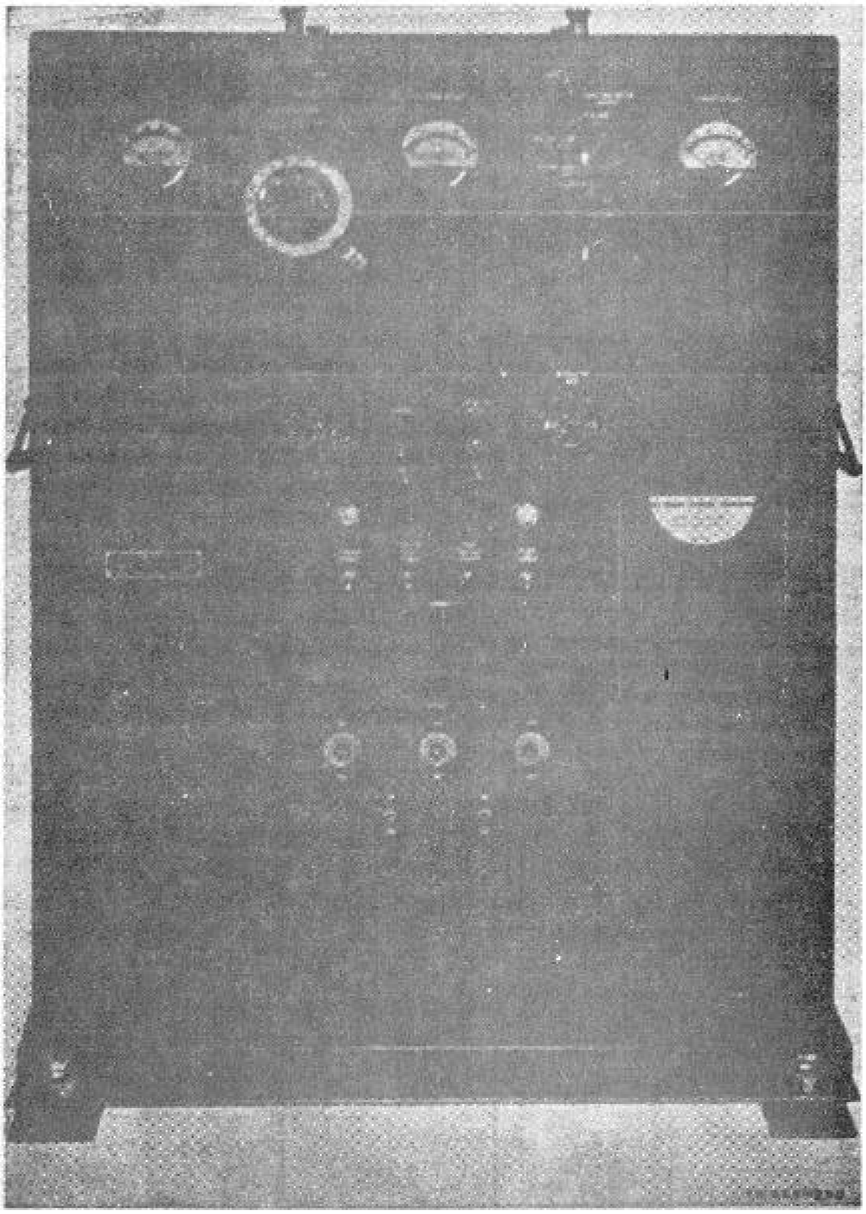


Figure 100. Typical military transmitter.

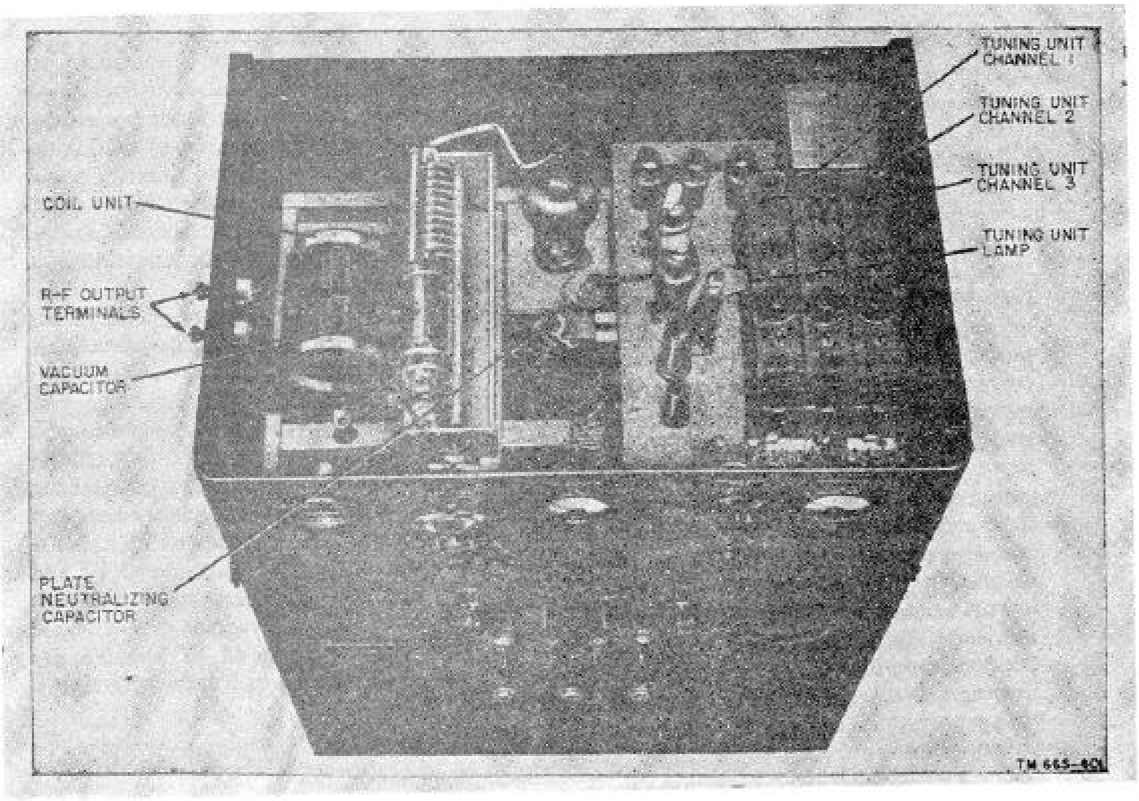


Figure 101. Top view of typical military transmitter.

teries, line operated power packs, hand- or motor-driven generators, or vibrator power supplies. Equivalent tubes having directly heated filaments, or miniature glass types, are used in the interest of saving space or reducing drain on the power supply. In some installations, it is desirable to have the exciter unit at a point remote from the operating position. For example, in fixed station installations the exciter may be on the operating desk next to the receiver and the transmitter amplifier circuits may be in another room. In such applications, the tank circuit of *V*3 usually is link coupled to the grid of the following stage.

(2) *Frequency multipliers.*

(*a*) Two multiplier stages, *V*4 and *V*5, have range selector switches which select the correct tank coil for a given tuning range. When the transmitter is operating between 1.5 and 3.8 mc, both tubes are operated straight through (without multiplying). Impedance coupling is used between *V*4, *V*5, and *V*6. Excitation to *V*5 and *V*6 is controlled by varying the screen and plate voltages of the preceding stage.

(*b*) By selecting the appropriate tank coils for the multiplier stages, it is possible to multiply the exciter frequency by 2, 3, 4, 6, 8, 12, or 16. Consequently, if it is desired to multiply the oscillator frequency by 6, one of the multipliers can be operated as a tripler and the other as a doubler. To multiply by 16, both tubes can be operated as quadruplers.

(*c*) The transmitter is keyed by means of an electron tube keying circuit in the cathode return circuit of *V*5. Under key up conditions, the keyer tube is cut off by a large amount of negative bias supplied by a battery or any regulated d-c source. Closing the key removes the blocking bias from *V*9. As a result, this tube and *V*5 both conduct. By inserting additional frequency multiplier stages between *V*5 and the following stage, this basic exciter and multiplier unit can be used in transmitters operating at much higher frequencies.

(3) *Intermediate amplifier.* The intermediate or driver amplifier, *V*6, is a medium power transmitting type beam power pentode capable of delivering up to 150 watts of output at frequencies up to 30 mc. Its purpose is to provide the driving power (approximately 80 watts) required by the final amplifier. Since pentodes and tetrodes are damaged easily by excessive excitation, provisions are made for metering the grid current and varying the excitation. *V*6 can deliver up to 150 watts and therefore can be used as the final amplifier of a transmitter delivering that amount of power. The only change required is to link couple the tank circuit to an antenna tuner instead of the grid circuit of *V*7 and *V*8 which comprise the 900-watt final power amplifier.

(4) *Final power amplifier.*

(*a*) Push-pull triodes *V*7 and *V*8, used in the final amplifier, deliver 900 watts output into the antenna. Plug-in coils are used in the plate circuit. To provide optimum *L-C* ratios on all tuning ranges, several variable capacitors are used in the plate circuit. The plug-in coils are equipped with jumpers to select the individual capacitors that may be required for a given inductance. Because it is difficult to get an r-f choke to operate efficiently over a wide range of frequencies, three chokes are used in the transmitter. A jumper on the coil selects the choke that is most effective in a given tuning range.

(*b*) The transmitter works into a conventional antenna tuner or into a doublet antenna. Coupling to the antenna or tuner is varied by changing the coupling between the plate tank coils and link coil. Conventional cross neutralization is used on the push-pull tubes.

(*c*) Power output can be increased by replacing the tubes used in the final power amplifier with tubes having a greater power output rating and by raising the plate voltage. Even greater power output from the transmitter is possible if the push-pull amplifier is used as a driver amplifier for an additional power amplifier.

(5) *Metering the transmitter.* The ability to measure grid and plate currents is important for the efficient operation of any transmitter. Circuit resonances are best indicated by meters in the plate and grid circuits. Full metering is particularly important in a multistage transmitter. Meter *M*1 measures the plate current of *V*3, and the grid currents of *V*4 and *V*5. *M*2 meters the plate currents of *V*4 and *V*5 and the grid current of *V*6. *M*3 measures the plate current of *V*6. Grid and plate currents of *V*7 and *V*8 are measured by *M*4 and *M*5, respectively.

67. Summary

a. Radiotelegraph (code) signals are sent out by a continuous wave transmitter.

b. The signals are produced by opening and closing one of the transmitter circuits by means of a telegraph key operated in accordance with a code.

c. A simple transmitter consists of an r-f oscillator to generate the signal and an antenna to radiate it into space.

d. Oscillator-type transmitters tend to be unstable and to have definite limits on the maximum power output and operating frequency.

e. When high power, good stability, and wide frequency range are required, one or more power amplifiers may be used between the oscillator and the antenna.

f. Coupling circuits which consist of combinations of inductance and capacitance are used to transfer energy between amplifier stages and between the power amplifier stage and the antenna.

g. Triode amplifiers require neutralization to prevent self-oscillation.

h. Oscillations are caused by energy fed back from plate to grid through the interelectrode capacitance of the tube.

i. The neutralizing system feeds to the grid a voltage equal in amplitude and opposite in phase to the voltage fed back through the tube.

j. Most radio-frequency power amplifiers operate class C for high efficiency.

k. Excitation voltage from the preceding stage must be sufficient to cause plate current to flow during the positive half cycles.

l. Oscillators are most stable when operating at low frequencies. Therefore, the oscillator often operates at a frequency considerably lower than the output frequency of the transmitter.

m. The frequency may be multiplied by a class C amplifier whose output is tuned to some harmonic of its input.

n. Frequency multipliers whose outputs are the second, third, and fourth harmonics of their input frequencies are called doublers, triplers, and quadruplers, respectively.

o. Frequency multipliers operate with grid bias voltage and grid excitation somewhat higher than that specified for normal class C operation.

p. The greater grid bias and excitation cause the plate current to flow for shorter portions of the excitation cycle.

q. The short plate-current pulses are distorted and have high harmonic content.

r. Keying can take place in any stage of the transmitter.

s. Keying the oscillator avoids backwaves but it is likely to cause chirps.

t. Keying following stages minimizes chirps but the backwave from the oscillator is likely to make break-in operation impossible.

u. Radiation of harmonics from the transmitter can cause serious interference to stations operating on frequencies that are multiples of the transmitter frequency.

v. Harmonics are minimized by using single-frequency antennas, low-power multipliers, adequate bypassing, and trap circuits tuned to the harmonic frequency.

w. Parasitic oscillations are spurious oscillations which occur at some frequency far removed from the frequency to which the transmitter is tuned.

x. Parasitics reduce power output from the transmitter and often damage capacitors and inductors in the parasitic circuit.

68. Review Questions

a. What are the types of emission?

b. What is a carrier wave?

c. Why is a carrier necessary?

d. What are the basic components of the simplest transmitter?

e. What is the objection to coupling an oscillator directly to an antenna?

f. What is a mopa transmitter?

g. What are the advantages of a mopa transmitter?

h. Why is a power amplifier necessary?

i. What are the general operating conditions for class C amplifiers?

j. Under what conditions is neutralization necessary?

k. Describe a simple neutralization indicator.

l. Draw a circuit showing shunt neutralization.

m. Describe the procedure to be followed when neutralizing an amplifier.

n. What is a frequency multiplier?

o. Is it unnecessary to neutralize a frequency multiplier?

p. Illustrate the basic interstage coupling systems and give one advantage and disadvantage of each system.

q. Draw circuits illustrating two methods of blocked grid keying. Which type is preferable? Why?

r. What is the purpose of a keying relay?

s. Describe how electron tube keying can be used in remote controlled transmitters.

t. Draw a circuit of a simple key click filter.

u. What is a parasitic oscillation?

v. What are the effects of parasitics?

w. How can harmonics be eliminated?

x. What are the effects of harmonic radiation?

y. Can improper tuning cause excessive harmonic radiation?

z. What is a Faraday shield?

aa. Why is an antenna tuner or coupler necessary?

CHAPTER 5

AMPLITUDE MODULATION

69. General

a. Another method of radio transmission, in contrast to c-w transmission, is accomplished by varying the carrier waveform in accordance with the variations in the intelligence to be transmitted. Using this method, speech, music, or any other form of intelligence, is first converted into alternating voltages, and these voltages, in turn, are superimposed on a carrier waveform and then transmitted. This varying process is called modulation. In practice, the frequency of the carrier wave is much higher than the highest modulating frequency.

b. In the basic block diagram of a modulated radio transmitter (fig. 102), the r-f oscillator generates the r-f frequency voltage. The output of the oscillator is amplified by a buffer stage, an intermediate power amplifier, and an r-f power amplifier before being radiated by the antenna. The source of modulating signal may be the output voltage of a microphone, a device which converts audio sounds into electrical voltages which vary at the frequency of the sounds—that is, at an audio frequency. The varying audio voltages are amplified in a modulator and are superimposed on the r-f carrier wave before being radiated by the antenna.

70. Types of Modulation

a. Amplitude Modulation. The process by which audio signal or modulating frequencies are impressed on an r-f carrier wave to vary its amplitude is called *amplitude modulation.* Figure 102 is a block diagram of an amplitude-modulated transmitter. The frequency and phase of the carrier is not affected by this type of modulation.

b. Frequency Modulation and Phase Modulation. Besides its amplitude, the carrier wave has two other characteristics that can be varied to produce an intelligence bearing signal. These are its frequency and its phase. The process of varying the frequency in accordance with the intelli-

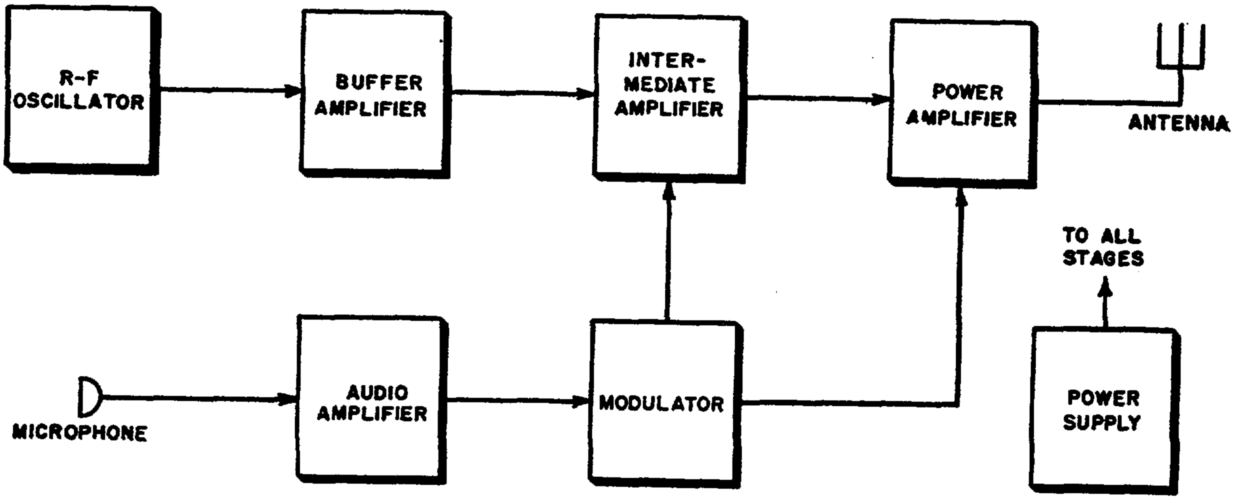


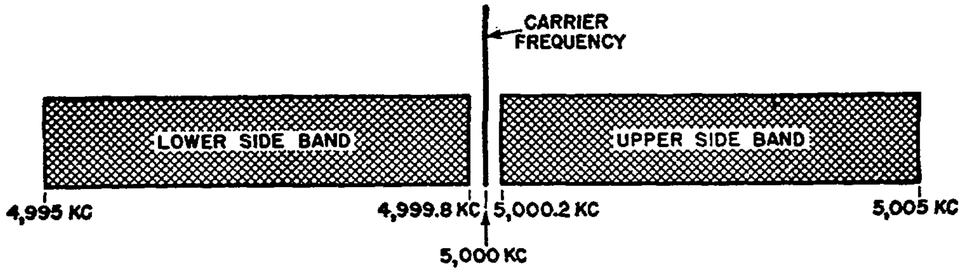
Figure 102. Basic block diagram of a modulated transmitter.

gence is f-m (frequency modulation), and the process of varying the phase is p-m (phase modulation). These two types of modulation are closely related. When frequency modulation is used, the phase of the carrier wave is indirectly affected. Similarly, when phase modulation is used, the carrier frequency is affected. A complete discussion of both types of modulation is given in TM 11-668.

71. Analysis of Amplitude Modulation

a. Modulated Waveshape (fig. 103).

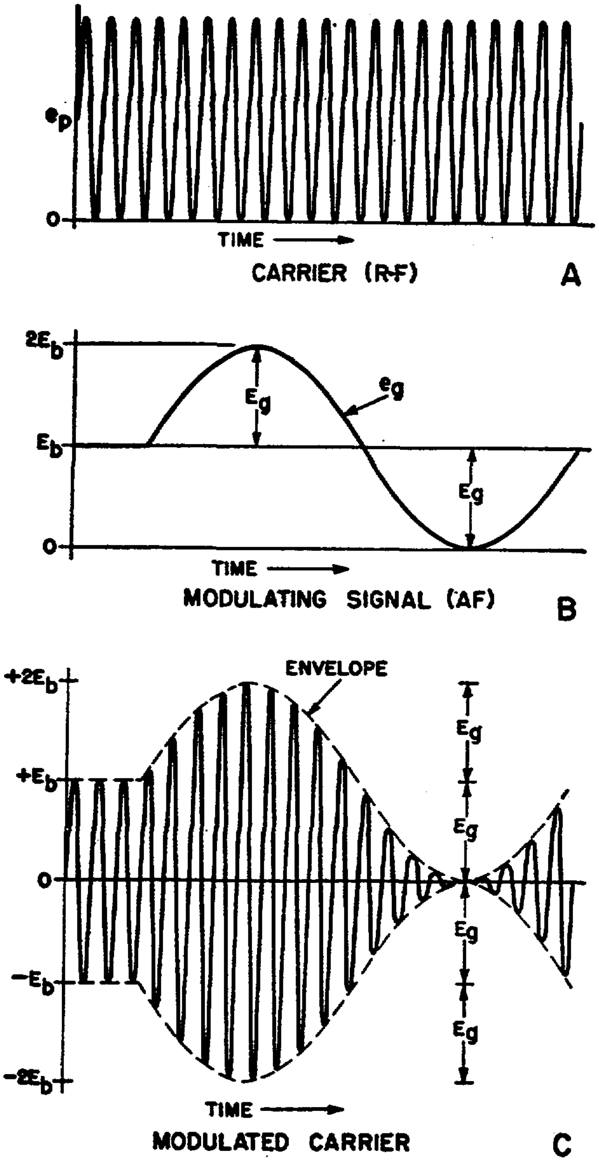
(1) When an r-f carrier is modulated by a single audio note, two additional frequencies are produced. One is the upper frequency, which equals the sum of the frequency of the r-f carrier and the frequency of the audio note. The other frequency is the lower one, which equals the difference between the frequency of the r-f carrier and the frequency of the audio note. The one higher than the carrier frequency is the *upper side frequency;* the one lower than the carrier frequency is the *lower side frequency.* When the modulating signal is made up of complex tones, as in music, each individual frequency component of the modulating signal produces its own upper and lower side frequencies. These side frequencies occupy a band of frequencies lying between the carrier frequency, plus and minus the lowest modulating frequency, and the carrier frequency plus and minus the the highest modulating frequency. The bands of frequencies which contain the side frequencies are called *side bands.* The side band which contains the sum of the carrier and the modulating frequencies is known as the *upper side band;* the band which contains the difference of the carrier and the modulating frequencies is known as the *lower side band.* The space which a carrier and its associated side bands occupy in a frequency spectrum is called a *channel.* The width of the channel (or *bandwidth*) is equal to twice the highest modulating frequency. Consequently, if a 5,000-kc (kilocycle) carrier is modulated by a band of frequencies ranging from 200 to 5,000 cycles (.2 to 5 kc) the upper side band extends from 5,000.2 to 5,000.5 kc, and the lower side band extends from 4,999.8 to 4,995 kc. The bandwidth is then 4,995 to 5,005, or 10 kc. The bandwitdh is twice the value of the highest modulating frequency, which is 5 kc. This is illustrated in figure 103.



TM 665-282

Figure 103. Side bands produced by amplitude modulation.

(2) The instantaneous plate voltage, e_p, of a carrier wave in a Class C amplifier is represented by the pulses shown in A of figure 104. The d-c plate voltage, E_b, is shown with the sine-wave modulating voltage, e_g, varying around it, so that plate voltage varies from zero to twice the value of E_b or $2E_b$. The peak value of the modulating voltage is represented by E_g. When e_p is varied in amplitude at a rate determined by e_g, the pattern in C results. The outline of the modulated carrier wave is shown by the dashed lines joining the tips of the successive r-f carrier pulses, and is called the *envelope.* The dashed lines appearing in the upper and lower sections of the modulated carrier correspond exactly to that of the modulating signal. The peak-to-peak amplitude of the modulated carrier varies from $+2E_b$ to $-2E_b$ or $4E_b$. This is an



TM 665-293

A. Plate-current pulses produced by an unmodulated carrier.
B. Effect of superimposing a large a-c voltage on a d-c voltage.
C. Modulated envelope of a sine-wave modulated carrier under full modulation.

Figure 104. Modulation of an r-f carrier.

ideal condition where no distortion of the modulating signal exists.

b. Percentage of Modulation.

(1) The *depth* or *degree* of modulation of a carrier wave is dependent on the amplitude of the envelope as compared with the amplitude of the carrier. If the amplitude of the envelope is twice as great as the amplitude of the carrier, then the modulated waveform is said to be *fully*, or *100 percent* modulated. If the envelope amplitude is less than twice the carrier amplitude, the waveform is less than 100 percent modulated. The percentage of modulation, M, can be computed from one of the following formulas:

$$M=\frac{E_{max}-E_{car}}{E_{car}}\times 100\%$$

and

$$M=\frac{E_{car}-E_{min}}{E_{car}}\times 100\%$$

where

E_{max} is the maximum amplitude of the envelope,

E_{min} is the minimum amplitude of the envelope,

E_{car} is the amplitude of the carrier.

This formula is valid only for waveforms which are not overmodulated. An overmodulated waveform is one whose percentage of modulation is greater than 100 percent.

(2) A of figure 105, shows a modulating signal, and B is the modulated carrier. By substituting in the modulation formulas the voltage values given in the figure, the percentage of modulation, M, equals

$$M=\frac{E_{max}-E_{car}}{E_{car}}\times 100\%$$

$$M=\frac{150-100\times 100\%}{100}=50\%,$$

and

$$M=\frac{E_{car}-E_{min}}{E_{car}}\times 100\%$$

$$M=\frac{100-50}{100}\times 100\%=50\%.$$

Consequently, the percentage of modulation is 50 percent.

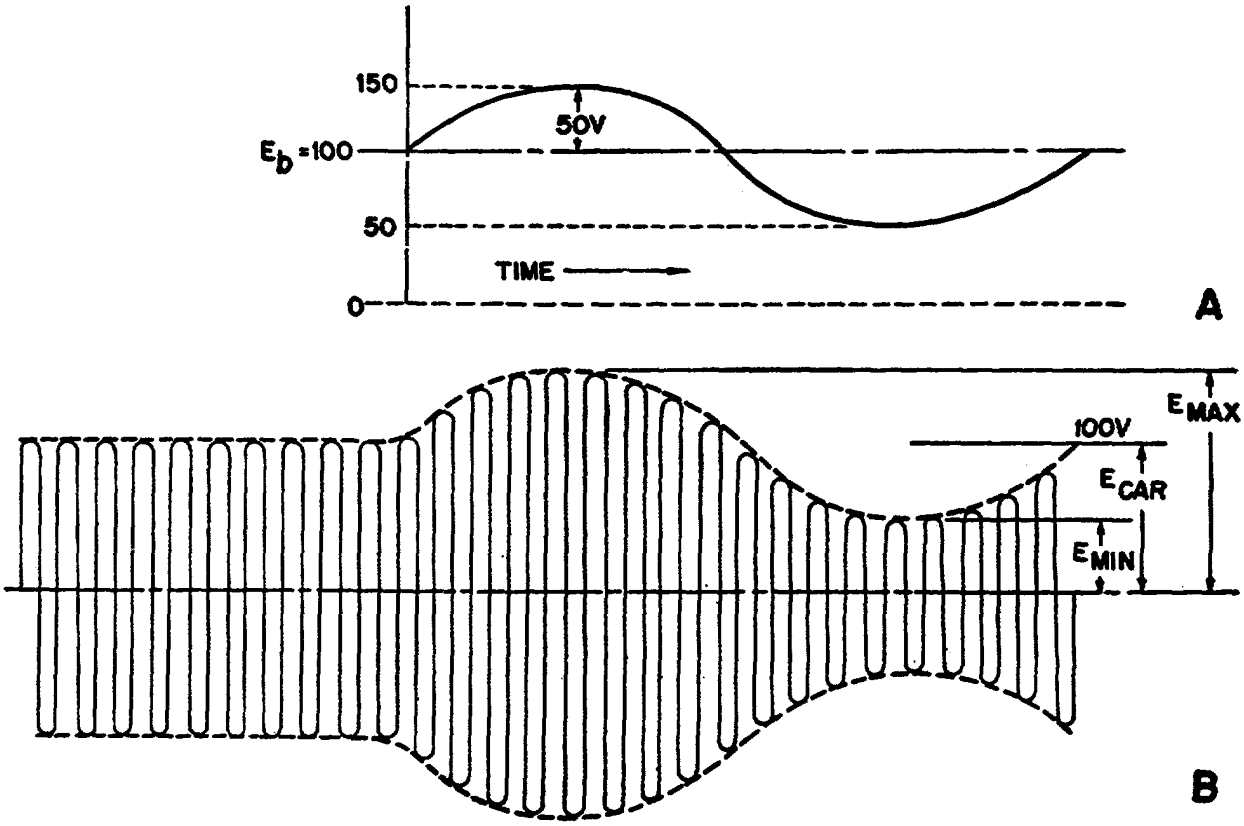
(3) If the peak of the modulating signal equals the d-c plate voltage (100 volts), the modulated carrier varies from 0 volt to 200 volts. This is shown in figure 106. Again, applying the modulating formulas,

$$M=\frac{E_{max}-E_{car}}{E_{car}}\times 100\%$$

$$M=\frac{200-100}{100}\times 100\%=100\%$$

$$M=\frac{E_{car}-E_{min}}{E_{car}}\times 100\%$$

$$M=\frac{100-0}{100}\times 100\%=100\%.$$



TM 665-294

Figure 105. Illustrating 50-percent modulation.

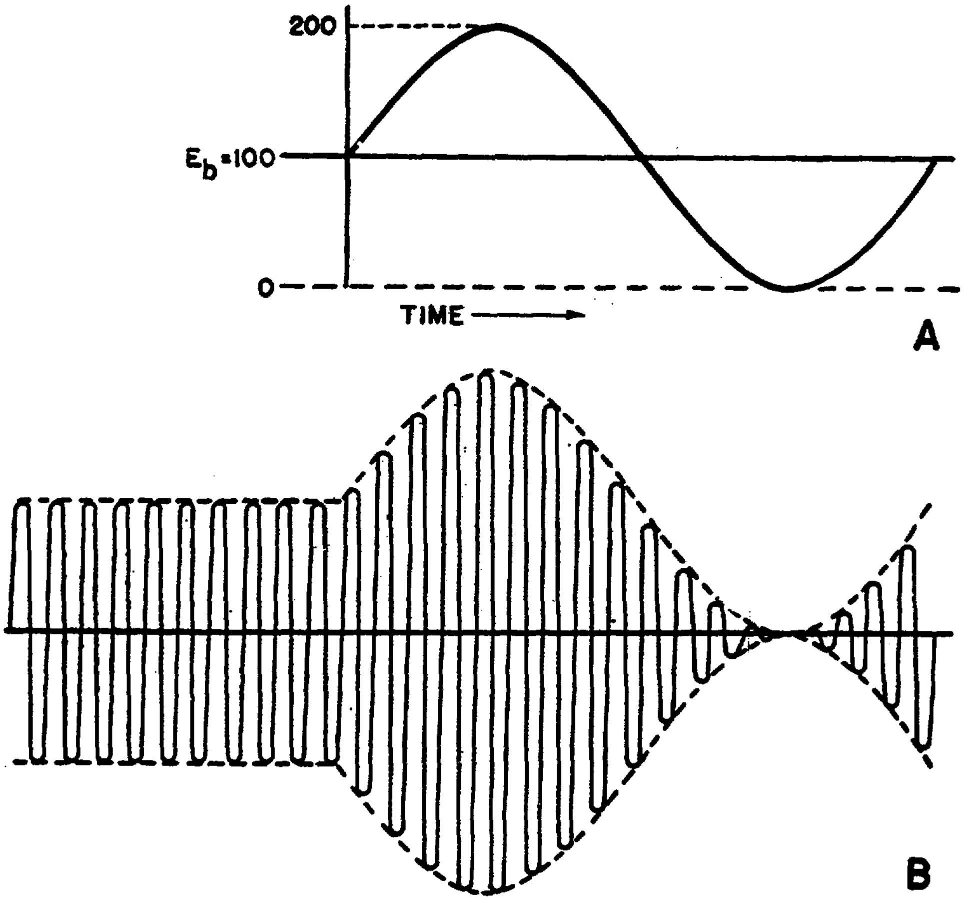
The percentage of modulation is 100 percent. Whenever the modulating signal varies between zero and twice the d-c plate voltage, there is 100-percent modulation.

(4) A transmitter usually is operated so that the average percentage of modulation approaches, but does not exceed, 100-percent modulation. That is, it is better to operate at 75 percent than at 50; 85 percent is better than 75; and so on up to 100 percent. This is true for the following reasons: The signal-to-noise ratio of the received signal is higher when the modulation percentage approaches 100 percent. Strong side bands make the received signal less susceptible to interference from stations operating on the same channel. Because of the increased power in the side bands, a fully modulated transmitter transmits a greater distance for a given carrier power.

c. Overmodulation.

(1) Consider the case where a modulator delivers an audio voltage of 150 volts peak to an r-f modulated amplifier operated with 100 volts d-c on its plate. The two voltages add to produce an instantaneous peak of 250 volts on the positive half of the modulation cycle. On the negative half cycle, the plate voltage will swing to 50 volts negative, thus cutting off the r-f amplifier for the period that the plate voltage is below the zero line, as in A of figure 107. This condition produces an overmodulated carrier, as in B, in which area A is the period during which the r-f modulated amplifier is cut off. This break in the r-f output of the transmitter produces distortion at the receiver. This condition exists whenever the peak a-f signal voltage exceeds the d-c plate voltage of the modulated amplifier.

(2) Whenever an amplifier is modulated in excess of 100 percent the momentary inter-



TM 665-295

Figure 106. Illustrating 100-percent modulation.

ruption of plate current in the r-f modulated amplifier produces serious changes in the wavelength of the original modulating frequencies. New frequencies and harmonics are created. Their number and intensity vary with the degree of overmodulation. These spurious modulating frequencies produce additional side bands which extend far beyond the normal bandwidth and cause interference to stations on adjacent channels.

(3) Overmodulation also can cause serious damage to a transmitter that is not adequately protected by fuses or circuit breakers. The sum of the peak audio and the d-c plate voltages may be sufficiently high to break down the insulation in modulation transformers, plate bypass capacitors, and r-f chokes.

d. Distribution of Power in an Amplitude-Modulated Wave.

(1) The power in an amplitude-modulated wave is divided between the carrier and the side bands. The carrier power is constant (except in cases of overmodulation) and so the side-band power is the difference between the carrier power and the total power in the modulated wave. When a carrier is modulated by a single sinusoidal tone, the total power output is found from the formula

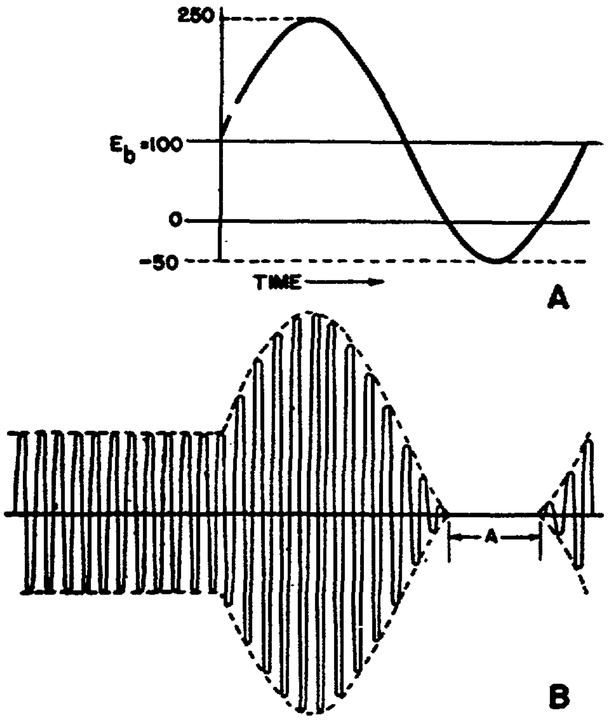
$$P_{mod}=\left(1+\frac{m^2}{2}\right)\times P_{car}$$

where

P_{mod} is the total power in the modulated wave,

m is the degree of modulation,

P_{car} is the power in the carrier.



TM 665-296

Figure 107. Overmodulation.

Assuming that a 500-watt carrier is modulated 100 percent, the power in the signal is

$$\left(1+\frac{(1)^2}{2}\right)\times 500=750 \text{ watts}$$

Of this total, 500 watts are in the carrier and 250 watts are in the side bands. The percentage of side-band power 250/750 times 100 percent equals 33.3 percent. Of the 250 watts of side-band power, there are 125 watts in each side band and the power content of each therefore is 16.6 percent of the total power output with 100-percent modulation.

(2) The available side-band power takes a marked drop when the average percentage of modulation is well below 100 percent. This is shown by modulating the carrier only 50 percent when the power in the carrier is 500 watts.

$$P_{mod}=\left(1+\frac{(.5)^2}{2}\right)\times 500=562.5 \text{ watts}$$

The total modulated power is now 562.5 watts. Since 500 watts exist in the carrier, only 62.5 watts of power remain in the side bands. Since 62.5 watts are one-fourth the value obtainable with 100-percent modulation, it is seen that reducing the modulation of 50 percent causes a 75-percent reduction in the available side-band power. Since all of the intelligence being transmitted is contained in the side bands, the desirability of a high percentage of modulation becomes evident.

72. Stages of Amplitude-Modulated Transmitter

a. General. Referring to figure 108, it is seen that a feeble voice signal entering a microphone is amplified by several a-f speech amplifiers and also by the a-f modulator. The r-f oscillator produces the r-f carrier wave which is amplified by the r-f buffer amplifiers. The outputs of the a-f modulator and r-f buffer amplifiers are mixed in the final r-f amplifier to produce the modulated carrier wave.

b. Radio-Frequency Circuits. Essentially, the r-f section of an amplitude-modulated transmitter consists of an r-f oscillator and several r-f amplifiers. In many cases, buffer amplifiers are used between the oscillator and the r-f amplifiers. As mentioned in the previous chapter, buffer amplifiers are used to isolate the oscillator from the following stages to minimize changes in oscillator frequency with changes in loading. Frequency multipliers are used to raise the oscillator frequency of the transmitter to the desired carrier frequency. It is desirable to have the oscillator operate at a comparatively low frequency for reasons of stability. Intermediate r-f amplifiers may be used to increase the driving power of the final r-f amplifier. The stage that the modulator feeds is known as the modulated r-f amplifier.

(1) The a-f voltages developed by a microphone or other signal source are comparatively low, usually less than 1 volt, whereas the d-c potentials applied to the tube electrodes are high. The addition of the low a-c voltage to the high d-c potentials on the tube electrodes results in a very small variation in the power output. Therefore, it is necessary to amplify the alternating signal voltage, audio frequencies for radiotelephone, and modulated c-w transmitters, to a level high

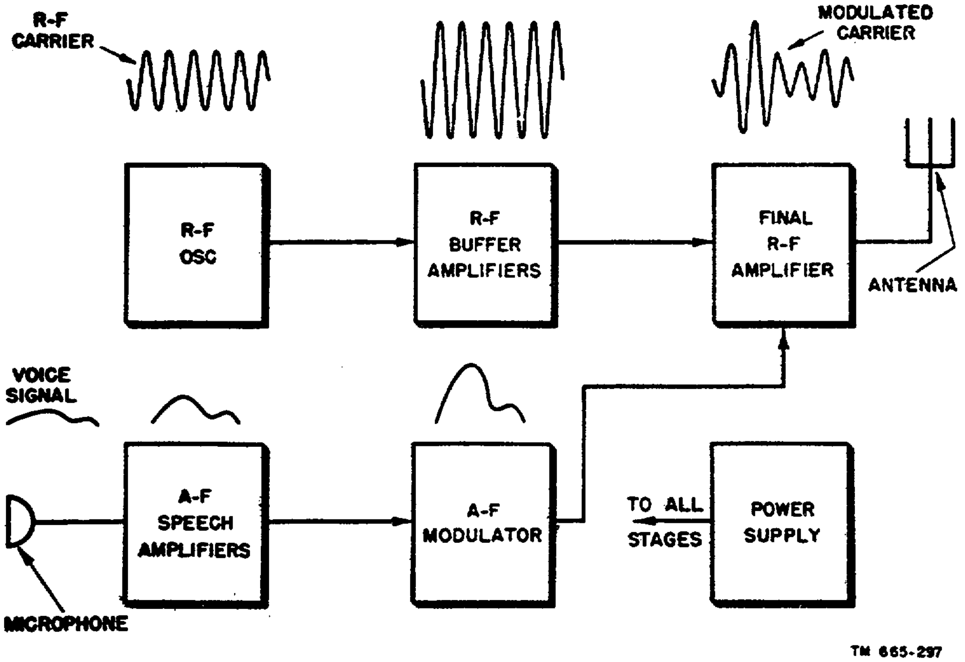


Figure 108. Block diagram of an amplitude-modulated radiotelephone transmitter and waveshape.

enough to cause considerable variation in the power output of the transmitter.

(2) The audio amplification usually takes place in at least two stages. The a-f speech amplifier is a class A voltage amplifier. The output of this stage drives a second stage which may be a voltage amplifier or a power amplifier, depending on the required input power to the modulator. In a small transmitter, the speech amplifier and modulator may be combined in one stage. In transmitters, the modulator is usually an audio power amplifier. It can be any type of power amplifier that will deliver the required amount of undistorted audio power to the modulated r-f amplifier. It may be operated class AB, or class B. If it is a class AB or class B amplifier, it must be a push-pull stage.

c. Power Supply. As in c-w transmitters, d-c operating power can be supplied by dry batteries, storage batteries, power lines, generators, or dynamotors. Many transmitters have a single high-voltage supply which is capable of supplying enough power for the r-f and a-f circuits of the transmitter. This is particularly true of most small transmitters used in the field and in mobile installations. High-power transmitters and those designed for semiportable and fixed station work often have a separate power supply for the audio equipment.

d. Figure 109 shows the rear view of a typical military transmitter (also shown in figures 100 and 101). The lower chassis is the power supply; the middle chassis is the speech amplifier and modular section, and the top chassis contains the r-f stages.

73. Systems, Methods, and Levels of Modulation

A radio carrier may be amplitude-modulated in various ways, the two principle systems being known as *constant efficiency, variable input modulation* and *variable efficiency, constant input modulation. Method of modulation* usually refers to the electrode or element of the r-f amplifier to which the modulating voltage is applied.

a. Constant Efficiency, Variable Input Modulation. In this system, the efficiency of the modulated stage remains constant, and the output is varied by varying the power input to the stage. In *plate modulation,* the most commonly used method, the modulating voltage is impressed on the d-c supply voltage to the plate of one of the r-f amplifiers of the transmitter. The output of

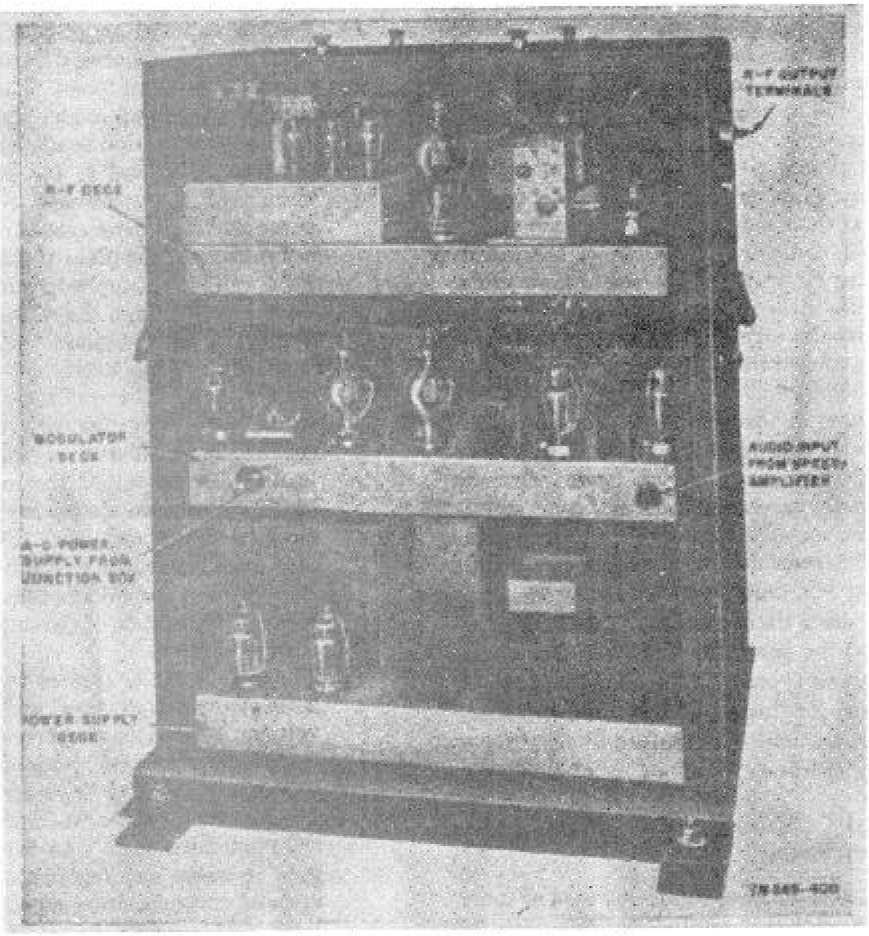


Figure 109. Rear view of military transmitter.

the modulated stage is varied by the varying input voltage, but its efficiency remains constant.

b. Variable Efficiency, Constant Input Modulation. In the following methods, the d-c input voltage to the modulated stage is constant and the output is varied by varying the efficiency. Application of the modulating voltage to the control grid of an r-f amplifier is called *grid modulation* or *grid bias modulation*. Pentode type power amplifiers can be modulated by applying the modulating voltage to the suppressor grid to produce *suppressor modulation*, or to the screen grid to produce *screen grid modulation*. Screen grid modulation can be applied also to tetrode type power amplifier tubes. *Cathode modulation* is a method in which the modulating voltage is applied to the cathode circuit of the modulated stage.

c. Levels.

(1) *High level modulation.* Since the modulating voltage is applied to the final r-f amplifier in high level modulation, the stages preceding it need not be perfectly linear. Therefore they may be operated class C with operating potentials adjusted for the desired circuit efficiency and gain. The final stage always is operated class C. The over-all efficiency of such a transmitter is high. A disadvantage of high level modulation is that comparatively high audio power is needed and several stages of voltage and power amplification may be required in the speech amplifier and modulator circuits.

(2) *Low level modulation.* In this method, modulation takes place in a buffer or intermediate power amplifier stage, and modulating voltage is applied to a stage preceding the final amplifier. The r-f amplifiers which follow the modulated stage must be operated in such a manner that their a-c output voltages are amplified, undistorted replicas of the modulated r-f voltages applied to their grids. Since little a-f power is required to modulate the carrier fully, the a-f section of the transmitter can be made comparatively simple. A disadvantage of this system of modulation is that the modulated stage must be followed by linear r-f amplifiers. Since lower efficiency usually is obtained from linear amplifiers, the efficiency of a low level modulated transmitter is low as compared with that of a high level modulated transmitter using the same type of tubes and identical d-c operating voltages. Some specialized types of linear amplifiers can be used for higher-than-normal efficiency but, because of difficulties in adjustment and operation, their use is not general.

74. Constant Efficiency Modulation—Plate Modulation

This method is the most commonly used of those suitable for high level amplitude modulation. It permits the transmitter to operate with high efficiency. It is simplest to apply and easiest to adjust for proper operation. The modulator, usually operated push-pull, is coupled to the plate circuit of the final r-f amplifier. For 100-percent modulation, the modulator must supply enough power to the r-f plate circuit to cause the instantaneous voltage on the plate of the modulated amplifier to vary between zero and twice the d-c operating plate voltage.

a. Heising Modulation.

(1) Any system of plate modulation may be called Heising modulation, after its inventor. However, popular usage of the term *Heising modulation* usually is limited to the choke coupled arrangement shown in figure 110. Other plate modulation circuit arrangements are considered to be transformer-coupled and are identified by the class of operation used in the modulator tubes. The system of plate modulation commonly known as Heising modulation consists of a class A modulator coupled to the plate supply circuit of the modulated r-f amplifier through a modulation choke coil, *L*. The a-f voltage on the plate of the modulated r-f amplifier is supplied from the modulator plate through the choke coil. Consequently, the r-f plate voltage can be varied by varying the voltage on the modulator plate. The modulator operates as an a-f power amplifier with the plate circuit of the modulated r-f amplifier as its load. The output of the modulator is super imposed on the d-c supplied to the modulated r-f amplifier. For 100-percent modulation, the modulator must develop a peak a-c voltage equal to the d-c voltage on the plate of the amplifier without modulation.

(2) The a-f signal is applied to the modulator grid through transformer *T*1. The voltage applied to the primary of this transformer is usually the output of a speech amplifier which brings the microphone voltages up to the level required at the modulator grid. As the modulator grid is made less negative on one half cycle of the modulating signal, the modulator plate current increases. This increased flow of current through inductor *L* induces a voltage in it which opposes the increase in current. Being 180° out of phase with the original voltage, this induced voltage subtracts from the voltage on the modulator plate. Since the plate of the modulated r-f amplifier is essentially tied to this point, its plate voltage, and consequenly its r-f power output, are reduced.

(3) Conversely, the modulator grid becomes more negative on the next half cycle of the modulating signal. This causes a reduction in the modulator plate current. The voltage induced in *L* is now a minimum which permits the plate voltage and r-f power output of the modulated r-f amplifier to be a maximum.

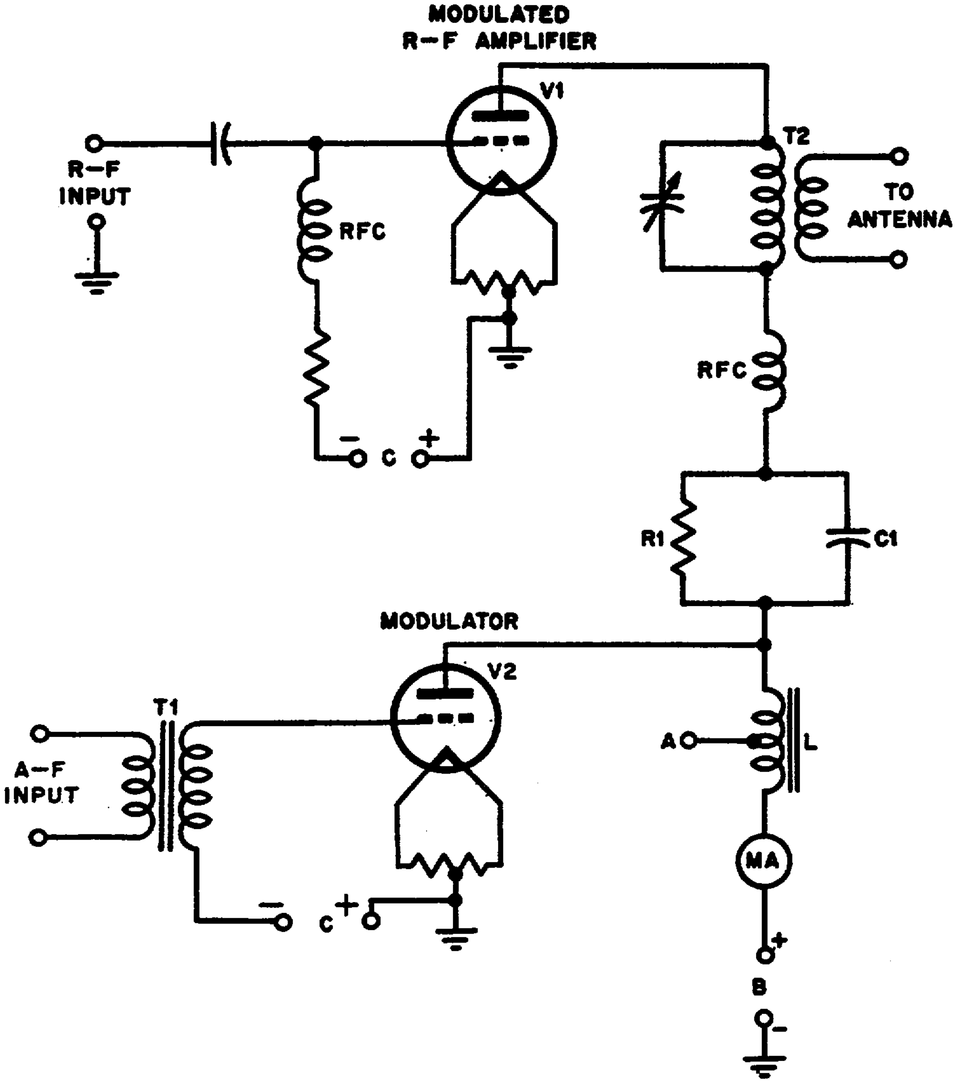


Figure 110. Basic Heising modulation system.

(4) For 100-percent modulation, the audio voltage developed across L must have a peak value equal to the d-c voltage on the modulated r-f amplifer plate. The instantaneous plate voltage varies from zero to twice the d-c plate voltage of the modulated r-f amplifier. The modulated r-f amplifier operates at some fixed value of efficiency, which means that the r-f power output is always directly proportional to the power input. The effective a-f output voltage of a class A amplifier is never equal to its d-c plate voltage because its operating range is restricted to the linear portion of the dynamic grid voltage plate-current characteristic curve for distortion free operation. Consequently, the d-c plate voltage on the modulated r-f amplifier must be reduced to a level equal to the maximum a-c peak voltage which can be developed with negligible distortion. The plate voltage for the r-f amplifier is dropped by resistor $R1$ which is bypassed by capacitor $C1$. The capacitive value of $C1$ is selected so that it prevents a negligible reactance to audio frequencies.

(5) Instead of reducing the d-c plate voltage applied to the modulated r-f amplifier or driving the class A modulator into the

high distortion region in an effort to obtain 100-percent modulation, an autotransformer arrangement can be used. In this case, the modulator plate is connected to some point *A* on modulation coil *L*. Resistor *R*1 and capacitor *C*1 then are omitted since a portion of *L* reduces the d-c plate voltage on the modulated r-f amplifier. A comparatively low a-c voltage developed across the modulator section of *L*, through autotransformer action, results in a higher a-c voltage applied to the plate of the modulated r-f amplifier. By selecting the proper tapping point on *L*, it is possible to obtain a turns ratio which results in a perfect match between the two stages so that maximum audio output and transfer of modulation power is obtained. The proper impedance match between the modulated r-f amplifier and modulator also provides for freedom from distortion over wider modulation levels.

(6) *Impedance-capacitance coupling* is another method of coupling a class A modulator to the modulated r-f amplifier (fig. 111). A separate modulation choke *L*2, is connected in series with the d-c plate supply lead to the modulated r-f amplifier. An audio-coupling capacitor, C_c, connects the plate side of choke *L*1 in the modulator plate lead to choke *L*2. This method of coupling seldom is used because of difficulties in matching the impedances of the modulator and modulated r-f amplifiers stages.

b. Transformer Coupling.

(1) In the most widely used method of coupling between a modulator and a modulated r-f amplifier (fig. 112), the modulator is transformer coupled by *T*1 to the plate circuit of the modulated r-f amplifier. The modulator plate current flows in the primary and the modulated r-f amplifier plate current flows in the secondary of *T*1. The audio power developed by the modulator appears in series with the d-c voltage that is applied to the modulated r-f amplifier. This produces a resultant voltage whose instantaneous value increases and decreases at an audio rate determined by the modulating frequency.

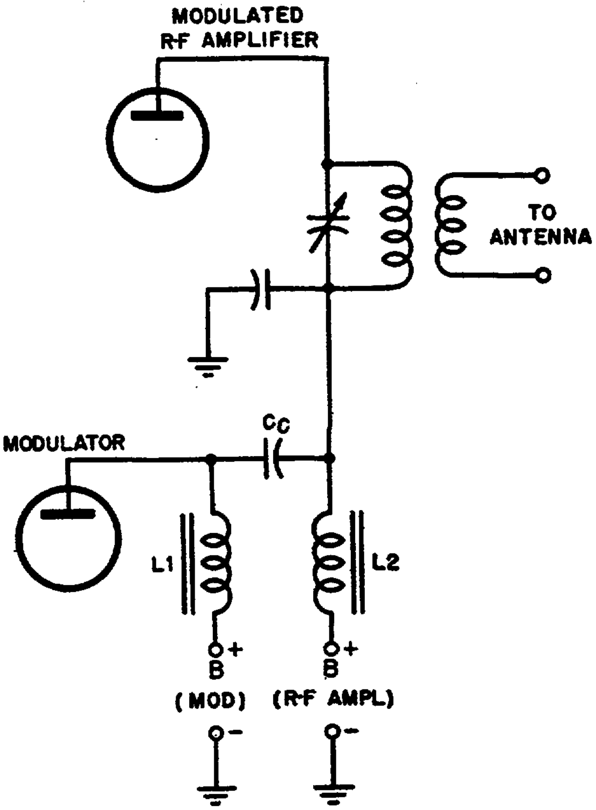


Figure 111. Plate modulation using impedance coupling.

(2) The modulator power output and the turns ratio of transformer *T*1 must be such that the a-c voltage on the plate of the r-f amplifier varies from zero to twice the d-c operating voltage for 100-percent modulation. The turns ratio is adjusted so that the modulator operates into its proper load impedance. The modulator tube can be operated class A, class AB, or class B. In all except class A, the modulator must be a push-pull stage.

(3) The discussion thus far has considered only the use of triodes as modulated r-f amplifiers. Pentode and tetrode r-f amplifiers are used also. However, a modulated r-f amplifier cannot be modulated satisfactorily by inserting the modulating voltage in series with its plate. Part of the modulating voltage must be applied also to the screen grid, because the plate current of a modulated r-f amplifier is

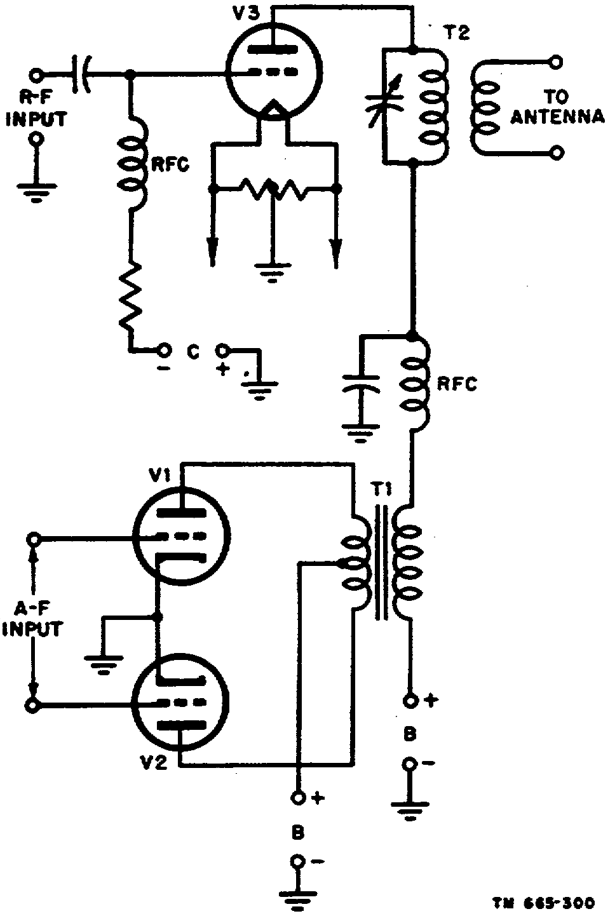


Figure 112. Plate modulated r-f amplifier with transformer coupling between modulator and modulated r-f amplifier.

determined by the screen grid voltage as well as the plate voltage. Therefore, in order to assure a linear variation in plate current, the modulating voltage must be applied to both the plate and the screen grid.

(4) One method of modulating the screen grid simultaneously with the plate is shown in figure 113. In this circuit, dropping resistor $R1$ is the screen-grid dropping resistor. $C3$, the plate bypass capacitor, has a low reactance to r-f. $C1$ bypasses the audio voltage around the screen grid dropping resistor, and $C2$ is the r-f bypass capacitor for the screen grid. Since the modulator must supply power to modulate the screen and plate circuits of the modulated r-f amplifier, the load impedance formula for pentode and tetrode tubes is

$$Z_p = \frac{E_{bb}}{I_p + I_{sg}} \times 1{,}000$$

where

E_{bb} is the d-c plate voltage,

I_p the d-c plate current in milliamperes, and

I_{sg} the d-c screen grid current in milliamperes.

c. Plate-Modulation Considerations. Five factors must be taken into consideration when modulating a class C amplifier if the modulated signal is to have minimum distortion and the circuits are to operate with a relatively high efficiency.

(1) The r-f excitation to the modulated r-f amplifier must be adequate. It should have sufficient amplitude to cause the r-f current in the plate tank circuit to follow the plate voltage as it varies under modulation. If the plate voltage is decreased to one-half its value, the plate current

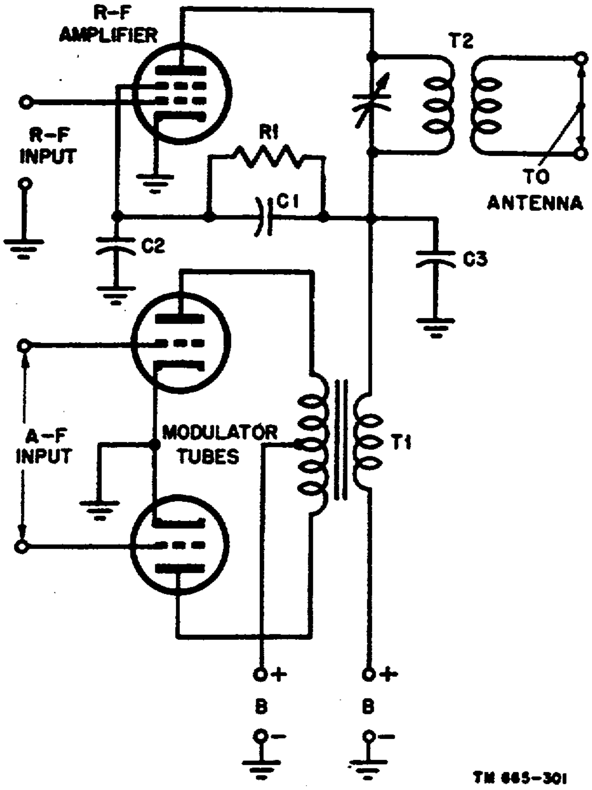


Figure 113. Method of plate modulating a screen grid tube.

drops likewise; if the plate voltage is doubled, the current increases in the same proportion. Since the plate voltage rises to twice its normal value at 100-percent modulation, the r-f excitation must be sufficiently high to cause the plate current to do likewise. The r-f excitation should be increased when necessary to maintain a linear relationship between the instantaneous power output and the instantaneous plate voltage for all modulation percentages up to 100 percent. The excitation preferably should be obtained from a source having relatively poor regulation, but not so poor as to affect the modulation adversely. This prevents the grid current, and hence the power dissipated in the grid, from becoming excessive when the plate voltage approaches zero under heavy modulation. The grid current increases as the grid is driven more positive and as the minimum plate voltage approaches zero. Therefore, if the maximum grid voltage is greater than the minimum plate voltage, secondary emission takes place at the plate. The secondary electrons from the plate are attracted to the grid and, thereby, will increase the grid current and the amount of power dissipated by the grid. If the driver for the modulated r-f amplifier has poor regulation, the excitation voltage tends to drop off when the load impedance changes. The use of grid-leak bias on the r-f modulated amplifier tends to stabilize the maximum grid potential. With grid-leak bias, any tendency to change the maximum grid voltage produces a large change in the grid current. This increased grid current develops a higher negative voltage drop across the grid resistor and the maximum signal voltage is effectively reduced.

(2) The grid bias should be at least twice the tube cut-off value. The major portion of the bias usually is obtained from a grid leak resistor. Sufficient fixed bias or cathode bias is used to limit plate current to a safe value in the absence of excitation. The reactance of the grid bypass capacitor is usually at least twice the resistance of the grid leak resistor at the highest modulation frequency. If this were not the case, the distortion would become pronounced because the grid bias cannot follow the plate circuit variations produced by modulation.

(3) The tank circuit of the modulated r-f amplifier is designed to have a relatively low *Q;* otherwise, the resonance curve may be sharp enough to attenuate the higher frequencies present in the upper side band. Although the *L-C* ratio should be high for good plate circuit efficiency, it should not be too high in a plate modulated transmitter because considerable flywheel effect is required for good linearity under modulation. Generally, if two coils are available for tuning to a desired frequency, the one requiring the higher tuning capacitance for resonance is used.

(4) The modulation transformer is designed or adjusted to match the modulator tubes to a load determined by the plate voltage and plate current of the modulated r-f amplifier. Therefore, if the plate voltage is fixed, the antenna coupling and loading should be adjusted so that the modulated r-f amplifier is drawing current which results in the desired load being presented to the modulator.

(5) The d-c power input to the modulated r-f amplifier for plate modulation is less than that rating for the same tube in using c-w. This is true because the power applied to the plate of the modulated r-f amplifier is 1.5 times its normal value and the tube must dissipate 50 percent more power than when the carrier is unmodulated. Since the tube operates at these peak values for such short periods of time, the power input ratings for radiotelephone service usually are about two-thirds the permissible value for c-w.

75. Variable Efficiency Modulation

a. Grid Bias Modulation.

(1) Class C amplifiers also may be modulated by applying the modulating voltage to the control grid instead of the plate. A circuit of a typical grid modulated r-f

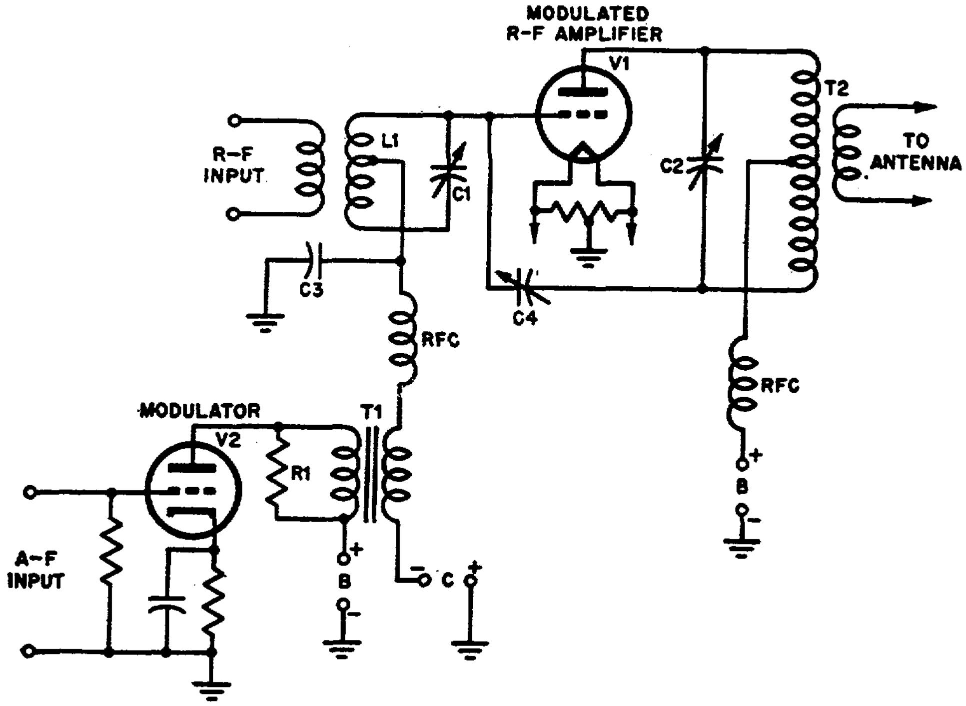


Figure 114. Circuit for grid-bias modulation.

amplifier is shown in figure 114. The modulator is coupled to the grid circuit of the modulated r-f amplifier by modulation transformer *T*1. The modulating signal currents flow in the primary and the modulated r-f amplifier grid currents flow in the secondary of *T*1. The fixed grid bias voltage for the modulated r-f amplifier is provided by a *C* supply. The r-f choke, RFC, in the grid circuit of *V*1, and capacitor *C*1 prevent the r-f current in the *L*1*C*1 tank circuit from entering the modulator and the power supply.

(2) Applying the a-f modulating voltage throught *T*1 to the grid of the modulated r-f amplifier does not change the average grid voltage, since the average value of a sine voltage is zero. This being the case, the average plate current and average plate power input are constant. Since the average power input is constant, the increase in power output is obtained by increasing the efficiency of the amplifier, or, in other words, decreasing the power loss within the tube. The operating conditions for linear modulation are so made that the efficiency of the stage is approximately 33 percent in the absence of modulation. During full modulation, the power output increases to 1.5 times its unmodulated value, and the plate current efficiency increases approximately 51 percent. The modulated carrier output is approximately one-fourth as great as the same tube adjusted for plate modulation.

(3) The d-c bias for a grid modulated r-f amplifier is the same as in normal c-w operation, but the excitation voltage is somewhat lower so that the grid will not be driven to the zero grid bias point. The modulating a-f voltage causes the instantaneous grid voltage to vary at an audio rate, thus shifting the operating point of the grid circuit and varying the efficiency and output of the stage. The change in grid voltages places a variable load on the stage driving the modulated r-f amplifier (the driver) and on the plate of the modulator tube. This change in loading causes distortion. Changes in modulator loading are minimized by placing a shunting resistor, *R*1, across the primary of the modulation transformer, *T*1. This resis-

tor should be equal to, or somewhat larger than, the normal load into which the modulator should work for normal output. To prevent changes in the loading on the driver, this stage should be capable of delivering several times the required driving power. The driver is loaded so that it delivers considerably more power than is required to the grid circuit of the modulated amplifier.

(4) The modulator tube must be operated as a class A amplifier. Its power output can be small, since it is necessary only to vary the negative grid bias slightly. The power output of the modulator is very low because the grid is not permitted to swing positive and draw grid current.

(5) An advantage of grid modulation is that comparatively little audio power is required for modulation purposes. This advantage is nullified by its many disadvantages. The efficiency of a grid modulated amplifier is low and it is difficult to obtain a high degree of modulation without severe distortion. Furthermore, a larger than usual modulated r-f amplifier tube is required for a given power output, because the limited r-f excitation makes it impossible to obtain anywhere near the normal power output from the tube. Grid modulated transmitters seldom are used in military service. Figure 114 shows a triode used as the modulated r-f amplifier, but tetrodes or pentodes may be used also.

b. Screen Grid Modulation.

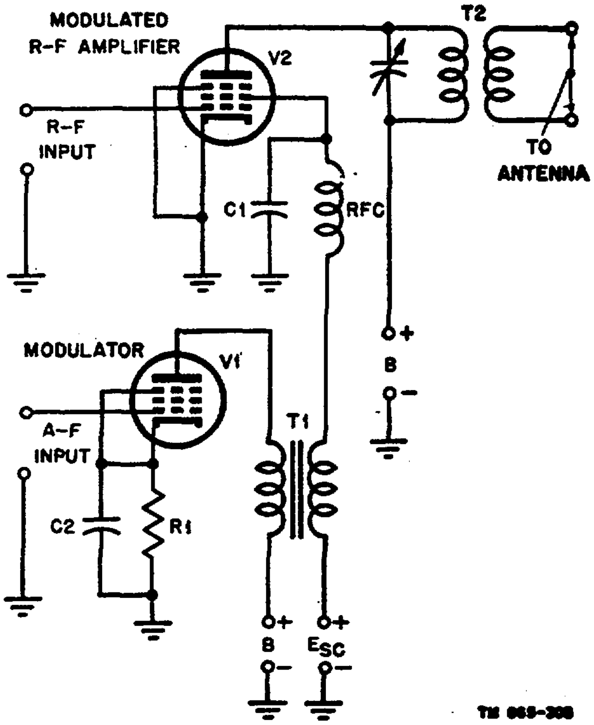


Figure 115. Circuit for screen grid modulation.

(1) Screen grid modulation is used to some extent in low power transmitters and in cases where space and power for a class B plate modulator are not available. In the typical screen modulated amplifier shown in figure 115, the d-c screen grid voltage is applied through the secondary of modulation transformer *T*1, the primary of which is connected to the plate of the modulator tube. Consequently, the modulating voltage is superimposed on the screen grid of the modulated r-f amplifier. The r-f choke, RFC, in the screen grid of the modulated r-f amplifier and capacitor *C*1 prevent r-f currents from entering the modulator and d-c power supply, where they may cause feedback. Capacitor *C*2 is the usual cathode bypass capacitor used to prevent degeneration in the modulator. Resistor *R*1 is a cathode return resistor for the bias voltage.

(2) The a-f power required for screen grid modulation is somewhat greater than that for grid bias modulation. The modulating a-f power is approximately one-quarter of the power input to the screen under normal c-w operation. The peak audio voltage is approximately equal to the d-c screen voltage which is adjusted to one-half the value used for c-w operation.

c. Suppressor Grid Modulation. Figure 116 shows the circuit of a suppressor grid modulated r-f amplifier in which the output of the modulator appears in the secondary of modulation transformer *T*1, which is in series with the suppressor grid of the modulated r-f amplifier. Capacitor *C*2 and r-f choke RFC prevent r-f currents from flowing through the secondary winding of *T*1 into the modulator and power-supply circuits. *C*2 has a low reactance to r-f and a high reactance to a-f; its average value is approximately .002 microfarad or smaller. Resistors *R*1 and *R*2 are the screen grid dropping resistors for the a-f and r-f tubes. They are bypassed by capacitors *C*1 and *C*4. Resistor *R*3 provides cathode bias voltage to the modulator stage; it is bypassed by capacitor *C*3 to prevent degeneration. *C*5 and the primary of *T*2 comprise the tank circuit in the modulated r-f amplifier.

d. Cathode Modulation.

(1) The modulator in figure 117 is coupled to the cathode circuit of the modulated r-f amplifier (in this case to the heater circuit) through modulation transformer *T*1. When a cathode tube is used as the modulated r-f amplifier, the secondary of *T*1 is connected to the cathode of the tube, instead of to the center tap on the filament transformer. The operating bias for the modulated r-f amplifier is applied between the C-minus and C-plus terminals. *C*1 is the grid bypass capacitor, *C*2 and *C*3 are filament bypass capacitors, and *C*7 is the plate bypass capacitor. *C*5, *C*6, and the primary of *T*2 make up

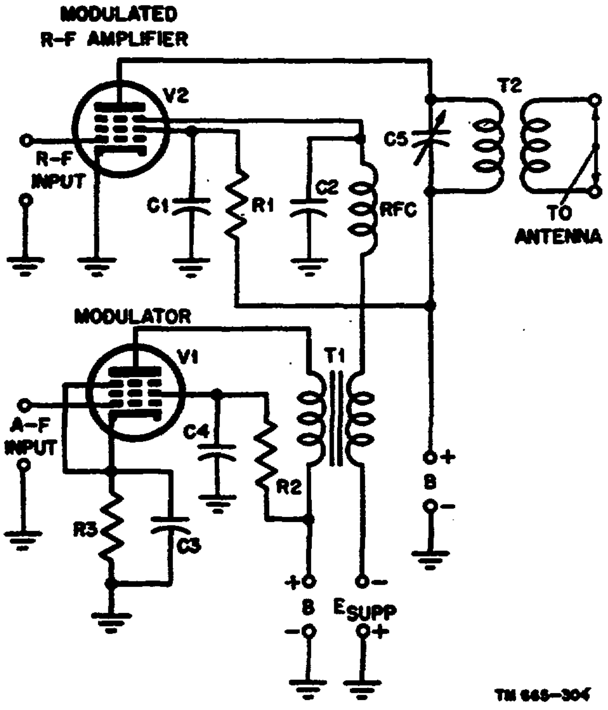


Figure 116. Circuit for suppressor grid modulation.

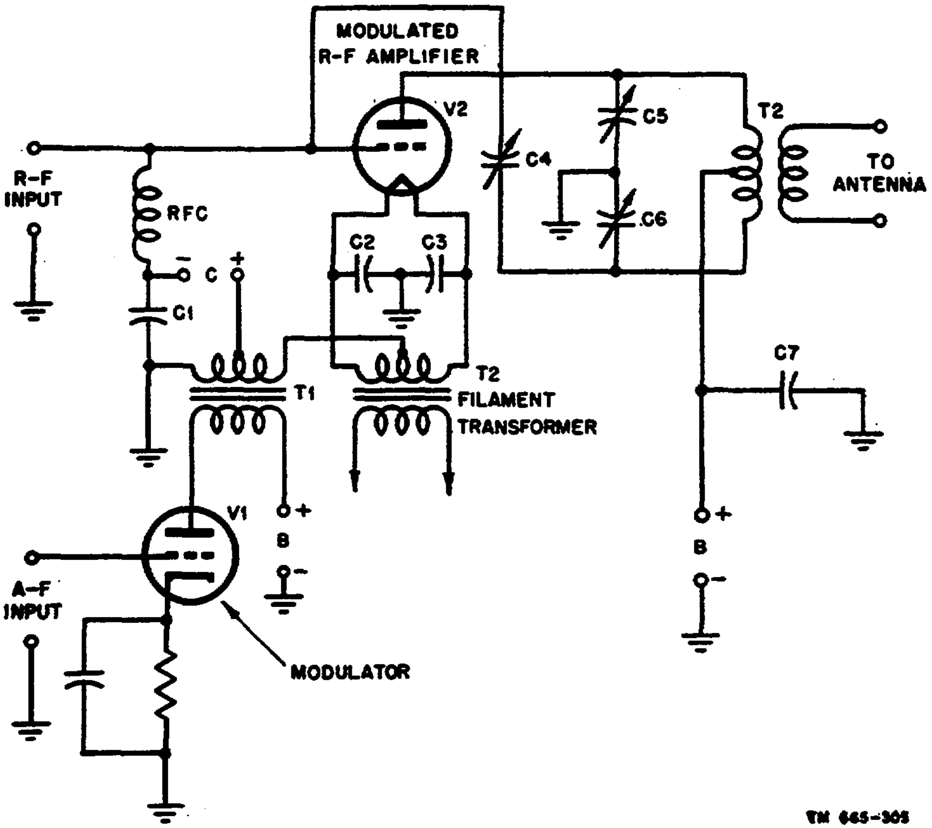


Figure 117. Circuit for cathode or center tap modulation.

the r-f tank circuit. *C4* is a neutralizing capacitor. The r-f choke, *RFC*, prevents r-f currents from entering the modulator and power supply.

(2) Cathode modulation, sometimes called *center tap modulation* (fig. 117), is a combination of plate and control grid modulation. The efficiency of some cathode modulated r-f amplifiers can be made to approach the efficiency of the average plate modulated amplifier. The average efficiency of a grid modulated stage ranges from 30 to 40 percent; a well designed plate modulated amplifier has an efficiency of approximately 78 percent. Since cathode modulation is a combination of these two methods working in phase, it is possible to obtain a wide range of efficiency by adjusting the relative percentage of modulation.

(3) The modulation transformer, *T*1, supplies an optimum match between the cathode circuit of the r-f modulated amplifier and the plate of the modulator tube. The d-c grid bias of the cathode modulated r-f stage can be supplied by any of the conventional means but provisions usually are made for varying the bias to compensate for moderate variations in excitation. The r-f grid excitation should not be too high, since this would cause difficulty in obtaining the desired amount of grid modulation. The grid excitation is approximately half that required for plate modulation. If grid-leak bias is used alone, the value of the grid-leak resistor should be approximately six times larger than that required for c-w operation. The tuned circuit in the plate of the modulated r-f amplifier should have a *Q* of approximately 10 to 15 so that its harmonic output is low and the flywheel effect permits good linearity. The antenna loading is such that a further increase in loading causes a slight drop in antenna current. For optimum performance, the grid excitation should be adjusted for minimum plate dissipation with maximum power in the antenna.

76. Grounded Grid Amplifiers

a. The *grounded grid* amplifier was developed as the answer to the problem of neutralization of r-f amplifiers at high frequencies. In the normal circuit arrangement, the input r-f signal is applied between the grid and the cathode and taken off between the plate and cathode. In the grounded grid amplifier, also called an *inverted amplifier* or *common grid amplifier*, the control grid is grounded for r-f. The r-f input signal, as shown in figure 118, is applied through transformer *T*1. Capacitance coupling to the preceding stage may be used also. The r-f signal output appears in the secondary of *T*2. *C*1 and the primary of *T*2 comprise the plate tank circuit of the amplifier.

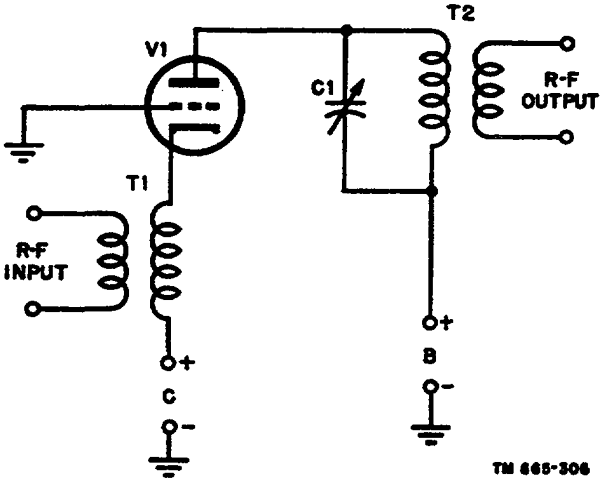


Figure 118. Grounded grid amplifier

b. The grounded grid acts as a shield to reduce the plate-to-cathode feedback capacitance in the same manner that the screen grid isolates the plate and cathode in a pentode or tetrode. In the conventional circuit, the suppressor and screen grids of tetrodes and pentodes reduce the feedback capacitance to the point where neutralization is seldom necessary up to frequencies in the neighborhood of 100 mc. At frequencies of several hundred megacycles, the screen- and suppressor-lead inductance makes it impossible to hold these leads at zero r-f potential and oscillation is likely to occur. In this case, grounded grid amplifiers are used.

c. As the operating frequency of a radio transmitter is increased, conventional circuit arrangements must be changed. The plate and grid leads begin to act as small inductances which effectively reduce the effect of the normal neutralizing capacitor. The frequency band over which the neutralization, once adjusted, can be maintained becomes progressively smaller, until the amplifier cannot be stabilized above a particular frequency. Furthermore, the normal neutralizing capacitance adds to the output capacitance of the tube, thus narrowing the effective r-f bandwidth and reducing the efficiency of the circuit because of excess circulating currents outside of the tank circuit. In the grounded-grid amplifier, the output capacitance is limited to the plate-to-cathode capacitance (plus stray capacitances) and greater operating bandwidths are possible, as well as higher efficiency caused by the lower circulating currents outside the tank circuit.

d. Another characteristic of the grounded grid amplifier is that the instantaneous r-f signal voltage between cathode and ground is in phase with the instantaneous r-f voltage developed between plate and cathode. These voltages appear in series across the load. Driving power requirements for a grounded grid amplifier are greater than for the same tube used as a conventional amplifier, because the driver supplies some of the output power appearing at the load of the grounded grid stage. However, this added power, which may be up to 10 times the driving power requirements of a conventional amplifier, is not lost, but simply transferred to the output circuit of the grounded grid amplifier.

e. Plate modulation of a grounded grid amplifier cannot be obtained at a modulation level of 100 percent. When a grounded grid amplifier is plate modulated, the output current and plate voltage are linear in respect to each other until about 60-percent modulation is reached. As the modulator output voltage exceeds this level, modulation becomes nonlinear. This is caused by the fact that the r-f driving voltage and d-c supply voltage are in series across the load; plate current does not drop to zero until the plate voltage reaches a negative value equal to the peak r-f driving voltage. However, frequency modulation, rather than amplitude modulation, generally is used at the very high frequencies for which the grounded grid circuit is particularly suited, so that this disadvantage is not a practical consideration in the use of the circuit.

77. Audio Components and Circuits

a. The audio section of an a-m transmitter converts sound waves into audio voltages and currents. It usually consists of a microphone and a series of electron tube a-f amplifiers to raise the output of the microphone to a power level sufficient to modulate the transmitter by the chosen method. With grid, screen, or suppresor modulation, the output power level is comparatively low; with plate modulation, it may vary from one-third to one-half the d-c power input of the modulated r-f stage. Knowing the voltage or current developed by a microphone used in the manner for which it was designed, and knowing the power output required from the modulator, it is possible to select the number and type of a-f amplifiers which will develop the required power with the least distortion.

b. There is little fundamental difference between the audio circuits used in modulators and those used in radio receivers, public address amplifiers, intercommunicators, and similar systems. In these devices, the power output may range from 1 watt for a small portable radio to several hundred watts for a public address system designed to cover a large outdoor area. A modulator may develop a power output ranging from 1 watt to several thousand watts, depending on its driving power. The output of an audio system generally is coupled to the load through a transformer; a radio or public address amplifier has an output transformer designed to match it to a loudspeaker, whereas the output of a modulator must be matched to a modulated r-f amplifier. Almost any public address amplifier which delivers the required audio power can be used as a modulator simply by replacing its output transformer with a modulation transformer which matches the load presented by the modulated r-f amplifier.

c. The criterion of radio communication is intelligibility of speech. This objective differs from the standards required in public address work and broadcasting, where naturalness of speech and tone and quality of music is important. For understandable speech, the voice frequencies between 100 and 2,500 cps are saitsfactory. Frequencies above and below these limits add to the naturalness of speech, but they do little to add to the intelligibility. Another most important consideration is the bandwidth of the channel used in communications. This bandwidth is directly proportional to the audio frequencies being transmitted (fig. 103). Therefore, if the voice frequencies transmitted are limited to those in the usable speech range, the channel width is reduced, and more stations can be operated in a given band of frequencies without causing mutual interference. Furthermore, frequencies outside the useful speech range absorb some of the side-band power which could be used to add more strength to the useful voice frequencies. For these reasons, the speech amplifiers of communication transmitters often include design features which accentuate these speech frequencies which contribute to intelligibility and attenuate (reduce) all others.

78. Microphones

a. *General.*

(1) The most commonly used microphone is one which converts the variations in air pressure produced by the human voice or a musical instrument into an electrical voltage or current of the same frequency and corresponding amplitude. Another type responds to vibrations by direct contact, rather than to the sounds produced by vibrations. Microphones may be designed to be selective in their freqency response. Those used for broadcast purposes, recording work, and some types of public address work, have uniform output in the range of frequencies from 30 to 10,000 cps and higher. The frequency response of communication type microphones often is limited to approximately 75 to 4,500 cps. Other design considerations involve the distance between the microphone and the sound source, as well as the ability of a microphone to pick up sound uniformly from different angles. Just as the intensity of sound waves decreases with the distance from the source, so the sensitivity of a microphone decreases as the distance between it and the sound source is increased. Maximum sound pick-up is obtained, therefore, when there is a minimum of distance between the microphone and the sound source. Depending on the service for which they are designed, microphones have little or great sensitivity as this distance is increased. Also depending on the service requirements, microphones may be designed to pick up sounds uniformly from all directions, from the front primarily, or from several angles. The physical shape of the microphone is determined by its use; some types are designed to be hand held, some to be mounted on floor or table stands or suspended from booms or cables, and some to be fixed in the correct operating position so that the operator has his hands free.

(2) The output of a microphone may be high impedance or low impedance, and microphones frequently are classified in these terms. The principle on which the microphone is constructed determines its output impedance; the low-impedance group includes carbon, dynamic, and velocity types; high impedance microphones include the crystal and capacitor types. Maximum output is obtained from a microphone when its impedance is matched to that of the load to which it supplies voltage. The turns ratio of the transformer which connects the microphone to an a-f amplifier must be such that the load reflected into its primary by the loaded secondary is equal to the impedance of the microphone.

b. *Carbon Microphone.*

(1) Operation of the most widely used microphone in military service, the *single button carbon microphone* (A of fig. 119), is based on the varying resistance of a pile of carbon granules as the pressure on the pile is varied. The insulated cup, called the *button*, which holds the loosely piled granules, is so mounted that it is in constant contact with the thin metal diaphragm shown in the illustration.

(2) Sound waves striking the diaphragm set up vibrations which vary the pressure on the button, and thus vary the pressure on the pile of carbon granules. The d-c resistance of the carbon granule pile is varied by this pressure in accordance with the vibrations on the diaphragm. The varying resistance is in series with a battery and the primary of microphone transformer *T*. The changing resistance of the carbon granule pile produces a corresponding change in the current of the circuit. The resulting pulsating direct

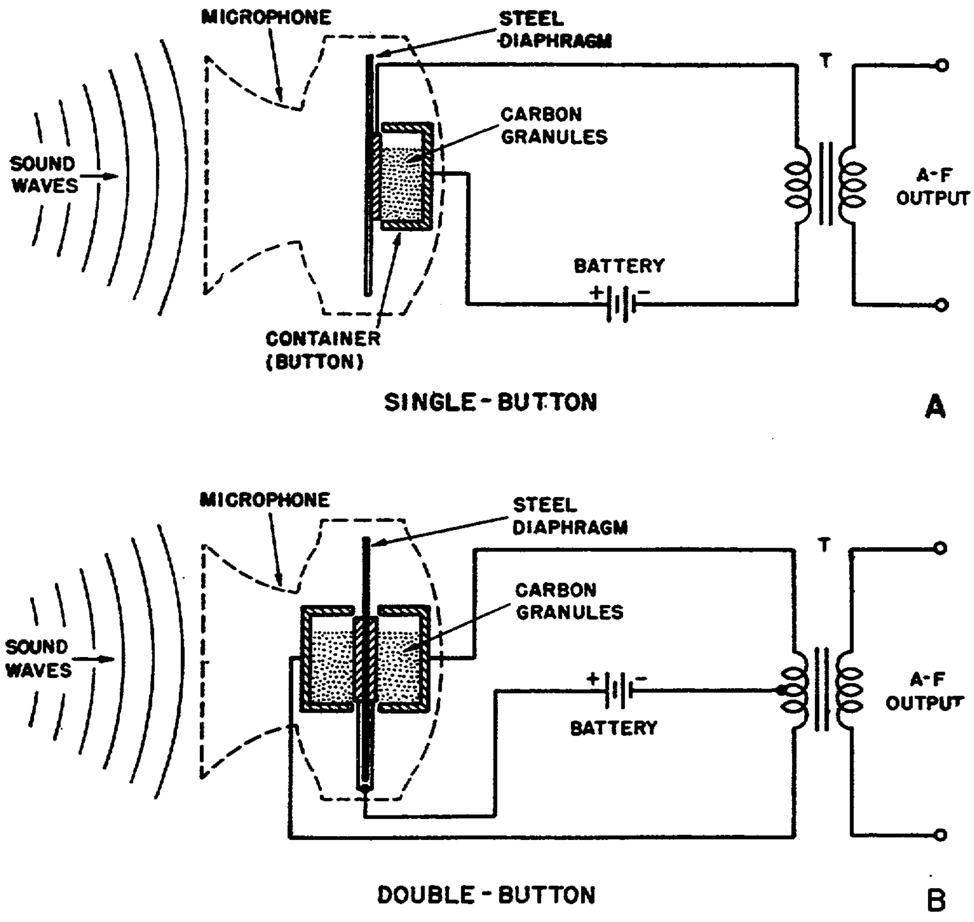


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Figure 119. Carbon microphone and circuit.

current in the primary of *T* produces an alternating voltage in the secondary circuit. Transformer *T* has two functions: It steps up the voltage while matching the low impedance microphone to the much higher impedance of the grid circuit of the first a-f amplifier. A good single button microphone will develop as high as 25 volts peak in the secondary of the transformer, whereas battery voltages range from 1.5 to 6 volts and currents from 10 to 100 milliamperes, depending on the design of the microphone. The impedance of the microphone is usually from 50 to 200 ohms.

(3) Some microphones have two buttons, one on each side of the diaphragm. These are *double button carbon microphones* (B of fig. 119). They are so constructed that when the diaphragm presses on one button, it relieves the pressure on the other. The buttons are connected to the ends of a center-tapped primary of a microphone transformer. The push-pull arrangement cancels even harmonics and minimizes distortion. The double-button microphone seldom is used. It has been replaced by other types which are more suitable from the standpoint of frequency response and trouble-free operation.

(4) A disadvantage of carbon microphones is that the random changes in resistance between individual carbon granules produce a constant hiss which masks weak sounds. Another disadvantage is that the carbon granules stick to each other or pack when they are subjected to excessive currents or pressure. Packing reduces the sensitivity of the microphone and lowers the output while producing serious distortion. This can be remedied sometimes by tapping the case of the

microphone. A further disadvantage of carbon microphones is that the frequency response is limited by mechanical resonance in the diaphragm. The response can be increased by stretching the diaphragm, but this decreases the over-all output, so that there is usually a compromise between frequency response and output.

(5) Despite these disadvantages, the single button carbon microphone has advantages which warrant its use in many military applications. It is the only microphone which is also an amplifier in that its electrical power output is greater than the mechanical power required to vibrate its diaphragm. It is lightweight, rugged, and can be designed for extremely high output when its frequency response is limited to those frequencies which contribute most to intelligibility.

c. Crystal Microphone.

(1) The ***crystal microphone*** operates on the principle that Rochelle salt, quartz, or other crystalline materials exhibit a characteristic called the *piezoelectric effect*. These materials generate a voltage when mechanical stress is applied to the crystal. Since Rochelle salt has greater voltage output than other piezoelectric materials, it is most frequently used in microphones. If a Rochelle salt crystal has a metal foil on both surfaces, a voltage is developed between the foils when the crystal is vibrated or stressed in any manner.

(2) The basic crystal microphone unit, sometimes called a *bimorph cell*, is made by clamping two thin crystal slabs together after a thin metal foil has been cemented to the surfaces of each. A lightweight diaphragm is coupled to the cell. Its vibrations are transmitted to the cell in such a way as to cause twisting of the crystal, and thus the generation of voltage between the foil terminals. The voltage output is comparatively high but the frequency response is limited because of the stiffness and inertia of the diaphragm.

(3) A superior type of crystal microphone is known as a *sound cell* or *grill type* microphone (fig. 120). A number of bimorph cells are connected in series or series parallel for greater sensitivity. Sound falls on the crystal plates and vibrates them directly. A diaphragm is not used. Bimorph cells *A* are mounted in a bakelite framework, *B*, and the assembly is covered with a flexible airtight and moistureproof covering, *C*, which permits the cells to vibrate freely with variations in sound pressure. When the entire unit is excited by sound waves, the voltages are in phase and are proportional to the sound pressure. If the unit is subjected to mechanical shock or vibration, the resultant voltages are out of phase and no output is generated as the result of these disturbances.

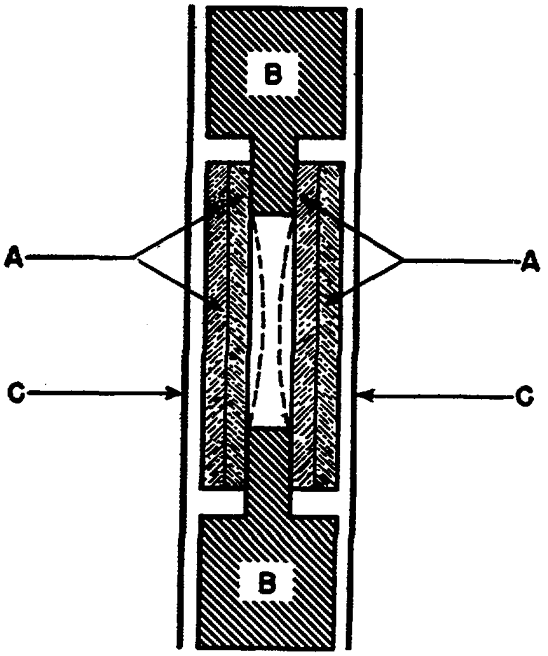

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Figure 120. Construction of crystal microphone unit.

(4) A crystal microphone has a high impedance and does not require an external voltage or current, and, therefore, it can be connected directly into the input circuit of a high gain a-f amplifier. Because its output is low, several stages of high gain amplification are required. Crystal microphones are delicate and and

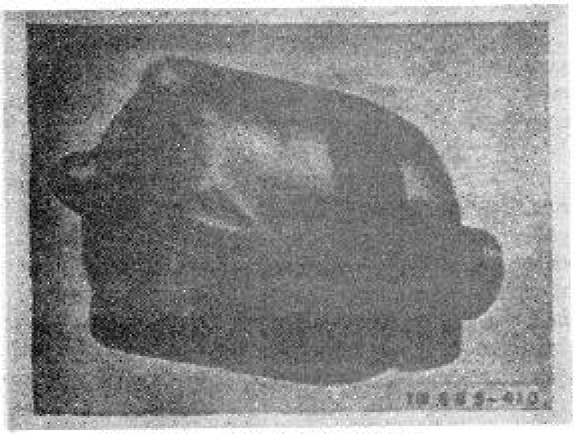

Figure 121. Military microphone.

fragile and must be handled with considerable care. Since exposure to high temperatures (above about 125°F.) may permanently damage the crystal unit, crystal microphones should never be exposed to the direct rays of the sun or the heat from radiators, or be operated close to high wattage electric lamps. The crystals are soluble in water and many other liquids, and precautions must be taken to protect them from prolonged exposure to moisture or excessive humidity. A typical military microphone is shown in figure 121.

d. Dynamic Microphone.

(1) The construction of a *dynamic microphone*, also called a *moving coil microphone*, is shown in figure 122. A coil of fine wire is fastened rigidly to the back of a diaphragm so that it is suspended in the field of a strong permanent magnet. When sound waves vibrate the diaphragm, this coil moves back and forth, cutting the magnetic lines of force of the permanent magnet at an audio rate; this induces in the coil a voltage which is the electrical representation of the sound waves.

(2) The sensitivity of a dynamic microphone (fig. 123) is higher than that of all other except carbon types. This microphone is comparatively light in weight and requires no external voltage. It is rugged and practically immune to effects of mechanical vibration, temperature, and moisture. Voltage output can be made independent of frequency over a wide range. A typical broadcast type dynamic microphone has a reasonably uniform response from 40 to 15,000 cps. A similiar microphone designed for communication circuits has a response of 100 to 6,000 cps. The average dynamic microphone has an impedance of 50, 100, 250, or 500 ohms

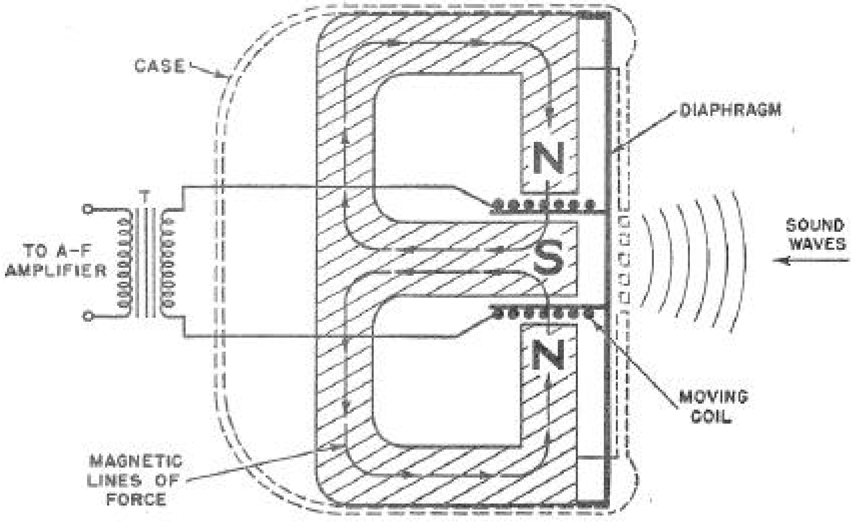

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Figure 122. Construction of dynamic microphone and matching transformer circuit connections.

and, therefore, requires a transformer for matching it to the input of an a-f amplifier (T, fig. 122). Some units have a built-in transformer which permits them to be used with amplifiers having high impedance inputs.

e. *Velocity Microphone.*

(1) A variation of the dynamic microphone, the *velocity microphone* has a thin, lightweight, flexible, corrugated, metallic strip suspended between the poles of a permanent magnet (fig. 124). Sound waves cause the corrugated strip to vibrate in the magnetic field produced by the magnet. It cuts the lines of force of the magnet, and voltage is induced in it which is proportional to the frequency and strength of the sound waves. The force exerted on the strip is proportional to the velocity of the sound waves, which is the reason for its name. Because the corrugated conductor resembles a ribbon, a velocity microphone often is called a *ribbon microphone.*

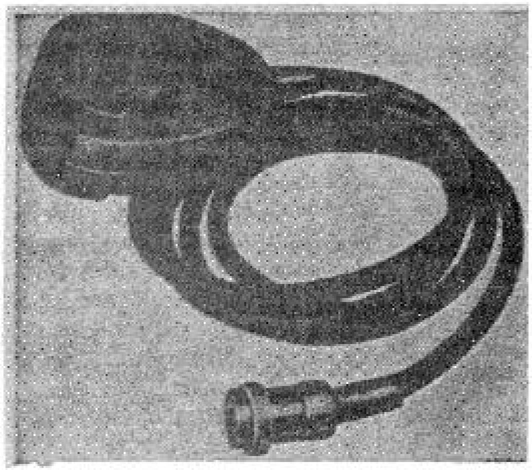

Figure 123. Dynamic microphone and cable.

(2) The velocity microphone has a good frequency response. It responds only to those sounds originating directly in front of it. The ribbon is so fragile that this type of microphone is difficult to use in drafts or outdoors where wind pressure may be sufficient to create considerable background noise. Because the resistance of the ribbon is less than 1 ohm, a velocity microphone usually has a built-in transformer which raises its impedance to 250 or 500 ohms. The voltage output is so low that leads between the microphone and amplifier must be shielded carefully to avoid hum pick-up. Velocity microphones are used in some broadcast stations and with some public address systems, but rarely with field equipment.

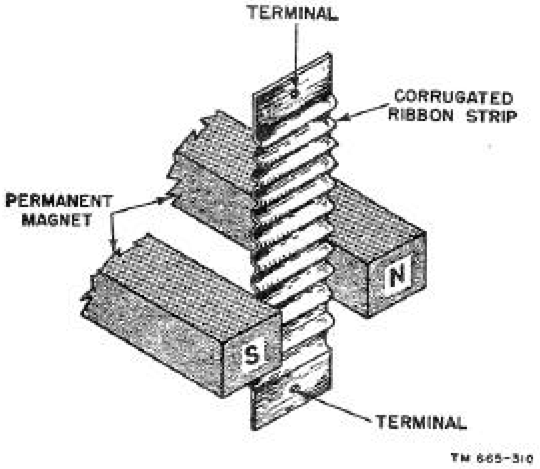

Figure 124. Construction of velocity microphone.

f. *Condenser Microphone.*

(1) *The condenser microphone* (A of fig. 125), so-named because it resembles a two-plate capacitor, consists of a movable metal diaphragm mounted close to but insulated from a heavier metal back plate. Vibration of the diaphragm caused by sound waves results in variations in the gap between the diaphragm and the back plate and thus changes the capacitance. When a d-c voltage is applied to the plates through a high resistance, $R1$, as in B, changes in capacitance cause a similar change in the current which flows through $R1$. This voltage is fed to the grid of the first a-f amplifier tube through coupling capacitor $C1$. $R2$ is the usual grid resistor for the amplifier.

(2) The condenser microphone has a high impedance. Its frequency response is good but the output is very low. The frequency response and the output voltage are affected by the capacitance of

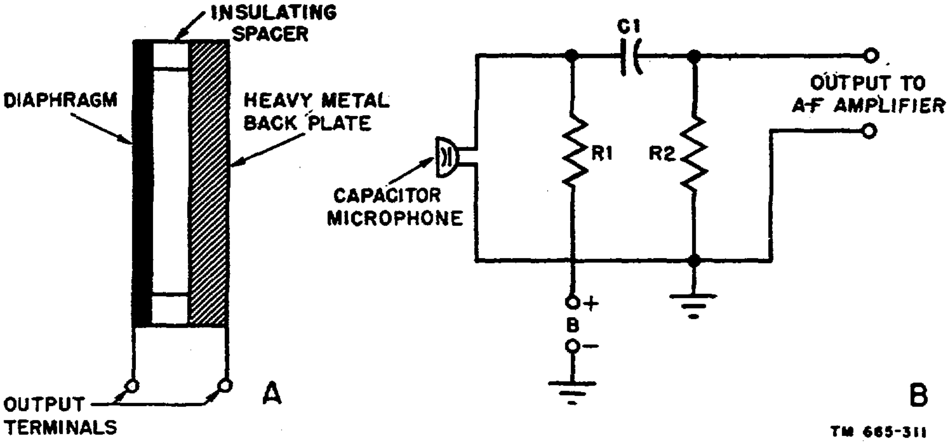

Figure 125. Construction of capacitor microphone and circuit.

the cable connecting it to the input of the amplifier. Usually, therefore, to compensate for losses in the connecting cable, at least one stage of a-f amplification is built into the microphone case. If this amplifier is self-powered, space must be provided for batteries; if it receives its operating voltages from an outside source, the connecting cable must have several additional conductors and is correspondingly bulkier. Condenser microphones seldom are used in radio or public address work, but they have some utility in certain types of sound measuring equipment.

g. Contact Microphone. The *contact microphone* responds to vibrations transmitted by contact with a solid rather than a fluid medium as in the case of the air pressure actuated microphone. It is used in areas where the background noise level is exceedingly high, as in tanks and aircraft. Examples are throat and lip microphones, which are strapped to these parts of the body and pick up vibrations directly from the throat and lip, respectively. Most contact microphones are crystal types, although they can be constructed around carbon button and dynamic units.

79. Speech Amplifiers

a. Purpose. A speech amplifier is needed in a radiotelephone transmitter whenever the output of the microphone is lower than the signal voltage required to drive the modulator tube. Therefore, the speech amplifier is considered to include all a-f amplifier stages between the microphone and the input of the stage whose output actually modulates the r-f carrier. When a class B modulator stage is used, the speech amplifier must include a power amplifier to supply power to the class B amplifier grids. The power amplifier that precedes the modulator is called the *driver* or *driver stage.*

b. Classes of Operation—Coupling. Audio amplifier circuits are designed to deliver *either* as much power or as much voltage as possible into a load impedance. When a large power output is the objective, the stage can be operated class A, class AB, or class B. When voltage gain is the objective, amplifiers usually are operated class A, because this class of operation is comparatively free from distortion. High voltage gain with minimum distortion is an important factor in the design of low level stages in a speech amplifier. Audio amplifiers commonly are classified according to the method of interstage coupling used; *resistance capacitance coupled*, *impedance coupled*, and *transformer coupled* amplifiers are a few examples.

c. Amplification Required in Speech Amplifier.

(1) The speech amplifier must supply a peak voltage equal to the value of d-c bias on the grid of the last class A amplifier if it is a single ended stage, and twice the d-c bias if the last stage is operated in push-pull. The *voltage gain* of an amplifier is the product of the voltage gain of each stage of the amplifier, including their interstage coupling networks. The approximate voltage gain of each stage is equal to E_{out}/E_{in}, where E_{out} is the peak a-c voltage appearing at the output of the stage and E_{in} is the peak a-c voltage appearing at the input of the stage.

(2) In actual practice, the speech amplifier must provide from 25 to 1,000 percent more voltage gain than needed to meet the requirements at the grid of the last a-f speech amplifier. This added gain compensates for circuit losses, deterioration of tubes, minor deviations in the values of circuit components and reductions in operating voltages. An audio gain control, similar to the volume control on a radio receiver, is used to adjust the output to the required level.

d. Class A Voltage Amplifiers. Class A amplifiers develop an output waveshape which is an amplified and faithful reproducton (for all practical purposes) of the input waveshape. In the interest of fidelity, the excitation voltage should never be large enough to drive the grid positive in respect to the cathode. Neither should it be large enough to drive the grid so far negative in respect to the cathode as to cause plate-current cut-off.

(1) *Resistance capacitance-coupled amplifiers.*

(*a*) In the circuit of a typical resistance capacitance-coupled triode voltage amplifier shown in A of figure 126, the voltage gain, VG, is equal to

$$VG=\frac{E_{out}}{E_{in}}=\mu\frac{R_1}{R_1+R_P}$$

where

E_{out} is the voltage appearing across the grid resistor R_g, of $V2$,

E_{in} is the voltage from grid to ground of $V1$,

r_p is the a-c plate resistance of $V1$,

R_1 is the equivalent load resistance of $V1$,

μ is the amplification factor of $V1$.

(*b*) In the typical resistance capacitance-coupled pentode voltage amplifier, in B, the voltage gain, VG, is equal to

$$VG=\frac{E_{out}}{E_{in}}=Gm\times R_{eq}$$

where

G_m is the mutual conductance of $V1$ and

R_{eq} is the equivalent resistance of r_p, R_c, and R_g in parallel.

The value of R_{eq} can be found from the formula

$$R_{eq}=\frac{1}{\frac{1}{r_p}+\frac{1}{R_c}+\frac{1}{R_g}}.$$

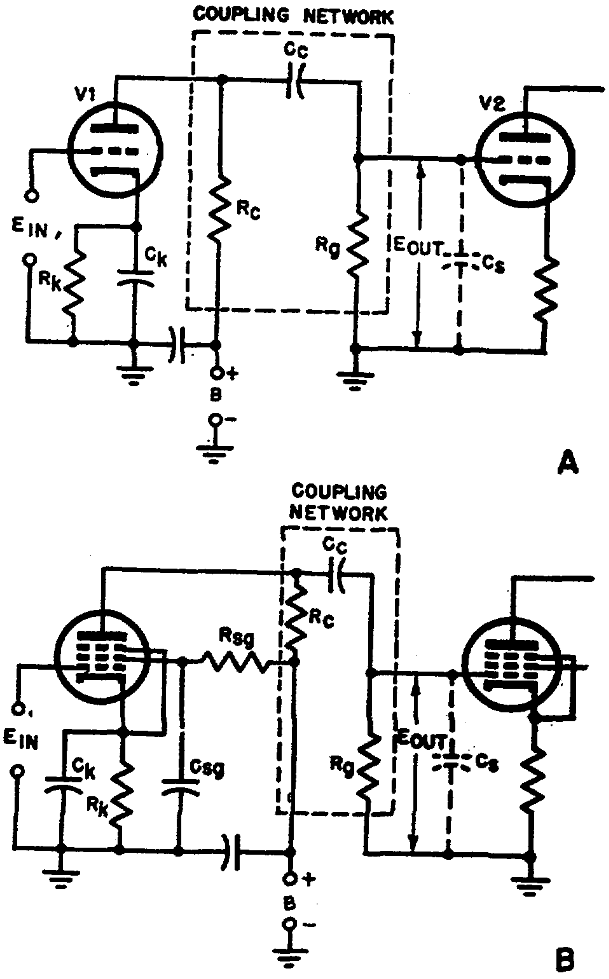

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Figure 126. Resistance capacitance coupling using triodes and pentodes.

The voltage gain of a resistance capacitance coupled amplifier, as determined by the formulas above, is correct for only the middle portion of the bandpass where the gain is considered to be fairly uniform or flat. The reduction in voltage gain begins to be noticeable when the frequency is higher or lower than two critical frequencies.

(*c*) The low-frequency response of a resistance capacitance-coupled amplifier, or simply a *resistance-coupled amplifier*, is determined mainly by the time constant consisting of C_c and R_g. The time constant of these components must be long as compared with the lowest audio input frequency to $V1$. To an extent, C_k also determines the low-frequency response. Its capacitive value must be large to obtain a very low reactance at the low frequencies. The larger the value of C_k, the better the low-frequency response. C_s (fig. 126) is one factor that determines the high-frequency response of a resistance-coupled amplifier. C_s is an imaginary capacitor existing from grid to ground of $V2$. This imaginary capacitor represents the input capacitance of tube $V2$ in figure 126, and has a value which is partly proportional to the voltage amplification of the tube. For triodes, C_s can become large, approximately 15 to 40 micromicrofarads, or even more in the case of high gain tubes. For tetrodes, largely because of the minute value of grid-to-plate capacitance (approximately .005 micromicrofarads) the input capacitance is much smaller than for a triode. It is still, however, appreciable, and may be approximately 5 to 10 micromicrofarads. C_s may be made effectively smaller in value so that it presents a higher reactance at the higher frequencies, thus improving the high-frequency response. This is accomplished by using tetrodes and pentodes (lower interelectrode capacitance) instead of triodes as the resistance-coupled amplifier tubes, making the connecting leads of the associated circuit components as short as possible, and by proper placement of circuit components on the amplifier chassis. Lowering the value of R_c also improves the high-frequency response, since it reduces the effects of C_s which is effectively in parallel with it. R_c cannot be made too small in value because the voltage gain of the resistance-coupled amplifier becomes very small. The selection of R_c as a load resistor depends on whether a greater voltage gain or a better frequency response is desired.

(2) *Transformer-coupled stages.*

(*a*) In figure 127, which shows a *transformer-coupled* amplifier, the plate of $V1$ is coupled to an inductive load, the primary of coupling transformer $T1$. The secondary of $T1$ is coupled to the grid of the following tube, $V2$. Coupling transformer $T1$ can have any desired degree of voltage step-up or step-down between its primary and secondary windings. Transformer coupling can be used between single-ended stages as shown, between a single-ended and a push-pull stage, or between two push-pull stages.

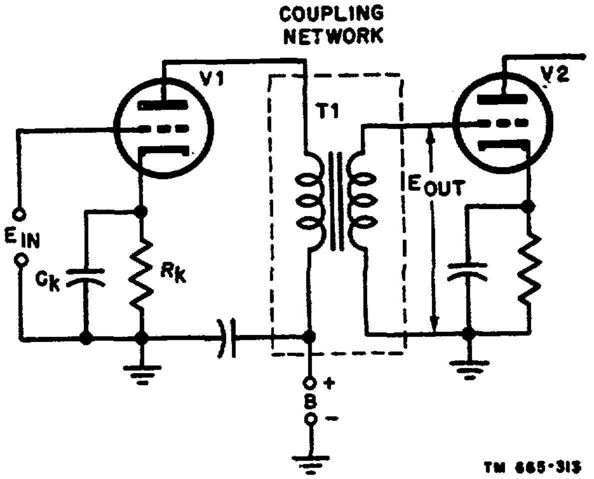

Figure 127. Transformer coupling using triodes.

(*b*) The voltage gain of a transformer-coupled stage in the middle portion of the amplifier bandpass is equal to E_{out}/E_{in}, which is equal to μN where μ is the amplification factor of $V1$ and N is the turns ratio of coupling transformer $T1$. As in resistance-coupled amplifiers, the circuit components cause a reduction in gain which becomes appreciable at the high and low frequencies. A transformer consists of resistance, capacitance, and inductance, the values of which affect the voltage gain of the transformer-coupled stage at all frequencies.

(*c*) The response characteristic of a resistance-coupled amplifier is usually more uniform over a wider frequency range than a transformer-coupled amplifier. As with the resistance-coupled amplifier, the response characteristic drops off rapidly as the frequency is decreased because the reactance of the primary inductance of $T1$ decreases with frequency. The result is a decrease in the output voltage gain. In the high-frequency range, the frequency response drops off also as the frequency is increased because the distributed capacitance between the winding of the secondary of $T1$ produces a low reactance path for the input signal frequencies. This results also in a decrease in the output voltage gain.

(*d*) Transformer coupling seldom is used when pentodes or tetrodes serve as the amplifier tubes, because it is extremely difficult to design a transformer which presents a high enough load impedance to the tetrode or pentode tube. The use of transformer coupling in pentode plate circuits generally results in poor gain and considerable reduction in low-frequency response.

(3) *Phase inverter* (fig. 128).

(*a*) Push-pull stages often are used in a speech amplifier. Such stages may be needed to supply adequate voltage to drive an a-f output stage; in addition, operation of tubes in push-pull reduces second harmonic distortion. The voltages applied to the push-pull grids must be equal in amplitude and 180° out of phase in respect to each other. The simplest method of obtaining equal voltages 180° out of phase is to use a coupling transformer having a split secondary winding. This method is efficient, but it is not always possible to get a transformer having the desired frequency response characteristics. The alternate method of developing the proper voltages for the push-pull grids is to use an electronic circuit called a *phase inverter.*

(*b*) In figure 128, A is a *cathode loaded* phase inverter. The load voltage is developed across two equal load resistors, R_{Lp} and R_{Lk}. Resistor R_{Lp} is placed in the plate circuit of $V1$ and feeds the grid of tube $V2$. Resistor R_{Lk} is placed in the cathode circuit of $V1$ and feeds the grid of tube $V3$. The voltages across R_{Lp} and R_{Lk} are equal in magnitude since R_{Lp} equals R_{Lk} and the same tube current flows through both of them. These voltages are 180° out of phase with each other because the plate load voltage is 180° out of phase with the grid voltage, and the cathode load voltage is in phase with the grid voltage. This is true since an increase in grid voltage increases the plate current. An increase in plate current decreases the plate voltage which decreases the voltage across the plate load resistor, R_{Lp}. The increase in plate current increases the voltage across the cathode load resistor, R_{Lk}. Consequently, as the voltage on the grid increases, the voltage across R_{Lp} decreases and the voltage across R_{Lk} increases. The voltage appearing at the grids of $V2$ and $V3$ are then 180° out of phase with each other. The a-f output consists of two voltages 180° out of phase with each other and of equal magnitude.

(*c*) In the *tapped output* phase inverter, in B, two tubes, $V1$ and $V2$, provide the proper phase inversion and amplification. $V1$ and $V2$ are identical triodes or separate halves of a dual triode. The output of $V1$ is fed to the grid of $V3$, and the output of $V2$ is fed to the grid of $V4$. The output voltage of $V1$ appears across resistors $R3$ and $R4$ in series which constitute the total grid-leak resistance of $V3$. This voltage is 180° out of phase with the input of $V1$. The grid of $V2$ is tapped onto the junction of $R3$ and $R4$; the voltage on the grid of $V2$ is therefore in phase with the voltage at the plate of $V1$, and the output voltage of $V2$ is 180° out of phase with the output of $V1$. Consequently, the voltages at the grids of $V3$ and $V4$ are 180° out of phase with each other. Proper values for the resistors used in this circuit enable the a-f output to have two voltages, equal in magnitude.

(*d*) Natural variations in the characteristics of tubes make it nearly impossible for two tubes to have identical characteristics. The *self-balancing* phase inverter, in C, is used to eliminate the need for precise values of

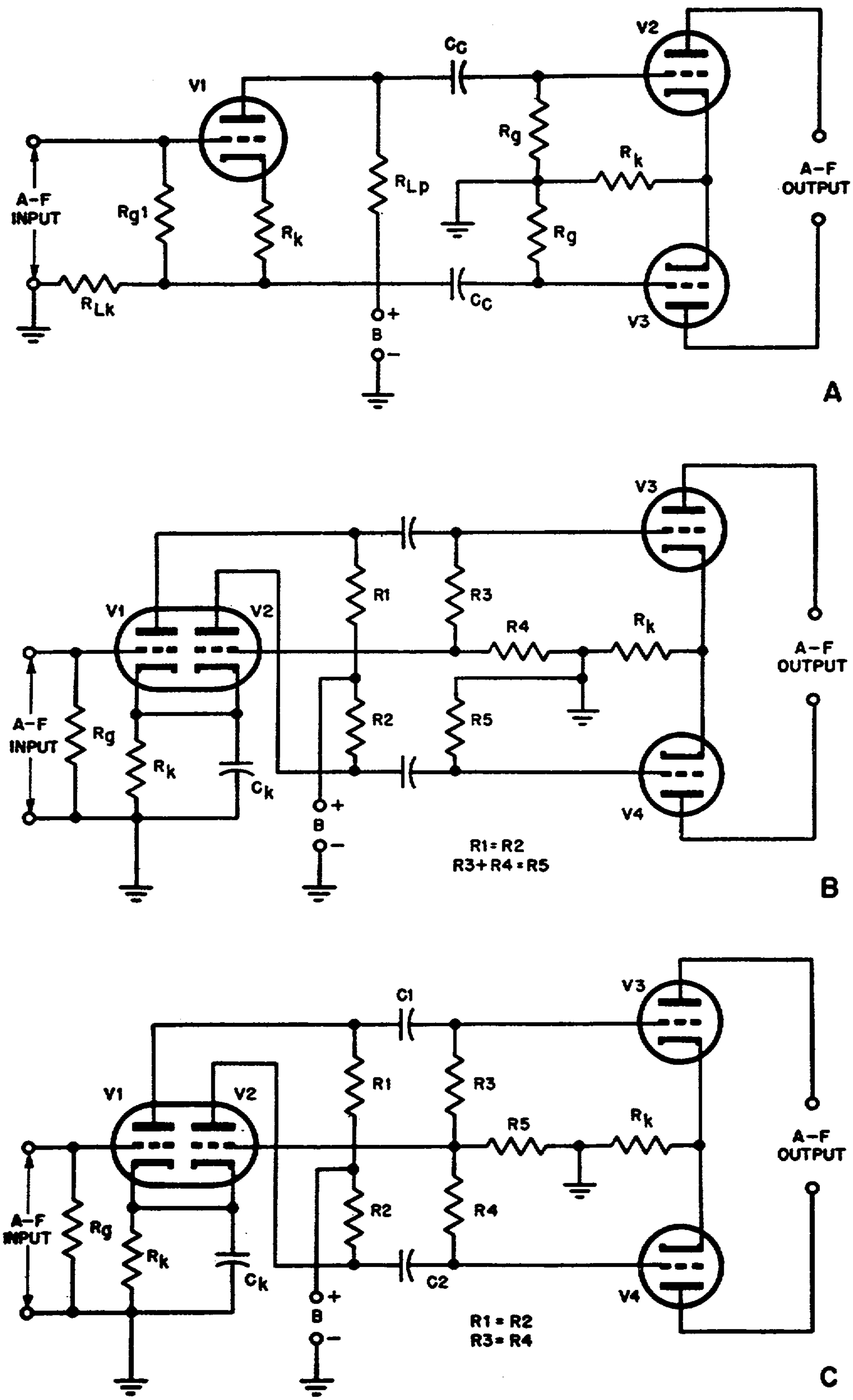

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Figure 128. Various types of phase inverter circuits.

components. The V1 output voltage appears across R3 and R5 in series. The voltage drop across R5 is applied to the grid of V2, and the output voltage of V2 appears across R4 and R5 in series. The voltage across R3 is 180° out of phase with the voltage across R4 for reasons explained in the preceding paragraph.

(*e*) The action of this circuit can best be understood by considering a typical set of values. Assume that the input to V1 is -1 volt and the output is $+10$ volts. For proper operation, the output of V2 should be -10 volts and the input to V2 should be $+1$ volt. This voltage is obtained in the folowing manner: The voltage divider of R3 and R5 is so designed that 20 percent of the V1 output voltage exists across R5. The voltage divider of R4 and R5 is so designed that 10 percent of the output voltage exists across R5. Consequently, if the V1 output voltage is $+10$ volts, the resultant voltage across R5 is $+2$ volts. However, since the V2 output voltage is -10 volts, there is also a -1 volt across R5, and the net voltage across R5 is $+1$ volt, which is the desired voltage. This grid voltage provides an output of -10 volts, and the circuit is balanced properly.

(*f*) Assume now that there is an instantaneous unbalance in the circuit. If the output of V1 is $+11$ volts instead of $+10$ volts, then the following occurs. The voltage across R5 caused by the increase in the V1 voltage increases by .2 volt and contains across it a net value of $+1.2$ volts. This increases plate current V2, so that its output voltage tends to decrease toward -10 volts. The circuit therefore tends to balance itself.

(*g*) In a similar manner, if the output of V2 increases instantaneously to -11 volts, the voltage across R5 decreases and the output voltage tends to decrease toward -10 volts again. Actually, there is usually a slight difference in voltage or unbalance between the two grids. However, this circuit tends to prevent the unbalancing from becoming too great.

e. Modulator Driver Requirements.

(1) Since the relationship between instantaneous grid voltage and grid current in class B modulators is not linear, the grids present a varying impedance to the driver over the a-f excitation cycle. To avoid distortion in the modulator caused by the change in grid impedance, the modulator driver must supply a constant voltage to the modulator grids, regardless of the change in grid impedance. When a modulator driver meets these requirements, it is said to have good *voltage regulation*. The fundamental factor in achieving good voltage regulation is a low internal resistance to be obtained in the modulator driver stage. This means that the modulator driver tubes must have a low value of plate impedance. Low-mu triodes best satisfy this condition. Pentodes and tetrodes are not as satisfactory for this service, but they may be used if sufficient *inverse feedback* is used to lower the effective plate impedance.

(2) In order to obtain maximum power transfer from driver to modulator, it is necessary to match the higher driver plate impedance to the relatively low modulator input impedance. This is done by means of a driver transformer having the highest possible voltage step-down between its primary and secondary. In this case, the plate resistance of the driver tubes, as seen by the modulator grids, is comparatively high. Conversely, the modulator grid impedance is low, as seen by the driver plates.

(3) As explained previously, variations in the instantaneous class B grid voltage and current are not linear, and this results in variations in input impedance and possible distortion in the modulating signal. If high-mu triodes are used as class B modulators, they can be operated with very little or no d-c biasing voltage on their grids. This reduces the variation in grid impedance over the audio-frequency cycle, and consequently gives the driver a more constant input impedance load. Distortion therefore is reduced.

Tubes operated in this manner often are called *zero bias* tubes.

(4) The driver transformer may couple the modulator driver plates directly to the modulator grids. It may also be designed to work into a low impedance line (usually 250 or 500 ohms) so that the speech amplifier may be located some distance from the modulator stage. In this case, the modulator grids are fed by a line-to-grid transformer designed for class B service.

f. Driver Circuits.

(1) The circuit shown in A of figure 129 is the usual single ended class A triode amplifier stage used as the modulator driver. Transformer coupling, *T*1, is used from the preceding speech amplifier stage, and transformer coupling, *T*2, is used similarly to couple the modulator driver to the following class B modulator. R_k is the normal cathode biasing resistor and C_k is the cathode bypass capacitor.

(2) The circuit in *B* is a push-pull driver fed by a tapped output phase inverter, *V*1 and *V*2. R_k and C_k are the cathode biasing resistor and cathode bypass capacitor, respectively. Other components function as explained in the description of the tapped output phase inverter.

(3) In some applications it is necessary to use pentode tubes, operating class AB as the modulator driver. Since the pentode normally has a high plate impedance, and since a low driver plate impedance is necessary, as explained previously, negative feedback or inverse feedback circuits are used, as in C. In this circuit, part of the plate voltage of each modulator driver stage is fed back to its grid through the voltage dividing networks, *R*1–*R*2 and *R*3–*R*4. *C*1 and *C*2 are d-c blocking capacitors. The feedback voltage is 180° out of phase with the voltage applied to the grids through the transformer secondary of *T*1. This, in effect, decreases the grid voltage and reduces the plate impedance of the modulator driver tubes. The percentage of feedback increases as *R*2, or *R*4, is made greater, since a greater voltage drop appears across it. As the percentage of feedback is increased, the impedance of the driver tubes is decreased. However, *V*1 must supply a higher signal voltage for a given output voltage. The percentage of feedback, therefore, cannot be made too large, as this would result in *V*1 being unable to supply the required voltage without distortion.

80. Modulator Stage

Triodes, pentodes, and beam power tubes are used in the modulator stage to provide the audio power necessary to modulate the r-f modulated amplifier. The modulator may use one tube, two or more tubes in parallel, two tubes in push-pull, or any even number of tubes in push-pull parallel. All classes of operation are used. Distortion, plate circuit efficiency, and power output are lowest for class A operation; both of these factors increase for class AB1, class AB2, and class B operation in that order. The type of circuit connection and class of operation depends on the required power output, permissible distortion, and on the plate voltage and current available from the power supply.

a. Class A Modulator.

(1) Class A modulators can be operated with comparatively low distortion. However, they also have a relatively low plate efficiency and consequently a low power output. For this reason, the output of a single tube class A modulator frequently is not great enough to modulate the r-f amplifier. To obtain increased power it is necessary to operate two, or more, of these tubes in parallel, push-pull, or parallel push-pull. In a parallel connected stage, both power output and d-c power input are increased.

(2) Power output in the class A modulator can be doubled, harmonics and hum caused by variations in plate supply voltage can be minimized or decidedly reduced, and the plate load resistance halved by connecting two tubes in push-pull. Distortion in a push-pull stage is considerably less than that for single tube operation. Appreciably more than twice the single tube output can be obtained by making the plate-to-plate load resistance approach the plate load resistance speci-

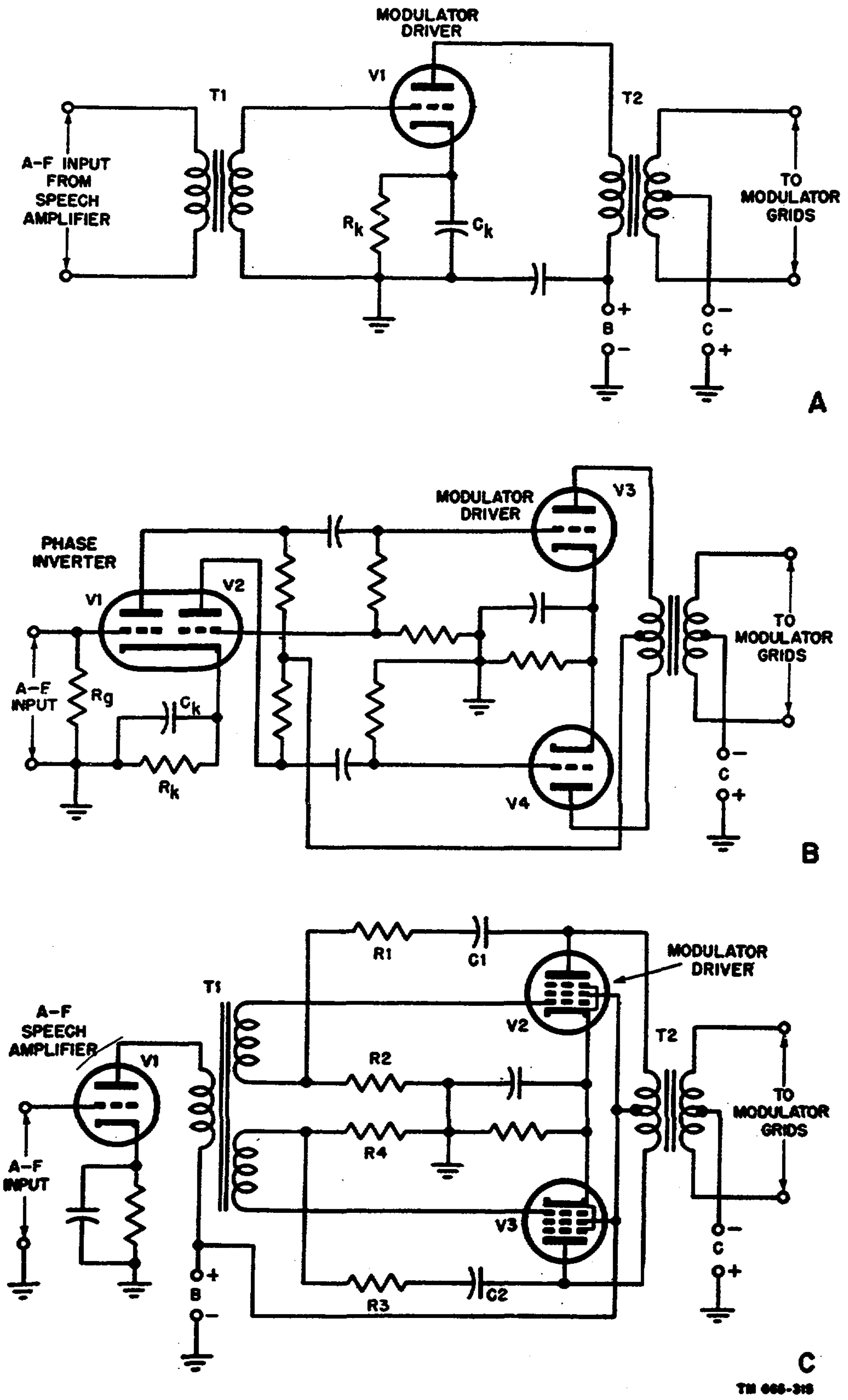

Figure 129. Various types of modulator driver circuits.

fied for a single tube. The grid bias for a push-pull class A modulator can vary from the value specified for a single tube to one-half the bias voltage which would produce plate-current cut-off at a plate voltage about 1.4 times the operating plate voltage. The peak-to-peak input signal voltage is twice that of the d-c bias voltage.

b. Class AB and Class B Modulators. Class AB and class B a-f amplifiers are always operated in push-pull to minimize distortion. In class AB1 operation, the bias voltage is about 40 percent greater than that for class A operation. The bias voltage is nearer the bottom of the straight portion of the i_p–e_g characteristic curve and therefore the power output, distortion, and efficiency are greater than for class A operation. The peak a-f grid voltage applied to each tube is slightly less than or equal to the d-c bias.

c. Class AB2 Operation. In class AB2 operation, the peak grid voltage applied to each tube is always greater than the grid bias. Grid current flows for more than one-half but considerably less than the full excitation cycle. The grid current flow represents a power loss which, when added to the loss in the driver transformer, equals the minimum power that must be supplied by the driver stage. Bias for a class AB2 stage must be supplied from a source having good regulation. The usual procedure is to use a separate well regulated bias supply. Tetrodes, pentodes, and beam power tubes generally are used in class AB2 modulators, because their higher power sensitivity makes it unnecessary to use a large modulator driver stage.

d. Class B Modulators.

(1) Class B audio amplifiers always are operated in push-pull. The tubes are biased so that the plate current is zero or almost zero when no a-f signal voltage is applied. Consequently, plate current flows in each tube for approximately one-half of each excitation cycle. Tetrodes operated with screen and control grids connected to each other (so that the tube operates as a triode) often are used as class B modulators. Tetrodes and beam power tubes operated in this manner have a high amplification factor because the grid potential acts on the electron stream over a considerable portion of the space between cathode and plate. The grid structure is such that grid current is not excessive, even when the grids are driven highly positive. Triodes having a high amplification factor or mu also are used as class B modulators. These triodes and tetrodes (connected as described above) require little or no bias. The high amplification factor results in low plate current, even with no bias.

(2) The bias voltage for class B modulators or a-f amplifiers must be obtained from a source having a low internal resistance. Batteries often are used when the bias voltage needed is relatively low. Unfortunately, the internal resistance of a battery increases with age, and it may become high enough to act as a grid-leak resistor so that the bias varies with the a-f excitation voltage. The changing bias produces distortion. Therefore, batteries should be replaced when excitation produces approximately a 10-percent change in bias voltage. If the bias is supplied from a separate power supply, the bleeder current should be at least 10 times the peak grid current.

(3) Class B modulators *must not* be operated without the specified load on the secondary of the modulation transformer. The plate voltage *must not* be applied until the modulated r-f stage is drawing the current which reflects the required load to the modulator plates. If the secondary is unloaded or operated with a load considerably lower than normal, the primary impedance rises abruptly and causes the a-f voltage across it to be excessive. This unusually high voltage is likely to break down the insulation and damage the modulation transformer. When testing a modulator alone, always load the secondary of the modulation transformer with a resistor equal to its output impedance and having a wattage rating equal to or greater than the power output of the modulator.

e. Modulator Circuits.

(1) When the modulator power requirements are low as in low power plate modulated transmitters or in higher-power grid, screen, suppressor, or cathode modulated transmitters, a class A modulator

can be used. The circuit of a class A modulator is the same as that of either of the class A drivers shown in A and B of figure 129. The grid of the modulator can be fed through an interstage transformer or resistance capacitance-coupling. The transformer in the plate circuit can be a modulation transformer or a plate-to-line transformer which matches the audio line to a second transformer which feeds the power into the modulated r-f amplifier load. Design factors for class A modulators are the same as those for class A drivers. The only difference is in the design of the coupling transformer in the plate circuit. A typical modulator chassis is shown in figure 130.

(2) The circuit of a class AB1 modulator is exactly like that of the class AB1 driver (C of fig. 129). Design factors are the same, and the only difference is that *T2* must be a modulation transformer instead of a driver transformer.

(3) The circuit of a class B modulator is similar to that of any other push-pull audio amplifier. It differs from other classes of amplifiers only in the selection of the driver and modulation transformers and in the values of operating bias and plate voltage.

81. Speech Compression and Clipping

a. General.

(1) In ordinary communications, when the operator speaks evenly at a uniform distance from the microphone, an average volume range of speech is established. If he shouts or deliberately accentuates certain words, syllables, or phrases, or changes his distance from the microphone, the volume range increases. If the transmitter is set for 100-percent modulation on volume peaks, the average percentage of modulation is low and the communication range of the transmitter is reduced.

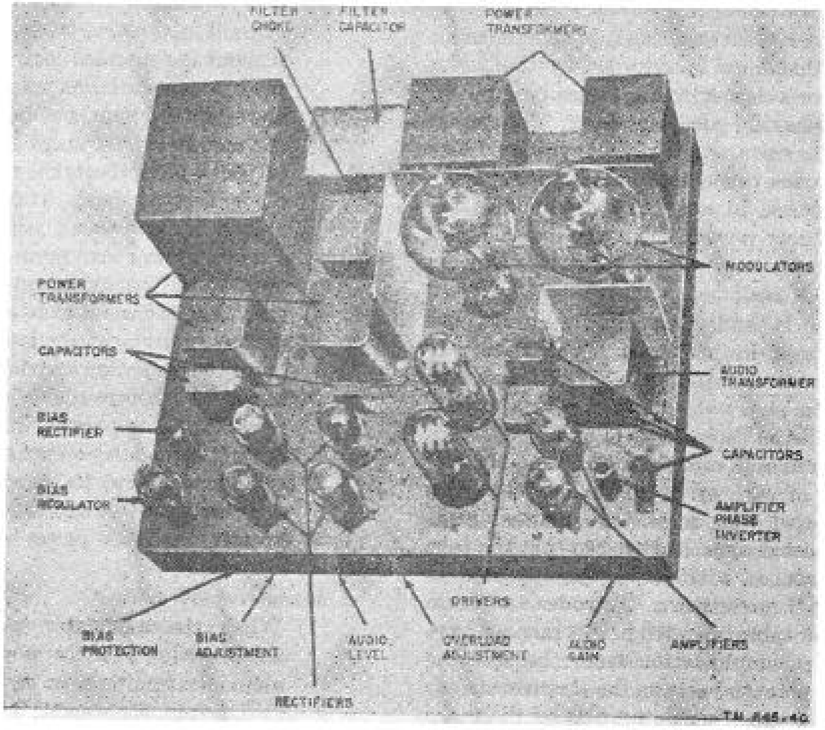

Figure 130. Typical modulator chassis.

(2) If the transmitter is adjusted for a higher average percentage of modulation, it is overmodulated on these volume peaks. The negative half of the modulation cycle is clipped because the plate of the modulated stage (when using plate modulation) is driven beyond tube cutoff. This clipping produces a modulated r-f wave which is high in harmonic content. The harmonics appear in the side bands and cause interference over a wide band of frequencies. A high average percentage of modulation with little or no danger of overmodulation is obtained through the use of *automatic modulation control* or *volume compression*. In this system, the gain of the a-f speech amplifier is constant until the input signal reaches a predetermined level. Above this point, the gain decreases rapidly as the signal voltage increases. A speech or volume compressor can be set so that the average modulation percentage is 80 to 90 percent, and volume peaks which are above the predetermined level are compressed to the point where they rarely exceed the level required for 100-percent modulation.

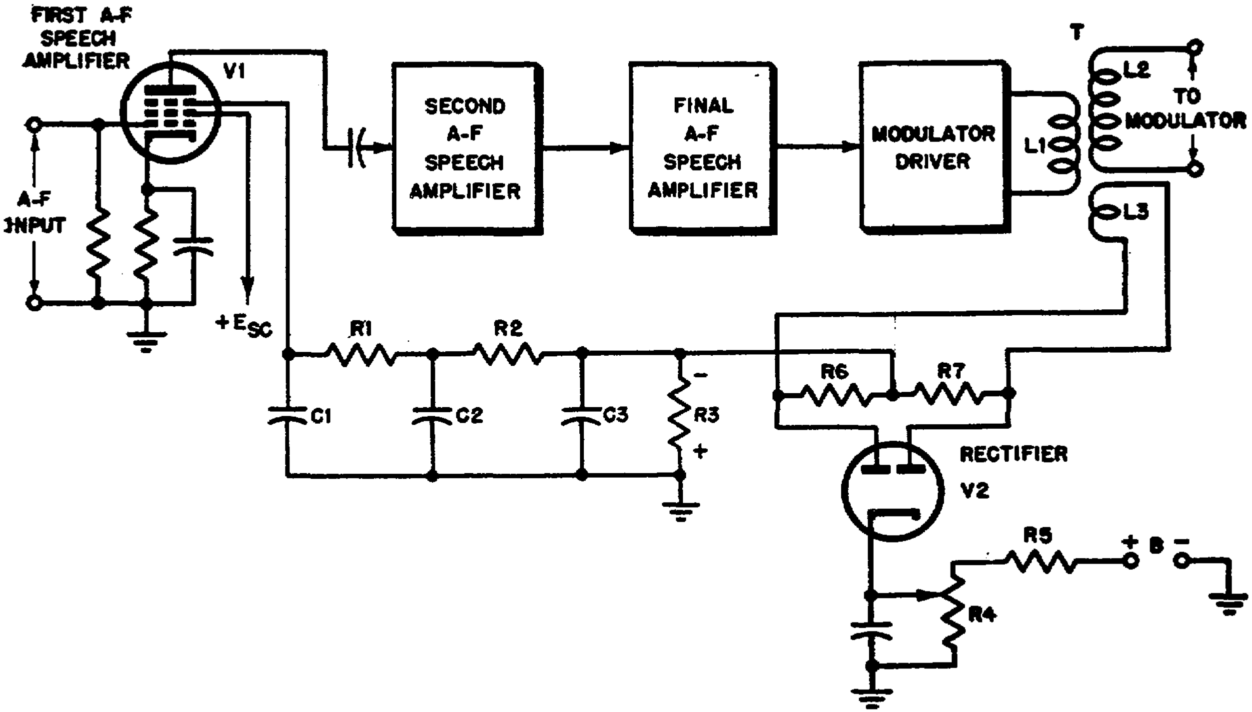

Figure 131. Volume compressor or automatic modulation control.

(3) *Speech clipping*, also called *speech limiting*, is a second method of obtaining a high percentage of modulation without overmodulating during volume peaks. This system clips or chops off the occasional high amplitude volume peaks so that their maximum amplitude is only equal to or slightly higher than that of the average voice peaks. Since the amplitude of the volume peaks determines the transmitter adjustments for 100-percent modulation, the gain of the speech amplifier can be increased until the average peaks produce nearly 100-percent modulation.

b. Volume Compressor Circuit.

(1) A basic volume compressor (fig. 131) consists of a rectifier which rectifies a portion of the voltage at the output of the modulator driver and develops a negative voltage which is used to bias the suppressor grid of the first a-f speech amplifier tube. A strong signal develops a large negative bias which reduces the

gain of the first a-f speech amplifier by making its suppressor grid more negative. The rectifier is biased so that it does not conduct until the input a-f signal reaches a level corresponding to 80- or 90-percent modulation.

(2) In the circuit illustrated, a portion of the a-f modulating voltage developed across the secondary winding, *L*3, of the driver transformer is applied to the plates of the full wave diode rectifier, *V*2. *V*2 conducts only during the positive half cycles of the a-f signal. The positive half cycles of a-f signal voltage are rectified to develop a negative voltage across *R*3, as shown. Since this resistor is in the suppressor grid return of the first a-f speech amplifier, *V*1, any negative voltage biases the suppressor and reduces the gain of *V*1. Consequently, positive peaks of a-f signal voltage which would ordinarily cause overmodulation are reduced in amplitude, preventing this condition. A positive voltage, called *advanced* or *delay bias*, is applied to the cathode of *V*2 through resistors *R*4 and *R*5, so that the tube does not conduct until the voltage on its plates is greater than that on its cathode. Consequently, if the delay bias is adjusted to equal the peak a-c voltage at the output of the modulator driver for 80-percent modulation, *V*2 will rectify and produce a biasing voltage whenever the signal exceeds this predetermined modulation level. The two 100,000-ohm resistors, *R*6 and *R*7, between the plates of *V*2 are used to balance the outputs from the separate halves of the rectifier. *R*1, *R*2, *C*1, *C*2, and *C*3 form a low pass filter which removes a-f variations from the output of the rectifier.

c. Speech Clipper Circuit (fig. 132).

(1) Speech clippers can be inserted between two stages in an a-f speech amplifier (*low level clipping*) as in A, or between the secondary of a modulation transformer and the B-plus line to the modulated r-f amplifier (*high level clipping*) as in B. A modulated waveform produced by a clipped wave looks much like that produced by overmodulation. It contains the same high order harmonics and wide side bands that cause interference to other stations. A *low pass filter* is used to reduce the harmonics. This usually is designed to pass only those frequencies needed for intelligible speech, and it attenuates or eliminates all others.

(2) In the low level speech clipper, in A, the clipper circuit, consisting of diodes *V*1 and *V*2 shunts the output of the second and the input of the third a-f amplifiers. *V*2 is so connected that it conducts on the positive half of the a-f signal voltage and *V*3 conducts on the negative half-cycles of a-f signal voltage. The diodes are biased by batteries BA1 and BA2 so that they do not conduct until the signal voltage exceeds the battery voltage. Consequently, if the bias voltages are made slightly more than the average value of the a-f peak signal voltage, *V*2 and *V*3 conduct and short circuit all higher than average peaks. The harmonics caused by clipping are removed by the low pass filter (shown in dotted lines) between the output of the third a-f amplifier and the following stage. Proper adjustment of the LEVEL CONTROL is an important factor in the operation of the low level clipper. This control must be set so that the transmitter cannot be overmodulated when speaking in a normal voice at a designated distance from the microphone.

(3) The high level clipper, in B, consists of a high voltage rectifier connected in series with the B-plus lead going to the modulated r-f amplifier. The rectifier tube is so connected that it conducts and supplies plate voltage to the modulated r-f amplifier at levels of modulation up to 100 percent. Above 100 percent, the negative modulated a-f peaks are greater than the d-c voltage; the rectifier therefore does not conduct and the d-c supply voltage on the modulated r-f amplifier drops to zero. This voltage cannot go in a negative direction as it would without the high level clipper. The function of the filter is the same as that shown in A.

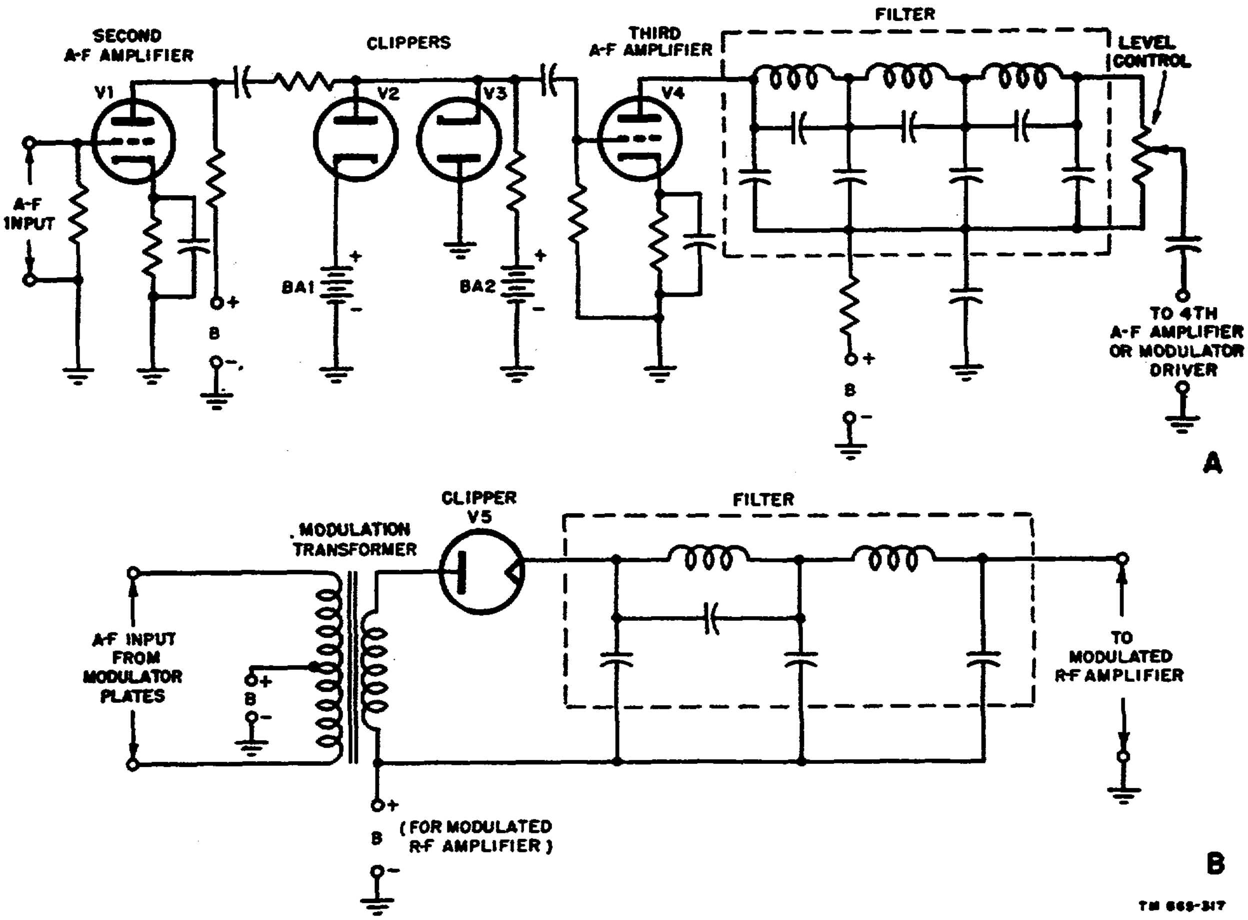

Figure 132. Low and high level speech clippers.

82. Tone Transmitters

a. When c-w telegraph signals are being received on a superheterodyne receiver, the unmodulated carrier is heterodyned with the output of a bfo (beat-frequency oscillator) in the receiver in order to obtain an audible beat. Under certain conditions, the transmitter or receiver, or both, may be so unstable as to cause the c-w signal to drift until the beat note between the carrier and bfo rises to the supersonic range. Under these conditions, copying may be difficult or contact may be lost. This trouble can be avoided by *tone transmission*—that is, by using a *tone modulated wave.*

b. In tone transmission, the carrier is modulated at a fixed audio rate between approximately 500 and 1,000 cps. A buzzer or an audio oscillator generally is used as the tone source. Since the tone source is constant, the modulation can be adjusted to exactly 100 percent. The tone source can be keyed simultaneously with the transmitter or it can be left in operation during the entire transmission. Tone modulation has a slightly greater effective range than voice transmission for the same transmitter output power. This is the case because static, interference, and weak signals may cause the loss of several words or phrases from voice transmission. The sharp keying of the tone modulated transmitter cuts through interference and is easier to copy under adverse conditions. The range of a tone modulated transmitter is less than that of a c-w transmitter of the same output power.

83. Low-Power-Modulated Radiotelephone-Telegraph Transmitter

a. R-F Circuits. A typical self-excited, low-power radiotelephone-telegraph transmitter is shown in figure 133. *V1* is a Hartley oscillator with *L1* and *C1* as its tank circuit. The plate section, A, of *L1* is connected between the plate and filament of *V*1 through *C*2, ground, and the center tap of the filament transformer, *T*5. The grid section, B, of *L*1 is connected between the grid and filament through *C*3, *C*2, ground, and the center tap on the secondary of *T*5. The circuit is biased by grid-leak resistor *R*5. *L*3 is an r-f choke which prevents r-f currents from entering the high voltage power supply and the keying circuits. The voltage developed across section C of *L*1 is applied to the grid of the r-f amplifier, *V*2. Interstage coupling capacitor *C*4 is tapped on *L*1 to minimize loading on the oscillator. The bias for *V*2 is developed by the total voltage drop across *R*1, *R*2, and *R*3 when code key *S* is closed, as shown. *L*4 serves as an r-f choke. Capacitors *C*5 and *C*11 bypass to ground any r-f currents which pass through r-f chokes *L*4 and *L*3, respectively. Variable capacitor *C*6 is the neutralizing capacitor for *V*2. Oscillation in the r-f amplifier can be prevented by adjusting *C*6 to cancel the out-of-phase voltages on the grids.

b. A-F Circuits. Sound waves striking the diaphragm of the microphone, *M*, cause audio-frequency currents to flow in the primary of *T*2 and induce an a-f voltage in its secondary. This voltage is applied to the grid of *V*3 which is the driver tube for class B modulator tubes *V*4 and *V*5. Bias voltages for the driver and modulator are taken from potentiometers *R*3 and *R*2, respectively. Note that these stages normally are biased by the voltage developed by grid current flow in the r-f amplifier, *V*2. The a-f plate current of the modulator tubes induces an a-f voltage in the secondary of the modulation transformer, *T*4. This induced a-f voltage is in series with the d-c plate voltage applied to the r-f modulated amplifier. Choke *L*5 and bypass capacitor *C*7 prevent the flow of r-f currents from the r-f modulated amplifier to the power supply. R-f transformer *T*1 consists of the r-f modulated amplifier tank coil and a coupling coil which goes to the antenna. Coupling between the coils is made variable to permit correct load matching between the r-f modulated amplifier and the antenna.

84. High-Power-Modulated Radiotelephone Transmitter

a. R-F Circuits.

(1) The r-f circuits in the transmitter shown in figure 134, are typical of those found in many military transmitters. The oscillator, *V*1, uses a modified electron-coupled circuit with *L*1 and *C*31 as its tuned circuit. R-f chokes *L*2, *L*3, and *L*4 prevent r-f currents in the grid and cathode circuits from entering the d-c power supply. Operating bias is provided by resistor *R*1. The transmitter is controlled by opening and closing key S in the cathode circuit of the oscillator. The r-f voltage on the oscillator plate is fed to the grid of buffer doubler *V*2 through capacitor *C*13.

(2) The current through *L*6 and *R*23 develops the *operating bias* voltage for this stage. Cathode resistor *R*24 develops sufficient *safety bias* to limit the buffer plate current to safe values with key *S* in the up position. *C*8 is the cathode bypass capacitor which prevents degeneration. Resistor *R*25 and capacitor *C*4 are the screen dropping resistor and bypass capacitor, respectively. Tank circuit *C*32 and *L*7 is tuned to the second harmonic of the oscillator. *C*26 is a plate bypass capacitor, *L*8 is an r-f choke, and *M*2 is the plate-current meter for the buffer doubler stage.

(3) *C*14 couples the output of *V*2 to the intermediate power amplifier consisting of two beam power tubes, *V*3 and *V*4, in parallel. The power amplifier stages can be operated as doublers or as straight amplifiers. The use of a beam power pentode eliminates the need for neutralization in these stages. *R*21 and *R*22 balance the grid excitation to the two tubes and minimize the possibility of parasitics. The output of this stage is fed to a power amplifier, *V*5, through *C*15. *C*18 is the neutralizing capacitor for the triode power amplifier. *T*4 and *C*12 comprise the tank circuit. The output of this stage is coupled from the secondary of *T*4 to the antenna. Bias for the intermediate amplifier and power amplifier stages is taken from the bias rectifier, *V*6. The power transformer is *T*1, *L*16 and *L*17 are the chokes, and *C*20 and *C*21 are the filter capacitors. The positive side of the supply (the rectifier filament) is grounded, and the voltage at the top of *R*11 is negative in

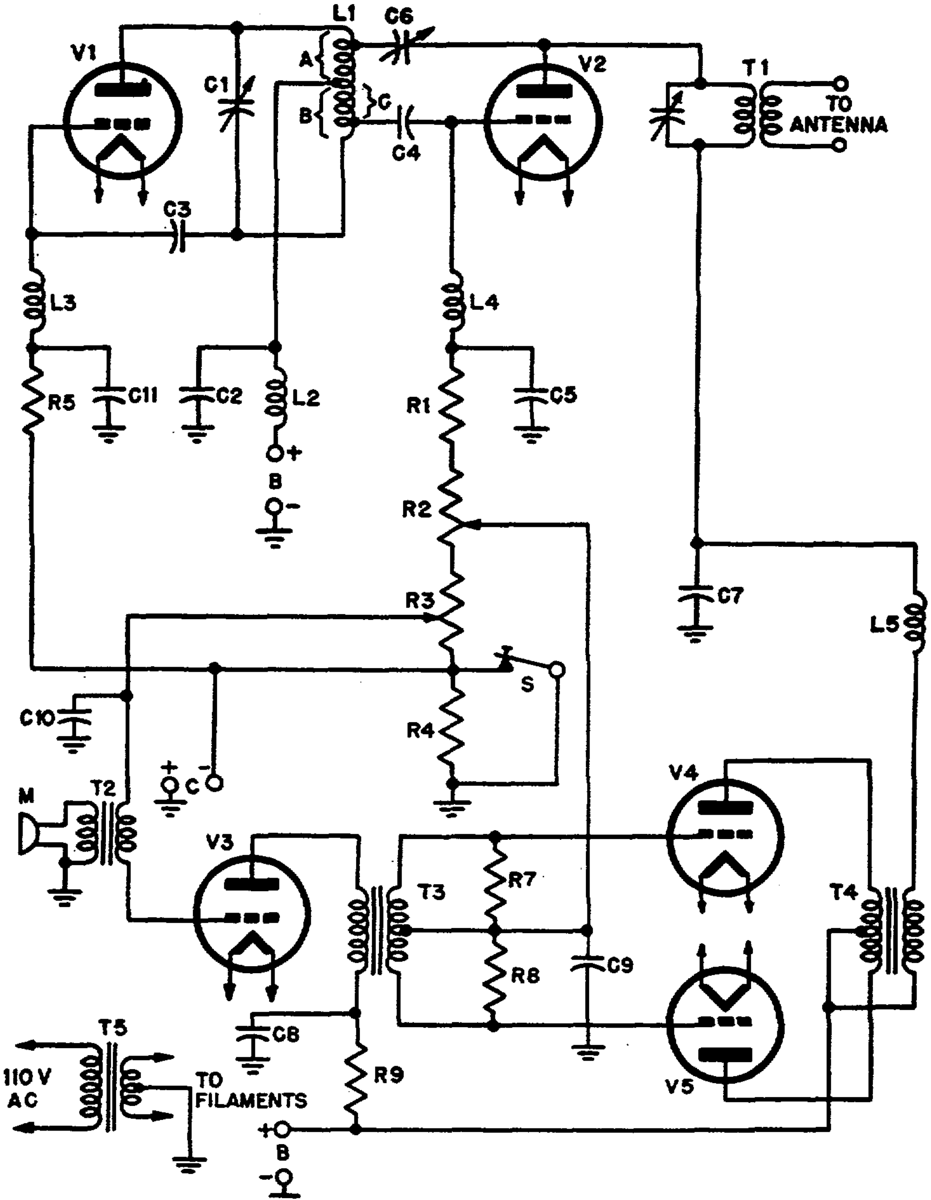

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Figure 133. Circuit of a low-power radiotelephone-telegraph transmitter.

respect to ground. The exciter rectifier supplies B plus to the oscillator. This circuit should be compared with that of the bias rectifier, *V*6.

b. A-F Circuits. The audio circuit is similar to the driver and modulator circuits described previously. The a-f speech amplifiers are coupled to the modulator driver, *V*11 and *V*12, through transformer *T*7. Fixed bias for the modulator driver stage (−60 volts) is developed across resistor *R*30 in the negative leg of the driver power supply. B plus for the modulator-driver stage (+300 volts) is developed across resistor *R*29. An example of a rectifier chassis for low-voltage and modulator voltage supply is shown in figure 135. *T*8 is the modulator driver transformer which couples the driver plates to the grids of the modulator stage, *V*13 and *V*14. Fixed bias for the modulator stage is obtained from potentiometer *R*12. *T*9 is the modulation transformer. Plate modulation is used for a high power output. Plate voltage for the modulator is applied

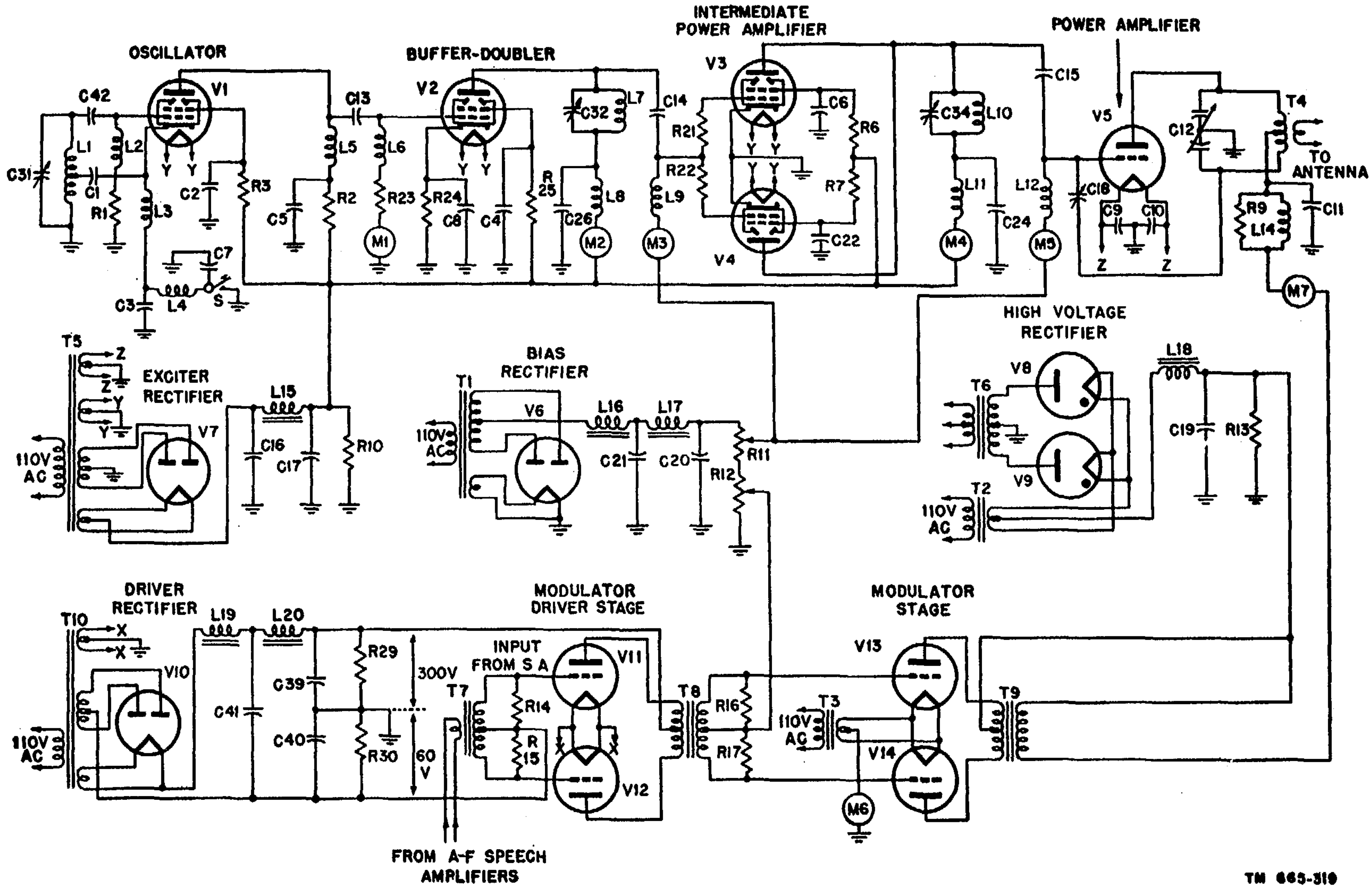

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Figure 134. Circuit of a high-power radiotelephone transmitter.

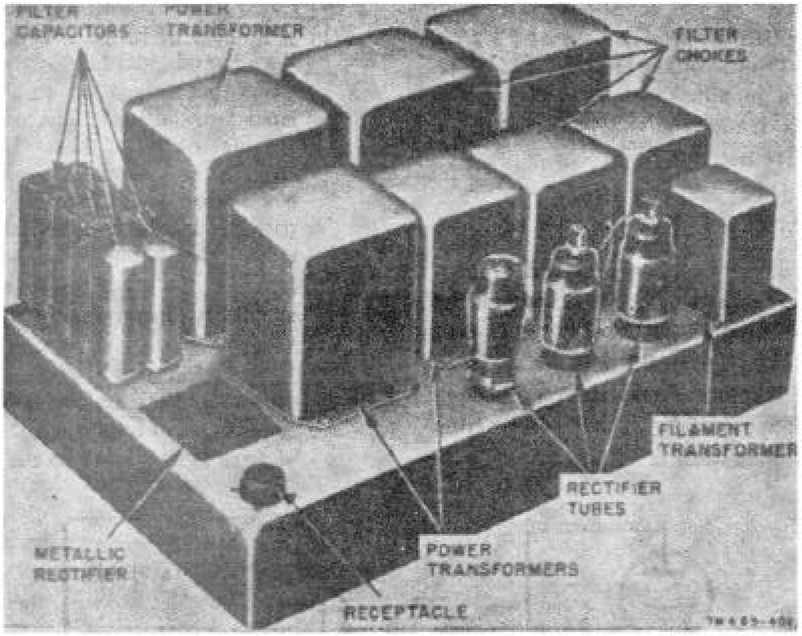

Figure 135. Transmitting type rectifier chassis for low-voltage and modulator-voltage supply.

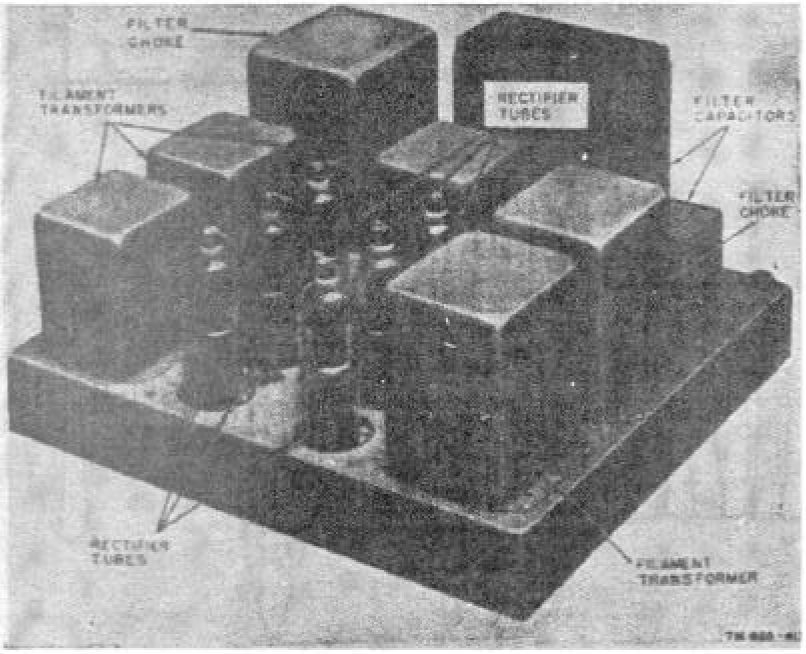

Figure 136. High-voltage chassis for transmitter.

to the primary of *T9* and voltage for the power amplifier is applied to the secondary of *T9* from *V8*. A typical high-voltage chassis for a transmitter is shown in figure 136. Meters M6 and M7 measure the modulator and power amplifier plate currents, respectively.

85. Modulation Indicators

a. General. If a transmitter is not fully modulated, the power in the side bands is low and the effective transmitting range is reduced. On the other hand, if the transmitter is overmodulated, the signal is distorted and may be broad enough to blanket stations operating on channels far from the offending transmitter.

b. Oscilloscope for Checking Modulation.

(1) A number of instruments have been designed or adapted for checking the modulation percentage of amplitude-modulated transmitters. The oscilloscope is the most useful of these. It is the most accurate and provides a picture of the modulation percentage. Two types of patterns can be observed on the oscilloscope. One is known as the *wave envelope* and the other the *trapezoid*. This manual is concerned only with the wave envelope type.

(2) Connections for wave envelope measurement (fig. 137) are the easiest to make. A testing coil consisting of a few turns of wire is connected to the vertical de-

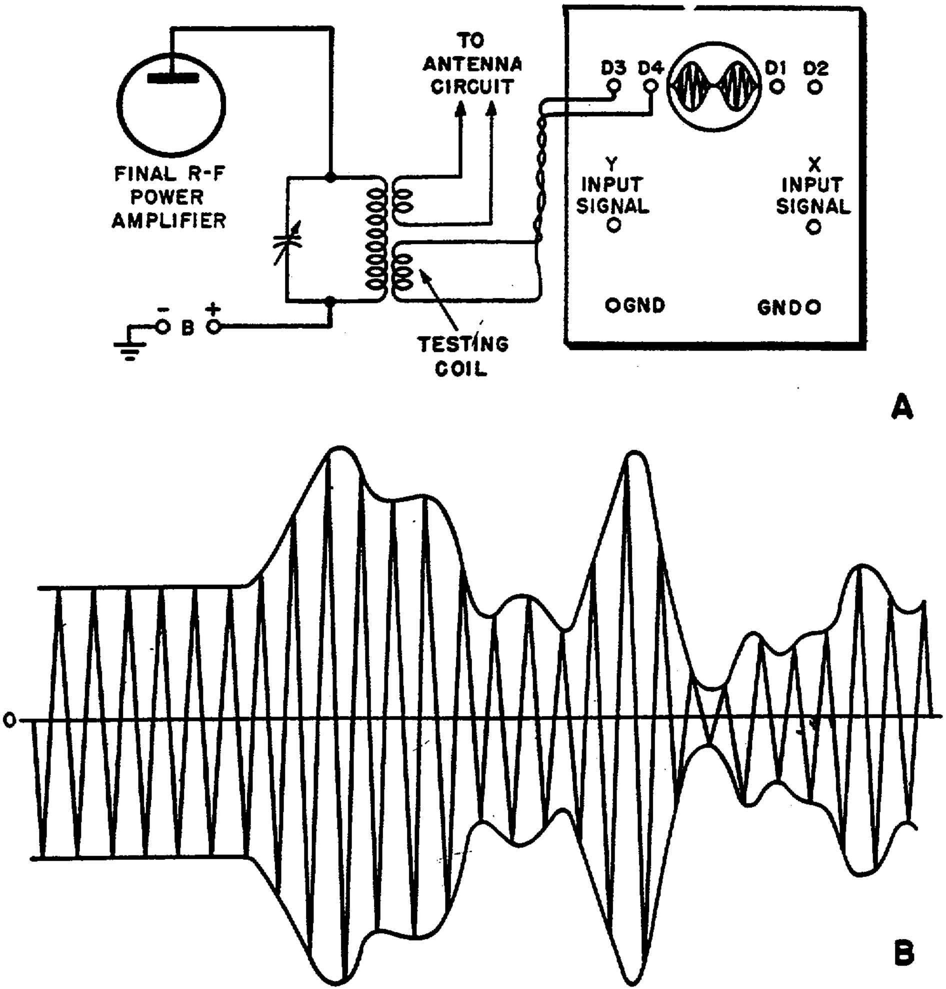

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Figure 137. Oscilloscope measurement of modulation percentage and waveshape

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