

Jan. 20, 1942.

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2,270,364

AMPLIFICATION OF ELECTRIC WAVES

Filed April 26, 1940

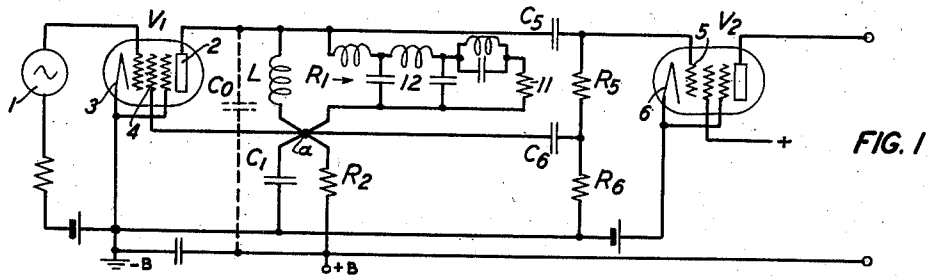


FIG. 2

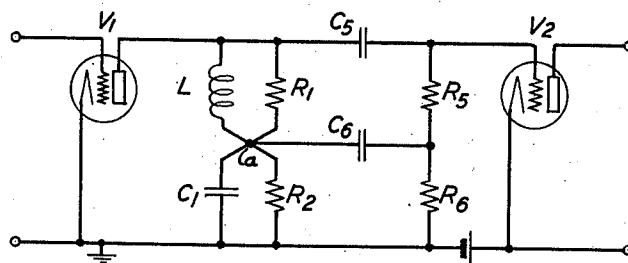


FIG. 3

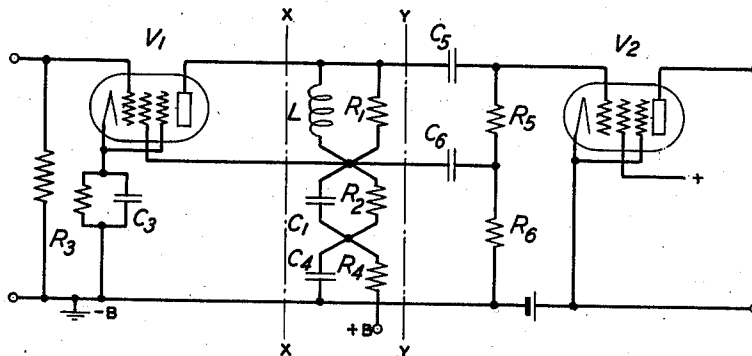


FIG. 5

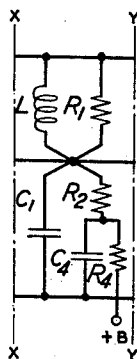
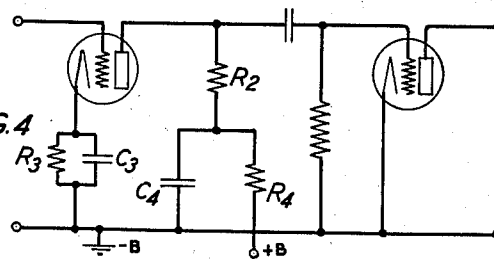


FIG. 4



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## UNITED STATES PATENT OFFICE

2,270,364

## AMPLIFICATION OF ELECTRIC WAVES

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Application April 26, 1940, Serial No. 331,728

13 Claims. (Cl. 179—171)

This invention relates to amplifiers comprising space discharge devices and it is more especially concerned with the design of multistage amplifiers adapted for electric currents occupying a wide range of frequencies extending upwards to radio frequencies. The principal object of the invention is to provide an amplifier, the gain of which is not only substantially uniform over the frequency band of interest but also maximum consistent with certain practical limitations hereinafter to be set forth. The features of the invention are to be found largely in the inter-stage coupling circuits provided.

The invention is especially adapted for the amplification of television signals, where an amplifier is required that has a substantially constant gain from a low audio frequency approximating direct current to a radio frequency of the order of several megacycles per second and that has a linear phase shift characteristic. Although it is with these and other stringent requirements in view that the present invention will be described, it is to be understood that in at least its broader aspects the invention is in no manner limited to the amplification of television signals or to amplifiers adapted for such signals.

One of the simplest, idealized forms which a multistage television amplifier may take comprises two space discharge devices with the anode of one connected to the control grid of the other and with the respective cathodes connected together, and a coupling impedance comprising a pure resistance connected across the circuit from the anode mentioned to the cathode. In attempting to realize this idealized form in practice difficulty is encountered in devising a coupling impedance that is purely resistive or that otherwise has the same impedance throughout the frequency range. The input or interelectrode capacitance of the second discharge device and the output capacitance of the first discharge device, for example, appear across the coupling circuit and thereby together contribute a shunt reactance that disturbs the idealized non-reactive circuit condition. An additional shunt reactance is introduced by the stray capacitance of the blocking condenser which must be interposed in the anode-grid connection to protect the grid from the high biasing voltage applied to the anode. Although this stray capacitance may be objectionably large in any type of amplifier, it tends to be especially troublesome in the case assumed, for the presence of television signal components of very low frequency and the desire to maintain the series impedance at a low and preferably

negligible value dictates that the blocking condenser be a large one despite the relatively large amount of stray capacitance associated with it. In so far as the objective of a coupling impedance constant throughout the frequency range is concerned, the effect of shunt capacitance can be minimized in the usual manner by constructing the coupling impedance as a constant-resistance artificial line of which the shunt capacitance is one of the lumped impedance elements. However, the presence of shunt capacitance remains as what appears today to be an inherent limitation on the flat or uniform gain that can be attained with a signal band of given frequency width.

In accordance with a principal feature of the invention the limitations and disadvantages incident to the use of a relatively large blocking condenser are substantially avoided, without relinquishing the advantages of an impedance coupling of constant resistance between stages, in a coupling circuit utilizing two blocking condensers, one of comparatively small capacitance traversed by the higher frequencies of the signaling band and the other of comparatively large capacitance adapted for and traversed by the lower frequencies. The large stray capacitance necessarily associated with the larger condenser is effectively shunted across only the portions of the coupling circuit that carry the lower frequencies and at these lower frequencies the shunt reactance due to the stray capacitance is negligible.

Another amplifier circuit condition that should obtain for high gain, assuming that the discharge devices are screen grid tubes, is substantial equality of the anode and screen grid biasing potentials. In accordance with a feature of the present invention this condition is brought about by a connection between the two electrodes that offers negligible impedance to direct current but that presents a high impedance to the signal frequencies, and by other cooperating circuit elements that are provided to maintain the resistive character of the coupling impedance.

It is often preferred to have the control grid of each space discharge device in an amplifier "self-biased" so as to avoid the use of a grid biasing battery or other separate source, and for this purpose a resistance and condenser in parallel with each other are usually connected in a common portion of the control grid and anode circuits. The self-biasing circuit, however, tends to introduce negative feedback and to reduce the gain of the amplifier at the lower end of the frequency range. This tendency requires special

attention in television signal amplifiers for at the very low signaling frequencies involved the condenser imperfectly performs its function of bypassing the resistor. In accordance with another feature of the invention the tendency noted is counteracted by a like condenser and resistance which modify the characteristics of the coupling impedance.

The nature of the present invention and its various objects, features and advantages will appear more fully in the following detailed description of the illustrative embodiments shown in the accompanying drawing:

Fig. 1 shows schematically a two-stage screen grid tube amplifier in accordance with the invention;

Fig. 2 represents a simplified modification of Fig. 1;

Fig. 3 shows the amplifier of Fig. 1 with compensation for the effect of self-biasing; and

Figs. 4 and 5 illustrate modifications of Fig. 3.

Referring now to the specific embodiment of the invention illustrated in Fig. 1, there is shown schematically the first two stages of an amplifier adapted to amplify with high and uniform gain a band of signaling frequencies delivered to it from source 1. Assuming that the signals from the source are television signals, the frequencies involved may range, for specific example, from forty cycles per second to four megacycles per second. The two discharge devices  $V_1$  and  $V_2$  comprising the amplifier are represented as being pentode tubes. The cathodes of the two tubes are connected together and the anode 2 of  $V_1$  is connected through a blocking condenser  $C_5$  to the control grid 5 of tube  $V_2$ . From the anode 2 of  $V_1$  to cathode 3 thereof there is connected a multi-element coupling network which may conveniently be thought of as constituting a single two-terminal impedance coupling. This network is intended and designed to present across the output terminals of  $V_1$  a pure resistance that is of the same magnitude at every frequency within the band occupied by the signals. Across the input terminals of  $V_2$  is connected a grid leak comprising resistors  $R_5$  and  $R_6$  which dissipate the static charge that tends to accumulate on control grid 5. As thus described the amplifier stages will be understood to be essentially impedance-condenser coupled.

From an intermediate point  $a$  of the coupling network a second blocking condenser  $C_6$  is connected to an intermediate point of the grid leak, viz., the junction of resistors  $R_5$  and  $R_6$ . Between the point  $a$  and the anode 2 the coupling network may be considered to be divided into two parallel branches. One of these branches consists of the inductance  $L$ , and the other comprises an artificial line 12 that is made up of lumped inductive and capacitive elements configured and proportioned with relation to the total stray capacitance  $C_0$  across the coupling circuit as an M-derived low-pass filter terminated in a resistor 11. The line 12 presents at its input terminals, as indicated, a resistance  $R_1$  that is constant, or substantially so, excepting possibly at the extreme top portion of the signal frequency range. As will be presently explained in greater detail, the inductance  $L$  is so proportioned in relation to the other circuit constants that it constitutes almost a short circuit for frequencies in the lower portion of the signal band so that across the terminals of the portion of the coupling circuit described there is developed principally only voltages corresponding to fre-

quencies in the upper portion of the signal range. The effect of inductance  $L$  may be achieved alternatively and preferably by shunting an inductor across resistor 11 where its distributed capacitance will not contribute to  $C_0$ , but for simplicity of exposition it is shown connected as above described.

Between point  $a$  and the cathode 3 the coupling network is divided into two parallel branches, one a condenser  $C_1$  and the other a resistor  $R_2$ . Although the lower end of resistor  $R_2$  is connected to the cathode 3 only indirectly through the anode biasing source, the latter is presumed to have such low impedance, as by virtue of a large by-pass condenser across its terminals, as to be negligible at all signal frequencies, so that the lower terminal of resistor  $R_2$  may be considered to be connected directly to the cathode in so far as the signal frequencies are concerned. As will be presently explained, condenser  $C_1$  is so proportioned as to present almost negligible impedance to frequencies in the upper portion of the signal band but substantial impedance to lower frequencies so that between point  $a$  and cathode 3 the signal voltage developed is due principally to signal currents in the lower portion of the signal band.

The unavoidable stray capacitance which, as explained hereinbefore, tends to appear across the coupling impedance is represented by capacitance  $C_0$ . This capacitance is significant only at high frequencies, and at such frequencies that capacitance is virtually connected between anode 2 and point  $a$  inasmuch as the condenser  $C_1$  is so proportioned as to have small, if not negligible, impedance at high frequencies. Capacitance  $C_0$ , then, may be considered as comprising one element of artificial line 12; indeed, it is the very presence of the capacitance  $C_0$  that gives rise to the necessity for resorting to an artificial line rather than a simple resistor, remembering that one objective is to maintain the coupling impedance virtually purely resistive. For analytical purposes the combination of  $C_0$  and the artificial line may be replaced with a non-reactive resistance  $R_1$ .

The interstage coupling circuit shown in Fig. 1 may now be understood to provide two paths for the more or less exclusive transmission of different portions of the frequency range. For high frequency currents, as for example the highest frequency in the signal band, the transmission circuit may be traced from anode 2 through condenser  $C_5$  to grid 5 on the one hand, and from cathode 3 to cathode 6 of  $V_2$  on the other. The only series element in the circuit traced, viz., blocking condenser  $C_5$  is of negligible reactance at the high frequency assumed. At the same time it will be found that every shunt path across the circuit traced has at least one series element of high impedance so that the shunting effect is negligible. Considering now currents in the low frequency portion of the signal band, for example the lowest frequency transmitted, a path can be traced from the anode 2 through inductance  $L$ , which is of negligible reactance at the frequency assumed, through blocking condenser  $C_6$  which is of large capacitance and through grid leak element  $R_5$  to the grid 5. The other side of the low frequency circuit comprises simply the connection between the two cathodes. It will be noted in this case also that the shunt elements are all of high impedance at the low frequency assumed.

For a better understanding of the circuit fea-

tures thus far described with reference to Fig. 1, reference is now made to Fig. 2 which shows a simplified circuit embodiment. Like elements are represented by the same reference characters in the two figures except that the artificial line 12 and stray capacity  $C_0$  have been replaced in Fig. 2 by an electrically equivalent resistor  $R_1$ . Considering first the coupling network in Fig. 2 comprising the elements  $L$ ,  $C_1$ ,  $R_1$  and  $R_2$ , it is to be noted that these four can be so relatively proportioned that the impedance appearing across the terminals of the coupling network is constant at all frequencies. To produce this constant resistance condition it is necessary only that the following relations obtain:

$$R_1 = R_2 = R \quad (1)$$

and

$$\frac{L}{C_1} = R^2 \quad (2)$$

Blocking condenser  $C_s$  may be of fairly small capacitance inasmuch as it is not traversed by low frequency currents. Since it is small it can be designed to have very little stray capacitance to ground. Condenser  $C_s$  on the other hand is of large capacitance compared with condenser  $C_1$  and it would tend to have proportionately greater stray capacitance which would effectively appear in parallel with condenser  $C_1$  and virtually form a part of the latter. Blocking condenser  $C_s$  is so proportioned with respect to resistor  $R_s$  as to accommodate the low frequencies transmitted. Preferably,  $2\pi f C_s R_s$  should be small compared with unity for all frequencies  $f$  lying between the top of the signal band and a frequency such that  $2\pi f L$  is much less than  $R_1$ . If in a particular case resistors  $R_s$  and  $R_2$  are not of negligibly high resistance they may be treated as being in parallel with  $R_1$  and  $R_2$  respectively and as correspondingly modifying the values of  $R_1$  and  $R_2$  in Equations 1 and 2.

Reverting now to Fig. 1, it will be noted that there is a connection from the screen grid of the pentode  $V_1$  to the point  $a$  and that biasing voltage for the electrode passes to this point from the anode biasing terminal  $+B$  through resistor  $R_2$ . Biasing voltage for the anode 2 is likewise derived from the point  $a$  through inductance  $L$ . Inasmuch as the direct current impedance of inductance  $L$  may be negligible, it is evident that anode 2 and screen grid 4 can be, and preferably are, operated at substantially the same positive potential, and high gain thereby achieved. At the same time it is to be noted that for low signal frequencies the screen grid 4 and anode 2 are virtually connected together so that the high gain effect a triode has for low frequencies can be realized. As hereinbefore explained, the coupling network can be proportioned in accordance with Equations 1 and 2 in such manner that its terminal impedance is purely resistive over the entire signal frequency range. Condenser  $C_1$  therefore serves, in so far as the feature described in this paragraph is concerned, to restore the resistive character of the coupling impedance that would be lost were only inductance  $L$  added.

Whereas the proportioning of the coupling network set forth in Equations 1 and 2 yields a constant coupling resistance, and constant gain also in the case shown in Fig. 2, the fact that the screen grid 4 in Fig. 1 contributes to the low frequency gain of the amplifier requires some modification of the network proportions if constant gain is to be had with the Fig. 1 circuit.

The necessary modification is defined by the following equations:

$$\frac{R_2}{R_1} = \frac{G_{mp}}{G_{mp} + G_{ms}} \quad (3)$$

and

$$R_1 R_2 = \frac{L}{C_1} \quad (4)$$

where  $G_{mp}$  is the mutual conductance of tube  $V_1$  as measured from the control grid to the anode 2 and  $G_{ms}$  is the mutual conductance as measured from the control grid to the screen grid 4. In using these two equations the internal cathode-anode resistance can be neglected but the internal screen to cathode resistance should be included in parallel with and treated as a part of  $R_2$ . The amplification as measured by the ratio of the voltage  $e_2$  appearing across the coupling network to the voltage  $e_1$  applied to the input terminals of tube  $V_1$  is then constant at all frequencies and of a magnitude expressed by the following equation:

$$\frac{e_2}{e_1} = G_{mp} R_1 \quad (5)$$

It will be evident from the foregoing description of Figs. 1 and 2 that the inductance  $L$  performs multiple functions, one being to provide a metallic connection between the anode 2 and screen grid 4 so that equality of biasing voltage obtains, another that of providing a frequency selective impedance operative to direct the high frequency signal currents to the high frequency portion of the coupling circuit, and another that of providing a low impedance connection from the anode 2 to one side of the low frequency portion of the coupling circuit. Condenser  $C_1$  likewise has manifold functions for it preserves the resistive or constant gain character of the coupling network despite the presence of the inductive element  $L$ , it distinguishes between the high frequency and low frequency currents in such manner as to direct the low frequency currents to the low frequency portion of the coupling circuit, at the same time providing a low impedance connection from the cathode 3 to one side of the high frequency portion of the coupling circuit, and it serves to maintain the large grid condenser  $C_s$  at substantially ground potential for those high frequency currents on which the stray capacitance of condenser  $C_s$  would otherwise have a serious shunting effect.

Although the control grid circuit of tube  $V_1$  in Figs. 1 and 2 is represented as including a grid biasing battery, it is feasible to replace the battery with a so-called self-biasing circuit and to introduce in the coupling network certain circuit elements properly proportioned to compensate for the gain-modifying characteristics of the biasing circuit. An illustrative example of this phase of the invention is shown in Fig. 3.

Fig. 3 is essentially the same as Fig. 1, or it may be, excepting for the insertion of a resistance  $R_3$  in parallel with a condenser  $C_3$  in the external lead from cathode 3 of  $V_1$  and excepting for the interposition of a like combination,  $R_4$  and  $C_4$ , between the coupling circuit elements  $C_1$  and  $R_2$  and ground. The resistor  $R_3$ , inasmuch as it is disposed in the common cathode portion of the anode and control grid circuits of the tube  $V_1$ , is traversed by the direct current flowing from the anode voltage source and the potential drop across it is impressed as a bias on the control grid. To suppress fluctuation in the grid bias so derived the resistor  $R_3$  is shunted

by condenser  $C_3$ . It is impractical to have the capacitance  $C_3$  so large that its reactance is negligible and its shunting effect substantially perfect at the exceedingly low frequencies involved in television transmission, hence there is a certain amount of impedance to signal currents of low frequency present in the common cathode portion of the circuit. The impedance is negligible at high frequencies but at frequencies in the lower portion of the signal band it may be large enough to introduce a substantial gain-reducing feedback and associated phase shift so that the gain characteristic of the amplifier tends to droop at the lower end of the frequency range. To compensate for the effect described applicant provides in Fig. 3 a resistor  $R_4$  and a condenser  $C_4$  connected in parallel with each other and disposed in series between the junction of  $C_1$  and  $R_2$  and ground. Inasmuch as the effect now under consideration is significant only at the lower end of the frequency range where the coupling impedance of Fig. 1 effectively degenerates to the resistor  $R_2$  alone, the proper proportioning of the significant circuit elements can be described with reference to a simplified circuit such as shown in Fig. 4.

In Fig. 4 the coupling resistance is designated  $R_2$ , for the reason just stated, and the compensating circuit is connected between its low potential end and ground. Actually, of course,  $R_4$  is grounded through the negligible impedance of the anode biasing source and not directly. For the voltage amplification  $e_2/e_1$  to be constant at all frequencies the several resistors should be proportioned in accordance with the relation:

$$R_4 = G_m R_2 R_3 \quad (6)$$

where  $G_m$  is the effective mutual conductance at the frequencies of interest; and the time constant of the biasing circuit should be equal to that of the compensating circuit, i. e.,

$$\frac{C_4}{C_2} = \frac{R_3}{R_4} \quad (7)$$

Although these last two equations specify the relative proportions of the circuit elements the absolute magnitude of the several impedance elements should be judiciously selected with the possible effect of these elements on other portions and functions of the circuit in view. Thus in the circuits shown in Fig. 3 the capacitance  $C_1$  should preferably be large compared with the stray capacitance to ground of condenser  $C_6$ .

Fig. 5 shows a permissible modification of the Fig. 3 circuit in which the compensating unit  $C_4$ — $R_4$  is interposed, as before, between the low potential end of resistance  $R_2$  and ground but in which condenser  $C_1$  is connected directly to ground. The circuit elements may be proportioned in accordance with Equations 6 and 7, but in this case capacitance  $C_4$  should be large compared with capacitance  $C_1$  so that the impedance in series with  $R_2$  is small or negligible at the lower end of the signal frequency band.

Quantitative data relevant to a specific amplifier embodying certain features of the invention may contribute to a better understanding of the invention and the foregoing exposition thereof. The specific amplifier circuit configuration may be assumed to be essentially equivalent to that shown in Fig. 2. It may be further assumed that the amplifier employs screen grid tubes and that it is designed for television signals ranging in frequency from 40 cycles per second to three megacycles. In such case the circuit elements

may have the following absolute values:  $L$ , 10 millihenries;  $R_1$  and  $R_2$ , 7000 ohms;  $C_1$ , 200 micro-microfarads;  $C_3$ , 500 micro-microfarads;  $C_6$ , 0.5 microfarad; and  $R_5$  and  $R_6$ , 50,000 and 250,000 ohms, respectively. It will be understood that these data are only illustrative, not necessarily typical, and not intended as limiting the invention in any degree to the values specified.

To those skilled in the art it will be apparent that the invention and its various features are susceptible of embodiment in a wide variety of forms within the spirit and scope of the appended claims.

What is claimed is:

1. A multistage amplifier comprising a first discharge device having a cathode and anode, a second discharge device having a cathode and control electrode, and an interstage circuit coupling said devices in tandem for the amplification of signals occupying a wide frequency range, said coupling circuit comprising two resistances connected in series across said cathode and anode of said first discharge device, an inductance effectively connected across the one of said resistances that is nearer said anode and effectively shunting said resistance only for frequencies in the lower portion of said frequency range, a capacitance effectively shunting the other of said resistances only for frequencies in the upper portion of said frequency range, a high resistance connecting said cathode and control electrode of said second discharge device, a blocking capacitance connecting said anode and said control electrode, said blocking capacitance having low reactance for said frequencies in the upper portions of said frequency range, a second blocking capacitance connecting the junction of said two resistances and an intermediate point of said high resistance, said second blocking capacitance having relatively low reactance for said frequencies in the lower portion of said frequency range.

2. A combination in accordance with claim 1 in which said two resistances, said inductance, and said shunting capacitance, are of such relative magnitudes that the impedance presented by them to said first discharge device is substantially the same at all frequencies within said frequency range.

3. In a signal amplifier comprising space discharge amplifying devices in a plurality of impedance coupled stages, a coupling impedance between two of said stages consisting essentially of two substantially equal resistances  $R$  connected in series with each other, an inductance  $L$  effectively shunting one of said resistances, and a capacitance  $C$  effectively shunting the other of said resistances, said elements being proportioned in conformity with the relation  $L/C=R^2$ , and means for transferring signal potentials from said coupling impedance to the second of said two stages comprising a coupling connection from the junction of said resistances to said second stage.

4. In an impedance coupled multistage signal amplifier, a coupling impedance consisting essentially of two substantially equal resistances  $R$  connected in series with each other, an inductance  $L$  effectively shunting one of said resistances, and a capacitance  $C$  effectively shunting the other of said resistances, said elements being proportioned in conformity with the relation  $L/C=R^2$ , the second of the stages coupled by said coupling impedance comprising a space discharge device having an input circuit, and circuit means

for separately applying to said input circuit the signal voltage appearing across said inductance and the signal voltage appearing across said capacitance.

5. A multistage amplifier for amplifying, with substantially uniform gain, signals occupying at least several octaves in the frequency spectrum, comprising an amplifying space discharge device having a cathode, an anode and a screening grid for said anode, a coupling impedance connected between said cathode and anode comprising two resistances  $R_1$  and  $R_2$  in series with each other with  $R_1$  connected to said anode, an inductance  $L$  effectively shunting resistance  $R_1$ , a capacitance  $C$  effectively shunting resistance  $R_2$ , and a direct connection from said screening grid to the junction of said resistances, the aforementioned elements comprising said coupling impedance being proportioned in conformity with the relation  $L/C=R_1R_2$  and so that the gain of said space discharge device is substantially the same at all frequencies occupied by said signals.

6. In a multistage signal amplifier comprising a first and a second amplifying discharge device in successive stages thereof, said first discharge device having a signal output circuit and said second discharge device having a control electrode and a signal input circuit connected thereto, a pair of blocking condensers for said control electrode, one of said condensers having a capacitance many times greater than the other, frequency selective means for applying signals lying principally in the upper portion of the frequency range occupied by said signals from said output circuit to the smaller of said condensers for application to said control electrode, frequency selective means for applying signals lying principally in the lower portion of said frequency range from said output circuit to the larger of said condensers for application to said control electrode, and an impedance of large magnitude interposed in said input circuit between said larger condenser and said control electrode.

7. A combination in accordance with claim 6 comprising means for maintaining said larger condenser at substantially ground potential for signal frequencies in the upper portion of said range, whereby the stray capacitance of said larger condenser is effectively shunted across only the low frequency portion of the signaling circuit.

8. In an amplifier for signals occupying a frequency range comprising many octaves, a signal amplifying space discharge device comprising a cathode and a control grid, a grid leak connected in circuit between said cathode and control grid, a signal input connection to the said grid comprising a small series capacitance constituting a blocking condenser having substantial reactance only for frequencies in the lower portion of said

range, a second signal input connection to an intermediate point on said grid leak comprising a series blocking condenser having negligible series reactance at said lower frequencies, frequency selective means for applying to said first signal input connection signal frequencies lying principally in the upper portion of said range, frequency selective means for applying to said second input connection signal frequencies lying principally in the lower portion of said range, and a third signal input connection to said cathode.

9. A combination in accordance with claim 8 including means for maintaining said blocking condenser in said second input connection at substantially ground potential for frequencies in the upper portion of said range.

10. A combination in accordance with claim 8 including means for applying said signals to said first and second input connections and means for maintaining said blocking condensers at substantially the same potential for frequencies in the lower portion of said range.

11. A combination in accordance with claim 8 comprising reactance means shunted between said first and second input connections, said reactance means having small impedance at a frequency in the lower portion of said range.

12. A signal amplifier comprising a space discharge device having a cathode and a control electrode, a high impedance element serially connecting said cathode and control electrode, signal input means for applying signal frequencies lying in the upper portion of the signaling frequency band across one portion of said impedance element, signal input means for applying signal frequencies lying in the lower portion of said band across another portion of said impedance element, and means for maintaining the low potential end of said one portion at substantially ground potential for signal frequencies in said upper portion of the band.

13. An amplifier comprising at least two amplifying stages and an interstage circuit coupling said stages, an impedance element shunted across the input of the second of said stages, said interstage circuit comprising a shunt branch divided into two series-connected impedance elements, and at least three signal transferring series branches extending from the several terminals of said series-connected impedance elements to the said input impedance element of the second of said stages, said series-connected impedance elements having different impedance-frequency characteristics such that low frequency signal voltages appear principally across one of said elements and high frequency signal voltages across the other, and means for maintaining the junction of said impedance elements at substantially ground potential for a frequency lying above said low frequency.

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