Jan. 5, 1960 A. R. MORGAN 2,920,140

ELECTROSTATIC MICROPHONE CIRCUITS

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Fig. 1.

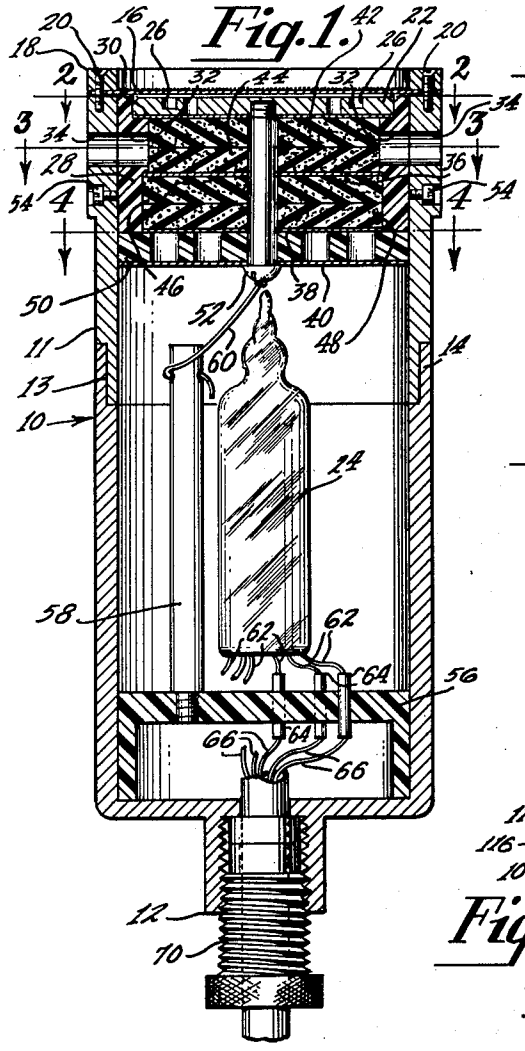


Fig. 2.

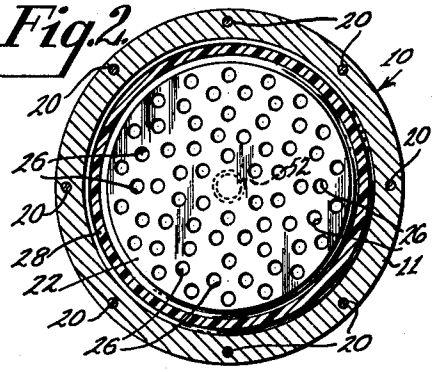


Fig. 3.

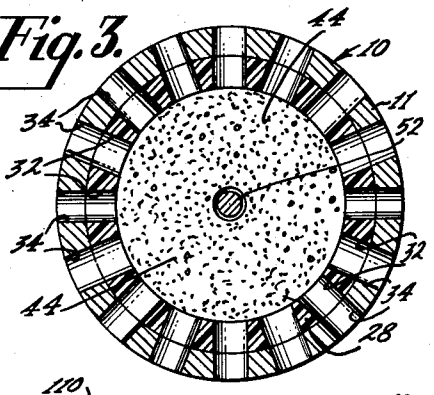


Fig. 8.

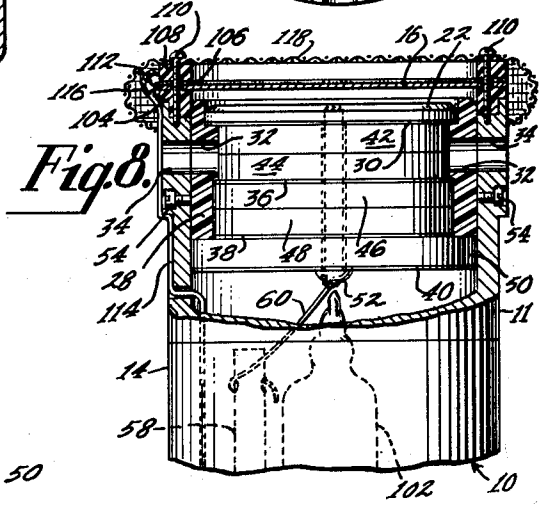
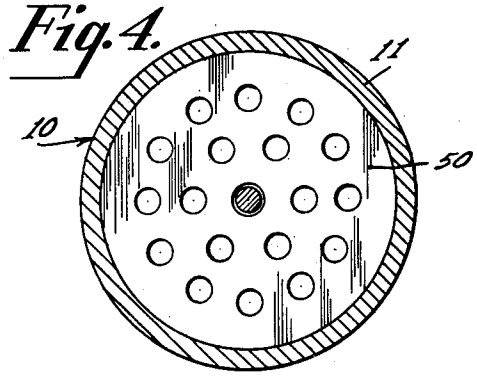


Fig. 4.



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ELECTROSTATIC MICROPHONE CIRCUITS

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Fig. 5.

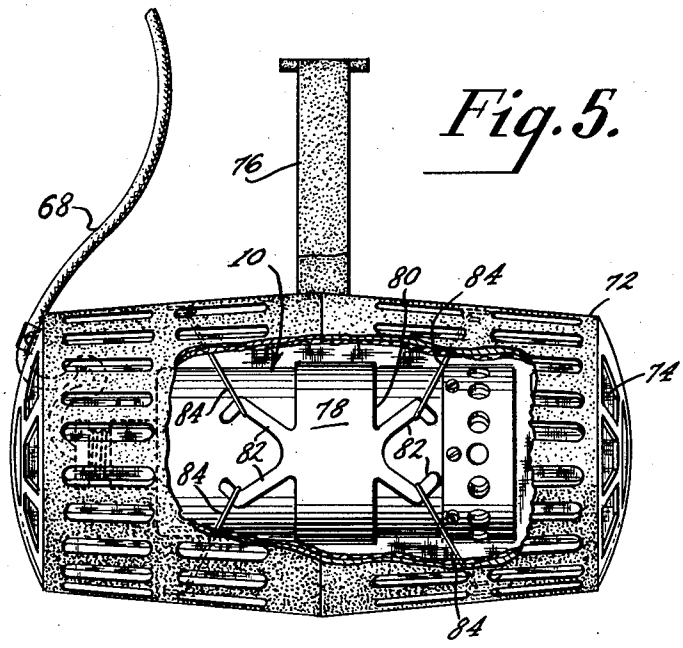


Fig. 6.

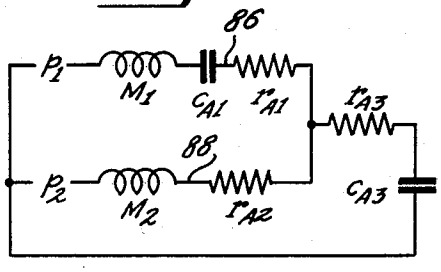
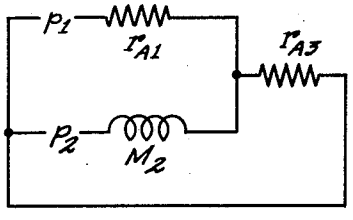


Fig. 7.



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ELECTROSTATIC MICROPHONE CIRCUITS

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Fig. 9.

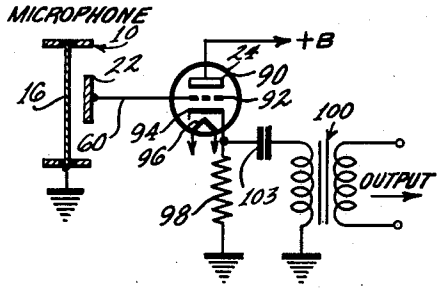


Fig. 12.

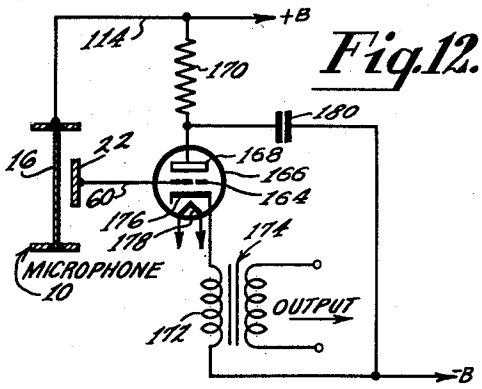


Fig. 11.

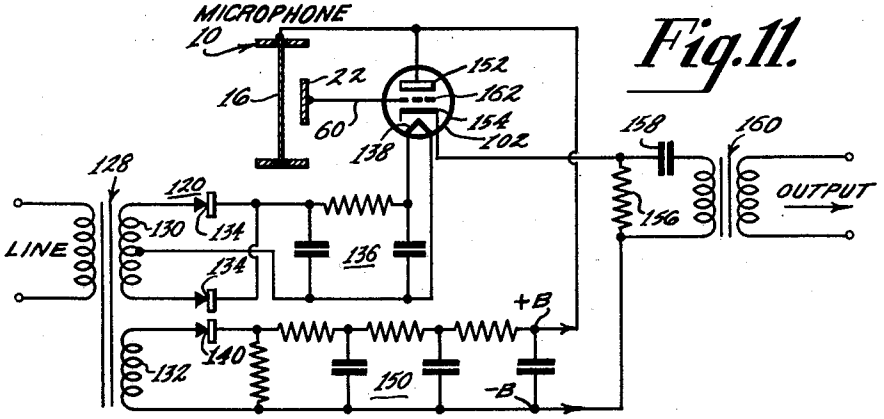
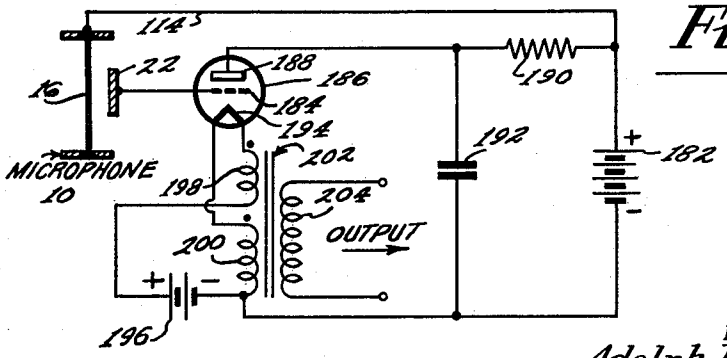


Fig. 13.



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ELECTROSTATIC MICROPHONE CIRCUITS

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Fig. 10.

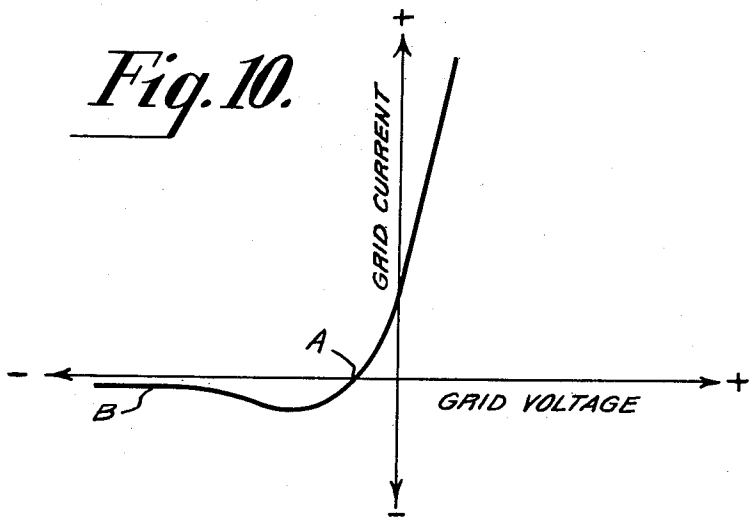
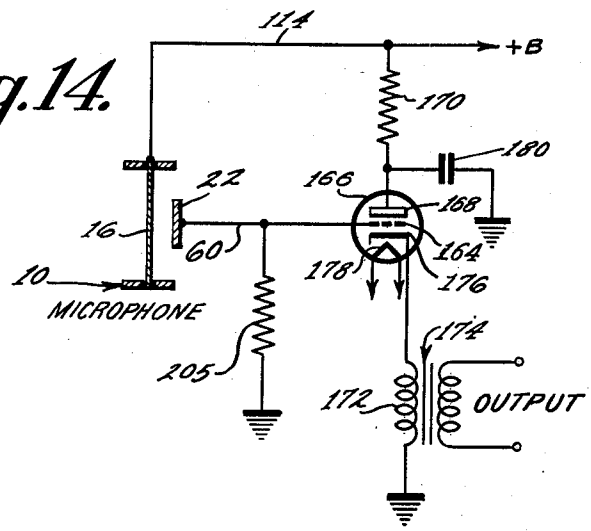


Fig. 14.



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2,920,140

ELECTROSTATIC MICROPHONE CIRCUITS

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Application March 14, 1958, Serial No. 721,539

8 Claims. (Cl. 179—1)

This invention relates to electrostatic microphones, and more particularly to circuits for operating such microphones.

In a typical electrostatic microphone, there are included a pair of plates, at least one of which is a vibratile element. A polarizing voltage is established across these plates. The voltage output of the microphone results from changes in this polarizing voltage due to the vibration of the spacing between the two plates. Before an appreciable output voltage can be obtained from the microphone, a polarizing voltage of sufficient magnitude must be established between the plates thereof. To provide this polarizing voltage, the capacitor formed between the electrostatic transducer is charged. With previous circuitry for electrostatic microphones and transducers, an appreciable charging time is required before a polarizing voltage of operating magnitude becomes established. In certain conventional circuits for operating electrostatic microphones, the elements of the transducer are charged by the grid current flowing from a grid element of an electron tube. Since the grid current of an electron tube is ordinarily small under operating conditions prior electrostatic microphones were not immediately available for use as soon as the circuitry therefore was energized.

In accordance with the present invention, an improved circuit for operating an electrostatic transducer, as may be incorporated in a microphone, is provided including means for providing a direct connection between a source of voltage for establishing the operating polarizing voltage in the microphone in combination with an amplifier. The circuit also has the feature of increasing the sensitivity of the microphone by providing for the establishment of polarizing voltage of larger magnitude than heretofore possible.

It is therefore an object of the present invention to provide improved circuits for operating electrostatic transducers.

It is a further object of the present invention to provide circuits for operating an electrostatic transducer which are capable of developing polarizing voltage of greater magnitude between the elements of the microphone than with circuits heretofore available.

It is a still further object of the present invention to provide circuits for operating electrostatic microphones which decrease the time required for establishment of the polarizing voltage in the electrostatic transducer thereof.

Other objects and advantages of the present invention will, of course, become apparent and immediately suggest themselves to those skilled in the art to which the invention is directed from a reading of the following description in combination with the accompanying drawing in which:

Figure 1 is a sectional view of a directional electrostatic microphone;

Figure 2 is a sectional view of the microphone shown in Figure 1, the section being taken along the line 2—2 of Figure 1 when viewed in the direction of the arrows,

Figure 3 is another sectional view of the microphone shown in Figure 1, the section being taken along the line 3—3 of Figure 1 when viewed in the direction of the arrows,

Figure 4 is still another sectional view of the microphone shown in Figure 1, the section being taken along the line 4—4 of Figure 1 when viewed in the direction of the arrows.

Figure 5 is a side view of a protective case for the microphone shown in Figure 1, the case being partially broken away to show the microphone,

Figure 6 is a schematic diagram of the acoustical network of the microphone shown in Figures 1 to 5,

Figure 7 is a simplified acoustical network of the microphone shown in Figures 1 to 5,

Figure 8 is a fragmentary front view, partially in section, of a modification of the directional electrostatic microphone shown in Figures 1 to 5,

Figure 9 is a schematic diagram of a circuit which may be used with the microphone shown in Figures 1 to 5,

Figure 10 is a curve showing a typical grid current characteristic for an electron tube,

Figure 11 is a schematic diagram of a circuit in accordance with an embodiment of the present invention which may be used with the microphone illustrated in Figure 8,

Figure 12 is a schematic diagram of a circuit in accordance with another embodiment of the present invention which may be used with the microphone illustrated in Figure 8,

Figure 13 is a schematic diagram of another circuit in accordance with still another embodiment of the present invention which may be used with the microphone illustrated in Figure 8, and

Figure 14 is a schematic diagram of still another circuit in accordance with a further embodiment of the present invention which may be used with the microphone illustrated in Figure 8.

The structure and construction of a directional electrostatic microphone having the features provided by the present invention are shown in Figures 1 to 4. The microphone is enclosed in a case **10** of light-weight metal such as aluminum. The case includes two separable cylindrical parts **11** and **13** which are joined to each other, as at a joint **14**. The bottom one **13** of the case parts is closed at its lower end. This closed end is provided with a centrally located hole. A cylindrical, internally threaded boss **12** projects from the bottom of the case. Electrical connections to the elements of the microphone may be brought through the boss **12** and the hole in the bottom of the case. The major portion of the elements of the electrostatic transducer are located in the top part **11** of the case **10**. The bottom of the case may contain components of an electrical circuit for operating the transducer. In the drawing, a small electron tube **24** is shown as being located within the case.

The electrostatic transducer includes a vibratile diaphragm **16**. This diaphragm may be a disc of flexible plastic material. A polyester plastic material, such as Mylar (a trademark of the Dupont Company) may be used. The diaphragm **16** shown in Figure 1 of the drawings is a disc of Mylar material which is coated with a conductive material on at least one surface thereof. In one embodiment, the surface which is coated faces outward of the case **10** so that it may cooperate with the other element of the electrostatic transducer. A conductive material, such as gold may be coated onto the surface of the Mylar sheet by any suitable technique, such as sputtering. The diaphragm is secured to the top of the casing **10** by means of a clamping ring **18**. This clamping ring may also be made of some conductive material such as aluminum. A plurality of screws **20**, which are spaced

at equal distances from each other around the ring 18 are used to fasten the ring and diaphragm 16 to the top of the case 10.

An electrode 22 cooperates with the diaphragm 16. This electrode is illustrated as a disc shaped plate of conductive material, such as brass. Another term descriptive of the electrode 22 is "back-plate." The top surface of the back-plate electrode 22 is spaced closely adjacent to the rear surface of the coated diaphragm 16. A plurality of holes extend through the electrode 22. A large hole is located at the center of the electrode 22 and is a blind hole which extends from the back surface of the disc. The holes are arranged along circular paths at successively greater radial distances from the center of the disc. The ones of the holes which are along the path at next to the largest radial distance from the center of the disc are blind holes 26 and extend only a predetermined distances into the disc from its front surface. The arrangement of holes, and particularly the blind holes 26 provides desirable acoustical characteristics for the microphone. The edge of the electrode 22 at the front surface thereof is slight beveled. This slight bevel also improves the acoustical characteristics of the microphone.

The electrode 22 is supported by a bushing 28 of insualting material, such as nylon. This bushing 28 also supports most of the other acoustical elements of the microphone. An acoustical resistance element provided by a disc 30 of porous material is disposed directly against the rear surface of the electrode 22. This acoustical impedance element is selected to provide an impedance characteristic which is substantially resistive. An element of controlled porosity has been found suitable. For example, the material of the disc 30 may be filter paper of a selected grade. Ordinary chemical laboratory quality filter paper may be found suitable.

It will be noted that the bushing 28 is provided with a plurality of apertures 32 in the walls thereof. The axes of each of these apertures is in the same plane. This plane is located at a predetermined distance behind the diaphragm 16, the electrode 22, and the acoustical resistance element provided by the filter paper disc 30. The apertures 32 in the bushing 28 are exactly aligned with apertures 34 in the walls of the casing 10. Sound waves may be conducted to the rear surface of the diaphragm through the apertures 32 and 34, the resistance element 30, and the back-plate electrode 22. Sound waves may be conducted through the apertures 32 and 34 into the cavity defined at the rear of the case 10 by way of other acoustical elements 36, 38, and 40, and the element 50. These elements permit sound pressure to be developed at the rear of the diaphragm which is related to the sound pressure developed at the front surface of the diaphragm in a predetermined manner. The relationship between the sound pressures is such that the desirable directional characteristics for the electrostatic microphone are obtained. The apertures 32 and 34 together with the filter paper disc 30, the apertured electrode 22 and the acoustical elements 36, 38, 40, and 50, which communicate the apertures 32 and 34 with the cavity at the rear of the case 10 comprise means for shifting the phase of the sound pressure developed at the rear surface of the diaphragm 16 with respect to the sound pressure at the front surface of the diaphragm. As will be more fully set forth hereinafter, certain of these elements present an acoustical network having a substantially resistive impedance characteristic.

The other acoustical resistance elements, which may be provided by discs 36, 38, and 40, of filter paper, similar to the disc 30 of filter paper used for the element at the rear of the electrode 22, are disposed behind the apertures 32 and 34 to provide an acoustical network which is substantially resistive. The acoustical resistance elements provided by discs 30 and 36 are spaced from each other by means of other discs 42 and 44 of foam rubber. The acoustical resistance element discs 36 and 38 are spaced from each other by further discs 46 and 48 of foam rubber material. The foam rubber discs are substantially equal in diameter to the inside diameter of the bushing 28. A circular plate 50 of insulating material, such as nylon, is disposed between discs 38 and 40 of a filter paper. This circular plate 50 is ported with a plurality of apertures. A centrally located hole extends through all of the discs of filter paper 30, 36, 38 and 40, the discs of foam rubber 42, 44, 46, and 48, and the apertured plate 50. A bolt 52 of conductive material extends through the plate and the disc element and this screws into the centrally disposed blind hole of the electrode 22. There is thereby provided a unitary structure of relatively inexpensive, easily manufactured and assembled elements which provide the desired acoustical elements of the microphone. The entire structure may be readily inserted into the top portion of the case 10 and fastened into place by means of the set screws 54.

The foam rubber discs, 42, 44, 46, and 48, provide the requisite, predetermined spacing between the acoustic held resistance elements provided by the filter paper discs 30, 36, 38, and 40. Any material, such as some plastics, having equivalent acoustical and mechanical properties, may be used in place of foam rubber in constructing the discs 42, 44, 46, and 48. The discs 42, 44, 46, and 48, have an acoustical impedance substantially less than the acoustical impedance provided by the filter paper discs. Therefore, the discs 42, 44, 46, and 48, have a negligible effect upon the acoustical characteristics of the microphone. However, the discs insure proper assembly of the other elements of the microphone in a convenient, inexpensive and efficient manner.

The electron tube 24 is mounted on the closed end of a hollow cylindrical member 56 which is closed at only one end. This member 56 is made of insulating material, such as nylon, since it functions as a socket for the tube 24. The cylindrical member is disposed in the bottom part 13 of the casing 10 and rests upon the bottom casing. A post 58 of insulating material such as nylon is inserted into the end of the cylindrical member 56. A lead 60 is held by the post. This lead 60 may be the grid lead for the tube 24. Thus, the lead 60 is held securely and vibration of the sensitive elements of the tube is prevented which might otherwise cause microphonics. The other leads 62 are inserted through socket members 64 in the bottom of the cylindrical member 56. Conductors 66 in a cable 68 are connected to the socket members 64. The cable 68 is mounted in a plug 70 which is screwed into the boss 12 on the bottom of the case 10. The conductors 66 in the cable 63 are connected to other components of the circuit for the microphone. These elements will be discussed later.

Referring now to Figure 5, the case 10 of the microphone is shown suspended within a protective outer 72. This casing is constructed of thin sheet metal and is perforated. The inside of the casing is covered with a porous cloth screen 74. By reason of the perforated casing 72 and the cloth screen 74, the microphone is protected against wind noise of the type encountered in the motion of microphone through the air on a boom. The boom support 76 is connected to the casing 72.

The microphone is supported within the perforated casing 74 by means of a yoke structure 78. This yoke structure includes a circular strap 80 having bifurcated elements 82 extending from opposite edges thereof. The bifurcated elements 82 are connected to the inside of the casing by means of yieldable supports, such as rubber bands 84. The microphone is therefore protected against external vibration. The cable 68 connects to the microphone element.

In operation, the microphone will be positioned with its cylindrical axis in the direction of the sources of sound which are to be picked up. For example, the microphone may be turned so that its cylindrical axis points

toward the performing actor on the sound stage with the end of the microphone having the diaphragm facing the actor. Unwanted noise is likely to be produced in a random manner due to production equipment around the sound stage. This noise will arise from sources all around the microphone and particularly at the back thereof. The desired sound will first strike the front surface of the diaphragm **16**. After a phase and time delay due to the displacement of the apertures **34** and **32** behind the diaphragm **16** and the acoustical network in the microphone, the sound waves will reach the rear surface of the diaphragm **16**. For sounds along the cylindrical axis of the microphone and emanating from the front of the diaphragm **16**, sound pressures will be produced at the front and rear surfaces of the diaphragm **16** having a maximum phase displacement with respect to each other. Thus, significant forces will be applied to the diaphragm **16** and the diaphragm will vibrate at relatively large amplitudes for sounds coming from the front of the microphone and along its cylindrical axis. Unwanted sounds and noise coming from the rear of the microphone will be subjected to a phase and time delay in passing through the apertures and acoustical network at the rear of the diaphragm. A similar phase and time delay will occur before such unwanted sounds reach the front of the diaphragm. Therefore, the sound pressures established at the front and rear surfaces of the diaphragm for unwanted sounds will be substantially in phase. Consequently, the diaphragm will not vibrate due to such unwanted sounds or will vibrate at a considerably smaller amplitude than for sounds which are to be picked up. The maximum sensitivity of the microphone will therefore be for sounds from the front of the microphone which are directed along the cylindrical axis thereof. Because of the symmetrical disposition of the apertures, the microphone will be uniformly unresponsive to sounds from all sides which are incident upon the diaphragm due to sources at the rear of the microphone. The microphone will be uniformly sensitive to sound from sources at the front thereof. The microphone may therefore be considered to have a uniangular response characteristic. Because the axis of maximum sensitivity of the microphone corresponds to the axis of the microphone assembly, the directional, electrostatic microphone provided by the present invention may be termed a uniaxial microphone. Uniaxial microphones of the electromagnetic type, which may have ribbon vibratile elements, are available. Such microphones are illustrated in Olson et al., Patent No. 2,680,787, issued June 8, 1954. The uniaxial electrostatic microphone provided by the present invention is therefore directly compatible with sound systems which may be uniaxial electromagnetic microphones, and will be especially useful where the features of small-sized, light weights and directivity of the uniaxial electrostatic microphones are desired.

It follows from the above discussion that the microphone provided in accordance with the present invention is responsive to the difference in sound pressure on the opposite surfaces of the diaphragm **16**. In other words, the microphone is a sound pressure gradient responsive microphone. The pressure gradient is established by the phase shift introduced in the apertures **32**, **34** and phase shift means, including the acoustical elements behind the diaphragm. Since phase shift imposed on acoustical waves by such phase shift means varies in accordance with the frequency of such waves, it would seem that the pressure gradient, which is the actuating sound pressure for the microphone, would be related to the frequency. It is desirable that the response of the microphone be independent of the frequency of the actuating sound waves. Expressed in other words, it is desirable that there be a constant relationship between the actuating sound pressure and the open circuit voltage output of the microphone.

In previous directional electrostatic microphones which are dependent upon pressure gradient of the actuating sound, complex acoustical networks were combined with the vibrating elements of the microphone to provide the requisite uniform response with respect to the frequency of the actuating sound waves. Another alternative was additional circuitry. The former increases the cost of the microphone and makes repair difficult. The latter requires careful and special design of the amplifiers associated with the microphone. Thus, prior directional electrostatic microphones may not be compatible with the available amplifiers in the sound studio. In accordance with the present invention, the requisite constant relationship between the voltage output of the microphone and the actuating sound pressure and a uniform response with respect to frequency is obtained with the acoustical network provided by the simple acoustical elements, such as the filter paper discs **30**, **36**, **38**, and **40**, which are inexpensive to build and easy to maintain. These acoustical elements provide an acoustical network which is resistance controlled, in an acoustic sense. The combination of an electrostatic transducer and phase shift means including the resistance controlled acoustical network provides a feature of the present invention.

In the electrostatic transducer of the illustrated microphone, the diaphragm **16**, which is coated with a conductive material and the back-plate electrode **22** provides two plates of a capacitor. A potential gradient will be established between these elements **16** and **22** by means of circuitry to be described hereinafter. The open circuit voltage developed by the electrostatic transducer is given by

$$e=\frac{e_0}{a}x_D \tag{1}$$

where

e=open circuit output voltage of the transducer, in volts:
e_0=polarizing voltage or potential gradient between the elements, in volts:
a=spacing between the surfaces of the elements, in centimeters; and
x_D=amplitude of vibration of the movable element, which is the diaphragm **16**, in centimeters.

It appears from Equation 1 that there is a constant relationship between the amplitude of vibration of the diaphragm **16** and the open circuit output voltage of the transducer. In accordance with the present invention, the actuating sound pressures in the microphone are controlled so that forces for actuating the diaphragm are related to the sound pressure in a manner to establish a constant relationship between the actuating sound pressures and the open circuit output voltage of the microphone, notwithstanding that the microphone is a gradient microphone and the intensity of the actuating sound pressures is proportional to frequency. Thus, the microphone will have a uniform response with respect to the frequency of the actuating sound waves.

The actuating force on the diaphragm may be expressed as follows:

$$f_{MD}=jK_1p\omega A \tag{2}$$

where,

f_{MD}=actuating force, in dynes;
K_1=constant of the vibrating system;
p=sound pressure, in dynes per square centimeter;
$_w=2\pi f$;
f=frequency of the actuating sound waves, in cycles per second; and
A=area of the diaphragm, in square centimeters.

The amplitude of vibration of the diaphragm **16** is given by:

$$x_D=\frac{f_{MD}}{j\omega z_M} \tag{3}$$

where,

x_D=amplitude of vibration of the diaphragm **16**, in centimeters, as was the case in Equation 1; and

z_M=mechanical impedance characteristic of the vibrating system of the transducer, in mechanical ohms.

Combining Equations 2 and 3, the amplitude of vibration of the diaphragm **16** will be:

$$x_D=\frac{jK_1p\omega A}{j\omega z_M}=\frac{K_2pA}{z_M} \quad (4)$$

Equation 4 shows that the amplitude of vibration of the diaphragm will be independent of the frequency of the actuating sound waves, if the mechanical impedance characteristic z_M is not dependent on frequency and therefore is a mechanical resistance. Thus, a resistance controlled vibrating system, as is provided by the acoustical elements disposed behind the diaphragm **16** in the microphone illustrated in connection with Figures 1 to 4, will have an output voltage which has a constant relationship with the actuating sound pressure. Consequently, the response of the microphone will be uniform with respect to frequency.

The resistance controlled nature of the electrostatic uniangular microphone shown in Figures 1 to 4 may be illustrated in connection with the schematic diagrams of the acoustical network thereof which are shown in Figure 6.

In that network:

p_1 is the sound pressure at the diaphragm 16;

p_2 is the sound pressure at the apertures **34**, **32**;

M_1 is the mass of the diaphragm **16**, and the air load on the front of the diaphragm;

C_{A1} is the acoustical capacitance of the diaphragm;

r_{A1} is the acoustical resistance behind the diaphragm;

M_2 is the inertance of the apertures **32**, **34**;

r_{A2} is the acoustical resistance of the apertures;

r_{A3} is the acoustical resistance of the termination; which includes the elements behind the aperture; and

C_{A3} is the acoustical capacitance of the volume of air in the case **10**.

In order to provide the uniform response and directivity of the microphone with respect to frequency, the acoustical resistance r_{A1} of the first branch **86** is the controlling acoustical impedance in that branch **86**. For the same reason, the acoustical resistance r_{A3} in the parallel branch **88** is the controlling acoustical resistance in that branch. Under these conditions, the acoustical network can be simplified by eliminating the acoustical elements which have a negligible effect on the system. The simplified acoustical network is shown in Figure 7. This acoustical network may be referred to in analyzing the operation of the vibrating system of the electrostatic uniangular microphone provided by the present invention. Thus, the volume current in the branch **86** due to the pressure p_1 is given in equation:

$$\dot{X}_{11}=\frac{p_1(r_{A3}+j\omega M_2)}{r_{A1}r_{A3}+j\omega M_2r_{A1}+j\omega M_2r_{A3}} \quad (5)$$

where,

$\dot{X}_{11}$=volume current, in cubic centimeters per second;

P_1=actuating pressure at the diaphragm of the micro phone, in dynes per square centimeter;

r_{A1}=acoustical resistance behind the diaphragm, in acoustical ohms;

r_{A3}=acoustical resistance of the termination, in acoustical ohms; and

M_2=the inertance of the apertures, in grams per (centimeter)^4.

The volume current in the branch **86** due to the pressure p_2 is given by:

$$\dot{X}_{12}=\frac{p_2r_{A3}}{r_{A1}r_{A3}+j\omega M_2r_{A1}+j\omega M_2r_{A3}} \quad (6)$$

where,

$\dot{X}_{12}$=the volume current, in cubic centimeters per second; and

P_2=the actuating pressure at the apertures of the microphone, in dynes per square centimeter.

In order to determine the characteristics of the actuating sound pressures on the microphone, it will be assumed that the reference point of zero phase is at the front surface of the diaphragm **16** of the microphone. Then, the expression for p_1 may be written:

$$p_1=p_{01}\epsilon^{j\omega t} \quad (7)$$

where,

p_{01}=the amplitude of p_1, in dynes per square centimeter, and

t=time, in seconds.

The expression for p_2 is written:

$$P_2=p_{02}\epsilon^{j\left(\omega t+\frac{2d\pi}{\lambda}\cos\theta\right)} \quad (8)$$

where,

p_{02}=amplitude of p_2, in dynes per square centimeter;

d=effective acoustic path from the diaphragm to the aperture, in centimeters;

λ=wavelength of the actuating sound wave, in centimeters; and

θ=angle between the axis of the microphone and the direction of the incident sound wave.

The resultant volume current in branch **86**, which is the volume current of the diaphragm **16**, is given by:

$$\dot{X}_D=\dot{X}_{11}=\dot{X}_{12} \quad (9)$$

If (a) the pressures, p_{01} and p_{02} are equal, (*b*) the distance d is small compared to the wave length of actuating sound, and (*c*) the values of r_{A1}, r_{A3} and M_2 are selected to provide a cardioid pattern, in the well known manner as, for example, set forth in the text, "Elements of Acoustical Engineering," by H. F. Olson, 2nd ed., pp. 264–65, the volume displacement of the diaphragm **16** can be expressed as

$$X_D=K_3p_1(.5+.5\cos\theta) \quad (10)$$

where,

X_D=volume displacement of the diaphragm in cubic centimeters; and

K_3=constant of the acoustical and electrical systems.

The amplitude of the diaphragm is given by:

$$x_D=\frac{X_D}{A} \quad (11)$$

Combining Equations 10 and 11, the open circuit output voltage developed by the microphone is given by:

$$e=K_4e_0P_1(.5+.5\cos\theta) \quad (12)$$

where,

K_4=the sensitivity constant of the acoustical and electrical systems.

It will be observed that the directivity pattern as given by Equation 12 is a cardioid. This directivity is improved, in the microphone shown in the drawings, by location of the apertures **32**, **34** along the cylindrical body of the case **10**. The improvement is provided by diffraction phase effects which are a function of the angle of the incident sound. Such diffraction phase effects are illustrated on page 20 of the aforementioned text. The response of the microphone as a function of the azimuth of the incident sound with the directivity maximized by the employment of phase diffraction effects is given by:

$$e=K_5e_0p_1\left(.4+.6\cos\theta\cos\frac{\theta}{3}\right) \quad (13)$$

where,

K_5=the sensitivity constant of the acoustical and electrical systems.

An examination of Equation 13 shows that the directivity of the microphone is greater than that of a simple cardioid microphone. For example, at ninety degrees with respect to the axis of the microphone, the response is down eight decibels from that at zero degrees or on the axis of the microphone as compared to six decibels for the cardioid pattern.

The frequency response of the microphone may be improved in the high frequency region by means of the blind holes 16 which are arrayed in the back-plate electrode 22. The presence of the blind holes in the closed area at the back surface of the diaphragm 16 establishes an auxiliary acoustical network which has a negligible effect upon the operation of the electrostatic transducer and its vibrating system except in the high frequency region of the response characteristic of the microphone. In that region, the auxiliary network produces a resonance effect which improves the sensitivity of the microphone. Thus, the disclosed improved uniangular directional microphone has a uniform response with frequency for all audio frequencies and is compatible with high fidelity sound and recording systems.

The microphone illustrated in connection with Figures 1 to 4 may be used with conventional circuitry to derive the output voltage therefrom. One such circuitry is shown in Figure 9 of the drawings. In Figure 9, the microphone is schematically illustrated as comprising the casing 10, the diaphragm 16 and the electrode 22. The electrode 22 is positioned in back of the diaphragm 16 and may be referred to as the back-plate electrode of the electrostatic transducer. The casing 10 of the microphone is connected to a point of reference potential, such as ground. The diaphragm 16 which is coated with a conductive material is also connected to ground since it is in contact with the casing 10. The physical connection of the diaphragm to the casing 10 is shown in greater detail in Figure 1. The circuit shown in Figure 9 includes the vacuum tube 24, having a plate 90, grid 92, a cathode 94 and a heater or filament 96. The filament may be connected to a source of heating voltage, which is desirably a direct current source. The grid 92 is connected to the back-plate electrode 22. The plate 90 is connected to a source of operating voltage shown on the drawing at B+. The cathode 94 is connected to ground through a cathode resistor 98 and to the primary winding of an output transformer 100 through a coupling capacitor 102. It will be observed that the grid connection to the back-plate 22 may be by way of the lead 60 which is shown in Figure 1.

As the diaphragm 16 vibrates, the distance between the adjacent surfaces of the diaphragm 16 and the back-plate electrode 22 varies in accordance with the actuating sound pressure. This variation causes the voltage between the plates of the capacitor constituted by the diaphragm 16 and to correspondingly vary as the capacity changes. This varying voltage appears at the grid 92. The tube circuit functions as a cathode follower to provide an output voltage across the cathode resistor 98. The direct current voltage across the cathode resistor 98 is blocked by the coupling capacitor 103 so that only alternating current passes through the primary winding of the transformer 100. The useful alternating current output signal of the microphone may be derived across the secondary winding of the transformer 100.

The potential gradient across the electrostatic transducer from the back-plate electrode 22 to the diaphragm 16 is established when the operating potential is applied to the tube 24. The electrostatic transducer functions as a capacitive element in the circuit, and charges to establish the polarizing voltage thereacross. However, the time required for the capacitor to charge to its operating voltage may be appreciable. As may be observed from Equation 1, the output voltage of the electrostatic transducer is proportional to the potential to which the electrodes thereof are charged. Until this potential is sufficiently great, the voltage output of the transducer and the signal output of the circuit is not of sufficient magnitude to properly operate amplifiers which are associated therewith.

With the circuit of Figure 9, the amount of time required to charge the electrostatic transducer may be appreciable. An analysis of the grid current-grid voltage characteristics of the vacuum tube 24, such as shown in Figure 10, will determine the reason for the charging time. A "free grid," i.e., a grid with no external connection, must assume the condition of zero grid current. Such a point is indicated as, A, in Figure 10. The "free grid" voltage for the majority of electron tubes is negative with respect to the cathode and is small and only a few volts in magnitude. The grid 92, in Figure 9, does not have a conductive return path connected thereto. Therefore, it is a "free grid" in the direct current sense and must ultimately assume the zero grid current condition, A in Figure 10. With a small negative grid voltage, appreciable current flow takes place through the tube 24 from plate to cathode. A large voltage drop occurs across the cathode resistor 98. This voltage drop raises the cathode substantially positive in voltage with respect to ground. Since the grid 92 and the transducer element 22 will have assumed a small negative voltage with respect to the cathode 94, the transducer element 22 will be charged to approximately the same voltage as the cathode 94.

In the interval preceding activation of the circuit of Figure 9 by applying B+ to the plate 90, all elements of the circuit will be at zero or ground potential. At the instant of applying B+ to the plate 90 the transducer element 22 and the grid 92 must, by the nature of the transducer capacitance, remain at substantially ground potential. The plate current of the vacuum tube 24 will therefore, in that instant, increase to a value which will raise the cathode 94 to a voltage approximating the grid cut off potential of the vacuum tube. In the first instant of activation of the circuit of Figure 9, the grid 94 will, therefore, have a voltage several volts negative with respect to cathode 94. This negative grid voltage will be at a point such as B in the grid current curve depicted in Figure 10. The resulting grid current is quite small under these conditions. In the interval following the instant of activation of the circuit of Figure 9, the electrostatic transducer capacitance is charged by the flow of grid current from grid 94 to the back plate electrode 22. Since the grid current, as described above, is quite small the charging time of the transducer capacitance must be appreciable.

Improved circuits decreasing the charging time may be provided. Illustrative embodiments of such circuits are shown in Figures 11, 12, and 13, of the drawings. The circuits of Figures 12 and 13 have the additional feature of causing the voltage across the elements 16 and 22 of the electrostatic transducer to increase to an extent that they are larger than the polarizing voltages available with the circuit shown in Figure 9. It will be noticed, however, that with the circuits shown in Figures 11, 12, and 13, the diaphragm 16 of the microphone is not connected to ground. Instead, it is connected to the source of operating potential.

In the embodiment of the microphone shown in Figure 8, means are provided for insulating the diaphragm 16 so that it may be connected to a source of high voltage and at the same time eliminate any hazard of electrical shock to the user of the microphone. The parts of the embodiment of the microphone shown in Figure 8 which are similar to the corresponding parts of the microphone shown in Figures 1 to 4 are designated with like reference numerals. It will be appreciated, however, that the improved circuits shown in Figures 11 to 13 of the drawings are useful with any electrostatic transducers.

Referring to Figure 8, there is shown an electrostatic

uniangular microphone similar to the microphone shown and described in connection with Figures 1 to 4. This microphone includes a case **10** having an electrostatic transducer in the upper part thereof and electrical components, such as an electron tube **102** in the lower part thereof. The electrostatic transducer includes a diaphragm **16** coated on at least one surface with a conductive material. A back plate electrode **22** is spaced adjacent the uncoated surface of the diaphragm **16**. Apertures **32, 34** are provided in the case. The interior of the case in back of the diaphragm contains similar acoustical elements to those shown in Figure 1 for introducing sound to the back surface of the diaphragm and establishing the directional response characteristic of the microphone. The acoustical operation of this microphone was discussed above.

The diaphragm **16** is supported on top of the case **10** in a manner to be insulated from the case. A ring **104** of insulating material which may be an insulating plastic, such as Bakelite, is disposed at the top of the case. The diaphragm rests on this ring. Another ring **106** of conductive material such as copper is placed on top of the diaphragm and overlies the plastic ring **104**. Another ring of insulating material, such as a plastic material, is placed on top of the conductive ring. Thus, the edge of the diaphragm **16** and the contact ring **106** are sandwiched between the plastic rings and are insulated by means of these rings from the case. A plurality of screws **10** extend through holes in the rings **104, 106,** and **108,** and in the diaphragm. The diameter of the holes is greater than the diameter of the screws so that the screws are not in contact with the conductive ring **106**. These screws are attached to the material at the top of the case **10**. The screws **110** may be equally spaced from each other around the rings as was the case with the screws **20** shown in Figures 1 and 2.

A tab **112** of conductive material is attached to the conductive ring **106**. A lead **114** is connected to this tab by means of soldering. A terminal cover **116** of insulating material, which may be cemented to the plastic rings **104** and **108** encloses the soldered junction. A screen **118** of stiffened cloth may be used to cover the entire top portion of the microphone. This screen **118** may be secured to the top of the microphone by means of the screws **110**. Thus, the entire unit is electrically insulated and isolated so as to eliminate any shock hazard.

The lead **114** may be connected to the cable at the bottom of the microphone case. A plug connection similar to that shown in Figure 1 may be used. This lead **114**, as will be observed from the circuit diagrams of Figures 11 to 13, is connected to the source of operating potential for the microphone.

In Figure 11, a microphone of the type shown in Figure 8 is schematically illustrated as including the diaphragm **16**, the back plate electrode **22** and the case **10**. The lead **114** is connected to the diaphragm and is insulated from the case as in the diaphragm. The circuit of Figure 11 includes a power supply **120** for providing low voltage direct current for operating the filament of the electron tube **102**. The power supply **120** also provides higher voltage direct current for operating the circuit and the microphone. The power supply transformer **128** has a primary winding which may be connected to the power lines and low voltage and high voltage secondary windings **130** and **132**, respectively. The low voltage alternating current across the low voltage winding **130** is rectified by means of a pair of diodes **134**. The rectified alternating current from the diodes is filtered is a resistance-capacitance filter circuit **136**. The filament **138** of the tube **102** is connected across the output of the filter **136**. Thus, the tube **102** is heated by direct current so as to prevent the introduction of hum into the circuit.

High voltage direct current is provided by a half wave rectifier power supply including a diode **140** which operates into a filter network **150**. The filter network **150** is a multi-stage filter of the resistance-capacitance type so that a substantially pure direct current voltage output is obtained. The high voltage terminal of the high voltage supply is labeled +B and the low voltage terminal of the power supply is labeled —B. The high voltage terminal of the power supply is connected to the plate **152** of the tube **102** and simultaneously to the diaphragm **16** of the electrostatic transducer in the microphone. The low voltage terminal indicated at B— is connected to the cathode **154** of the tube **102** through a cathode resistor **156**. The signal voltage output of the circuit is obtained across the cathode resistor through a blocking capacitor **158** and an output transformer **160**.

In operation, the electrostatic transducer is immediately charged upon energization of the circuit, as by connecting the transformer **128** primary winding to the power line. A high polarizing voltage is established between the diaphragm **16** and the back plate electrode **22**. When the high voltage from the power supply, indicated at B+ is applied to the diaphragm **16**, the capacitive electrostatic transducer initially acts as a short circuit and applies a positive voltage to the grid **162** of tube **102**. As may be seen in Figure 10, a positive grid causes a large amount of grid current to flow and the transducer element immediately charges to a sufficiently high polarizing voltage to permit proper operation of the electrostatic microphone. The plate current, through the tube, is initially higher than normal, since the grid **162** is positive. However, the bias voltage developed across the cathode resistor **156** is not sufficient to cut off conduction through the tube before the capacitive transducer element is charged to requisite polarizing voltage by grid current conduction.

When the circuit reaches its quiescent operating condition, the grid voltage will return to a magnitude such that grid current conduction is zero. The operation takes place because of the characteristics of the grid **162** as a "free grid" in the circuit as explained above.

After initial energization of the circuit of Figure **11**, the polarizing voltage across the transducer elements **16** and **22** will be approximately equal to the voltage drop across the plate to cathode of the electron tube **102**. The "free grid" potential is small compared to the potential of the cathode **154**. More accurately, the polarizing voltage will be equal to the supply voltage at B+, added to the voltage from the grid **162** to the cathode **154**, less the voltage drop across the cathode resistor. The last voltage will be substantial in magnitude, consequently the polarizing voltage will be correspondingly less than the supply voltage.

In the circuit of Figure 9, the electrostatic transducer eventually becomes charged to a polarizing voltage equal to the voltage drop across the cathode resistor **98**, less the bias voltage from the grid to the cathode. In other words, the polarizing voltage in the circuit of Figure 9, will be approximately equal to the voltage drop across cathode resistor **98**. This is because the grid to cathode voltage of the vacuum tube **24** will be small as explained above.

The circuit of Figure 11 is an improvement over the circuit of Figure 9 inasmuch as the transducer charging time is considerably reduced in the circuit of Figure 11 as compared to the charging time of the circuit of Figure 9. The polarizing potential developed in either circuit will be substantially less in magnitude than the potential of B+.

A consideration of Equation 1 will show that it is desirable to have a polarizing potential as large as possible. A circuit which will increase the polarizing voltage to approximately B+ potential is shown in Figure 12 which schematically illustrates the microphone shown in Figure 8 having the diaphragm **16** and the back plate electrode **22**. The back plate electrode is connected to

the grid 164 of a vacuum tube 166. The plate 168 of the tube 166 is connected to the source of operating voltage indicated at B+ through a plate current limiting resistor 170. The primary winding 172 of an output transformer 174 is connected between the B— terminal of the source of operating voltage and the cathode 176 of the tube 166. The B— terminal may be grounded, if desired. The filament 178 of the tube 166 may be heated by direct current voltages in the manner shown in Figure 11. A capacitor 180 is connected between the B— terminal and the plate 16 so as to shunt any transients, occurring in the power supply around the tube and winding 172 of the output transformer. In other words, the resistor 170 and capacitor 180 function in the same manner as the last section of the filter circuit 150 shown in Figure 10.

A high polarizing voltage is immediately established between the diaphragm 16 and the back plate electrode 22 when the operating voltages are applied to the circuit. The operation of the circuit in quickly charging the electrostatic transducer to operating voltage is similar to that described in Figure 11. The polarizing voltage developed across the transducer elements of this circuit is greater than was the case with the circuit shown in Figure 11. When the circuit reaches its quiescent operating condition, the grid current conduction ceases and a bias voltage develops between the grid 164 and the cathode 176 which is sufficient to cause grid current cut off. The polarizing voltage across the transducer elements is equal to the voltage of the source of operating voltage at B+, plus the bias voltage which is developed between the grid 164 and the cathode 176, since there is substantially no direct-current voltage drop across the primary winding 172 of the output transformer 174. The bias voltage between the grid 164 and the cathode 176 is only a few volts. Therefore, the polarizing voltage developed across the transducer will be approximately equal to the voltage of the source of operating voltage at B+. This higher polarizing voltage results in a higher output voltage from the microphone.

Figure 13 shows another embodiment of the improved circuit for operating an electrostatic microphone. This circuit is particularly advantageous when the source of operating voltage for the microphone is a battery or batteries. The microphone elements are shown schematically as including the diaphragm 16, back plate electrode 22 and case 10. The diaphragm 16 is connected over lead 114 to the positive terminal of a battery 182 which provides the source of high operating voltage for the circuit and microphone. The manner of connection of the microphone elements and the disposition of the lead 114 is illustrated in Figure 8 of the drawings. The back plate electrode 22 is connected over the lead 60 to the grid 184 of a tube 186. The plate 188 of the tube 186 is connected to the battery 182 by way of a filter circuit including the current limiting resistor 190 and the shunt capacitor 192. This resistance-capacitance circuit operates in the same manner as the circuit of resistor 170 and capacitor 180 shown in Figure 12. The filament 194 functions as the cathode of the tube. It is a feature of this circuit that the filament is connected to the battery 196 which supplies the filament heating power through the primary windings 198 and 200 of an output transformer 202. The signals from the circuit are obtained across the secondary winding 204 of the transformer 202. The primary windings 198 and 200 are connected, in bucking relationship, as indicated by the dots at the ends thereof which are shown on the drawing, in series with the battery 196 and the filament 194. Thus, the filament current does not produce flux in the core of the transformer. The windings 198 and 200 are in parallel with the plate circuit of the tube. Thus, signals passing through the tube and the windings 198 and 200 in its cathode circuit will be reflected in the output voltage across the secondary winding 204. If desired, the windings 198 and 200 may be wound in a bifilar manner. The polarizing voltage is established in the electrostatic transducer in a rapid manner as was the case for the circuit illustrated in Figure 12. Similarly, the voltage between the diaphragm 16 and the back plate electrode 22 will be a higher polarizing voltage than possible with prior circuits as was explained in connection with Figure 12.

Another circuit incorporating improvements in addition to the improvements provided by the circuits shown in Figures 11 to 13 is illustrated in Figure 14. This circuit is similar in most respects to the circuit shown in Figure 12 except that (1) connections are made to ground instead of to B— and (2) a resistor 205 is connected between the grid 164 and ground.

In certain applications of an electrostatic microphone, for example in motion picture studio work, the microphone may be exposed to explosive sound, such as gunshot sounds. After exposure to severe gunshot sounds the microphone may suffer a momentary decrease of sensitivity. Such decrease may possibly be attributable to the effect of the gunshot sound on the capacitive transducer element of the microphone which causes the grid 164 of the tube 166 to become positive. Upon becoming positive, the grid draws current. The capacitive transducer element charges so that the back plate 22 becomes sufficiently negative to reduce signal transmission through the tube 166 for a short interval of time.

The provision of the grid resistor 205 permits the transducer element to discharge and return to its normal charge immediately after the gunshot sound terminates. Thus, the interval of decreased microphone sensitivity is alleviated. In all other respects the circuit of Figure 14 operates similarly with the circuit of Figure 12.

What is claimed is:

1. A circuit for operating an electrostatic transducer including two electrodes having opposed surfaces spaced from each other to define a gap therebetween comprising an electron control device having an input terminal and two output terminals, said input terminal being electrically isolated from said output terminals, means for applying operating voltage simultaneously to one of said electrodes and one of said output terminals for immediately energizing said device and said transducer, means for connecting the other of said electrodes to said input terminal, and means for deriving a signal output from said device connected between said output terminals.

2. A circuit for operating an electrostatic transducer including two electrodes having opposed surfaces spaced from each other to define a capacitive element comprising an electron control device having a control electrode, said control electrode being electrically free of said discharge and collecting electrodes, an electron discharge electrode and an electron collecting electrode, an output circuit, said source of operating voltage being connected between said collecting electrode and said discharge electrode through said output circuit, means for connecting one of said transducer electrodes to said source of operating voltage, and means for connecting said control electrode to the other of said transducer electrodes.

3. A circuit for operating an electrostatic transducer including two electrodes having opposed surfaces spaced from each other to define a gap therebetween, comprising an electron discharge device having a control electrode, an anode electrode and a cathode electrode, said control electrode being electrically free of said discharge and collecting electrodes, means for connecting said control electrode to one of said transducer electrodes, means for conecting said source of operating voltage simultaneously to said anode electrode and the other of said transducer electrodes for simultaneously energizing said transducer and said device, and means for deriving output voltages connected between said cathode and said anode electrodes.

4. The circuit as set forth in Claim 3 including a resistor and direct current coupling means for connecting

said resistor between said control electrode and said cathode.

5. A circuit for operating an electrostatic transducer having a pair of electrodes, said electrodes having opposed surfaces spaced from each other to define a capacitive element, an electron tube having a plate, a grid and a cathode, said grid being connected to one of said electrodes, an impedance element connected to said cathode having direct-current transmission characteristics, means for connecting a source of operating voltage between said plate and said element for energizing said tube, means for connecting said source to the other of said electrodes for immediately establishing a polarizing voltage across said electrodes simultaneously with energization of said tube, said grid being electrically isolated from said plate and cathode to provide a free grid, and means for deriving signal output voltages across said element.

6. A circuit for operating an electrostatic transducer including two electrodes having opposed surfaces spaced from each other to define a capacitive element comprising an electron tube having a grid, a plate and a cathode, an output transformer having a primary and secondary winding, a current limiting resistor, one of said electrodes being connected to said grid, said grid being otherwise a free grid, and means for connecting a source of operating voltage simultaneously to said resistor and to the other of said electrodes for simultaneously energizing said tube and establishing a polarizing voltage across said transducer electrodes, the output voltage from said circuit being derived from said secondary winding.

7. A circuit in accordance with claim 6 including a resistor connected between said grid and said primary winding.

8. A circuit for operating an electrostatic transducer having a pair of electrodes, said electrodes having opposed surfaces spaced from each other to define a capacitive element, an electron tube having a plate, a grid and a filament, an output transformer having a primary winding and a secondary winding, said primary winding having two sections, a filament supply voltage source, a plate supply voltage source, means for connecting said filament supply source in a series circuit with said filament and said primary winding sections, said primary winding sections being connected in bucking relationship with each other, one of said electrodes being connected to said grid, said grid being otherwise a free grid, and means for connecting said plate supply source simultaneously to said plate and to the other of said electrodes.

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