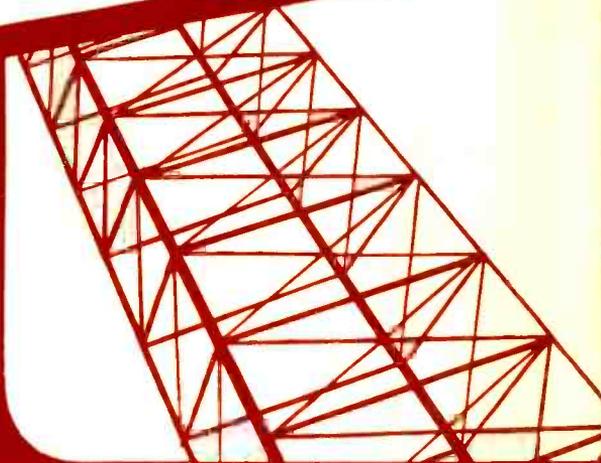




# AMPLITUDE MODULATION TRANSMITTERS

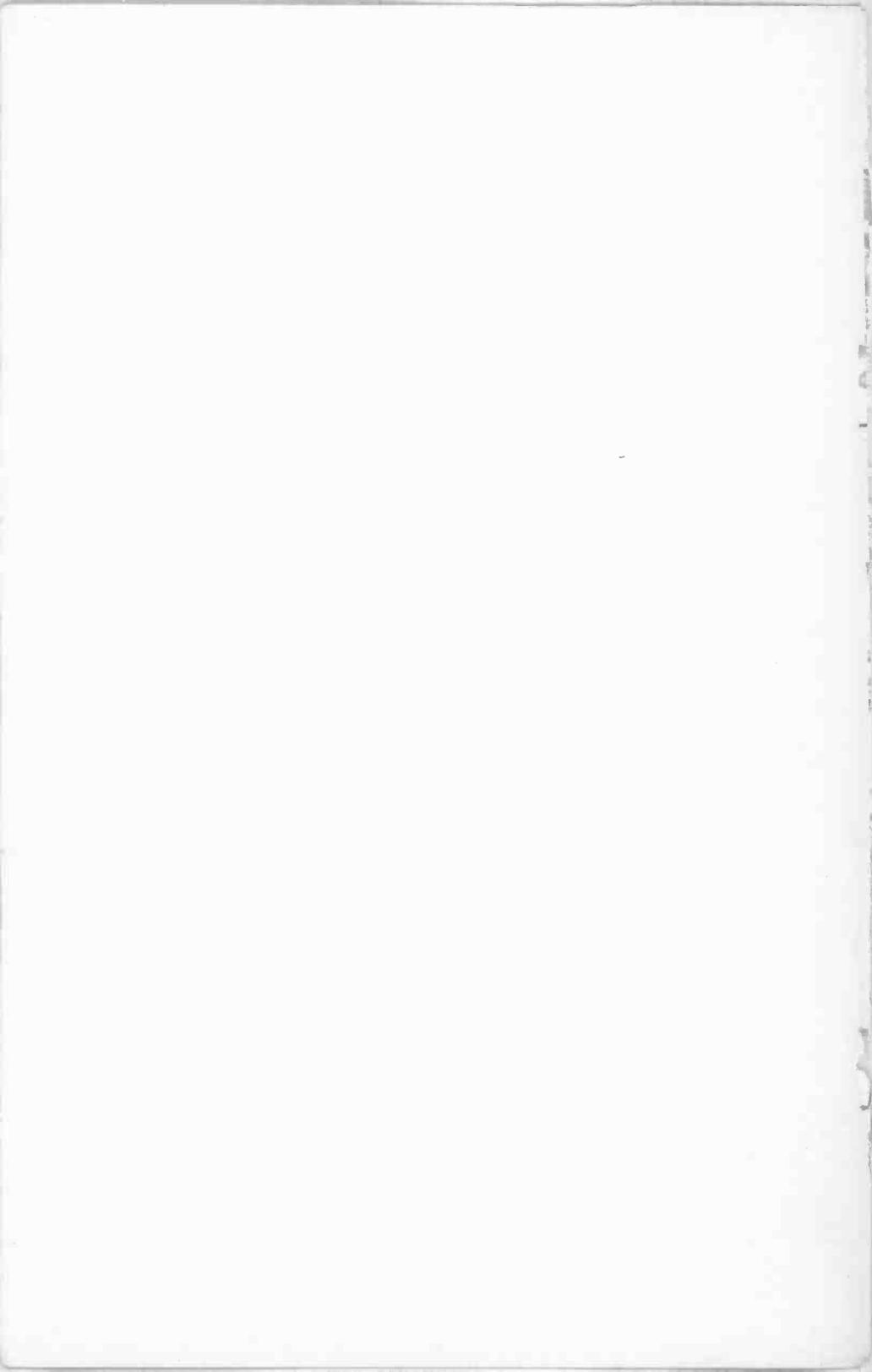
*Lesson* RRT-14



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RRT-14





## LESSON RRT-14

# AMPLITUDE MODULATION TRANSMITTERS

### CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

- 1924—RCA transmitted first photograph by radio from New York to London, where it was returned by radio and recorded at New York.
- 1924—Vladimer Zworykin developed a complete television system in the laboratory of the Westinghouse Electric Corporation, including the iconoscope or pickup tube, and the kinescope or receiving tube.
- 1925—The first international program was transmitted from Chelmsford, England, and picked up at Belfast, Maine, from where it was relayed by shortwave to New York and re-broadcast over Station WJZ.
- 1926—Picturegram of a check sent from London to New York by RCA radiophoto was honored and cashed in New York.

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# RADIO RECEPTION AND TRANSMISSION

## LESSON RRT-14

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#### THE DYNAMIC POWER OF THOUGHT

Thought is dynamic. The more we think constructively about our business, our desires and our ambitions — the more we concentrate on a task and think it out — the more certain will be our success. This is the law of which Henry Ford spoke as a universal law. It operates in varying degrees on every human psychology. All great achievements — all industrial and professional triumphs — have come first through the channel of the mind.

—Ediphone Voice Writing

# AMPLITUDE MODULATION TRANSMITTERS

## RADIO TRANSMITTERS

Radio is a system or method of communication and as such, must provide the transmission or exchange of information. Like the earlier telegraph and telephone systems, radio carries code and voice, which can be classed as audio signals. Also, by facsimile and television, it transmits pictures or images which can be classed as visual signals. Thus, in general, radio is employed for the almost instantaneous exchange of nearly all forms of information between all parts of the earth.

The popular radio broadcast system compares quite closely to a greatly expanded public address system because it provides one way communication only. The millions of home type receivers reproduce programs that originate in a few hundred broadcast stations, the signals of which are taken more or less for granted. In preceding lessons we have explained the construction and operation of receivers but, at this time, want to describe the circuits by means of which a radio frequency carrier is generated and then modulated by the various classes or types of signals.

The general layout of a complete radio transmitter or broad-

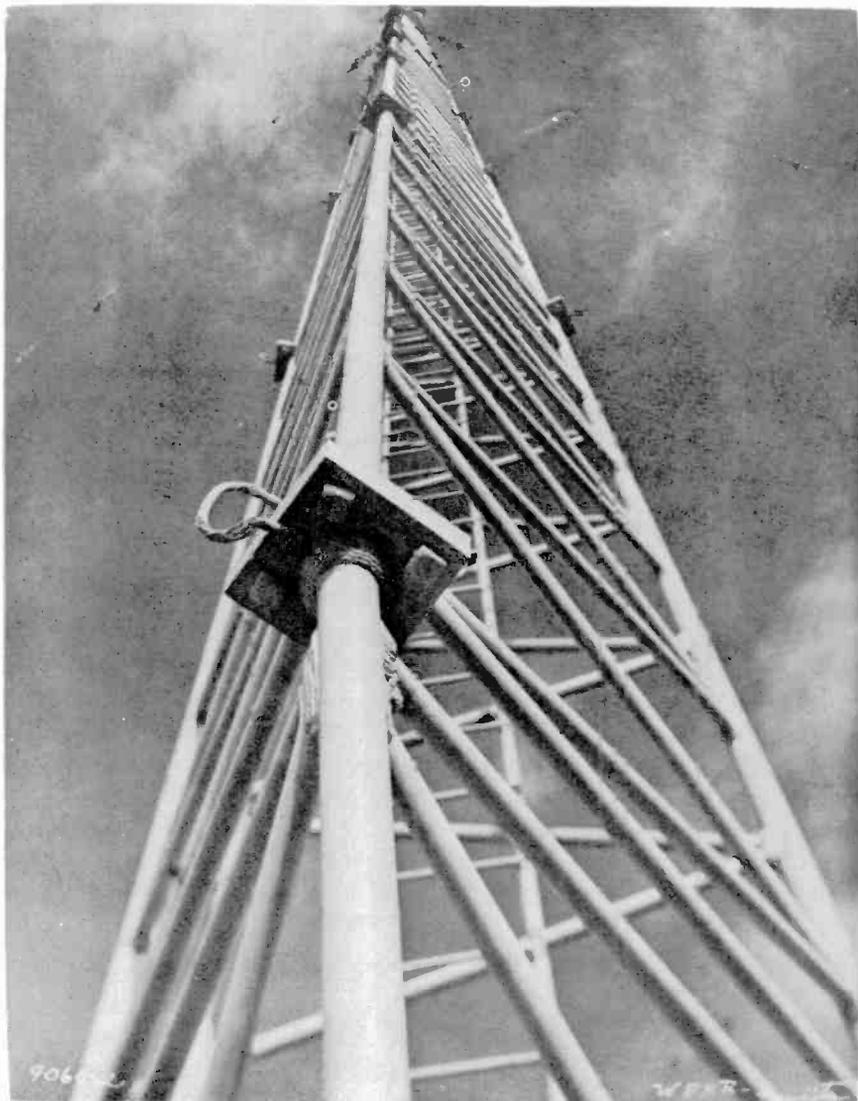
cast station is indicated by the simplified block diagram of Figure 1 which is arranged in three horizontal lines or levels. Starting at the upper left, the carrier frequency is generated by an r-f oscillator, usually of the temperature controlled crystal type. As the sole function of the oscillator is to generate a stable or constant frequency, it is operated at low power output.

To increase the carrier to the desired power level, the oscillator output is carried through a number of r-f amplifier stages all of which operate at the oscillator frequency. The power output of the final r-f stage is carried by a transmission line to the radiator or transmitting antenna. This part of the transmitter provides a constant frequency, constant amplitude carrier which is radiated into space. For radio-telegraph systems, the carrier can be interrupted according to the dots and dashes of the international morse code.

To transmit voice, music and other similar signals, the output of the r-f amplifier must vary in accordance with their frequencies which are carried by the middle line of blocks in Figure 1. In general, this line-up resembles a pub-

lic address system with its microphone and phonograph inputs at the left followed by a pre-

amplifier and mixer. As the oscillator output is amplified to comparatively high power levels, the



Worm's eye view of the ABC-WENR antenna located in Estes Park, Illinois.

Courtesy American Broadcasting Company

same plan is followed for the signal frequencies and the pre-amplifier output is carried through a speech amplifier and modulator.

Although named to describe their functions, the speech amplifier includes one or more stages of voltage amplification while the modulator provides the required output power. This output is connected to the final r-f stage, as shown by the solid arrowed line, or to a preceding r-f amplifier, as indicated by the broken line, in order to control or "modulate" the carrier.

Like other electron tube apparatus, the various "blocks" of Figure 1 require external power and, in most transmitters, the required power supplies are constructed as separate units, represented by the lower large rectangle. There are many variations in the constructional and electronic details of transmitter design but all of them function on this same general plan.

## OSCILLATORS

The complexity of the r-f generating portion of a transmitter depends upon the carrier frequency, the power to be transmitted, and the degree of stability desired. The simplest form of radio transmitter consists of an oscillator feeding an antenna directly, while a more complex unit contains a highly stable oscillator followed by several stages of r-f

amplification. These stages increase the power of the carrier, and also isolate the antenna so that changes in its circuit will not cause variations of oscillator frequency.

The operation of r-f electron tube oscillators was described in an earlier lesson therefore we will not repeat but suggest you review the subject if the details are not clear in your mind. The oscillators employed for the generation of the r-f carrier for conventional radio transmitters can be divided into the two general classes of 1: Self excited and 2: Crystal controlled.

The frequency of the self excited type of oscillator is controlled mainly by the tuning of its tank circuit and therefore it finds application in transmitters which are designed to operate over one or more bands of frequencies. However, it is subject to variations of frequency due to slight changes in its operating voltages, load, circuit constants and so on.

The frequency stability of the crystal controlled oscillator is superior to other types and, due to the stringent requirements of the FCC, it is employed in practically all commercial broadcast transmitters. Regardless of its type, in a transmitter the purpose of the oscillator is to generate and maintain the carrier frequency.

## R-F AMPLIFIERS

The subject of radio frequency amplifiers should not be new, because they are used in most of the receivers explained in the previous lessons. In receivers, these amplifiers increase the amplitude of the modulated carrier so that it will be of sufficient intensity to operate the demodulator, and no thought is given to the power output. In other words, their purpose is to increase the signal voltage and thus they are classed as voltage amplifiers.

In transmitters, the output of the oscillator stage must be kept to a low level in order to maintain stability and to avoid fracture of the control crystal. Here, the radio frequency amplifiers are used to increase the low power output of the oscillator to the required higher level for driving the antenna circuit, and accordingly, they are classed as power amplifiers.

In order to obtain a linear output with high amplification, the tubes used in the r-f and i-f sections of radio receivers are designed for an output of but a fraction of a watt, and are operated in class A. For the r-f amplifiers used in transmitters, however, the power output is rated in watts and kilowatts, and therefore, to obtain this power with good efficiency, the tubes are operated in class B or C. From

your previous study of audio amplifiers, you will remember that when a tube operates in class B, it is biased practically to plate current cut-off, and therefore plate current exists only during the positive alternations of the input signal. Thus, the tube action is similar to that of a half-wave rectifier and because of this effect, two push-pull connected tubes are required for class B audio amplifiers. For r-f work, however, a single-tube class B amplifier can be employed to amplify the carrier without appreciable distortion.

## CLASS B OPERATION

To explain this action, for Figure 2 we have drawn a typical r-f power amplifier stage which requires external plate (B) and grid (C) voltage supplies. A radio frequency choke,  $RFC_1$  is connected between the grid and the "C—" or grid bias voltage supply while the plate load consists of a parallel, tuned LC circuit. A second radio frequency choke,  $RFC_2$  is connected between the plate load and  $B+$  while the screen grid, bypassed to ground, obtains its supply voltage through a dropping resistor. The input voltage is impressed across the grid  $RFC_1$  choke, through a coupling condenser, and the output appears between ground and a tap on plate coil L.

When a stage of this type is in operation, the high negative grid bias allows plate current only in short pulses that do not have a sine wave form, even though the grid may be excited by a sine wave voltage. However, these current pulses store up a definite amount of energy in the form of a magnetic field around the plate tank coil  $L$ , and as the current drops back to zero, this energy discharges and is stored up in the form of an electric field in the tank condenser  $C$ . A constant interchange of energy thus occurs between  $L$  and  $C$ , on exactly the same order as was explained in a previous lesson in connection with the operation of an oscillator. As a result, a sinusoidal oscillating current is set up in the tank circuit. To maintain this oscillating current, the values of  $L$  or  $C$  are adjusted so that the resonant frequency of the tank circuit is the same or a harmonic of that at which the plate current pulses occur.

This action is frequently referred to as the fly wheel effect, in that it resembles the operation of the fly wheel on a gasoline engine. Part of the energy released during each explosion is stored in the fly wheel as kinetic energy, which is dissipated during the intervals between explosions, to maintain a more constant and uniform motion. The sinusoidal voltage built up across



High-power, radio-frequency amplifier tube.  
Courtesy Machlett Laboratories

the plate tank circuit constitutes the output of the amplifier stage, with the result that the input

voltage is amplified with a minimum of distortion.

In class B amplifiers, the grid is driven positive on high amplitude inputs and the resulting grid current introduces a power loss in the stage. As the peak plate current occurs at the instant of peak grid voltage, the power output will be determined largely by the amount the grid is driven positive. However, the grid current causes grid power dissipation in the form of heat, and therefore the maximum rated d-c grid current should not be exceeded under normal operating conditions.

Another limiting factor is that minimum plate voltage occurs at maximum positive grid voltage. To clarify this phase relationship, remember that the plate of the tube and its load are in series with the plate supply voltage. Thus, when the grid is driven positive, the plate current increases and causes a larger drop across the load, which in turn, reduces the voltage at the plate. Physically, the grid is closer to the cathode, and if the minimum plate voltage approaches the maximum positive grid voltage, the grid tends to capture electrons which normally would go to the plate. This action results in a distorted plate current waveform and overheating of the grid.

Operating as a power amplifier, the tube acts to convert the d-c

power available at the plate supply into a-c power in the plate tank circuit. The more efficiently this conversion is made, without objectionable distortion, the greater is its usefulness. This effect is called plate efficiency, and can be expressed as follows:

$$\% \text{ Efficiency} = \frac{P_o}{P_{i_a}} \times 100$$

When

$P_o$  = the a-c power output

$P_{i_a}$  = the d-c plate power input.

For example, assume a certain transmitting tube has a safe plate dissipation of 100 watts and a plate efficiency of 90%. 90% efficiency means that 10% of the d-c power input is dissipated as heat within the tube, and 90% is available for the useful a-c output. If the maximum plate dissipation of 100 watts constitutes 10% of the input, then the maximum d-c input, or 100% can be  $10 \times 100$  or 1000 watts. With 90% available as useful output, the tube can furnish 900 watts to the load.

However, if the same tube operates at a plate efficiency of 70%, the 100 watts plate dissipation will constitute 30% of the total d-c input. On this basis, the maximum d-c input can be  $10/3 \times 100$  or 333.3 watts with 70% or  $.7 \times 333.3 = 233.3$  watts available for the output. Notice that by reducing the efficiency from 90%

to 70%, the actual output has been reduced from 900 watts to 233.3 watts, about one-fourth of what it was, although in both cases, the plate dissipation is the same.

cycle of the input signal. The shorter the period per cycle of this plate current pulse, the lower the average value of current drawn from the power supply,



Transmitter room showing equipment and control desk.

Courtesy Station WMAQ in Chicago

### CLASS C OPERATION

For transmitters in which a fairly large excitation power is available and a high plate circuit efficiency is desired, the r-f amplifiers are operated in class C. As explained in an earlier lesson, a class C amplifier is biased beyond cut-off so that plate current exists for only about one-third of each

and the higher the efficiency of the stage. Under certain conditions, the efficiency of a class C stage can be as high as 85 per cent, with power gain values anywhere from 3 to 20. More distortion is produced than with class B, but due to the comparatively high efficiency obtained, class C operation is employed in transmitters whenever it is possible.

Within reasonable limits, the grid bias for class C operation can be of any value beyond plate current cutoff, but experience has shown that for amplifiers working with an unmodulated carrier, a negative bias of about twice cutoff is to be recommended. That is, if  $-30$  volts produces cutoff, the bias should be  $-60$  volts. However, for the stage in which modulation of the carrier takes place, a bias of approximately three times plate current cutoff is preferable.

Earlier in this lesson, we assumed the amplifiers were operating with fixed bias, but it is also possible to obtain self-bias by connecting a resistor in series with the grid circuit. Under these conditions, grid current in the resistor produces a voltage drop that biases the grid. The bad fault of this arrangement is that the grid bias varies with the input or exciting voltage, and if it reduces or drops to zero, the plate current may rise high enough to damage or completely ruin the tube. Therefore, it is considered good engineering practice to use a combination of fixed and self-bias with a value of fixed bias just large enough to hold the plate current to a safe value in case the excitation voltage fails.

### NEUTRALIZATION OF R-F AMPLIFIERS

In the former lesson on oscillators it was stated that a triode

tube can be made to oscillate because of the feedback through the grid-plate capacitance, and that some types of oscillators depend on this action for their operation. However, oscillation must not occur in amplifiers and therefore some means of overcoming the feedback voltage must be employed.

In receiving circuits, this is accomplished by using tetrode and pentode tubes with a small internal grid-plate capacitance, but as the use of triodes is common in the transmitting field, special circuits are employed to neutralize or cancel the feedback voltage.

In general, the effects of this undesirable feedback voltage are overcome by applying some of the radio frequency output voltage to the input circuit in such a way that it opposes the plate-to-grid feedback voltage. When this applied portion of the output voltage is  $180^\circ$  out of phase and of an amplitude equal to the grid-plate capacitance feedback voltage, the resultant voltage is zero and the amplifier stage is neutralized.

There are several methods by which this neutralizing voltage can be obtained, but in general they fall into two main classifications. When the neutralizing voltage is obtained from the plate circuit and fed back to the grid, the amplifier stage is plate-neutralized, and when the neutral-

izing voltage is obtained from the grid circuit and fed to the plate, the amplifier stage is grid-neutralized.

One form of a plate-neutralized stage is shown in the circuit of Figure 3, where the plate voltage is supplied to the tube through a center tap instead of at the lower end of the coil L. As a result, with respect to the tap the r-f voltages at the opposite ends of the coil are  $180^\circ$  out of phase with each other. Thus, voltages applied to the grid through the grid-plate capacitance of the tube from the upper end of coil L are  $180^\circ$  out of phase with those applied to the grid through  $C_3$  from the lower end of the coil.

This condition meets the phase requirements for neutralization, and all that remains is for the neutralizing voltage to equal the feedback voltage. For this purpose, condenser  $C_3$  is variable, and as it controls the amplitude of the neutralizing voltage, it is called a neutralizing condenser.

A method of plate neutralization for a push-pull stage is shown in Figure 4. Here the problem is quite simple, because in push-pull operation, the voltages on the opposite grids and plates are  $180^\circ$  out of phase. Therefore, it is necessary only for the plate of one tube to be coupled to the grid of the other through the neutralizing conden-

ser  $C_2$ , while the other plate and grid are coupled through the neutralizing condenser  $C_3$ . In actual operation, condensers  $C_2$  and  $C_3$  are adjusted until the neutralizing voltage equals that fed back by the grid-plate capacitance of the tubes.

In the circuit of Figure 5 we show a method of grid neutralization, and you will notice that the neutralizing circuits are very similar to those of Figure 3, except that they are in the grid circuit instead of the plate circuit. The voltages fed back through the grid-plate capacitance of the tube are applied to one end of coil L, while similar voltages are applied to the other end through condenser  $C_2$ . When these voltages are made equal by an adjustment of condenser  $C_2$ , their effects on coil L will cancel and the stage will be neutralized.

### SCREEN GRID R-F AMPLIFIER

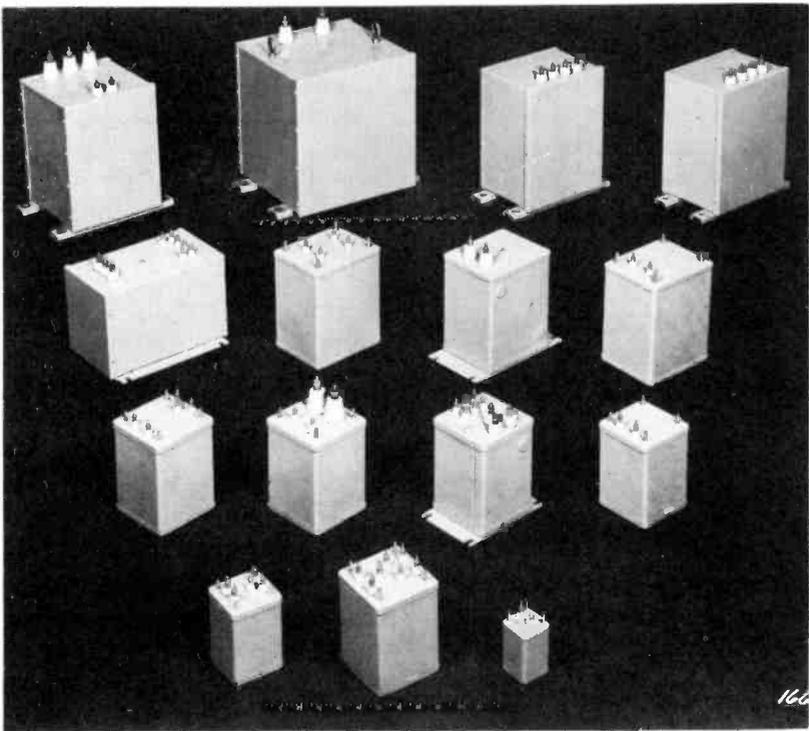
As indicated in Figure 2, tetrode or pentode type tubes can be used as r-f amplifiers in transmitter circuits. Compared to a triode, their grid-plate capacitance is very low and the screen grid acts also as a shield between them. Thus the feedback coupling, due to interelectrode coupling, is not sufficient to cause oscillation and, if the input and output circuits are well shielded, in most

cases no external neutralization is required.

### FREQUENCY MULTIPLIERS

In class C amplifier operation, the harmonic output increases as the duration of the plate current pulses is decreased. Due to this action, it is possible to tune the plate tank circuit to a harmonic

input frequency. When operating in this way, an r-f amplifier stage is called a Frequency Multiplier. With its output frequency equal to twice the fundamental or input frequency, an amplifier stage is known as a doubler, and when the output frequency is three times the fundamental, it is called a tripler, etc.



Group of high-voltage power transformers as used in the different sections of radio transmitters.

Courtesy New York Transformer Company

of the input frequency and obtain an output frequency which is a multiple of the fundamental or

In order to provide a frequency multiplier with a sufficiently strong harmonic output, usually

it is necessary to operate with a negative grid bias considerably higher than that required for straight class C amplification. Due to this higher grid bias, for good doubler efficiency the driving power should be at least two or three times as great as that required for efficient straight amplification. To keep the driving power requirement as low as possible, a tube with a high amplification factor and low bias voltage is recommended, while a tank circuit with a high L/C ratio should be used.

Almost any class C amplifier, with a single tube or several tubes in parallel, can be used as a frequency multiplier provided the driving power and grid bias requirements are met. Push-pull amplifiers, because of their cancellation of second harmonic voltages, cannot be used as doublers, but can be tuned to the third harmonic to operate as triplers.

The principal advantage of frequency multipliers is found in their application in short wave transmission where a less expensive, more stable, lower frequency crystal oscillator can be employed and the output frequency multiplied until the desired carrier frequency is reached.

## R-F COUPLING CIRCUITS

Like all the other multi-stage electronic units described in the

earlier lessons, a radio transmitter requires some method by means of which the signal energy can be carried over or coupled from one stage to the next. In general, these methods can be divided into the three main classifications: capacitive, inductive and link coupling. The link is really a form of inductive coupling, but on account of its individual arrangement and extensive use it is classed separately.

The requirements of an interstage r-f coupling unit are not many in number, but sometimes may prove a little difficult to meet. First, the unit must be capable of delivering the desired excitation from the driver tube to the following stage without overloading the driven grid circuit. Second, there must be no coupling between the interstage circuit and any other electrical networks because r-f feedback may cause the transmitter to be unstable. The third requirement is a low-impedance, high-frequency path from the grid to the cathode. If this is not provided, the circuit will have a tendency to favor parasitic oscillations, which cause erratic operation of the system and incur additional power losses.

With these general requirements of an r-f coupling device in mind, consider the simple type of capacitive coupling circuit of Figure 6 in which the plate of the

driver tube obtains its d-c energy through the coil of the LC tank, and is therefore known as a series fed arrangement. The r-f excitation is developed across the plate tank LC, which is coupled to the grid of the following tube through

condenser  $C_2$  and the RFC, while bypass condenser  $C_1$  provides a low-reactance r-f path to ground.

The first excitation requirement is quite easily met, because by varying the position of the tap



Typical air-cooled high-frequency power tube.

Courtesy Machlett Laboratories

on coil L, any portion of the full excitation can be applied to the grid of the following tube. The second requirement can also be met with this circuit, but there are several precautions which must be observed. In ordinary receivers and amplifiers, it is common practice to run ground wires to the most convenient point on the chassis. For r-f work with transmitters, this is not considered good practice as it may provide coupling between the ground returns of several stages and introduce regeneration and instability.

Instead, all ground leads of each stage should be run separately to a common ground connection which is placed so as to make the leads as short as possible. With this arrangement, all the ground leads are kept at the same r-f potential, and thus the tendency toward coupling is minimized. Also, as a further protection against coupling, the magnetic flux which is set up in the coils and other units should be kept in its proper circuit by means of suitable shielding.

A modification of the circuit of Figure 6, is shown in Figure 7 and by checking through the plate circuit here you will find a parallel feed arrangement, with the d-c plate voltage supplied through choke RFC<sub>1</sub> and the r-f voltage coupled to the tank cir-

cuit L-C<sub>1</sub>-C<sub>2</sub> through condenser C. From the junction between C<sub>1</sub> and C<sub>2</sub> the signal is coupled to the grid of the following tube through C<sub>3</sub> and RFC<sub>2</sub>. Notice also that condenser C blocks the d-c plate potential and condenser C<sub>3</sub> serves as a coupling unit, consequently there is no d-c potential applied to the tuning condensers.

A circuit of this type meets all three of the above requirements, and the excitation applied to the grid can be varied by changing the relative capacitances of C<sub>1</sub> and C<sub>2</sub>. Also, there will always be a low-impedance r-f path to ground through C<sub>3</sub> and C<sub>2</sub>. Of course, the precautions for grounding and shielding explained for Figure 6 must be observed here also.

Figure 8 illustrates a driver stage feeding a pair of tubes connected in push-pull. The driver plate circuit is shunt-fed, as d-c energy is applied through RFC<sub>1</sub>, and the r-f voltage is coupled to the plate tank L-C<sub>1</sub> through condenser C, much the same as the parallel-feed arrangement of Figure 7. Here however, coil L is coupled inductively to L<sub>1</sub>, which is tuned by condensers C<sub>2</sub> and C<sub>3</sub>, and the voltage drop across it is applied to the grids of the push-pull connected tubes.

Neglecting the tuning condensers, C<sub>1</sub>, C<sub>2</sub> and C<sub>3</sub>, the circuit is very similar to that of the ordi-

nary push-pull input stage of an audio amplifier, and the action also is about the same. The voltages at the opposite ends of coil  $L_1$  are  $180^\circ$  out of phase with respect to the center tap, and thus the voltages on the push-pull grids are in their proper relation to each other. However, with the tuning condensers  $C_2$  and  $C_3$  in place, their capacitances must be equal in order to maintain the necessary balanced condition of the circuit. Compared to the circuits of Figures 6 and 7, where the signal energy is carried over or coupled by means of capacitance, here in Figure 8, coils  $L$  and  $L_1$  are placed to provide an inductive coupling. As the signal is carried over by this arrangement, we say the circuit is Inductively Coupled.

In an inductive circuit of this kind, the excitation voltage applied to the grids is controlled by varying the coupling between the two tank coils. In Figure 8 this variable coupling is indicated by the slanting arrow drawn through coils  $L$  and  $L_1$ . Notice also, that this circuit will meet the three requirements listed earlier in this lesson, provided the precaution regarding shielding is properly observed. Inductive coupling provides for a smooth adjustment of excitation voltage and generally is preferable to capacitive coupling. The main disadvantage of this form of cou-

pling is the mechanical difficulty in arranging some means to vary the coupling between the tank coils.

By using a transmission line to transfer the energy from the plate tank to the grid tank circuit, the advantages of inductive coupling with separately tuned circuits can be retained without the necessity of direct inductive coupling between the two tank coils. An arrangement of this kind, commonly called a link-coupled circuit, is shown in Figure 9 with a push-pull driver stage exciting the grids of two output tubes also connected in push-pull. Here the plate voltage for the driver is supplied through the RFC<sub>1</sub> to the center tap of coil  $L$ , which is tuned by condensers  $C$  and  $C_1$ . The r-f voltage across  $L$  is transferred inductively to coil  $L_1$ , which is connected directly to coil  $L_2$ . As coil  $L_2$  is inductively coupled to coil  $L_3$ , which is tuned by condensers  $C_2$  and  $C_3$ , the signal energy is transferred to the grids of the following two tubes.

The inductances  $L_1$  and  $L_2$ , commonly called links, usually consist of one or two turn coils connected together by a twisted pair of leads. The assembly results in a fairly low-impedance line which may be of any convenient length, from several inches to a few feet, without an

appreciable loss of power in the transfer. With this type of coupling, the proper excitation voltage can be secured by changing the position of either coupling coil with respect to its tank circuit, or by changing the number of link coil turns.

### TRANSMITTER KEYING

Figures 2 to 9 inclusive illustrate the circuits used in the r-f amplifier and final r-f stage blocks of Figure 1. Their purpose is to amplify the high frequency output of the oscillator until the desired power level is obtained. However, this r-f energy has little practical application, as far as the transmission of intelligence is concerned, unless some method of control is employed. In general, any means of controlling the r-f carrier for the transmission of intelligence is known as modulation.

One of the first methods of conveying a message through space was by interrupting the generation of the continuous carrier. Today this method is called Keying, and is used in all telegraph or continuous wave (c-w), radio transmission. There are many ways by which keying can be accomplished, and in Figure 10 we show a simple system incorporated in the final stage of a transmitter. The input circuits consist of tank LC, coupling con-

denser  $C_1$ , and the bias resistor  $R_1$ . In the plate circuit, tank  $L_1-C_2$  is inductively coupled to the antenna coil  $L_2$ , while the key is connected between cathode and ground, placing it in series with both the grid and plate circuits.

In operation, the key is really nothing but a single-pole, single-throw switch which, when closed, allows the stage to operate continuously and transmit power to the antenna. However, if the key is open as shown, the plate circuit will be broken, there will be no plate current in the tank  $L_1-C_2$ , and thus no power to the antenna. Of course, this is strictly true only when the stage is properly neutralized, but for simplicity we will assume this has been done.

Thus, by closing and opening the key in the circuit of Figure 10, it is possible to interrupt the carrier; and if this is done according to some prearranged code, an intelligible message can be transmitted. Although the circuit of Figure 10 is satisfactory for the transmission of code, it simply interrupts the carrier and thus is not suitable for the transmission of speech and music.

Audio frequencies, and low frequencies in general, cannot be transmitted efficiently through space, and consequently radio telephone communication is carried on by employing a series of uniform high-frequency waves

and loading or superimposing the audio signal voltages on the higher frequency as a carrier.

This mixing process can be arranged so that either the amplitude or the frequency of the carrier waves can be varied according to the audio signal. The first system is known as Amplitude Modulation (abbreviated a-m), and is employed by all standard broadcast stations. The second is known as frequency modulation (abbreviated f-m), and is being adopted rapidly by many broadcast stations. The sound broadcasts accompanying television programs all are frequency modulated. For the remainder of this lesson, we will take up the subject of amplitude modulation and then continue with frequency modulation in the following lesson.

## SIDEBANDS

Amplitude modulation can be defined as the process of causing the amplitude of a constant frequency r-f carrier to vary in accordance with the frequency and amplitude of the audio signals that are to be transmitted. At the same time that this modulating process occurs, two new frequencies are formed. One of these consists of the carrier plus the signal frequency, while the other consists of the carrier minus the signal frequency. The

former is known as the upper sideband and the latter as the lower sideband.

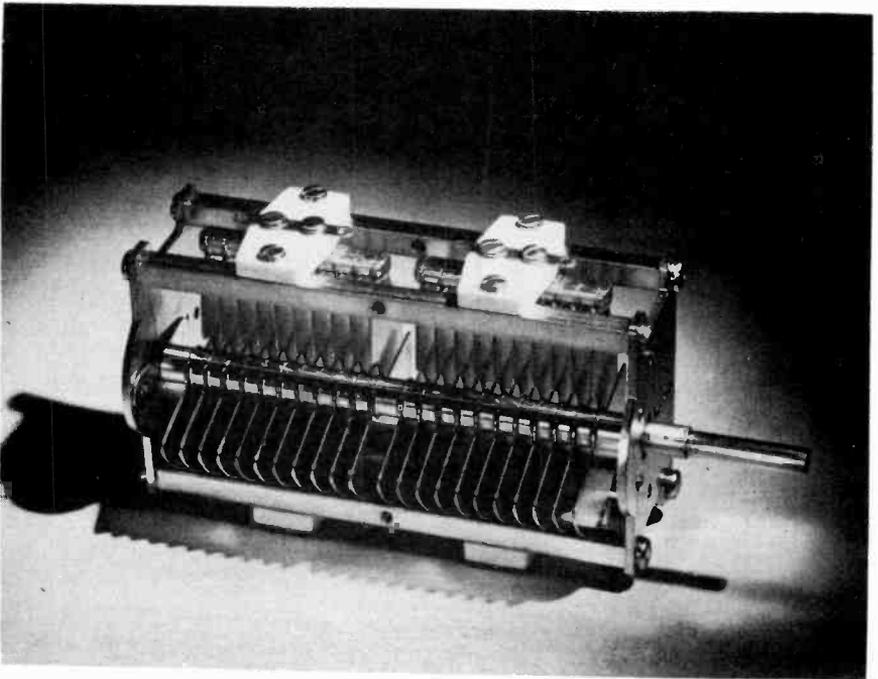
For example, if a 1000 kc carrier is amplitude modulated by a pure tone of 3000 cps (3 kc), two new sideband frequencies will be formed: one at 1003 kc or the sum frequency, and the other at 997 kc or the difference frequency. The frequency of each sideband is determined only by the respective frequencies of the carrier and the modulation, and is independent of their amplitudes, providing however, that the amplitude of the modulating a-f signal is not so great as to cause distortion during the modulation process.

Actually, the amplitude of the carrier remains constant during and after modulation; but the total r-f voltage, representing the composite signal and known as the envelope, will vary in accordance with the frequency and amplitude of the modulating audio signal. Also, as long as the amplitude of the modulating voltage does not vary, the amplitude of the sidebands will be constant.

When the modulating signal consists of a band or extended range of frequencies, as in the case of speech or music, two new sidebands will be formed, one above and one below the carrier, for each group of modulating frequencies. As a result, the

radiated signal will be very complex and will consist of two bands of frequencies, one the sum and the other the difference of the carrier and modulation frequencies.

per station is 10 kc. Thus, the highest modulation frequency that can be employed is 5000 cycles, which will cause the radiated signal to occupy a band extending from 5 kc below to 5



Variable tuning condenser as used in radio transmitter systems.

Courtesy Hammarlund Manufacturing Company

The total bandwidth, or frequency spectrum space required by the amplitude modulated signal, is equal to twice the highest modulating frequency. For example, in the standard broadcast band the total bandwidth allowed

kc above the carrier. For good speech intelligibility, the transmitted audio frequencies need be only as high as 3000 cycles therefore, for voice only, the radio telephone signal can be limited to a total bandwidth of 6 kc.

**MODULATION PERCENTAGE**

The process of modulation consists of combining an r-f carrier with a lower frequency audio signal and is represented graphically by combining two curves. For example, curve A of Figure 11 represents a uniform amplitude, constant frequency carrier while curve B represents a lower frequency audio signal. Combining both frequencies so that signal controls the amplitude of the carrier, produces curve C which represents the waveform of the modulated envelope.

The amplitude of the carrier is shown as B while that of the signal is shown as A and for simplicity, they have been drawn of equal value. When these two equal amplitude frequencies are combined, the resulting wave has the form of curve C, the amplitude of which varies, according to the signal, from twice the normal carrier amplitude to zero.

The ratio of these two amplitudes is expressed usually as the percentage of modulation and is given by the general formula—

$$M = \frac{A}{B} \times 100$$

When

M = percentage of modulation

A = peak modulating voltage

B = peak unmodulated carrier voltage

For the conditions indicated by curve C, with A and B equal,

$$M = \frac{1}{1} \times 100 = 100\%$$

When the modulation voltage is lower than that of the carrier, the resulting waveform or envelope is illustrated by curve D. For example, if A equals  $\frac{1}{2}$  B or B = 2A,

$$M = \frac{1}{2} \times 100 = 50\%$$

and the carrier is 50% modulated. Therefore, depending on the ratio, the percentage of modulation can vary from 100% to zero. However, it is possible for the modulation voltage to exceed that of the carrier to produce the waveform of curve E. This is known as overmodulation and as the peaks of the carrier cycles do not follow the modulation waveform exactly, the signal is distorted. Also, overmodulation produces unwanted frequencies which cause interference with carriers of adjacent channels.

Over a complete modulation cycle, the average r-f voltage of the modulated wave is the same as for the unmodulated carrier, however, the average power increases with modulation. With 100 per cent modulation, the average r-f radiated power increases by 50 per cent and as the carrier component power does not vary during modulation, this ad-

ditional power is represented by the sidebands.

Since it is through the medium of these sidebands that intelligence is transmitted, the greater the percentage of modulation, the higher the average amplitude of the sidebands and, other conditions remaining the same, the greater the audio signal reproduced at the receiver. However, as mentioned previously, because of the resulting distortion and interference, the percentage of modulation should never exceed 100%.

### AMPLITUDE MODULATION METHODS

Most of the many different methods for amplitude modulation of a carrier may be classified as: 1: "constant efficiency" systems in which the d-c plate voltage of the modulated r-f stage is varied by one means or another, or 2: "variable efficiency" systems in which the average plate voltage of the modulated stage remains constant with or without modulation and the modulating voltage is employed to cause variations in the efficiency of the stage. The characteristics of each system determine its suitability to particular applications.

Most constant efficiency systems involve the addition of power from the audio output am-

plifier or modulator to the modulated r-f stage as indicated in the block diagram of Figure 1. This group constitutes the various methods known as plate modulation, two of which are called "Heising modulation", and "class B plate modulation". At the present time, plate modulation systems are the most popular for communications work because of their relatively high efficiency, 75 to 80 per cent, and because they are the simplest to adjust for proper operation.

### HEISING MODULATION

A simplified schematic diagram of a Heising modulation system is shown in Figure 12 where  $V_1$  represents the final r-f amplifier stage the output of which is modulated by the audio power from the  $V_2$  modulator stage. The output of the class A modulator appears across the audio choke,  $L_1$ , which is connected in series between the plate circuit of  $V_1$  and B+. Therefore, as the audio signal across  $L_1$  varies in magnitude and polarity, the resultant voltage available for the plate of  $V_1$  will vary accordingly.

More specifically, when the a-f voltage is positive at the plate end of  $L_1$ , it will add to B+ to raise the plate voltage of  $V_1$ . Conversely, when the a-f voltage is negative at the plate end of  $L_1$ , it is in opposition to B+, so

that the plate voltage of  $V_1$  is decreased below its average value. The  $V_1$  stage is operated class C so that its radio frequency output changes in exact accordance with the variation of the instantaneous values of plate voltage.

To provide 100% modulation, as indicated by the curve of Figure 11-C, the peak a-f output voltage of the modulator must equal the d-c voltage applied to the r-f tube plate. Under this condition, the positive a-f voltage peaks increase the instantaneous  $V_1$  plate voltage to twice its d-c value and the negative a-f peaks decrease the instantaneous  $V_1$  plate voltage to zero.

Operating as a class A amplifier, the a-f output of tube  $V_2$  will not equal its d-c voltage. Therefore, the circuit must be arranged to provide  $V_1$  with a plate voltage lower than that of  $V_2$ . This must be done so that the a-f output of  $V_2$  can be made to equal the d-c voltage applied to the r-f tube. The required difference in the respective plate voltages is obtained by means of the dropping resistor,  $R_1$ , which reduces the  $V_1$  plate voltage to the desired value. The bypass condenser  $C_1$ , prevents audio frequency voltage drops across  $R_1$ , and the RFC prevents the radio frequency currents from passing through the power supply.

## CLASS B PLATE MODULATION

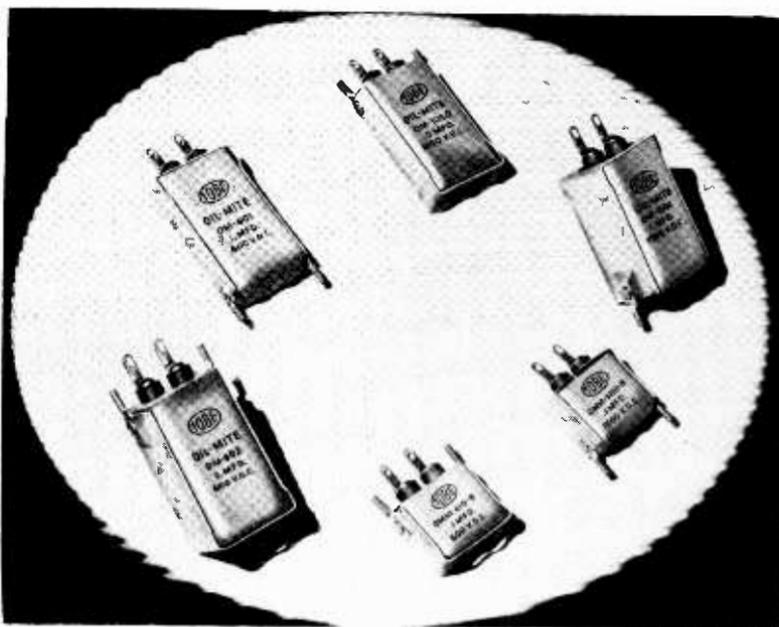
For higher outputs than can be obtained efficiently with the Heising system, the class B plate modulation circuit of Figure 13, is employed. Here again,  $V_1$  represents the r-f final stage, but the modulator consists of the push-pull class B a-f amplifier circuit of  $V_2$  and  $V_3$ . The "modulation transformer",  $T_2$  replaces the audio choke,  $L_1$  of Figure 12, and the respective stages each have their own B+ or plate supply. Since the modulator is operated class B, an external bias or C- supply voltage is applied to the grids through the respective halves of the secondary winding of  $T_1$ .

The modulation action here is about the same as that of the Heising system. The r-f final stage is operated class C and the output of the push-pull modulator, which appears across the secondary of  $T_2$ , causes the  $V_1$  plate voltage, and thus the r-f power output, to vary in accordance with the frequency and amplitude of the audio signal.

It was stated previously that with 100 per cent modulation of a class C r-f amplifier, the audio power supplied by the modulator increases the r-f power output by 50 per cent. It has been stated also that, for 100 per cent modulation, the a-f output voltage must

be equal to the d-c plate voltage of the r-f tube. When this is the case, the power output of the modulator is equal to one-half the d-c power input supplied to the r-f amplifier.

This means that, in a transmitter used for the communication of speech only, a modulator having an output of 100 watts can 100 per cent modulate an r-f final stage with an input up to



Metal-encased high-voltage condensers as used in radio transmitter systems.  
Courtesy Tobe Deutschmann Corporation

However, experiments have shown that this ratio of audio power to the r-f stage input power is necessary only when the modulating signal is sine wave in shape. When speech waveforms constitute the modulating signal, the a-f power output of the modulator need be only about one-quarter the d-c power input supplied to the r-f amplifier.

about 400 watts. This cannot be accomplished with the Heising modulator because of the limitations imposed by its class A single ended mode of operation, however, it can be done when the system of Figure 13 is used. Therefore, because of the large saving in required audio power, for a given r-f output, the class B plate modulation method is the

most economical of the plate modulation systems.

### MATCHING MODULATOR TO R-F AMPLIFIER

The plate to plate load impedance, specified for the rated power output of a class B modulator, seldom corresponds to the required modulating impedance of a class C r-f stage, so that a match must be brought about by adjusting the turns ratio of the coupling transformer. As pointed out in earlier lessons, for proper impedance match, the required turns ratio of the coupling transformer should be,

$$N^2 = \frac{R_p}{R_s} \text{ or } N = \sqrt{\frac{R_p}{R_s}} \quad (1)$$

when,

$N$  = turns ratio

$R_p$  = primary circuit impedance

$R_s$  = secondary circuit impedance

As an example in the use of this formula, assume that a 9660 ohm plate to plate load of a modulator stage is to be matched to a plate modulated class C amplifier which, when unmodulated, draws 300 ma, from a 1200 volt supply. When a plate modulated class C amplifier is properly adjusted, the plate current is almost exactly proportional to the applied plate voltage. Thus, the load presented to the modulating voltage is equal to the plate supply voltage of the

amplifier divided by the unmodulated d-c current.

As an equation:

$$R_s = \frac{E_b}{I_b} \quad (2)$$

when,

$R_s$  = secondary impedance of modulation transformer

$E_b$  = plate supply voltage of class C amplifier

$I_b$  = d-c plate current of class C amplifier when unmodulated

For this example,

$$R_s = \frac{E_b}{I_b} = \frac{1200}{.300} = 4000 \text{ ohms.}$$

Therefore the proper turns ratio of the modulation transformer is:

$$N = \sqrt{\frac{R_p}{R_s}} = \sqrt{\frac{9660}{4000}} = \sqrt{2.415} = 1.55$$

and the primary should have 1.55 times as many turns as the secondary.

It is commercial practice to give the specifications of class B modulation transformers in terms of the plate impedance of the class B output tubes to the secondary impedance. This, however, is nothing but a short-cut method of stating the turns ratio which can be found by the proper use of equation (1). Also, many modulation transformers, known as "universal" types, are provided with primary and secondary taps

so that various turn ratios can be obtained to meet the requirements of a large number of tube combinations. While seldom used in commercial stations, this latter type is popular with amateurs who change their equipment quite often.

### CLASS C GRID MODULATION

The most commonly used method of variable efficiency modulation is class C grid modulation, the efficiency of which is somewhat higher than that of a class B linear amplifier. However the distortion is higher also but can be kept within tolerable limits for communications work. A circuit employing class C grid modulation is shown in Figure 14 where again,  $V_1$  is the final stage r-f amplifier, and  $V_2$  is the power output amplifier or modulator of the audio section. The grid of  $V_1$  obtains its bias voltage from the "C" supply connected in series with the secondary of modulation transformer, T.

For plate modulation, the plate voltage of the r-f amplifier is made to vary at an audio rate but here, in the circuit of Figure 14, the grid bias voltage is made to vary in accordance with the modulating signal. That is, the a-f output of  $V_2$ , which appears across the secondary of transformer T, alternately aids and opposes the d-c "C" supply of  $V_1$ . This causes the operating point,

and thus the efficiency of the class C r-f amplifier,  $V_1$ , to shift in accordance with the audio modulation, and results in a corresponding fluctuation in the amplitude of the final r-f output.

For the proper operation of a grid-modulated amplifier, the conditions at the peak of the modulation are very similar to ordinary class C operation. The main differences are that the minimum instantaneous plate voltage is somewhat smaller and the grid current is less than with customary class C operation. Grid current has a tendency to flatten or distort the positive peaks of the a-c modulating voltage and also tends to make the r-f exciting voltage drop off at the modulation peaks. These actions flatten the positive peaks of modulation and are the principal cause of distortion, provided the conditions at the crest of the modulation cycle make the instantaneous minimum plate voltage small.

As the grid circuit impedance of the modulated stage varies widely over each audio cycle, provision must be made to prevent large changes in r-f and a-f input voltages from the preceding r-f amplifier and the modulator stages. Such changes, which would produce severe distortion, are minimized by the use of the "swamping" resistors,  $R_1$  and  $R_2$  of Figure 14.

The advantage of grid modulation is that very little modulation power is required but, it has the disadvantage of low average plate efficiency. Also, unless there is very little power output, the linearity of a grid modulated class C stage is not as good as that of a class C plate modulated amplifier.

### SCREEN GRID MODULATION

A second variable efficiency method consists of varying the screen grid d-c voltage of a tetrode or pentode r-f amplifier. The modulation transformer secondary is placed in series in the screen grid circuit, and the resulting audio variations of screen voltage cause corresponding fluctuations of the plate current, and, therefore, the r-f output of the stage. For proper operation as a modulated stage, the r-f amplifier screen voltage must be reduced to between one-third and one-half the value used for amplification of unmodulated r-f, thereby causing a corresponding reduction of r-f output. Furthermore, about 80 per cent modulation is the acceptable maximum compared to 90 to 100 per cent for control grid modulation. Because of these limitations, screen grid modulation is seldom employed.

### SUPPRESSOR GRID MODULATION

Another form of efficiency modulation can be obtained by

applying audio voltage to the suppressor grid of an r-f pentode amplifier tube which is operated class C. This provides a simple method of obtaining modulation as any change in bias voltage on the suppressor grid of a pentode tube will result in a variation of its r-f output.

A circuit illustrating this system is shown in Figure 15 where the suppressed grid of  $V_1$  is biased negatively to a point which reduces the plate efficiency of the tube to about 35 per cent, or approximately half the possible maximum. Low distortion modulation of 90 to 95 per cent is easily obtainable with suppressor grid modulation, but 100 per cent modulation is difficult to attain without the distortion increasing to an objectionable value.

The action in the circuit of Figure 15 is very similar to that explained for grid-modulation because the audio signal appears across the secondary of modulation transformer T where it aids or opposes the normal suppressor grid voltage. Variations in the output of the amplifier, caused by this variation of suppressor grid voltage, result in an amplitude modulated carrier.

The modulating power requirements, efficiency and power output are of the same order as explained for the grid-modulated amplifier. This arrangement has an advantage in that the modula-

ting and excitation signals, applied to separate grids, result in simpler operation because best adjustments for proper excitation and modulation requirements are more or less independent. Its disadvantage is that the linearity of modulation does not equal that of conventional grid modulation. Although used but very little for commercial work, this type of modulation is employed quite frequently in amateur transmitters.

### CATHODE MODULATION

As explained earlier in this lesson, plate modulation provides high plate efficiency with low distortion but requires a comparatively high power modulator. In comparison, control grid modulation provides lower plate efficiency with higher distortion, but requires a lower power modulator. Essentially a combination of these two methods, cathode modulation provides a practical compromise.

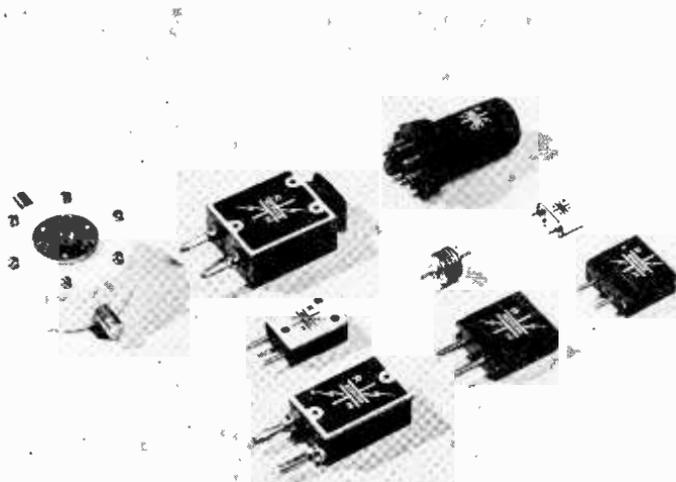
In previous explanations, we have considered only a single ended r-f amplifier which may be a single tube or tubes operated in parallel. However a push-pull operated stage can be modulated just as efficiently and in fact, is in more common use. To illustrate this arrangement, the cathode modulated final stage of Figure 16 consists of the push-pull operated class C r-f amplifiers,  $V_1$  and  $V_2$  and the push-pull modulator stage includes tubes

$V_3$  and  $V_4$ . The d-c bias for the grids of the r-f stage is obtained through the r-f secondary  $L_1$ , the center tap of which connects through audio choke L to the "C" supply negative. The cathodes of this stage connect to ground and "C" supply positive through the secondary of modulation transformer T, which is tapped so that the grid end of audio choke L may be coupled through condenser C to various points on this winding.

The total voltage across the grid and cathode of a tube is the algebraic sum of all the voltages in the complete grid-cathode circuit. For example, for  $V_1$  there is a circuit from the grid through the upper half of  $L_1$  to the center tap, down through audio choke L, the "C" supply, and up through the secondary of modulation transformer T to the cathode. Assuming, for the moment, that condenser C connects to the grounded end of the secondary of T, the audio output of the modulator, appearing across this coil, is in series with the c-bias supply. Thus, as in grid bias modulation, the a-c audio voltage will alternately aid and oppose the initial bias voltage, causing the total grid-cathode voltage to vary in proportion to the amplitude and at the frequency of the audio signal. Therefore, for this part of the action, the arrangement of Figure 16 can be said to provide grid modulation.

However, the cathode is also a part of the plate circuit which can be traced from the plate of  $V_1$  through the upper half of  $L_2$  to the center tap, down through the RFC, through the "B" supply to ground, and up through the

the grid bias method, the plate efficiency of the r-f amplifier varies during modulation and therefore it must be operated so that its efficiency at carrier level is lower than that at the modulation peaks. The required reduc-



A group of mounted crystals for oscillator frequency control.

Courtesy Reeves-Hoffman Corporation

secondary of T to the cathode. Thus, the a-f voltage output of the modulator is in series with the B supply of the r-f amplifier also and will, therefore, cause a-f variations in the total voltage across the respective plates and cathodes of the r-f tubes in the same manner as explained for plate modulation.

Because part of the modulation in the circuit of Figure 16 is by

tion in carrier efficiency depends upon the proportion of grid modulation to plate modulation, and this proportion may be adjusted by means of the taps on the secondary of modulation transformer, T.

For example, if condenser C is connected to the cathode end of the secondary of T, it acts as an a-f short between this point and audio choke L, placing the grids

of the r-f amplifier at the same a-f potential as the cathodes. That is, due to the a-f short provided by condenser C, no portion of the output signal of the modulator will appear in the r-f amplifier a-c grid-cathode circuit. As far as the d-c bias is concerned, this circuit is the same as explained above, but the a-c grid-cathode path of  $V_1$  is now from the grid, through  $L_1$  to the center tap, down and through condenser C and up to the cathode.

Thus, with no a-f signal in the grid-cathode circuit, the r-f amplifier,  $V_1$ - $V_2$ , is entirely plate modulated. However, as condenser C is connected to successively lower taps on T, the grid modulation is increased while the plate modulation becomes a smaller and smaller percentage of the total modulation applied.

Normally, the selected tap on T provides at least 40% plate modulation for an efficiency of about 56 per cent which is about midway between the values obtainable with grid and plate modulation respectively. Under these conditions, the required audio power is about 20 per cent of the d-c plate input to the r-f amplifier, about ten times the a-f power needed for grid modulation and about two-fifths that required for plate modulation.

## HIGH AND LOW LEVEL MODULATION

In general, when the final r-f stage of a transmitter is modulated, a high level of modulator a-f output is required and the arrangement is known as "High Level" modulation. When an intermediate r-f stage is modulated, a lower level of modulator output is sufficient, and the arrangement is known as "Low Level" modulation.

With high level modulation, all the r-f stages may be operated in class C, with the resulting high efficiencies but, this advantage is offset by the larger power requirements of the modulator. With low level modulation, all stages following the modulated stage must be operated class B linear so that undistorted amplification can be obtained. While this arrangement reduces the efficiency in the r-f stages, it also reduces the power requirements of the modulator.

Thus, the choice of system is more or less dependent on the particular installation. Although the modulator power requirements are larger, due to the high efficiency of all r-f stages, usually high level modulation is employed in commercial a-m transmitters.

## SPEECH AMPLIFIER

A check of Figure 1 will show, that, with the exception of the

antenna and its connections, all of the components of the radio transmitter have been described, in either this or preceding lessons. The various types of sound pickup equipment, as well as mixer circuits have been explained in detail, and the "speech amplifier" is about the same as those used in p-a systems.

In general, the speech amplifier may be defined as that portion of the audio channel between the microphone or its pre-amplifier and the modulator stage. When certain types of microphones are employed, it is possible to dispense with the pre-amplifier by designing the speech amplifier to operate with low level input. However, this arrangement requires that the speech amplifier have high voltage gain which may cause it to be subject to hum and feedback trouble.

The speech amplifier consists of from one to three stages of voltage amplification with resistance, impedance, or transformer coupling. Should the modulator operate in class B, which is most generally the case, then the last speech amplifier stage must furnish the power to drive the class B grids and is commonly called the driver. In a circuit of this kind, the type of tube will depend on the amount of driving power required and for larger values, it is customary to use two driver tubes connected in push-pull. Be-

cause the load into which the driver works is continuously variable, low mu power triodes are most suitable. Pentode or beam power tubes can be used but, in order to prevent serious distortion, inverse feedback should be employed to reduce their effective plate resistance and provide better voltage regulation.

### ANTENNA COUPLING CIRCUITS

Some method of coupling is needed to transfer the energy from the final amplifier to the transmitting antenna. As all tubes provide maximum output in a load of proper value and, as the plate impedance of the tubes is comparatively high while that of the antenna input is low, the coupling unit must act also as an impedance matching device. Thus, the antenna coupler performs the same general function as the output transformer of an audio amplifier which transfers the energy from the high impedance plate circuits of the output tubes to the low impedance voice coil of the speaker and at the same time provides for a proper impedance match.

In a transmitter, the final amplifier may be coupled directly to the antenna or by means of capacitive, inductive and link coupling as already explained. With certain exceptions, direct

or capacitive coupling to the antenna is forbidden by the FCC because such arrangements favor harmonic radiation which causes interference, therefore the following explanations will include only inductive and link coupling.

A simplified form of an inductive coupled network is shown by the circuit of Figure 17A in which the tuned LC circuit represents the plate tank of the final r-f stage. Coil L is inductively coupled to  $L_1$ , tuned by condensers  $C_1$  and  $C_2$ , which, in turn, are connected to the feeders or transmission line that carries the energy to the antenna. The coupling between L and  $L_1$  is made variable so that the amount of "loading" can be adjusted to the desired value. Because coil  $L_1$  and condensers  $C_1$  and  $C_2$  are all in series with the antenna, at resonance the current in the circuit will be maximum and therefore this arrangement is known as a "series tuning" or "current feed" system

In Figure 17B, we show a similar circuit but coil  $L_1$  is now tuned by a single parallel connected condenser  $C_1$ , while the feeders are connected across the tuned circuit  $L_1$ ,  $C_1$ . With an arrangement of this kind, at resonance the voltage will be maximum and the current minimum, therefore it is known as a "parallel tuning" or "voltage feed" system. As explained for the circuit of Figure 17A, the

coupling between L and  $L_1$  is made variable so that the desired amount of loading can be secured.

For the third or "link" form of coupling, we have drawn the circuit of Figure 17C which is exactly the same as 17B except that coils L and  $L_1$  are now coupled by the link. As explained for the interstage coupling methods, the amount of coupling is varied by changing the position of each link with respect to its tank. Although we show a voltage feed arrangement, current feed could be used just as well.

In the above circuits, the choice of the voltage or current feed arrangement depends on the length of the feeders and the antenna itself. From the explanations of an earlier lesson, you will remember that for a half wavelength doublet type of antenna, the current is greatest at its midpoint and minimum at the ends. Therefore, if the energy from the final amplifier is fed at the midpoint of the antenna, the coupling device must be of such design that the current will be maximum when it reaches the antenna proper.

## TRANSMISSION LINES

In the earlier explanations of this lesson we mentioned feeders, or transmission lines and now we want to give you a little more information in regard to them. As you know, their purpose is to

transfer energy, from the source to some other unit, with as little loss as possible. When a transmission line carries r-f current, as in transmitters, it tends to radiate energy and, to minimize this action as much as possible, special design is necessary.

The amount of radiation can be decreased by using a line with a comparatively high impedance and a resulting low current or by using two conductors arranged so that equal current in them is in opposite directions. By this method, the fields set up by the conductors are  $180^\circ$  out of phase with each other and, being of equal amplitude, they cancel.

There are several common types of transmission lines and perhaps the simplest is made up of a pair of insulated wires twisted much like the old style lamp cord. Because of its arrangement this is known as a "twisted pair" line.

Another type, quite popular with amateurs, is made up of two parallel wires, held two to six inches apart by means of insulation strips called "spacers". Here again, the construction indicates its common name of "open wire" line.

A third type, quite commonly used in commercial installations, is made up of a relatively small diameter conductor placed centrally inside an outer tubular

conductor. The inner conductor, held in its central or axial position by means of regularly spaced insulators, forms one side of the line while the outer tubular conductor forms the other side. This arrangement is known commonly as a "coaxial" cable or "concentric" line.

Still another type of line, known as a "single wire feeder" uses only a single wire, and radiation is minimized by keeping the line current low.

Although considered somewhat as a special field, the generation and transmission of modulated r-f carriers is important to everyone in Radio and Television. It is the form of energy induced in all receiving antennas and which must be accepted, amplified and demodulated by the receivers. Also the popular Wireless Microphones and Wireless Phonographs are miniature transmitters while the same general form of energy is generated by the common types of signal generators used for receiver alignment.

With the growing popularity of frequency modulation, (f-m), which will be described in the following lesson, it is convenient to make comparisons with the older methods of amplitude modulations, (a-m). Therefore we urge a careful study of the principles explained in this lesson before proceeding to the next.

**IMPORTANT WORDS USED IN THIS LESSON**

**FLY WHEEL EFFECT**—The ability of the plate tank circuit in a class B or class C amplifier to convert the short-time current pulses into sinusoidal current oscillations.

**FREQUENCY MUTIPLIER**—An r-f amplifier with a resonant plate circuit tuned to an integral harmonic of the input frequency in the grid circuit.

**GRID NEUTRALIZATION**—Neutralizing an r-f amplifier by feeding back externally a portion of the grid circuit signal voltage.

**HEISING MODULATION**—A system of modulation in which the plate supply of the modulator and modulated amplifier is obtained from a common supply through a high inductance, low resistance choke coil.

**HIGH-LEVEL MODULATION**—Modulation injected into the plate circuit of the final r-f power amplifier stage in a radio transmitter.

**KEYING**—Interrupting the output of a radio transmitter with a telegraph key in accordance with some pre-established code.

**LOW-LEVEL MODULATION**—Modulation produced in one of the early r-f stages in a radio transmitter.

**MODULATION**—The process of varying the amplitude or frequency of a high-frequency carrier in accordance with the audio-frequency signal voltage that is to be transmitted.

**MODULATION ENVELOPE**—A line drawn through the peaks of the modulated r-f carrier waves. It takes on the waveform of the modulating signal.

**100% MODULATION**—That degree of amplitude modulation when the modulation envelope varies between zero and twice the average amplitude of the carrier.

**OVERMODULATION**—Amplitude modulation exceeding 100%, resulting in distortion because the carrier is reduced to zero during portions of each cycle.

**PERCENTAGE OF MODULATION**—The ratio (expressed in per cent) of the signal voltage amplitude to that of the carrier.

**PLATE EFFICIENCY**—The ratio (expressed in per cent) of the a-c power output of an amplifier tube to the d-c power input.

**PLATE NEUTRALIZATION**—Neutralizing an r-f amplifier by feeding back externally a portion of the plate circuit signal voltage.

**R-F NEUTRALIZATION**—Nullifying the internal voltage feedback in an r-f amplifier by means of an external feedback equal in value but 180° out of phase.

**SIDEBANDS**—Two new bands of frequencies formed during amplitude modulation, one above the carrier frequency and equal to the sum of the carrier and signal frequencies, and the other below the carrier and equal to their difference. The former is known as the upper sideband and the latter as the lower sideband.

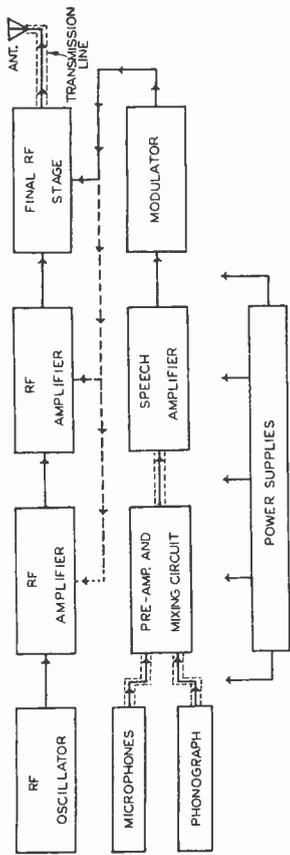


FIGURE 1

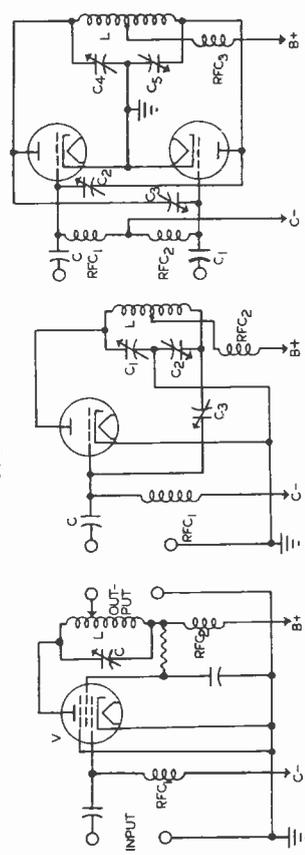


FIGURE 2

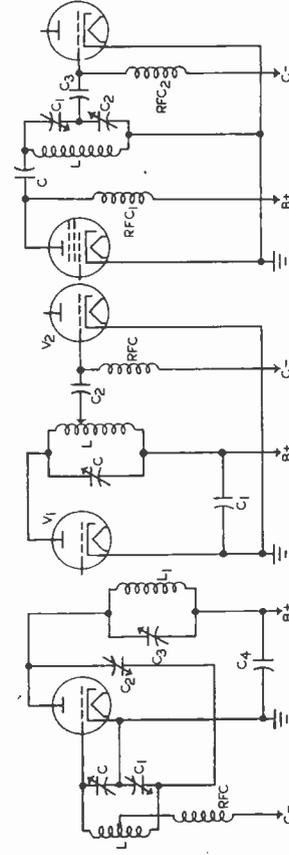


FIGURE 3

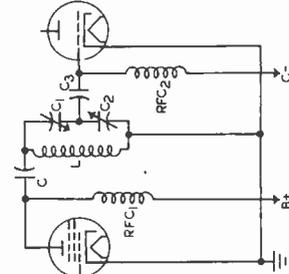


FIGURE 4

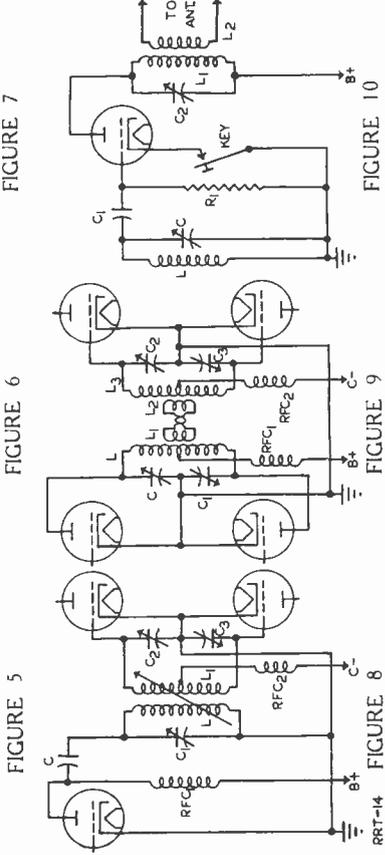


FIGURE 5

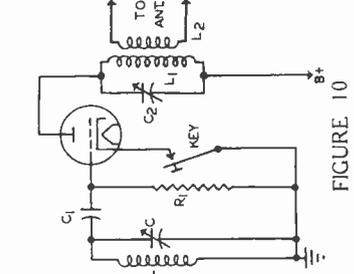


FIGURE 6

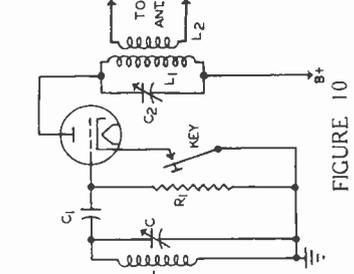


FIGURE 7

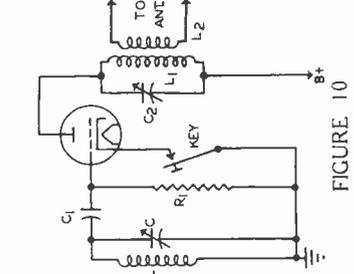


FIGURE 8

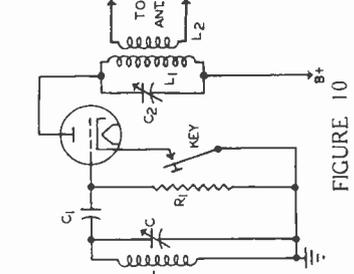


FIGURE 9

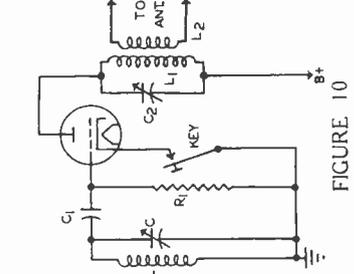


FIGURE 10

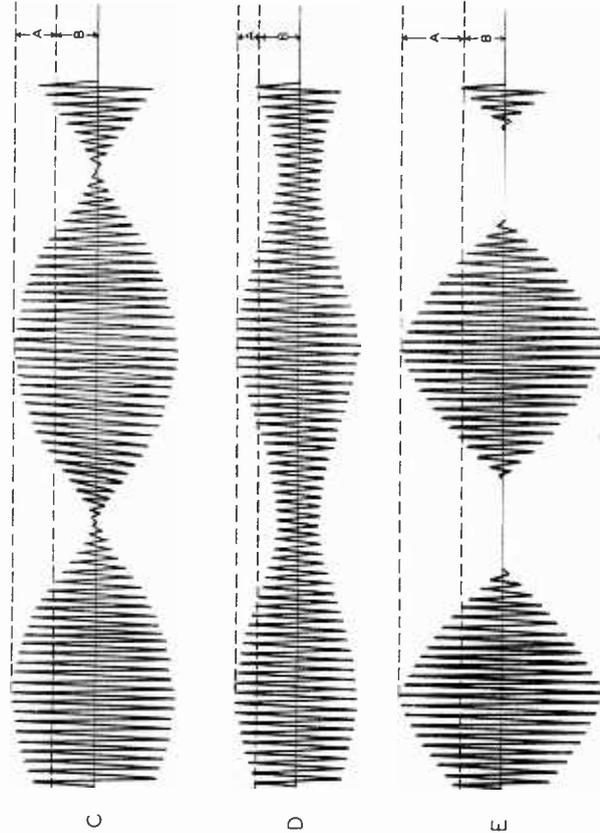
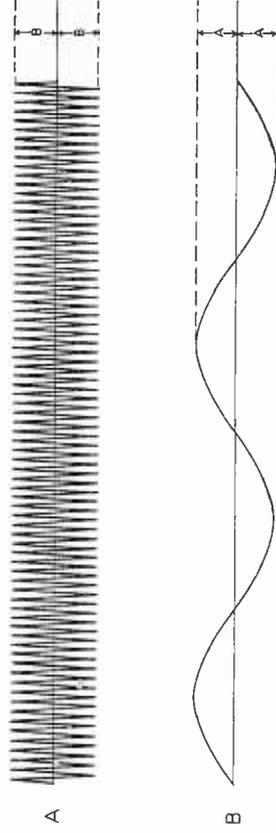


FIGURE 11

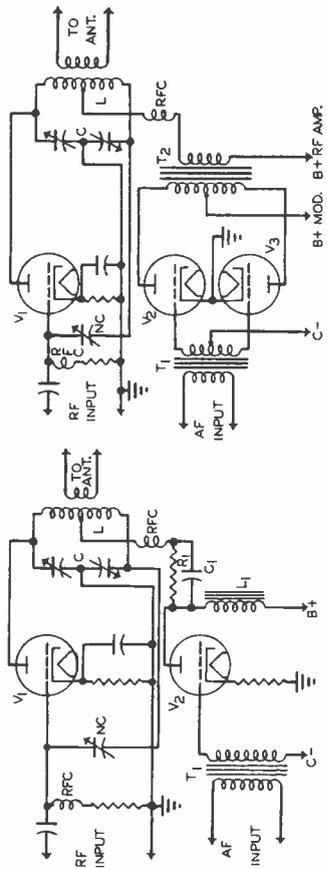


FIGURE 12

FIGURE 13

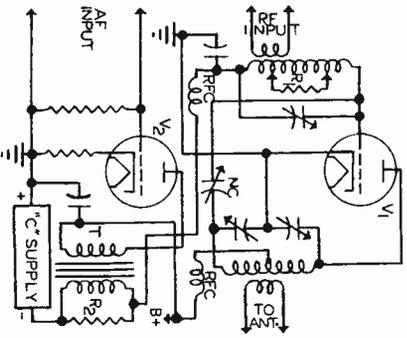


FIGURE 14

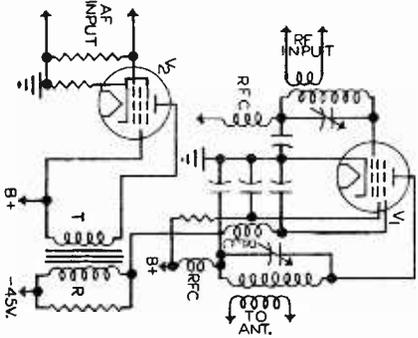


FIGURE 15

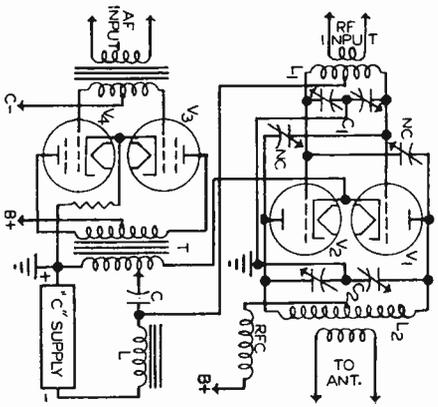


FIGURE 16

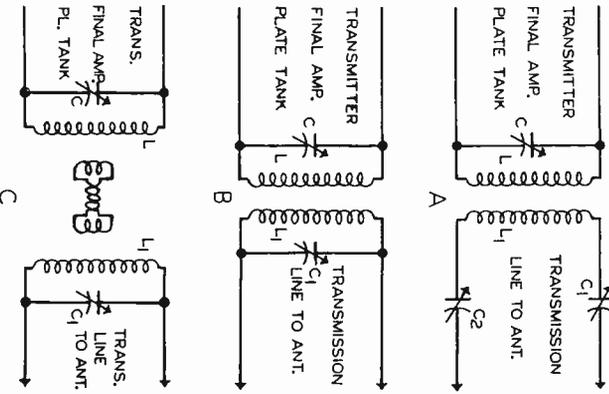


FIGURE 17





FROM OUR *President's* NOTEBOOK

T O D A Y

YESTERDAY is gone forever. Tomorrow never comes. Today is in my own hands.

If I shirk today's task, I shall be adding to my wasted Yesterdays.

If I postpone Today's duty, I shall be increasing Tomorrow's burden.

If I accomplish what Today sets before me, I shall be doing my best to atone for Yesterday's failures, and prepare for Tomorrow's successes.

Therefore, I will endeavor so to use my time and opportunities that Today shall leave me a little wiser and abler than it found me.

*E. B. Selvy*

PRESIDENT