AN HOUR A DAY...

with

RIDER

on

ALTERNATING CURRENTS

in

RADIO RECEIVERS

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Alternating Currents in Radio Receivers

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AUTHOR'S FOREWORD

THIS volume on alternating currents is predicated upon the idea that a more detailed and elaborate presentation of certain basic a-c. phenomena is desirable—particularly those points that are seldom discussed in detail in the average text and yet are becoming more and more important in the design and operation of modern receivers. In the following pages will be found a discussion of a number of general basic facts about alternating currents encountered in radio receivers. It is our belief that these basic facts are extremely important in themselves because of their diverse applications.

It may be felt by the reader that too much space has been devoted to electron motion; to what constitutes a cycle; to sine waves and the use of degrees as the time base; to phase relations, etc. However it is our opinion that we have aided in the comprehension of what occurs in radio systems and in the power of analysis to differentiate between the action taking place in the different circuits.

We have omitted a discussion of capacity, inductance, and resistance effects in a-c. circuits, for we honestly believe that this subject deserves a volume of its own, which will appear later as another of this "An Hour a Day With Rider" series.

JOHN F. RIDER.

March 13, 1937.

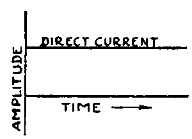
Chapter I

INTRODUCTION

WHAT is alternating current?—As in the case of direct current, discussed in another of this "An Hour a Day with Rider" series, alternating current is the electron in motion. However, in contrast to the type of electron motion exhibited in the case of direct current, the electron motion exhibited in the case of alternating current is substantially different.

In a direct-current circuit there is a steady and constant drift of electrons in one direction around the circuit. This drift is due to the application of a voltage which likewise is constant in value and polarity. An illustration of this conception of direct current is shown in Fig. 1. The constant character and unidirectional flow of the current is represented by the straight, horizontal line above the zero or time axis line.

Fig. 1. The straight horizontal line that is parallel to and above the time axis indicates that direct current flows in one direction and is unchanging in value with respect to time.



In alternating-current circuits we find a somewhat different situation. Alternating current, identified as A.C., does not at all times flow in the same direction. Instead, it reverses its direction of flow periodically and the reason why this happens is that the voltage which causes the current to flow alternately reverses its polarity.

Electron Motion

A large number of men believe that in an a-c. circuit electrons first drift in one direction *around the circuit,* in a manner similar to that found in d-c. systems—and then reverse themselves and drift back in the opposite direction *around the circuit.* It is true that as the consequence of the alternating voltage which is applied to the circuit, the electrons in the circuit move first in one direction—then in the opposite direction, but this is a *to-and-fro* motion or oscillation of the electrons and occurs about a central position and over a very limited distance. It might be well if we portray this motion in the case of a single, typical electron.

To start with, let us assume a varying voltage which changes its polarity. Just how this voltage is generated is of no consequence at this time. Let it suffice to say that the voltage *does* exist. Such a voltage, represented graphically with respect to

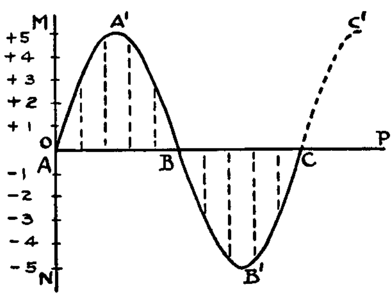


Fig. 2. The curve OA'BB'C is a graphic representation of an a-c. voltage. The horizontal axis, OP, represents time and the vertical axis, MN, represents plus and minus voltage values. The first portion of the curve or wave, OA'B, being above OP, is positive and the other half, BB'C, being under OP, is negative.

amplitude and polarity, appears as shown in Fig. 2. The horizontal line OP represents the zero reference line. The divisions upon this line designate time in arbitrary units so that we can say that the zero reference line is also the time axis. For our purpose we establish 10 divisions upon this time axis and each of these divisions is said to be the equivalent of one one-tenth of a second so that the total number of divisions shown represents a lapse of time of one second. Actually these time intervals are extremely large with respect to normal a-c. practice, but these figures will serve for the purpose of illustrating our point. . . . The divisions upon the vertical line MN represent arbitrary units of electric voltage. For the sake of simplicity, we assume that each of these divisions is the equivalent of one volt.

You will also note in Fig. 2 that the divisions along the vertical axis above the zero line bear plus or positive designations and the divisions along the vertical axis below the zero line bear minus or negative designations. If you examine the curve representative of the voltage, you will find that for a certain period of time—five-tenths or ½ second in this case—the voltage varies between zero and its maximum value above the time axis and in the zone designated as being positive. This means that during this time interval the voltage is plus or positive with respect to the zero line and if applied to an imaginary circuit, one end of the circuit, say "A," would be plus or positive with respect to the other end, "B."

Referring again to Fig. 2 you will find that in another interval of time—again five-tenths of a second—the voltage varies between zero and maximum below the time axis or in the zone identified as being minus or negative. This means that during this interval the voltage is negative with respect to the zero line. If the voltage we speak of is applied to a circuit, the hypothetical point "A" which was originally positive with respect to the other point "B," now would become negative with respect to that point.

What we show in Fig. 2 is actually a graphic representation of an a-c. voltage—wherein the polarity is referred to with respect to the horizontal zero reference line or time axis line.—This is a very meagre discussion of the voltage, it is true—but more details will be given later.

Let us now visualize a single, typical electron being at rest at point X in Fig. 3 and acted upon by the voltage shown in Fig. 2. The application of such a voltage of a certain polarity will tend to cause the displacement or movement of this electron in a certain direction, the direction depending upon the polarity of the voltage. As it happens, the electron always moves towards the plus or positive end of the circuit so that if the voltage shown in Fig. 2 is applied to this electron, it will displace the electron from this point of rest in the direction indicated by the solid line arrow. In making this statement we further assume that when the electron is at point X in Fig. 3, the applied voltage is at zero or point A in Fig. 2.

Starting from point A in Fig. 2, the applied voltage gradually increases and the electron moves in the direction of the solid line arrow until it reaches point Y (Fig. 3)—this, when the voltage has reached point A′ in Fig. 2. Now, while it is true that the voltage starts decreasing in value—its polarity has not changed; hence it continues to exert a displacing force upon the electron, until, when the voltage reaches point B in Fig. 2, which is zero, the electron has reached its furthest point of displacement equivalent to Z in Fig. 3. **Once again we repeat that while it is true that the voltage is decreasing between points A′ and B and it may appear as if it has changed its polarity or direction, such is really not the case—because as you can see the voltage is still in the positive zone.**

At point Z in Fig. 3, the electron is momentarily at rest. This is so because, at this instant, the voltage is passing through point B and for the instant is zero. Progressing from point B in Fig. 2 we now find that the voltage is increasing from zero to a maximum value, but in the *opposite* direction. If, during the first five-tenths of a second when the voltage passed through values A, A′ and B,—the top of Fig. 3 was positive or plus with respect to the bottom—consequently causing the electron to move in the upward direction,—the voltage when passing through points B, B′ and C makes the bottom of Fig. 3 positive or plus with respect to the top, so that the electron, moving towards the positive end of the circuit, now will move from Z towards X. As the voltage increases from B towards B′, the electron moves downwards from point Z until it again reaches point Y—this, when the voltage reaches B′.

Now, we find a situation identical to that which was described before. While it is true that the voltage is decreasing from point B′ to C, it has not changed its polarity from that when it changed in value from B to B′, so that the electron continues moving until it again reaches point X and comes momentarily to rest when the voltage reaches the zero value, point C in Fig. 2.

If we assume, as would be natural, that the voltage is applied to the circuit for a prolonged period of time—then we can see that the electron will move to and fro between points X and Z, about the hypothetical central position Y for as long as the voltage is applied. It is because of the nature of this motion that we made the original statement that the electron in an alternating-current circuit goes through a *to-and-fro* motion about a central position.

It is possible that you may wonder what would happen if the voltage applied to the circuit would not start at zero but would start at point A′ in Fig. 2. Under such circumstances the normal position of the electron still would be viewed as being point X in Fig. 4 and the motion of the electron for the voltage variation

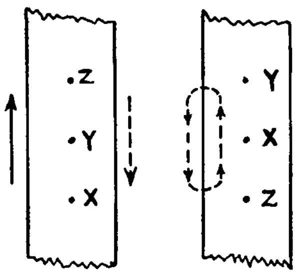


***Fig. 3, left.* Assume an electron at X acted upon by the voltage of Fig. 2. The electron reaches Y when the voltage is at A′ and Z when the voltage is at B. The electron returns to X as the voltage varies through points BB′C. *Fig. 4, right.* Here the voltage is at its maximum value, A′ in Fig. 2, before it acts on the electron, which starts at X, but the reasoning is the same as for Fig. 3.**

between A′ and B would be from point X to point Y in Fig. 4. Then, when the voltage reversed itself and varied between points B and B′, the electron would move back from Y to X and when the voltage continued through points B′ and C, the electron would continue moving through point X until it reached point Z. Then when the voltage reversed itself and moved from point C to C′ (as shown in dotted lines), the electron would reverse its direction of motion and move back from Z to X, as shown in Fig. 4. Thus, the movement of the electron would still be a to-and-fro motion, as indicated by the dotted line arrow. No matter where the voltage would start, the to-and-fro motion of the electron would prevail.

Amount of Electron Motion

At this time it would be quite in order if you asked about the distance the electron moves. . . . Not that this information is of importance from the practical angle—but it is interesting. . . . The distance that the electron moves is a function of the voltage applied, but this displacement is not very great. As a matter of fact, the distance involved in this displacement is extremely minute. The following is given as being illustrative of these distances. As a general rule, the to-and-fro motion of the electron in an alternating-current circuit is less than one ten-thousandth of an inch. It is also interesting to note the speeds at which these electrons travel. These are also surprisingly slow, being almost invariably less than one-hundredth of an inch per second.

A few typical examples will give you an idea as to the speeds and distances which are involved when alternating current flows through a wire. If we consider a #10 wire which is carrying a current of 50 amperes at 60 cycles, then the average to-and-fro motion of the typical electron is about .00002 inch. The maximum speed of drift of the electron in this case is about .003 inch per second.

Suppose that we take a case which is more typical of radio circuits rather than power circuits. Specifically, let us consider the motion of the electron in a piece of #24 wire which is carrying an alternating current of 50 microamperes at a frequency of 1,000 kilocycles. (It is possible that this reference to cycles, kilocycles and frequency is somewhat premature, but we feel that with the discussion which will follow, this reference will be understood.) The to-and-fro motion of the electron under the aforementioned conditions is about .00000000000003 inch or 3 one-hundredths of a millionth of a millionth of an inch.—This most certainly is a very small distance. In this case the maximum speed of the electrons, as they oscillate to and fro, is exceedingly small—being about one-tenth of a millionth of an inch per second.

All Electrons Move

We have stated that as the consequence of the voltage applied, the electron is caused to move in a to-and-fro motion. If this is true of one electron, it naturally is true of all of the electrons in the circuit. Consequently the electrons in an alternating-current circuit do not drift around the entire circuit as in the case of a direct-current circuit—but do drift first in one direction over a small distance and then back in the opposite direction over a small distance—a to-and-fro motion.

Chapter II

CYCLE AND FREQUENCY

Cycle of Current and Voltage

BEARING in mind that the electron in motion is the electric current, let us refer back to Figs. 2 and 3 and again consider the movement of this typical electron—this time for a different purpose. If we assume that the starting point of the electron is X in Fig. 3, then, as the consequence of the voltage applied, the electron moves to its maximum point of displacement, point Z, and then returns to point X—and thereby completes a *cycle* of travel or motion.

If, in accordance with the second example of the movement of the electron due to the voltage applied, the starting point is point X in Fig. 4 and the two points of maximum displacement are points Y and Z—and the electron passes through these two points and again returns to Y—the electron again completes a cycle of motion.

Now, if, instead of speaking about just one electron, we embrace all the electrons in the circuit and recognize a similar motion on the part of all the electrons, then each of these electrons undergoes a complete cycle of travel or motion—and we can feel free to say that alternating current is cyclic,—because the motion of the electron is cyclic. Furthermore, since both the electron and the current are said to be cyclic—it stands to reason that the voltage which causes the motion of the electron—consequently the current—also must have this same character.

Appreciating the significance of the term cycle as it relates to the movement of the electron—you can readily interpret the term as it relates to the voltage. Based upon what is a cycle of electron motion—a cycle of voltage is that period during which the voltage passes through all of its variations of amplitude or value —and polarity. Fig. 2 illustrates one cycle of voltage. Starting at point A, the voltage passes through all of its "positive" amplitude variations between points A and B. Then the voltage passes through all of its "negative" variations between points B and C. Thus, between points A and C, the voltage has passed through all of its amplitude variations and through both designations of polarity—hence has completed a cycle.

Frequency

Referring again to the electron, you can readily see that it is possible for this motion to occur at a slow rate or at a rapid rate. By this we mean that it is possible for the electron to complete a cycle slowly or rapidly. If we use the graphic representation of the voltage shown in Fig. 2 as our basis, and each of the divisions along the horizontal time axis line represents 1/10 of a second, the electron shown in Fig. 3 completes its cycle in a period of time amounting to one second. In other words, the *frequency* of the cyclic motion in this case is one cycle per second.

As a rule, the frequency or periodicity of the cyclic motion is referred to with respect to the number of whole cycles completed in a second.—In the case in point, the frequency of the voltage and of the electron motion is *one cycle per second.* If, on the other hand, the voltage shown in Fig. 2 and the electron shown in Fig. 3 would complete a cycle of amplitude, polarity and motion respectively, in 1/60 of a second, 60 complete cycles would take place in one second and the frequency would then be *60 cycles per second.*—If the cycle is completed in 1/120 of a second so that 120 complete cycles of voltage and electron motion occur in a second, then the frequency of the voltage and electron motion is 120 cycles per second.—If a million-cycle voltage is applied, the cycle of electron motion is completed in one one-millionth of a second.

While speaking of frequency expressed in cycles per second, use is often made of prefixes which denote a multiplying factor. The table which follows illustrates the use of these prefixes and the conversion from one quantity to another:

1000 cycles	=	1 kilocycle	
1,000,000 cycles	=	1,000 kilocycles	(kc.)
1,000 kilocycles	=	1 megacycle	(mc.)

Thus a frequency of 1200 cycles can be expressed in the whole quantity or as 1.2 kilocycles per second. A frequency of 1,750,000 cycles can be expressed as 1750 kilocycles or 1.75 megacycles. A frequency of 20,250,000 cycles can be expressed as 20,250 kc. or as 20.25 megacycles.

Alternating Current

If we now interpret the motion of the electron into current, the same designations apply. . . . In other words, alternating current is identified with reference to both frequency and cycles. . . . An alternating current representative of electrons which complete one million cycles per second is an alternating current of one million cycles or one thousand kilocycles or one megacycle. . . . An alternating current which is representative of electrons in motion which complete sixty cycles in a second, has a frequency of sixty cycles, etc.

A graphic representation of alternating current is illustrated in Fig. 5. . . . The upward direction along the vertical axis or the portion above the horizontal (zero) reference line, represents current flow in one direction along the wire and the downward direction along the vertical axis—or the portion below the horizontal (zero) reference line—represents the current flow in the opposite direction. . . . By means of these two axes—the horizontal for time and vertical for amplitude and direction—it is possible to represent the magnitude and direction of an alternating current at any instant of time. . . . In all such representation of alternating current—the magnitude or the value of the current is shown with respect to time. . . .

Referring to Fig. 5, you will note that we begin plotting the current at the zero value and moving in the upward direction.

. . . Arbitrarily we can set this point as coinciding with the electron at point X in Fig. 3—or momentarily at rest. This point also coincides with point A in Fig. 2. . . .

The current now starts flowing and in accordance with the time designations in Fig. 5, in 1/240 of a second it has reached its maximum value. . . . This corresponds to point Y in Fig. 3 or where, as the consequence of the voltage applied, the electron drift is moving at its greatest speed. . . . In the next 1/240 of a second the current again drops to zero—which point corresponds to point Z in Fig. 3—where the electron, having gradually slowed down after passing through point Y, reaches point Z and momentarily comes to rest. . . . This completes a half cycle or an *alternation*. . . .

The current now reverses its direction of flow as indicated by being shown below the horizontal axis. . . . The electron now starts back from point Z in Fig. 3 towards point X. . . . In 1/240 of a second the current reaches its maximum value in the opposite direction—which means that the electron drift is through point Y towards X at maximum speed. . . . In the next 1/240 of a second the current again decreases to zero, because, as the consequence of the voltage applied, the electron drift speed decreases as Y is approached and the electron again comes to rest at Y. . . . This completes the second alternation and the entire cycle.

Thus you note that the cycle of current is completed when the current goes through all of its variations of magnitude and direction. . . . In the example cited the current cycle is completed in 4/240 of a second or 1/60 of a second. . . . It therefore stands to reason that in one second, 60 such complete cycles of *current variation* and direction occur and the current is identified as having a *frequency of 60 cycles per second.* The illustration in Fig. 5 shows four cycles of such a 60-cycle current.

If we continue with another example of either alternating current or voltage, which has a frequency of, say, 120 cycles per second, then this wave will complete one cycle in 1/120 of a second. . . . Consequently, a wave of this frequency would be represented as shown in Fig. 6. If you compare Figs. 5 and 6, you will find that the shape and character of the two waves are identical, but the one shown in Fig. 6 has twice the frequency of the wave shown in Fig. 5. It completes the cycle of amplitude variation and direction in half of the time required for the current illustrated in Fig. 5.

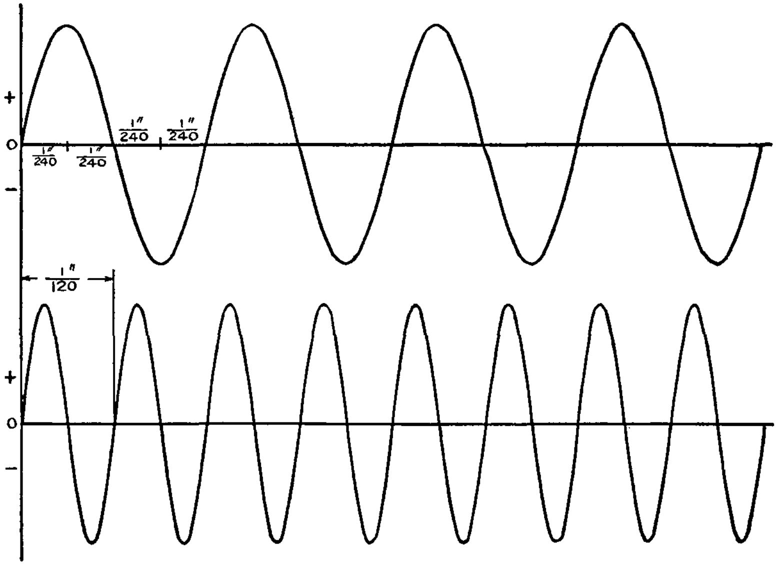
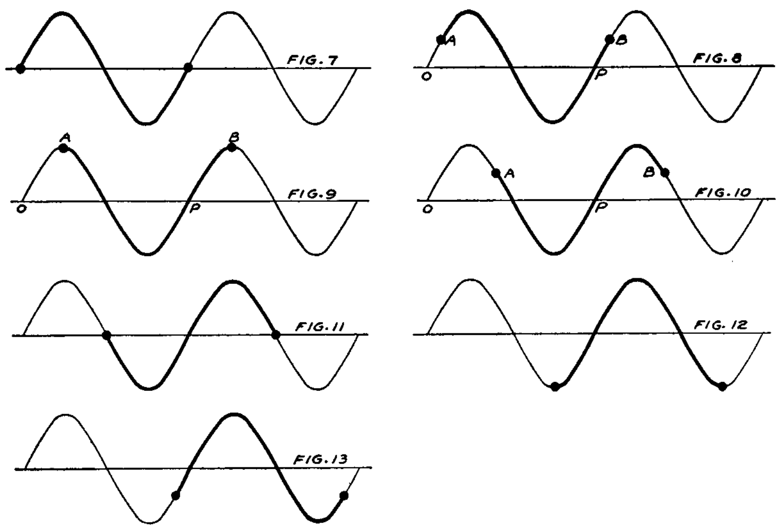


Fig. 5, above. Four cycles of a 60-cycle alternating-current wave, showing the points reached every 1/240 of a second. The wave in Fig. 6, below, is that of a 120-cycle current, which may be seen to have twice the frequency of the one above.

Start of Cycle

By this time it is possible that you may have formed the opinion that a cycle of voltage or current can be represented only by showing the voltage or current starting from zero and ending at zero. . . . Such is not the case. . . . It is possible to start at any point along the cycle, which means at any point along the positive half—or at any point along the negative half. . . . What we mean is illustrated in Figs. 7 to 13 inclusive. These are graphic representations of voltage or current—whichever you may desire.

In each example shown in Figs. 7 to 13 inclusive, the heavily shaded line designates a complete cycle with respect to any one of a number of starting points. . . . As you can see, a number of complete cycles are shown and one cycle is identified. If we consider the illustrations as being representative of current and you examine the points at which the cycles start and at which they end, you will find that between these two limits, the current has passed through all of its variations of magnitude as well as direction of flow. On the other hand, if you consider the il-



Figs. 7 to 13. No matter where the cycle begins, it passes through all the positive and negative values and both polarities.

lustrations as being graphic representations of voltage, you will then find that between the two limits indicated, the voltage has passed through all of its variations of amplitude as well as polarity.

Again considering the illustrations as being representative of alternating current, if we compare Fig. 8 with Fig. 7 and start with point A and end at point B, the current has passed through exactly the same variations as if we started at point O and ended at point P. The current variation represented by OA and apparently lacking from the cycle is compensated for by the current variation of PB. . . . By the same method of reasoning, the current variation shown between points A and B in Fig. 9 is the same as points O and P in Fig. 9. . . . In Fig. 10, the cycle is shown between points A and B and the current variation between these two points is exactly the same as between O and P in Fig. 10.

As you can see in Figs. 11, 12 and 13, it is not imperative to consider the cycle as starting at zero and moving in the upward direction. As a matter of fact, the cycle can start at zero and move in the negative direction, as shown in Fig. 11, or begin at any point below the zero reference line. . . . So much for the discussion of the cycle. Let us now consider some of the other terms relating to alternating current and alternating voltage.

Chapter III

VALUES OF ALTERNATING CURRENT AND VOLTAGE

IN THE previous chapter we discussed the meaning of alternating currents and voltages and had occasion to consider the terms "frequency" and "cycle." Now we are going to concern ourselves with the means of comparing different alternating currents not only as regards frequency, but with respect to amplitude or strength as well.

Peak Value

Referring to Fig. 14, which represents a typical alternating current, we note that although the current varies in magnitude

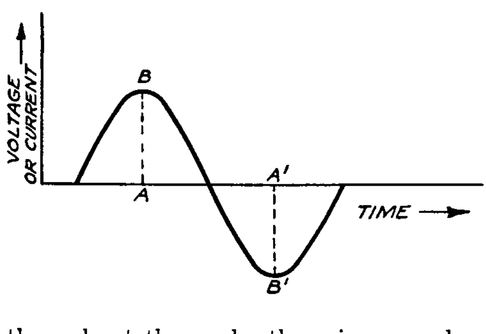


Fig. 14. The positive peak value of this a-c. wave is indicated by the line AB and the negative peak value by A'B'. Note that these are equal but opposite in polarity.

throughout the cycle, there is one value which can be used as a measure of the current strength. This is the so-called *instantaneous peak value* or *maximum value of the current* and is denoted on the diagram by the line AB. AB indicates the *positive* peak value while A′B′ represents the *negative* peak value. Under ordinary conditions these two peak values are equal, but as we shall see later on, special cases occur when the positive peak value is not equal to the negative peak value.

Continuing with the discussion of the peak value, it is evident that it is an instantaneous value which under normal conditions occurs but once in each half cycle, or twice during a complete cycle. We know that other values of current exist in the circuit during the other instants, consequently, the instantaneous peak or maximum value cannot be used as the value representative of all of the instants during which current flows in the circuit.

If we are to use current and voltage, it is necessary to establish a means of comparing values of current and voltage which is based upon *work done*—and whatever this basis of comparison, it then becomes one which is practical, because it embraces all of the instants during which the current varies between zero and maximum. . . . This practical value is known as the *effective value*. . . .

Effective or RMS Value

Let us examine the manner in which this so-called effective value is found. To do so we must accept certain established facts: first, when a current flows through a resistor, a definite amount of heat is developed in the resistor. Second, the amount of this heat depends upon the strength of the current, and third, heat is developed regardless of the direction of current flow, which means regardless of whether the current is a direct current or an alternating current.

Suppose that two resistors of equal value are connected to an alternating-current generator and to a direct-current generator, as shown in Fig. 15. In general, heat will be developed in R1 and R2 and the relative quantities of heat developed will depend upon the relative voltages produced by E1 and E2 and the currents I1 and I2. As a matter of fact, one of the early methods for the measurement of alternating currents was to adjust the direct-current generator E2 until the amount of heat developed in R2 was the same as that developed in R1. When this condition existed, the alternating current through R1 was said to be the "effective" value of current and equal to the direct current in R2.

Let us stop to consider the significance of the above statement. What it really means is that a certain alternating current has an *effective* value of 10 amperes, if this alternating current will produce the same amount of heat in a given resistor as 10

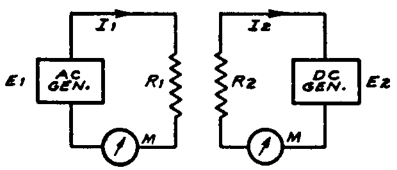


Fig. 15. R1 and R2 are equal in value. When the heat developed in each is the same, then the alternating current is said to have an effective value equal to the current in the d-c. circuit.

amperes of a direct current. Similarly, if the a-c. line voltage is stated as being 110 volts effective, this means that if a resistor is placed across the line, the amount of heat produced in that resistor will be the same as in the case where the same resistor is placed across a direct-current source of 110 volts.

The term *rms* value, which is an abbreviation of the *"root mean square"* value, is often used when the effective values of alternating currents or voltages are indicated. That is, .3 ampere rms is simply an abbreviated way of saying that the *effective value* of the current is .3 ampere. Incidentally, it is interesting to see where the term "rms" comes from. As we stated before, the effective value is arrived at by a comparison of the heat developed by an alternating current with that developed by a direct current. How this is tied up with the root mean square value will be clear to you from the following consideration.

Heating Effect and Effective Value

When an alternating current flows through a resistor, the rate at which heat is delivered varies from zero to a maximum throughout the cycle in accordance with the variation in current. From your study of direct currents, you know that at each instant the heat produced depends upon the *square* of the current rather than upon the current itself. This means that the rate at which heat is delivered will vary in the manner shown in Fig. 16. The reason that the dotted line heat curve is entirely above the zero axis is because the amount of heat delivered to the resistor is always positive and independent of the direction in which the current flows. (If this reference to "heat" and the "square of the current" is confusing to you, just remember that heat is the basis for the unit of power used in electrical circuits.)

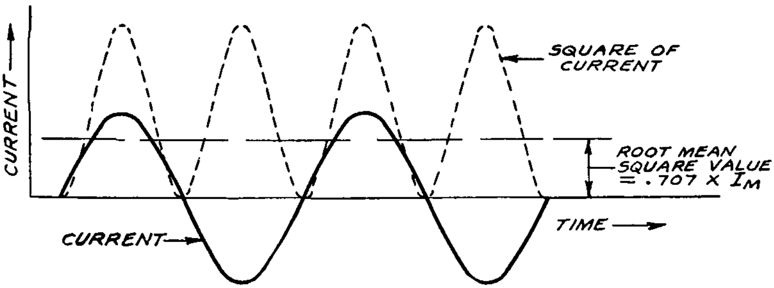


Fig. 16. The rate at which heat is delivered by an alternating current is shown by the dotted wave. This is always above the zero axis, because it is positive no matter which way the current flows. See text for explanation of effective value.

As you can see, the heat curve or the power curve, as it is more generally called, is arrived at by squaring the instantaneous values of the current at each interval during the cycle. In this way, we can establish the average value for the heat produced during the complete cycle by averaging the instantaneous values indicated by the power curve in Fig. 16. The square root of this value—which is the root mean square or rms value, is the *effective* value of the current and from the way in which it is obtained, you can see that it is the current responsible for work done. The mathematics of finding this root mean square value of current is far too complicated for us to work out here. **However, it turns out that the effective or rms value of an alternating current or voltage is equal to .707 times the peak value.**

The explanation for the effective value given above coincides with the definition, wherein

> *"the effective value of an alternating current or voltage is equal to the square root of the mean (or average) of the squares of the instantaneous values."*

It is quite natural to expect the effective value to be *less* than the peak value, because the peak value is the maximum value maintained for only a short space of time during each cycle and during the rest of the cycle the actual instantaneous values of the current are less than the peak value.

The relation between the peak value and the effective value can be stated by the following equation:

$$I_{eff} = .707 \times I_m.$$

For example, if the peak value (I_m) is 10 amperes, the effective value of current is

$$\begin{aligned} I_{eff} &= .707 \times 10 \\ &= 7.07 \text{ amperes} \end{aligned}$$

If the peak value of current is 1.5 amperes, the effective value is

$$\begin{aligned} I_{eff} &= .707 \times 1.5 \\ &= 1.0605 \text{ amperes} \end{aligned}$$

In every case where the peak value of an alternating current is known, you can find the effective or rms value of that current by multiplying the peak value by .707. However, as a general rule, it is the rms value of the current which is known, because this is the value indicated upon the normal run of a-c. meters and it is necessary to find the peak value. Under this condition, the relationship which is useful is

$$I_m = \frac{I_{eff.}}{.707} = 1.414 \times I_{eff.}$$

That is, when the effective value is given, the peak value can be found by multiplying the effective value by 1.414.

For example, if the effective value of current, as indicated upon an a-c. current meter, is 7.5 amperes, the instantaneous peak current, I_m, is

$$\begin{aligned} I_m &= 1.414 \times 7.5 \\ &= 10.605 \text{ amperes} \end{aligned}$$

If the effective value of current is 1. ampere, then the peak current is

$$I_m = 1.414 \times 1.$$
$$= 1.414 \text{ amperes}$$

Whatever the effective value, you should understand that it embraces all of the instantaneous values and is in a sense, a composite value.

It is possible that you may be wondering about the fact that a single peak value is being considered in all of these equations—whereas two moments of peak current are shown in Fig. 14. . . . That is quite in order in as much as the effective value is taken over a complete cycle and in a sine wave, as shown, the magnitude of the peak current for a half cycle is the same as the magnitude of the peak current for the other half cycle—so that only one instant of peak current need be considered in the computations.

Referring once more to the peak value, we want to take this opportunity of stating that as a general rule, the instantaneous peak value of current is not an important consideration with respect to the practical application of the current.

On the other hand, the instantaneous peak value of voltage is an important item, because voltage possesses the ability to puncture a dielectric or to flash across two points and thereby cause damage to equipment. Consequently, both peak and effective value of voltage are to be considered in all circuits. This is so despite the fact that the usual a-c. voltmeter indicates the effective value only. As it happens, equipment designed to withstand certain effective values of a-c. voltage will withstand the peak values encountered in those circuits, because the peak voltage is automatically considered in selecting the insulation or dielectric which is to be subjected to a steady effective value of a certain amount.

Average Value

There is another composite value of current known as the average value. While this is not used to as great an extent as the effective value, it should be included in this text. The average value of an alternating current, as we shall see later, is chiefly of importance in rectifier circuits. For the time being, it will be sufficient for us to explain what is meant by the average value and defer its application until later.

The average value of an alternating current over a complete cycle is zero because the current flows just as long in one direction as it does in the other. In other words, as far as average value is concerned, the positive and negative alternations cancel each other. However, the average value *over a half cycle,* as you can see by reference to Fig. 17, is certainly quite different from zero.

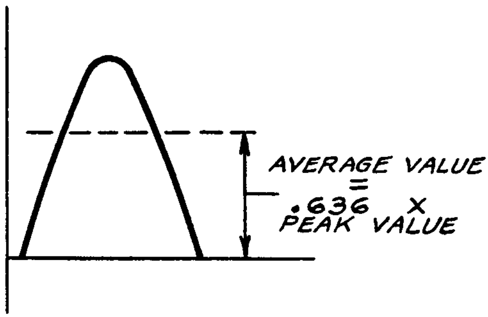


***Fig. 17.** The dotted line indicates the average value of an alternating current for half a cycle.*

Mathematically, the average value of the current is .636 times the peak value of the current.

This relation when expressed in an equation is

$$I_{av} = I_m \times .636$$

For example, if the peak current or voltage is 2.5 amperes or volts as the case may be, the average value over a half cycle is

$$\begin{aligned} I_{av} &= 2.5 \times .636 \\ &= 1.59 \text{ amperes or volts} \end{aligned}$$

Pulsating Currents

We feel that before concluding this chapter we should consider another type of current found in radio systems. This is known as *pulsating current.* While it is true that pulsating current is really direct current—it nevertheless belongs in this volume on alternating currents because pulsating current varies in amplitude. In this respect, it is similar to, although not exactly like, alternating current.

Once again, we are not concerned with the source of pulsating current but rather with the manner in which it differs from direct and alternating currents. The various facts relating to the sources of pulsating current and the parts in a receiver where it appears, will be dealt with in due time. At the present moment let us compare pulsating current with alternating and direct current.

In Fig. 1 is shown a graphic representation of direct current—illustrating the relation between magnitude and time. As has already been mentioned, the constant character of the current is indicated by the fact that the current line is constant at a certain level (indicated upon the vertical axis) with respect to time.

In Fig. 5 is shown a graphic representation of a 60-cycle alternating current. In view of the detailed discussion of alternating currents already presented upon the preceding pages, further details are not necessary.

Now, in Fig. 18 is illustrated a graphic representation of pulsating current. The various axes used are identical to those employed in connection with direct and alternating currents—

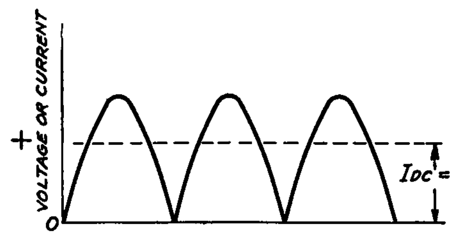


Fig. 18. When all the variations in current are shown above the time axis, this means that the current flows in one direction only and it is called pulsating current.

namely, magnitude and time. Certain important details are to be seen in this figure. First, the current is at all times shown *above* the zero line or time axis. This indicates that the current is unidirectional in flow and that it does not undergo a reversal as in the case of alternating current. Second, the current varies between zero and a maximum value and does so at a regular rate. Correlate these two conditions and we have a direct current which varies in value or amplitude at a periodic rate. Another example of pulsating current is shown in Fig. 19. This illustration looks very much different from that shown in Fig. 18, but in reality the two are the same. One difference between these two currents is simply that the fluctuations in the current shown in Fig. 19 are not as great as those illustrated in Fig. 18. Another difference is that the current in Fig. 18 momentarily is zero whereas the current in Fig. 19 never approaches zero. In Fig. 19 it fluctuates above and below an average steady value within a certain small range.

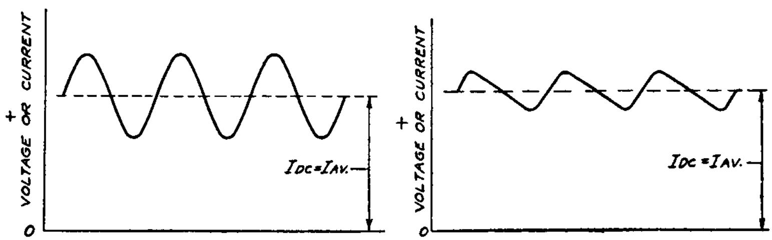


Fig. 19, left. This pulsating current is unlike that of Fig. 18 in that it never reaches zero, but is always positive in value. Fig. 20 shows another form of pulsating current, having the same average value. The wave shape of the alternating component is different.

Referring again to Fig. 18, the fact that the current is shown as varying between zero and maximum does not mean that a d-c. meter placed in that circuit would momentarily indicate zero. Instead it would indicate an average value of current equal to .636 of the peak current, as shown by the dotted line. This is so because the d-c. meter responds to the average drift of the electrons in the circuit.

Components of Pulsating Currents

All such pulsating currents can be said to consist of two parts or components. One of these is the direct-current component and the other is the alternating-current component. Viewing the pulsating current as a composite current, it can be said that the alternating component, whatever its source, is superimposed upon the steady direct current. This is clearly evident in Fig. 19, in that the character of the fluctuations in current resemble the alternating current shown in Figs. 7-13. The greater the magnitude of the alternating-current component with respect to the magnitude of the direct-current component, the greater is the fluctuation of the total current.

Bearing in mind that pulsating current is essentially direct current with a superimposed alternating component, you can readily understand that there always exists some value of steady current which represents an average value. When the fluctuations are of "sine" character, such as shown in Fig. 19, the average value of direct current present in the circuit is the same as if there were no alternating component—because, as has already been stated earlier in this volume, the average value over a complete cycle of a sine wave of current or voltage is zero. Expressed in another manner we can say that the increase in total current during one-half cycle is offset by the decrease in total current during the next one-half cycle; thus the net change in the total current over a cycle is zero—consequently, the value of the direct current does not change over a complete cycle. This average value of current is shown as the horizontal dotted line in Fig. 19. Note that the location of this dotted line, with respect to the alternating-current component, is really the zero line as used in the various alternating-current representations given before.

In this connection it is necessary to bear in mind that we are speaking specifically about the *average* value of the direct current present in the system. While it is true that the sine-wave alternating-current component will not change the average value, —these alternating-current fluctuations occurring at a definite frequency will still give rise to certain effects—which effects, as it happens, must be recognized as far as receiver operation is concerned. Just what happens to this alternating-current component of a pulsating current found in a radio receiver, is deferred to the last chapter.

As to the average value of a pulsating current, which varies in amplitude between zero and maximum as shown in Fig. 18, it is equal to the maximum current times .636. The average value of a wave of current like that shown in Fig. 19 is indicated by the dotted line. Fig. 20 illustrates another example of pulsating current.

In all of the references to pulsating current, the representations can be for voltage rather than current and the average value of voltage is established in a manner identical to that employed for current.

Alternating Voltage

A number of facts have been stated concerning alternating current. These same facts apply in practically every case to alternating voltage. In accordance with what has already been said, we can state simply that a cycle of alternating voltage is completed when the voltage goes through all its variations in value as well as in polarity. Hence, the significance of the cycle as stated for alternating current applies equally well to alternating voltage.

As to the start and finish of a cycle, that which has been said in connection with current and illustrated in Figs. 7 to 13, applies in every respect to alternating voltage with similar identifications being used for both. From what has been said it is clearly evident that the graphic representation of alternating voltage is carried out along exactly the same lines as the graphic representation of alternating current.

When speaking about actual values of voltage, we find a parallel between the voltage and current. In every case the designations and description which we used in discussing the peak value, the average value, and the effective or rms value, apply with equal force and meaning regardless of whether we are considering current or voltage. The equations which specify the relation between the peak and effective value likewise take on the same form for voltage as they did for current. Thus we have

$$E_{eff} = E_m \times .707$$
$$E_m = E_{eff} \times 1.414$$
$$E_{av} = E_m \times .636$$

Applying these formulae, we observe, for instance, that a peak voltage of 1,000 volts a-c. is equivalent to an effective voltage of 707 volts. Similarly, if an ordinary a-c. voltmeter—which incidentally reads effective values—indicates 400 volts, then the application of the above formula shows that the peak value of the voltage is 565.6 volts.

At this time it might be well to clarify the use of the multiplying factors .707, .636 and 1.414. Although it may be premature, it should be understood that these factors apply only when the character of the alternating voltage or current is "sine." This reference to the sine character of an alternating voltage or current will receive more attention later, but we mention it at this time to avoid misunderstanding.

Units

When expressing peak, effective, or average values of current, the following conversion table can be used:

1 ampere	=	1,000 milliamperes	=	1,000,000 microamperes
.1 ampere	=	100 milliamperes	=	100,000 microamperes
.01 ampere	=	10 milliamperes	=	10,000 microamperes
.001 ampere	=	1 milliampere	=	1,000 microamperes

Similarly when expressing values of voltage, regardless of whether they happen to be the peak, the average, or the effective values, the following table applies:

1 volt	=	1,000 millivolts	=	1,000,000 microvolts
.1 volt	=	100 millivolts	=	100,000 microvolts
.01 volt	=	10 millivolts	=	10,000 microvolts
.001 volt	=	1 millivolt	=	1,000 microvolts
1,000 volts	=	1 kilovolt		

Both peak and effective values of current and voltage play an important part in connection with the life and operation of devices used in radio receivers. As a matter of fact, they are of interest in connection with the actual operation of the radio receiver. However, the time is not yet ripe for the correlation between these a-c. terms and receiver operation. At the present time, we are speaking in terms of general theory and much more must be said before the receiver can be brought into the picture. As a matter of fact the manner in which alternating current appears in different parts of the receiver will not be discussed in detail until the very last chapter of this book.

Chapter IV

SINE WAVES

WE HAVE made reference to the word "sine" in connection with the character of alternating voltage and current. . . . What does this mean?

In the first place it refers to a certain type of wave form. . . . Perhaps it would be better expressed as a type of voltage or current which possesses certain definite characteristics. . . . One of these characteristics is that the voltage or current wave has identical positive and negative alternations. . . . But this is not sufficient, because waves other than sine waves can have identical positive and negative alternations. . . . The more complete definition would be—a wave of voltage or current which varies in amplitude in a certain specific manner with respect to time. . . . A definition—but not wholly complete until the manner of amplitude variation is also described. . . . Here we strike a snag.

The reason for our problem concerning the description of a sine wave is because a true definition or description entails reference to trigonometric functions and since this "An Hour a Day With Rider" series is not intended as a mathematical treatise, we must find some means of minimizing such mathematical references. The second reason is that the time element has been brought into the description and that has received but little attention thus far. . . . Hence it must be discussed before we can completely define a sine wave.

It is possible at this time that you wonder why we place so much stress upon the "sine" wave. This attention is due to the fact that, in general, alternating current and voltage calculations are based upon the assumption that the voltage or current under consideration possesses the characteristics of a sine wave. Supplementary to this is the fact that the sine wave represents the basis of comparison; it is the basis of all other types of waves, and is a wave of a single frequency, which in sound is representative of a pure tone. Last, and by far not the least, is the fact that a great deal of testing of radio systems is dependent upon the use of a sine wave.

The Time Axis

Getting back to the time element as it relates to the definition of a sine wave, we have shown the time axis in a number of illustrations thus far. In a few cases the voltage or current being discussed has been associated with a lapse of time expressed in seconds or fractions thereof and the frequency of the current or voltage was identified by stating the time duration for a cycle and the number of cycles which occur in a second.

Unfortunately such time intervals do not serve well when we speak in generalities—because the reference to time elapsed in fractions of a second refers specifically to waves of certain frequencies. To be able to establish time intervals which are suitable for application to all waves of all frequencies and to enable the description of the sine wave—we must express time intervals in *degrees*. The degree is the most convenient time interval, for it is suitable for general description and yet is applicable to specific waves of any frequency. This is so because it allows a division of a cycle into time intervals irrespective of the frequency of the current or voltage.

To illustrate the division of a cycle of alternating current or voltage into time intervals expressed in degrees—it is customary to refer to the rotating type of a-c. voltage generator. This practice, however, should not be construed as limiting such division of a cycle to alternating voltages generated by such rotating machinery only. . . . The division of a cycle of voltage into time intervals expressed in degrees or the use of a time axis divided into degrees is applicable to any and all types of alternating voltages and currents—irrespective of their origin.

This is so because a wave of voltage of a certain character and amplitude developed by one source is identical to another wave of voltage of like character and amplitude developed by any other type of device. The same is true of current which is due to the application of identical voltages developed by different sources.

The added value of the rotating a-c. generator as an illustration is that it permits of the simultaneous mechanical development of a sine wave. . . . In this connection it is of interest to note that sine waves of voltage may be generated by a number of devices other than the rotating type of a-c. generator. However, we use the latter because it is the simplest.

The Rotating Type of A-C. Generator

In order that you have a clear picture of just what happens in such a development we deem it worthwhile to give a brief outline of the unit. Essentially the operation of this type of alternating voltage generation depends upon a basic electrical law. This law states that if a conductor is caused to move through a steady magnetic field in such manner as to cut the magnetic lines of force or flux lines—a voltage will be induced in the conductor and current will flow through the said conductor, if it is a part of a complete electrical circuit. The same electrical law also states that if a conductor is moved parallel to the direction of the magnetic lines of force, no voltage is induced.

Accordingly, the rotating type of alternating voltage generator consists of a uniform magnetic field within which is rotating a conductor arranged in such manner that it cuts the magnetic lines of force. A general idea of such a device is shown in Fig. 21. . . . A conductor in the form of a loop is arranged in such manner that it may be mechanically rotated between the concave-shaped pole pieces of a magnet. The magnetic flux lines fill the space between these pole pieces and as a consequence of the nature of the magnet, this magnetic field is of uniform intensity throughout the space. . . . One of these pole pieces is the north (N) pole and the other is the south (S) pole and the direction of the flux lines is from the north pole to the south pole.

The active sides of the conductor loop are AB and CD. The side AD serves solely as the electrical connecting link between AB and CD. In order to provide contact between the external circuit connected to the generator and the two sides of the loop, use is made of the two collector rings CR1 and CR2, and the two contact brushes, B1 and B2. The collector ring CR1 is permanently connected to side AB and CR2 is permanently connected to side CD. These rings rotate simultaneously with the sides and make a friction contact with the two stationary contact brushes—thereby providing a link between the external circuit and the conductors within the generator.

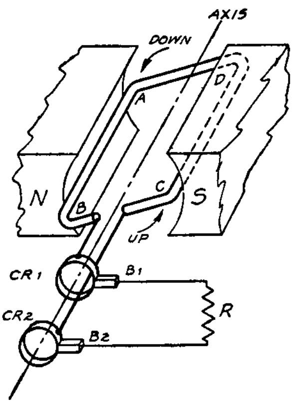


Fig. 21. When the side AB of this a-c. generator moves down through the lines of magnetic force, going from the north pole to the south, it is positive with respect to the other side of the coil, CD. This condition is reversed when CD is moving downward through the lines of force, with the result that the current generated flows first in one direction and then in the other through the resistor R.

As the consequence of the manner in which the flux lines are cut by the moving conductor—certain forces are produced and these result in the condition that the coil side as a whole which moves down past the N pole and cuts the flux lines in the downward direction is positive with respect to the other coil side. In other words, as the side AB is moving down past the N pole and side CD is moving up past the S pole, the net result is that CR1 is positive with respect to CR2.

However, since the polarity is always relative, we can also say that the side CD, moving up past the S pole, would cut the flux lines in the upward direction and be negative with respect to the side AB. The change in polarity of the voltage output of such a generator occurs because at one moment, side AB is moving past the N pole and is positive—and the next moment the side CD moves down past the N pole and then that is positive. With the external circuit connected to the collector rings—first one end of the circuit is positive and then the other end is positive.

As to the magnitude of the voltage developed—this depends upon the manner in which the conductors cut the flux lines. Inasmuch as the conductors describe a circular motion, there are moments when they move in a direction parallel to the flux lines—and there are other moments when they cut the flux lines at right angles—and still other moments when the angle at which they cut the flux lines lies between the two stated limits and is less than a right angle. This is illustrated in Figs. 22-A to 22-I. Only one side AB of the loop is shown, because it suffices to illustrate the manner in which the coil side moves parallel to the flux lines and also cuts across them. The various illustrations show an end view of the movement of coil side AB.

As is evident, the starting point AB in Fig. 22-A represents zero voltage, because at this instant the coil is moving parallel to the flux lines and consequently does not cut these lines of force. However, after passing through point AB1 (all positions of the conductor are indicated by the arrowheads) in Fig. 22-B, and moving through point AB2 in Fig. 22-C, the conductor is cutting the flux lines at exactly a right angle or a 90° angle—and the voltage at that instant is maximum. At AB4 in Fig. 22-E the conductor is again moving parallel to the flux lines—and there is no voltage generated. Thus the movement of the coil side AB from AB to AB4 results in the development of voltage which makes one end of the circuit plus (CR1 in Fig. 21) with respect to the other end—and which voltage varies from zero to maximum and again falls to zero.

When the coil side moves past AB4 and reaches AB6 in Fig. 22-G it again is cutting across the flux lines at a right angle and the voltage is again maximum. At AB8 in Fig. 22-I, which is the starting point as well as the finishing point, the conductor again moves parallel to the flux lines and at that instant the voltage is zero. This completes the cycle of motion or travel of the coil side and likewise the cycle of voltage which is generated during the movement of the conductor. The movement of coil side AB up past the S pole between points AB4 and AB8 results in the development of a voltage, which makes CR1 in Fig. 21

negative with respect to the other end of the circuit—and which voltage rises from zero to maximum, and again falls to zero.

It should, of course, be understood that the movement of the coil sides occurs at a uniform rate and that the variation in voltage described is recurrent as long as the conductors rotate within the magnetic field at the same uniform rate. Furthermore, the conductors do not come to rest at any point during

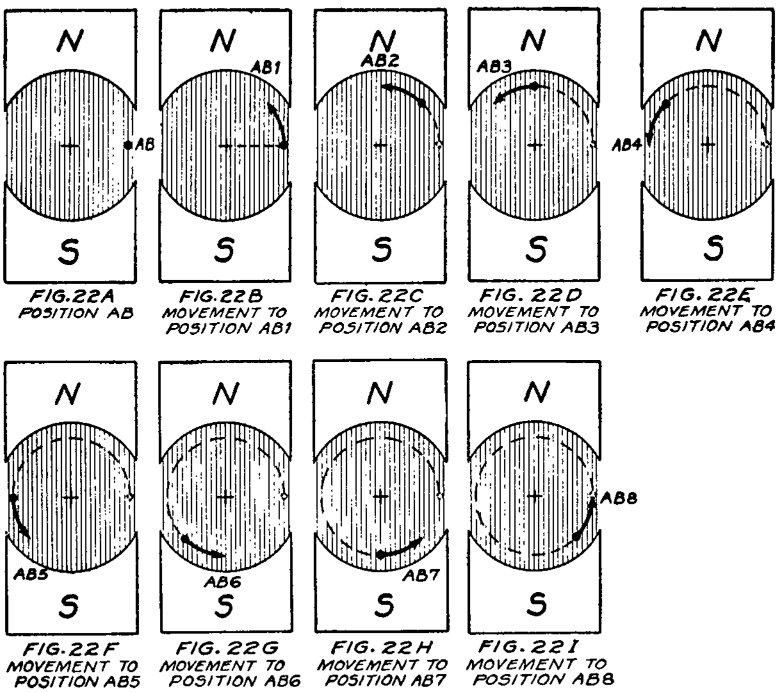


FIG. 22A POSITION AB — FIG. 22B MOVEMENT TO POSITION AB1 — FIG. 22C MOVEMENT TO POSITION AB2 — FIG. 22D MOVEMENT TO POSITION AB3 — FIG. 22E MOVEMENT TO POSITION AB4

FIG. 22F MOVEMENT TO POSITION AB5 — FIG. 22G MOVEMENT TO POSITION AB6 — FIG. 22H MOVEMENT TO POSITION AB7 — FIG. 22I MOVEMENT TO POSITION AB8

Figs. 22-A to 22-I, inclusive. The side of the coil AB, see Fig. 21, is shown rotating through a complete cycle of 360°, instantaneous positions being indicated by the arrowheads. The voltages developed as the coil rotates through the various positions are explained in the accompanying text.

the cycle. They arrive at and move past all points at a rate dependent upon the speed of rotation and the various voltages developed as the result of this motion are instantaneous.

Time Interval In Degrees

If you will examine Fig. 22-I you will note that a complete cycle of voltage—that is, both the positive and negative alternations—are completed when the coil side describes a complete circle and returns to its starting point. However, in this connection it is not necessary that the coil side start its cycle of motion from the zero position indicated in Fig. 22-A. It can just as readily start from point AB2 or any other point and the cycle is completed when the side describes a complete circle and returns to its original starting position. In doing so, it would pass through all the points described in Figs. 22-A to 22-I inclusive.

Referring again to Fig. 22, a definite relation exists between the voltage developed and the position of the coil side along the circumference of the circle it describes when it completes a cycle of travel within the space between the pole pieces. In other words, a certain voltage is developed or a certain change in voltage takes place when the coil side moves through one-fourth of the complete circle—through one-half of the complete circle—through three-quarters of the complete circle, or through the entire circle.

If we wish to break this down still further, we can select smaller portions of the complete circle, as for example—one-tenth—one-eighth—two-tenths—three-eighths, etc. . . . But if we work in this manner it becomes necessary to correlate these portions of the complete cycle of motion of the coil side with the voltage generated by using similar terms so that the time divisions of the voltage cycle will correspond with the time divisions of the motion of the coil side in the generator. It happens that it is not convenient to refer to portions of a cycle of voltage or current in fractions such as one-tenth—one-eighth—one-fifth—one-half—five-eighths—etc. A much more convenient method is to establish time intervals expressed in degrees—which correspond definitely with the movement of the coil side as it describes its circle of travel.

Take as an example the illustration shown in Fig. 23. The dotted circle is the equivalent of the path of the coil side as it describes its circle of travel in the generator so as to develop a cycle of voltage, as shown in Figs. 22-A to 22-I inclusive. The solid dot AB represents the location of the coil side AB in Fig. 22-A and we can for the moment assume this coil side to be a point which moves around this imaginary circle or circumference.

Now, when speaking about circles it is customary to speak of a circle as being an arc of 360°. Every circle, no matter how large or small, contains 360°. Consequently any point which travels in a circle and returns to its starting point has traveled through 360°. Accordingly the coil side AB in Figs. 22-A to 22-I inclusive, in describing a circle and returning to its original starting point, describes an arc of 360° each time that it completes a revolution.

In view of what has been said, it is easy to see that a portion of a circle or circumference is the equivalent of a part of the arc of 360°. Thus, one-fourth of a circle is the equivalent of 360° ÷ 4 or 90°. One-half of a circle is the equivalent of 360° ÷ 2 or 180°. Three-fourths of a circle is the equivalent of 360° × .75 or 360° × ¾ or 270°. Smaller portions of the circle are described in a similar manner, for example one-tenth of a circle is the equivalent of 360° × 1/10 or 36° and one-sixteenth of a circle is the equivalent of 360° × 1/16 or 22.5°. Further breakdown into 360 parts would make each part of the circle equal to an angle of 1°.

If we now divide a circle into, shall we say sixteen equal sectors or portions, each portion will represent 22.5 degrees and this is shown in Fig. 23. If we assign designating numbers along the circle at the extreme ends of each of these sixteen sectors so that between each of these designated points there is an arc of 22.5°—and consider these identified points with respect to a fixed point, such as AB in Fig. 23—point 1 will be 22.5° away from AB. Point 2 will be 22.5° + 22.5° or 45° away from AB and in this same manner, point 5 would be 5 × 22.5° or 112.5° away from point AB. This is shown in Fig. 23 by the circular arrows and degree identifications. . . . We can also state the above as the angular displacement of point 1 with respect to AB being 22.5°; that of point 4 being 90°; that of point 8 being 180°; that of point 12 being 270°, etc.

With the above in mind let us correlate Fig. 23 with Figs. 22-A to 22-I inclusive. Imagine for the moment that AB in Fig.

23 is the coil side AB in Figs. 22-A to 22-I inclusive and this coil side moves through points 1 to 16—the latter being the starting point as well as the finishing point in Fig. 23 and that the movement of this coil side around the circle of Fig. 23 always

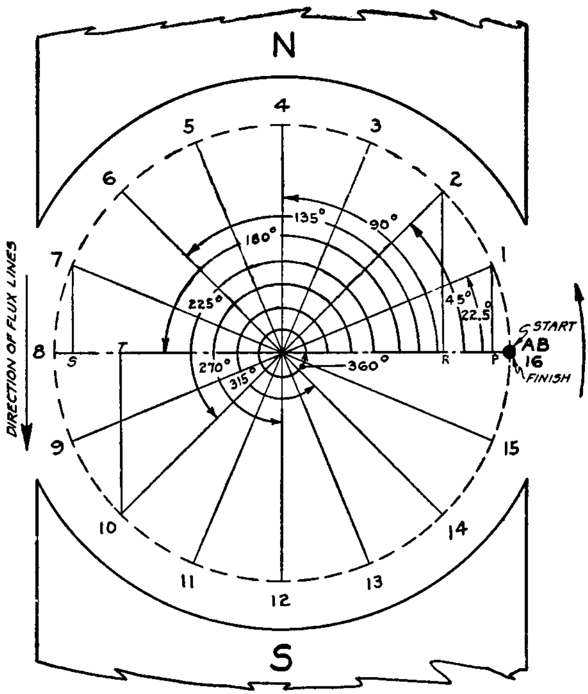


Fig. 23. The rotation of the coil side AB, Fig. 21, is here expressed in degrees of a circle. At 90° and 270° the voltage reaches maximum positive and negative values respectively, while at 0°, 180°, and 360° its value is zero.

is relative to the starting point. . . . If you examine the position of AB in Fig. 22-A and AB in Fig. 23, both with respect to the pole pieces and the flux lines (not shown in Fig. 23 although their presence is assumed) you will find that they are identically located. Hence the starting point AB in Fig. 23 is the zero voltage position.

If you now imagine that AB has moved up to point 1 the angular displacement with respect to its initial position or starting point is 22.5° and if it advances to point 2, it is about in the same position as AB1 in Fig. 22-B. The angular displacement is now 45° and it has moved through one-eighth of the complete cycle—so that we can say that a time interval of 45° represents one-eighth of the complete circle or cycle of motion. The actual time elapsed in moving over this 45° arc in fractions of a second —whether it be one-tenth or one-thousandth of a second is of no consequence. If and when stated, all it identifies is the frequency of the voltage or current, which means the rapidity of rotation. . . . No matter what the time elapsed—one thing is certain and fixed—and that is the fact that 45° represents one-eighth of a complete cycle. . . . Similarly 22.5° represents one-sixteenth of a cycle no matter what the frequency.

Continuing further, imagine that AB in Fig. 23 moves to position 4, which corresponds to AB2 in Fig. 22-C. This incidentally, as you will remember, is the point where the voltage is maximum. As far as angular displacement of AB in Fig. 23 is concerned, it is 90° from its initial starting point and represents movement of AB over one-fourth of the entire circle. In accordance with what was said in connection with Figs. 22-A to 22-I inclusive—one complete revolution of AB represents one complete cycle of voltage; hence one-fourth of the complete circle or 90° represents one-fourth cycle of the voltage generated.

Progressing further around the circle the coil side AB covers more and more of the arc of 360°. It is halfway around at point 8 and this represents one-half cycle or 180° of the motion of the coil side between the pole pieces. It therefore is the equivalent of one-half cycle or 180° of the generating voltage cycle. Of course, the points 5, 6 and 7 located between points 4 and 8 also represent different angular displacements of the coil side and consequently they represent different time intervals of the cycle. Thus, three-eighths of the cycle of motion of the coil side is 135°, consequently three-eighths of the cycle of voltage when expressed in time intervals using the degree as the basis, likewise represents 135°.

The second alternation of the complete cycle and the equivalent of the motion of the coil side, as shown in Figs. 22-E to

22-I inclusive, is made when the coil side AB in Fig. 23 moves from point 8 to point 16 and covers the arc of 180° from the 180° point to the 360° point. At the 270° mark (point 12) three-fourths of the cycle has been completed. At the 360° mark (point 16) the entire cycle has been completed. The application of the various time intervals expressed in degrees as shown in Fig. 23, when applied to the sine wave produced by such a generator, appears as shown in Fig. 24.

The Sine Wave

So once more we find a reference to the sine wave—but now we are familiar with the significance of time intervals expressed in degrees—therefore we can define the sine wave. . . . As has already been stated, the sine wave is one which varies in amplitude in a certain definite manner with respect to time. The value of amplitude variation with respect to time necessary to form a sine wave is as stated in the following table—where a decimal figure represents the amplitude at different time intervals in degrees with respect to the maximum amplitude. This table shows the amplitude change in steps of 15°. A more elaborate breakdown is possible—as for example in steps of 1 or 5 degrees—but we do not think it necessary. Concerning the relation between the maximum amplitude and the amplitude at various time intervals, the following examples should illustrate the case in point.

Angle	*Fraction of Peak Value*	*Angle*	*Fraction of Peak Value*	*Angle*	*Fraction of Peak Value*
0°	0	135°	0.707	270°	–1.000
15°	0.259	150°	0.500	285°	–0.966
30°	0.500	165°	0.259	300°	–0.866
45°	0.707	180°	0	315°	–0.707
60°	0.866	195°	–0.259	330°	–0.500
75°	0.966	210°	–0.500	345°	–0.259
90°	1.000	225°	–0.707	360°	0
105°	0.966	240°	–0.866		
120°	0.866	255°	–0.966		

Suppose that the maximum or peak voltage generated is ten volts. In accordance with the table showing the rate of amplitude variation at the 0° mark upon the time axis of Fig. 24, the voltage is zero. At the 15° mark, the voltage amplitude is, according to the table, 0.259 times the peak, or 2.59 volts. At the 30° mark the voltage amplitude is, in accordance with the table, 0.500 times the peak, or 5.0 volts. At the 45° mark the voltage amplitude is 0.707 times the peak, or 7.07 volts. At the 60° mark the voltage amplitude is 0.866 times the peak, or 8.66 volts. At the 75° mark it is 0.966 times the peak voltage or 9.66 volts. At the 90° mark the voltage amplitude according to the table is 1.0 times the peak or equal to the peak voltage of 10 volts.

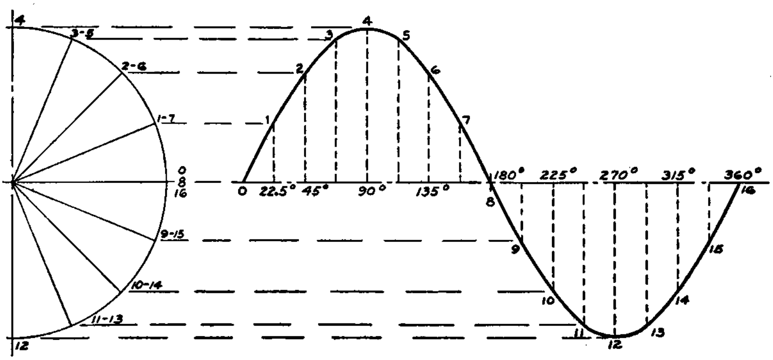


Fig. 24. The numbered positions on the semi-circle at the left correspond to the degrees of rotation in Fig. 23. The horizontal time axis is divided into equal parts, designated as degrees, and the relations between the maximum amplitude and the amplitudes at other points, taken from the table on the page opposite, when set off at the various degree marks on the time axis, show the current values at these points. When these are connected, a sine wave is developed.

Advancing another 15° to 105° the voltage decreases by the same amount that it increased over the 15° between 75° and 90°. At 105° the voltage falls to 0.966 times the peak or 9.66 volts. At 120° it is 0.866 times the peak or 8.66 volts. Once again take note that an *increase* in 30° of time above the 90° time interval results in the same *decrease* in voltage as the increase in voltage over the 30° interval between 60° and 90°. . . . As the time interval advances to 180° the voltage falls to zero and you will note that the increase over the first 90° of time of the positive cycle, per unit time interval is the same as the decrease over the next 90° per unit time interval.

The same relation continues during the second alternation—or second half of the cycle. The minus sign ahead of the decimal figure establishes the negative value of the voltage. The figures without any sign ahead of them should be construed as signifying that the voltage is of positive polarity. It would be suitable, although not necessary, to show a plus sign ahead of these figures.

No doubt you recall a mention in the early part of this book that the polarity of an alternating current or voltage is relative to the zero or time axis. The zone above the time axis is considered positive and the zone below the time axis is considered negative.

When 180° is the zero voltage position and the starting point of the second alternation—the amplitude change per time interval of 15° increases and decreases exactly in the same manner as during the positive alternation. . . . Starting at the 180° position and zero voltage—the voltage 15° later is 0.259 times the peak of 10 volts or 2.59 volts. 15° later or at 210°, representing a total time interval, since the start, of 30°, the instantaneous voltage is 0.500 times the peak or 5 volts. At the 225° position—representing an advance of another 15°, the instantaneous voltage is 0.707 times the peak or 7.07 volts.

If you continue the advance of the cycle with respect to the time intervals, you will see that the rise and fall of the voltage of the negative alternation is exactly like the rise and fall of the positive alternation per unit of 15°—or smaller intervals if you subdivide the axis into 1° or 5° units.

It is possible that you may have noticed one very significant detail in the table of relative amplitudes and in the two waveform curves of Figs. 24 and 25—namely that while the time interval steps are linear or uniformly divided, the variation in the amplitude of the voltage is not linear. . . . Actually this variation is a sine variation and that is why the curve is known as a sine wave curve.

An idea of what is meant by a sine wave, to supplement the specific values given in the table of relative amplitudes, can be had by again referring to Fig. 23. If you look closely, you will see that when the coil side AB moves to point 1—it is displaced in two ways. . . . First, the angular displacement as previously stated—in this case 22½°; second, the vertical displacement of the coil side from the horizontal—or initial starting point or zero point. This vertical displacement for the angle of 22½° is indicated by the perpendicular 1-P. Increasing the angular displacement does not increase the vertical displacement in exact proportion—as you may see by measuring the height of points 2, 3 and 4 above the horizontal line and comparing the length of these lines with line 1-P; also by checking the multiplying factors in the table for various angles of displacement.

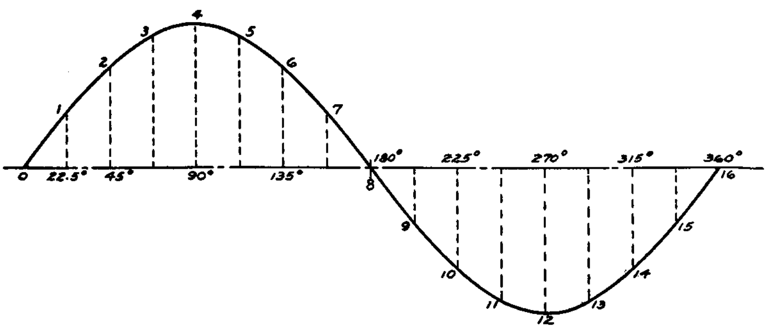


Fig. 25. The amplitude of this sine wave is just the same as that of the wave of Fig. 24, yet this one appears to be flatter. This is because the time intervals on the horizontal axis are greater than those of Fig. 24; yet both can be considered to be the same wave.

The manner in which these lines vary in length and the table we have classified as showing multiplying factors—is in reality a mathematical progression based on what is known as the "sine of the angle," the angle in this case being the angular displacement. Without any attempt to go into a mathematical discussion we can say that sine values are definite quantities which vary in polarity as shown in the accompanying table:

Sine Variation	*Angle Variation*
0 to +1	0 to 90 degrees
+1 to 0	90 to 180 "
0 to —1	180 to 270 "
—1 to 0	270 to 360 "

What we have called multiplying factors in the first table are actually sine values for the various angles of displacement. These sine values are usually shown in tabular form in mathematical books and can be referred to if you so desire.

It is possible that you may have noticed that the sine of the angle displays the greatest change in numerical value as the angle changes at the zero, 180° and 360° position—and displays the least variation as the angle changes around the 90° and 270° positions.

The mechanical construction of a sine wave is carried out by combining Figs. 22 and 23. The motion of the coil side is divided into degrees as for example, the sixteen divisions of 22½° each. The time axis of the wave to be drawn is also divided into an equal number of time intervals in degrees. Then the vertical displacement of the coil sides from the horizontal, being representative of the instantaneous amplitudes, is extended to the curve for each of the time intervals. The amplitude of the voltage for all the points above the time axis and for all of the points below the time axis, depending upon the position of the coil side, corresponds with the vertical displacement of the coil side. The vertical displacement of the coil side during the positive alternation, or from zero to 180°, is established by drawing perpendiculars in the downward direction from the various points indicating angular displacement to the horizontal, as for example 1-P, 2-R and 7-S. The vertical displacement of the coil side during the negative alternation or from 180° to 360° in Fig. 23 is established by drawing a perpendicular to the horizontal in the upward direction, as for example 10-T—for each time interval. When the operation is completed and the different points of the curve are joined, the graphic representation of the voltage is a sine wave, similar to the curve of Fig. 24 which corresponds with the motion of the coil side for the various time intervals shown in Fig. 23. The numbers along the curve of Fig. 24 correspond with the vertical displacement of the coil side of Fig. 23 for angular displacements in steps of 22.5°.

We trust that you now have an idea of what a sine wave is. If, at any time you have occasion to check the graphic representation of a cycle of voltage or current and, having divided the time axis into time intervals expressed in degrees, you find that the amplitude of both alternations does not vary as in the table given or in a table showing the sine of angles—then the wave is not of sine character. Another thought in connection with sine waves is that the actual physical spacing of the time interval upon the drawing may change the appearance of the wave—yet it may be sine—as for example Fig. 25. This curve appears flatter than that of Fig. 24—yet it is sine. The reason for the apparent flatness, despite identical amplitudes, is that greater spacing was used between the points established as the time intervals. . . . By the same token, it is possible that a wave may appear to be sine and yet not be so.

As the final thought before closing this chapter—we suggest that you study closely the facts relating to Figs. 23 and 24 because they play a dominant part in what follows in the next chapter.

Chapter V

PHASE RELATION IN A-C. CIRCUITS

PHASE, sometimes called "phase difference," "phase displacement" or "phase relation," is such an important factor in connection with the operation of alternating-current circuits that we feel that a more detailed discussion is justified.

The significance of the term "phase" used in one of the manners stated, can best be described by stating that it denotes a certain relation which exists between two or more periodic quantities. Expressed in another manner, we can state that phase—or phase relation—or phase displacement, when spoken of in connection with alternating currents or voltages, denotes the manner in which these alternating currents or voltages pass through their maximum or zero values with respect to each other at any one instant. In other words, the manner in which they do or do not keep in step with each other as they pass through the maximum or zero values. Two currents or voltages, or a current and a voltage which keep in step throughout the cycle are "in phase." Two currents or voltages which do not keep in step as they pass through the maximum or zero values are "out of phase."

At this time it is quite natural for you to wonder why attention should be paid to the manner in which two alternating voltages or two alternating currents or, for that matter, any two periodic quantities, keep in step with each other. In the first place, the operation of alternating-current devices, with the exception of resistors or purely resistive circuits, is such that the current and voltage do not always keep in step. In very many cases, they are out of step by a predetermined amount and only when this condition prevails can it be said that the circuit or the device is operating in the proper manner. Just why the current and voltage are not in step in certain devices is not of importance at this time, because our primary concern is with the significance of a certain phase condition—rather than with the cause thereof. However, to establish if the proper conditions are existing in the certain phase relation, observations are made and in many cases the information obtained is interpreted in terms of the electrical efficiency of the system or the component in question.

In the second place—operation of radio systems entails the presence of two or more alternating currents or voltages in the same circuit. These voltages or currents may combine in a certain manner to produce a certain complex wave (discussed in the next chapter)—and the formation or shape of this resultant wave depends to a great extent upon the phase relation existing between the various component voltages or currents.

In the third place, the design of modern radio systems is such that certain alternating voltages representative of signals received are definitely arranged to be out of step or out of phase with each other by a predetermined amount in a certain part of the system. . . . To make certain that the system functions properly—the phase relations between these voltages are observed or checked. Examples of such observations appear in the last chapter of this book.

There are a number of other reasons why comprehension of phase is essential, but in view of the fact that they will be described in the last chapter of this book—we feel that the three reasons given above will suffice at this time.

To illustrate what is meant by phase or phase relation or phase difference, let us take as our basis two sine-wave alternating voltages developed by two generators, such as those shown in Fig. 26. These two generators are identical in operation to the unit shown in Fig. 23. Consequently, details of operation are not necessary at this time. AB and XY represent the two coil sides, whose motion will be followed and which motion is identical to that of AB in Fig. 23.

Referring again to Fig. 26, the two generators are identified as I and II. The two voltages developed are shown graphically at the right of the respective generators. With both generators at rest, the two coil sides AB and XY are at their initial starting positions, indicated by the number 16. With the frequency of rotation—when they do rotate—established arbitrarily at one cycle per second, so as to simplify the explanation—let us assume that generator I is started and generator II remains stationary. However, after a short lapse of time, or when coil side AB (generator I) reaches position 4, generator II is started. Thereafter both rotate at uniform speed. . . . What have we now?

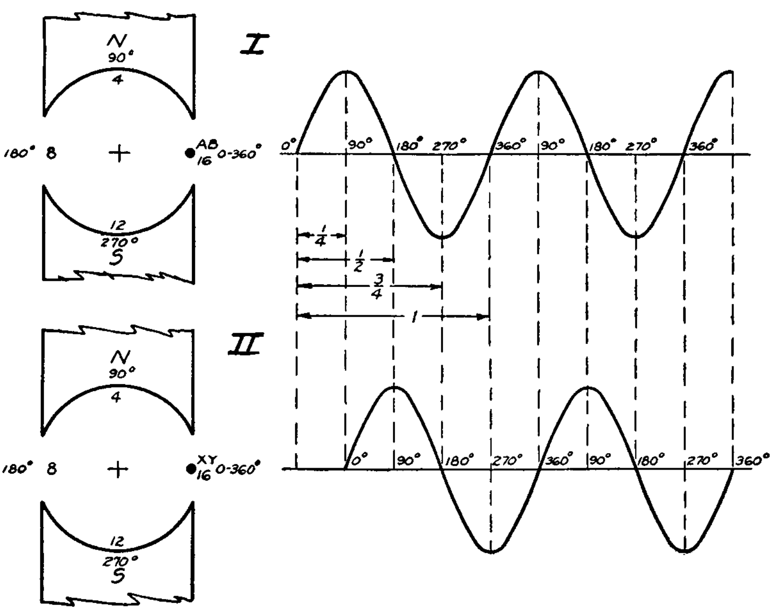


Fig. 26. Generator II starts after generator I has traveled through 90° and so its sine wave lags 90° behind that of generator I.

To start with, we have two a-c. generators developing individual voltages. From what we have already learned in the previous chapter, we know that each time that the two coil sides complete a cycle of motion, a cycle of voltage is developed. . . . Two cycles of such voltage are shown in Fig. 26. We assume that the amplitudes of these voltages are identical although that is not a specific requirement in order to carry on the discussion.

Continuing the discussion of the generators, you will remember that one of them, namely generator II, started one quarter of a second later than generator I. . . . The same condition can be expressed by stating that generator I started one quarter of a second earlier than generator II. If we express this condition in terms of the displacement of the two coil sides at any one instant and bear in mind that in this case one quarter of a second represents one quarter of a cycle—the two coil sides are 90° apart at any instant. From this point on, the actual speed of rotation, namely *one cycle per second,* is of no importance. If we recognize that the two coil sides are one quarter of a cycle or 90° apart, the frequency of rotation in cycles per second is of little moment. It can just as readily be ten cycles or a million cycles per second.

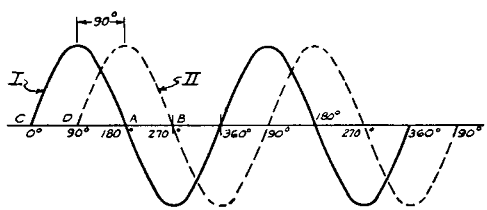


Fig. 27. Here the sine waves developed by the two generators of Fig. 26, are drawn on the same time axis. Note that the phase difference of 90° is constant throughout.

This phase condition can be expressed, as already shown, in two ways. With generator II as the reference basis, the voltage of generator I is one quarter of a cycle ahead of that of generator II—or is 90° ahead of generator II. This can also be stated by saying that the voltage of generator I *leads* the voltage of generator II by 90°. If we consider generator I as the reference basis, then we can say that generator II is behind generator I by one quarter cycle, or 90°—or the voltage of generator II *lags* the voltage of generator I by 90°.

Let us examine the voltage representations. The two shown in Fig. 26 are combined into a single illustration using a single time axis in Fig. 27. The solid line curve represents the voltage generated by generator I and the dotted line curve represents the voltage generated by generator II. When voltage I reaches its first peak or has passed through 90°, voltage II starts rising towards its maximum so that when voltage I has passed through one half a cycle or 180°, voltage II has completed one quarter cycle. . . . When voltage I has passed through 270° or three quarters of a cycle, voltage II has passed through 180° or one half of a cycle. . . . When voltage I has completed a cycle of 360°, voltage II has passed through three quarters of a cycle, or 270° of variation. . . . Thus there is a constant difference between the two voltages of 90°.

The determination of this difference or phase relation is usually made by knowing the relative instants when the two quantities, or two currents, pass through their maximum values. For example, voltage I has reached its first maximum at the 90° point along the time axis. Voltage II on the other hand, reaches its maximum at a point which corresponds to 180° along the time axis with respect to voltage I. It is therefore easy to see that the two maximum values of voltage occur 90° apart—and that voltage I reaches its maximum before voltage II—consequently voltage I leads voltage II or voltage II lags voltage I. This is the condition which exists in the positive half of the cycle and if you examine the instants at which the two voltages reach their maximum during the negative half of the cycle, you will find that the two occur 90° apart. Consequently, the phase relation is the same in both the positive and negative halves of the cycle. As a matter of fact, it is sufficient when establishing the phase relation to consider just one half of any cycle, because whatever phase difference exists in the positive alternation prevails in the negative half-cycle as well.

As to the points selected for reference in order to establish the phase difference, it is possible to use the zero value rather than the peak value. When using the zero value, it represents those points through which the voltage passes *after having reached a maximum.* For example, in Fig. 27 these two points would be A and B rather than C and D. The phase difference of 90° between the two voltages is evidenced by the fact that points A and B—the two zero voltage reference points are 90° apart along the time axis.

The fact that we have elaborated upon a 90° phase difference has no particular significance. It is not the standard value. The standard phase relation is really zero phase difference or when the two voltages or currents are exactly in step throughout their amplitude variation. Such will hold true if both generators start at the same instant and revolve at uniform speed. The voltage developed by these two generators under such conditions is shown in Fig. 28. Illustration A is that of the generator I voltage and

Fig. 28. When the generators of Fig. 26 start at the same instant, then the two sine waves developed are "in phase," i.e. both waves start off at 0° at the same time, as may be seen on the right. If these waves were drawn on the same time axis, they would appear as only one wave, since they have the same frequency and amplitude.

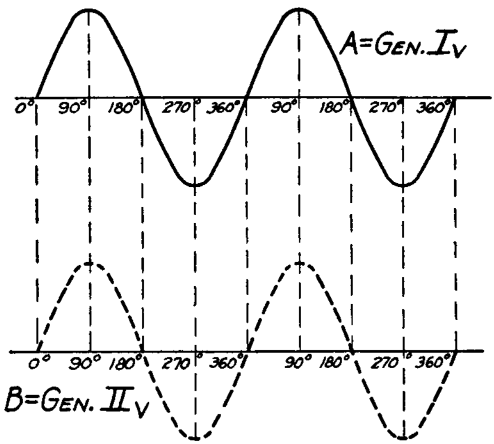


illustration B is that of generator II voltage. If you check the amplitude variation with respect to time—you will see that both voltages are exactly in step.

Continuing with this discussion, you can very readily see that it is possible to start generator II at some instant before generator I has passed through one quarter of a cycle (90°), so that the two voltages would differ in phase by some value less than 90°. For example, suppose that generator II is started when generator I has passed through one eighth of its cycle or 45°. The two voltages when shown upon a single time axis would have to be represented as shown in Fig. 29—out of step or out of phase with each other by 45°. The two peaks or points of maximum voltage occur 45° apart.

By the same reasoning it is possible that generator II is started when generator I has completed one half of a cycle or 180°. These two voltages are shown upon a single time axis in

Fig. 30. The two positive peaks occur 180° apart. At the same time it is also significant to note that when two voltages differ by 180°, the positive peak of one voltage occurs at the same instant as the negative peak of the other voltage. This is an important point and should be remembered for future reference, because if two such voltages exist in a circuit—they oppose each other. The net result is that the two voltages tend to counteract each other or oppose each other. If they are both of the same amplitude,

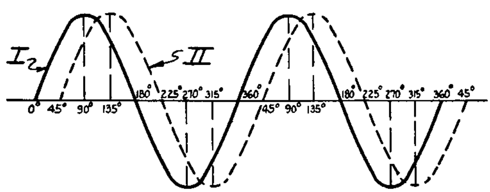


Fig. 29, left. Here the sine wave of generator I leads that of generator II by 45°.

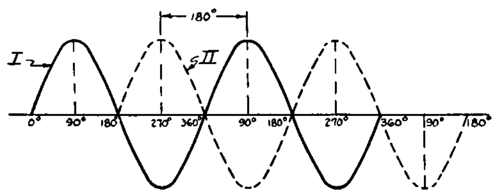


Fig. 30, right. The phase difference between these two sine waves is 180°. generator I leads generator II.

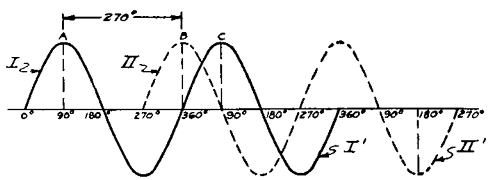
the net result is the absence of a difference of potential between any two points in a circuit which carries two such voltages. This will be explained in greater detail later, but we feel that the reference is necessary at this time.

While it is true that 180° is to all practical purposes the maximum phase difference, it is possible from the theoretical viewpoint to have a phase difference of varied degree up to slightly less than 360°. For example, Fig. 31 shows two voltages developed by the two generators of Fig. 26, with generator II started after generator I passed through three quarters of the cycle or after an angular displacement of coil side AB of 270°. The peak of voltage I occurs 270° sooner than the peak of voltage II so that the former leads the latter by 270°.

When two voltages differ by 360°, there is no phase difference. The reason for this is that the 360° position is also the starting position. If generator II is started after generator I has finished one complete cycle, then both start at the same instant. Hence, there is no phase difference between the two voltages at any time after generator II is started in operation—and both move at the same speed.

At this time we would like to stress that it is not sufficient merely to state the phase difference between two voltage waves as being a number of degrees. *In addition, it is necessary to specify which of the two voltage waves lags or leads the other wave.* In view of the fact that increasing values of time, as shown upon the horizontal time axis, move from the left towards the right, the reference point is usually located closest to the left end of the time axis.

Fig. 31. The sine wave of generator I leads that of the other generator by 270°.



It might also be well at this time to mention that the selection of two generators as the sources of the two voltages utilized to illustrate the various phase relations, was not made because it was typical of actual conditions in a radio system. Various types of a-c. voltage generators are used in connection with radio operation and servicing, but these are, as a rule, of the vacuum-tube oscillator type. This, however, does not change what has been said concerning phase relation. It is possible that you may be somewhat familiar with the additive and subtractive effects of phase upon two voltages or two currents—and you may be surprised at the absence of data concerning such effects in this chapter. This omission is deliberate because the effect of phase when two voltages or currents are combined, is discussed in the chapter which follows.

Measurement of Phase Difference

As to the measurement of the phase difference existing between the two voltages, this can be done by examining the two voltages upon a single time axis. The first step is to establish a complete cycle of the reference wave and then the adjacent complete cycle of the other wave. Then designate time in degrees upon the time axis. This is shown upon the time axes utilized in Figs. 26 to 31, inclusive. With the reference wave established, the distance is measured between this reference peak and the next successive peak of the other wave. A vertical projection is dropped from these points to the zero reference line and the number of degrees representative of time indicated between these two points upon the time axis is the phase difference in degrees between the two waves. In making these measurements, you can use the positive or negative alternations—but whichever is selected, both peaks selected must be of like polarity. This is illustrated in Fig. 31 wherein the peak of voltage I occurs at the 90° point along the time axis and the first peak of voltage II corresponds with the 360° point along the time axis. The difference between 360° and 90° is 270°.

Phase Difference in Alternating Currents

It is true that up to the present time we have considered a-c. voltages only. What is true about alternating voltages is likewise true about alternating currents. In other words, each of the graphic representations of voltage and everything said about the phase difference existing between two voltages, is true about two currents.

Phase Difference Between Current and Voltage

One of the differences between alternating-current and direct-current circuits is that in alternating-current circuits the current does not vary in phase with the applied voltage. The operation of certain a-c. devices is such that the current due to the application of a voltage will lag behind the applied voltage by some value dependent upon operating conditions. In still other cases the current will lead the applied voltage. Whenever a number of such devices are combined into a single circuit and an alternating voltage is applied, the current may lag or lead the applied voltage by a number of degrees—depending upon the relative values of the components. The vacuum tube used in a radio receiver is one of the important items in connection with the phase relation existing between the various signal voltages present in the tube. This subject is discussed in full detail in another of this "An Hour a Day" series, but it might be well at this time to mention that a brief summary of the phase conditions existing in a vacuum tube are discussed in the last chapter of this book.

Before closing this chapter, we would like to make specific reference to one point relating to phase and somewhat connected with the examples given previously. If you will recall, we did make the reservation that the frequency of the generators was the same so that a constant phase difference of some specific value will exist if the two waves are not in phase. In this connection, we wish to stipulate that a constant phase difference will exist only when the frequencies of the two waves remain the same. If, however, the frequencies of the two waves are not the same—then, the phase difference will vary continuously between zero and 360°.

So much for the subject of phase relation. While it is true that the practical man who works upon receivers has been fairly successful without understanding the subject of phase, the present design of radio receivers is such that the man who intends performing any operations upon such receivers—as a means of a livelihood or as an experimenter—must understand this subject in order to comprehend why certain devices are employed in a definite manner. As a matter of fact, incorrect phase relations are often responsible for defective operation and these defects are of the nature which cannot as a rule be detected by voltage or current measuring devices.

Chapter VI

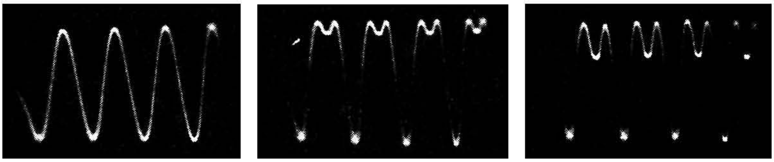
COMPLEX WAVES

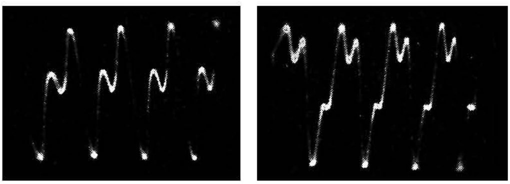
WE SAID that the sine wave is the basic electrical wave of alternating character. . . . While the statement is true, it is necessary for you to understand that there are other classifications of electrical waves which appear in radio nomenclature and which are of interest to us, because they come within the category of alternating-current waves. One in particular is known as the "complex" wave—in contrast to the "sine" wave.

"What is a complex wave?" you naturally ask. . . . In the simplest language a complex wave is the composite wave resulting from the combination of a number of sine waves of different frequencies. . . . The same applies to a number of sine waves of current as well as of voltage. . . .

The distinction between a sine wave and a complex wave is two fold: first, the sine wave has but a single frequency, whereas the complex wave consists of a number of different frequencies; second, the variation in amplitude of a sine wave follows a certain definite law as stated in the preceding chapter, whereas the variation in amplitude of a complex wave depends upon a number of different factors: the number of component frequencies, the relative amplitude of these frequencies, and the phase relation between the different voltages or currents which compose the wave.

Graphic representations of what we mean are shown in Figs. 32, 33, 34, 35, 36, 37, and 38. The first five are oscillograms. Fig. 32 illustrates a simple sine wave of 1000 cycles. Fig. 33 shows a complex wave formed by combining two sine waves of voltage of 1000 and 2000 cycles. Fig. 34 is like Fig. 33 except that the amplitude of the 2000-cycle voltage has been increased.





Figs. 32 to 36, left to right. Oscillograms showing a sine wave and complex waves. See adjacent text for explanation.

The same two voltages are shown in Fig. 35, but the phase of the 2000-cycle voltage has been changed. In Fig. 36 is shown the complex wave resulting from the combination of a 1000-cycle, a 2000-cycle, and a 3000-cycle voltage. In Fig. 37 is shown a complex wave which appears as a square topped wave and is the result of the presence of very many frequencies. The same is true of the triangular shaped wave illustrated in Fig. 38. . . . Just why these variations occur and other pertinent facts relating to complex waves will be discussed as we progress through this chapter.

Origin of Complex Waves

The origin of complex waves is a very lengthy subject, entirely too long for discussion in this volume, but a few brief moments can be devoted to some of the facts relating thereto. In the case of the rotating type of a-c. generator shown in several preceding illustrations, certain requirements must be fulfilled in order that the voltage wave generated be of sine character. One of these is that the conductor rotate at uniform speed throughout the cycle, and second that it rotate through a uniform field. When this is done, the movement of electrons in the circuit will be of a symmetrical character. However, if the motion of the conductor is not uniform, or expressed differently, if the angular velocity is not uniform, or if the magnetic field through which the conductor rotates is not uniform, the voltage generated will depart from sine character. The voltage generated will be of complex character to an extent dependent upon the degree of departure of the operating conditions from those required. Complex waves of voltage or current, whichever is being considered, are often deliberately created by the mixing of voltages of certain definite related frequencies,—as for example the voltages mentioned in connection with Figs. 32 to 36. The human voice is representative of a complex sound wave and its electrical equivalent is a complex electrical wave. The same is true of sounds produced by musical instruments.

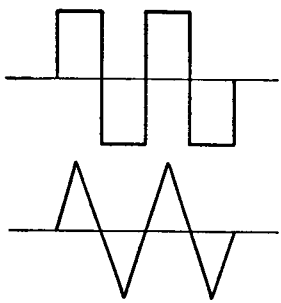


Fig. 37, top, Fig. 38. Complex waves may assume either the square-topped shape or the triangular. These forms are due to the presence of many frequencies in the make-up of the wave.

Other sources of complex voltage or current waves are many parts of a radio system which is not operating in an ideal manner. Perhaps it is premature to mention the term distortion, but all units which tend to create such a condition are productive of complex waves. More will be said about this subject in the last chapter of this book.

Harmonics

We stated that a complex wave differed from a sine wave in a number of ways. One of these explanations referred to the fact that the complex wave represented voltages or currents of more than one frequency. To understand fully what will be said, the following should be borne in mind. . . . *Whenever the wave form of an alternating current or voltage differs from a sine wave, then that waveform is complex and contains a fundamental frequency* *and other related frequencies.* Note that this statement stipulates that the *frequencies present in a complex wave are related to each other.* This is quite an important point, because it introduces the term *harmonics.*

As to the definition of a harmonic, *it is a component of a periodic quantity which is an integral multiple of the fundamental frequency.* Let us break this down into simpler sentences. Since the sine wave of any frequency is a periodic quantity as previously stated—and since the complex wave consists of a number of such sine waves, *the complex wave becomes the periodic quantity.* . . . By component is meant a part of the whole so that any one of the frequencies present in the complex wave is a component frequency—and *any one of the sine waves of voltage or current, which contributes to the composition of the complex wave, would be a component wave.* . . . Now, the harmonic is a component of the complex wave, and bears a definite stipulation in the definition—*namely, that its frequency is an integral multiple of the fundamental frequency.* In other words, a harmonic frequency is one which bears a certain relationship to the fundamental frequency—and this relationship is that it is an integral multiple of the fundamental.

In accordance with the above, if the fundamental frequency of a complex wave of voltage or current is 1000 cycles, the harmonic frequencies of this fundamental are 1000×2, 1000×3, 1000×4, 1000×5, etc.—up to whatever order of harmonic is being considered. Thus, it is possible that a complex wave may consist of a 60-cycle fundamental and harmonics up to the 50th . . . From what has been said in preceding chapters, the fundamental frequency may be any figure and the harmonic frequencies may be of any order—that is any number. . . .

If we select "f" as the fundamental frequency, a short tabulation of the relation between the fundamental and the harmonics would be:

$$
\begin{aligned}
\text{Fundamental frequency} &= f \\
\text{Second harmonic} &= 2f \\
\text{Third harmonic} &= 3f \\
\text{Fourth harmonic} &= 4f \\
\cdot \qquad & \quad \cdot \\
\text{Nth harmonic} &= nf
\end{aligned}
$$

In connection with harmonic frequencies, they may or may not be desired—depending entirely upon the conditions required. In certain instances, the source of voltage generates the fundamental as well as the harmonic frequencies and the latter are deliberately removed—whereas in other instances, the unit responsible for the complex wave is deliberately arranged to produce a complex wave very rich in harmonics. As far as harmonics are concerned—they can be produced for all fundamental frequencies—regardless of the numerical value of the fundamental.

The Fundamental Frequency

Speaking about the fundamental frequency of a complex wave, it is, to start with, the lowest frequency—there being no sub-harmonics below the fundamental.* . . . Expressed in another manner, it is the number of times per second that a complete cycle of the complex wave repeats itself. This is true no matter how complex the wave or the number of harmonics contained in the wave. For example, in Fig. 39 is shown a complex

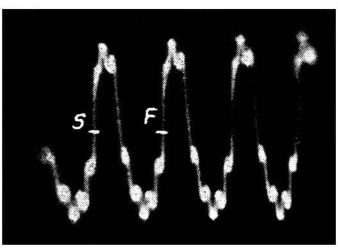


Fig. 39. The start and finish of a complete cycle of the complex wave at the left are indicated by S and F respectively. The fundamental of this wave is 1000 cycles.

wave containing a number of harmonics. Four cycles are shown. If the duration of one complete cycle is 1/1000th of a second, the fundamental frequency is 1000 cycles. 1000 such cycles occur in a second.

As to what constitutes a cycle of a complex wave—the definition given for a cycle of a sine wave applies, namely—that period during which the voltage or current passes through all of its variations in amplitude and polarity. This is shown in Fig. 39.

* Because of the nature of this book, we are omitting illustrations relating to cases wherein the fundamental and certain harmonics are mathematical terms of zero value and physically are not present in the complex wave.

If you examine the portion designated as being a cycle, you will find that the voltage has passed through all of its variations in the positive alternation and all of its variations in the negative alternation. As a matter of convenience, it is best to employ the zero voltage points as the reference points, representing the limits of the cycle.

Electron Motion For a Complex Wave

If you remember, we described the symmetrical motion of an electron representative of a sine wave of current. This motion is easy to comprehend in that the variation in amplitude of the voltage responsible for the movement of the electron is symmetrical. However, when we speak of complex waves of voltage and current and consider the motion of the electrons which constitutes this current, we must realize that more than one voltage is present and acting upon the electron. . . . How do these electrons move?

Let us imagine a complex wave consisting of two voltages—a fundamental voltage of 60 cycles and a second harmonic of 120 cycles. . . . The exact frequencies are of no consequence—other than that they bear the proper relation to each other. Bearing in mind what was said in the beginning of this book concerning the motion of the electron when acted upon by two voltages of different frequency—you would be tempted to imagine a number of different conditions. . . . Do some of the electrons oscillate at 60 cycles and others at 120 cycles? . . . Or do the electrons first move at 60 cycles per second and then at 120 cycles per second? . . . Neither of these thoughts is correct.

What is accepted as being the mode of action is of the following order: The two voltages are present—each of its own frequency. . . . At every instant, these two voltages have a definite value—either positive or negative with respect to the zero time axis. . . . At every instant, the electron is under the influence of both voltages and its motion is the result of the *combined* influence of the two voltages. If there are three voltages of different frequency, the electron at each instant moves in accordance with the *combined* influence of the three voltages, etc. . . .

To explain this motion of the electron with respect to what is meant by the combined influences, consider the following analogy of an airplane. . . . Suppose that an airplane is moving through still air at a ground speed of 200 miles an hour. It then comes into an area where a wind of 50 miles per hour is blowing in such direction that the plane moves head on into the wind. Two forces are now acting upon the plane. One is that developed by the propeller; the second is the head wind. At any instant when these two forces are at work, the resultant ground speed is governed by the combined influence of the two forces. In this particular case the ground speed is 200 — 50 or 150 miles per hour. Suppose that the plane then moves into an area where the head wind is 30 miles per hour. The resultant ground speed then becomes 200 — 30 or 170 miles per hour. In other words—the ground speed is dependent upon the combined forces. Since the head wind retards the plane, we can consider the still air speed of the plane as being a "positive" force and the head wind velocity as a "negative" force. The combined force then becomes the sum or difference of these two forces—depending upon their relative directions.

Let us follow the same procedure in examining how the motion of the electron is influenced by two sine-wave voltages which constitute a complex wave voltage. For the sake of simplicity we

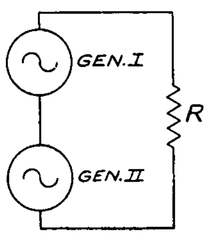


Fig. 40. Generator I develops a 60-cycle, 100-volt alternating current and generator II a 120-cycle, 40-volt alternating current. The sine waves of these two generators are shown in Fig. 41 together with the resultant complex wave.

can assume that the complex wave of voltage is the equivalent of the voltage obtained from two separate sine-wave generators. Also that for the present the two voltages are in phase or exactly in step and further that the peak voltage of generator I is 100 volts and that of generator II is 40 volts. Figure 40 shows the two generators connected in series across a resistive load. The two generators electrically connected, generate the respective voltages at two different frequencies. If we establish the resultant voltage at any instant—it becomes the combined force acting upon the electron—similar to the resultant force of the wind velocity and airplane speed in still air.

It does not require much imagination to visualize the airplane traveling in one direction against the wind and in another direction with the wind—or for that matter, a constant direction of the plane and the wind changing from a head wind to a tail wind. The same occurs in the case of the two voltages. . . . It is possible to conceive of a positive polarity for voltage I and a negative polarity for voltage II,—vice-versa—or both positive or negative. . . . But whatever the combination, at any one instant the force acting upon the electron is the resultant of the two and can be resolved into a single wave of voltage of complex character.

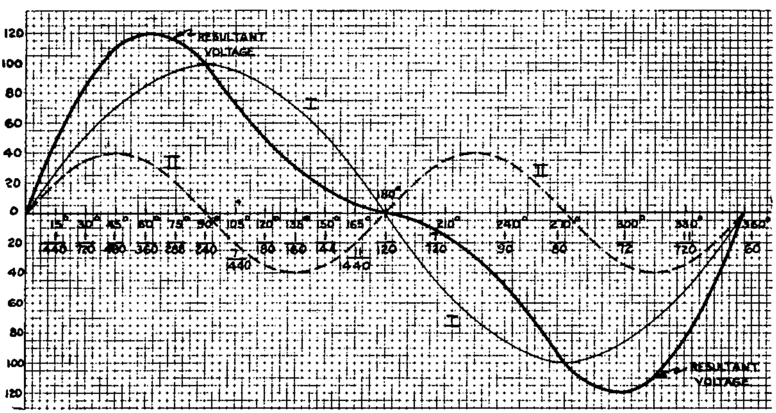


Fig. 41. The sine waves marked I and II are the 100-volt and 40-volt alternating voltages generated by generators I and II of Fig. 40. The wave marked Resultant Voltage is developed by connecting the various points found by adding the voltages algebraically.

This is shown in Fig. 41. A single cycle of the 60-cycle voltage (Gen. I) is plotted upon a time axis marked off in time and also degrees. Upon the same time axis are shown two cycles of the 120-cycle voltage (Gen. II). It is natural that two cycles of the 120-cycle voltage will occur during the interval required for one cycle of the 60-cycle voltage, because the frequency of the number II voltage is twice as great as that of the number I voltage.

Being in phase, the two voltages are shown starting from zero (although this condition is not essential) and moving in the same direction. At the 15-degree point, which represents a lapse of time of 1/1440th of a second, the 60-cycle voltage is +26 and the 120-cycle voltage is +20. The two voltages are acting in the same direction so the resultant force is in the same direction, and has a value of 26 + 20 = 46. . . . At that instant the force acting upon the electron is +46 volts. . . . The plus sign preceding the voltage indicates that it is positive or plus with respect to the zero axis.

At the 30-degree position, or after a lapse of 1/720th of a second, the 120-cycle voltage is +34.6 volts and the 60-cycle voltage is 50 volts. The sum of the two voltages is +84.6 volts, as shown. At the 45-degree point, or after a lapse of 1/480th of a second, the 120-cycle voltage is +40 volts and the 60-cycle voltage is +70 volts and the sum of the two voltages is +110 volts. Beyond the 45-degree point, the 120-cycle voltage starts falling, whereas the 60-cycle voltage is still rising. . . . At the 60-degree point, or after a lapse of 1/360th of a second, the 120-cycle voltage is +34.6 volts and the 60-cycle voltage is +86.6 volts. The resultant voltage at that instant is +121.2 volts. At the 75-degree point, or after a lapse of 1/288th of a second, the 120-cycle voltage is +20 volts and the 60-cycle voltage is +96 volts. The resultant voltage is the sum, and is +116 volts.

At the 90-degree point, or after a lapse of 1/240th of a second, the 120-cycle voltage has fallen to zero, whereas the 60-cycle voltage has reached its peak of 100 volts, so that the resultant voltage is +100 volts. . . . It might be well at this time to remind you again that the variation in the 120-cycle voltage between the 45 degree and 90 degree positions, is not a change in polarity. . . . The voltage decreases, but it is still positive with respect to the zero line. . . . In addition, in order to avoid confusion, we feel that we should mention that the two voltages I and II are in phase, even if they do not appear to be so. . . . The phase of the harmonic is stated with respect to the fundamental. . . . If the harmonic passes through its zero point at the same instant and same direction as the fundamental at the two zero limits of the fundamental cycle—the harmonic is in phase. . . .

If this condition does not prevail, the harmonic is out of phase with the fundamental.

Going back to Fig. 41, we note a different condition existing during the next quarter cycle between the 90 and 180 degree points on the time axis. The 120-cycle voltage now is negative—whereas the 60-cycle voltage is still in the positive zone. The development of the resultant voltage over the first 90 degrees is similar to the airplane analogy with a tail wind. . . . The development of the resultant voltage over the second quarter cycle, or from 90 to 180 degrees, is like the airplane analogy with a head wind—wherein the 120-cycle voltage is the head wind which tends to keep the airplane speed down. . . . In Fig. 41, the 120-cycle voltage being negative is subtracted from the 60-cycle voltage, which is positive. . . . The resultant voltage remains positive, because the original positive voltage is greater than the negative voltage. . . . The polarity and value of the resultant voltage depends upon the relative values and polarities of the component voltages.

In the second half cycle, or between the 180 and 360 degree points along the time axis, the 60-cycle voltage is negative, whereas the 120-cycle voltage is first positive and then negative. However, because of the fact that the 60-cycle voltage at all times is greater than the 120-cycle voltage—the resultant voltage bears the polarity of the greater voltage—and is negative. The resultant voltage at any instant, as shown in the table (next page), is the sum of the two component voltages where they are of like polarity, and the difference between the two component voltages, when they are of opposite polarity. The resultant voltage under the last named condition bears the polarity of the greater of the two component voltage values.

The construction of the complex wave, as outlined in connection with Fig. 41 to show the resultant voltage acting upon the electron, is the same no matter how many harmonics are present or whatever their phase. . . . Any number of harmonics can be combined with the fundamental to constitute a single complex wave which will show the resultant force acting upon the electron. . . . *In turn, any complex wave can be resolved into its fundamental and harmonic frequency components.* However, such operations are beyond the scope of this book and will not be attempted in this volume.

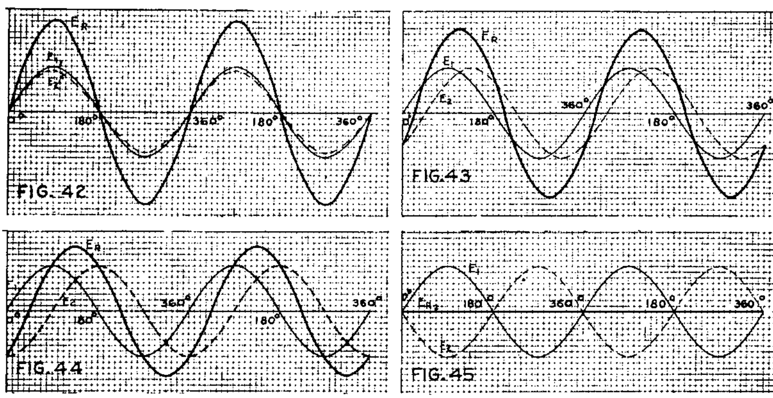
If you examine Fig. 41, you will note that such a complex wave retains the same fundamental frequency—namely the 60 cycles in this case—although it bears the modifications due to the presence of the 120-cycles-a-second harmonic. If you trace the resultant complex wave—you will find that a complete cycle of amplitude variation and polarity variation occurs in exactly the same period required for a cycle of the lowest frequency present in the system—namely, the fundamental frequency. . . . The resultant complex wave completes its cycle in 1/60 of a second—and 60 such cycles occur in one second.

Time In Degrees	*Voltage I, 60 Cycles*	*Voltage II, 120 Cycles*	*Resultant Voltage*
0°	0	0	0
15°	+26	+20	+46
30°	+50	+34.6	+84.6
45°	+70	+40	+110
60°	+86.6	+34.6	+121.2
75°	+96	+20	+116
90°	+100	+0	+100
105°	+96	—20	+76
120°	+86.6	—34.6	+52
135°	+70	—40	+30
150°	+50	—34.6	+15.4
165°	+26	—20	+6
180°	0	0	0
195°	—26	+20	—6
210°	—50	+34.6	—15.4
225°	—70	+40	—30
240°	—86.6	+34.6	—52
255°	—96	+20	—76
270°	—100	0	—100
285°	—96	—20	—116
300°	—86.6	—34.6	—121.2
315°	—70	—40	—110
330°	—50	—34.6	—84.6
345°	—26	—20	—46
360°	0	0	0

Addition of Components and Effect of Phase

It is possible that as a result of what you have read so far and the analogy given, you may imagine that the determination of two or more voltages or two or more currents in the circuit is the simple addition of the respective values. In other words, if two a-c. voltages of 100 volts each are present in a circuit—the resultant voltage is 100 + 100 or 200 volts. . . . Such is not the case—at least in all instances. . . . The controlling factor is the phase relation existing between the two voltages.

When the two or more sine wave component voltages are of like frequency, and are in phase—the combined voltage is equal to the sum of the component voltages. However, if the



Figs. 42 to 45. Sine waves of equal voltage and equal frequency with the resultant waves due to various phase differences. Fig. 42 shows 0° phase difference; Fig. 43, a difference of 45°; Fig. 44, 90°, and 180° in Fig. 45. E_R is the resultant voltage. The two sine waves of Fig. 42 should occupy the same position throughout, but were drawn separated to show the presence of both waves.

voltages are out of phase, it becomes necessary to consider the phase in the computations. Incidentally, the resultant wave will always retain the sine wave character because two sine wave of like frequency when mixed will combine into another sine wave. The peak amplitude of this resultant sine wave will depend upon the phase of the relative components.

Suppose that we investigate two sine wave voltages of like frequency—with individual peak values of 100 volts and zero phase difference between the two voltages as shown in Fig. 42. Being in phase—the two voltages correspond at each instant and the resultant voltage is the arithmetical sum of the two voltages at any instant. . . . The two instants of peak voltage coincide—hence the peak voltage of the resultant wave is 100 + 100 or 200 volts. The sine-wave character of the resultant voltage is evident.

What happens when we combine these voltages 45° out of phase? The two waves and the composite wave are shown in Fig. 43. The sine-wave character is retained, but the peak value of the two voltages is no longer the sum of the two peak values of the individual voltages. Instead, a new peak is developed which is the sum of the voltages, which corresponds with a point midway between the two instants when the two peaks occur. The peak voltage of the resultant wave is 184 volts—instead of the 200 volts when they are in phase.

The combination of the two voltages with a phase difference of 90° is shown in Fig. 44. The resultant peak voltage has a value equal to 1.414 times the peak of either component or 141.4 volts instead of the 200 volts when the two voltages are in phase.

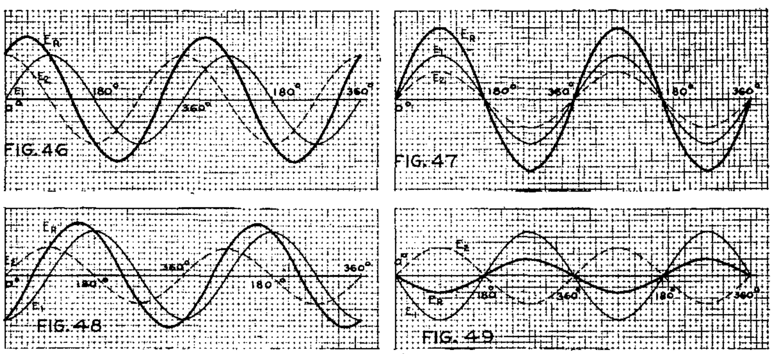
When the two voltages are 180° out of phase—the resultant voltage is zero, because the two component voltages are of equal value with opposite sign at every instant. This is shown in Fig. 45.

When the two voltages are 270° out of phase they add in exactly the same manner as if they were 90° out of phase—as shown in Fig. 46. When they are 360° apart, they add exactly as if they were zero degrees apart, as shown in Fig. 42.

Thus, the addition of two sine waves of voltage of equal amplitude but of varying phase, results in a final value which varies between zero and twice either of the individual amplitudes.

What happens when two component sine voltages are not of equal amplitude? At zero-degree phase difference they are additive in normal manner because both voltages are of identical sign at each instant—so that the result is the sum of the two, as shown in Fig. 47. The sine character is retained.

When the phase difference is between zero and 360°, the final value depends upon the phase as well as the individual values—just as in the case of component sine-wave voltages of equal amplitude. Likewise, the resultant voltages retain the sine characteristic. Examples of the addition of voltages of unequal amplitudes are given in Figs. 48 and 49. The former shows a phase difference of 90° and the latter shows a phase difference of 180°. Compare Fig. 49 with Fig. 45.

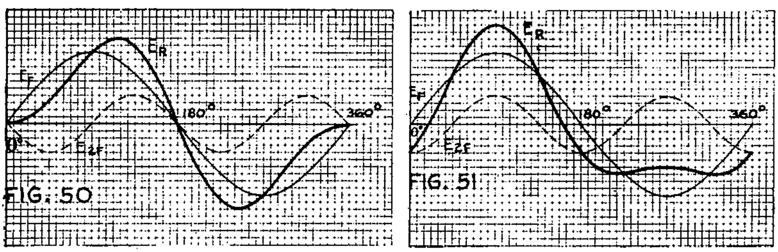


Figs. 46 to 49. Fig. 46 shows the resultant wave for two equal voltages of the same frequency with a phase difference of 270°. Figs. 47 to 49 are waves of equal frequency but different voltages with various phase relations. Fig. 47 has a phase difference of 0°; Fig. 48, 90°, and Fig. 49, 180°.

So much for the discussion of voltages of like frequency and varying phase. However, before concluding we must state that what has been said is applicable in every respect to currents of like frequency but varying phase. This is quite natural in that the addition of two voltages present in a circuit leads to the addition of the currents due to the two voltages. To summarize, two sine waves of current of like frequency with zero phase difference result in a sine wave of current with a peak value equal to the sum of the individual current peaks. If the two currents are of like magnitude and the phase differs between 0 and 360 degrees, the resultant current will have some value between 0 and twice the peak amplitude of either current. . . .

Effect of Phase Upon Complex Waves

The discussion of the effect of phase relation or phase difference upon the combination of sine waves of like frequency, leads us into the discussion of the effect of phase relation upon the combination of sine waves of unlike frequency—namely a fundamental and harmonic frequencies. One such example has already been given in Fig. 41, wherein we combined a fundamental and its second harmonic, with the two in phase. . . . If you remember, we stated that the phase displays a great effect upon the shape of the resultant wave, in this case a complex wave. . . . Let us see why this is so. With the complex wave of Fig. 41 as the basis, let us examine Fig. 50. This illustration is a graphic

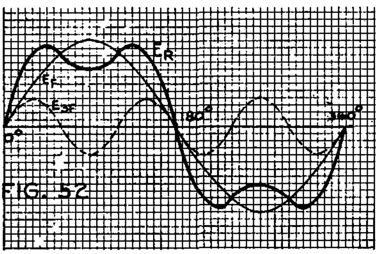


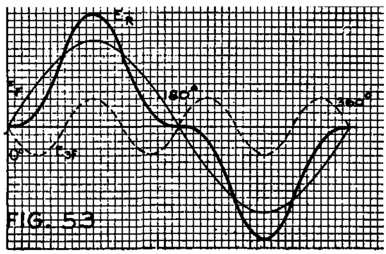
Figs. 50 and 51. E_F is the fundamental wave and E_{2F} is its second harmonic. E_R is the resultant wave in Fig. 50 when the phase difference is 180° and in Fig. 51 when the phase difference is 90 harmonic degrees.

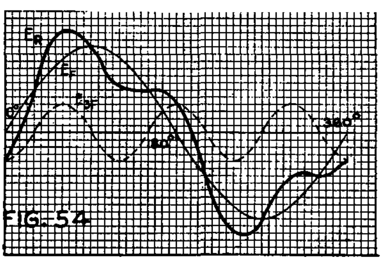
representation of a single cycle of the fundamental and two cycles of the second harmonic voltage, with the latter 180 degrees out of phase with the fundamental. Compare Fig. 41 with Fig. 50. The relative amplitudes of the fundamental and the harmonic are the same in both, yet the shape of the resultant complex wave is definitely different. In Fig. 51 is shown the same combination of frequencies, with similar amplitudes for the two component voltages, but with the harmonic voltage lagging the fundamental voltage by 90 harmonic degrees, which is the equivalent of leading the fundamental by 270 degrees. . . . Note the definite difference between Figs. 41, 50 and 51—all due to the variation of the phase relation between the fundamental and the harmonic. The development of the resultant complex wave is carried out in a manner exactly like that employed in connection with Fig. 41. The instantaneous amplitudes are algebraically added.

Third Harmonic

Examples of the effect of the third harmonic when added to the fundamental are shown in Fig. 52, 53 and 54. In Fig. 52, the harmonic and the fundamental are in phase. In Fig. 53, they are 180 degrees out of phase and in Fig. 54, the harmonic voltage leads the fundamental by 270 degrees—or if you wish to so interpret it, lags the fundamental by 90 degrees. Whatever the phase relation, the fact still exists that the addition of the harmonic to the fundamental changes the wave shape so that the resultant wave is of complex, rather than sine character. This,







Figs. 52 to 54. E_F is the fundamental and E_{3F} is its third harmonic. E_R is the resultant wave for the following phase differences: 0°, Fig. 52; 180°, Fig. 53, and 270° in Fig. 54.

of course, applies to any harmonic—and is not necessarily limited to the second or the third.

The number of harmonics which may be present in any one system depends entirely upon the existing conditions. Each of these harmonics will manifest its influence upon the character of the complex wave. As it happens, the most prominent harmonics present in radio systems are the second and the third, but harmonics of much higher order are also to be found. Perhaps you wonder why we devote so much space to this subject. . . . It is simply to acquaint you with the character of images which may be seen upon such testing instruments as the cathode-ray oscillograph. As to the significance of phase, that is an extremely important point because very many developments in the modern radio receiver revolve around the creation and maintenance of certain definite phase relations.

Mirror Symmetry

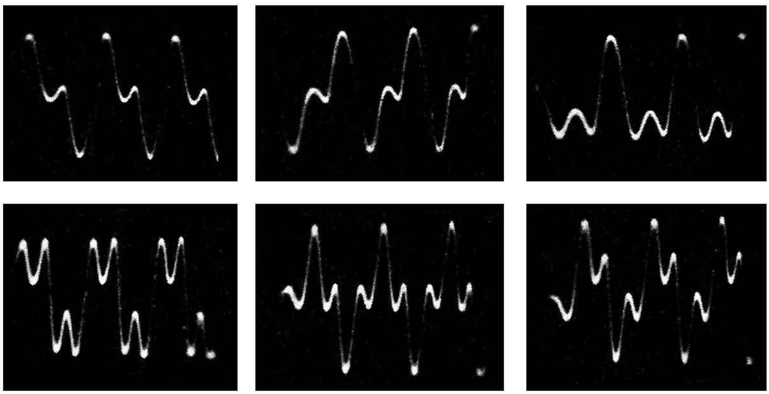
A very interesting characteristic of complex waves is known as *mirror symmetry*. If you make a comparison of Fig. 41, 50 and 51, with Figs. 52, 53 and 54, you will note a definite type of symmetry in the complex waves due to the odd or third harmonic, which is not present in the complex wave due to the even or second harmonic. This symmetry is known as mirror symmetry and means that one half cycle of the complex wave is a mirror reflection of the other half cycle. For example, if you folded back the positive alternation of the complex wave of Fig. 52, so that both appeared below the zero line, the two half cycles would be identical. . . . The same applies to Fig. 53 and 54 . . . . For that matter, the same is true of all complex waves which consist of the fundamental and odd harmonics only. . . . This is true no matter how many odd harmonics comprise the complex wave. . . . By odd harmonics is meant the 3rd, 5th, 7th, 9th, 11th, etc. . . . The presence of even harmonics, as shown in Figs. 49, 50 and 51, destroys such mirror symmetry.

The fact that a complex wave may contain a number of odd harmonics, as well as the even order of harmonics, does not change matters. . . . The presence of the even harmonics is still effective in destroying mirror symmetry.

Effect of Amplitude Upon the Resultant Wave

We stated that the amplitude of the component voltages or currents displayed an effect upon the shape of the resultant complex wave. Examples of such changes are shown in Figs. 55 to

60 inclusive. Compare Figs. 41 and 55. In Fig. 55, the magnitude of the second harmonic is greater than that shown in Fig. 41. The phase difference in Fig. 55 is zero degrees, just as in Fig. 41. In Fig. 56, the amplitude of the second harmonic is also greater than that in Fig. 50 and the phase relation is the same as in the



Figs. 55 to 60, left to right. These oscillograms show the effect of changing the amplitude of the harmonics, as explained in the accompanying text.

latter case. A similar condition exists in Figs. 57, 58, 59 and 60. In each case the phase is the same as in Figs. 51, 52, 53 and 54 respectively. . . . All that has been changed is the amplitude of the harmonic.

General Summary of Complex Waves

While it is true that we have used comparatively low frequencies in all of these cases, you should understand that whatever has been said is just as readily applicable if the fundamental frequency is 600, 6000, 50,000 or 5,000,000 cycles instead of the 60 cycles used. . . . The same is true of the harmonic frequencies. . . .

The greater the number of harmonics present in a complex wave, the greater the departure of the shape of that wave from a sine wave. This is shown in the rectangular and triangular shaped waves of Figs. 37 and 38. . . . Such waves are due to the presence of very many harmonic frequencies. . . . The greater the amplitude of the harmonics, few though they may be, the greater the departure of the resultant complex wave from the sine wave.

As far as general practical application is concerned, understanding the development of complex waves is of value only insofar as recognition of the presence of undesired frequencies. . . . The breakdown of a complex wave into its component sine waves is strictly an engineering problem and entirely out of the field of men who are interested in radio from the experimental angle, other than serious research and from the viewpoint of maintenance. Recognition of the shape of the complex wave and interpretation of the major contributing harmonics is of interest insofar as it may lead to easier analysis of operating conditions within the radio receiver system.

As to the various oscillograms shown in this chapter, it should be understood that they do not represent the entire range of complex wave patterns which can be secured by combining the frequencies stated. These patterns represent the condition stated and no other. You will no doubt experience many others in practice, because there is no rigid rule that a fundamental and its second harmonic must be of the exact amplitudes and phase relation shown in this chapter.

Chapter VII

MODULATED AND UNMODULATED WAVES

ANOTHER type of wave, which requires discussion in this volume, is generally known as a *modulated* wave and under different conditions it is spoken of as an *unmodulated* wave. This subject deserves representation because the components of a modulated wave are alternating currents and voltages and the same is true of the unmodulated wave—which is alternating current or voltage—whichever is being discussed.

Inasmuch as the title of this book stipulates that the subject matter relates to radio receivers—the type of modulated wave of interest to us is that which is associated with radio receivers. . . . This definitely narrows down the field. . . . Not that expansion of the subject introduces many complications—but we feel that by limiting ourselves to one certain variety—we can accomplish our aim: utmost comprehension with the greatest ease.

In order to explain the significance of the term and its construction, it will be necessary to pursue somewhat of a roundabout method. Instead of considering the radio receiver as the starting point, we will talk about the broadcast transmitting station. The transmission of broadcast programs—for that matter other type of transmission as well—entails certain definite operations. . . . One of these is the generation of an alternating voltage, which we commonly call the *broadcast carrier*—or just *carrier* for short. This carrier is of a predetermined frequency—and all stations are identified by these frequencies—the numerical value of which is allocated to the station by the Federal Communications Commission.

These carriers are sine-wave alternating voltages and are subject to each and every one of the statements which have been made in preceding chapters. The fact that they are used for transmission purposes does not influence their generation or their structure as alternating voltages. . . . Certain modifications are accomplished during the process of actual broadcasting of speech and music—but as far as the carrier voltage is concerned, it is in every respect a sine-wave alternating voltage.

It differs only in frequency from those voltages and currents which we have discussed. . . . Whereas the frequencies we considered were very low—from 60 to several thousand cycles per second,—broadcast carriers range in frequency from about 60,000 cycles to as high as 40,000,000 cycles. . . . Once again we repeat that these high-frequency carriers do not differ from the low-frequency voltages we have described—as regards waveform, harmonics (if any), peak and effective values, etc. . . . The primary difference is in the frequency—or if we wish to introduce another term, the *wavelength* of the wave.

Whereas a 100-cycle voltage requires .01 second to complete a cycle—a 1000-kc. (1,000,000 cycle) signal requires 1. microsecond or .000001 second or 1 one-millionth of a second to complete a cycle. For that matter, a 15-megacycle (15,000 kc.) carrier requires .0000000667 second to complete a cycle. Now based upon the speed of propagation of the electric field (electric voltage), which is approximately 300,000,000 meters per second, (exact figure 299,820,000), the distance a wave travels during the time elapsed for one cycle, when expressed in meters, is the wavelength. Thus the

$$\text{wavelength in meters} = \frac{v}{f}$$

where "v" is the velocity and "f" is the frequency in cycles.

If the frequency is 1000 kc., or 1,000,000 cycles, the wavelength is

$$\text{Wavelength}_M = \frac{300{,}000{,}000}{1{,}000{,}000}$$
$$= 300 \text{ meters}$$

Getting back to the carrier, an oscillogram showing several cycles of a 100,000-cycle voltage, which is in the carrier frequency range, is illustrated in Fig. 61. The voltage is sine and in every respect is like any other sine wave of voltage illustrated in this volume. . . . As to the operation of a broadcast station, such a sine-wave carrier is broadcast during the time that the station is "on the air"—but the program is not being transmitted. . . . By the program not being transmitted, we mean that the studio microphone is not being excited. . . . Expressed in another manner, if we understand the speech or music when con-

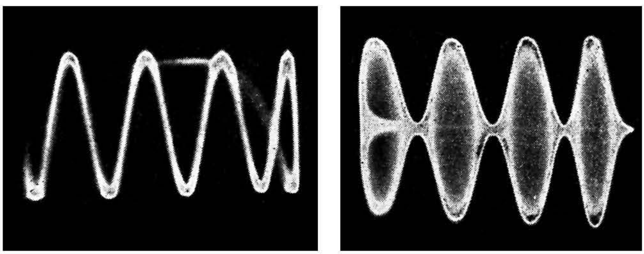


Fig. 61, left, Fig. 62. An unretouched oscillogram of several cycles of a 1000-kc. unmodulated carrier is shown in Fig. 61. Fig. 62 is an oscillogram of a 100% modulated carrier wave.

verted into electrical impulses, to constitute the modulating signal—and the studio is not on the air—the carrier being radiated is an *unmodulated carrier.* This term unmodulated carrier also appears in connection with the operation of certain devices employed for the repairing of radio receivers. . . .

In contrast to this first type of carrier, the unmodulated carrier—we have the *modulated carrier*—which is the same carrier or same alternating voltage as before, except for the fact that upon it has been superimposed the speech or music being transmitted from the station. . . . This speech or music or intelligence being broadcast is the modulating signal. . . . The unmodulated carrier transmitted from a broadcast station does not convey any intelligence, whereas the modulated carrier broadcast from the same station, conveys intelligence. . . . (In this instance we are excluding the stations which transmit code signals and which signals, when interpreted, convey intelligence.)

How does a modulated carrier differ from an unmodulated carrier? . . . Pictorially, the difference is shown in Fig. 62. . . . Compare Fig. 61 with Fig. 62. Note that the unmodulated carrier consists of cycles which are uniform in amplitude, whereas the modulated carrier consists of cycles of varying amplitude. . . . Modulation of this type is known as *"amplitude modulation"*—modulation by varying the amplitude of the carrier. This is the most widely used arrangement. The past year witnessed the introduction of what is known as "frequency modulation." . . . But a comparison of the two systems is beyond the sphere of this book.

It is interesting to note the manner in which such modulation is accomplished. . . . The modulating signal and the carrier are combined in such manner that the modulating voltage is in effect added to the carrier. The positive alternations of the modulating signal increase the amplitude of the carrier voltage during that half cycle and the negative alternations of the modulating signal reduce the amplitude of the carrier. . . . The net result is that the shape of the carrier is modified by the presence of the modulating signal and the shape of the wave envelope conforms with the modulating voltage.

What has been said is shown in Figs. 63 and 64. In Fig. 63 is shown the waveform of a 400-cycle signal. . . . This can be assumed to be a steady tone produced by a 400-cycle tuning fork and converted into an electrical voltage. The time axis starts at A and we assume that during the time AB, there is no modulating voltage because the tuning fork is not in operation. The points B, C, D, E and F designate moments of peak and zero amplitude for the modulating voltage. Two cycles are shown and the duration of each cycle is 1/400th of a second. . . . Of course, the exact duration of the modulating voltage cycle depends upon the frequency of the voltage and the 400-cycle signal is used purely as an illustration.

In Fig. 64 is shown the carrier, unmodulated and modulated. The unmodulated carrier exists during the time interval AB in Fig. 63,—that is, during the time that the modulating voltage is absent. Suppose that we assume this carrier to be 1000 kc. The carrier voltage cycles, shown in Fig. 64, are not intended to convey an idea of the number occurring during a cycle of the modulating voltage. . . . The few cycles of the carrier illustrate the manner in which the amplitude changes when the modulation voltage is applied. . . . Based upon the frequency of the modulating signal, the number of carrier voltage cycles occurring during one cycle of the modulation voltage is 1,000,000/400 or 2500 cycles. In other words, 2500 cycles of the carrier voltage occur during one cycle of the 400-cycle modulating voltage.

If you examine Fig. 64 closely, you will note that the amplitude of the carrier voltage increases on both sides of the zero line, during the time that the modulating voltage is positive. The reason for this action—rather than an increase on just one

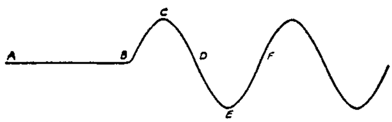


Fig. 63. From A to B, no modulating voltage exists. At B the 400-cycle voltage starts and the points C, D, E, and F show peak and zero voltages.

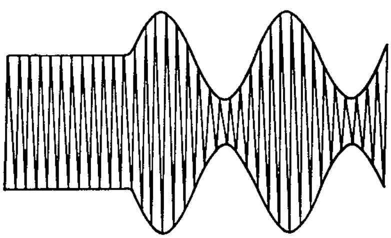


Fig. 64. The 400-cycle voltage of Fig. 63 here is modulating a 1000-kc. carrier.

side—as would be imagined at first glance—is that the modulation is accomplished by varying the voltage of the system which produces the unmodulated carrier in accordance with the amplitude variation of the modulating signal, by applying that voltage to the circuit. The same is, of course, true during the time that the modulation voltage is passing through its negative cycle; consequently, the amplitude of the carrier decreases in conformity with the amplitude variation of the negative half cycle of the modulating voltage. This continues as long as the modulating voltage is applied to the circuit. . . . The net result is that the carrier increases in amplitude over the normal unmodulated level to an extent corresponding to the peak of the negative alternation of the modulating voltage. Therefore, the upper half of the modulated carrier varies in amplitude in exact conformity with the variation of the complete audio cycle and the same is true of the lower half of the modulated carrier.

With the zero time axis as the reference line, the portion of the modulated carrier above this line is identified as the *"upper envelope"* and the portion below the zero reference line is the *"lower envelope."*

Without attempting a discussion of vacuum tube operation, we find it necessary to discuss in brief the ultimate end of this modulated carrier. . . . Assuming that the signal has been transmitted, it is picked up by the receiver and after a process of amplification arrives in the demodulator tube (the detector tube),

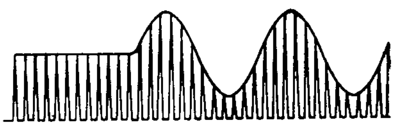


Fig. 65. This shows the lower half of the modulated wave removed by the process of detection.

Fig. 66. Here the high-frequency carrier has been removed and the audio voltage shown actuates the loud speaker.

wherein the modulating component is removed from the carrier —or at least the two are separated. As the consequence of the action in this part of the receiver, the lower half of the modulated carrier is removed, so that a graphic representation of the resultant carrier would be like the illustration shown in Fig. 65. You can see that part of the modulated wave remains after detection—and if you remove the high-frequency component, the remaining wave is exactly like the audio voltage originally used to modulate the carrier. This is shown in Fig. 66. This audio voltage is amplified and actuates the loud speaker.

It is, of course, essential that you understand that the shape of the modulation component need not be sine. As a matter of fact, it is seldom sine during the broadcasting of a program, because the sound waves due to speech and music are complex waves and remain complex waves after conversion into electrical impulses. However, complex as they may be, the amplitude variation of the carrier conforms exactly with the amplitude variations of the modulating voltage. A carrier modulated with a complex audio wave is shown in Fig. 67.

Let us return to a further consideration of the modulated wave and consider its makeup from the point of view of the frequencies which it contains. From observation, this wave is an alternating voltage having a frequency of 1000 kc. and varying in amplitude at the rate of 400 cycles. This explanation is simple, but not complete, because it is not a full picture of the frequency composition of the modulated wave. Once more it is necessary to assume a certain license—to make a statement which should be accepted as fact without the presentation of a detailed analysis establishing the fact. This fact is that a modulated wave consists of three frequencies. First, the basic carrier

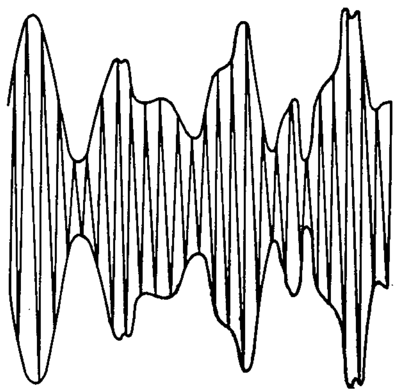


Fig. 67. A carrier modulated by a complex audio tone.

frequency. Second, the upper sideband frequency, which is the carrier plus the modulating frequency and a lower sideband frequency, which is the carrier minus the modulating frequency. In the specific case cited, that is the 400-cycle modulating frequency, the three frequencies are 1000 kc., 1000.4 kc. and 999.6 kc.

When the modulating component is a complex wave, consisting of a number of frequencies, the highest frequency is used to establish the width of the sidebands. For example, if a series of frequencies are present, as when music is being played and a number of frequencies, say up to 7500 cycles, are fed into the system via the microphone, the cycles and the limit of the upper sideband is the carrier frequency plus the 7500 cycles and the limit of the lower sideband is the carrier frequency minus the 7500 cycles.

Now, if this 7500-cycle band consists of ten fundamental frequencies, representative of ten sine waves, such as 50 cycles, 140 cycles, 300 cycles, 450 cycles, 670 cycles, 1000 cycles, 3500 cycles, 4000 cycles, 5000 cycles, and 7500 cycles, the resultant wave of voltage representing this band will be a single complex wave, but as far as the content of each side band is concerned, the modulated carrier will have within it the carrier frequency of 1000 kc. + and — 50 cycles; 1000 kc. + and — 140 cycles; 100 kc. + and — 300 cycles, etc., until the 7500-cycle limit is reached. If it so happens that the 7500-cycle band is produced by an orchestra, a very great number of frequencies are present, all within the 7500-cycle limit and the modulated carrier then consists of a great number of frequencies higher and lower than the carrier, by the limit of the side band. You can therefore see that it would be a very detailed task to show the complete structure of the modulated wave. . . . As it happens, the practical application of the contents of this book can be very successfully accomplished despite the omission of the complex structure of the modulated wave. All we must understand is that the modulated carrier is a form of alternating voltage. (The relation between the side bands and the tuning of a receiver is explained in detail in another of this "An Hour A Day" series entitled "Resonance and Alignment.")

Chapter VIII

ALTERNATING CURRENTS IN RADIO RECEIVERS

In the previous sections of this book we discussed the more important ideas associated with alternating currents. For the most part, these concepts were explained apart from the specific ways in which they may happen to appear in radio receivers. This method of development was selected because the ideas developed were general and related to many different applications. In this, the last chapter, we want to show the manner in which these various developments of alternating currents appear in different sections of radio receivers and the transition which takes place as the consequence of correct or incorrect operation of the components of receivers.

Electron Motion

The concept of an alternating current is explained in this book by relating it to the motion of electrons in a conductor. While it is true that this data may not be of great practical significance, nevertheless it is important, because it enables you to visualize the fact that different types of alternating currents are all based on the same oscillatory or vibratory motion of electrons. Furthermore, full comprehension of the fact that the motion of the electron when acted upon by a complex voltage, is due to the combined influence of all the voltages, should serve well in later discussions relating to alternating-current systems.

Cycle

As you no doubt recall, we devoted a substantial amount of space to the discussion of what constitutes a cycle. We consider this point to be quite important, particularly in view of what followed that discussion. It is true, that as a general rule, when one speaks about a cycle, the word is invariably used in connection with a numerical designation of frequency. Consequently, it becomes a part of a complete identifying term. However, in our estimation, there is a more important application of the knowledge relating to a cycle: we are referring to the visual observation of electrical phenomena by means of the cathode-ray oscillograph. For that matter the same applies to any form of analysis which requires a comparison of two or more electrical waves. In order to compare such waves properly, it is essential that you be familiar with what represents a cycle. This is true when reference is made to certain phase conditions which exist in radio receivers—particularly in modern receivers where the operation depends upon the existence of certain phase relations. These are often described in service-text illustrations showing a number of cycles of the voltage present and are identified in accordance with time expressed in degrees. In order to enable you to understand these classifications, it is necessary that you comprehend the reference cycle and the other cycle being compared. This, of course, supplements the general knowledge relating to a cycle, which is necessary for ordinary comprehension of alternating current.

Frequency

Frequency, like the cycle, when expressed numerically, is an identifying term—but unlike the cycle, it is more often referred to in connection with receiver operation. Speaking in generalities, essentially five divisions of frequency are to be found in radio receiving systems. The first group is known as the audio-frequency range and embraces frequencies between approximately 20 cycles and 20,000 cycles. In this class are to be found a subdivision known as the power frequencies, which in turn are divided into two very narrow limits: 25 to 40 cycles and 50 to 60 cycles. These are the frequencies of the a-c. power supply systems which are in general use. In this range, the most frequently found are the two represented in the latter band.

The second major band is the supersonic range, which extends from about 20,000 cycles to approximately 100,000 cycles or 100 kilocycles. As a general rule, frequencies within this range are not found in present-day receivers, although it is true that some of the older superheterodynes did employ intermediate-frequency amplifiers which were peaked at frequencies within this range and in some cases were as low as 30 kilocycles.

Reference to the intermediate-frequency band in the preceding paragraph brings us to the third frequency division: the intermediate frequency range. This range of frequencies are those which extend from approximately 100 kc. to 500 kc. As it happens, however, certain particular frequencies are more commonly employed. At one time the frequency most commonly used in superheterodyne receivers was 175 kc., although in some of the older receivers and in some of the comparatively modern receivers two or three years old, 115 kc., 125 kc., and 130 kc. were very commonplace. Today the most commonly used intermediate frequencies are to be found between 440 and 480 kc. with 456 and 465 being the two most popular peaks.

Part of this intermediate-frequency band is oftentimes identified as the "weather" band and embraces what would be the lower half of the band, or from about 100 kc. to approximately 350 kc. In this case, however, the band is not that which is used in the intermediate-frequency amplifier, but rather represents a tuning band over which the radio-frequency amplifier, the oscillator, and the mixer circuits are tuned. This weather band is not necessarily a frequency division in the true sense of the term, and in the manner in which we employ the term.

The fourth major division of frequencies is known as the radio-frequency band and extends from approximately 500 kc. to about 75 megacycles, or 75,000 kc. This band is covered by approximately five or six tuning ranges. The upper limit is more commonplace in amateur communication receivers than in the regular commercial broadcast receivers—which in very many cases have an upper limit for the radio-frequency band of about 25 megacycles, or 25,000 kc.

The fifth major frequency division is known as the ultra high-frequency band and extends from about 75 megacycles to 300 megacycles and even higher. Recent experiments in the generation of waves of less than 1 meter in length have extended this ultra high-frequency range to frequencies much higher than 500 megacycles.

Let us now consider the application of these frequency ranges to radio receivers. Starting with the audio-frequency band, the usual audio range of a receiving system—that is prior to the development of what is known as high-fidelity transmission—was from about 100 cycles to 4000 cycles. With the advent of high-fidelity systems, this band width was increased so as to extend from about 30 cycles to approximately 7500 cycles—in a few cases to as high as 10,000 cycles. . . . In special audio-frequency amplifiers, the upper limit of the audio range which can be passed by the amplifier, is sometimes extended to higher than 10,000 cycles. In some special cases, as for example in cathode-ray oscillographs, the design of the vertical and horizontal deflection amplifiers is such that they are capable of passing all frequencies between 10 cycles, as a lower limit, and about 100,000 cycles, as the upper limit.

It is possible that you are familiar with the fact that many receivers are designed with dual audio channels, wherein one channel is designed to operate over a band of frequencies extending from about 30 cycles to 3000 or 4000 cycles and the second channel is extended to operate at frequencies from above 4000 cycles to 10,000 cycles. In connection with such dual channel arrangements, are to be found multi-speaker systems wherein one speaker is designed to operate over the lower half of the audio range and the other speaker, or speakers as the case may be, sometimes known as "tweeters," are used to reproduce the high audio frequencies.

Intermediate-frequency amplifiers are intended to operate only over some range of frequencies classified as being in the intermediate-frequency band. In this connection it might be well to state at this time, that while we speak about an intermediate-frequency range, it should be understood that each superheterodyne receiver operates at one fixed i-f. peak. This is so despite the fact that the intermediate-frequency circuits are variable-tuned. They are made variable so as to allow the correct adjustment, alignment, or tuning—whichever term you wish to use.

Moreover, this fixed frequency has some numerical value within the stated intermediate-frequency range. When we speak about the i-f. amplifier and the frequency to which it is tuned, we must include the output circuit of the mixer tube, or first detector, and the input circuit of the second detector, or demodulator tube—because both of these portions of the receiver are very closely identified with the i-f. amplifier and are tuned to the i-f. peak employed in the receiver.

The c-w. oscillator, sometimes known as the beat-note oscillator and used in amateur communications receivers, also operates in the i-f. range, usually within several kilocycles higher or lower than the actual i-f. peak of the receiver.

The radio-frequency amplifier, the first detector input circuit, and the oscillator system are tuned over the radio-frequency range, and as a general rule, this range is covered by means of five or six tuning bands. In some instances, the complete range is not covered, but rather certain particular portions of the range are embraced by the tuning bands.

For example, some receivers may include a short-wave band extending from 5.5 to approximately 19 megacycles so as to cover the 31 meter and 25 meter foreign broadcast channels, also the police and aircraft band, and the broadcast band. On the other hand, other receivers may cover all of the popular foreign broadcast bands, the amateur bands, the aircraft and police bands, and the broadcast band. Still others may include foreign broadcast bands such as those at 25, 31 and 49 meters, the American broadcast band and the weather band.

Values of Current and Voltage

It would appear as if there is very little that can be said about values of alternating current and voltage, but we feel it is worthwhile devoting some time to a discussion of the values of alternating current or voltage as they relate to measurements made during maintenance operations upon the receiver. Accordingly, we shall consider in this section of the last chapter peak, average and effective values as well as the units employed to designate these values of current and voltage.

Peak Value

The peak value of current, as has been stated, does not have much bearing upon the life of the receiver in that the operation of those units which depend upon the heating effect of the current are invariably operated at effective values. However, peak values of voltage are items of definite importance. For example, fixed condensers in radio receivers are very closely allied with the peak value of alternating voltage encountered in the circuits where these condensers are used. The reason for the importance of the peak value as against the effective value in this case is that the peak value, although existing only momentarily, has the ability to puncture a dielectric or insulation used within the condenser. Consequently, it is necessary to employ condensers which can withstand the peak values found in the circuit.

As a general rule, condensers bear both a-c. and d-c. ratings, although in very many cases the label shows only a d-c. working voltage. Whichever form of designation is used, it is still necessary to appreciate the fact that the d-c. working voltage of a condenser is equal to the peak a-c. value and not to the effective value. As a general rule, the effective value of a-c. voltage comparable to the d-c. working voltage specification of a condenser, is approximately 40% lower than the d-c. rating. In other words, a condenser which is rated at approximately 1000 volts d-c. should not be used at effective values in excess of 650 volts a-c., and if greater safety is desired, the maximum working voltage of a-c. should not exceed 600 volts. The reason for this is that a-c. voltages have a tendency to heat the dielectric to much higher temperature than d-c. voltages, as a result of which the dielectric is more prone to break down under the influence of the electric voltage. Consequently, a margin of about 40% between the d-c. value and the effective a-c. value should be allowed.

Another item related to the peak a-c. value is the signal voltage applied to the various grids and the selection of the control grid bias with respect to these peak values of signal voltage. It should be understood that the control grid bias is based upon the peak value of voltage and not the effective value. This is of much greater importance in the audio system than in the r-f. or i-f. systems. This is because the value of the signal voltage encountered in the r-f. and i-f. stages is, as a rule, calculated in terms of microvolts or millivolts, whereas the control grid bias is usually in terms of volts. Consequently, the actual numerical relation between the signal and the control grid bias is such that there is very little fear of operating difficulty on account of the presence of a signal voltage which exceeds the control grid bias.

However, the condition is somewhat different in the audio system. Here the signal voltage is considered in peak values, and the control grid bias must be predicated upon these peak values. In the audio system the signal voltages assume substantial proportions and unless the control grid bias is sufficiently high with respect to the signal voltage expressed in peak values, defective performance will result.

Effective or RMS Value

The effective or rms value of voltage or current is ordinarily understood unless peak or average values are specifically mentioned. This applies to all voltages, inclusive of signal voltages, which are present in the receiver and to the voltages which are produced by signal generators employed during the process of testing. As a matter of fact, most vacuum-tube voltmeters employed for measurement purposes are also calibrated in effective or rms values and in these cases the observed voltage must be multiplied by 1.414 so as to establish the peak value. In this connection, some of the vacuum-tube bulletins released by tube manufacturers, showing the operating specifications of vacuum tubes, stipulate signal voltages in effective values.

As has already been stated, all a-c. voltage measurements, which are made with the ordinary type of meters, indicate effective values. This likewise applies to rectifier type a-c. voltmeters, such as are used as output meters. What has been said is likewise true of alternating currents. Thus, if we speak about value of voltage and current applied to the a-c. type of vacuum tube heater or filament, we refer to effective values. When we speak of power available from a vacuum tube we likewise talk in effective values as against peak values. Again, when we are concerned with the transformation or step-up of voltage in a power transformer, which voltage is applied to one or more rectifier tubes, we speak in terms of effective values.

In other words, if a power transformer steps up 110 volts to 1100 volts, which then is applied to the rectifier plate, we are speaking in terms of effective values. In this connection we would like to mention, so as to avoid confusion, that the reference which often appears in vacuum-tube specifications charts covering rectifiers, to the effect that a rectifier tube will withstand the application of a specified number of volts identified as "maximum,"—the reference to maximum does not signify a peak value. What is really meant is that this maximum figure is the highest value of *effective* voltage which the rectifier tube can withstand without breakdown.

Average Value

When we speak of average values, we almost invariably refer to current and seldom to voltage. In the case of current, the average value is represented by a direct current found in rectifier circuits. This applies just as readily to the output of a power supply rectifier as it does to the output circuit of a detector tube. Another item of interest relating to average values is that the a.v.c. voltage is dependent upon the average value of rectified currents which flow through the detector tube load. For a more complete discussion of this subject, we refer you to another of this "An Hour a Day" series entitled "Automatic Volume Control."

Pulsating Current

As the consequence of the composition of a pulsating current, that is, since it is a direct current upon which has been superimposed an alternating current, pulsating current is found in the plate circuit of every vacuum tube which is passing a signal.

The a-c. parts of this pulsating current are the r-f., i-f., and a-f. components of the signal, which is passing through the system and is transferred from stage to stage through the medium of the coupling unit employed between the stages. In power supply systems, however, the a-c. component of the pulsating current output of the rectifier is representative of the hum voltage and this voltage is filtered out by means of the various condensers and chokes used in the filter system, until the output of the rectifier across the voltage divider is a substantially pure d-c. voltage.

Units

As to the units of voltages which appear in different parts of the receiver as operating voltages—such as filament or heater, control grid bias, screen grid, suppressor grid and plate voltages, these are expressed in terms of the unit volt or multiplies thereof. However, signal voltages which appear in different parts of the receiver are usually referred to in different units. Signal voltages appearing in the antenna and i-f. systems are usually expressed in terms of microvolts. Signal voltages appearing in the i-f. stage are usually spoken of in terms of millivolts, while those appearing in the detector and audio-frequency stages, as well as in the oscillator employed in superheterodyne receivers, are usually expressed in terms of volts and multiples thereof. Voltages which are produced by signal generators employed for service operations, employ the complete range from microvolts to volts, and the unit used, when stating the voltage, depends entirely upon the magnitude of the voltage secured from the device.

Phase

Phase considerations of various kinds occur in practically every part of the receiver and these relate to phase relations between different voltages as well as combinations of voltage and current. To start with, let us consider the vacuum tube by itself. The operation of this device is such that when utilized as an amplifier, which also is a function of the average three or four-element detector tube, the output signal voltage is in general 180° out of phase with the input signal voltage. This is primarily a theoretical condition in that the actual phase may differ from this theoretical figure.

As a general rule, the phase relation existing in any individual vacuum tube is not of great practical importance by itself but it does become of practical importance when we correlate the condition with other operating facts.

For example, excessive regeneration present in an amplifier can often be traced to the consequence of a certain phase relation. By this is meant the presence of feed back between the output circuit and the input circuit of a vacuum tube which occurs in such phase that a portion of the output voltage finds its way back into the input circuit and consequently increases the magnitude of the input voltage until a point is reached where the tube,—intended to function as an amplifier—becomes a generator of sustained oscillations, or in other words, an oscillator. This matter of feed back between input and output circuits is not necessarily limited to the same tube. It can occur between various stages in an amplifying system. The net result of such feed back—that is, whether it will increase or decrease signal output—depends entirely upon the phase relation between the voltage fed back and the voltage present in a circuit which receives the feed-back voltage.

In some cases, depending upon the actual circuit conditions, the action which takes place may be such that instead of the feed-back voltage being in such phase as to be additive with the signal, the voltage fed back to the input may be out of phase with the input voltage so that *degeneration* takes place. Wherever it takes place, the amplification is reduced. Often a certain amount of degeneration is desirable, because of the improved performance which it makes possible.

Neutralization of various types consists of a process of feeding back a voltage from one circuit to another which is of such phase and amplitude as to offset or neutralize the feed-back voltage taking place through the grid plate capacity of the vacuum tube.

Phase Inverter Tube

An example of the specific use of the property of phase inversion in a vacuum tube is the use of a tube for that purpose in resistance-coupled audio amplifiers wherein push-pull action is desired in the output stage and a transformer is not used in the input system of the push-pull output stage. This is a practice found in a large number of commercial receivers. The action in this system is as follows:

To start with, a push-pull stage requires that the signal voltages applied to the respective grids be 180° out-of-phase. This condition normally is achieved by the use of a push-pull transformer which feeds the push-pull output stage. However, when the use of such a transformer is to be avoided—normally to achieve greater economy—the signal from the preceding stage is divided into two channels. One channel feeds one of the grids of the output stage. The phase of this voltage is the same as the phase at the output of the preceding stage. The other channel consists of

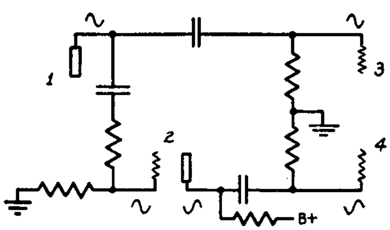
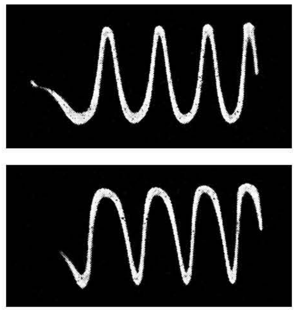


Fig. 68. Tube No. 1 is the source of a-f. voltage. Tube No. 2 is the phase inversion tube, which shifts the phase of the voltage 180° with respect to that in the plate of Tube No. 1. Nos. 3 and 4 are the push-pull output tubes. Note the small sine waves showing the phase shift.

the phase inversion tube. This is shown in Fig. 68—wherein tube No. 1 is a source of the audio voltage which may be the detector tube or the first stage audio amplifier. Tube No. 2 is the phase inversion tube and tubes 3 and 4 are the two tubes used in the output push-pull stage. The voltage from the output circuit of tube No. 1 is fed to tube No. 3 through the condenser shown and the phase of this voltage corresponds with the phase of the voltage in the output of tube No. 1. A portion of this output voltage from tube No. 1 is then fed into the grid of tube No. 2. A 180° phase shift takes place in this tube, so that the voltage in the output circuit of tube No. 2 is 180° out-of-phase with the voltage at the output circuit of tube No. 1. The output of tube No. 2 is fed to the grid of tube No. 4 and since the phase of these two voltages is the same—the phase of the voltage at the grid of tube No. 3 is 180° different from that at the grid tube of No. 4. By the suitable selection of resistors and amplification in tube No. 2, the voltages at grids 3 and 4 are made equal in amplitude.

The basis of push-pull operation is also the achievement of a definite phase condition. In order to secure push-pull operation, it is necessary that the phase of the voltages of the two tubes differ by 180°. This phase difference is maintained in the output circuit and when the two voltages are combined by means of the transformer located in the output system, or the coupling device located in the output system—the positive and negative halves of the output wave have the same shape and this means that this output wave has no even harmonics and consequently has less distortion in it. This is shown in Figs. 69, 70 and 71, wherein are illustrated three oscillograms showing the output of the two push-pull tubes considered individually and the combined output of the two tubes. Note the presence of even harmonics in Figs. 69 and 70 and the absence of all even harmonics in Fig. 71. The absence of these even harmonics is indicated by the fact that mirror symmetry is possessed by the wave form.



Figs. 69 and 70. Oscillograms of the output of each of the two push-pull tubes. Note that in each case the upper and lower peaks are unlike, showing the presence of even harmonics.

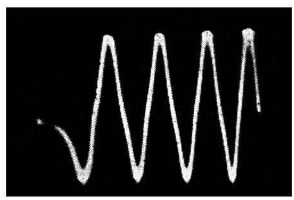


Fig. 71. Oscillogram of the combined output of the two push-pull tubes used in the above two figures. Note that all the peaks are now symmetrical, showing that no even harmonics are present; this wave shows mirror symmetry.

Another example of phase relation as it may influence operation, is to be found in systems which employ a number of different speakers, all of which are being used to reproduce similar frequencies. In these cases it is important that the diaphragms of these speakers move in the same direction at each instant, as the consequence of the signal voltage which is being applied to the voice coils. If this does not take place, then the phase difference existing between the sound waves developed as the result of the motion of the diaphragms, will tend to cause the sound waves to offset or neutralize each other because the motion of the diaphragms is 180° out of phase. The operation of connecting voice coils in proper phase, so that all the diaphragms are acting in the same direction, is known as "phasing speakers."

Another example of the application of a definite phase condition so as to accomplish a certain result is to be found in some of the older receivers, wherein a series combination of resistance and capacity was connected between the plate and the grid circuits of a vacuum tube in order to feed back a certain portion of the hum voltage from the plate circuit into the grid circuit. The phase of this voltage fed back through this network, was 180° different from that present in the grid circuit and the net effect was to cancel the hum voltage present in the system, and thereby secure greater freedom from distortion—due to the presence of this hum voltage.

A modern application of phase relations to accomplish a definite objective is to be found in automatic frequency control systems. In these systems a double diode rectifier circuit receives its voltage through a split winding. Each half of this split winding feeds its respective diode rectifier system. (The rectifier tube is generally a 6H6.) In turn, the load upon the rectifiers is likewise split so that a d-c. voltage is available from each of these diode rectifier systems. The arrangement of the load circuit is such that the two voltages obtained after rectification are additive and are of opposite polarity with respect to a common terminal. The resultant d-c. voltage developed after rectification is therefore positive or negative—depending upon the respective magnitudes and polarities of the two rectified voltages. This in turn is dependent upon the magnitude of the a-c. voltages which are fed to the two diodes. The a-c. voltages in turn are dependent upon the phase relations existing between the voltages across the two halves of the winding, which feeds the diodes, and other related parts.

The phase of the signal voltages fed into this diode circuit depends upon the degree of accuracy with which the receiver is tuned. If the receiver is properly tuned, the voltage across the two halves of the split winding differ in phase with respect to a common reference voltage by a like amount but of opposite sign. The result is that equal voltages are applied to the two diode rectifiers and since they are of opposite sign, the two d-c. voltages produced, as the result of rectification, are of equal magnitude and opposite sign. The net result is a zero control voltage. However, when the receiver is not properly tuned, the voltage, across the two halves of the split winding do not differ in phase by an equal amount with respect to this common reference voltage. One will lead by more than 90° and the other will lag by less than 90°. Consequently, a greater signal voltage will be applied to one diode than to the other—with the result that a net positive or negative control voltage is produced which acts upon the control tube and causes a change in tuning in the system. Thus, it is evident that the heart of the entire arrangement is the development of certain phase relations between the respective a-c. voltages present in the system. (A complete discussion of the manner in which automatic frequency control functions is to be found in another of this "An Hour a Day" series entitled "Automatic Frequency Control.")

We have made reference in this chapter to phase difference expressed in degrees, and you can possibly appreciate just why we stressed the subject of time expressed in degrees rather than in fractions of a cycle. It is much more convenient to state that the voltage across a secondary differs by 180° from that across the primary of a transformer, than to say that the voltage across a secondary differs from that across a primary by a half cycle. The same is naturally true in connection with other phase relationships.

Phase relation is also an important consideration in connection with the study of the behavior of condensers, inductances and resistances. In other words, the reasons why the voltage applied across a condenser lags the current due to this voltage by 90°. Also why the voltage applied across an inductance or choke leads the current due to the voltage by 90° and why the current flowing through a resistor is in phase with the voltage applied across the resistor. This subject like some of the others mentioned herein, is discussed in greater detail in another of this "An Hour a Day" series entitled "L, C, and R."

It is possible to quote very many more instances of the application of phase in radio receivers, but we feel that those already mentioned should suffice, particularly in view of the fact that many of the remaining are variations of those already mentioned.

Waveform and Harmonics

As a general rule, all the alternating currents present during the normal operation of a radio receiver are of complex character. This statement is made with the understanding that the receiver is being used for the reception and reproduction of signals transmitted from a broadcasting station which is putting a program on the air. The possible exception to the original statement is the wave of voltage which is secured from the power supply system and applied to the power transformer. This is particularly assumed to be a sine wave, but upon very close analysis will be found to contain harmonics and consequently is not a pure sine wave. This condition does not introduce any complications in that the presence of harmonics in this voltage does not influence the operation of the power supply rectifier or the operation of the filter system, which eliminates the a-c. components in the pulsating-current output of the rectifier.

You can very readily appreciate why all of the signal currents would be of complex character. To start with, the program of speech or music transmitted from the broadcasting station consists of complex sound waves originally picked up by the microphone. Consequently, the modulation superimposed upon the carrier is complex in character. The received modulated carrier is, therefore, of complex character and after due amplification the carrier is eliminated and the resultant audio signal, representing the original modulating signal developed in the broadcasting station, remains as complex in character as the sounds which were picked up by the microphone.

Thus, the a-c. components present in the plate circuits of the respective tubes are always of complex nature. The exception to this is to be found in the event that the broadcasting station is transmitting a carrier which is modulated by a sine wave representing a single pure tone picked up by the studio microphone or perhaps fed into the modulating system from an electrical source.

The oscillators, which are to be found in superheterodyne receivers, likewise develop complex waves. In other words, the heterodyning oscillator, which develops the signal which is mixed with the received carrier in the first detector or mixer tube, produces a fundamental frequency and a number of harmonics. Consequently, the resultant voltage developed by that tube is of complex nature. The same is true of the beat oscillator which is employed in amateur communication receivers.

The pulsating current present in the output of the rectifier system likewise contains an a-c. component of complex character. The reason for this is that during the process of rectification a number of frequencies are developed which are harmonics of the fundamental ripple frequency. (By ripple frequency is meant the frequency of the alternating-current components of the output of the rectifier.) The fundamental frequency of this a-c. component is the same as the power supply system when a half-wave rectifier is used and is twice the power supply frequency when a full-wave rectifier is used. In other words, if a 60-cycle power supply is employed with a half-wave rectifier system, the fundamental frequency of the a-c. component of the rectifier output is 60 cycles and the harmonics are multiples of 60 cycles. If the power supply were 25 cycles under the same circumstances, then the fundamental frequency of the a-c. component present in the rectifier output would be 25 cycles and the harmonics multiples of 25 cycles. However, if a full-wave rectifier were used with the same power supply systems, then the fundamental frequency of the a-c. component would be 120 cycles and 50 cycles respectively and the harmonics would be multiples of 120 cycles and 50 cycles respectively.

Distortion

Various kinds of distortion may arise in a radio receiving system. Such distortion may be of a number of types, all of which are related to the waveform of the signal being passed through the receiver. Bearing in mind that the signal is of complex nature and consequently contains a number of different frequencies, we find that as the result of imperfect operation, a change can be created in this complex waveform. This change may take one or more of the following forms: the unequal amplification of different frequencies; the introduction of one or more frequencies, in other words harmonics; or it may be a change in the phase relations existing between the various frequencies present in the signal. Of these the latter is least noticeable to the ear when such altered signals are converted into sound waves. Each one of the other two, however, will manifest its presence in a change in the quality of the reproduction. Of course, in order to appreciate that such a change has taken place—when judgment is rendered by the ear—it is necessary to know how the original sounded. However, when observations are being made by means of the cathode-ray oscillograph, it is fairly simple to note the introduction of such undesirable conditions by comparing the character of the wave as it exists at two different points in the system.

Oftentimes, in order to check the existence of such undesirable conditions, a sine wave of voltage is introduced into the audio system and a visual observation is made of the character of the wave available at the output of the complete audio system. Any departure from the sine character can then be interpreted as indicating the presence of a condition which results in the introduction of harmonic frequencies. Supplementary tests over a range of audio frequencies can be interpreted to show the accentuation of different frequencies during the process of amplification. A similar test can also be used to establish the presence of phase distortion, which in reality is nothing more than a condition wherein all frequencies are not transmitted with the same speed through the amplifier.

Undesired conditions which may also develop in the radio frequency, intermediate frequency, or detector portions of the receiver, are of somewhat similar nature and each result in some change in the character of the wave of voltage which is being passed through the system.

This distortion, for example, may take the form of the elimination of some of the outer sidebands, as a result of excessive selectivity in the i-f. amplifier. This would have the effect of removing the higher audio frequencies from the output of a receiver. Or again, it sometimes happens that in the case of strong signals, the envelope of the modulated wave is distorted so that frequencies not originally present in the signal are introduced. With the widespread use of variable-mu tubes, this effect is no longer common; however, it is quite commonplace in the older receivers.