

July 7, 1942.

J. P. ARNDT, JR

2,288,600

ELECTRICAL DEVICE

Filed Dec. 19, 1940

2 Sheets-Sheet 1

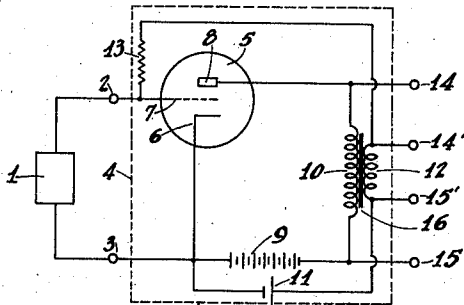


fig 1.

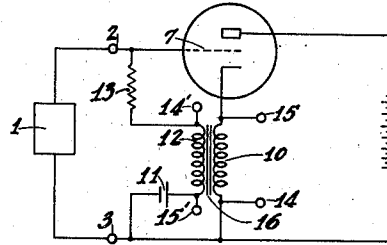


fig 3.

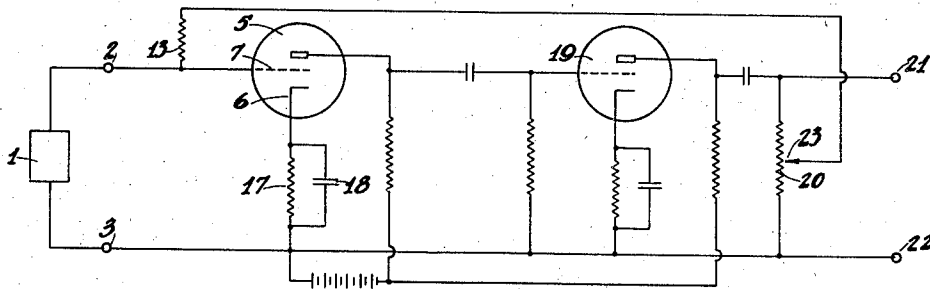


fig 2.

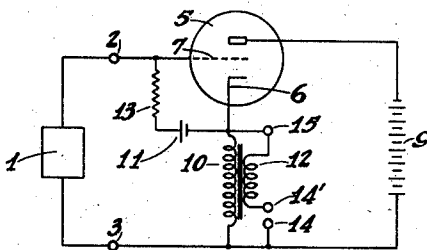


fig 4.

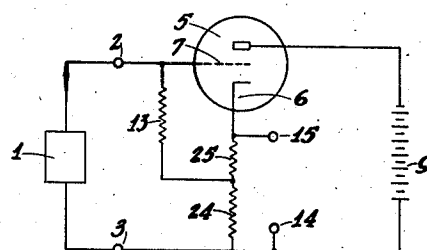


fig 5.

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2 Sheets-Sheet 2

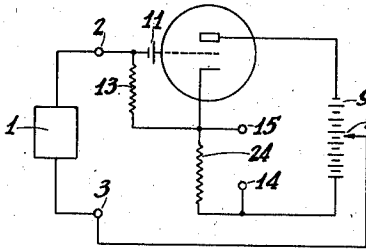


fig 6.

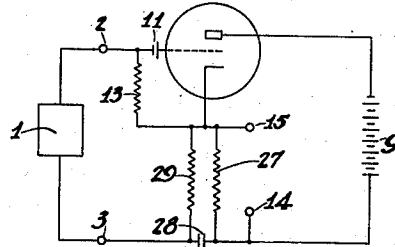


fig 7.

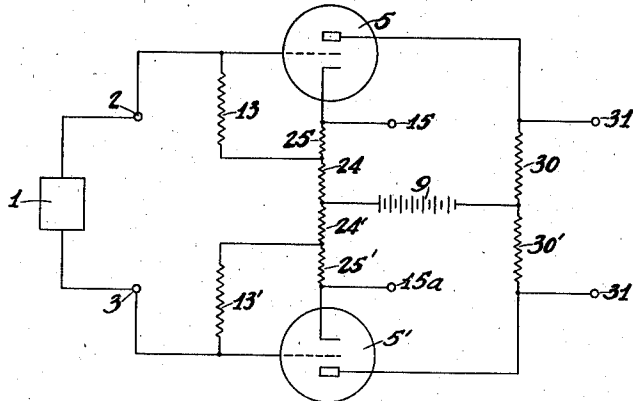


fig 8.

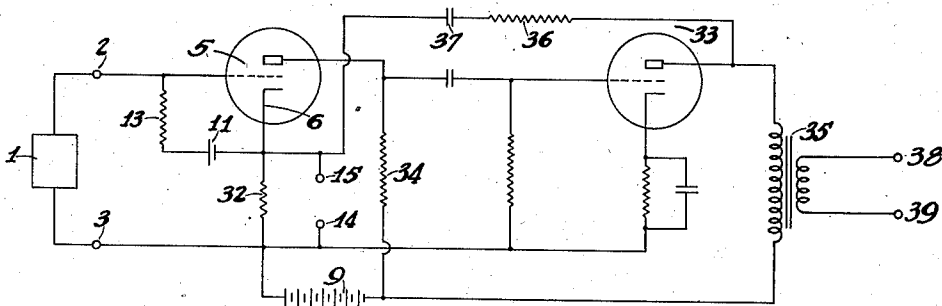


fig 9.

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2,288,600

ELECTRICAL DEVICE

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Application December 19, 1940, Serial No. 370,773

12 Claims. (Cl. 179-1)

This invention relates to electrostatic apparatus and more particularly to circuits embodying electrostatic generating devices. The invention relates more especially to means for reducing the flow of current from electrostatic generators when the latter are used in combination with amplifiers. Specifically, it relates to amplifier circuits of particular design used in combination with electrostatic signal generating devices.

Electromechanical transducers such as microphones, phonograph pickups and vibration pickups employing the electrostatic principle of transduction are now in common use. By this principle an interchange of mechanical energy to electrical energy may take place through the medium of a piezoelectric body or, alternatively, of an electrostatic field which may be supplied by an external polarizing source or by an electret. Such electrostatic generators are commonly used in combination with vacuum tube amplifiers. However, difficulties are often encountered with such combinations in obtaining satisfactory low-frequency response because the internal impedance of electrostatic generators of the type mentioned is predominantly capacitive while the input impedance of the usual amplifiers is generally resistive. The impedance of the electrostatic generating device may be low enough over a wide range of frequencies so that the major part of the generated voltage is applied to the input of the amplifier. At frequencies below this range, however, the capacitive impedance becomes relatively very high and a large part of the signal voltage is then developed across the internal impedance of the generator and very little is applied to the amplifier. In other words, the combination exhibits an undesired low-frequency cutoff. In many cases it is difficult to avoid having the cutoff within the frequency range which the combination should accommodate. This is because the grid resistance of the amplifier must be increased to many megohms if the cutoff is to be avoided and because most amplifiers become unstable or display other undesirable effects when the input grid resistance is so increased. This difficulty has been encountered in the design of high output, sound-cell microphones when a plurality of sound-cells of the type disclosed in Sawyer Patent No. 2,105,010 and Williams Patent No. 2,126,438, are connected in series to obtain increased output. The series connection results in a small capacity for the microphone and thus requires an excessively high amplifier input re-

sistance for satisfactory low-frequency response. To avoid this situation and to permit the use of grid resistance of moderate size, it has been necessary in the past to connect in parallel a plurality of such series-connected groups of cells. Such construction is expensive and bulky, and introduces acoustical errors which arise from the large size of the assembly. As will be understood from the subsequent explanation, this invention largely avoids such difficulties. A similar problem has been encountered in the past in the design of condenser microphones since the capacity of such a microphone is relatively low. In order to place the cutoff at a sufficiently low frequency, it has been necessary to use excessively large grid and polarizing circuit resistances. Likewise, the problem has been encountered in devices such as the piezoelectric pressure measuring instrument disclosed in Gravley Patent No. 2,207,439, and Schrader Patent No. 2,096,826, where the device is required to operate at very low frequencies.

It is an object of this invention to extend the frequency response range of electrostatic generator-amplifier combinations to lower frequencies than have heretofore been readily obtainable.

It is another object to provide an amplifier circuit which has less loading effect on electrostatic generating devices than conventional amplifiers.

It is another object to provide a vacuum tube coupling circuit for coupling a high impedance generating device to a relatively low impedance load circuit.

It is a further object to provide amplifier circuits of the type described which are particularly suitable for use in combination with piezoelectric signal generating devices, the circuits being characterized by the fact that they apply no biasing potential to the piezoelectric device.

It is still another object to combine a condenser microphone with an amplifier circuit of the type described which is particularly suitable for use in combination therewith, the amplifier circuit being characterized by the fact that it uses a minimum number of elements.

Another object of this invention is to provide a circuit which is especially adapted for use in combination with a plurality of electrostatic generating devices connected in series.

Other objects will be apparent from the following description taken in conjunction with the accompanying drawings.

Figures 1, 2 and 3 illustrate embodiments of

the invention which permit over-neutralization, complete neutralization, or under-neutralization of signal current where the term neutralization is understood to mean that condition of operation wherein no signal current flows from the generator. In these figures,

Fig. 1 illustrates the invention in connection with an otherwise conventional single-stage amplifier.

Fig. 2 illustrates the invention in connection with a two-stage cascade amplifier supplying signal voltage to a potentiometer.

Fig. 3 illustrates the invention in connection with a single-stage amplifier having inverse feedback.

Figures 4, 5, 6, 7, 8 and 9 illustrate embodiments of the invention wherein one may obtain under-neutralization which approaches complete neutralization. In these figures,

Fig. 4 illustrates a modification of the invention which is particularly suited for use with a piezoelectric or electret signal generator.

Fig. 5 illustrates a modification which is particularly suited for use with a condenser microphone or a similar electrostatic signal generator.

Figures 6, 7 and 8 illustrate embodiments of the invention wherein the application of direct-current potentials to the signal generator is avoided.

Fig. 6 illustrates a modification wherein a tapped battery is employed to avoid the said direct-current potential.

Fig. 7 illustrates a modification wherein the direct-current potential is avoided by means of a blocking network.

Fig. 8 illustrates a modification wherein the direct-current potential is avoided through the use of a push-pull amplifier circuit.

Fig. 9 illustrates an embodiment of the invention analogous to that illustrated in Fig. 5 but which substantially avoids the direct-current potential which the latter applies to the signal generator. In this embodiment an additional amplifier stage is provided to supply the amplified neutralizing signal voltage.

Referring now to Fig. 1, a high impedance signal generating device, 1, as for example, a piezoelectric microphone, applies signal voltage between input terminals 2 and 3 of an amplifier designated by the reference character 4. The amplifier comprises a vacuum tube 5, having cathode 6, grid 7, and anode or plate 8. Input terminal 2 is connected to the grid 7 and input terminal 3 is connected to the cathode 6. Between the plate and cathode is connected a plate supply battery 9 and the primary 10 of transformer 16. Battery 11 supplies bias potential for the grid 7, the positive terminal being connected to the cathode 6 and the negative terminal being connected to the grid through transformer secondary 12 and grid resistance 13. When connected as shown, the bias battery 11 applies a direct-current potential difference between the generator terminals. Usually this will be too small to harm a piezoelectric device but, if desired, other bias arrangements may be used, some of which are illustrated in some of the succeeding figures of the drawings. Output from the amplifier may be taken between terminals 14 and 15 connected to the transformer primary or alternatively between terminals 14', 15' connected to the transformer secondary.

When the various elements of this circuit are adjusted to have a particular relationship described below, the amplifier has very little or no

resistive loading effect on the signal generator 1. That is, the amplifier draws little or no signal current from the generator. The desired relationship is obtained by proportioning transformer 16 in relation to the characteristics of tube 5 so that over the frequency range where high input resistance is required, the instantaneous signal potential at terminal 14' is substantially the same as the instantaneous signal potential at terminal 2. When this relationship is obtained, little or no signal current flows from generator 1 through resistance 13 because both ends of the resistance have the same instantaneous signal potentials. Since electrostatic generator 1 supplies little or no current in this circuit, there is little or no voltage drop across the internal impedance of the generator; or stated in another way, the effective input impedance of the amplifier has been raised to a very high value.

The cutoff frequency F_c in a circuit consisting of a generator having an internal capacity C , and a load resistance R is given by the expression

$$F_c = \frac{1}{2\pi CR}$$

At frequency F_c the signal voltage across resistance R is 70.7% of the generated voltage. When utilizing the above described circuit, the effective input resistance corresponds to R in the formula and it will be observed that since this resistance may be increased to a very large value, approaching infinity, the cutoff frequency of the circuit may be greatly lowered, approaching zero. Usually leakage across the generator terminals will prevent the attainment of a zero cutoff frequency. Preferably the inductance of the primary of the transformer should be sufficiently high to introduce little or no phase shift or relative attenuation down to the lowest operating frequency. If this condition is not obtained, phase and amplitude correcting networks may be introduced. If a phase shift is present, there will be a difference of potential between opposite ends of resistance 13 even though the voltage drop across the secondary 12 of the transformer is equal to the input voltage applied between terminals 2 and 3. However, if the phase angle is not too large, the said potential difference will be smaller than the voltage that would be applied across resistance 13 if the resistance were connected in conventional manner between grid and cathode and most of the benefits of the invention will still be obtained. In this connection it may be observed that if there is a phase difference, the effective input impedance of the amplifier will have a reactive component as a result.

If the transformer 16 is so proportioned that the signal voltage developed across the secondary 12 is greater than the signal voltage supplied between terminals 2 and 3, the flow of current through resistance 13 will be reversed with respect to the flow obtained when resistance 13 is connected directly in shunt with terminals 2 and 3, or with respect to the flow of current when the voltage drop across the secondary of the transformer is less than the signal voltage applied between terminals 2 and 3. Under this condition the effective input impedance of the amplifier will have a negative value and the amplifier will tend to be unstable unless terminals 2 and 3 are shunted by a positive impedance of suitable magnitude to make the combination positive. This effect may be used to neutralize leakage resistance across the terminals 2 and 3.

If a high input impedance is required at very

low frequencies, it may be impractical to construct a suitable transformer 16. In this case it may be desirable, for example, to obtain neutralizing voltage of suitable output polarity by employing a two-stage resistance-coupled amplifier of the type shown in Fig. 2. In this circuit, electrostatic generator 1 is connected via input terminals 2 and 3 to grid 7 and cathode 6 of vacuum tube 5. A bias resistance 17 is provided in the cathode circuit and it is by-passed by condenser 18. The output of tube 5 is resistance-capacity coupled to the grid and cathode of the second stage of the amplifier in conventional manner. The output of tube 19 is developed across resistance 20 at output terminals 21 and 22. The signal voltage developed between terminals 21 and 22 is, in general, in phase with but larger in magnitude than the input signal voltage applied via the terminals 2 and 3. An adjustable tap 23 is provided on resistance 20 and connected to grid resistance 13. When tap 23 is so adjusted that the voltage drop between it and terminal 22 is substantially the same as the signal voltage applied between terminals 2 and 3, there will be substantially no flow of signal current through resistance 13 because under these conditions both ends of resistance 13 have the same instantaneous signal potentials. Tap 23 may be adjusted to vary the effective input impedance of the amplifier. When it is placed at the lower end of resistance 20, the input resistance of the amplifier is equal to the magnitude of resistance 13. When the tap is raised to a point higher than the above mentioned neutral tapping point, the input resistance becomes negative. If the various coupling and by-passing condensers in the amplifier are not sufficiently large they will introduce some phase shift which will prevent complete cancellation of current through resistance 13 and as a result, the effective input impedance of the system will have a reactive component. However, it is usually possible to maintain suitable phase relations down to lower frequencies than when transformer coupling is employed. For most applications, complete neutralization of signal current is not necessary and the circuit as shown is entirely satisfactory. However, if more complete neutralization is desired at very low frequencies, the amplifier may be changed to the direct coupled type by omitting the coupling and by-passing condensers and introducing suitable biasing batteries. When this is done, no low frequency phase shift or attenuation can occur and substantially complete neutralization of input signal current may be obtained at all low frequencies down to direct current.

In Fig. 3 the invention has been embodied in an inverse feedback type amplifier. In this circuit the electrostatic signal generator 1 is connected via terminals 2 and 3 to grid 7 and to the plate-cathode circuit at the plate side of the plate-cathode impedance. This impedance consists of primary 10 of transformer 16 together with whatever load impedance is connected across output terminals 14 and 15 (or the reflected value of the load if connected across terminals 14', 15'). Thus the full output voltage is fed back in opposition to the applied signal voltage so that only a small signal is effective between grid and cathode. The action of such circuits in reducing the effective, output impedance and in reducing distortion is well known. The bias circuit used in Fig. 3 is, however, unconventional. Battery 11 provides grid bias and is connected between grid and cathode through re-

sistance 13 and transformer secondary 12. It also applies direct current to the generator, as in Fig. 1, and other biasing means may be used. For example, a by-passed resistance in the cathode circuit, as in Fig. 2, would be satisfactory. The transformer 16 may be so designed that the signal voltage appearing across secondary 12 is just equal to and substantially in phase with the signal voltage applied between terminals 2 and 3. There will then be no flow of signal current through resistance 13 because both ends of that resistance have the same instantaneous signal potentials. If the voltage appearing across secondary 12 is greater, the effective input impedance will be negative and if the voltage is slightly less, the input impedance will have a high positive value. A potentiometer could be provided to adjust the amount of secondary voltage introduced in series with resistance 13, thereby to adjust the effective input impedance of the amplifier. If desired, the output of the amplifier may be taken from secondary terminals 14' and 15' rather than from the primary terminals 14, 15. It will be observed that the circuit of Fig. 3 is substantially the same as the circuit of Fig. 1 except that inverse feedback is introduced into the former by connecting terminal 3 to the output circuit at terminal 14 rather than directly to cathode.

In the foregoing circuits the signal current through the input circuit is reduced by introducing into the grid bias circuit an output signal which opposes the flow of signal current, and under some conditions this opposing effect may be made complete so that substantially no signal current flows. In the modifications shown in Figs. 4 to 9 inclusive, although the input signal current is reduced, and the effective input impedance thereby increased, complete neutralization of the input signal current is not achieved. The reduction of signal current is accomplished by introducing an opposing output signal in series with the signal generator and the grid cathode circuit. The grid resistance is so connected in the circuit that the signal voltage which is applied to it is the difference between the generator terminal-voltage and the said opposing signal, with the result that only small signal current flows therethrough.

The modification illustrated in Fig. 4 is similar in some respects to that of Fig. 3 but the grid bias path is connected directly between grid 7 and cathode 6. As pointed out in connection with Fig. 3, the feedback voltage developed across the plate-cathode impedance (the latter comprising primary 10 together with the load connected across the output terminals) opposes the signal voltage applied between terminals 2 and 3 so that only a small part of that signal voltage is developed between cathode 6 and grid 7. In Fig. 4 the grid leak resistance 13 is connected between these points and thus a correspondingly small signal current flows through grid resistance 13, and the effective input impedance is correspondingly increased. It will be observed that in this modification the signal current cannot be reduced to zero since a small signal drop across resistance 13 is necessary to actuate the control grid of the tube. For this reason the input resistance of the amplifier cannot be raised to infinity as in the circuits of Figs. 1 to 3, but yet may easily be increased to a value many times greater than the value of resistance 13. Under some conditions, the feedback voltage may not be quite in phase with the grid cathode sig-

nal voltage due to the action of the inductance of primary 10, and if this is the case, the input impedance of the amplifier will have a reactive component. Output may be obtained from the secondary 12 of the transformer at terminals 14', 15'; or across the primary 10 at terminals 14, 15, in which case the secondary could be omitted.

To further explain the action of the circuit, an expression for the effective input impedance will now be derived, and typical values substituted to better illustrate the advantage of the invention. In the analysis some simplifying assumptions will be made, i. e., that the effects of tube, wiring and other stray capacitances are negligible; that the resistance of inductance 10 is negligible; that a negligible load is connected across the output terminals (for example, the grid circuit of a succeeding amplifier); and that the grid cathode signal is sufficiently small that linear operation of the tube is obtained. The following notations will be used:

- i = signal current supplied to amplifier through terminals 2, 3
 e = signal voltage applied between terminals 2 and 3
 e_L = signal voltage developed across transformer primary 10
 e_g = net signal voltage applied between grid and cathode
 L = inductance of primary 10
 R = resistance of grid leak resistor 13
 u = amplification factor of tube
 R_p = plate resistance of tube
 Z = input impedance of amplifier measured between terminals 2, 3.

From inspection of the circuit, four equations may be written:

$$(1) \quad e_L = \mu e_g \frac{J\omega L}{R_p + J\omega L}$$

$$(2) \quad e_g = e - e_L$$

$$(3) \quad Z = \frac{e}{i}$$

$$(4) \quad i = \frac{e_g}{R}$$

The voltage e_g is found by combining Equations 1 and 2:

$$(5) \quad e_g = \frac{e}{1 + \mu \frac{J\omega L}{R_p + J\omega L}}$$

The current i is found by combining Equations 4 and 5:

$$(6) \quad i = \frac{e_g}{R} = \frac{e}{R \left(1 + \mu \frac{J\omega L}{R_p + J\omega L} \right)}$$

The input impedance is found by combining Equations 3 and 6:

$$(7) \quad Z = \frac{e}{i} = R \left(1 + \mu \frac{\omega^2 L^2}{R_p^2 + \omega^2 L^2} + J \frac{\mu \omega L R_p}{R_p^2 + \omega^2 L^2} \right)$$

It will be seen from Equation 7 that the input impedance Z contains an inductive reactance term. Also it will be noted that the resistance component is a function of frequency, decreasing as the frequency decreases and also decreasing as inductance L decreases, and therefore the circuit is not suitable for use where high input impedance is required at very low frequencies.

The amplifier circuit of Fig. 4 may be used advantageously with a sound-cell microphone

which may consist of a group of cells connected in series with a net internal capacity C of .0001 microfarad. If a cutoff frequency of approximately 48 cycles per second is desired

$$(\omega_c = 2\pi \times 48 = 300)$$

it will be found that an input resistance of

$$R = \frac{1}{C\omega_c} = \frac{1}{300 \times 10^{-10}} = 33.3 \text{ megohms}$$

will be required. In a conventional amplifier the grid leak resistance would thus have to be 33.3 megohms and this most likely would lead to instability. A much smaller grid leak resistance may be used in the circuits of this invention as will now be illustrated in connection with Fig. 4.

Typical values for Fig. 4 are:

$$R_p = 10,000 \text{ ohms}$$

$$u = 20$$

$$20 \quad L = 100 \text{ henries}$$

Substituting these in Equation 7 we find, at 48 cycles ($\omega = 300$):

$$Z = 19R + J6R$$

For a cutoff frequency of 48 cycles, Z (if a pure resistance) must be 33.3 megohms. Thus, neglecting the reactive component $J6R$, we find

$$R = \frac{Z}{19} = \frac{33.3}{19} \text{ megohms} = 1.75 \text{ megohms}$$

Thus with the circuit of Fig. 4, a relatively high impedance microphone may be used with a practical value of grid leak resistance (i. e., only 1.75 megohms) whereas with conventional circuits an excessively high value of grid leak resistance would be required (33.3 megohms). The reactive component of the input impedance (neglected in above example) tends to neutralize the capacitive reactance of the microphone and extend the cutoff to a lower frequency. A similar analysis may be applied to the other circuits of this invention.

In Fig. 5 the circuit of Fig. 4 has been modified by replacing primary 10 of transformer 16 with resistance 24, which may have a value in the order of the resistance that would be used in the plate-cathode circuit of a conventional amplifier using the same type of tube. Additional resistance 25 is connected between cathode and resistance 13 to provide grid bias for the tube. The operation of this circuit is substantially the same as that of Fig. 4 except that it does not have the reactive input impedance or the low frequency limitation imposed by the inductance 10 in Fig. 4 since no inductances are involved in the plate-cathode circuit. The direct current voltage-drop across the resistance 24 is applied to the terminals of the signal generating device 1. This circuit is especially advantageous when used with signal generators of the condenser microphone type since the last-mentioned direct-current potential may be utilized to polarize the generator. Thus this circuit eliminates the additional resistance and blocking condensers normally used in the polarizing circuit of such devices, and provides an unusually high input impedance. Since the capacity of condenser microphones is usually very low, this high input impedance is especially desirable as it has been difficult in the past to obtain sufficiently low frequency cutoffs in conventional amplifier circuits for the reasons explained above. Although this invention is concerned primarily with the reduction of the loading effect of the grid leak resistance of the amplifier, it

should be noted that in the circuits of Figs. 4 to 9 inclusive, the loading effect of the grid-cathode capacitance (and any shunting capacitance) is reduced in a similar manner. This may be of importance when low capacity generators such as condenser microphones are used. If a conventional polarizing circuit is used, all or a part of its resistance may be arranged in shunt with the grid circuit resistance 13 over the operating frequency range so that the signal current through it will also be reduced in the same manner that signal current through the grid resistance is reduced.

When a piezoelectric signal generator is substituted for the condenser type of generator, the polarizing voltage applied to terminals 2 and 3 in Fig. 5 is undesirable since piezoelectric devices may be damaged by the application of direct-current voltages, or the operation may otherwise be impaired by the resulting mechanical bias.

Fig. 6 shows a modification of the circuit which eliminates the direct-current voltage between terminals 2 and 3. In this circuit, terminal 3 is connected to battery 9 at a tap 26 thereon which has the same direct-current potential as terminal 2. The signal current impedance of battery 9 is relatively low so that for signal currents the terminal 3 is effectively connected to the plate side of resistance 24. Accordingly, the operation of the amplifier is the same as that of the amplifier of Fig. 5. In Fig. 6, grid bias for the tube is obtained from battery 11. It will be understood that other suitable bias means could be used, as for example, a cathode-circuit resistance as in Fig. 5.

Fig. 7 shows another modification of the circuit which avoids direct-current bias on the generator. Its operation at signal frequencies is substantially the same as that of Figs. 4, 5 and 6. The direct-current voltage drop across resistance 27 is prevented from affecting generator 1, which may be any suitable electrostatic generating device, by introducing between terminal 3 and the plate side of resistance 27, the condenser 28 having low impedance to signal currents. To prevent leakage across condenser 28 from applying some direct-current voltage between terminals 2 and 3, resistance 29 is connected between terminal 3 and the cathode in shunt with resistance 27. The resistance 29 should be large compared with the reactance of condenser 28 over the useful frequency range, and preferably of the same order of magnitude as resistance 27. The leakage resistance of condenser 28 should, of course, be high compared with resistance 29. It will be seen that as far as direct current is concerned, terminals 2 and 3 are substantially at the same potential, while for signal frequencies, the terminal 3 is effectively connected to the plate side of the plate-cathode impedance as in Figs. 4, 5 and 6. Also at signal frequencies, resistances 27 and 29 are connected effectively in parallel. If one of these resistances is much smaller than the other, then the smaller one determines the signal voltage drop in the plate-cathode circuit. If the two resistances are nearly equal in magnitude, then the parallel combination must be used in calculating the signal voltage drop. If desired, the lower end of grid leak resistance 13 may be connected to an adjustable contact arranged to slide along resistance 29 to vary the effective input impedance of the circuit.

In Fig. 8 the terminals 2, 3 are held at the

same direct-current potential by employing a push-pull circuit. The resistances of the plate-cathode circuits of the two tubes 5 and 5' (consisting of resistances 24, 25 and 30, and 24', 25' and 30', respectively), are equal and the tubes 5 and 5' have similar characteristics so that their plate currents are equal. For this reason there is no direct-current difference of potential between the cathode ends of grid resistances 13 and 13' and therefore no direct-current difference of potential between terminals 2 and 3. Bias for the tubes is provided by the voltage drop across the plate-circuit resistances 25 and 25'. The plate-circuit signal voltage developed across resistances 24, 24' opposes the signal voltage applied to terminals 2 and 3 to reduce the signal current through grid resistances 13 and 13'. For this reason it will be understood that the circuit offers a high impedance at terminals 2 and 3 in the same or similar manner as a high impedance is offered by the circuits of the foregoing figures. The output from this circuit may be taken between terminals 31, 31', or if a low output impedance is desired as in the case of the circuits of Figs. 3 to 7 inclusive, the output may be taken between terminals 15 and 15a. In the latter case the resistances 30, 30' may be reduced or omitted, thus increasing the opposing signal voltage drops across resistances 24, 24'.

Fig. 9 shows another modification which is directed at removing direct-current potential from the signal generator. In this circuit the potential is not entirely omitted but is reduced to a value which is harmless in most applications. This is accomplished by introducing into the input circuit a signal voltage drop as in some of the preceding circuits, but the feed-back resistance is much smaller so that the plate current through it causes only a small direct-current voltage drop. In order to provide a sufficient signal voltage drop across this resistance to obtain the desired increase in the effective impedance between terminals 2 and 3, an additional amplifier stage, designated generally by the character 33, is provided. The input signal for this stage is obtained from the signal current drop across a resistance 34 in the plate circuit of first tube 5. The output is taken from the secondary of transformer 35 whose primary is connected in the plate circuit of the amplifier stage 33. A resistance 36 is connected between the plate of stage 33 and cathode 6 of tube 5 through a blocking condenser 37 so that a part of the amplified signal current produced by stage 33 is passed through resistance 32, thus increasing the signal voltage drop sufficiently to provide the required input impedance magnification. The output of the circuit may be taken at terminals 38 and 39, or alternatively at terminals 14 and 15.

The foregoing illustrations of the invention represent only a few of the many circuits which may be designed around the basic principles which have now been disclosed. They should therefore be regarded in an exemplary rather than a limiting sense. Furthermore, the circuits themselves may be modified in their minor details without departing from the invention. For example, batteries and cathode-circuit resistances may be used interchangeably to obtain the proper grid bias relative to the cathode. While triode tubes have been illustrated, other types such as pentode or screen-grid tubes may of course be substituted. Furthermore, transformers may usually be used in place of potentiometers in the output circuit in order to obtain the proper neu-

tralizing potentials if due regard is given to the inherent low frequency limitations of transformers. Those skilled in the art will appreciate, however, that when substitutions of the character here mentioned are made, it may be necessary to make slight alterations or readjustments in other elements of the circuit. If a two-stage amplifier, such for example as shown in Fig. 2, were being used with satisfaction and it were desired to replace the amplifier with one having three stages, those skilled in the art will realize that the output of the three-stage amplifier will be approximately 180° out of phase with the generator signal so that it is necessary to use a transformer, or other phase reversing means, to obtain the proper polarity. In making these substitutions, however, new elements have been added and they may introduce additional phase-shifts. If this were the case and if complete neutralization were desired, suitable phase-correcting means should be coupled to the circuit to compensate for the shifting introduced by the transformer, and/or additional stage of amplification.

The cathode heating circuits which are necessary to secure operation of the vacuum tubes have not been shown in the drawings for the reason that such circuits and their requirements are fully understood by those skilled in the art and need no explanation. Batteries have been shown in the plate circuit to illustrate a suitable source of plate current, and it will be understood that rectifiers, motor-generator units, and the like could be substituted for the batteries when due regard is given to the individual characteristics of the various devices.

The circuits of the invention have been shown to have a pair of output terminals which are not connected to other apparatus. It is pointed out, however, that in general use, the amplifier would be connected to other equipment, such as meters, additional amplifier units, loudspeakers, or motivated apparatus of many kinds. In making such connections, regard should be had to the fact that in some circuits, there may be direct-current potentials as well as alternating signal potentials at the output terminals. When such direct-current potentials should not be applied to the input of the succeeding apparatus, a blocking condenser should be inserted, or the voltage may be confined to its own amplifier in other ways. Due regard should be given to the input impedance of the succeeding apparatus when designing the circuit.

It has already been pointed out above that many of the circuits shown in the drawings do not apply direct-current potentials to the signal generator, or apply only small biasing potentials. Thus, the circuits of Figs. 2, 6, 7 and 8 do not apply direct-current to the generator, while the circuits of Figs. 1, 3, 4 and 9 apply small direct-current voltages. The circuit of Fig. 5 applies a rather large voltage, however. This feature of the circuits should be carried in mind when selecting a circuit for use with a particular kind of signal generator. Thus, the condenser microphone requires a polarizing direct-current potential, so that the circuit of Fig. 5 is well adapted for use with it. On the contrary, piezoelectric devices should not be subjected to biasing potentials; accordingly, the circuits of Figs. 1, 2, 3, 4, 6, 7, 8 and 9 are especially useful in combination with them. In Figs. 1, 3 and 4, the small direct-current potential applied to terminals 2, 3 by bias battery 11 could, if desired, be avoided by adopt-

ing a different biasing arrangement as will be understood by those skilled in the art.

In view of the many modifications which may be made of the circuits here illustrated, it is apparent that the scope of the invention should not be determined from the specific examples which have been relied upon to explain the invention, but should instead be determined from the following claims. In the preceding specification and following claims, the term "amplifier" is used to mean an amplifier device whose output is controlled by the input through the valve action of an electron discharge device.

Having now disclosed the invention, what I claim is:

1. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier which has an input circuit connected to said generator, and is capable of developing an output signal voltage at a pair of output terminals, said input circuit tending to load said generator by drawing signal current from the latter; and means for utilizing at least a part of the output signal voltage to reduce the flow of signal current in the input circuit, and thereby to reduce the loading effect of the input circuit.

2. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier which has an input circuit connected to said generator, and is capable of developing an output signal voltage at a pair of output terminals, said amplifier including a tube having a grid and cathode, and a bias circuit adapted to bias said grid with respect to the cathode, said bias circuit tending to load the generator by drawing signal current from the latter; and means for utilizing at least a part of the output signal voltage to reduce the flow of signal current in the bias circuit.

3. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier having a pair of input terminals connected to said generator, and an output circuit connected to a pair of output terminals, said amplifier being adapted to develop an output signal voltage at its output terminals, and including a tube having a cathode and a grid, circuit means connecting said grid to one input terminal, and a bias circuit adapted to bias said grid with respect to the cathode, and extending between said grid and a point on the output circuit so located on the latter that the signal potential difference between it and grid is less than the signal potential difference between the input terminals.

4. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier having a pair of input terminals connected to said generator, a tube having a grid and cathode, an output circuit in which is developed an output signal corresponding to the input signal, a grid-to-cathode leakage path in shunt with said input terminals for biasing said grid relative to said cathode, and an input circuit for applying between said grid and cathode at least a part of the signal voltage applied at said input terminals, and means in said leakage path for utilizing at least a part of said amplified output signal to reduce the flow of generator signal current in the leakage path.

5. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier having a pair of input terminals connected to said generator, a tube having a grid and cathode, an output circuit in which is de-

veloped an output signal corresponding to the input signal, a biasing circuit between grid and cathode for biasing said grid relative to said cathode, and an input circuit for applying between said grid and cathode at least a part of the signal voltage applied at said input terminals, and means in said input circuit for utilizing at least a part of said amplified output signal to reduce the flow of signal current in said input circuit.

6. In combination: an electrostatic signal generator adapted to supply a signal voltage; an amplifier having a pair of input terminals connected to said generator, and an output circuit connected to a pair of output terminals, said amplifier being adapted to develop a signal voltage at its output terminals, and including a tube having a grid connected to one input terminal and a cathode connected to the other input terminal, and a bias circuit adapted to bias said grid with respect to the cathode, said bias circuit extending between said grid and a point on the output circuit so located on the latter that the signal potential difference between it and grid is less than the signal potential difference between the input terminals.

7. In combination: an electrostatic generating device which provides a signal voltage; an amplifier comprising a tube which includes at least a grid, a cathode and a plate; a direct current source of plate current and an impedance connected in series with the latter between said plate and cathode; and means for maintaining the grid negative with respect to the cathode, said means including a high resistance direct current path connecting the grid to the plate-cathode circuit at a point on the latter lying between the cathode and the impedance; and means for applying at least a part of the said generator signal voltage between the grid and the plate-cathode circuit at a point on the latter lying between the plate and said impedance.

8. In combination: an electrostatic generating device adapted to provide a signal voltage between a pair of terminals; an amplifier comprising: a tube which includes a grid, a cathode and a plate; a direct current source of plate current and an impedance connected in series with the latter between said plate and cathode; means for

maintaining the grid negative with respect to the cathode, said means including a high resistance direct current path connecting said grid to the plate-cathode circuit at a point on the latter lying between the cathode and said impedance; and means for maintaining the terminals of the generating device at substantially the same direct current potential while applying at least a part of the said generator signal voltage between the grid and a point on the plate-cathode circuit which lies between the plate and said impedance.

9. In combination: an electrostatic generating device adapted to provide a signal voltage; an amplifier comprising: a vacuum tube which includes a grid, a cathode and a plate, a direct current source of plate current and an inductance connected in series therewith between said plate and cathode, and means for maintaining the grid negative with respect to the cathode, said means including a high resistance direct current path connecting said grid to the plate-cathode circuit at a point on the latter lying between the cathode and said inductance; and means for applying at least a part of the signal voltage of the generator between the grid and a point on the plate-cathode circuit which lies between said plate and said inductance.

10. In combination: an electrostatic generating device which provides a signal voltage; an amplifier comprising: a vacuum tube which includes at least a grid, a cathode and a plate, a battery, a plate resistance connected in series with the battery between said plate and cathode, and means for maintaining the grid negative with respect to the cathode, said latter means including a high resistance direct current path connecting the grid to the plate-cathode circuit at a point on the latter lying between the cathode and said plate resistance; and means for applying at least a part of the said signal voltage of the generator between the grid and the plate-cathode circuit at a point on the latter lying between the plate and said plate resistance.

11. The combination as claimed in claim 10 wherein said generating device is a condenser microphone.

12. The combination as claimed in claim 10 wherein said amplifier is of the push-pull type.

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