HOW THE RADIO CARRIER IS AMPLITUDE MODULATED

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STUDY SCHEDULE NO. 20

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

☐ 1. Fundamentals of Amplitude Modulation .... Pages 1-10

A review of the types of modulation, followed by a full discussion of the production of side bands, and of modulation distortion. Answer Lesson Questions 1, 2, 3, 4, and 5.

☐ 2. Plate-Modulation Systems .... Pages 10-19

The most widely used system of amplitude modulation is the one of plate modulation. There are two types; the Heising, and the transformer-coupled methods. Here you learn the advantages and disadvantages of both, then learn how to adjust them for proper modulation. Answer Lesson Questions 6, 7, and 8.

☐ 3. Control-Grid Modulation .... Pages 19-23

Next to plate modulation, this is the most used commercially. The modulated stage must be carefully adjusted for this service according to the instructions given in this section.

☐ 4. Other Methods of Amplitude Modulation .... Pages 23-29

Lesser used methods, such as screen-grid and suppressor-grid modulation are discussed here. Also, you are introduced to special systems of controlling or suppressing the carrier such as are used in certain special services.

☐ 5. Keying the Transmitter .... Pages 29-36

Code transmission is one of the most important of the methods of communication. While not as familiar to the general public as is standard broadcasting, far more code messages are transmitted in a day than any other kind. Here are presented the special problems of keying the transmitter, and of eliminating undesired thumps and clicks. Answer Lesson Questions 9 and 10.

☐ 6. Start Studying the Next Lesson.

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HOW THE RADIO CARRIER IS AMPLITUDE MODULATED

Fundamentals of Amplitude Modulation

PRECEDING Lessons have shown how radio-frequency power of constant amplitude and frequency is generated by a vacuum-tube oscillator. You learned, also, how the low power of a master oscillator can be amplified by one or more cascade amplifiers, and finally applied to a high-power output stage.

Output power from the final stage may be used in various ways. Commercially, for induction heating of metals and non-conductors; in medicine, for diathermy or "artificial fever" producing purposes; and in the laboratory, for certain types of measurements. In each of these applications, the radio-frequency power is allowed to remain constant in amplitude and frequency.

On the other hand, if the output stage feeds into an antenna system, the radio-frequency energy which is radiated into space must be controlled or varied so as to carry intelligence of one type or another. The simplest form—historically, the first form—of control over the radio wave is obtained by interrupting the carrier (the same as if the transmitter were turned on and off) in accordance with the "dot-dash" system of the telegraphic code. Somewhat more involved are the methods used to vary the radio wave in accordance with sound (voice or music) and video (television) images.

The result of any process which serves to change the radio wave is called *modulation*. The r.f. power that is modulated is called the *carrier*, and the intelligence to be transmitted is called the *modulating signal*. With these definitions in mind, let us now turn to a study of the methods by which modulation is accomplished.

TYPES OF MODULATION

As you know, the r.f. carrier of a transmitter has three characteristics which can be varied independently of each other, namely: amplitude, frequency, and phase. Modulation can be accomplished by varying any one of these characteristics in accordance with the modulating signal.

► In amplitude modulation (a.m.), the *strength* of the carrier is varied to correspond to the signal; in frequency modulation (f.m.), the *frequency* is varied; and in phase modulation (p.m.), the *time interval* between successive peaks of the carrier wave is varied continuously with the signal.

To be able to get a physical picture of these three types of modulation, think of an ordinary a.c. alternator having a revolving armature and stationary d.c. field as illustrated by the schematic drawing in Fig. 1A. Let this alternator rotate at a given speed. Then, the amplitude of the a.c. output will depend on the strength of the field, and the frequency of the generated alternating current will be determined by the number of poles and the speed of rotation.

Now let us suppose that we wish to

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modulate the alternating current output of the alternator, and that the modulating signal we wish to impress upon it is the low-frequency square wave shown in Fig. 1B. If we compare the a.c. output of the alternator in Fig. 1A to the r.f. power generated by a transmitter, we find that then the low-frequency square wave in Fig. 1B could correspond to audio-frequency signals coming from the microphone.

Amplitude Modulation. If we disconnect the field-supply battery in Fig. 1A, and substitute some means of making the field current jump up and down like the wave in Fig. 1B, then the voltage induced in the armature will rise and fall with changes in field current. The output of the alternator will look like the voltage wave in Fig. 1C. Since the alternating voltage is not left constant but is made to increase or decrease in magnitude in exactly the same way as the modulating signal does, the alternator output is said to be *amplitude modulated.*

Frequency Modulation. Suppose that we restore the steady d.c. field to the alternator by replacing the battery, and then for modulation purposes we vary the speed of the rotating armature. If we *increase* the speed of the armature when the square wave rises, and *decrease* the speed when the square wave falls, then the alternator voltage output will look like Fig. 1D. In this case the modulating square wave is represented by *frequency changes* in alternator output because increased armature speed means higher output frequency, and lower speed generates a lower frequency. Fig. 1D, therefore, is a *frequency-modulated* wave.

Phase Modulation. Finally, if we keep the field current constant and the rotation of the armature steady, but rock the frame of the alternator back and forth over a central point, we can get another type of modulation. Since this movement changes the position of the field windings, the *instantaneous phase* of the generated voltage will be altered. Under these circumstances the alternator output becomes the *phase-modulated* wave shown in Fig. 1E.

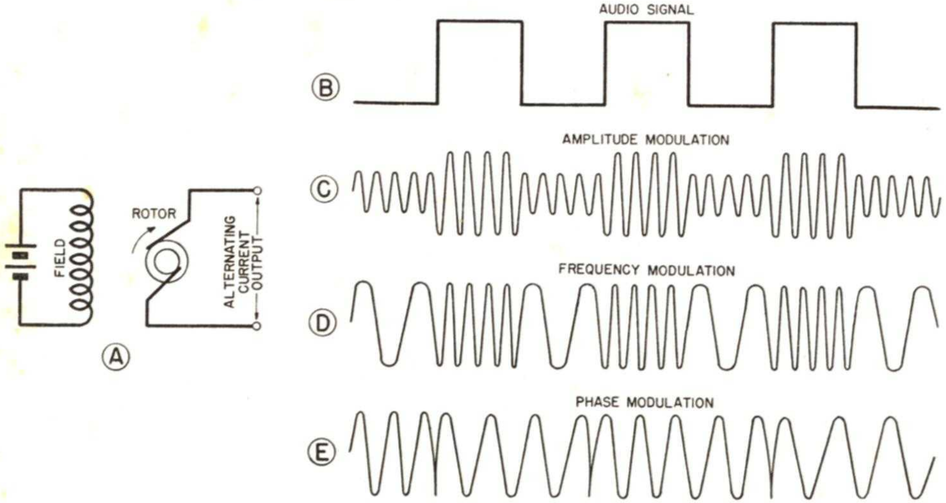

FIG. 1. The output of an alternator can be modulated in three different ways—by changing at an audio rate the field current, the speed of rotation, or the physical position of the field windings.

Modulation Applications. All of the types of modulation discussed above are used commercially today. Both f.m. and p.m. (phase modulation) are finding widespread use in the field of police, railroad, utility and emergency services, and in the armed forces where the higher frequencies are used. F.M., also, is being used more and more for high-fidelity broadcasting at the ultra-high frequencies; such use, however, is limited to short distance transmissions. One of the advantages of f.m. and p.m. is the possibility of getting a high signal-to-noise ratio. These two types of modulation are rather complex, and because of their growing importance, a separate Lesson will be devoted to their study.

Code-keying the transmitter, however, is still of great importance in point-to-point communication handling messages, press work, and ship-to-shore traffic. Although automatic high-speed machine transmissions may be used in a great number of cases, manual sending and receiving is still used to a great extent.

The oldest form of voice or music modulation is a.m., and next to keying, it has the most widespread use. Indeed, all broadcast stations in the present-day broadcast band use this form of modulation. A.M. is not being superseded by the other forms of modulation. This is true because a.m. alone is practical for use at comparatively low r.f. frequencies where a strong ground wave can be produced, or at medium r.f. frequencies where the advantages of "skip distance" can be put to good use. Particularly where distance is of importance, such as in international short wave broadcasts, a.m. signals will not be replaced.

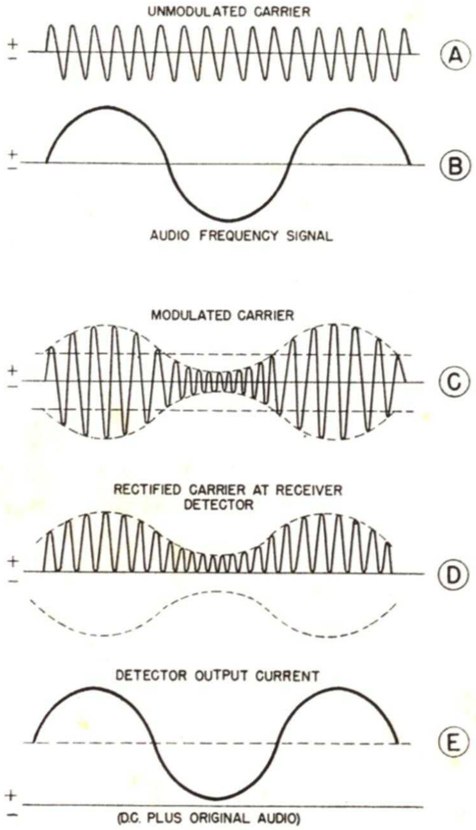

FIG. 2. Wave forms showing amplitude modulation at the transmitter, and how the original signal is recovered at the receiver by rectification.

AMPLITUDE MODULATION

Before we study how amplitude modulation is accomplished in the transmitter, let us consider the modulated carrier itself to see what it is and how it must be treated at the receiver in order to reproduce faithfully any intelligence transmitted.

First, let us assume that the *unmodulated* transmitter r.f. output appears as shown in Fig. 2A. As indicated, the amplitude, frequency, and phase of

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the transmitted carrier are constant.

Next, suppose the intelligence with which we wish to modulate the transmitter consists of the audio-frequency sine wave of Fig. 2B. Actually, the wave forms of speech and music are much more complex, since a number of audio frequencies together with harmonics or overtones may be present. The action with a simple sine wave, however, is identical, and the performance much easier to understand.

Now, if by one of the methods to be discussed later, the carrier wave of Fig. 2A is amplitude-modulated by the audio sine wave in Fig. 2B, the transmitter output will be changed to look like Fig. 2C. During the time the audio signal is positive, the r.f. wave increases above its former level; similarly, whenever the audio signal becomes negative, the r.f. wave drops below its former constant value.

If we were to trace out the *envelope* of the modulated wave by connecting all the r.f. peaks together as indicated by the dotted lines in Fig. 2C, we would see that the *peak* value of the r.f. wave changes at an audio-frequency rate identical to the modulating signal wave in Fig. 2B. However, in spite of modulation, the *average* value of the r.f. wave, as shown by the dashed line, has not been altered.

Action at the Receiver. The modulated carrier energy radiating from the transmitting antenna, of course, has the wave form of Fig. 2C, and feeble currents varying in the same manner are induced in the receiving antenna. Fed into the receiver, these modulated currents are then amplified by one or more r.f. stages until of sufficient magnitude to be applied to the receiver detector.

A detector is nothing more than a rectifier—that is, it has the property of passing current in one direction much more easily than in the other. Hence, when the modulated r.f. wave of Fig. 2C is fed to the detector, the r.f. peaks of one polarity only will get through. As a result, the output current of the detector looks like Fig. 2D. Note that although the lower peaks of the modulated wave are missing, the positive peaks remain, and their amplitude still changes to give an envelope carrying the original audio sine wave.

Finally, if the pulsating direct current wave of Fig. 2D is filtered by means of an r.f. choke and a by-pass condenser, the r.f. pulses will be smoothed out. The output of the detector, therefore, becomes as shown in Fig. 2E, simply a direct current which is varying at the audio signal rate. By its rectifier action, the detector has "demodulated" the radio wave and delivered a reproduction of the original audio signal.

Degree of Modulation. If you study the wave forms in Fig. 2 for a moment, you will see that the amplitude of the carrier itself is not of prime importance. Indeed, as far as the receiver detector is concerned, it is the amount the carrier *changes*, hence, its "degree of modulation" that determines primarily the detector output.

Let us look at Fig. 3. In Fig. 3A we have the unmodulated carrier of peak amplitude E_o. If by modulation the r.f. peaks are increased 50% during the positive modulating alternation, and decreased 50% during the negative alternation, then the carrier is said to be 50% modulated. This condition is illustrated in Fig. 3B.

On the other hand, if the r.f. peaks are exactly *doubled* during the positive alternation and just barely reduced to *zero* during the negative alternation, the modulation becomes complete or 100%. *This condition, shown in Fig. 3C, represents the highest degree of modulation it is possible to get without serious distortion.*

If the *peak* amplitude of the modulating audio signal is ever allowed to become greater than the r.f. peak value E_o, an over-modulated wave like Fig. 3D will be obtained. Even though the transmitter may be capable of delivering an *increase* in r.f. voltage greater than twice E_o, the output certainly cannot *decrease* below zero. It is obvious that the envelope of the over-modulated wave no longer is identical to the original modulating audio signal. As a result, when such a wave is demodulated by the receiver detector, the audio output is severely distorted. Over-modulation in all instances should be strictly avoided.

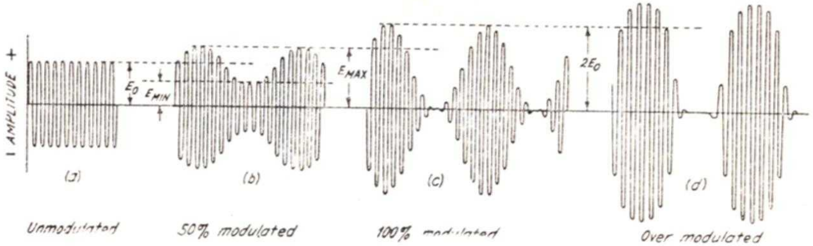

FIG. 3. Wave forms of an unmodulated carrier and carriers with different degrees of modulation.

When the modulated wave form of a transmitter can be observed with a cathode ray oscilloscope, and the maximum and minimum peak values are measured as shown in Fig. 3B, the *degree of modulation (m)* can be determined by the following formula:

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

The *percentage of modulation* also can be determined simply by multiplying the m value by 100.

Since the signal amplitude should never be allowed to become greater than that of the carrier, the greatest value that m should have is unity, or m = 1. This corresponds, of course, to 100% modulation as shown in Fig. 3C.

Side-Band Frequencies. It can be shown mathematically and proved experimentally that amplitude modulation *does not change* the *carrier frequency;* instead, modulation introduces two new frequencies, one being equal to the *sum* of the carrier and signal frequencies, and the other equal to their *difference*. For example, if a 1000-kc. carrier is amplitude-modulated with a 5000-cycle (5 kc.) audio signal, the new frequencies generated will be 1000 + 5 = 1005 kc., and 1000 — 5 = 995 kc. These sum and difference frequencies, called *side frequencies*, will be radiated *with* the 1000-kc. carrier frequency.

If a transmitter were radiating a 1000-kc. carrier that was modulated 100% with a 5-kc. sine-wave audio signal, a highly-selective laboratory receiver actually would pick up three separate r.f. signals: at 995 kc., 1000 kc., and 1005 kc. If by means of suitable instruments the intensity of each of these signals were measured, it

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would be found that the 995-kc. and 1005-kc. side frequencies each had exactly *half* the intensity of the carrier. Amplitude modulation, therefore, keeps the carrier frequency at its original amplitude and gives to each of the two side frequencies, for 100% modulation, an amplitude equal to half the carrier amplitude. These facts are presented graphically in Fig. 4. For modulation percentages less than 100, the amplitude of a side frequency is equal to one-half the degree of modulation m multiplied by the carrier amplitude E_o, or simply $mE_o/2$.

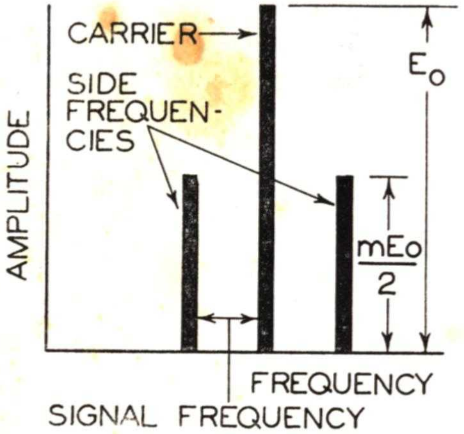

FIG. 4. Relationship of carrier and side frequencies at 100% modulation (m = 1) with pure sine-wave signal.

Power in the Side Frequencies. Since transmitter output power at any frequency is proportional to the *square* of the voltage or current, and we know that for 100% modulation the maximum amplitude of a side frequency is one-half that of the carrier, then the maximum power in each side frequency is one-quarter or 25% of that in the carrier. Hence, the two side frequencies together have a power equal to 50% of that of the carrier when the carrier is 100% modulated. For less than 100% modulation, of course, the power in each side frequency will be correspondingly less. For any degree of modulation m, the power in each side frequency with respect to the carrier power will be given by the formula $100\ m^2/4$—the result being in *per cent of carrier power*. The manner in which side-frequency power varies with the degree of modulation is illustrated by curve (1) of Fig. 5. At 20% modulation (m = 0.2) each side frequency contains only 1% of the power in the carrier frequency; at 50% modulation this power is only 6%.

It is the power in the side frequencies alone which determines the useful signal intensity at the receiver, because the side frequencies contain the intelligence. Hence, it is highly important that modulation of a transmitter be kept as near 100% as possible without actually causing over-modulation and bringing about distortion. High carrier power itself serves no useful purpose if the degree of modulation is kept low, and furthermore, the strong carrier may seriously interfere with stations on adjacent channels or produce strong heterodynes (squeals) with distant stations operating on the same carrier frequency.

The inefficiency of low modulation is further brought out by this example: a station with a 5000-watt carrier which is modulated at 40% will have a power in each side frequency, as determined from curve (1) in Fig. 5, of only 4% of the carrier power. This gives 0.04 × 5000 = 200 watts. But the same side-frequency power can be obtained with only an 800-watt carrier if it is modulated at 100%, thus 0.25 × 800 = 200 watts.

The facts just discussed hold true only for sine-wave modulations. Since no one talks, sings, or plays continuously at the same frequency, and no televised scene has equal numbers of light and dark areas uniformly spaced, in practical cases, the effective power in each side frequency is between ¼ and ½ the maximum values given by carrier power curve (1) in Fig. 5.

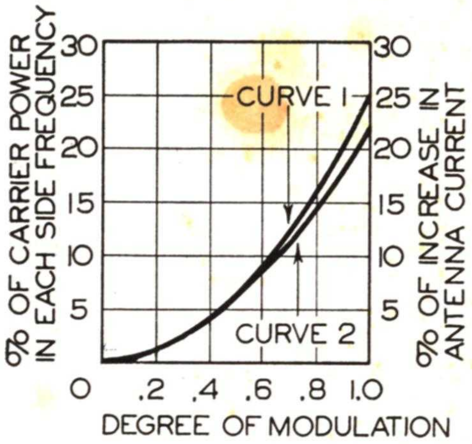

FIG. 5. These curves show the effects of various degrees of modulation upon the antenna current, and upon the power in each side frequency.

Increase of Antenna Current. Since modulation brings about the generation of side frequencies which for a 100% modulation condition contribute 50% more power to be radiated, the antenna current of a transmitter will rise when modulation is applied. Curve (2) in Fig. 5 shows the per cent of increase in antenna current meter reading to be expected for different degrees of modulation using a continuous audio sine wave.

You can see that 100% modulation gives a 22.5% increase in *effective* antenna current over the no-modulation value. Effective current, of course, is the root-mean-square value as indicated by a thermo-ammeter. For normal speech or music transmissions, the increase in meter reading will be ¼ to ½ that for a pure sine-wave modulation, the meter needle flickering higher only on accentuated syllables or loud passages.

The Side Bands. Speech, music, and television signals, as well as the

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"dot-dashes" from a telegraph key, are not of simple sine-wave form but are complex waves made up of sine-wave fundamentals, harmonics, and overtones, each varying in amplitude from instant to instant. Ordinary speech usually is considered to be between 250 and 2700 cycles, and musical frequencies range from about 30 to 5000 cycles for fundamentals. (Harmonics range up to 16,000 cycles.) Hence, standard broadcast stations transmit side frequencies up to 7000 cycles above and below the carrier frequency. Video signals may have a range of 30 to 4,000,000 cycles, producing side frequencies as much as 4 mc. above and below the carrier value. Since a great number of different r.f. side frequencies are produced close to the carrier value, and these may exist simultaneously, the portions of the frequency spectrum which they occupy are commonly referred to as the *"side bands."*

MODULATION DISTORTION

In a properly adjusted transmitter, the envelope of the modulated carrier is a true reproduction of the intelligence being transmitted, but the *average* value of the carrier is not changed by modulation, if this does not exceed 100%. This can be demonstrated by coupling a diode detector to the transmitter output and measuring the rectified current (pulsating d.c.) with a meter which is calibrated to read average carrier amplitude. There will be no change in the meter reading if the modulation is perfectly reproduced and is less than 100%. Often an improperly adjusted transmitter will produce a change in the meter reading, indicating that the average carrier value has changed or, as it is often said, *carrier shift* is present.*

Carrier Shift. It is customary when referring to the modulation envelope of a carrier to call the half-cycle *greater* than the unmodulated carrier the *positive alternation;* likewise, that part of the envelope *smaller* than the unmodulated carrier is known as the *negative alternation.* [illegible]

If the positive and negative alternations of the envelope are not identical, that is, the envelope of modulation is distorted, the average carrier current will change. This case is illustrated in Fig. 6. With an unmodulated carrier, a carrier-shift meter would give a reading corresponding to average current value A, this reading dropping to value B after modulation if the modulation is distorted as shown. A drop like this in the meter reading indicates that the negative alternation or *drop* in carrier value is greater in amplitude than the positive alternation or carrier *rise.* Such envelope distortion, of course, generates spurious harmonic audio frequencies at the receiver, reducing the fidelity of transmission; it can also produce additional r.f. sideband frequencies, some of which actually may be outside the frequency-band width allotted to the station.

Over-modulation always results in carrier shift. A carrier-shift indicator will show a *rise* in rectified current the instant 100% modulation is exceeded. Modulation values below 100% with signals that are not distorted, however, do not affect the average carrier current value and do not cause a change in meter reading. The carrier-shift indicator, therefore, is a convenient instrument for checking against over-modulation conditions.

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*The circuit diagram of the carrier shift indicator just described will be given later in this text. (See Fig. 11.)

Sources of Distortion. Modulation distortion occurring in a transmitter can be traced to four different sources: *1,* the signal or speech amplifiers prior to the modulator stage; *2,* the modulator stage itself; *3,* the r.f. amplifier stage being modulated; *4,* the r.f. stages, if any, following the modulated stage.

Signal distortion produced by the speech amplifier stages can be eliminated by properly adjusting these audio stages for linear amplification and uniform frequency response. Too high or too low a C bias, for example, or degeneration due to insufficient by-passing of cathode circuits in self-biased tubes, may cause amplifier stages to be operated off the straight-line portion of their E_g-I_p characteristic curves and hence, introduce distortion.

Troubles in the modulator stage, which is merely a high-power audio amplifier, may be cured in a similar manner by making adjustments while the stage is feeding into a fixed normal resistance load instead of the modulated r.f. amplifier.

The r.f. stages are taken care of by tuning each to the exact carrier frequency, making the resonance curve for each stage symmetrical in shape and sufficiently broad to pass the sideband frequencies, and adjusting each stage carefully for linear amplification.

There remains, then, distortion introduced by the modulated r.f. stage; this subject will be covered in detail in this text.

Phase Shift. Briefly, non-uniform phase shift or phase "distortion" is present if different lengths of time are required for different frequencies in an intelligence signal to travel through a transmitter. Phase shift can take place in both the speech or signal amplifiers and the modulator. Although freedom from phase shift is not absolutely essential in radiotelephone transmission systems, it is, nevertheless, highly desirable to keep phase shift at a minimum. In television transmitters where signal frequencies cover a relatively wide range such as 30 to about 4,000,000 cycles per second, elimination of phase shift becomes of great importance; otherwise, light and dark areas may be displaced in the reproduced image, giving a distorted picture. Phase shift is difficult to correct, and can be prevented only by proper design of the signal amplifier and modulator.

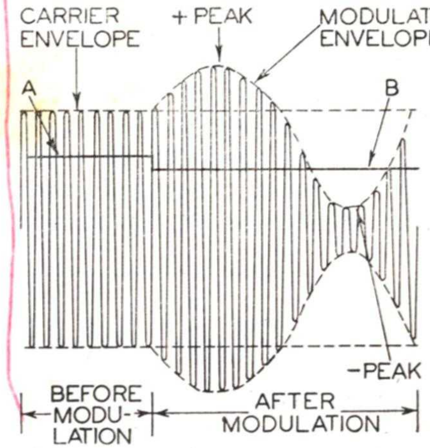

FIG. 6. Line A indicates average carrier current before modulation; line B represents average carrier current after modulation with distortion present.

Capability of Modulation. It is important to notice that with 100% modulation the instantaneous *peak* power output during a positive alter-

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nation is four times the no-modulation carrier power value. This is true because the *peak* amplitude of the modulated carrier current is exactly *twice* the amplitude of the un-modulated carrier, and we know power is determined by the *square* of the current or voltage. In any method of amplitude modulation the transmitter should be designed to handle these peak conditions without too much distortion or danger of overload.

A transmitter, therefore, may be relatively free of distortion at a low degree of modulation but may not give satisfactory operation at 100% modulation. In one case, the acceptable amount of distortion may limit transmitter operation to 55% modulation, while in another it may be possible to extend the modulation to 75% without serious distortion. Thus, even though 100% modulation may be achieved by making the peak of the r.f. current rise to twice the no-modulation value, acceptable modulation is limited by the permissible amount of distortion. Transmitters are rated according to the maximum percentage of modulation at which they are capable of operating satisfactorily with permissible distortion, this rating being known as the *capability of modulation.* As an example, a 1-kw. transmitter of a well-known manufacturer had a specification of audio distortion of less than 2.5% measured at 400 cycles at 95% modulation.

Plate-Modulation System

In the modern master-oscillator power-amplifier type of transmitter, modulation is always accomplished in an r.f. amplifier stage, and this modulated stage is separated from the master oscillator by one or more buffer stages to keep the oscillator frequency stability at a maximum.

Modulation of an r.f. amplifier which is driven by constant-amplitude carrier-frequency power involves nothing more than a means of changing the mutual conductance of the stage in accordance with the modulating signal. When the mutual conductance is varied, the power gain of the stage is changed, and the transmitter output power is given the desired amplitude modulation.

There are a number of ways of producing amplitude modulation—it is possible to vary the plate, the control grid, the screen grid, or the suppressor grid voltages, or any combination of these electrode voltages, in accordance with the intelligence signal and secure modulation. Maximum capability of modulation and maximum efficiency, however, can be obtained only by careful circuit design and adjustment, and by proper application of the signal to the modulated r.f. stage. Let's first study plate modulation, then study other types in another section of this Lesson.

Plate modulation is used extensively in broadcast and radiotelephone transmitters and to some extent in television transmitters. Basically, there are two systems in use; one uses a high-inductance choke and the other uses a transformer as the means of coupling the modulator to the plate circuit of the modulated stage.

CONSTANT CURRENT SYSTEM

The basic diagram of the system using a choke coil is shown in Fig. 7. This system gets its name from the older of two theories of how it works. To understand the "constant-current" theory, notice that both the plate current of the modulated stage and the plate current drawn by the modulator must pass through the iron-core modulation choke L_1. Since this choke has a high inductance, it will oppose any change of current flowing through it. Therefore, the *total* current flowing through the choke L_1 (indicated by the meter M_2) tends to remain *constant* regardless of what happens in the modulator or the r.f. amplifier.

If a signal is now applied to the modulator grid, during one instant, the modulator plate current may be *increased;* the total current cannot change, however, so the plate current supplied to the r.f. amplifier stage must *decrease.* Similarly, when the modulator plate current is *dropped,* the plate current drawn by the r.f. amplifier must *rise.* In this manner, the plate power fed to the class C amplifier is made to follow the modulating signal. Since the action of the circuit depends upon the *total* plate current remaining constant, this modulation system is commonly called "constant-current" modulation. It is also called "Heising" modulation after its originator.

Plate Voltage Change. A more modern theory of the operation of this circuit is that of changing the r.f. amplifier plate voltage. The modulated stage is operated as a class C amplifier. Hence, the r.f. amplifier grid is biased beyond cut-off, but the r.f. input is made sufficient to carry the short-duration plate current pulses to the saturation point. In this case, the r.f. output voltage developed across the tank circuit L_2-C_2 will vary practically linearly with plate voltage over a wide range of plate voltage values.

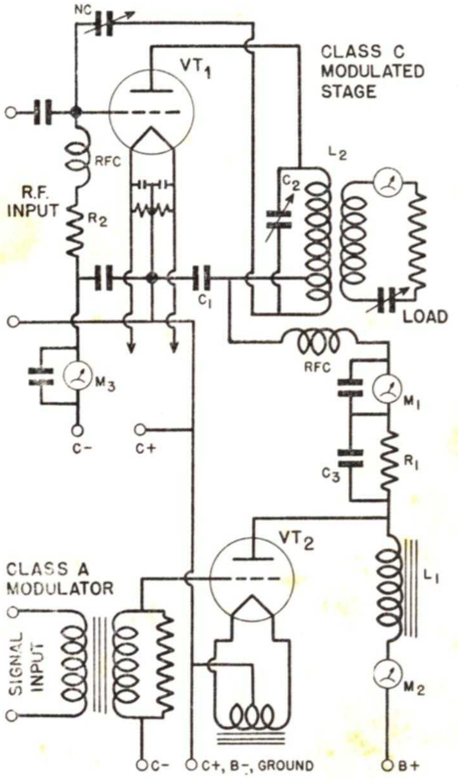

FIG. 7. The Heising or "constant-current" method of plate-modulating a class-C r.f. amplifier.

The modulator develops an a.c. signal voltage across choke coil L_1, which is in the plate circuit of the class C stage. Therefore, as the modulator signal adds to and subtracts from the class C plate voltage, the tank voltage varies up and down. Hence, the r.f. output is forced to vary in step with the desired modulating signal.

Getting 100% Modulation. For 100% modulation, the peak value of

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the modulator signal voltage must be equal to the *amplifier* plate supply voltage, so that on a positive signal alternation, the effective amplifier plate voltage will be doubled, and on a negative alternation, the effective plate voltage will be reduced to zero.

However, if the modulator and amplifier in Fig. 7 are operated at the *same* plate voltage, it will be impossible to achieve 100% modulation, because for the required voltage swing, the modulator would need to draw zero current during one part of the signal cycle and an infinite current the next. Not only is this impossible, but a class-A modulator cannot even approach such operating conditions without serious distortion.

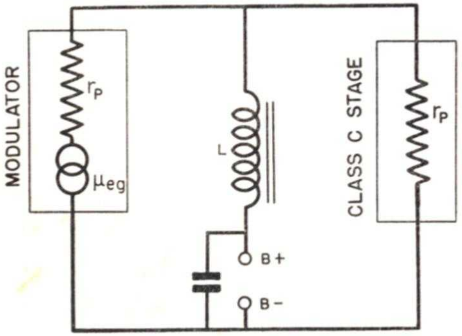

FIG. 8. The class-C stage d.c. plate resistance is the load into which the modulator must work.

This can be overcome to a great extent by operating the modulator at a plate voltage approximately 40% *higher* than that of the r.f. amplifier, by inserting a voltage-dropping resistor in series with the amplifier in the plate lead. Such is the purpose of the resistor R_1 in Fig. 7. (The condenser C_3 is merely a by-pass condenser which shunts signal currents around R_1.) The voltage drop in resistor R_1 lowers the average plate voltage applied to the r.f. amplifier so that the voltage swing required at the modulator plate need not be excessive. That is, it is now possible to swing up to twice the r.f. amplifier plate voltage with a reasonable modulator plate current value. This reduces the distortion on the positive swing, where it is the worst. However, there is still a curvature on the lower knee of the tube characteristic, so some distortion will still occur on modulation peaks above about 95%.

Furthermore, the r.f. amplifier must self-bias itself somewhat. Otherwise, when modulation drives the plate voltage to very low values, the grid current will become excessive. Therefore, the grid circuit of VT_1 contains resistor R_2, so that increases in grid current will automatically increase the bias, and thus tend to stabilize the grid circuit. This also increases the linearity of modulation, as it prevents the grid from excessively robbing the plate of electrons near the modulation troughs, hence permitting the plate current to follow the plate-voltage variations more accurately.

Modulator Power Output. When the constant-current modulation system is operating properly, the *average* plate current drawn by the r.f. amplifier as indicated on meter M_1 will not change for no-modulation and full-modulation conditions. This is the case because with no distortion in the systems, all instantaneous *increases* in amplifier plate current will be counterbalanced by equal and opposite *decreases* the following instant. This means, then, that *the class-C modulated amplifier draws the same amount of average plate power no matter whether it is modulated or not.*

But we know that a 100% modulated carrier has 50% more power than one that is not modulated, this extra power being contained in the side-band frequencies generated. Where does the added power come from? *The added power going into the side bands must be furnished by the modulator. The modulator stage in Fig. 7, therefore, must be capable of delivering audio-frequency or signal power equal to at least one-half the r.f. output power of the modulated class-C stage.*

Since the modulator is developing a.c. power, it must work into the proper load resistance in order to deliver the required power with little distortion and maximum efficiency. This modulator load is not the inductive reactance of the choke L_1 as you might expect; it is the effective d.c. plate resistance of the class-C modulated amplifier, as may be seen from Fig. 8. The choke impedance is extremely high, so only the r.f. amplifier plate resistance approaches that of the modulator. The amplifier plate resistance is assumed to be its applied plate voltage divided by its average plate current. Thus, for the r.f. amplifier in Fig. 7, the load into which the modulator must work is equal to the full B-supply voltage minus the drop in resistor R_1, divided by the plate current (in amperes) indicated on meter M_1. We see then that the class-C amplifier must be adjusted to draw a specific current at a definite plate voltage in order to load the modulator properly to obtain optimum operation.

► Although the constant-current modulation system is capable of giving good fidelity, and was used extensively in early-day transmitters, it is not often employed in modern installations. There are two reasons for this: *1*, it is sometimes difficult to adjust the modulated r.f. amplifier to present the correct load impedance to the modulator; and *2*, the d.c. power lost in the voltage-dropping resistor quite often is excessive.

TRANSFORMER COUPLING

In Fig. 9 is shown a plate-modulation system which does not have the shortcomings of the constant-current arrangement. Here, the signal voltage from the modulator is superimposed upon the class C amplifier d.c. plate potential by means of the modulation transformer T_1. The turns-ratio of the transformer is so selected that the

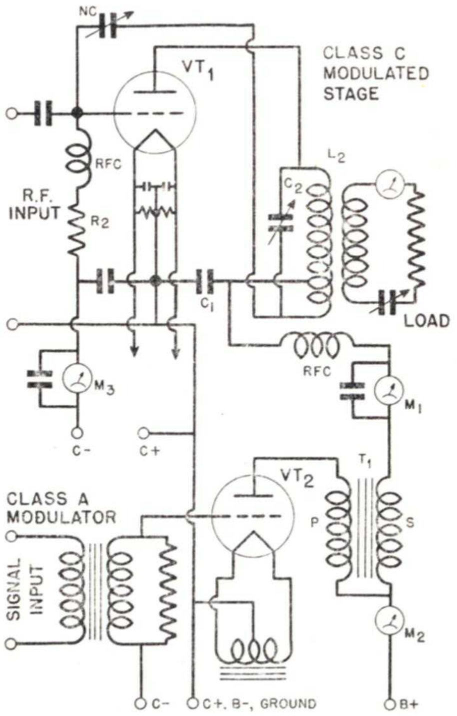

FIG. 9. By use of transformer coupling between the modulator and modulated r.f. stage, 100% modulation can be accomplished without a power-wasting voltage-dropping resistor.

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modulator will not only work into the proper impedance load, but the signal current in the primary P will produce exactly the required voltage swing in the secondary S to give 100% modulation. Notice that a series voltage-dropping resistor is unnecessary. The modulator and amplifier stages may be operated from a common B-supply as indicated, or as is sometimes done, from two separate power supplies.

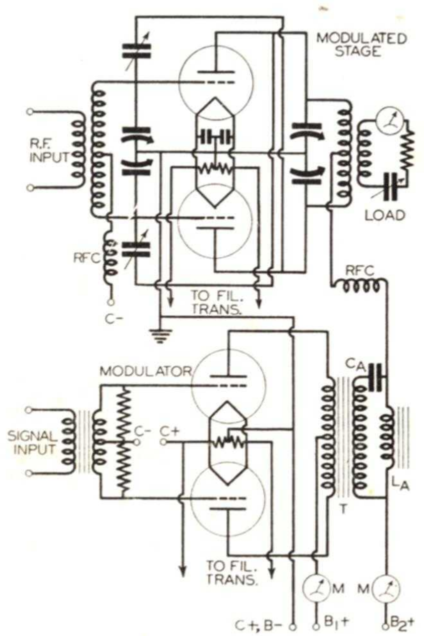

FIG. 10. With transformer coupling, a push-pull class-B modulator can be used for plate modulation, thus increasing the over-all efficiency. In this particular circuit, "impedance coupling" is used between the transformer and the r.f. amplifier plate circuit to keep direct current out of the secondary winding.

But transformer coupling offers other worthwhile advantages. In the constant-current system of Fig. 7 we are limited to the use of a class-A modulator—indeed, no other type of modulator can be used without serious distortion. With transformer coupling, however, such as in Fig. 9, we can substitute a push-pull class-B modulator, and since this type of audio power amplifier has approximately twice the efficiency, we can almost double the power efficiency of the system.

The typical manner in which a class-B transformer-coupled modulator is used to modulate the plate voltage of a class-C stage is illustrated in Fig. 10. Although a push-pull r.f. circuit is shown, the action is identical with a "single-ended" high-frequency amplifier.

► You may notice that in Fig. 9 the plate current of the r.f. stage is allowed to flow directly through the transformer secondary S. This is permissible where the modulator draws a d.c current (through the primary) that is about equal to the class C current, because the two d.c. fluxes can be made to cancel. Hence, the transformer can be far smaller than the choke needed in the constant-current system.

However, where the d.c. currents are far different, the transformer must be properly designed if distortion caused by core saturation is to be avoided. This is particularly a problem when the modulator is a push-pull type as in Fig. 10. As you know, the d.c. currents in a push-pull circuit produce cancelling fluxes, so in Fig. 10, the transformer T essentially has no primary d.c. flux. Hence the r.f. amplifier d.c. current must be kept out of the secondary if an exceptionally costly transformer design is to be avoided. This may be accomplished, as in Fig. 10, by "impedance-coupling" the transformer secondary to the modulated stage plate circuit. Condenser C_A, large enough in capacity to pass signal currents without attenuation, acts as a blocking condenser to keep direct current from flowing through the secondary. At the same time, the high-inductance choke L_A presents a low-resistance d.c. path through which plate current to the r.f. amplifier can flow.

PARTS VALUES

The inductance values of the iron-core chokes L_1 in Fig. 7 and L_A in Fig. 10 are important. These coils must have a large inductance so that their reactance at the *lowest* signal frequency will be at least five times greater than the plate impedance of the class-C amplifier being modulated if low-frequency signals are not to be attenuated more than 1 db. These chokes, also, must have negligible distributed capacity so that their reactance will not decrease at the higher signal frequencies.

► The capacity values of r.f. by-pass condensers C_1 in Figs. 7 and 9 also are important. These condensers should be large enough to by-pass the r.f. current effectively, but they must not be so large that signal currents also are by-passed to ground through them. At the *highest* signal frequency the reactance of each of these condensers must be at least five times greater than the plate impedance of the class-C amplifier for no more than 1 db signal attenuation.

It is interesting at this point to consider the push-pull class-C modulated stage in Fig. 10. Since this stage is perfectly balanced by the use of cross-neutralization and split-stator tuning condensers with rotors grounded, there are no r.f. voltages present between the grid and plate supply leads and ground; consequently, no r.f. by-pass condensers are necessary. With no r.f. by-pass condensers present, very little signal current from the modulator will be shunted to ground through the remaining small capacity. As a result, it is found that a push-pull r.f. amplifier usually can be modulated with less attenuation at higher signal frequencies than a single-ended stage. In addition to the improved efficiency and lower harmonic radiation obtained with push-pull operation, this better response at high signal frequencies is another reason why high-fidelity transmitters quite often use push-pull modulated stages.

DESIGN CONSIDERATIONS FOR PLATE MODULATION

Although you may never be required to design a constant-current or transformer-coupled plate-modulated transmitter, the general principles followed are of interest, and indeed, they serve to illustrate the relative merits of the two plate-modulation systems.

Constant-Current System. It is customary in designing a Heising modulation system like Fig. 7 to select first as nearly correct tubes as possible and then adjust the class-C amplifier for the desired impedance match to the modulator.

Let us suppose we are to design a station having a carrier power of 200 watts. Assuming that the r.f. amplifier has an efficiency of 66%, the (d.c.) supply power input to the amplifier will be 200 ÷ .66, or about 300 watts. The *modulation* efficiency is the same as the amplifier efficiency; hence, if the modulator is to furnish a power equal to half the carrier power, *its power output must be half the d.c. in-*

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put power for 100% modulation. Half of 300 watts is 150 watts.

Class-A modulation is to be used. Tube charts show that a type 851 tube operated as a class-A amplifier at a plate voltage of 2500 volts will deliver about 160 watts of undistorted power; its required plate load is about 5000 ohms. This is close enough to the required 150 watts, so let's use it.

The next step is to determine the requirements for the class-C amplifier, at no modulation. As above, its d.c. input is 300 watts, and it is to deliver 200 watts; hence, it must dissipate 100 watts at its plate. Also, it must look like 5000 ohms to the modulator. Furthermore, its plate-supply voltage must be less than that of the modulator—in fact it should not exceed 2500 ÷ 1.4, or 1785 volts.

Now from this, we can set its plate voltage and plate current from the known conditions that the d.c. power input is 300 watts and the d.c. plate resistance is 5000 ohms. Hence:

$$\begin{aligned} E_P &= \sqrt{PR} \\ &= \sqrt{5000 \times 300} \\ &= \sqrt{1{,}500{,}000} \\ E_P &= 1224 \text{ volts.} \end{aligned}$$

This is under the 1785-volt maximum, and is near the standard value of 1250 volts used in transmitters. Using 1250 volts, the plate current is:

$$I = \frac{P}{E} = \frac{300}{1250} = .24 \text{ ampere.}$$

Therefore, our class-C stage must use a tube that operates at 1250 volts, draws .24 ampere, delivers 200 watts, and can dissipate 100 watts on its plate. No standard tube of exactly this rating is made; however, two 805 tubes in parallel, at 1250 volts, will draw .32 ampere and deliver 280 watts. By adjusting the tank circuit load and driving conditions we can make these tubes draw less current and deliver the required 200 watts.

Since the B-supply voltage available for the modulator tube is 2500 volts, the resistor R_1 in Fig. 7 must have a voltage drop equal to the difference between 2500 and 1250, or 1250 volts. Therefore, resistor R_1 is equal to 1250/.24 or 5200 ohms.

The power loss in resistor R_1 can be calculated from the formula $I^2 \times R = .24^2 \times 5200 =$ almost 300 watts—a large loss in comparison to the radiated power.

You can see that there is a large loss of power by using a class-A modulator; the resistor loss is excessive; and the modulation efficiency is only about 66%. In fact, the over-all efficiency is only about 20%. Of course, if the tubes are specifically designed for this system, the efficiency can be improved, but even so, the load-matching requirements, and the use of the dropping resistor inherently make this an inefficient system.

Transformer Coupling. For this example let us assume that we have a circuit similar to Fig. 9, and that we wish to transmit 1000 watts of carrier and be able to get 100% modulation.

A tube handbook shows that an 833A tube operating in class C with forced-air cooling will be satisfactory for the r.f.-modulated amplifier. This tube requires 3000 volts at 415 milliamperes, or 1245 watts plate power. The efficiency then is $\frac{1000}{1245} \times 100$ or approximately 80%.

To modulate the carrier 100% we will need a modulator capable of delivering approximately 625 watts. Let

us select a class-B push-pull modulator instead of a single-tube circuit as in Fig. 9. Again referring to the tube handbook, we see that a pair of 806 tubes operating at 3000 volts will give 700 watts; and the recommended load impedance (plate-to-plate) is 20,000 ohms.

But the impedance of the r.f. amplifier will be its plate voltage divided by its plate current or:

$$3000/0.415 = 7250 \text{ ohms.}$$

The specification for the modulating transformer then would be:

primary impedance $Z_p = 20{,}000$ ohms,

secondary impedance $Z_s = 7250$ ohms.

And the primary-to-secondary turns-ratio would be determined as:

$$\sqrt{\frac{Z_p}{Z_s}} = \sqrt{\frac{20{,}000}{7250}} = \sqrt{2.75} = 1.66.$$

The transformer, too, must be of sufficient physical size, having a large enough core and large enough wire to handle the required 700 watts without dissipating too much energy in heat. However, this system is far more efficient than the other—no power is lost in a series resistor, and a class B modulator is used, increasing the over-all efficiency greatly.

HOW TO ADJUST PLATE-MODULATION SYSTEMS

Since a plate-modulated r.f. amplifier is essentially a class-C stage, the initial steps taken in putting the circuit into operation are exactly the same as those discussed previously for this type of amplifier.

Adjusting the R.F. Stage. In an arrangement like that in Fig. 9, the r.f. stage first should be neutralized. Next, with coupling between the load and tank coils very small and all voltages normal, r.f. excitation is applied, and the tank condenser C_2 is quickly tuned to resonance as indicated by a sharp *minimum* reading on plate current meter M_1.

Coupling to the load then is increased slightly, and the load series tuning condenser is adjusted for a *maximum* reading of the plate meter M_1. Resonance in the load circuit also will be indicated by a maximum value of current through the load thermoammeter. The tank condenser C_2 is readjusted for a new *minimum* plate-current reading—higher this time because of loading.

Coupling to the load is increased gradually in steps, both the tank and load circuits being tuned to resonance each time, until the minimum reading on plate meter M_1 climbs to the normal recommended value.

Since the modulated r.f. stage will not perform properly unless it is operating in true class C, it is advisable at this point to check for adequate excitation. A slight *decrease* of excitation should make an immediate decrease in current through the load. A slight *increase,* however, should raise the load current but slightly. If an increase in excitation results in a proportionate rise in load current, then the excitation should be raised until no further increase in load current is noted. With this adjustment we make certain that the class C stage is being driven to plate saturation but that excessive drive which might result in abnormally high grid current is not being supplied.

Now, the exact reading of the plate current meter M_1 should be noted.

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This should be very close to the value of current which we know we must draw in order to present the proper load impedance to the modulator. If the r.f. amplifier plate current is too *high*, then the coupling between the tank and load coils should be *decreased;* if the plate current is too *low*, then this coupling should be *increased.* After either adjustment, of course, both the tank and load circuits should be re-tuned to resonance.

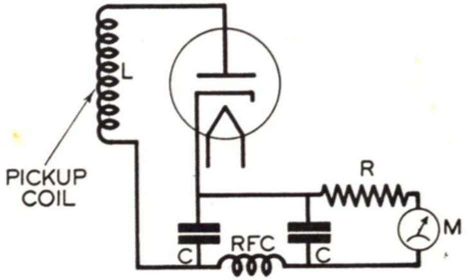

FIG. 11. Carrier-shift indicator circuit.

Checking the Modulation. Once the r.f. amplifier is performing properly, the next step is a test for 100% modulation capability. This is accomplished by introducing into the signal amplifier a *sine-wave current* having minimum harmonic distortion. The gain of the signal amplifier then is raised and the corresponding increase in r.f. load current noted. This is continued until the load current shows an increase of 22.5% over its no-modulation value. There should be *no* change in reading of the r.f. plate meter M_1 while the signal intensity is being increased in this way to the point of 100% modulation. Any variation in r.f. amplifier plate current definitely indicates carrier shift.

Although the plate current meter reading gives a rough check on carrier shift and linearity, it is best to use an independent device such as a cathode-ray oscilloscope or modulation percentage meter. The simple carrier-shift indicator circuit shown in Fig. 11, however, may be used when other means are not available.

When coil L_1 of the indicator is loosely coupled to the tank coil of the r.f. amplifier stage, the rectified current indicated on meter M will be proportional to the average intensity of the carrier. Thus, when the signal drive to the modulator in Fig. 9 is gradually increased to the 100% modulation point and the r.f. load current rises 22.5%, the carrier-shift indicator should show a constant reading during the entire adjustment. Any variations in the indicator meter are to be interpreted as follows:

1. If the reading of the carrier-shift indicator meter *drops*, the trouble may be due to insufficient grid excitation to the r.f. amplifier, to poor power-supply regulation, or to too high a load impedance (too small a load on the plate tank circuit). Increase the grid excitation and increase the coupling between the plate tank coil and the load, and repeat the test for carrier shift. Voltage regulation may be checked by repeating the test while watching the plate-supply voltmeter.

2. If the reading of the carrier shift indicator *increases* before 100% modulation is reached, the trouble is due to improper load (too low a load impedance) on the r.f. amplifier. Loosening the coupling between the tank coil and the load coil is the obvious solution. Modulation greater than 100%, of course, will cause a rise in the carrier-shift indicator reading. In making this test, therefore, be sure the signal voltage is limited to the 100% modulation value.

3. If during the test run the carrier-shift indicator first shows a decrease and then an increase in reading, or vice versa, the trouble probably is due to distortion in the signal amplifiers or the modulator itself. Distortion in the former is checked by the procedure usually followed in improving the fidelity of low-frequency amplifiers, and in the case of the modulator, by making certain that the plate voltage supplied to the r.f. amplifier, divided by its d.c. plate current, is exactly equal to or slightly greater than the plate-load resistance recommended for the modulator.

Control-Grid Modulation

In the discussion of plate modulation systems we discovered that the 50% increase in radiated power occurring at 100% modulation is actually supplied by the modulator. Such is the case because the efficiency of the modulated r.f. stage and the plate power it draws do not change between full-modulation and no-modulation conditions. To supply this relatively high signal power, however, is sometimes inconvenient. Even if the modulator is a class-B push-pull amplifier, it still will be large and bulky in comparison to the r.f. stages of the transmitter.

One method of reducing the modulator requirements is to modulate the r.f. amplifier through its grid circuit instead of the plate. Since the necessary modulator power becomes almost negligible, this method is especially applicable to low-cost transmitters and to emergency or mobile units.

A TYPICAL GRID-MODULATED CIRCUIT

A typical r.f. amplifier circuit to which grid-modulation is applied is shown in Fig. 12. The circuit is operated somewhat between class B and class C, as we shall see. Basically, however, both the r.f. input and the plate voltage applied to the tube are kept constant. The signal voltage is introduced directly into the grid circuit through the transformer T_1. Since the signal voltage is superimposed upon the fixed grid bias, the effective instantaneous grid potential changes with the signal. Therefore, the size of the plate current pulses flowing through the output tank L_1-C_4, and hence, the power output of the stage, are made to vary with the signal, and the desired amplitude modulation is accomplished.

The principle of grid modulation

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can be better understood by referring to Fig. 13A. The tube is adjusted so that it operates along the linear portion of its E_g-I_p characteristic curve, up to but not beyond the saturation point T. The operating grid bias is beyond the cut-off bias value by an amount equal to one-half the grid voltage which would be required to swing the plate current from point T to point R on the E_g-I_p characteristic curve.

The r.f. exciting voltage then is adjusted so that the *peaks* of the plate current pulses will be mid-way on the E_g-I_p curve as at point S. When the modulating signal then is superimposed upon the grid bias, the instantaneous grid voltage may be carried positively up to the saturation point t or negatively down to the cut-off point R. For zero distortion, of course, the operating curve must be perfectly linear, and the rise in plate current pulses from point S to point T must be exactly equal to the drop in current pulse height from point S to point R. The exact manner in which the modulating signal serves to change the grid bias and shift the peak of the plate current pulses up and down the curve is illustrated in Fig. 13B.

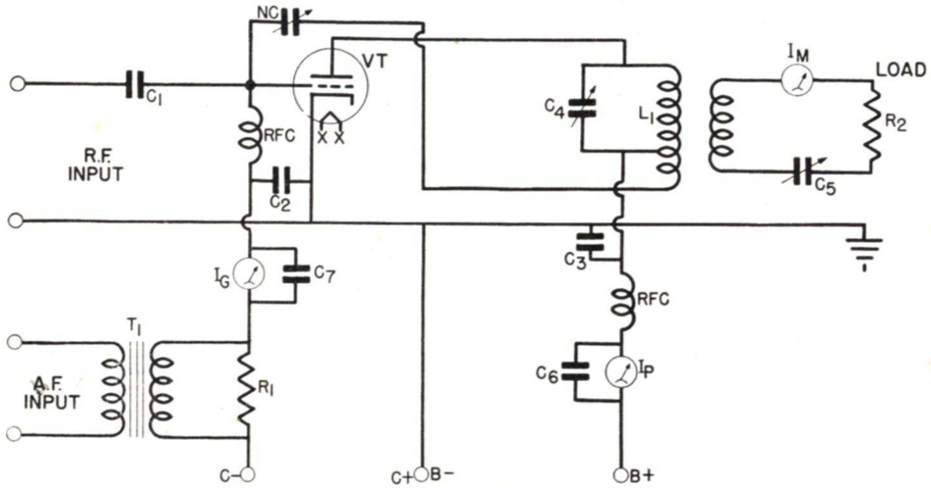

FIG. 12. In this typical grid-modulated circuit, both the r.f. input and the modulating signal are fed to the grid of the class C r.f. amplifier.

The operating grid bias is set in the class-C region, but the excitation is less than usual for class C operation. Operation actually shifts between class B (180° or half-cycle plate current pulses) and class C. Hence, although some engineers call this a class C stage, many consider it a *linear class B* because of the operation over the linear tube characteristic.

Power and Efficiency Relations. The audio or signal power necessary to effect 100% modulation in the circuit of Fig. 12, of course, is very small. Even if the grid is driven appreciably positive as it sometimes is, the power required will not be large. It is usually possible to modulate fully a 1000-watt carrier with only 20 watts of audio power.

The average carrier power obtainable from a given tube in a grid-modulated circuit, however, is only about one-fourth that which can be obtained from the same tube operated as a plate-modulated stage. Why this is so can be understood by referring to Fig. 13B. When the tube is not being modulated, the plate current pulses, as at (1), are only one-half their maximum value. This means that the unmodulated carrier power is only one-fourth that power the tube is capable of handling. It is only during the positive modulation alternation, as at (2), that the plate current pulses are carried all the way to the saturation point, and the full power capability of the tube is utilized.

In any properly adjusted grid-modulation system such as that shown in Fig. 12, the *average* d.c. plate current I_p will be exactly the same no matter whether the stage is modulated or not. Such is the case, just as with the plate-modulation systems, because with no distortion present, any decrease in average current at one moment is always followed by an equal and opposite increase the following instant.

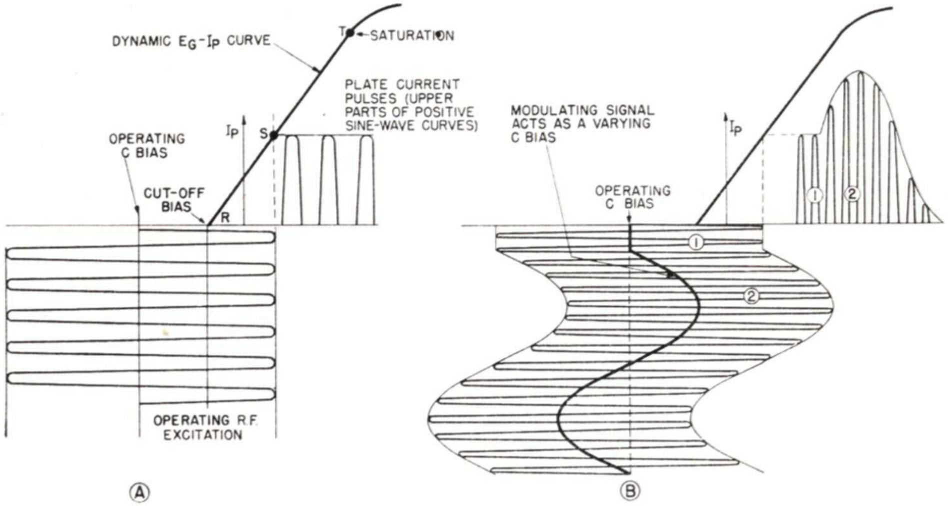

FIG. 13. At A, the unmodulated condition of a grid-modulated amplifier. At B, how the modulating signal changes the grid bias to vary the height of the plate current pulses flowing.

But we know that a 100% modulated wave has 50% more power than an unmodulated one, this additional power being contained in the side bands. If the average d.c. power fed to the stage does not change, and the very small signal power from the modulator certainly is not sufficient to supply this power increase, from what source does the additional power come?

A grid-modulated r.f. amplifier does not have the same efficiency for zero modulation and 100% modulation conditions. Thus, for no modulation as at (1) in Fig. 13B, the efficiency of a grid-modulated amplifier is only approximately 35%. For 100% modulation, however, as at (2), the efficiency rises to about 70%—or just about double!

In other words, when modulation is applied, the amplifier makes more effective use of the d.c. power fed to its plate, and raises its output to supply the added power necessary for the side

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bands. Because of this changing efficiency characteristic, grid-modulation systems are sometimes called "variable efficiency modulation" systems.

Modulation Distortion. The linearity of a grid-modulation system can be made quite good and distortion very low if the grid is not driven positive enough to draw appreciable current; also, the tank impedance acting as load for the r.f. amplifier must be relatively high. These conditions, of course, do not make for maximum power output. If some distortion can be tolerated, as in police and aircraft work, positive grid operation and the use of a lower tank impedance will result in increased output power.

The distortion which may be present in a grid-modulation system most often is caused by non-linearity in the dynamic operating characteristic of the tube being modulated. In modern broadcast transmitters using grid modulation, some form of inverse feedback usually is incorporated to reduce this inherent distortion.

With sufficient drive to make grid current flow, distortion also can be caused if the load imposed upon both the r.f. driver and the modulator does not remain constant throughout a modulation cycle. Modulator and driver, therefore, each must have good regulation. In practical cases, good modulator regulation is obtained by designing the modulator to deliver two or three times the power necessary, and then dissipating the excess in a constant load (resistor R_1 in Fig. 12).

HOW TO ADJUST A GRID-MODULATED STAGE

Just as with any other type of triode r.f. amplifier, the first step in "tuning up" the grid-modulated amplifier in Fig. 12 is to neutralize the stage properly. After this has been accomplished, all further steps are carried out with the express purpose of adjusting the fixed C bias, the r.f. grid excitation, and the loading of the output tank so that the most linear operation possible (consistent with satisfactory output) is obtained. The general procedure is as follows:

First, with the C bias somewhat greater than the plate current cut-off value, set the plate voltage at the recommended value. With no r.f. excitation supplied, the C bias then is gradually reduced until the tube just begins to draw plate current.

A small amount of r.f. excitation is next applied, and this input voltage is gradually increased while the readings of both the plate milliammeter and the load ammeter I_M are noted. When the plate current begins to rise abruptly with no further *proportional* increase in the reading of I_M, the peak operation point has been reached.

At this time the load current meter I_M should be read closely. The negative C bias is then increased until the load current reading is reduced to exactly *one-half* value. The C bias for this condition will be very near the proper operating value—indeed, it will be the exact operating value if the tube is operating in a linear manner, and the load coupling to the tank is optimum.

Plate current drawn by the amplifier also should be very near the normal recommended value for the tube. If not, then plate current may be increased or decreased by tightening or loosening the coupling between the tank and load pick-up coils.

An approximate check for linearity can be made by shifting the C bias temporarily from the operating point back to the plate current cut-off value. This bias change should exactly double the r.f. current to the load. If it does not, then the operating bias should be increased or decreased slightly, and the bias shift test made again.

Now, when a sine wave modulation signal is introduced into the stage, no carrier shift should be indicated as modulation is increased from zero to 100%.

► Two carrier shift conditions may exist when the modulating signal voltage is increased: *1*, The carrier shift indicator reading first rises and then falls; *2*, the carrier shift first falls and then rises.

The first condition can result from poor regulation of the r.f. driver. The remedy is to load the driver tank with a medium-value resistor, then increase the coupling to the grid-modulated stage until normal d.c. plate current flows once more. Either condition could result from distortion in the signal amplifier or modulator stages. The linear operation of these stages should be checked in the customary manner for determining the fidelity of low-frequency amplifiers. Either condition also could be caused by the output tank circuit, with load coupled, presenting the improper impedance to the tube. This is the most difficult adjustment of all, and several test runs using various degrees of load coupling may need to be made before the optimum adjustment for minimum carrier shift is found. A good guide in making proper load adjustment is to see that the r.f. power output with no modulation is approximately 30% of the plate power input.

When all adjustments have been completed, the r.f. output meter will show a 22.5% increase in reading over the no-modulation value when a sine-wave signal sufficient for 100% modulation is applied.

Other Methods of Amplitude Modulation

There are a number of ways of obtaining amplitude modulation in addition to plate or control-grid modulation. However, only a few of these methods are in practical use. In this section we shall cover only the more important types.

MODULATING THE SCREEN GRID OR THE SUPRESSOR GRID

An r.f. amplifier using a pentode tube can be amplitude-modulated by superimposing the modulating voltage upon the voltage applied to either the screen grid or the suppressor grid. Fig. 14 shows where the modulating voltage may be applied in either case.

The curve of r.f. output versus suppressor-grid voltage is shown in Fig. 15. As can be seen, it is impossible to obtain complete modulation without introducing distortion, and the distortion for modulation greater than 80% increases severely. It is possible, however, to obtain 100% modulation with very little distortion using tubes especially designed for the purpose.

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Suppressor-grid or screen-grid modulation, like control-grid modulation, gives a carrier efficiency of only about 35%, but an extremely small amount of modulator power is required. Suppressor-grid or screen-grid modulation is used to a large extent in aircraft transmitters.

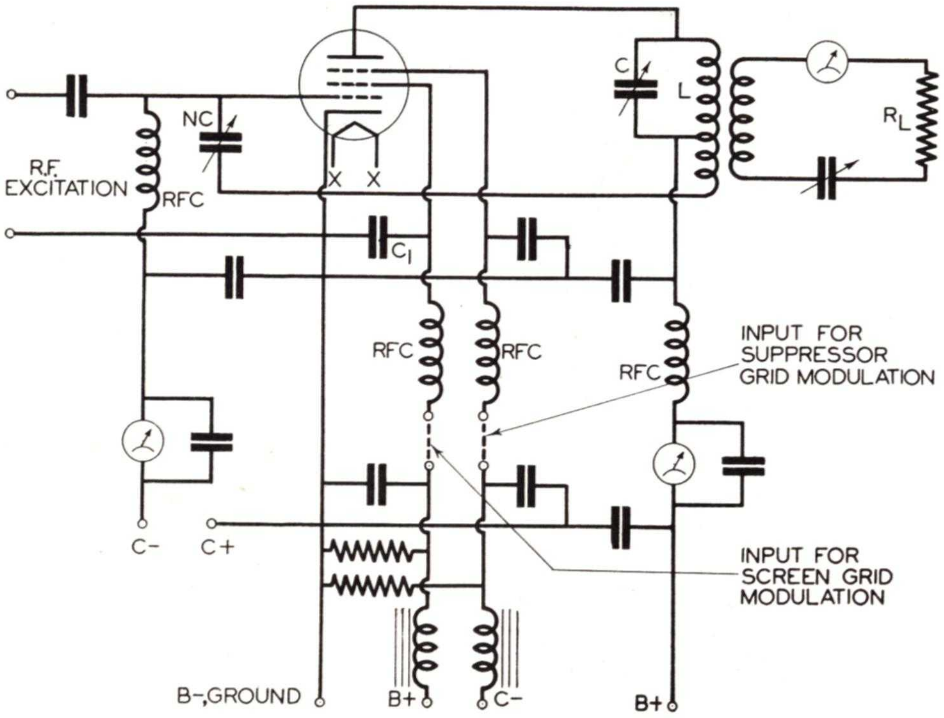

FIG. 14. Typical r.f. amplifier circuit for suppressor-grid or screen-grid modulation.

Method of Adjustment. The adjustment of screen-grid or suppressor-grid modulated amplifiers is very similar to that of the control-grid modulated circuit. With C bias greater than cut-off, the plate, screen-grid and suppressor-grid voltages are first set. With no r.f. excitation, the C bias then is reduced gradually until plate current just begins to flow.

Excitation next is applied and is increased slowly until the output current fails to show a proportionate rise. Recognizing that the tube operates at about 35% efficiency, you should adjust the coupling to the load for proper plate current.

After this peak operating condition has been reached, the negative suppressor grid voltage is increased in steps (or the positive screen voltage is reduced) and the value of r.f. current to the load for each step is recorded. The results are then plotted in a curve similar to Fig. 15, and the mid-point of the straight or linear portion of the curve determined. For final adjustment, the screen or suppressor bias voltage then should be set to give this mid-point value. Modulating signals introduced into the screen or suppressor grid should be limited so that the voltage peaks do not exceed the shift from the original screen or suppressor voltage to the final operating value.

UNIQUE SYSTEMS

In all the amplitude modulation systems just described, the radiated carrier has a fixed value of power and exists at all times no matter whether it is being modulated or not. Once modulation has produced the side bands by interaction with the carrier, the carrier no longer serves any useful purpose *in transmission;* the side bands alone carry the intelligence. In a sense then, the carrier power radiated by a transmitter represents an unnecessary waste of power. A high-powered carrier can cause undesirable heterodyne interference with distant stations; the presence of the carrier, therefore, increases the "nuisance range" of a transmitter.

Several special modulation systems have been devised to overcome some of these objections. One system removes the carrier before it reaches the transmitting antenna and uses a local oscillator at the receiver to supply a new carrier. This latter step is necessary because a small amount of carrier must be present at the receiver detector to "heterodyne" with the side bands and bring about a true reproduction of the original signals. Another system does not remove the carrier but reduces its value, leaving only enough to be fully modulated by the signals being transmitted from moment to moment. Both of these systems are in some commercial use today.

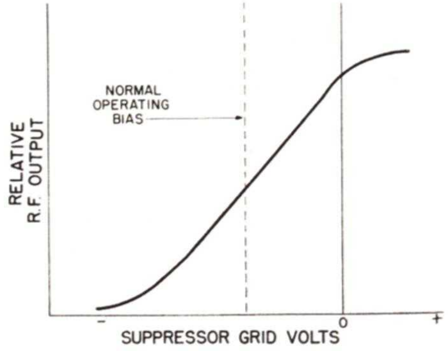

FIG. 15. Linearity curve for typical suppressor-grid modulated class-C pentode.

Controlled - Carrier Modulation. In this method of modulation, the effective carrier current is made to rise and fall in proportion to the intensity of the modulating signal. Thus, as shown in Fig. 16A, with no modulation, the carrier amplitude will be very small. When a low-level modulating signal is introduced, the carrier level is increased slightly as illustrated in Fig. 16B—just enough to accommodate the modulation. The *average* value of the carrier in this case is shown by the dashed lines. For a high-intensity modulating signal, the aver-

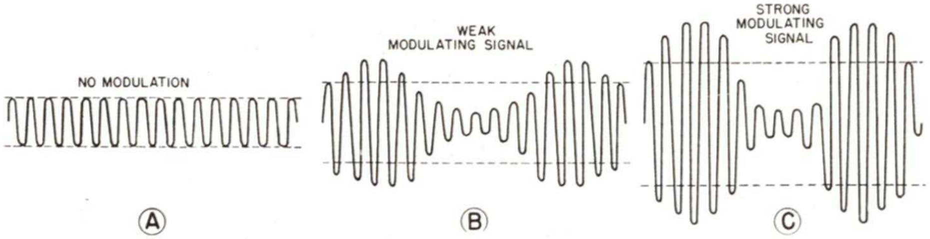

FIG. 16. In controlled-carrier transmission, the carrier is made just great enough to accommodate modulation. Modulation percentage, therefore, is always near 100%.

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age carrier is increased still more as pictured in Fig. 16C. The carrier power thus varies with the strength of the modulating signal, and a strong carrier is used only when a strong signal is present. Of course, when speech or music is being transmitted there will be many signal frequencies present at any one time. For this condition the carrier power will vary with the *average* signal intensity.

In order to secure this type of controlled carrier it is necessary that the plate voltage, and hence, the input power, of the r.f. stage be changed in some way to follow the *average* variations in signal intensity. Many circuits have been devised to do this satisfactorily. One of the simplest methods is illustrated in Fig. 17.

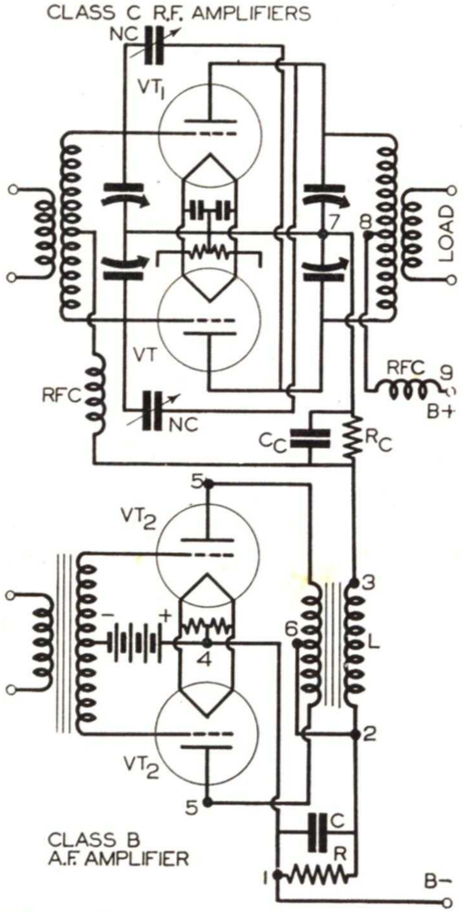

FIG. 17. Circuit for controlled-carrier method of modulation.

Tubes VT and VT_1 are arranged in a conventional push-pull r.f. amplifier circuit. Since the applied plate voltage will be changing from moment to moment, fixed C bias cannot be used; instead, the tubes are self-biased by means of a bias resistor R_C and bypass condenser C_C so that true class-C operation will be obtained at any plate voltage.

Tubes VT_2 are used to form an ordinary push-pull class-B modulator. It should be noted, however, that the modulator is inserted in *series* with the r.f. stage, appearing between the filaments of the r.f. stage and the negative power-supply terminal. (Trace the circuit from B+, at terminal 9, to 8, through VT_1 to 7, through R_C to 3 of L, to 2, then to 6, through VT_2 to 4, thence to 1 and B—.) This arrangement does *two* things: *1,* modulation is introduced in the cathode leg of the B supply; and *2,* since the plate current of the r.f. tubes must also flow through the modulator tubes, the total B-supply voltage will be divided between the r.f. amplifier and modulator stages.

When there is no signal applied to the modulator grids, these tubes will pass very little current and there will be a large voltage drop across them. As a consequence, there will be very little plate current flowing through the r.f. stage, its effective plate voltage will be low, and the no-modulation carrier output will be reduced to a small value.

When the modulator tubes VT_2 are driven with a signal, however, two things result: *1,* the *average* voltage drop across the modulators decreases, thereby permitting a larger fraction of the plate-supply voltage to appear between the plates and filaments of the r.f. amplifier tubes, so that the *average* carrier power is increased; and *2,* the modulator current flowing through the primary of the modulation transformer will induce signal voltages in the secondary which bring about plate-modulation of the r.f. stage in a normal manner.

The average carrier current increase with modulation is controlled to a great extent by the values of resistor R and condenser C; these components are so chosen that sudden signal peaks will not be modulated proportionately.

► This controlled-carrier system is used in certain mobile stations. One of the main advantages is that the percentage of modulation is always very near 100 regardless of the intensity of the signal, and the efficiency of the system is very high. Some over-modulation will result because the carrier cannot be made to follow the signal intensity changes instantaneously. In transmission of speech, however, this is no serious disadvantage, for considerable distortion is permissible without loss of intelligibility.

Carrier Suppression Systems. Instead of limiting the carrier power to a value just sufficient to maintain modulation, the carrier power may be suppressed entirely and then a new carrier from a local oscillator can be supplied at the receiver. With the carrier eliminated at the transmitter, the only power radiated is the useful power contained in the side band frequencies.

The carrier usually is suppressed in the r.f. stage being modulated, the preceding master oscillator and low-power amplifiers working in normal manner. One suppressed-carrier modulator in actual use is the "balanced modulator" illustrated in Fig. 18.

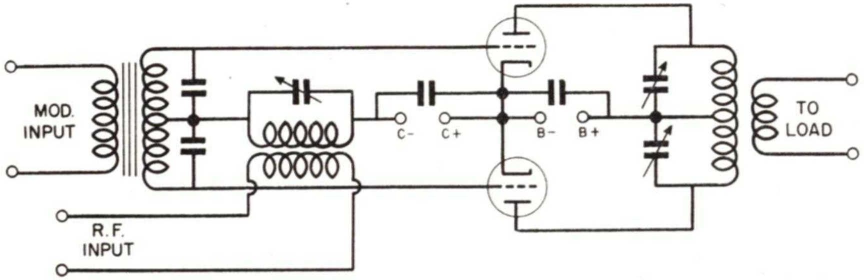

FIG. 18. The balanced modulator for suppressed-carrier transmission. Output to the load consists of side bands only, with the carrier reduced to zero.

This modulator is essentially a grid-modulation arrangement for both the r.f. input and the modulating signal are fed into the grid circuit. However, notice that the r.f. excitation is fed into the center-tap of the signal input transformer. Both the grids thus get identical r.f. input voltages—that is, both tube grids are driven positive at the same time and negative at the same time by the r.f. voltage. On the other hand, the center-tapped output tank, which is tuned to the r.f. carrier frequency, is connected in push-pull. We find, then, that although r.f. excitation

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is supplied to the two tubes so that they draw plate current, the two plate currents flow through the output tank coil in *opposite* directions, and hence, the resultant magnetic fields tend to cancel each other. As a result, if the circuit is perfectly balanced and the two tubes draw exactly the same current, the r.f. carrier output without modulation will be zero.

A modulating signal can now be applied to the signal input transformer. Because of the push-pull connection, the tube grids will be fed modulating signals that are *180° out of phase*—that is, when the signal voltage at one grid is positive, that at the other grid is negative, and vice versa. This action, of course, upsets the normal balance of the circuit. As a consequence of the plate current having to "jump" into step with the combined grid signals, we find that two frequencies are produced; one at a frequency equal to the carrier frequency *plus* that of the modulating signal, while the other has a frequency equal to the carrier frequency *minus* that of the modulating signal. These two "sum and difference" frequencies, of course, actually are the side bands, and since they do not cancel each other in the push-pull output tank, they are passed on to the load through the load coupling.

In over-all performance then, the balanced modulator output is zero when there is no modulating signal; and during modulation, only the side bands are fed to the load, the carrier output remaining zero.

Actually, for complete carrier suppression, it is essential that the modulator circuit be perfectly balanced. In addition to identical tube characteristics, it is necessary that the transformer and output tank be accurately center-tapped and all stray inductance, resistance, and capacity be exactly the same on each side of the balanced circuit. In practice it is usually necessary to incorporate additional variable resistors and capacitors to balance up the circuit. These are not shown in the circuit diagram.

The power efficiency of a balanced modulator is extremely low, and for this reason it is almost invariably used in a very low-level stage in the transmitter. Since the output still changes in amplitude with modulation even though the carrier is missing, the following high-power stages must be class-B linear amplifiers.

Single Side-Band Transmission. *Both* upper and lower side-band frequencies are transmitted in the suppressed-carrier system of modulation, and it is highly important that the new carrier supplied at the receiver has exactly the same frequency as the original carrier and also be properly phased in relation to the side-band frequencies. This is not easily accomplished. Furthermore, any frequency drift in the receiver local oscillator will cause considerable distortion.

Much more satisfactory reception can be obtained if only *one* side-band frequency is transmitted. With a single side band instead of two, it has been found that the receiver oscillator frequency may change as much as 50 cycles without making speech unintelligible. Besides making reception conditions less critical, the transmission of only one side band reduces the frequency spectrum required, thus allowing two stations to operate where only one could before.

Briefly, single side-band transmission is accomplished by first suppressing the carrier in a balanced modulator circuit, and then passing the resulting side bands through special filters which are sufficiently selective to remove one side band while passing the other.

At the receiver, the single side band is combined with the output of a local oscillator tuned to the frequency of the original suppressed carrier—just as is done with dual side-band transmission.

Keying the Transmitter

In the transmission of telegraph code signals, the transmitter carrier power is simply turned on and off in a particular manner to produce at the receiver an audible tone which is broken up into short and long pulses representing dots and dashes. Each short and long tone should be clear and distinct, and the intervals between dots and dashes must be free of any residual tone if the operator or the automatic receiving device is to distinguish the different characters readily.

Constant-amplitude carrier energy radiated by a transmitter, however, even though broken up into dots and dashes, will not ordinarily produce a tone at the receiver; indeed, all that will be heard will be a series of clicks. To make the dots and dashes appear as an interrupted tone it is necessary either that the transmitter carrier be modulated by an audible tone or that the received energy be "processed" in some manner at the receiver.

There are several ways of making the dots and dashes audible. One of the first methods used accomplished this by using 60-cycle alternating current instead of direct current for supplying plate power to one or more r.f. stages in the transmitter. The result, of course, was a 60-cycle amplitude-modulated r.f. output; and when the transmitter was keyed, the dots and dashes at the receiver were really short and long periods of 60-cycle hum. Audibility accomplished in this manner gave signals that were rough, harsh, and unpleasant; and worst of all, the 60-cycle frequency was so near the lower limit of hearing that it was often difficult for the operator to distinguish the various dot-dash combinations. This method of modulation has been entirely discarded.

A second method of making the dots and dashes audible involved grid-modulating one of the transmitter stages with an audio-frequency tone of about 500 cycles. The result was dots and dashes of pleasing tone well within the range of hearing. This method, once very widely used, is still employed to a limited extent today. Its principal disadvantages are that it requires auxiliary modulator equipment and the fact that the 500-cycle modulation produces side bands at least ½ kilocycle above and below the carrier frequency so that the transmitter occupies more of the frequency spectrum than is actually necessary.

A third method, and now the one most widely used, does not modulate the carrier frequency at all. Indeed, the constant-amplitude continuous-wave carrier is simply turned on and off with the telegraph key. For audibility at the receiver, the received car-

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rier signals are heterodyned against the output of a local oscillator to produce an audio-frequency "beat note."

There are several reasons why this continuous-wave method has supplanted nearly all others: Not only does it permit a maximum amount of power to be radiated, but since there is no tone modulation, the transmitter can operate over a very narrow frequency band. The receiving operator also can adjust the tone of the received signals simply by varying the frequency of the receiver "beat" oscillator. This feature is particularly helpful in discriminating against interfering signals.

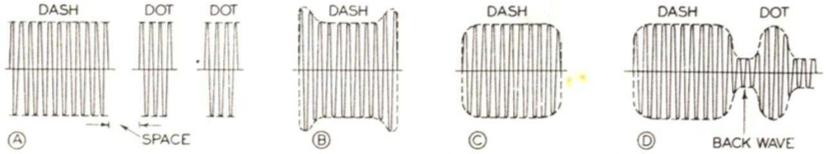

FIG. 19. Envelope shapes of dots and dashes that may be radiated by a code transmitter. Form at C is preferred because it creates the least interference.

Since the difficulties which arise in all keyed transmitters are much the same, the following discussion of continuous-wave telegraphy will cover the various types of code transmission.

DIFFICULTIES WITH KEYING

At first glance, it might appear that the keying of a continuous-wave transmitter should produce wave transmissions similar to those in Fig. 19A. It does seem reasonable to expect that this type of transmission would produce side-band frequencies separated from the carrier by no more than the relatively low frequency determined by the time interval of a dot or a dash.

As an actual fact, however, such a "square-top" keyed carrier will contain very many harmonics of the fundamental signal frequency determined by the dot or dash length. The second harmonic will be one-half as great as the fundamental signal frequency, the third harmonic one-third as great, and so on. Even the 50th harmonic—fifty times the signal frequency—will have an intensity of 1/50 or 2% of the fundamental signal.

Another disadvantage of such "sharp" keying is that the very sudden starting and stopping of carrier generation may cause surges of current at the beginning and end of each dot or dash as illustrated in Fig. 19B. This "overshoot" makes the amplitudes of the harmonics even greater. Thus, instead of limiting the side-band frequencies to approximately 26 cycles per second (the average when transmitting up to 100 letters per minute), we may have a broad wave which creates intense interference on adjacent channels.

"Rounding" the Dots. By allowing the carrier to rise and fall relatively slowly from maximum carrier power, as shown in Fig. 19C, the higher harmonics of the keying signal frequency may be attenuated greatly. Without higher harmonics, the side bands on each side of the carrier are comparatively narrow, and more code stations can be operated in a given radio-frequency spectrum.

► Not only should the rise and fall of the carrier which produces a dot or dash be gradual, but the interval between must be entirely free of carrier. If the carrier persists when the key is open to form a space, as pictured in Fig. 19D, the so-called "back wave" makes the keying very difficult to decipher.

Key Clicks and Thumps. The process of keying a transmitter may introduce several undesirable effects. Surges of power in r.f. circuits may bring about parasitic oscillations which cause considerable interference. For example, clicks or thumps heard at the end of each dot or dash may indicate that an improperly neutralized circuit is attempting to continue to amplify or oscillate as the plate and grid voltages change under variable loading. Although these sudden parasitic oscillations are of very short duration in an individual r.f. stage, their total time may become appreciable in a multistage transmitter, since each stage increases the duration of the trailing note, causing in effect low-frequency thumps.

Improving the regulation of the power-supply system and suppressing all parasitic oscillations by proper neutralization for all feedback conditions are the remedies for these undesirable effects. In most cases, time delay devices, usually called "click or thump filters" also must be introduced into the keying circuit to make the "build-up" and "dying away" of each dot and dash more gradual.

It is well known that telegraph transmitters that are adjusted for slow speed keying will not be satisfactory for high sending speeds because the time lags in the keying relay and filter circuits may produce "tails" of sufficient length to make the characters run together. In general, however, a transmitter adjusted for high-speed keying will function satisfactorily when keyed slowly.

THE KEYING CIRCUIT

The ideal keying circuit is one that will cause a more or less smooth instead of abrupt change in carrier current when the key or associated keying relay is opened and closed. A number of different keying methods have been used satisfactorily. Let us determine the relative advantages and disadvantages of these methods.

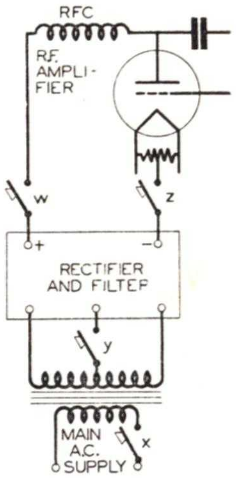

FIG. 20. Four methods of controlling power in plate-power keying.

Plate-Power Keying. It is obvious that removing the plate-supply voltage of one or more r.f. amplifier tubes will stop carrier radiation.

Fig. 20 shows four possible key positions. At x the a.c. power from the power line is keyed; at y the high voltage to the rectifier is keyed; and at w and z the plate supply to the r.f. amplifier is broken. Since it is unsafe to key directly any circuits which carry

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voltages over 110 volts, keying relays are used with plate-power keying.

Each of the keying positions shown in Fig. 20 has its special disadvantages. Keying at point x is practically impossible in high-power transmitters, because huge relays would be required to make and break the large current flowing. For low-power installations, such keying in the transformer primary would be possible only at low speeds; fast sending would be accompanied by chirps and tails, producing signals which are not clear-cut — due primarily to the inductance and capacity in the filter network following the power rectifier stage.

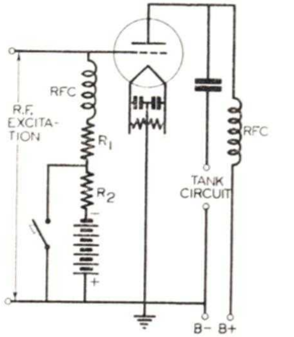

FIG. 21. Grid keying, accomplished by using the key to change the grid bias applied to the r.f. amplifier tube.

These same disadvantages apply to keying at point y, with the additional drawback that suitable high voltage relays are difficult to obtain. Keying at points w and z has proved the best of all plate supply keying methods for high-speed keying. With these, however, clicks and thumps must be eliminated by the use of high-voltage, high-current filter coils and condensers (to be described later).

Keying the Grid Circuit. The carrier output of an r.f. amplifier tube, of course, can be controlled by changing its grid excitation or bias voltage. In grid circuit keying, the grid bias is increased to a high negative value which will cause plate current cut-off; then, the closing of the key reduces this bias to the normal operating value.

One acceptable method of grid keying is shown in Fig. 21. In this arrangement, when the key is open, the battery supplies a high fixed voltage, causing plate current cut-off. When the key is closed, the grid circuit is completed through RFC, R_1, and the key, to ground. While the key is closed, the r.f. amplifier is self-biased by the rectified grid current flowing through R_1. Resistor R_2 prevents short-circuiting of the bias battery or bias supply when the key is closed.

When a voltage divider is used across the power supply, the keying method in Fig. 22 can be used. Plate current cut-off bias is obtained when the key is open because of the large voltage drop in the resistance between the negative supply lead and ground. Closing the key reduces this bias to the normal operating value.

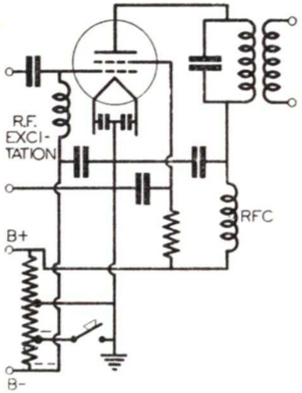

FIG. 22. Method of grid keying when a voltage divider is used across the power supply.

Grid keying of one or more r.f. amplifier stages is generally considered the best available method. Only low-voltage, low-current circuits are handled, and the control over the carrier is positive. This permits fast keying and gives clean-cut characters. This method is widely used.

Keying Multi-Element Tubes. Multi-element tubes can be keyed in their screen-grid or suppressor-grid circuits in the manner shown in Fig. 23. When keying in the screen-grid circuit, as at point y, the screen-grid voltage is varied from zero with the key open to the normal screen-grid operating voltage when the key is closed. The suppressor grid keying method shown at x alternately places a negative and a positive potential on this grid, this in turn causing plate current cut-off with the key open, and normal plate current when the key is closed. By using a double-pole-double-throw relay both grid circuits may be keyed simultaneously.

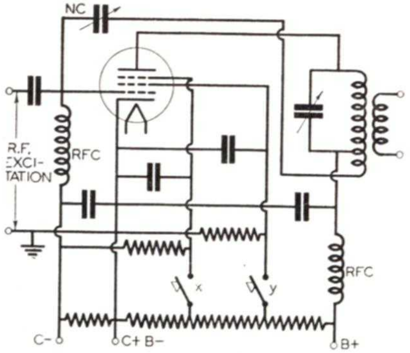

FIG. 23. Keying in screen-grid and suppressor-grid circuits.

These methods are simple, requiring only low-power keying devices. Key clicks are easily eliminated. The outstanding difficulty encountered will be obtaining complete cut-off — that is, eliminating the back wave when a high excitation voltage is applied to the control grid. Some improvement is obtained by controlling more than one stage at the same time.

Filament Center-tap Keying. It is possible to increase the grid bias voltage and reduce the plate voltage simultaneously simply by opening the filament center-tap lead to the high-voltage plate circuit as illustrated in Fig. 24.

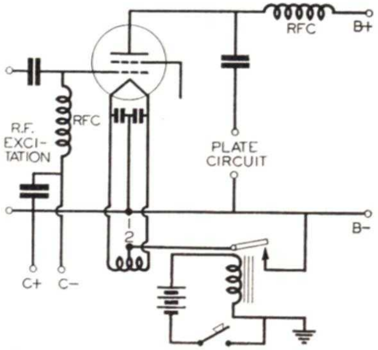

FIG. 24. Filament center-tap keying circuit.

This method is convenient as well as positive in its action and permits fast keying. It does, however, have the one important disadvantage associated with all plate-circuit keying methods; that is, the key circuit and any click or thump filters which may be necessary are at a high potential with respect to ground when the key is open. Then, too, the contacts of the keying relay must not only carry the d.c. plate current but the rectified grid current as well.

PRACTICAL KEYING PROBLEMS

Since most commercial code transmitters must maintain close frequency tolerances, the master oscillator is rarely keyed. As a matter of fact, one or more buffer stages usually separate

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the oscillator from the keyed stage or stages, thus preventing load or plate supply voltage changes from affecting the frequency of the oscillator.

On the other hand, the final high-power output stage of a transmitter is seldom keyed, for this would involve the breaking of high-voltage, high-current circuits.

Keying is most conveniently accomplished in the r.f. driver stage, in amplifiers preceding the driver, or in both.

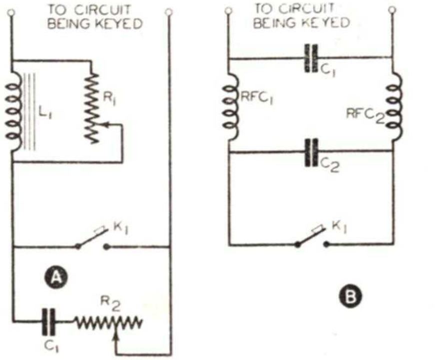

FIG. 25. Keying circuit giving slow build-up and release for elimination of key thumps.

Although the keying of any single stage may be sufficient to control the transmitter, leakage across this stage may allow some r.f. energy to get through and produce a back wave. For this reason, several stages generally are keyed simultaneously; this eliminates all difficulty with back waves, and increases the over-all efficiency by removing plate power when not needed.

In low power code transmitters, where buffer and driver stages are not used, a pentode electron-coupled crystal-controlled oscillator may drive the output stage directly. In such cases, the screen, suppressor grid, cathode or control grid of the oscillator may be keyed. The power supply feeding the oscillator stage, however, must have good voltage regulation to prevent slight frequency variations at the beginning or end of each character which might result in "chirps."

Eliminating Thumps and Clicks. We have already found that it is desirable that dots and dashes build up and die away comparatively slowly in order to reduce unnecessary side bands and to eliminate interfering thumps and clicks. Refer again to Fig. 19.

In order to secure the slow build-up of a dot or dash, it is sometimes necessary to insert a choke coil in series with the keying leads as shown in Fig. 25A. Various coils ranging in inductance from 2 to about 5 henrys must be tried to find the correct value giving just enough lag to prevent thumping. In some instances, as shown in the figure, a large inductance may be shunted with a variable resistor R_1 of about 5000 ohms which can be varied to give the desired time lag.

To increase the die-away time of a dot or dash, the keying contacts also may be shunted with a condenser and resistor as illustrated in Fig. 25A. The amount of "rounding" at the end of a dash or dot is controlled by varying the value of the resistance. Condenser C_1 is usually between 0.05 and 0.25 mfd., and resistor R_2 is approximately 50,000 ohms.

The exact values of capacity, inductance and resistance used in the thump "filter" shown in Fig. 25A will depend to a great extent upon the values of inductance and capacity used in the power-supply filter and the speed with which the transmitter is being keyed. This particular circuit is generally employed in plate and filament center-tap keying circuits.

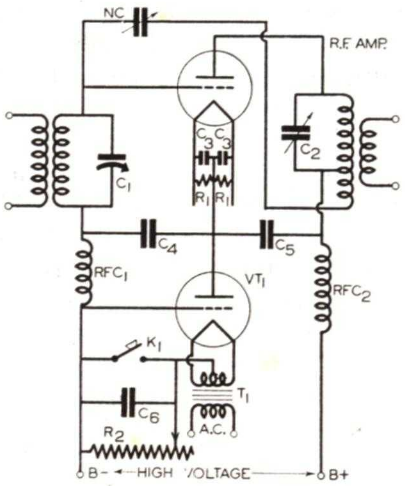

FIG. 26. Circuit for suppressing key clicks.

In control-grid, suppressor-grid and screen-grid keying circuits, key thumps ordinarily are not bothersome. Key "clicks," however, usually arising from stray r.f. current flowing through the "arcing" at the key contacts, may need to be eliminated. Clicks can be suppressed by using a simple r.f. filter as shown in Fig. 25B. If one side of the keyed circuit is grounded, one r.f. choke and one condenser will suffice, the choke being placed in the "hot" lead. Two chokes are required where the keyed circuit is at an r.f. potential at all times. The r.f. chokes may have approximately the same inductance as the chokes used in the supply leads of the amplifier circuit. The condensers ordinarily are about 0.005 mfd. or less.

Use of Keying Tube. When the center-tap filament keying method is employed, the make-and-break can be delayed by using a vacuum tube as an automatic variable resistor. This use of a "keying tube" is illustrated in Fig. 26.

When the key is closed, the tube VT_1 has zero grid bias so that its plate-to-filament resistance is low, thus allowing the r.f. amplifier to operate normally. When the key is open, the bias applied to VT_1 is very high because of the large voltage drop across resistor R_2. The plate resistance of the keying tube, therefore, becomes very high and effectively cuts off plate and grid supply voltages to the r.f. amplifier.

Tube VT_1 does not reach its high plate resistance immediately after the key is opened, however, because it

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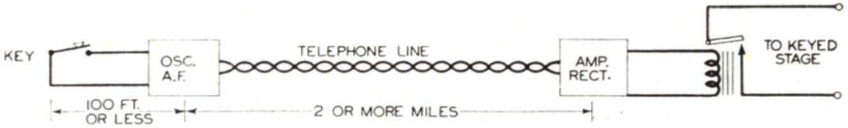

FIG. 27. Use of vacuum tube as automatic variable resistor for keying delay action.

takes a definite time for condenser C_6 to charge. When the key is closed, the plate resistance of VT_1 may drop instantaneously, but the r.f. amplifier builds up the carrier gradually because of the time required in discharging condenser C_4 and charging C_5.

Remote Keying Circuits. Although telegraph keys are drawn in all the circuit diagrams showing the different methods of keying, it should be understood that these actually may represent the contacts of keying relays. Such relays are always used in high-voltage circuits and they are also needed if the operating key is located several hundred feet from the transmitter.

When the transmitter is located many miles away from the keying point, it is not desirable to interrupt direct current flowing to the relay over a long telephone line, because the inductance and capacity of the line will very likely lower the permissible keying speed. In such cases it is usually necessary to employ a remote keying circuit similar to Fig. 27. The key is used to turn on and off a local audio-frequency oscillator, the output of which is fed over the line to the remotely keyed transmitter. At the transmitter, the audio-frequency dots and dashes are amplified and rectified, and the resulting d.c. pulses are used to actuate the keying relay.

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Lesson Questions

Be sure to number your Answer Sheet 20RC.

Place your Student Number on *every* Answer Sheet.

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

1. What three types of modulation may be employed for the transmission of voice signals?
2. What three frequencies are present in the output wave of a transmitter operating on a carrier frequency of 1100 kc. and being modulated by a 400-cycle sinusoidal tone?
3. During 100% modulation, what percentage of the carrier power is contained in the two side bands?
4. Why is a high percentage of modulation desirable?
5. What percent increase in antenna current will be observed when a radiotelephone transmitter is modulated 100% by a sine-wave audio tone?
6. A modulator stage is to plate modulate a class C radio-frequency amplifier. What is the load into which the modulator must work, and to which it must be matched?
7. Suppose you are using a carrier shift indicator to check a plate-modulated transmitter. What possible troubles are indicated when the carrier shift meter reading drops when the modulation percentage is increased?
8. Draw a simple sketch of a plate-modulated system using transformer coupling between the modulator and the modulated stage.
9. Why is it desirable that the dots and dashes radiated by a code transmitter be more or less rounded instead of square-topped?
10. What is usually done to eliminate back waves in code transmission?

YOUR HEALTH

There is a definite relationship between a man's mental ability and his physical condition; for example, overeating is generally followed by a lazy feeling and a desire to sleep. The mind becomes less active. A headache may develop, along with a gloomy, crabby, or disgusted-with-life-in-general feeling. Certainly a man cannot do his best work when feeling this way.

Blue Mondays are quite real, and are caused by too much food and too little mental and physical exercise on Sunday, combined with a troubled sleep or too little sleep Sunday night. It takes several days for the human system to get back to normal after a week-end of excesses, so it may not be until Wednesday that you work with a clear mind. Then you find it easy to concentrate, and work becomes a pleasure. You say to yourself: "How much happier I would be if every day were like this!"

But every day *can be like this*—if you take proper care of yourself, with physical exercise each day in the open air, and a good sound sleep each night. See a doctor if your sleep is not entirely restful.

Give your health the attention it deserves, and you will be rewarded many times by increased happiness and increased success in your work.

J. E. SMITH

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