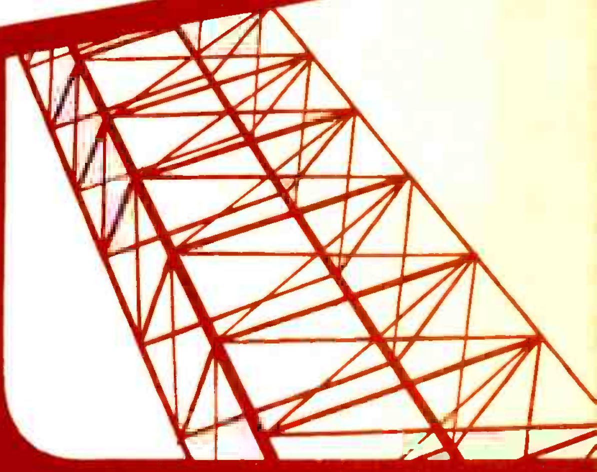
# MICROPHONES

## Lesson RRT-3



DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

RRT-3

Radio Reception and Transmission

# LESSON RRT-3

# MICROPHONES

## CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1827—Georg Ohm, German physicist, announced the law which was named after him: the current in a circuit varies directly with the applied voltage and inversely with the resistance.

1831—Faraday discovered electromagnetic induction, that is, the generation of electricity from magnetism, the principle on which all inductive devices and dynamo machinery is based.

1832—Joseph Henry produced high-frequency oscillations. Also developed the electromagnetic relay which made long-distance telegraph transmission possible.

1834—Henri Lenz, Russian physicist, announced the law named after him, relating to the direction of an induced current.

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# RADIO RECEPTION AND TRANSMISSION

## LESSON RRT-3

## MICROPHONES

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**When you get into a tight place and everything goes against you, till it seems as though you could not hold on a minute longer, never give up then, for that is just the place and time the tide will turn.**

**—Harriet Beecher Stowe**

# MICROPHONES

## TYPES OF MICROPHONES

The function of a microphone is to convert sound energy into electrical energy, which, in turn, can be amplified in electron tube amplifiers for operating a speaker or other reproducing device. If the microphone is working properly, its output of electric energy variations will correspond in every detail to the pattern of the original sound waves

Microphones can be classified as pressure operated, velocity operated, or a combination of the two. A pressure operated microphone is one in which the electrical response is caused by variations in the pressure of the incoming sound waves on a thin membrane called the diaphragm. In this type of unit, the front of the diaphragm is open to the sound waves, while the back is enclosed in a chamber. A velocity microphone is one in which the electrical response corresponds to the difference in sound pressure on the opposite sides of a narrow metallic strip called a ribbon. In this type, also known as a P.G. (pressure gradient) microphone, both sides of the ribbon are open to the sound waves.

Electrical pressure is measured in volts while sound wave pressure is measured in "bars" a unit which is equal to a force of one dyne per square centimeter. To complete the definition, a dyne is a unit of force which will cause an acceleration of one centimeter per second, during each second it is applied to a free mass of one gram. In case you have forgotten, there are about 28½ grams in one ounce.

Ribbon type studio microphone for broadcasting, quality recording and public address work. Has frequency response from 40 to 14,000 cycles per second.

Courtesy Amperite Corporation

The pressure of sound waves is relatively weak, and the resulting voltage output produced by the feeble movements of a microphone diaphragm or ribbon may be only from about .0001 to .01

An inexpensive crystal microphone mounted on desk stand and suitable for amateur, public address, and home recording purposes.
Courtesy The Astatic Corporation

volt per bar of sound pressure. Due to this low output, a large amount of amplification of the microphone signal is necessary, and in some cases the microphone preamplifier is located very close to or actually in the housing of the microphone itself.

In historical order the following types of microphones have been or still are used in studio work: carbon, condenser, moving conductor, velocity, and crystal. In this lesson we will explain the construction and operation of each type.

## CARBON MICROPHONE

The essential elements of a carbon microphone are shown in the simplified sketch of Figure 1. A circular metal diaphragm is supported at its edge and mounted so that its center portion projects into a cup filled with carbon granules. Electrical connections from the external circuit are made to the diaphragm and to the carbon cup. Thus there is a circuit from the d-c supply to the diaphragm, through the carbon granules to the cup, and then through the transformer primary back to the supply. The greater portion of the resistance of this circuit is that provided by the points of contact between the various carbon granules. If each point of contact is considered as an individual resistance element, then the entire arrangement of granules can be thought of as a complicated series-parallel resistance network, the total resistance of which is determined by the amount of pressure at the various contact points.

Sound waves striking the front of the diaphragm, cause it to move from its normal position and cause a change in pressure between the carbon granules. This action changes the resistance of the contacts between the granules to produce a change in the total resistance between the diaphragm and the cup.

In the microphone circuit of Figure 1, the magnitude of the current is dependent upon the amount of resistance in the circuit. Therefore, when sound waves strike the diaphragm, the resulting changes in the electrical resistance between the granules cause corresponding variations in the circuit current. When the diaphragm moves inward, the pressure between granules is increased, their contact resistance decreases and the circuit current rises. When the diaphragm springs outward, the pressure becomes less, the contact resistance increases, and the current decreases. These changes of current produce a changing magnetic flux around the transformer primary and a corresponding emf is induced in the secondary. Thus, the sound waves striking the diaphragm finally result in a transformer secondary emf which corresponds in frequency, amplitude, and waveform to that of the initial sound waves.

A cross section view of a commercially manufactured carbon microphone is shown in Figure 2. In order to make a good electrical contact between the granules and diaphragm, and between the granules and the cup, the inside of the cup as well as the projecting portion of the diaphragm are made extremely conductive by means of a coating of aquadag or gold plating.

A tension spring is employed to insure that the diaphragm rim is held tight against the aluminum microphone frame, for this contact is also a part of the electrical circuit. Two insulating fibre washers support the carbon cup to prevent its shorting against the frame and a felt washer prevents leakage of the carbon granules from the carbon cup without impeding the motion of the diaphragm.

The protecting front grid is provided with large holes to permit the entrance of sound waves, and a thin sheet of rubberized silk or rayon is used to exclude moisture. A small hole in the diaphragm permits rapid equalization of low-frequency pressures of high intensity, thus preventing damage to the diaphragm or other parts. Electrical connection to the external circuit is made with the two contact screws, one of which may be removed to permit filling of the cup with carbon granules.

Because the resistance of the carbon microphone is low (around 200 ohms), it must be used in conjunction with a step-up transformer to match the usual high-impedance input circuit of an audio amplifier. Its useful frequency range is from about 100 cps to 5000 or 6000 cps.

## DOUBLE-BUTTON MICROPHONE

Because it contains but one cup of carbon granules, the microphone described above is known as a "single-button" and the frequency response can be improved by employing two groups of granules arranged one on each side of the diaphragm. This permits push-pull connections to the external circuit with the advantage of minimized even harmonic distortion. However, the output of a double-button microphone is lower than that of the single-button type, and because better tone quality is obtained with later types of microphones, the double-button carbon mike is not in common use for the reproduction of music.

## CONDENSER MICROPHONE

The condenser microphone derives its name from the fact that its operation depends upon the variation in the capacitance between two plates. To follow this action, consider A and B of Figure 3 as two metallic plates placed parallel to each other and spaced a distance "t" apart. If the space between these plates is occupied by a non-conducting material such as air, then, by definition, the arrangement is a condenser, and due to its capacitance, has the ability to store a charge of electricity.

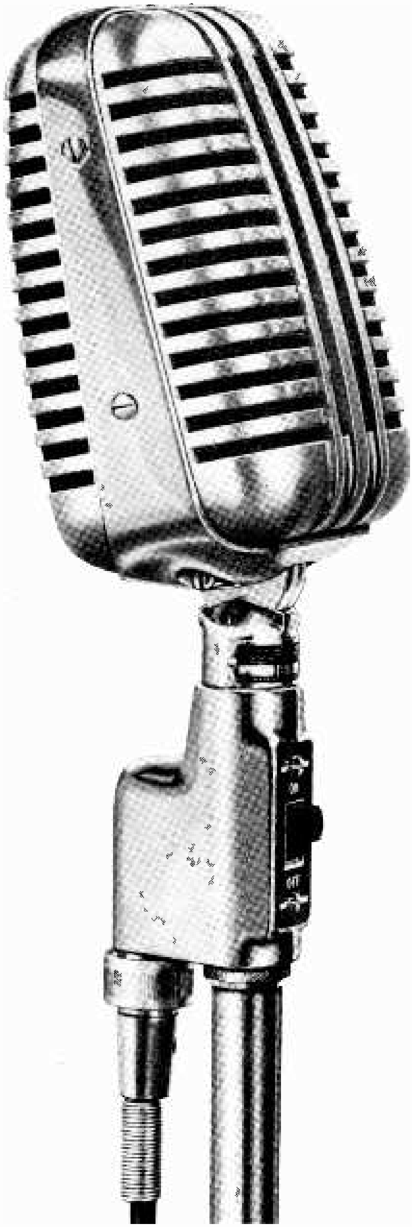
Suppose also that plate A is connected through a resistor, $R_L$, to one terminal of a d-c source, the other terminal of which is connected to plate B as shown. When these connections are made, the condenser will charge through $R_L$ to the potential of the d-c supply. The amount of charge Q, measured in coulombs, which the condenser will accumulate, depends upon its capacitance C, and the value of the applied voltage E. This relationship can be stated mathematically as:

$$Q = CE \qquad (1)$$

Dividing both members by C, in respect to the applied voltage E, the equation states:

$$E = \frac{Q}{C} \qquad (2)$$

Since the condenser charges to the supply potential, the voltage value E of these equations is equal to that of the condenser as well as that of the supply. The difference, however, is that the condenser voltage, $E_c$, is in series opposition to the supply voltage, $E_s$, as indicated by the polarity marks in Figure 3.



Multi-cell crystal microphone suitable for studio, public address, and high quality recording purposes. Has flat response up to 10,000 cycles.

Courtesy The Astatic Corporation

As long as nothing occurs to disturb the components, once the condenser has charged, the potentials will remain constant and there will be no current in the circuit. However, the capacitance of a parallel plate condenser is as given by the following general formula:

$$C = 0.2248 \times K \times \frac{A}{t} \qquad (3)$$

when—

C = capacitance in mmfd

K = dielectric constant of spacing material

A = area of spacing material in square inches

t = spacing between plates in inches.

Checking the terms of formula (3), if, without making any other changes, the spacing between the plates is reduced there will be an increase of capacitance represented by "C" in formula (2). Then, according to formula (2), with the charge "Q" remaining the same, an increase of capacitance "C" will cause a reduction of voltage "E".

Thus, in the arrangement of Figure 3, if plate A is moved closer to plate B, their capacitance will be increased and cause a reduction of the voltage across them. When this occurs, the d-c supply will charge the condenser and increase the Q until the voltage across it equals that of the supply. This charging current will cause a proportional voltage drop across the series connected resistor $R_L$.

Likewise, if plate A is suddenly moved away from plate B, the capacitance is decreased and the voltage across the condenser becomes greater than that of the supply. When this occurs, the condenser will discharge and cause circuit current in the opposite direction until its voltage is equal to that of the supply.

Dynamic Microphone designed for high-quality broadcasting, recording, and public-address work. It has a super-cardioid pickup pattern.

Courtesy Shure Brothers, Inc.

If plate A is made to vibrate rapidly and continuously toward and away from plate B, the alternate charging and discharging of the condenser results in an alternating current which in turn produces an a-c voltage drop across $R_L$. In a practical condenser microphone, plate A of Figure 3 takes the form of the vibrating diaphragm which is suspended near a fixed plate B. The pressure of the impinging sound waves causes displacement of the diaphragm, and the resulting a-c output of the microphone has the same frequency and waveform as the sound waves.

The cross sectional sketch of Figure 4 shows the construction of a practical condenser microphone in which the diaphragm, a thin metal disk, is mounted between the frame and the clamping ring. Threaded in the clamping ring, the stretching ring is adjusted until the tension on the diaphragm causes it to have the desired mechanical resonant frequency. The back plate, insulated from the frame by a fibre ring, is mounted very close to the diaphragm. Compared to Figure 3, the diaphragm acts as plate A and the back plate as B. The narrow air space, between the diaphragm and back plate of Figure 4, introduces mechanical resistance which acts to reduce the amplitude of the vibrations of the diaphragm at its resonant frequency. Acting in a similar manner, the damping grooves and central vent connected to an enclosed air space in the back plate, provide a more uniform amplitude of diaphragm vibration over its entire range of frequencies.

The condenser microphone responds to a considerably wider band of frequencies than the carbon type, but the amplitude of its output is lower. The capacitance of the diaphragm and back plate is approximately 300 mmfd, which at 1000 cycles per second, has an impedance of about 500,000 ohms. Because of the high impedance and low output signal level of the condenser microphone, a preamplifier is located at the microphone to afford a greater signal-to-noise ratio. For this reason, it is common practice to build an amplifier in a tubular housing with the microphone mounted at one end, the whole arrangement being supported as a single unit so that it may be turned in any direction.

Because of these characteristics and the need of a d-c polarizing voltage across the capacitance, the condenser microphone has lost its former popularity and, in most cases, has been discarded for the more modern types of the following explanations.

## DYNAMIC MICROPHONE

Invented as early as 1877 by Siemans, the moving coil or dynamic microphone is one of the oldest types, but, due to its low output level, had no practical application until the advent of the modern audio amplifier.

An examination of the cross-sectional view of Figure 5 will show that the general construction of a dynamic microphone closely resembles a moving coil type of speaker. Here, the diaphragm is dome shaped for rigidity and a light aluminum coil, fastened at its base, extends into an air gap in the magnetic field set up by the permanent magnet located centrally in the frame.

In a speaker, signal frequency currents in the voice coil set up a varying flux which, by reaction with the field flux, causes the coil and attached diaphragm to vibrate and produce sound waves. In a dynamic microphone, the action is reversed because when sound waves strike the diaphragm they cause it and the coil to vibrate and an emf is induced in the coil as it cuts the field set up by the permanent magnet. Thus, if the speaker is considered as a form of motor, converting electrical energy into mechanical motion, the microphone can be thought of as a generator because it converts the motions of the diaphragm into electrical energy. This reversal of action has practical applications in some intercommunication system in which a single moving coil unit acts as a speaker to receive signals and as a microphone to transmit signals. The proper circuit changes are made by a manually operated "Talk-Listen" switch.

Although the principle of operation is comparatively simple, a number of refinements are necessary to make the movements of the diaphragm follow the variations of the sound waves more closely. As shown in Figure 5, the diaphragm is clamped to, but held a short distance from the pole pieces by the ring and washer. The small air space behind the diaphragm is closed except for the narrow annular slit S1, which connects into the larger space within the body of the magnet. This slit serves to control the response of the diaphragm by air resistance.

A familiar example of the use of air resistance to obtain constant velocity is the parachute. The speed of a man falling without a parachute would be governed almost entirely by the force of gravity, and would increase continuously. With a parachute, however, enough air resistance is introduced to become a controlling factor, and the velocity of the fall becomes constant. The various slits and openings in a dynamic microphone operate somewhat in a similar way to cause the required damping action of the diaphragm and provide a good frequency response.

For example, cavity C is formed within the central pole piece and connected to the air space behind the diaphragm by the narrow slit S2 to further increase the damping action and improve the frequency response.

At the low frequencies, the stiffness of the diaphragm controls its motion and produces a velocity that decreases with the frequency. Such stiffness control begins at about 200 cycles, and if this effect were not corrected, below this frequency the sensitivity of the microphone would tend to fall off. However, if the force on the diaphragm can be increased at a rate corresponding to the falling off of velocity due to stiffness, a uniform response will be obtained.

In the dynamic microphone this action is secured by an air connection made through a tube which connects the front of the diaphragm to the air chamber within the magnet. By proportioning the length and diameter of this tube, it is possible to exert a suction on the rear of the diaphragm at the same time that pressure is applied to the front. This suction increases as the frequency decreases, and at low frequencies acts to increase the velocity of the diaphragm, thus tending to offset the effect of increasing stiffness.

The impedance of the coil of a dynamic microphone is generally between 50 and 100 ohms, and therefore it is classed as a low-impedance type. When it is desirable to connect the microphone directly to the amplifier, (with but a short line) an impedance matching or step-up transformer is included as part of the complete microphone assembly. Because of its relatively rugged construction, and good frequency response of from 30 or 40 to as high as 10,000 cycles, the dynamic microphone is one of the most popular types in use.

The three types of microphones already described are sensitive to sounds from all directions because the diaphragms, open on one side only, respond to the varying air pressures of the sound waves. In many cases, this is an advantage while in others it is a decided disadvantage. For example, in recording sound pictures of street scenes, it is necessary to include all the background noises but to obtain good dialogue between two characters, the background noises must be minimized.

Velocity microphone with high-fidelity response and bi-directional pickup, from 80 to 10,000 cycles per second.
Courtesy The Turner Company

## VELOCITY MICROPHONE

The "directional" velocity microphone was developed to meet this latter kind of condition, as it is sensitive to sounds coming from the front and rear but insensitive to sounds coming from the sides. As shown in the constructional details of Figure 6, the moving element is a thin metallic ribbon suspended between the pole pieces of a powerful permanent magnet, in such a way that its length is perpendicular to, and its width in the plane of the magnetic lines of force. The pole pieces are constructed with internal passages to allow free movement of the sound waves through the microphone.

Cardioid type microphone with a combination two-element structure. Has a smooth response from 70 to 10,000 cycles per second.
Courtesy The Turner Company

The ribbon element, made of very thin duralumin, is suspended from metal .cross pieces which, although not shown in Figure 6, rest on four insulating bushings. These insulating bushings are the only non-metallic parts of the microphone, and therefore, temperature and humidity changes will have but little effect on its operation.

Like the dynamic type, the velocity microphone operates on the principle of an electric generator, in that a voltage will be induced in a conductor when it is moved in a magnetic field. When sound waves strike the ribbon, it will vibrate in the magnetic field at their frequency and therefore a voltage of like frequency will be induced in it. As the resistance of the ribbon is but a fraction of an ohm, its changing voltage output is transferred directly to the primary of an impedance matching transformer which is considered as an integral part of the microphone. The transformer secondary may be wound for most any desired impedance, and thus it is possible to have both low and high-impedance velocity microphones.

Referring to Figure 6, you will notice the passages in the pole pieces permit a free movement of air in a direction at right angles to the broad surfaces of the ribbon. Therefore the microphone responds equally well to sounds originating either in front or back. However, sounds originating at either side will cause equal pressures on both sides of the ribbon and there will be minimum response. Thus, as the output of the microphone varies from maximum, for sound originating directly in front or back, to minimum for sounds originating at either side, it is considered as bidirectional.

The operation depends upon the pressure gradient or difference between the front and back pressures on the ribbon which, because of its low inertia, closely follows the motion of the air particles of the sound wave. Because of this action, a unit of this type is classed as a velocity microphone.

Mechanically, the ribbon is very delicate and must be protected from sudden draughts or puffs of wind therefore, it is surrounded by an inner and outer screen of fine mesh silk attached to its magnetic assembly and outer case. These and a metallic screen help protect against mechanical injury or the accidental entry of magnetic material into the assembly.

The frequency response is excellent from 20 to 15,000 cycles, provided the source of sound is at a greater distance than about eighteen inches from the microphone. If the source is closer than about six inches, distortion may occur, causing overaccentuation of the lower notes. This characteristic makes the ribbon microphone difficult to use where unusual sound conditions must be overcome.

The output of the ribbon microphone is somewhat greater than that of the condenser type, and therefore it requires moderate amplification. However, it is not always necessary to use a preamplifier, although in the case of long transmission lines, it is commonly done.

Velocity microphones are suitable for high quality recording, radio broadcasting, and outdoor use when not exposed to winds. Its bidirectional characteristic is helpful in reducing acoustical feedback, audience noise and room reverberation.

In the above explanation, we told you that the secondary of the integral transformer could be wound so that the unit becomes either a high or low-impedance microphone. With the high-impedance type, the output of the microphone can be fed directly to the grid circuit of an audio amplifier tube but with the low-impedance type, an impedance matching transformer must be employed. However, for all low-level microphones, the audio amplifier must have a high gain in order to raise the signal to a proper level where it will satisfactorily operate a loudspeaker or other reproducing device.

## DIRECTIONAL CHARACTERISTICS

To indicate the directional characteristics of a microphone it is customary to employ diagrams like those of Figure 7. The microphone is represented by the central rectangle, the longer sides of which indicate the front and back. The distance between the microphone and any point on the outer curved line is proportional to the response of sounds originating at that angle to the front or back of the microphone.

The diagram of Figure 7B indicates the directional characteristics of pressure type microphones like those shown in Figures 1, 2, 4 and 5. Here, the microphone is in the center of an outer circle to show equal response to sound from all directions. The bidirectional characteristics of the microphone of Figure 6 are shown by the diagram of Figure 7A. Here the outer curved lines resemble a Figure "8" and, as previously explained, indicate maximum response at front or back diminishing to minimum response at the sides.

The diagram of Figure 7C represents the directional characteristics of a unidirectional microphone. Here, the response is maximum directly in front and diminishes to minimum at the rear.

## UNIDIRECTIONAL MICROPHONE

To obtain unidirectional characteristics, both the pressure and velocity principles may be incorporated in a single microphone. For example, a common magnetic structure can be employed for a moving element consisting of a continuous ribbon divided into two sections. One section is responsive to the pressure-difference of the sound wave as in the usual velocity microphone, while the other acts like the diaphragm in the pressure-operated types.

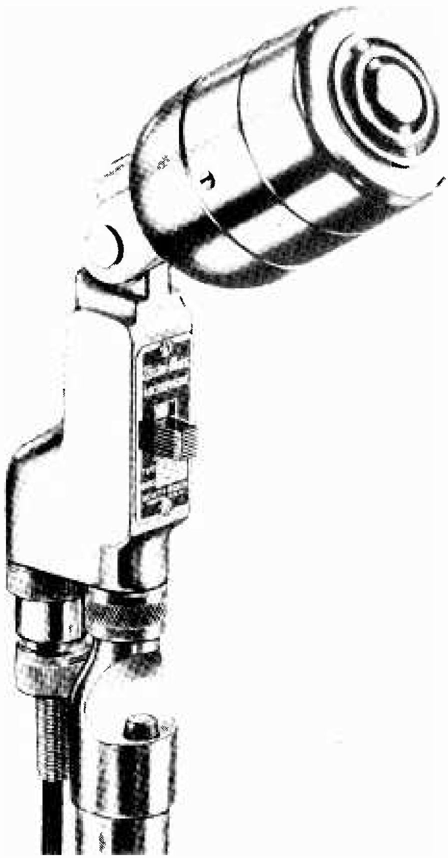
The pressure-operated section is open in front and closed at the back by a folded tube packed with a sound-absorbing material such as tufts of felt. This produces an arrangement the impedance of which is essentially resistive over its entire frequency range. This feature is necessary in this type of microphone because the correct relationship must be maintained by both the phase and magnitude of the output voltages of the two sections.

As the ribbon is continuous, the voltages induced in the two sections of the ribbon are in series, and their addition provides the directional response. For sounds coming from the front, the voltages developed by the two sections add but for sounds coming from the rear, the voltages are 180° out of phase and, therefore, cancel. Thus the directional characteristic of this microphone has the cardiod shape of Figure 7C, and for this reason it is sometimes called a "cardioid" type.

This type of microphone has a frequency response comparable to the velocity and dynamic types, and is extremely useful where it is necessary to discriminate against sounds which, coming from the rear, would be picked up by the pressure-difference type.

## CRYSTAL MICROPHONE

The crystal type of microphone operates because of the piezo-electric effect characteristic of certain crystals. That is, when a properly cut crystal is subjected to a mechanical stress, there will be a difference of potential produced between its two faces. In a microphone, this mechanical stress is obtained by the pressure of the sound waves which causes the crystal to bend.



Dynamic microphone with high output for general purpose use. Has a frequency response from 40 to 9,000 cycles per second.
Courtesy Electro-Voice, Inc.

The piezo-electric effect of Rochelle Salts has been found superior to that of other crystals, and therefore it is most commonly used in this type of microphone. Although the salts are soluble in water, rigid experiments have shown that suitable protection against moisture and humidity can be obtained by enclosing the crystal in waterproof paper and waxes.

Dynamic microphone with a cardioid wide-angle pickup and the greater part of the reflected sounds eliminated. Has a frequency response from 40 to 10,000 cycles per second.
Courtesy Electro-Voice, Inc.

The effect of temperature variation has also been reduced to a minimum by the use of very thin sections of crystals arranged in two sections or plates cemented together in such a manner that when electrodes are attached and an emf applied, one of the plates will expand and the other will contract. This results in a bending effect, similar to that of a bi-metallic thermostat, and when arranged in this way, the crystal is known as a "bimorph element".

There are two common types of crystal microphones namely: the direct actuated and the diaphragm actuated. In the first type, the sound pressure acts directly upon the crystal, while in the second type, the sound pressure acts upon a diaphragm which is coupled mechanically to the crystal.

The directly actuated type, the essential parts of which are shown in Figure 8A, is known as a "sound cell" or "grille type" microphone, and it consists of an outer frame of bakelite on each side of which a thin Rochelle Salts Bimorph unit is supported at two points. The space between the crystal and frame is sealed by a flexible but air tight ring which permits the crystal to vibrate freely with variations due to sound pressure. The entire cell is impregnated with wax to maintain the elements in an air-tight and moisture proof chamber.

When the entire unit is subjected to sound waves, the two sides of the crystal unit vibrate in phase with each other and produce an emf across them in direct proportion to the sound pressure. However, if the unit is subjected to mechanical vibration or shock, the voltages generated by both sides are out of phase with each other and tend to cancel, therefore, the output emf developed by these disturbances is of minimum amplitude.

Because of the condition of mechanical resonance, the physical dimensions of the sound cell are one of the most important considerations in the design of the crystal microphone. That is, if the mechanical resonance of the crystal is in the frequency band to be reproduced, the response will be seriously impaired. This condition is prevented by designing the crystal to have a natural resonant frequency above that of the highest audio note to be reproduced.

One of the exceptionally fine characteristics of the crystal microphone is its ability to amplify the higher frequencies up to 17,000 cycles. This is because the crystal has a resonant period slightly above the audio range, therefore the frequency characteristic will rise as it approaches this value.

The output of a single sound cell is quite low, but this can be increased by connecting several cells in series. Also, the impedance is very high, but can be reduced effectively by connecting several cells in parallel. Therefore, commercial microphones of this type usually consist of from 4 to 24 cells connected in series or series-parallel to provide an output comparable to that of a dynamic microphone.

The other type of crystal microphone, shown in Figure 8B, consists of a conical duralumin diaphragm connected mechanically to the crystal element. The diaphragm causes considerable mechanical stress on the crystal due to the fact that it acts as a coupling unit between relatively low impedance of the air and the high impedance of the crystal. Therefore, as the generated voltages are proportional to the stress, the output of this microphone is greater than that of the sound-cell type. However, due to the inertia of the diaphragm, microphones of this type do not have a completely uniform frequency response, and as a rule are found in the lower price class services such as home recording, small public address systems, and amateur radio.

In general, crystal microphones are high impedance types and may be connected directly across the grid circuit of an amplifier tube which should have a grid load of approximately 5 megohms.

Like the other pressure types, the crystal microphone is sensitive to sound from all directions, a characteristic which may be used to advantage as explained for the condenser and carbon microphones.

## MICROPHONE TRENDS

All microphones have a common purpose namely, to convert the motion of the air particles in sound waves into corresponding changes of electrical energy. Due to the motion of the particles, sound travels through the air as a series of alternate high and low pressure areas. In all diaphragm types of microphones, these changes of pressure constitute the actuating force which is converted into mechanical motion or vibration.

In the carbon types of Figures 1 and 2, the movement of the diaphragm causes corresponding changes of resistance and thus varies the current supplied by an external d-c supply. In the condenser types of Figures 3 and 4, the movement of the diaphragm causes corresponding changes of capacitance and the resulting displacement currents cause variations of voltage drop across a resistor connected in series with an external d-c supply. In the dynamic type of Figure 5, the movement of the diaphragm induces a corresponding emf by causing a coil to cut through a magnetic field. The velocity type of Figure 6 has the same basic action as the dynamic type but the coil is replaced by a ribbon both sides of which are exposed to the sound waves.

In the crystal types, the varying pressures of the sound waves are supplied directly or through a diaphragm to impose mechanical strains on a crystal which develops corresponding voltages by the piezo-electric effect.

The development of microphones follows the two general classifications of improved operation and special applications. As far as the operation is concerned, the trend is to reduce both size and weight yet provide greater output with higher fidelity over a broader band of frequencies.

In respect to special applications, there are desired response characteristics as illustrated in Figure 7. For military purposes, there are lip microphones, pickups which are actuated by throat movement during speech, and others with unique construction which provides some desired characteristic such as interference elimination, compactness, and freedom of movement of the wearer.

Another recently developed unit is the differential microphone, which is responsive not only to sound pressure but also to distance of sound origin. It works on the principle that, leaving its original source, sound falls off rapidly in intensity at first but then remains quite constant, decreasing slightly with distance.

The differential microphone is constructed to admit sound waves equally on both sides of the diaphragm, and therefore, random noise created at a distance will strike both sides with about the same intensity and restrict the diaphragm movement. This action makes a microphone of this type suitable for use in noisy locations and also ideal for public address work, as acoustic feedback caused by the sound output of a speaker actuating the microphone is reduced.

Any microphone which has a flat frequency response will provide less strain on the listener, give higher articulation, and contain less possibility of acoustic feedback because peak resonant effects are eliminated.

## TRANSMISSION LINES

Now that we have explained the action of various types of microphones, we want to describe one important characteristic of the wire, or Transmission Line, which connects them to the input of the audio amplifier. The general subject of transmission lines

Crystal microphone with cardioid pickup characteristic. Equipped with screwdriver adjustment for changing from flat response to high-frequency boost.

Courtesy Electro-Voice, Inc.

is quite lengthy and involved, therefore, at this time we want to give you only a practical idea of the advantages of a low-impedance line.

In Figure 9A we show a common type of microphone cable made up of stranded wire, covered by two layers of braided cotton and a flexible shield of braided copper. Then to protect the shield, there is an outer covering of flexible rubber. When the cable is attached to an amplifier input circuit, the inner stranded wire is connected to the grid of the amplifier tube and the shield to ground. In the input circuit of Figure 10, the stranded wire would be connected to the upper terminal H, while the shield would be connected to the ground terminal G. With ground as the reference point, the H terminal is considered as "Hot" or "High" potential.

In this way the shield is at ground potential, and as it completely surrounds the hot inner wire, it acts to prevent any undesirable fields from inducing a voltage into the input circuit. Therefore, by using this type of cable, the noise level in the line, caused by pickup, will be kept at a minimum value.

However, from your early Lessons you know that a condenser is made up of two conductors separated by a dielectric, and as the microphone cable of Figure 9A has two conductors separated by insulation, it acts like a condenser. The capacitance of the cable will depend on the area of the conductors and the distance between them, the same as for any other condenser.

As we will show you a little later in our explanation, this capacitance is undesirable, and to reduce it, the common types of low loss microphone cables have many more layers of insulation between the shield and hot wire than we show in Figure 9A. This type of construction reduces the capacitance because of the increased distance between the conductors.

As we told you above, in order to transfer the energy from the microphone to the amplifier, the cable is connected across the grid circuit of the input tube. However, this connection places the capacitance of the cable across or in parallel to the grid resistor of Figure 10.

In order to see this more clearly, in Figure 9B we show an equivalent circuit made up of $R_1$, C and R all connected in parallel by two conductors. You can think of R as the microphone impedance, $R_1$ the grid circuit impedance, and C, the capacitance of the cable. For maximum transfer of power, the terminating impedances must be equal, that is, R must equal $R_1$.

Under these conditions, and with a hypothetical no-loss cable, the power in $R_1$ would equal that in R. It is needless to say that such a cable is not available and in practice there will be some losses, the amount of which will depend on several factors. Here, we are interested only in the effects of the capacitance of the cable on high and low-impedance lines, and will therefore assume there are no other losses. Also, for simplicity, we will consider R and $R_1$ as resistors.

To show you the losses introduced by the capacitance of the cable, we will first consider a high-impedance line in which the terminating resistors R and $R_1$ each have a value of 500,000 ohms. Also we will assume the cable is 100 ft. long, with a capacitance of 30 micro-microfarads per foot, and the output of the microphone R remains constant at 1 microwatt.

Under these conditions, the power in the parallel combination of C and $R_1$ will be equal to that in R. However, it is the voltage across $R_1$ which drives the grid of the amplifier input tube therefore it is first necessary to find the impedance of the combination made up of $R_1$ and C. Here, one branch is made up of capacitive reactance $X_c$, the other of $R_1$ and, as stated in the Lesson on Impedance, they must be added vectorially by means of the formula:

$$Z_t = \frac{R_1 X_c}{\sqrt{(R_1)^2 + (X_c)^2}}$$

The right member of the above expression is then the equivalent value of $Z_t$ shown in Figure 9B.

Diaphragm type crystal microphone with high output. For general use, either as a hand mike or with a conventional desk or floor stand.

Courtesy Shure Brothers, Inc.

Assuming a frequency of 10,000 cycles, which is in the upper band of the audio spectrum, and the 100 foot cable with a capacitance of 30 mmfd per foot, for a total of 100 x 30 = 3000 mmfd =

.000000003 farads, the cable reactance would be,

$$X_c = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 10000 \times .000000003}$$

$$= 5308 \text{ ohms}$$

The total impedance of the combination $Z_t$ would then be,

$$Z_t = \frac{R_1X_c}{\sqrt{(R_1)^2 + (X_c)^2}}$$

$$= \frac{500{,}000 \times 5308}{\sqrt{(500000)^2 + (5308)^2}}$$

$$= 5307 \text{ ohms}$$

The power, P, in the combination of $Z_t$ was given as 1 microwatt or .000001 watt, and the voltage across $Z_t$ is therefore equal to

$$E_{Zt} = \sqrt{P\,Z_t} = \sqrt{.000001 \times 5307}$$

$$= .0729 \text{ volt}$$

Due to the parallel connection this is also the voltage drop across $R_1$.

If capacitance C had no effect, the voltage drop across $R_1$ would be

$$E_{R1} = \sqrt{PR_1} = \sqrt{.000001 \times 500000}$$

$$= \sqrt{.5} = .707 \text{ volt.}$$

Thus, due to the shunting effect of capacitance C, there is a loss of voltage of .707 − .0729 = .6341 volt.

Now let's see what happens when the frequency is in the lower audio band, and for this condition we will assume 50 cycles, with the other values remaining the same. Then,

$$X_c = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 50 \times .000000003}$$

$$= 1{,}061{,}000 \text{ ohms, and}$$

$$Z_t = \frac{500000 \times 1061000}{\sqrt{(500000)^2 + (1061000)^2}}$$

$$= 452{,}300 \text{ ohms.}$$

The voltage drop across $Z_t$ (and $R_1$) is,

$$E_{Zt} = \sqrt{PZ_t} = \sqrt{.000001 \times 452{,}300}$$

$$= .6725 \text{ volt.}$$

Here, we thus have a loss of only .707 − .6725 = .0245 volt, as compared to .6341 volt given above for 10,000 cycles. This is easily understood when we remember that capacitive reactance varies inversely with the frequency. With the high-impedance line, therefore, severe attenuation of the high frequencies is encountered. In other words, as the frequency increases, the efficiency of the line is reduced.

Suppose that we again analyze the circuit of Figure 9B, but this time for a low-impedance line. We will assume R and $R_1$ each have values of 50 ohms, the other values being the same as given above. We will proceed the same as before, but to avoid repetition, will not repeat all the steps. From above at 10,000 cycles,

$$X_c = 5308 \text{ ohms}$$

With a 50-ohm line

$$Z_t = \frac{50 \times 5308}{\sqrt{(50)^2 + (5308)^2}}$$

$$= 50 \text{ ohms approx.}$$

At 50 cycles,

$$X_c = 1061000 \text{ ohms}$$

$$Z_t = \frac{50 \times 1061000}{\sqrt{(50)^2 + (1061000)^2}}$$

$$= 50 \text{ ohms approx.}$$

Thus, at both the high and low frequencies, the voltage drop across $Z_t$ (and $R_1$) is,

$$E_{Zt} = \sqrt{P_{Zt}} = \sqrt{.000001 \times 50}$$

$$= .00707 \text{ volt (approx.)}$$

For the 50-ohm line, therefore, the capacitance of the cable has such a very slight effect that we consider it as being negligible. Under these conditions there is only a small attenuation of any of the frequencies in the audio band.

The above examples are more or less self-explanatory, and we do not think you will have any difficulty in seeing the advantages of a low-impedance transmission line for microphone-to-amplifier connections. Notice here, the voltage across the 50-ohm line is but .01 of that across the 500,000-ohm line but with equal power in both cases, the higher voltages can be obtained easily by the use of impedance-matching transformers.

For proper matching, the turns ratio of the transformer should equal the square root of the primary-secondary impedance ratio. Thus, when R and $R_1$ of Figure 9 each have a value of 500,000 ohms, to connect them with a 50 ohm transmission line the impedance ratio will be 500,000/50 = 10,000 and the turns ratio of the transformers should be $\sqrt{10,000}$ = 100. At the microphone, the transformer will step down the voltage to provide a value across the line equal to .01 of that across the microphone. At the amplifier, the transformer will step up the voltage to provide a value across the input circuit equal to 100 times that across the line. Neglecting the small losses, in the transformers and line, the amplifier input voltage will equal that developed by the microphone.

In general, a high-impedance line can be used only for short runs without severely attenuating the high frequencies. For all long runs and good frequency response, low impedance transmission lines should be used.

## IMPORTANT WORDS USED IN THIS LESSON

**BIDIRECTIONAL**—A microphone that responds to sound waves arriving at both the front and rear sides.

**BIMORPH CELL**—A microphone element consisting of two Rochelle Salt crystal units cemented together, so as to minimize the effects of changes in temperature.

**CARBON MICROPHONE**—A form of microphone in which a stretched diaphragm presses lightly against carbon granules contained in a small box or button. The incoming sound waves cause the diaphragm to move in and out, and this alternately increases and decreases the contact pressure between the granules. The resulting change in contact resistance causes a correspondingly variable current through the microphone.

**CARDIOID MICROPHONE**—A microphone with a heart-shaped response characteristic, that is, it responds fairly uniformly over a wide range in one direction, but to a minimum degree in the opposite direction.

**CONDENSER MICROPHONE**—A type of microphone in which the diaphragm is mounted close to a rigid metal plate so as to form a 2-plate condenser. As the incoming sound waves cause the diaphragm to vibrate, the capacitance of the condenser is varied, and the resulting displacement currents develop corresponding signal voltages.

**CRYSTAL MICROPHONE**—A type of microphone in which the incoming sound waves deform or distort a piezoelectric crystal (usually Rochelle Salt), and in doing so cause it to develop a corresponding signal voltage.

**DIAPHRAGM**—A thin membrane that is set into vibration by the sound waves entering a microphone.

**DOUBLE-BUTTON MICROPHONE**—A form of carbon microphone containing two buttons filled with carbon granules, one on each side of the diaphragm. As the diaphragm vibrates, it increases the contact resistance in one button and decreases that in the other, thus causing a push-pull electrical action.

**DYNAMIC MICROPHONE**—A form of microphone in which the diaphragm is attached to a small coil located in the field of a strong permanent magnet. As the diaphragm vibrates, the coil cuts the flux lines, and signal voltages are induced in it.

**FREQUENCY RESPONSE**—The manner in which a microphone responds to the various frequencies throughout the audio range.

**MICROPHONE**—A device for transforming sound waves into corresponding audio-frequency electrical signals.

**MICROPHONE PREAMPLIFIER**—A sensitive high-gain amplifier used to raise the signal output of a microphone to the required input level of the main audio amplifier.

**PRESSURE MICROPHONE**—A microphone in which the variations in pressure caused by the sound waves actuate the operating mechanism. Carbon, condenser, and crystal microphones are forms of pressure microphones.

**RIBBON MICROPHONE**—A type of microphone in which a thin corrugated metal ribbon or strip (usually duralumin) is supported between the poles of a strong permanent magnet. The incoming sound waves set this ribbon into a vibratory motion, with the result that it cuts the flux lines and has a corresponding voltage induced in it. Also called a velocity microphone.

**SHIELDED CABLE**—A transmission line surrounded with an outer sheath of braided copper wire. The sheath usually is grounded.

**TRANSDUCER**—A term commonly applied to devices that transform energy from one form to another. Thus, a microphone is a transducer that transforms acoustical energy into electrical energy.

**TRANSMISSION LINE**—A twin-conductor wire used to transfer electrical energy from the source to a distant operating device.

**UNIDIRECTIONAL MICROPHONE**—A microphone that responds to sound waves coming from one direction only.

**VELOCITY MICROPHONE**—A form of microphone in which the operating mechanism is actuated by the motion or velocity of the air particles resulting from the incoming sound waves. The ribbon microphone is a form of velocity microphone.

# STUDENT NOTES

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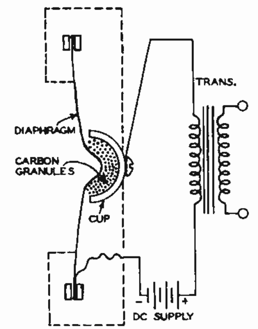


FIGURE 1

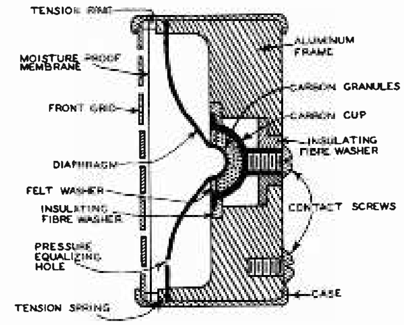


FIGURE 2

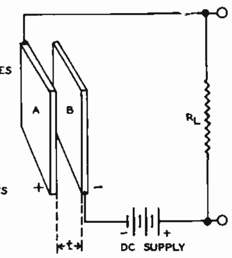
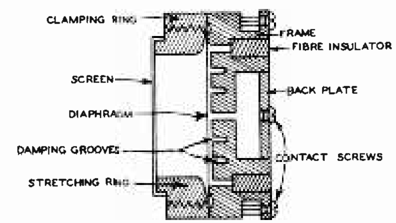


FIGURE 3



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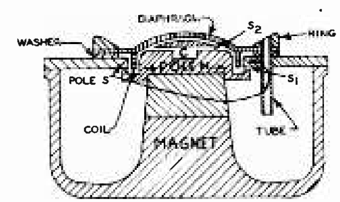

FIGURE 5

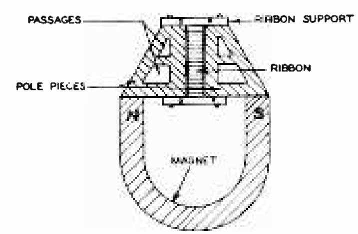

FIGURE 6

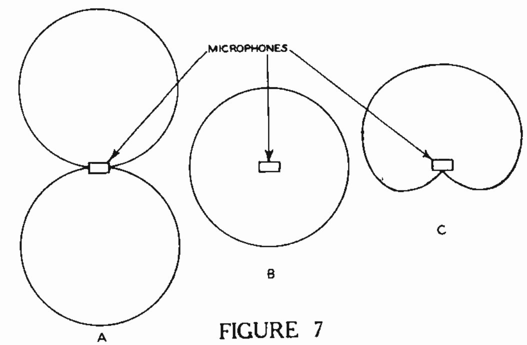

FIGURE 7

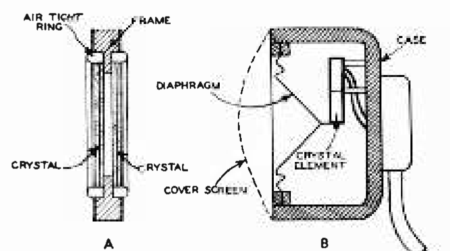

FIGURE 8

RRT-3

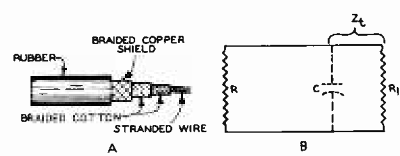

FIGURE 9

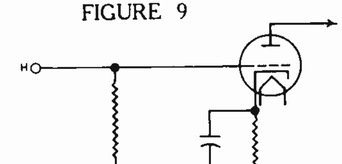

FIGURE 10

## FROM OUR *President's* NOTEBOOK

### OPPORTUNITY

"They do me wrong who say I come no more
When once I knock and fail to find you in;
For every day I stand outside your door,
And bid you wake, and rise to fight and win.

"Wail not for precious chances passed away,
Weep not for golden ages on the wane;
Each night I burn the records of the day;
At sunrise every soul is born again."

**Yours for success,**

E. B. deVry
PRESIDENT



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