March 7, 1939. A. D. BLUMLEIN 2,149,331

ELECTRIC CIRCUITS FOR REDUCING THE EFFECT OF SHUNT CAPACITY OR REACTANCE INTRODUCED BY CIRCUIT ELEMENTS

Filed July 8, 1936 3 Sheets-Sheet 1

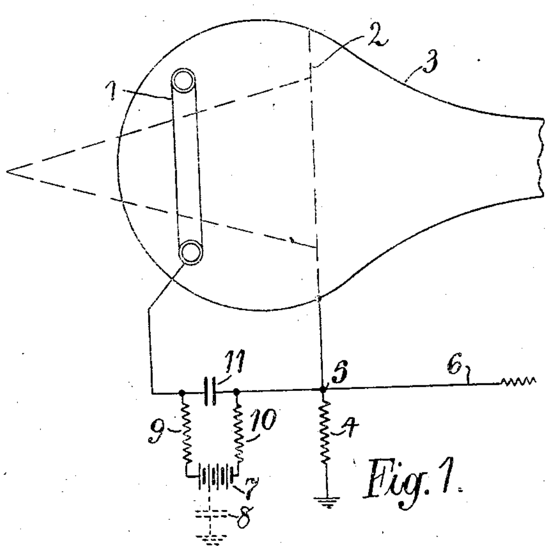

Fig. 1.

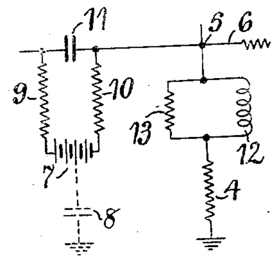

Fig. 2.

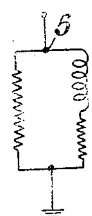

Fig. 3.

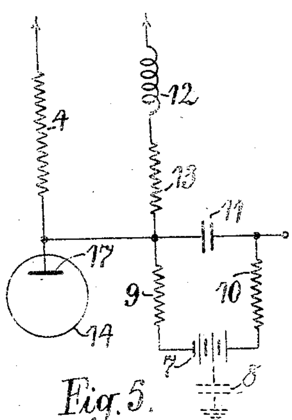

Fig. 5.

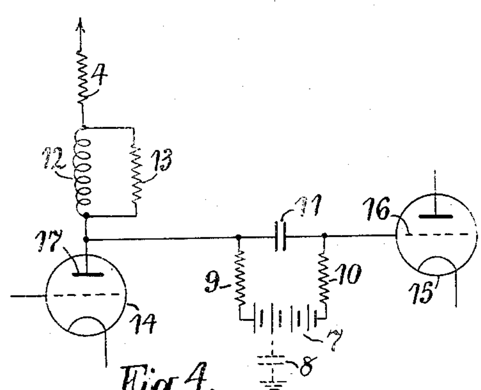

Fig. 4.

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ELECTRIC CIRCUITS FOR REDUCING THE EFFECT OF SHUNT CAPACITY OR REACTANCE INTRODUCED BY CIRCUIT ELEMENTS

Filed July 8, 1936 3 Sheets-Sheet 2

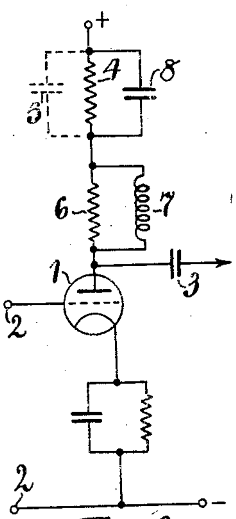

Fig. 6.

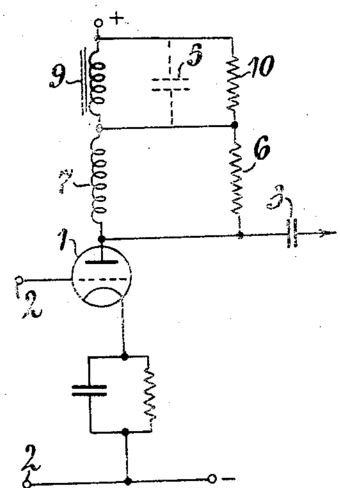

Fig. 7.

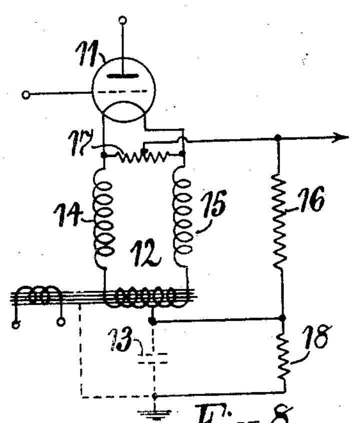

Fig. 8.

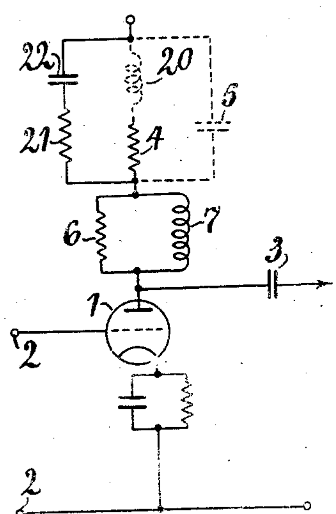

Fig. 9.

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ELECTRIC CIRCUITS FOR REDUCING THE EFFECT OF SHUNT CAPACITY OR REACTANCE INTRODUCED BY CIRCUIT ELEMENTS

Filed July 8, 1936 3 Sheets-Sheet 3

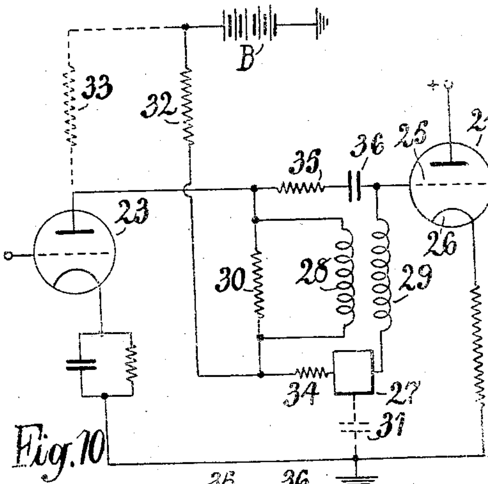

Fig. 10

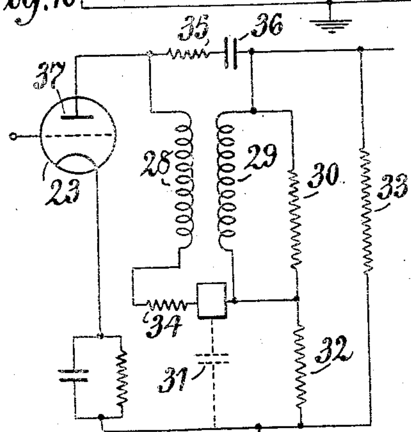

Fig. 11

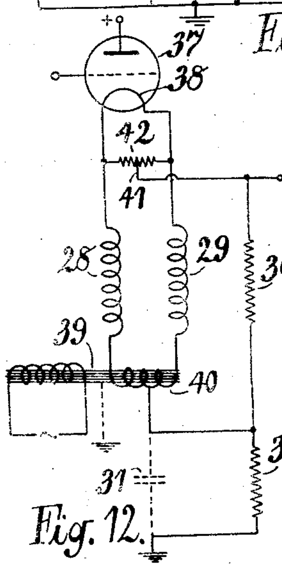

Fig. 12

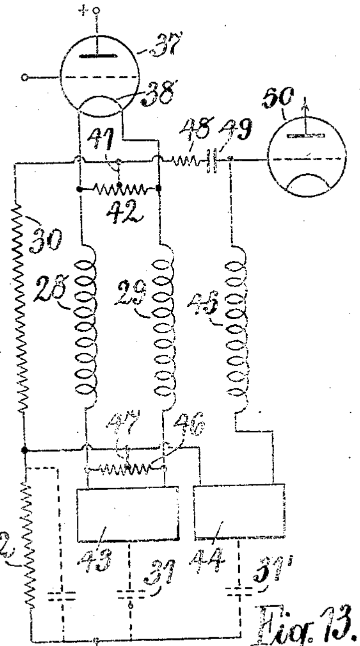

Fig. 13.

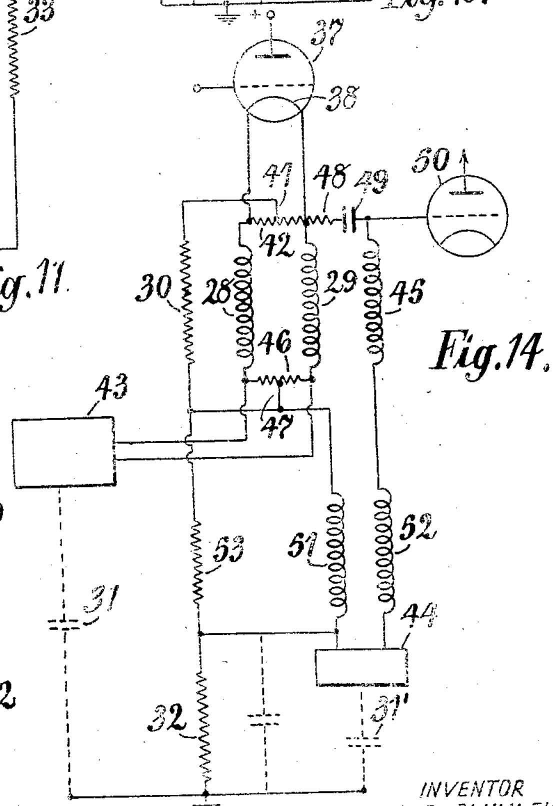

Fig. 14.

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Patented Mar. 7, 1939

2,149,331

UNITED STATES PATENT OFFICE

2,149,331

ELECTRIC CIRCUITS FOR REDUCING THE EFFECT OF SHUNT CAPACITY OR REACTANCE INTRODUCED BY CIRCUIT ELEMENTS

Alan Dower Blumlein, Ealing, England, assignor to Electric & Musical Industries Limited, a British company

Application July 8, 1936, Serial No. 89,676
In Great Britain July 8, 1935

7 Claims. (Cl. 178—44)

This invention relates to electric circuit arrangements and is particularly concerned with the provision of means for reducing the effect of unwanted capacity or reactance, introduced by circuit elements, such as, for example, electric batteries, the inherent capacity and inductance of electric resistances and the inherent capacity of inductance coils. The invention relates more particularly, but not exclusively to circuit arrangements which are required to handle electric signals covering a wide range of frequency.

The effects of stray capacity are observed, for example, in many resistance-coupled circuits, such as amplifiers for handling television and like signals; thus if a D. C. coupling is effected between two valves by connecting a battery between the anode of one valve and the control grid of the other, the stray capacity of the battery to earth or chassis may result in a relative attenuation of the higher frequencies of the signals to be amplified. Similarly, when a thermionic valve has a load impedance arranged in its cathode circuit, the stray capacity of the cathode-heating battery, or other source, to the chassis may introduce a similar relative attenuation of the higher frequencies. Furthermore, the stray capacities may produce other harmful effects, such as undesired phase shifts.

It has already been proposed, in order to avoid the effects of the capacity to earth of a coupling battery, to connect the poles of the battery to the two points to be coupled, respectively, through resistances, the ends of these resistances remote from the battery being connected together through a condenser. Such an arrangement is, however, of restricted application, since in practice there is often a limit to the maximum value which the resistances can have, and hence to the amount of reduction of effective stray capacity which they provide; thus, for example, it may happen in a D. C. amplifier that grid current flows during operation at peak signal amplitudes, and if the resistances are too large, there may be serious amplitude distortion. Also in practice, if the resistances used to hold off the capacity are made very large, undesirable operating characteristics are obtained. For example, a thermionic valve may ordinarily have a leakage between anode and grid of many megohms, but an occasional valve may have an insulation resistance of only a few megohms. If resistances of the order of megohms or even a tenth of a megohm are employed, then such a valve may pass sufficient current through these resistances to cause a serious alteration of grid bias.

The reduction of the effects of stray capacity which can conveniently be effected by the known arrangement may, therefore, be inadequate in many cases, and it is one of the objects of the invention to provide improved means for substantially eliminating the effects of the unwanted capacity in electric circuit arrangements resulting from the use of circuit elements, such as coupling batteries or polarizing batteries, without introducing the disadvantages referred to above.

The effects of stray capacity, for example, are also observed in resistance-coupled circuits such as amplifiers, in which a thermionic valve has in its anode circuit a resistance which constitutes its load: if the valve is one which is required to dissipate considerable power, the load resistance must be of a robust construction so as to be capable of passing substantial current without overheating, and its self-capacity may be so high that relative attenuation of the higher frequencies of the signals to be amplified takes place. A similar effect may be present when the anode circuit load is constituted by a choke coil, the stray capacity of the coil serving as a relatively low impedance shunt at the higher frequencies. The inherent inductance of a load resistance in a thermionic valve amplifier may give rise to undesirable resonances with the stray shunt capacity, or, if the latter has been substantially eliminated by a method such as that of this invention, may produce a relative accentuation of the higher frequencies. Furthermore, such stray reactances may produce other harmful effects, such as undesired phase shifts.

It is a further object of the present invention to provide novel or improved means for reducing the effects of unwanted reactance introduced in electric circuit arrangements by circuit elements such, for example, as resistances and inductance coils. With the previously proposed arrangement, since the resistances are often required to be of high value and to pass substantial current, there then is a large dissipation of power and loss of potential in the resistances, and consequently the known arrangement for such purposes is again impracticable.

A further object of the invention is, therefore, to provide means for reducing the effects of unwanted capacity introduced in the electric circuit arrangements by circuit elements such as electric batteries and the like which, in practice, are required to deliver power.

One feature of the invention consists in a circuit arrangement which includes an element (or elements) which introduces undesired stray capacity or reactance and in which for the purpose of substantially eliminating the effect of the stray capacity or reactance, building-out means are provided which, together with said element (or elements) cause the circuit, as a result of a combination of inductance and resistance, to simulate substantially a pure constant resistance.

Another feature of the invention consists in a circuit arrangement comprising a circuit element which, in operation, is required to carry relatively large currents, wherein, for the purpose of reducing the effects of the inherent shunt capacity of said element, there are provided in series with said element with respect to a source of power, building-out means comprising a resistance and an inductance coil in shunt with one another, said resistance being one rated to carry less current than that carried, in operation, by said element, and wherein said building-out means are so constituted and arranged that, together with said circuit element, they simulate substantially a pure resistance.

The invention further provides a circuit arrangement comprising a circuit element which is required to have negligible inductance and which, in operation is required to carry relatively large currents, wherein for the purpose of reducing the effects of the inherent inductance effectively in series with said element, there are provided in shunt with said element with respect to a source of power, building-out means comprising a resistance and a condenser in series with one another, said resistance being one rated to carry less current than that carried, in operation, in said element, and wherein said building-out means are so constituted and arranged that, together with said circuit element, they simulate substantially a pure resistance shunted by the self-capacity of said element.

The circuit element may be a resistance, in which case the resistance selected to form part of the building-out means is one having a relatively small power-dissipation rating; the power-dissipation rating of a resistance decreases as its power to carry current without overheating decreases. In this way, the inherent capacity and inductance of the building-out resistance can be made negligibly small compared to that of the resistance constituting the circuit element.

A further feature consists in a circuit arrangement comprising a circuit element which has stray capacity to earth, said element being connected between two points in said circuit between which, in operation, a potential difference is required to be established, wherein between each of said points and said element respectively there is provided a resistance of a magnitude such that the effects of said stray capacity are to some extent reduced, and wherein a path which permits the passage of alternating current is provided between the ends of said resistances remote from said circuit element, characterized in that, for the purpose of substantially eliminating effects of said stray capacity, the circuit is provided with building-out means such that the circuit simulates substantially a pure constant resistance.

A still further feature of the invention consists in a circuit arrangement comprising a circuit element which is associated in series with a first conductor and has stray capacity to a second conductor, wherein, in order to reduce or eliminate the effect of said stray capacity, an inductance-coil is provided between each of the terminals of said circuit element and the points of connection of said element to said first conductor, the two coils being coupled to one another by mutual inductance and wherein there are provided damping means for substantially reducing or eliminating the effects of resonances within a predetermined working range due to said coils and the said stray capacity.

The first conductor referred to in the preceding paragraph may, for example, be the lead between the anode of a thermionic valve and the control grid of a further valve, or it may be the filament of a valve. The second conductor may, for example, be the chassis of an amplifier, or any other part of the circuit arrangement the potential of which does not vary substantially in operation; the second conductor may be connected to earth.

The circuit element referred to in the last mentioned feature may be one which is required, in operation, to deliver power; in this case, the arrangement according to the invention provides the advantage that the inductance coils which are employed to "hold off" the stray capacity of the circuit element may be arranged to cause only a relatively small drop of potential.

The damping means may comprise a resistance arranged in shunt with one of the coils or with the stray capacity, or two resistances arranged in shunt with one or both of the coils and with the stray capacity respectively; where two resistances are employed, the arrangement may be made such that these resistances form with the coils and the stray capacity a composite circuit which simulates substantially a pure resistance. This composite circuit may form the whole or a part of the load impedance of a thermionic valve.

A coupling condenser may be connected between the ends of the coils remote from the circuit element the coupling condenser tending to by-pass the coils and the circuit element for currents at frequencies in the upper part of the working range. Means may be provided for reducing or eliminating the effects of resonances between the coils and the coupling condenser.

For the purposes of this specification, the term "earth" is to be accorded the meaning usually attributed to it in the radio and allied arts; thus the expression "having stray capacity to earth" covers not only cases in which the circuit element has stray capacity to physical earth, but also cases in which the circuit arrangement is isolated from earth and is built up on a chassis or like structure to which the circuit element has considerable capacity.

Various embodiments of the invention will be described, by way of example, with reference to the accompanying drawings in which:—

Fig. 1 illustrates a typical circuit to which the invention may be applied.

Figs. 2 and 3 illustrate the application of the invention to the substantial elimination of the effects of the stray capacity of a battery serving to bias the anode of a cathode ray tube of the transmitting type as shown in Fig. 1.

Figs. 4 and 5 show diagrammatically D. C. amplifiers according to the invention.

Fig. 6 illustrates the application of the invention to reducing the effects of the self-capacity of the anode load resistance of a thermionic valve.

Fig. 7 shows a modification of the arrangement of Fig. 6 in which the anode load comprises a choke coil.

Fig. 8 illustrates a further embodiment of the invention, as applied to the reduction of the self-capacity of a resistance.

Fig. 9 illustrates the application of the invention to the reduction of the inherent series inductance of a resistance.

Fig. 10 shows a part of a D. C. coupled amplifier according to the invention.

Fig. 11 illustrates the application of the invention to a modulator which is required to work over a wide range of frequency down to zero frequency.

Fig. 12 shows a circuit arrangement according to the invention in which means are provided for reducing the effects of stray capacity due to a source of cathode heating current.

Fig. 13 shows a modification of the arrangement of Fig. 12 in which provision is made for the supply of bias potential to the control electrode of a subsequent valve, and Fig. 14 shows a modification of the arrangement of Fig. 13.

Referring to Fig. 1, the battery 7 serves for maintaining the potential of a collecting electrode 1 positive with respect to the signal plate 2 of a cathode ray transmitting tube 3 of the so-called double sided mosaic type. The signal plate 2 carries a large number of conducting mosaic elements insulated therefrom, and from one another, each element having an exposed conducting surface on each side of the plate 2. The exposed surfaces if the elements on the left of the plate 2 are rendered photo-electrically active, an image of the object to be transmitted is cast upon the photo-electric mosaic surface thus formed and photoelectrons emitted by the mosaic surface are collected by the electrode 1 which, for this purpose, is maintained at a suitable positive potential with respect to the signal plate 2. The surfaces of the mosaic elements on the right of the signal plate are scanned by an electron beam from an electron gun (not shown). The elements are thereby consecutively caused to return to a datum potential and currents representative of the light and shade of the image to be transmitted are set up in a load resistance 4 which is connected between the signal plate 2 and earth. Potential differences are thus set up between the point 5 and earth and may be fed by means of lead 6 to the input of an amplifier.

It is desired to apply a difference of potential between electrode 1 and the signal plate 2; if battery 7 were directly connected between electrode 1 and point 5, its capacity to earth (indicated by the dotted condenser 8) would appear as a shunt capacity across the load resistance 4. This shunt capacity would reduce the effective impedance of load 4 at high frequencies and would therefore attenuate the output of the tube at these frequencies.

The battery 7 is accordingly connected between electrode 1 and point 5 through two series resistances 9, 10 of high value, a by-pass condenser 11 of a capacity which is large compared with the capacity 8 being connected between point 5 and electrode 1. The effective shunt impedance across load resistance 4 is then the resultant of capacity 8 in series with the two resistances 9, 10 in parallel. By making resistances 9, 10 of sufficiently high value, for example one or two megohms each it is sometimes possible to arrange that this effective shunt impedance has a negligible effect on the frequency characteristic of the tube 3 and its associated circuits over the range of frequencies to be handled.

In some cases, however, the shunt impedance may still cause an undesirable amount of attenuation of the highest frequencies, and it may be inconvenient to compensate for this by increasing resistances 9 and 10, for the following reason; the return path for the photo-electric current between signal plate 2 and electrode 1 is through the circuit 9, 7, 10, and the higher resistances 9 and 10 are made, the larger is the voltage drop across them; to compensate for this, the voltage of battery 7 must be increased, and an increase in the magnitude of stray capacity 8 may result.

In general, it is bad practice to employ grid leaks or feed resistances for photoanodes and the like, which are very high, since any leakage effects are liable to alter the operating potential. For example, with the arrangement shown in Fig. 1, if the resistances 9, 10, are made unduly large, for example, one or two megohms as stated above, any leakage in the tube may alter the voltage applied to the anode 1, and furthermore, the photo-currents will produce unnecessary fluctuations in the voltage on the electrodes. Therefore, the degree by which the effects of the shunt capacity 8 are reduced by the use of resistances such as 9 and 10, is limited.

According to the invention, therefore, the residual shunt impedance is built out so that the whole circuit, including the shunt impedance, behaves as a pure constant resistance equal to R, where R is the magnitude of load resistance 4. If each of the resistances 9, 10 has a magnitude $2r$ and if the capacity 8 has a value C, then the effective shunt impedance is the resultant of a resistance r in series with a capacity C.

Now if an inductance coil 12 shunted by a resistance 13 is inserted in series with load resistance 4, as shown in Fig. 2 (which illustrates a part of the circuit of Fig. 1) it is possible to correct the effective impedance of the load for the effect of capacity C. The shunt resistance r may be considered as made up of two parts, one equal to R, and the other equal to $(r—R)$. The required inductance for coil 12 is then the inverse of C and $(r—R)$ about the resistance R. In Fig. 2, the inductance coil 12 has a magnitude L, and is shunted by a resistance 13 of magnitude r', load resistance 4 having the magnitude R as before; r' is made equal to

$$\frac{R^2}{r—R}$$

and L is made equal to CR^2. In this example, the impedance between the point 5 in the part of the circuit shown in Fig. 2 and earth is a pure resistance equal to R.

The load circuit 4, 12, 13 of Fig. 2 may be replaced by an equivalent circuit such as that shown in Fig. 3 without departing from the spirit of the invention; the arrangement of Fig. 3 can be made an exact equivalent of that of Fig. 2. In this case the value of the inductance will have the value r, and the value of the other resistance will be

$$\frac{Rr}{R—r}$$

Fig. 4 shows a circuit similar to that of Fig. 2, but used to provide a direct coupling between two valves 14, 15, of a direct-coupled amplifier. In Fig. 4, the battery 7 (which may, if desired, be replaced by any other suitable source of potential, such as a rectifier), serves to maintain the potential of the grid 16 of valve 15 at a suitable value with respect to the anode 17 of valve 14, and resistances 9, 10 are provided to "hold off" the stray capacity, represented by condenser 8, of the battery to earth; the anode resistance 4 of valve 14 has in series with it an inductance coil 12 and resistance 13 in parallel, these ele-

[redacted]

circuit is required to have above the predetermined frequency referred to. The effects of the stray capacity **5** (the magnitude of which will be referred to as C) are then reduced by shunting coil **9** by a resistance **10** of magnitude R, and connecting in series with the coil **9** between the anode of valve **1** and the positive terminal of the anode current source (not shown) a further resistance **6** of magnitude R shunted by an inductance coil **7** of magnitude L given by $L=CR^2$. Since, above the predetermined frequency, the impedance of coil **9** is large compared with the resistance R, the arrangement is then such that, above this predetermined frequency, which can be relatively low, the anode circuit impedance is substantially constant and equal to R.

The resistance **6** and the coil **7** are arranged to have self-capacities which are small compared with that of coil **9**; the self-capacity of resistance **10** may be regarded as forming a part of condenser **5**. As in the arrangement of Fig. 6, the magnitude of resistances **6** and **10** may be modified slightly to take into account the losses of coils **7** and **9** respectively, while resistance **10** may be reduced slightly in value to take account of the series resistance of coil **7**. Coil **7** may be air-cored, or may have a core of comminuted magnetic material.

In Fig. 8 the valve **11** operates with a cathode impedance and its filament is fed with alternating current from the secondary winding **12** of a transformer, the iron core of which is at earth potential. The stray capacity **13** of the secondary winding **12** to the core, and thus to earth or chassis, is "held off" (or prevented from having an undesirable effect) in the manner described by means of the coupled choke coils **14** and **15**; a resistance **16** is connected between the centre point of a relatively small resistance **17** shunted across the cathode and the centre point of secondary winding **12**, and a further resistance **18** is connected from this point to earth. The parallel-aiding inductance, L, of the coils **14**, **15** is made equal to CR^2, where C is the magnitude of stray-capacity **13**, and R is the value of each of resistances **16** and **18**, and the arrangement is then such that the effective impedance between the cathode of valve **11** and earth is substantially a pure resistance of magnitude R.

Now the resistance **18** has to carry the direct and low-frequency currents passing through the valve **11**, and it is accordingly necessary in practice to employ here a resistance having substantial stray capacity. For purposes of design, however, this stray capacity is treated as forming part of capacity **13**, and if the stray capacities of coils **14**, **15** and of resistance **16** are made relatively small, and if the parallel-aiding inductance of the coils **14**, **15** has the value postulated, the effects of the stray capacity of resistance **18** as well as of the stray capacity of winding **12** to earth or other earthed conductors, are eliminated or much reduced. It will be noted that resistance **16** has only to carry high frequency current, and can therefore be made of low current-carrying capacity.

In Fig. 9 in which parts which are common to Fig. 6 have the same references, the anode load resistance **4** of valve **1** has an inherent series inductance, shown dotted at **20**, of magnitude L_1, as well as self-capacity shown dotted at **5**. To reduce the tendency of the effective anode load to increase with increase of frequency, resistance **4** is shunted by a resistance **21** in series with a condenser **22** of magnitude C_1. Resistances **4** and **21** are given the same magnitude, R, and it is arranged that C_1 is such that the relationship

$$\frac{L_1}{C_1}=R^2$$

is substantially satisfied. Then, if resistances **4** and **21** have no substantial effective shunt capacity, and if resistance **21** and condenser **22** are substantially non-inductive, the elements **4**, **20**, **21** and **22** are effectively a constant resistance equal to R. The capacity **5** shunting this resistance is then compensated by the elements **6** and **7** in the manner of Fig. 1, the anode circuit load of valve **1** is effectively a pure resistance equal to R.

The self-capacity of resistance **4**, which is indicated by **5**, can be built out as shown in the manner described with reference to Fig. 6.

Referring now to Fig. 10, the arrangement shown illustrates a D. C. coupling circuit according to the invention arranged between two amplifying valves **23** and **24**, the cathodes of which are at earth potential. The two valves are coupled by a floating battery **27**, or other suitable source of potential, the battery **27** having a capacity to earth which is shown in dotted lines at **31**. According to the invention, in order to reduce the effects of the capacity **31**, the poles of battery **27** are connected into the lead joining the anode of valve **23** and the control grid of valve **24** (this lead constituting the first conductor referred to above) through chokes **28** and **29** which are coupled to one another by mutual inductance; the resistance **34** represents the resistance of battery **27** and the inherent resistances of chokes **28** and **29**, together with any resistance which may be added in order, as explained more fully below, to give resistance **34** a convenient value. The ends of chokes **28** and **29** remote from battery **27** are connected together through a coupling condenser **36**; for the moment, it will be assumed that resistance **35** is omitted. The junction of battery **27** and choke **28** is connected through a resistance **32** to the positive terminal of a source B of anode current, the negative terminal of which is earthed.

The chokes **28**, **29** are preferably wound side by side on the same form so as to constitute, in effect, one bifilar choke, and so that there is a tight coupling between them; a tight coupling may also be achieved in other ways, for example by winding the two chokes on a common core of magnetic material. The chokes **28**, **29** serve effectively to isolate the battery **27** from the remainder of the circuit at the higher frequencies to be handled, so that attenuation of the higher frequencies due to the stray capacity **31** is reduced. It will be noted that, in operation, there is a difference of potential between the ends of chokes **28**, **29** remote from the battery at all frequencies within the range to be amplified, and if grid current flows in valve **24**, power is supplied by the battery **27**.

The arrangement as so far described has the disadvantage that, as the circuit is required to handle very high frequencies, it may be found that resonances between the chokes and the stray capacities of the circuit may occur within the working frequency range, and the amplifier will then not have a rectilinear characteristic. According to the present invention, therefore, damping means are associated with the chokes, or with the stray capacities or with both in order to damp out such resonances. In Fig. 10, resistance **32** serves effectively as a damping resistance across capacity **31**, and the resistance **30** arranged in shunt with choke 28 may also serve a damping function. By a suitable choice of the values of the damping resistances, it can be arranged that the impedance of the coupling circuit as a whole, within a desired working range of frequency, does not vary by more than about ±20% due to resonances between the chokes and the stray circuit capacities.

In a preferred arrangement, however, the coupling circuit is made to simulate a pure resistance, or a purely resistive network; thus, if the capacity 31 is equal to C, and the resistances 30 and 32 are both of the same magnitude R, then the parallel aiding inductance L of chokes 28, 29 is made such that the relationship $L=CR^2$ is substantially satisfied; in these circumstances, assuming the two chokes to be coupled as tightly as possible, so that the series impedance introduced thereby is negligible, the whole coupling circuit simulates a pure resistance of magnitude R, this pure resistance constituting the anode load of valve 23. If desired, this valve may have a separate load resistance 33, shown dotted, and resistance 32 may then if desired be taken to earth instead of to the positive terminal of the anode current source. By taking resistance 32 to the positive terminal of the source, however, loss of current is avoided.

The coupling between chokes 28 and 29 need not be so tight as that effected by winding the chokes in a bifilar manner, or on a common magnetic core; in the case in which the coupling is looser than this, it is preferably arranged that the mutual inductance between the chokes 28, 29 is substantially equal to the inductance of coil 28, that is, the coil which is shunted by a damping resistance.

If the chokes 28, 29 are air-cored and are required to be of large inductance, the length of wire in each choke 28, 29 may be such that at some frequency within the working range, a resonance occurs between the coil and its distributed self-capacity, the resonance usually occurring at a frequency at which the length of wire in the coil is substantially half a wavelength. The effect of this resonance is that, at the resonant frequency, the impedance of the chokes becomes very low; the effect can be avoided by making either or both the coils 28, 29 in a plurality of separate sections, each section having in shunt with it a separate damping resistance; thus each coil may be wound in two halves, each half being damped by a resistance equal to

$$\frac{R}{2}$$

Now it may be found that the series opposing inductance of the chokes 28, 29 resonates within the operating frequency range with condenser 36, and this residual may be damped by means of series resistance 35; preferably, however, resistance 35 is given the same value, say r, as resistance 34 (which, as has been explained, may be made up to a suitable value) and it is arranged that

$$\frac{l}{c}=r^2$$

where l is the series opposing inductance of chokes 28, 29 and c is the capacity of condenser 36; the series impedance between the anode of valve 23 and the grid 25 of valve 24 is then a pure resistance equal to r.

It will be noted that, in the amplifier described, the grid 25 of valve 24 may be allowed to become positive relative to the cathode thereof—in other words, grid current may flow, without the introduction of substantial wave form distortion, since the grid circuit of valve 24 is one of relatively low resistance; it will of course be observed that when grid current flows, battery 27 serves not only as a source of bias, but also to supply power.

Fig. 11 shows a circuit of the same general character as that shown in Fig. 10, and illustrates the application of the invention to a direct coupled modulator suitable for a wide range of frequencies. In Figs. 10 and 11 the magnitudes of components bearing like references are denoted by like symbols; referring to Fig. 11, the valve 23 is arranged to establish modulation signals across the modulation resistance 33, the floating anode battery high-tension rectifier or other D. C. source 27 being inserted between the anode 37 of valve 23 and modulation resistance 33 and serving as a D. C. coupling. The end of the modulation resistance 33 remote from earth is connected to the input of a radio frequency modulator (not shown). The source 27 of anode potential is connected into the circuit through two mutually-coupled inductances 28, 29, which are arranged to present as small an impedance as possible for the passage of normal anode electron current, which flows from the valve 23 through inductance 28, through the source 27, through inductance 29 and so to the modulation resistance 33.

The two inductances are preferably tightly coupled, for example, by being wound on a common magnetic core. If the coupling is less tight than this, it is preferably arranged that the mutual inductance is substantially equal to the inductance of coil 29. As before, a condenser 36 and a resistance 35 are used to build out the battery resistance 34 and the series-opposing inductance of the chokes 28, 29 to simulate a pure resistance equal to r. The choke 29 is shunted by a resistance 30, and similarly the capacity 31, which represents the capacity of source 27 to earth together with any capacity which it may be convenient to add thereto, is shunted by a resistance 32, resistances 30, 32 having, as before, the same magnitude R. The combined battery feed and coupling circuit then appears as a resistance of value R between the anode of valve 23 and earth, provided the parallel-aiding inductance of the two chokes equals CR^2.

If desired, the resistance 33 may be omitted, the composite resistance R then constituting the whole modulation resistance. If resistance 33 is included in the circuit, the effective modulation resistance is R in parallel with the resistance 33. If the source 27 is a rectifier, the latter may conveniently be built out to simulate a pure resistance equal to r less the series resistance of the two chokes, and built out again as described with reference to the drawings, to correct for the leakage inductance of the tightly-coupled chokes. Furthermore, resistance 30 may be divided into two parts, each equal say to 2R, one shunted across each of chokes 28, 29. Again it will be noted that the D. C. component of the anode current of valve 23 is dissipated in resistance 32, and this resistance can have substantial self-capacity, since such self-capacity forms part of the capacity 31.

Fig. 12 illustrates the application of the invention to circuits for feeding current to the cathode of a valve which is operated, for example, with its load in the cathode circuit. Such a valve may be one known as a cathode follower, the potential of the cathode of which can be arranged substantially to follow that of the control grid thereof. Referring to Fig. 12, the filament **38** of valve **37** is fed with alternating current from a transformer **39**, the secondary **40** of which has capacity to the earth core **39**, or to both the primary winding and the core. In this case, filament **38** constitutes the first conductor. The effects of the stray capacity, which is indicated in dotted lines by condenser **31**, which will be referred as C, is eliminated by feeding the filament **38** through two tightly-coupled chokes **28, 29**. These chokes are shunted by a resistance **30** and a further resistance **32** shunts the stray capacity **31**. The end of resistance **30** remote from earth is taken to the centre tap **41** on a low resistance **42** across the filament **38**, and the two halves of resistance **42** in parallel constitute in effect a portion of resistance **30**.

As the choke effectively constituted by inductances **28, 29** requires to have a low self-capacity and has to carry heavy currents, so that thick wire is necessary, it is advantageous to wind the inductances **28, 29** on a magnetic core resembling a transformer core, but having a large gap (preferably in the middle of the coil) and formed of very thin laminations. As the filament current passes through the coils in series opposition, the core is not magnetized by the filament heating current, but is magnetized by the space current of the valve **37**. The transformer capacity **31** also comprises the self-capacity of the resistance **32**.

As in the previous arrangements of Figs. 10 and 11 it is arranged that L, the parallel-aiding inductance of chokes **28, 29** is equal to CR^2, R being the magnitude of resistances **30** and **32**. The capacity to earth of a battery, machine, or rectifier feeding the filament with direct current may be effectively eliminated in a similar manner. Fig. 13 shows a modification of the arrangement of Fig. 12 in which a D. C. coupling is provided between valve **37** and a second valve **50**; in this case it is required not only to supply cathode heating current to the valve **37**, but also to supply a grid bias potential for the subsequent valve **50**, the grid of which requires, instead of the positive potential of the cathode **38** of the valve **37**, a negative potential relative to earth. The valve **37** works into a load resistance arranged in its cathode circuit, and it is required to eliminate, as far as possible, the effects of capacities to earth of the load resistance (which, since it is required to dissipate the heat produced by the steady component of the anode current of the valve, has a substantial self capacity), the total capacity to earth of the source of cathode-heating current, and finally the effective total capacity to earth of the rectifier or other source supplying the bias potential for valve **50**.

In Fig. 13, **43** represents a low voltage heavy current rectifier providing the cathode-heating current for valve **37**, and **44** represents a comparatively high voltage rectifier supplying the bias to the valve **50**, which it is assumed is liable to run into grid current on extreme amplitudes. The cathode-circuit load of valve **37** is formed by two resistances **30, 32** in series, of which resistance **32** is required to dissipate the heat produced by the steady and low frequency space current. Resistance **30** is only required to dissipate the heat produced by the high frequency alternating currents. The unwanted capacities are held off by means of a triple-wound choke coil, the three windings **28, 29** and **45** of which are coupled together as tightly as possible. The two windings **28, 29** correspond to windings **28, 29** of Fig. 12 and are of thick copper wire, so as to carry the cathode current without overheating, whereas the winding **45** is of thinner wire but is well insulated from the other two windings on account of the higher voltage of rectifier **44**. The insulation of the composite choke, from end to end, must be such as to be capable of withstanding the peak amplitude of the output of valve **37**. The inductances of coils **28, 29** are preferably made substantially equal, and the average mutual inductance between the coil **45**, and the coils **28, 29** is preferably made substantially equal to the average inductance of coils **28, 29**.

The cathode rectifier **43** and the cathode are shunted by resistances **46, 42** respectively, the centre points **47, 41** of which are connected through resistance **30**. The resistances **46, 42** are of small value, and if desired, they can be regarded for purposes of design as forming part of resistance **30**. The stray capacity **31** of rectifier **43** and the stray capacity **31′** of rectifier **44** are eliminated in the manner discussed with reference to Fig. 12.

The centre point **41** of the resistance **42** and the upper end of the choke winding **45** are connected by a resistance **48** and a condenser **49** in series; the magnitudes of components **48** and **49** are so chosen that the effective impedance of rectifier **44** as seen through the leakage inductance of the composite choke, is effectively a pure resistance. Any capacity due to the windings of the choke which effectively shunts the leakage inductance can be allowed for to a large extent by a modification of the circuit employed to build out the rectifier impedance to a pure resistance by application of the principles already discussed which govern such building out. In this way, the effective stray capacity across the cathode load due to the heat-dissipating resistance **32** and to the two rectifiers **43** and **44** is effectively removed, any residual self-capacity being relatively small and due solely to the choke coils. If the choke is suitably designed and particularly if it is given an iron core to reduce its size, it is, in general, possible to effect a reduction of stray capacity of as much as 10:1 for a frequency range extending from 0 to 2 megacycles per second.

Difficulties may be encountered in certain practical cases in carrying the invention into effect in the ways so far described, since it may be found that it is difficult or impossible to construct or utilize components of the desired values; thus it may be found that choke coils of the desired inductance have objectionable resonances within the band of frequency to be handled, or are excessively bulky or expensive.

A further arrangement according to the invention, by the use of which the difficulties referred to may be eliminated or much reduced, will now be described with reference to Fig. 14, which illustrates a modification of the arrangement of Fig. 13. Like parts in Figs. 13 and 14 bear the same references.

Referring to Fig. 14, a doubly-wound choke comprising coils **51, 52** is connected in the leads to the grid bias rectifier **44**, coil **52** being connected in series with coil **45** and coil **51** being connected between the rectifier and tapping point **47** on resistance **46**. Resistance **32** is, as in Fig. 13, connected between the left hand terminal of rectifier **44** and earth. A resistance **53** is shunted across coil **51**.

It will be seen that coils **51, 52** do not have to carry the heating current for valve **37**. Coil **51** carries only the anode current of valve 37 and coil 52 carried only the grid current of the valve 50. It is therefore readily possible to make the inductance of the doubly-wound choke 51, 52 substantially greater than that of the triply-wound choke 28, 29, 45. If C_2 is the value of the capacity 31′ to earth of rectifier 44, L_2 the magnitude of the inductance 51 and R_1 the magnitude of resistance 32 and also of resistance 53, then this part of the circuit behaves as a pure resistance if $L_2=R_1^2C_2$. The capacity C_2 may be regarded as comprising in addition to capacity 31′, the shunt stray capacity of resistance 32.

If C_1 is the magnitude of the capacity 31, to earth, of rectifier 43, if L_1 is the effective inductance of the triply-wound choke as seen from the cathode 38, and if resistance 30 has a value R_1, then the whole system behaves as a pure resistance if $L_1=R_1^2C_1$, and if L_2 has the value given above.

In the circuit of Fig. 13 the necessary inductance L_1 of the triply-wound choke 28, 29, 45 is given by $L_1=R_1^2(C_1+C_2)$, C_1 and C_2 having the values given above. In many cases C_1 is much less than C_2 and therefore, by employing the circuit of Fig. 14 instead of that of Fig. 13 the magnitude of the inductance of the triply-wound choke can be very much reduced.

It will be seen that in the arrangement of Fig. 14 the stray shunt capacity 31 of rectifier 43 is shunted by resistances 53 and 32 in series with one another, resistance 32 being also in shunt with the stray capacity 31′ of rectifier 44.

In practice, it may be preferable to provide heating current for the cathode by means of a direct current generator instead of from a rectifier. If this method is employed, the generator is connected in place of rectifier 43 and, by well spacing and insulating the generator from earth, it is possible to keep capacity 31 small compared with the capacity 31′ of the floating rectifier 44.

It is to be noted that, provided it is relatively small, the self-capacity of coil 51 may be included in the effective value C_2 of capacity 31′.

The source 43 of cathode heating current may be so shielded that it has capacity to rectifier 44 only. In this case the upper end of coil 51 is connected to tapping point 41 instead of to tapping point 47, and the upper end of coil 52 is connected directly to the right hand terminal of condenser 49, coil 45 being omitted. It will then be seen that the stray capacity of source 43 is shunted by resistance 53 and the circuit so constituted is in series with the effective inductance of coils 28, 29 shunted by resistance 30. This part of the circuit is arranged to form a substantially constant resistance network by application of the principles already stated. The stray capacity of rectifier 44 is shunted by resistance 32 and is built out by inductance 51 shunted by the resistance network last referred to, to form a further substantially constant resistance network.

The above description is given by way of example only and many modifications of the invention, within the scope of the appended claims, will be apparent to those versed in the art.

What is claimed is:—

1. A coupling circuit between two thermionic elements comprising a condenser connected to a current carrying electrode of one of said thermionic elements, a load resistance connected to a current carrying electrode of one of said thermionic elements, a circuit element connected in said current carrying electrode circuit and having distributed capacity to ground, said distributed capacity being small as compared with said condenser, a pair of resistances for connecting the circuit element in parallel with said condenser, a resistance, an inductance connected in parallel to said resistance and inserted in the connection between said load resistance and the coupling circuit whereby the entire coupling circuit will be in effect a substantially constant resistance over substantially the frequency range transmitted by the thermionic elements, said effect being accomplished by making the ratio of the inductance to said distributed capacity equal to the square of the load resistance

$$\left(\frac{L}{C}=R^2\right)$$

2. A coupling circuit between two thermionic elements comprising a condenser, a circuit element having distributed capacity to ground, said distributed capacity being small as compared with the condenser, a pair of resistances for connecting the circuit element to the coupling circuit in parallel with said condenser, and a load connected to said coupling circuit comprising a resistance with an inductance and resistance connected in parallel therewith whereby the entire coupling circuit is effectively a constant resistance over substantially the entire frequency range to be transmitted by said thermionic elements, the value of the ratio of said inductance to said distributed capacity being such as to equal the square of the resistive value of the load on said thermionic elements

$$\left(\frac{L}{C}=R^2\right)$$

3. A coupling circuit between two thermionic elements comprising a condenser, a source of current having distributed capacity to ground, said distributed capacity being small as compared with the condenser, a pair of resistances for connecting the source of current to the coupling circuit in parallel with said condenser, and a load connected to said coupling circuit comprising a resistance with an inductance and resistance connected in parallel therewith, whereby the entire coupling circuit is effectively a constant resistance over substantially the entire frequency range to be transmitted by said thermionic elements, the value of the ratio of said inductance to said distributed capacity being such as to equal the square of the resistive value of the load on said thermionic elements

$$\left(\frac{L}{C}=R^2\right)$$

4. A circuit arrangement comprising an electrical resistance which, in operation, is required to carry relatively large currents, means for reducing the effects of the inherent shunt capacity of said resistance comprising a second resistance and an inductance in shunt with one another, said second resistance being one rated to carry less current than that carried, in operation, by said first resistance, and means for connecting said second resistance and inductance in series with said first resistance whereby, together with said first resistance, they simulate substantially a pure resistance, the ratio of said inductance to said capacity being such as to substantially equal the square of the value of both of said resistances

$$\left(\frac{L}{C}=R^2\right)$$

5. A circuit arrangement comprising an inductance having a pre-determined current capacity, means for reducing the effects of the inherent shunt capacity of the said inductance comprising a second inductance having a smaller current capacity connected in series with said first inductance, and two resistances of substantially the same magnitude arranged in shunt respectively with said inductances, said second inductance being so chosen that, upon a pre-determined frequency, the impedance of said circuit is substantially constant and simulates a pure resistance.

6. A circuit for coupling electronic devices comprising a load circuit for at least one of said devices, said load circuit having a resistive value R, means for connecting said load circuit to a current carrying electrode of said electronic device, a circuit element having a definite reactance connected to said electronic device and to said load circuit, means connected to said latter element and to said load having a reactance in opposition to said first reactance whereby the ratio of inductive reactance to capacitive reactance in the circuit is equal to the square of the load resistive value

$$\left(\frac{L}{C}=R^2\right)$$

said means connecting a second electronic device to said circuit whereby the coupling circuit behaves as a substantially constant resistance for the whole of the band of frequencies transmitted by said electronic devices.

7. A coupling circuit for two thermionic devices comprising a circuit element connected in a current carrying electrode circuit of one of said thermionic devices, said element having a determinable value of distributed capacity, a condenser connected serially to said current carrying electrode and substantially in shunt with said distributed capacity, a resistance connected serially with said circuit element, an inductance connected in shunt with said resistance, the ratio of the value of said inductance to the capacities being equal to the square of the resistive load in said current carrying electrode

$$\left(\frac{L}{C}=R^2\right)$$

whereby the coupling circuit formed by said elements simulates a substantially constant resistance over the entire range of frequencies transmitted by said thermionic elements, and means for connecting the second thermionic device to said coupling element.

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