America's Oldest Radio School

RCA INSTITUTES INC.

A Radio Corporation of America Subsidiary

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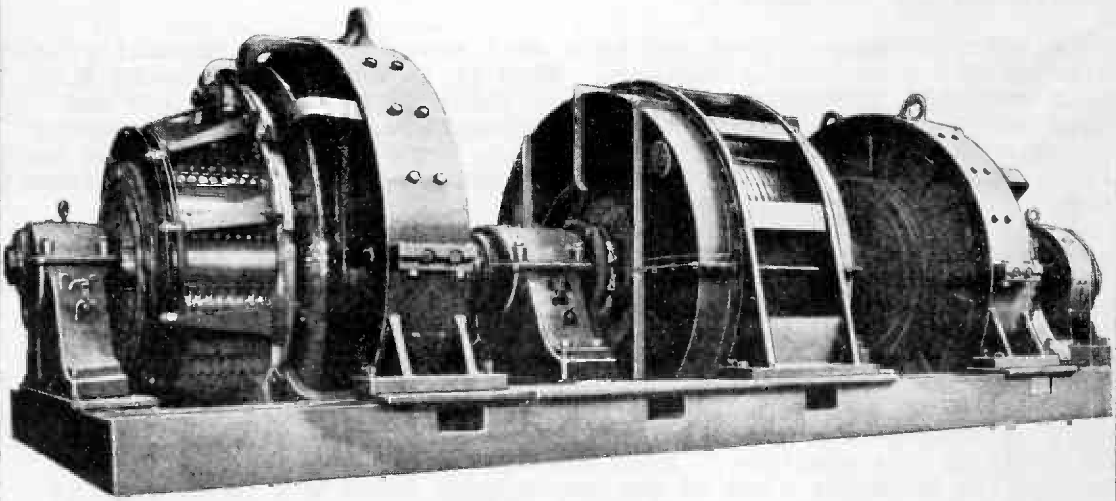
75 Varick Street, New York



Westinghouse 12,000 Ampere, 3-Unit Synchronous Motor Generator

ALTERNATING CURRENT

Vol.10#10

Dewey Classification R100

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ALTERNATING CURRENT

Generators may be classified as follows; alternating current generators and direct current generators. More specifically A.C. generators are often called "alternators", and D.C. generators are called either "generators" or "dynamos".

The electrical energy produced by a coil revolving in a magnetic field is primarily alternating current. When it is desired to obtain D.C. in an external circuit, i.e., current which is steady in value and which moves continuously in the same direction, it becomes necessary to equip the generator with a commutator. The commutator, as you know, allows the current to flow through the external circuit in one direction only.

In radio telegraphy and telephony it is often necessary to utilize alternating current therefore we do not equip the machine with a commutator, but employ slip rings which permits the induced current to flow from the coils of the armature into the external circuit just as it is generated, or as alternating current.

In your lesson on direct current generators you learned that the armature, revolving in a magnetic field, produced alternating currents in the coils of the armature. When one side of the closed coil moved through the magnetic flux of the north pole there was induced in it an E.M.F. which caused current to flow through the armature coil in one direction. The other half of the coil begins to cut the magnetic flux of the south pole of the magnet at the same time which also causes a current to move in this half of the coil for the same reason as caused current flow in the first half.

If the terminals of this revolving coil are connected to a pair of brass rings, or slip rings, and a pair of brushes rest against and make contact with these rings, (to which is connected the external circuit), the induced current can be made to follow the conducting wires forming the external electrical circuit.

In order to better explain the fundamental action going on in the alternating current generator, or alternator, we will consider a single coil instead of an armature containing many coils, and study each effect as it takes place during the revolution of a closed coil, or conductor, through the magnetic field or flux.

Now refer to Figure 1. Here we have arranged a single armature coil; the terminals, as shown, are connected to the slip rings. The rings themselves are held in place by an insulated shaft. The brushes and external circuit are clearly shown and marked.

As the coil is forced to revolve in the magnetic field the slip rings must move with the armature coils, all being mounted on a common shaft. The brushes are stationary and merely serve to provide a sliding contact on the rings.

Side "A" has induced in it an electromotive force as it cuts through the magnetic field, causing the induced current to flow in a definite

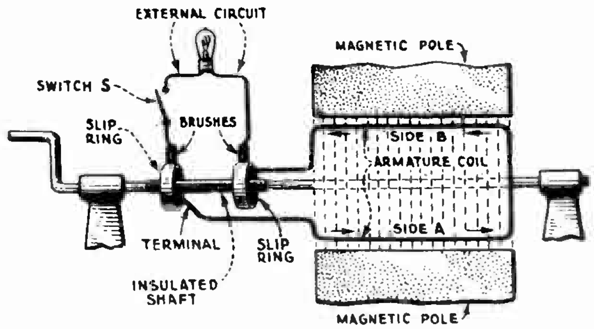

Figure 1

direction as shown by the arrow, if the circuit is closed by closing the switch "S". Likewise side "B" also has induced in it an E.M.F. with current flowing as shown by the arrow.

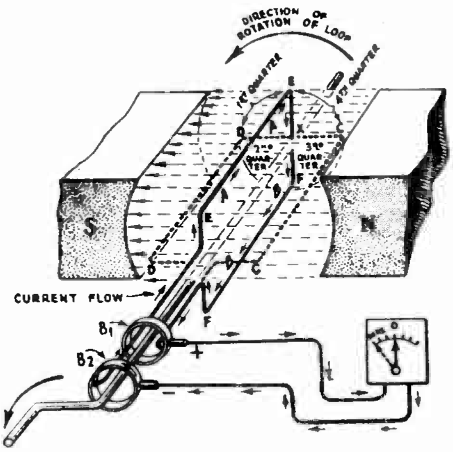

Figure 2

Remember this,-- any wire cutting a magnetic field will have induced in it an induced electromotive force and the current flow is a direct result of this induced E.M.F. but it will not flow until the coil forms a closed loop. Since we know the parts of this simple alternator we can go further and trace the current as it alternates or reverses its direction through the circuit.

Let us study Figure 2 where we have the same piece of apparatus as shown in Figure 1 but drawn in a different position allowing us to see the full circular path of the loop or armature coil through the magnetic field. The side of the coil marked "AA", you will notice, is at the top of the magnetic flux or field at position "EE" while the side "BB" is at the bottom of the field, position "FF".

The meter needle is pointing to zero indicating that while the loop is in this position relative to the magnetic field there is no induced E.M.F. and consequently no induced current will flow because the sides of the loop "AA" and "BB" are parallel with the lines of force and are not cutting the flux.

Before we consider the flow of current suppose we first cause the loop to revolve to show the positions the side "AA" will assume during a complete revolution of the coil. "AA" side of the loop is shown at the position "EE". The loop begins to revolve in a counter clockwise direction, shown by arrows, on its shaft "X", and immediately begins to cut the lines of force or flux of the "S" pole of the magnet.

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When it arrives at position "DD", the end of the first quarter revolution, it will be cutting the maximum number of lines of force, leaving position "DD" it cuts less lines of force until at position "FF", the end of the second quarter of revolution, it is again parallel with the lines of force, cutting no flux.

Continuing into the third quarter of revolution it again cuts the magnetic flux, upward this time, gradually cutting the lines of force at a greater angle each fraction of upward movement until at position "CC", or end of the third quarter of revolution, it will be cutting the greatest number of lines of force under the "N" pole or magnetic field of north polarity.

Leaving position "CC", and continuing into the fourth and last quarter of revolution, less and less lines of force are cut per unit of time and, upon arriving at position "EE", the end of the fourth quarter of revolution, it is again parallel to the magnetic field and no lines of force are being cut.

This completes one revolution of the coil through the magnetic field. The loop can be rotated another full revolution and the same cycle of events would be repeated over again.

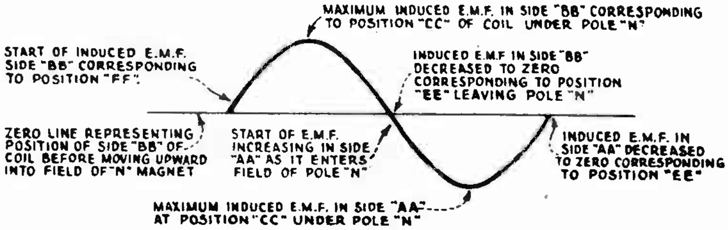

Figure 3

On the second journey of the loop we are going to study how the induced E.M.F. is affected by the cutting of the lines of force,- how it rises from zero strength to maximum strength, and then falls again to zero value.

On the second revolution we will concentrate upon side "BB". The armature starts, "BB" moves upward into the north magnetic field and, because of the cutting of the lines of force, it has induced in it an electromotive force, the strength depending upon the speed it moves and upon the strength of the magnetic field through which it travels.

The induced electromotive force will cause current to flow in this side of the loop in the direction shown by the arrows, making brush "B1" positive. The current increases in strength due to the increased electromotive force induced by the greater number of lines of force cut per unit of time, until the coil reaches position "CC". Here the maximum number of lines of force are cut and the maximum electromotive force is induced. Therefore the maximum current strength possible is obtained at this position, assuming the field to be uniform and the speed constant.

While side "BB" has moved to position "CC", side "AA" has moved into position "DD". An E.M.F. and current is induced in "AA" exactly as in side "BB", but opposite in direction, as shown, making the brush "B2" negative. The resulting induced current has moved through the circuit causing the meter needle to move to the left, pointing to maximum.

Side "BB" now moves out of the maximum field position "CC", cutting less lines of force per unit of time as it moves toward position "EE", therefore less E.M.F. is induced and consequently the induced current decreases in strength, until it reaches "EE" where no lines of force are cut and the E.M.F. drops to zero as indicated by the needle of the meter when it returns to zero position.

We may plot this rise and fall of current taking place in side "BB" of the coil as it passed under the north pole of the magnetic field, as shown in Figure 3, by a curved line which moves upward from zero to a maximum height and then as gradually decreases again to zero.

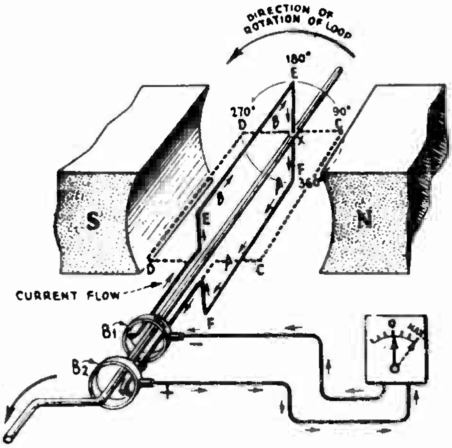

Figure 4

The position of the loop now indicates side "BB" at position "EE" and side "AA" at position "FF". "BB" now moves downward, under the influence of the south magnetic field, and the current induced flows through "BB" and the external circuit opposite to the direction of flow when "BB" was under the north magnetic field. See Figure 4.

The induced E.M.F. rises from zero to maximum and falls again to zero as the coil was moving under the "N" pole, and as shown by the meter needle which has moved across the scale, this time to the right, returning to zero when side "BB" has reached position "FF"; this reversal of current flow will cause the needle to move in the opposite direction.

In Figure 3 we have shown a sine curve which graphically illustrates the continuously varying values of E.M.F. induced in the conductor as it moves through the magnetic field.

VALUE OF E.M.F.

The value of the induced E.M.F. depends upon the following factors:

- 1st. The number of conductors revolving in the field.
- 2nd. The strength of the magnetic field.
- 3rd. The rate at which these lines of force constituting the magnetic field are cut.

In our simple alternator only one conductor was used and we assumed the field strength to be constant.

TIME A DETERMINING FACTOR OF INDUCED E.M.F.

We may now consider the rate at which the lines of force are cut and why the value of the induced E.M.F. varies as the armature coil completes a revolution through the field.

In Figure 5 we have a diagram intended to show how time, or the rate of cutting the field, and the field strength, determines the value of the E.M.F. It is obvious, after studying Figure 5, that a conductor moving through the magnetic field, either from "A" directly to "C" or along the path "A", "B", "C", will cut exactly the same number of lines of force, both having moved through the entire field, and both having cut every line of force in the field. The distance, however, from "A" to "C" is shorter by approximately two thirds the distance than along the path A, B, C.

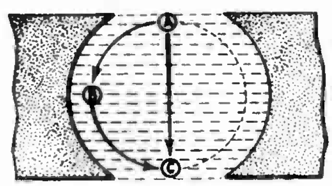

Figure 5

Now assume that the conductor is moving at a speed requiring one second of time to travel from "A" to "C" thereby cutting through all the lines of force with a definite value of E.M.F. being induced. At the same speed it now follows the path A, B, C, and, this path being fifty percent longer than path A, C, it requires 1 1/2 seconds of time to complete the distance. All the lines of force are cut, but at a slower rate, therefore less lines of force are cut in one second in this path than the path "A", "C", and less induced E.M.F. will be the result.

The rate at which the lines of force are cut then in a given time is also going to depend upon the angle at which the conductor moves through the field. When the conductor moves from "A" to "C" every line of force is cut at right angles and, at the given speed of one second , the induced E.M.F. is maximum.

Now revolve the conductor through path A, B, C; it is obvious that as the conductor leaves "A" it is moving nearly parallel with the magnetic field. As it progresses towards "B" its path becomes more nearly at right angles to the field and an increasingly greater E.M.F. is induced, until at "B" the conductor is moving directly at right angles to the field and, at this point, the induced E.M.F. is at its highest value.

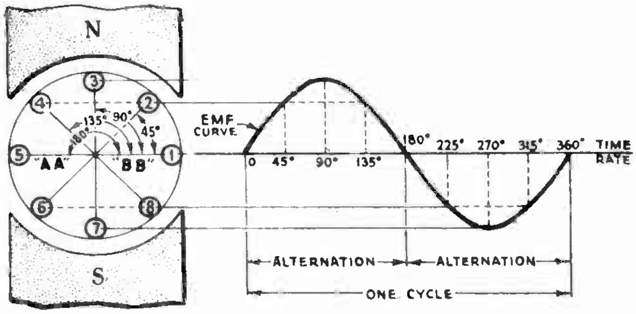

Figure 6

On leaving "B" the conductor ceases to cut the lines of force at right angles and, as it progresses from point "B" to "C", it cuts the lines of force less and less at right angles, consequently the induced E.M.F. gradually decreases until at "C" the conductor is again parallel to the field and induction ceases, with a consequent cessation of induced E.M.F. and current flow.

TIME RATE EXPRESSED IN DEGREES

The armature coil is so arranged on the armature core that it must describe a complete circle in the magnetic field. In the construction of a sine curve indicating alternating current this is expressed as the time rate in degrees.

In any complete circle there are 360 degrees and, if we wish to show the increase and decrease of induced E.M.F. in an armature coil in successive steps, we may do so by dividing the circle so described by the armature coil through the magnetic field into degrees of time. This will be explained with the assistance of Figure 6.

When the side of the coil "BB" is in position 1 Figure 6, in the magnetic field, no flux is being cut, hence no E.M.F. is induced in the coil. At this point of the base line representing time rate in degrees, we start our E.M.F. curve. The coil now moves from position 1 to 2, or 45 degrees, and cuts the flux and, the induced E.M.F., being of positive polarity, is plotted above the base line.

Now draw a vertical line from the base line until it intersects the horizontal line extending from position 2 of coil "BB" to the right and parallel to the base line. The point of intersection will indicate the rise of the induced E.M.F. of coil "BB" and by connecting this point and "45 degrees" on the base line we show graphically the rise in the induced E.M.F.

The coil now reaches position 3, or 90 degrees from position 1. A vertical line is erected from 90 degrees on the base line and the horizontal line drawn from position 3. From the point where these lines intersect another line is drawn to the 45 degree position indicating the amount of increase that has taken place.

As the coil proceeds we plot position 4, or 135 degrees, and from your study of Figure 2 you know that the induced E.M.F. is now decreasing. When position 5 is reached (180 degrees) no E.M.F. has been induced in the coil. This completes the first alternation of E.M.F. Side "BB" now continues to rotate and, upon passing through points 6, 7, 8 and back to 1, (the starting point), it completes one revolution. During the last half of this revolution exactly the same inductive action takes place as in the first half revolution but with this difference; the current induced in the side "BB" now flows in the opposite direction, for the side "BB" is now under the influence of the south pole and not the north pole as in the first half revolution. This reversal of the current flow is clearly shown in Figure 6. As already mentioned, the inductive action is the same and, therefore the procedure of plotting the value of the induced current upon the curve is the same as for the first half revolution of this coil.

ALTERNATIONS, FREQUENCY AND CYCLES

The induced E.M.F. in side "BB" rises from zero to maximum value between 0 degrees and 90 degrees then falls in value from 90 degrees until zero is again reached at 180 degrees; this is termed an alternation. From position 5 to position 1 side "AA" has induced in it an E.M.F. which changes in value similar to that in side "BB".

This rise and fall in the value of the induced E.M.F. takes place twice during each complete revolution of the armature coil. In every cycle, then, there are two alternations of E.M.F., i.e., one positive and one negative alternation. The frequency of an alternating current generator is expressed in cycles per second.

When the coil "AA", "BB", rotates 60 complete revolutions per second 120 separate reversals of current per second are induced therein and since one cycle consists of two alternations, or reversals, the FREQUENCY of the current is said to be 60 cycles per second.

This is only true in the case of our simple alternator which employed two field poles. In most commercial alternators, however, you will find more than two field poles and, as the speed and the number of field poles determine the frequency, we are going to give you a simple formula whereby you can easily determine the frequency of any alternating current generator.

The frequency will equal the number of poles in the alternator multiplied by the speed at which the armature revolves and divided by the alternations per cycle - which is always two. We must not overlook the fact that if we wish to know the frequency in cycles per second, the speed of the generator must be given in revolutions per second. In working out this formula for cycles per second it is necessary, therefore, to change the speed of the generator to revolutions per second and this is easily done by simply dividing the speed (as stated in RPM) by 60.

Assume that our simple two-pole alternator of Figure 2 revolves at the speed of 3600 RPM, what will be the frequency of the generated alternating current?

Write down your formula in this fashion; $F = \frac{N \times S}{2}$, where F = frequency, N = number of poles and S = the speed of the machine in revolutions per second.

If the speed of the alternator is 3600 RPM then its speed in revolutions per second will equal $\frac{3600}{60}$, or 60 revolutions per second.

Substituting these values in the formula we have $F = \frac{2 \times 60}{2} = \frac{120}{2} = 60.$

Therefore, F (frequency) is 60 cycles per second.

The majority of commercial alternators have more than two poles and it is just as easy to find the frequency of a multi-pole machine as it was to find the frequency of our simple two-pole alternator. Simply substitute the known number of poles for N and also the other known values in the formula and solve as shown above.

PHASE

The phase of an alternating current wave can be any point on that wave.

You learned in plotting the sine curve of Figure 6 that degrees were used to denote time as regards the values of the E.M.F. and current as they rise and fall during each alternation. Hence, the term "phase" may also refer to time. More specifically, phase may also be said to be the time instant when some maximum, zero, or any intermediate value is reached by the wave.

In Figure 6 we used 45 degree intervals so in further describing phase we will also use 45 degree intervals of time and illustrate it in Figure 7. The phase, "A" "A'", unless otherwise specified in such a curve, is regarded as a 360 degree phase; that is, the phase begins at 0 degrees and ends at 360 degrees.

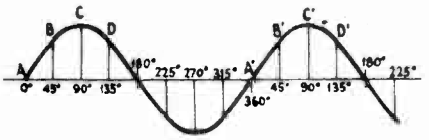

Figure 7

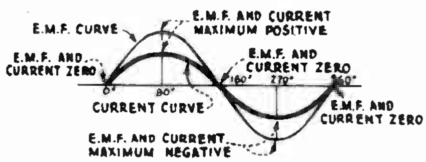

Figure 8

Any other point may constitute the phase of the curve, such as "B" and "B'" which is a 45 degree phase, "C" and "C'" a 90 degree phase, "D" and "D'" a 135-degree phase, and so on.

PHASE RELATIONS, CURRENT AND VOLTAGE

The current of the alternator alternates as well as the E.M.F. and will have the same general form as to frequency etc., and both current and E.M.F. can be plotted from the same base line. The circuit through which the alternating current flows will have, however. an influence on the current and will either cause the current to lag or lead the electromotive force. Capacity and inductance are the determining factors in regards to the lag or lead of the current. This will be taken up in detail in a later lesson.

In this lesson we will show you three curves having different phases. The first, shown in Figure 8, is one which would be obtained in an alternating current circuit where resistance only is present in the circuit. Notice the E.M.F. and current curves. Both start to rise at the same instant and continue to rise and fall keeping in step with each other throughout the cycle. In other words, they are in phase with each other. This condition, as stated, results only when pure ohmic resistance is present in the circuit.

Figure 9 illustrates the resulting effect on the current when pure inductance only is in the alternating current circuit, and in this case causes the current to lag behind the voltage or E.M.F. by 90 degrees. In other words the retarding effect of inductance prevents the current from starting through the circuit until after the E.M.F. has increased in value corresponding to 90 degrees.

Figure 10 illustrates the phase relationship between the current and the E.M.F. when pure capacity only is present in the circuit. In this instance the action is quite the opposite of that when the alternating current was flowing through pure inductance, i.e., the current now leads the voltage by 90 degrees.

These curves simply show graphically how, first, a current and E.M.F. which is in phase is depicted and, second, how the current is out of phase with the E.M.F. by 90 degrees with the current lagging the E.M.F. and, third, the current leading the E.M.F. by 90 degrees.

The reasons why this phenomena is apparent will be taken up in detail later on.

EFFECTIVE CURRENT AND VOLTAGE

The ampere is the unit of electrical current flow and we told you that it was the rate of unit flow that would pass through a resistance of one ohm at a pressure of one volt. More correctly it is stated as follows: "The ampere is that unvarying current which, when passed through a solution of nitrate of silver in water, will deposit silver at the rate of 0.001118 grams per second." From this standard method we may determine exactly the amperes flowing in a D.C. circuit.

We are, however, dealing with alternating current and you know alternating current varies, changing its value every instant of the cycle and reversing its direction every 180 degrees, or each alternation. This standard of measurement cannot, therefore, be used in determining the amperes in an A.C. circuit. The first alternation would deposit a certain amount of silver, true enough, but the next alternation would be opposite in direction to the first and it would take away the silver just deposited. For that reason some other means of finding the current in amperes in an A.C. circuit must be used.

This may be determined by the heat produced. We know the effect of heat is entirely independent of the direction of the current producing it and as alternating current has no special unit of its own we will use the direct current ampere as a unit for comparison purposes.

With that in mind we can say than an alternating current is equivalent to a direct current when it produces the same average heat effects, contingent upon exactly similar conditions. This is called the effective value of alternating current, measured in amperes, and is the value which is measured by alternating current measuring instruments. Heat is present in a current carrying wire regardless of the amount of the current flowing. Heat is produced even though you may not be able to physically detect it. It is known that the heating

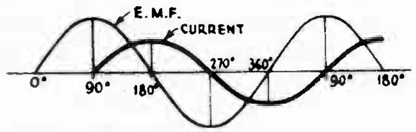

Figure 9

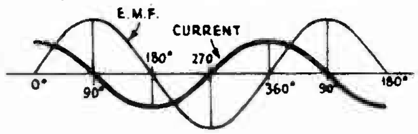

Figure 10

effect of an unvarying current in a circuit of fixed resistance varies as the current squared. For example, Figure 11, we have shown a current curve and heat curve; at any instant the heat effect is equal to the current squared.

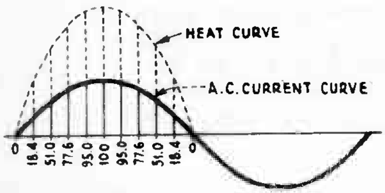

Figure 11

Since the heating effects of an electric circuit is equal to the current squared (I^2), then to find the heat effects of our curve, Figure 11, we must find the square of each individual current value over the alternation. This we do and then extend dotted lines above the verticals proportional to each squared current value. Connecting the ends of these extensions by a line we have a second curve which is the heat curve. It is necessary now to obtain the average of these heat squares which is done by dividing the sum of the squares by 9, since we have 9 instantaneous values of current.

The square root is now found of this average which gives us the final result,- the effective current. It is this result which is read by all electrical meters and is the current useful in calculating the power of the circuit.

It is not likely you will, in your practical work, have occasion to do work of this kind. It is done here simply to show you how it is calculated because this forms the basis from which all alternating current and voltage values are found. The step by step solution follows: Taking the values of instantaneous current values from the curve we write:

1st	instant	of	value	18.4
2nd	"	"	"	51.0
3rd	"	"	"	77.6
4th	"	"	"	95.0
5th	"	"	"	100.0
6th	"	"	"	95.0
7th	"	"	"	77.6
8th	"	"	"	51.0
9th	"	"	"	18.4

and squaring the above current values we have:

18.4	=	338.56
51.0	=	2601.
77.6	=	6021.76
95.0	=	9025.
100.0	=	10000.
95.0	=	9025.
77.6	=	6021.76
51.0	=	2601.
18.4	=	338.56

The sum of these squares equals:

```
  338.56
 2601.00
 6021.75
 9025.00
10000.00
 9025.00
 6021.76
 2601.00
  338.56
--------
45972.64
```

Dividing the sum of the squares by 9 to obtain the average of these squares:

```
9)45972.64(5108.071
  45
  --
   9
   9
  --
   72
   72
   --
    64
    63
    --
     1
     9
```

Extracting the square root of the average squares:

```
   71.47
 √5108.0710
  49
  ---
   208
   141
   ----
    6707
    5696
    ------
    101110
    100009
```

which equals 71.47 the effective current.

The effective voltage has the same relation to the maximum voltage that the effective current has to the maximum current and is found in the same manner. You will note that the effective current is less than the maximum current.

In dealing with voltage the effective voltage is also less than the maximum voltage, because the maximum voltage reaches a higher potential than the effective voltage. This accounts for the insulation requirements of an A.C. circuit being higher than in a direct current circuit.

POWER

The power of an alternating current circuit is expressed in watts just as in direct current circuits and is found by multiplying the current by the voltage. Thus, $W = I \times E$.

This only holds good in a circuit where resistance only is present; in other words, the current must be in phase, or in step, with the voltage, as illustrated in Figure 8. When the current lags or leads the E.M.F. due to the presence in the circuit of inductance or capacity, or both, a power factor is used which is the ratio of the true watts to the apparent watts (the watts you would obtain by multiplying the volts by the amperes). In other words it is the ratio between the useful current and total current.

The formula for finding the POWER FACTOR follows: $\text{POWER FACTOR} = \frac{\text{RESISTANCE}}{\text{IMPEDANCE}}$

EXAMINATION QUESTIONS

1. Is alternating current necessary for the operation of a radio transmitter?

2. What are "slip rings" and why are they used instead of a commutator?

3. Explain the fundamental action of an A.C. Generator.

4. Upon what factors does the value of E.M.F. of a generator depend?

5. (a) What is an alternation? (b) A cycle?

6. (a) What is frequency? How is frequency determined?

7. What is the meaning of "Phase"?

8. What is meant by "effective value" of A.C.?

9. What is meant by the term "power factor"?

10. What is the relation of voltage and current when only actual (ohmic) resistance is present in an A.C. circuit?