Aug. 13, 1940. R. L. FREEMAN 2,211,718

ULTRA-HIGH-FREQUENCY SIGNAL-TRANSLATING STAGE

Filed Jan. 12, 1939

FIG. 1.

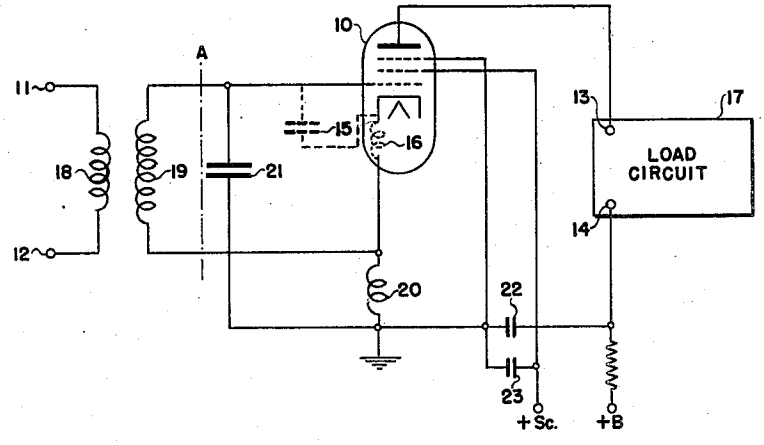


FIG. 3.

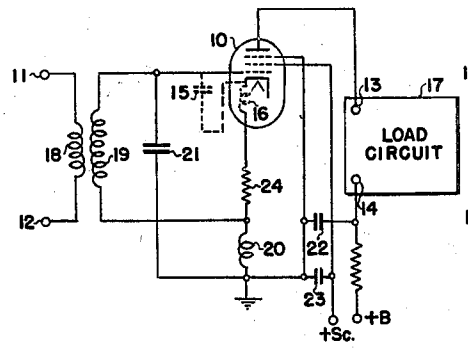


FIG. 4.

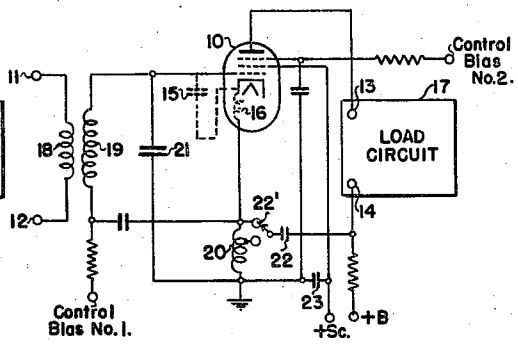
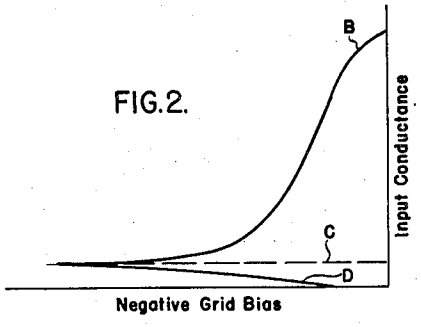


FIG. 2.



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UNITED STATES PATENT OFFICE

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ULTRA-HIGH-FREQUENCY SIGNAL-TRANSLATING STAGE

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11 Claims. (Cl. 179—171)

This invention relates generally to ultra-high-frequency signal-translating stages for operation at such high frequencies that the conductance of the input circuit of the stage is an appreciable factor in determining the response characteristic of the stage.

The input conductance of conventional vacuum tubes utilized in ultra-high-frequency translating stages, such as a stage of ultra-high-frequency amplification, materially reduces the response of the stage. At frequencies above ten megacycles, or thereabout, the input conductance of a conventional vacuum tube is appreciable and at frequencies higher than fifty megacycles the input conductance, rather than the inherent tube and circuit capacitance, becomes the limiting factor in the response of the stage. The reason for this condition is that the maximum impedance which can be developed across the input circuit of the stage at such ultra-high frequencies is limited by the input conductance of the tube.

Also, at ultra-high frequencies, the input capacitance of such a stage and the variation of input capacitance with variations of the transconductance of the tube are both appreciable, adding other limitations to the response characteristic of the system. While there have been proposed arrangements for reducing the input capacitance and for maintaining it substantially uniform with variations of transconductance of the tube of such an ultra-high-frequency stage, such arrangements in themselves have not been effective to compensate for the conductance of the input circuit and some arrangements for stabilizing the input capacitance have even introduced appreciable additional conductance into the input circuit. It is, therefore, desirable to provide an arrangement which may be used with such systems for maintaining relatively constant input capacitance and which is effective also to reduce to a low value the conductance of the input circuit of the stage.

It is an object of the present invention, therefore, to provide an improved ultra-high-frequency signal-translating stage which is not subject to the above-mentioned disadvantages of arrangements of the prior art.

It is a further object of the invention to provide an improved ultra-high-frequency signal-translating stage, the response of which is not substantially limited by the input conductance of the vacuum tube included in the stage.

It is also an object of the invention to provide an ultra-high-frequency signal-translating stage, including means for stabilizing or maintaining relatively constant the input capacitance of the stage, the response of the stage being not substantially limited by the input conductance of the vacuum tube included in the stage.

In accordance with the invention, there is provided an ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits. The screen circuit, and in some cases the output circuit, is returned for signal frequencies to a common terminal, such as ground. The input circuit of the vacuum tube comprises a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, the cathode and the control electrode of the vacuum tube having capacitance therebetween, and the cathode terminal and the control-electrode terminal having a positive conductance therebetween. Capacitance means are provided between the control-electrode terminal and the common terminal, together with a connection including inductance between the cathode and the common terminal. The reactive constants of the capacitance means and the inductance are so proportioned that the voltage developed across the inductance and coupled to the control electrode through the capacitance means effectively reflects a negative conductance between the cathode and control-electrode terminals which neutralizes a substantial portion of the above-mentioned positive conductance.

In other embodiments of the invention there are provided means for stabilizing the input capacitance of the stage, due to variations in transconductance of the tube utilized, together with means for eliminating at least a substantial portion of the conductance of the input circuit, which is due to either or both the transit time of electrons through the tube and the inherent inductance of the cathode lead, as well as for compensating for the conductance reflected into the input circuit by the capacitance-reducing means.

The novel features which are believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with other and further advantages thereof, will best be understood with reference to the following specification taken in connection with the accompanying drawing in which Fig. 1 is a circuit diagram of a stage of amplification incorporating the invention; Fig. 2 is a graph of certain operating characteristics of the circuit of Fig. 1; while Figs. 3 and 4 are circuit diagrams of modifications of the invention utilized in conjunction with different input-capacitance stabilizing arrangements.

The input conductance of conventional vacuum tubes is determined by three factors: (1) the dielectric losses of the tube insulators and the tube base; (2) feedback from the anode-cathode circuit to the grid-cathode circuit through the grid-cathode capacitance of the tube and the

self-inductance of the cathode lead, the latter being common to the input and output circuits; and (3) the transit time of electrons through the tube. The component of input conductance due to dielectric losses is usually small compared to that due to feedback through the grid-cathode capacitance and the self-inductance of the cathode lead and also is small as compared to that component of the input conductance dependent on the transit time of electrons through the tube.

The circuit of Fig. 1 illustrates the general principles of the invention which may be utilized to compensate for the two last-mentioned components of input conductance. Referring now to Fig. 1, there is illustrated an ultra-high-frequency signal-translating stage including a vacuum tube 10, input terminals 11, 12, and output terminals 13, 14. The grid-cathode capacitance of tube 10 is represented by condenser 15, shown in dotted lines for the reason that it is usually comprised entirely of inherent interelectrode capacitance. The inductance of the cathode lead of tube 10 is represented by inductance 16, also shown in dotted lines for the reason that it represents inherent inductance, the simulated inductance due to transit time effects, or both, in the cathode lead. The impedance of the output circuit is represented schematically by load circuit 17 connected across output terminals 13, 14. The signal input, applied at input terminals 11, 12, is impressed upon the input electrodes of tube 10 through inductively coupled inductances 18 and 19. Inductance 20 is connected between the external terminal of the cathode lead and a common terminal, such as ground, which terminal is coupled to the external terminal of the control electrode of the tube through a condenser 21 effectively to eliminate the conductance introduced across the input circuit of tube 10 by the feed-back circuit comprising inductance 16 and capacitance 15. It will be understood that inductance 16 may represent either or both of the actual inherent inductance of the cathode lead of tube 10 and the simulated inductance equivalent in effect to that of the transit time of electrons through the tube 10, and that condenser 21 is, in the usual ultra-high-frequency stage, comprised in whole or in part of the inherent capacitance of the input circuit. The screen and anode circuits of tube 10 are returned for signal frequencies to the common terminal through by-pass condensers 22 and 23, respectively.

In considering the operation of the circuit just described, it will first be assumed that the input conductance due to transit time effects are negligible and that the input conductance of the system is caused only by feedback through inductance 16, which under the conditions assumed represents the actual inherent inductance of the cathode lead of tube 10, common to both its input and output circuits, and condenser 15. In the following analysis the symbols I, L, and C, together with subscripts corresponding to the reference numerals of the circuit elements of Fig. 1, identify, respectively, the current, inductance, and capacitance associated with the particular circuit element, ω represents the angular frequency of the signal input, and g_m represents the transconductance between the control electrode of tube 10 and all other electrodes whose currents flow through inductance 20.

Let Y equal the admittance of the input circuit of tube 10 to the right of dotted line A of Fig. 1 and assume a voltage E developed across inductance 19. Also, let

$$\frac{1}{j\omega C_{15}}+j\omega L_{16}=Z_1 \tag{1}$$

Then,

$$E=I_{15}Z_1-I_{20}j\omega L_{16} \tag{2}$$

Since,

$$I_{20}=\frac{-g_mI_{15}}{j\omega C_{15}} \tag{3}$$

$$I_{15}=\frac{EC_{15}}{Z_1C_{15}+g_mL_{16}} \tag{4}$$

Assume,

$$Z_2=\frac{1}{j\omega C_{21}}+j\omega L_{20} \tag{5}$$

Then,

$$I_{21}=\frac{E}{Z_2}\left(1+\frac{g_mL_{20}}{C_{15}Z_1+g_mL_{16}}\right) \tag{6}$$

Since,

$$Y=\frac{I_{20}+I_{15}}{E} \tag{7}$$

From Equations 4 and 6

$$Y=\frac{I}{Z_2}\left(1+\frac{g_mL_{20}+C_{15}Z_2}{g_mL_{16}+C_{15}Z_1}\right) \tag{8}$$

Let,

$$\frac{L_{20}}{L_{16}}=\frac{Z_2}{Z_1} \tag{9}$$

Then,

$$Y=\frac{1}{Z_2}\left(1+\frac{Z_2}{Z_1}\right)=\frac{1}{Z_2}+\frac{1}{Z_1} \tag{10}$$

Under the conditions of Equation 9 from which Equation 10 was derived, the admittance Y of the input circuit to the right of dotted line A is independent of the transconductance of tube 10 and furthermore is a pure susceptance.

From Equation 9 it is seen that

$$L_{20}=L_{16}\frac{Z_2}{Z_1}=L_{16}\frac{\left(\frac{1}{j\omega C_{21}}+j\omega L_{20}\right)}{\left(\frac{1}{j\omega C_{15}}+j\omega L_{16}\right)} \tag{11}$$

For the ultra-high-frequencies under consideration, L_{20} and C_{21} as well as L_{16} and C_{15} are resonant well above the signal frequencies. (This is true for most conventional vacuum tubes for frequencies lying within the band from 40 to 100 megacycles.) Therefore,

$$\frac{1}{\omega C_{21}}\gg\omega L_{20} \text{ and } \frac{1}{\omega C_{15}}\gg\omega L_{16} \text{ and } L_{20}=L_{16}\frac{C_{15}}{C_{21}} \tag{12}$$

It is thus seen that a circuit proportioned in accordance with the above expressions is effective to provide zero input conductance for tube 10 at any frequency well below the resonant frequency of the feed-back circuit elements and for any value of transconductance of tube 10.

Characteristic curves for the circuit of Fig. 1 are shown in Fig. 2. The normal operating characteristic of the tube utilized in a circuit not incorporating the invention is shown by curve B of Fig. 2. The characteristic of the circuit of Fig. 1 proportioned in accordance with the above principles is shown in curve C. The residual input conductance which is not eliminated is that due to dielectric losses, mentioned above. The system of Fig. 1 may also be proportioned to reduce the input conductance to zero for any particular value of transconductance by providing additional feed-back energy at the selected

transconductance over that necessary to neutralize only the effect of inductance in the cathode lead, the characteristic curve for this arrangement being shown in curve D.

The foregoing analysis of the operation of Fig. 1 was based upon the assumption that conductance due to transit time effects was negligible and that only the feedback through inherent inductance 16 and capacitance 15 effected the input conductance of the system. The magnitude of the component of input conductance of a conventional vacuum tube which is dependent on the transit time of electrons through the tube has been derived mathematically by D. O. North (see "Proceedings of the Institute of Radio Engineers," vol. 24, No. 1, January, 1936, page 108 et seq.). A mechanical explanation of the effect of transit time of electrons on the input conductance of a vacuum tube has been developed by W. R. Ferris (see "Proceedings of the Institute of Radio Engineers", vol. 24, No. 1, January, 1936, page 82, et seq.). These authors have shown that the component of input conductance G_t of conventional vacuum tubes dependent on the transit time of electrons through the tube is, $G_t=F\omega^2 g_m$, where F is a function of the transit time.

The function F changes only slightly with variations of the transconductance g_m and for present purposes may be considered to be a constant. The total input conductance G may then be expressed as

$$G=G_L+G_t=\omega^2 C_{15}L_{16}g_m+Fg_m\omega^2 \qquad (13)$$

where G_L is the component of input conductance due to inductance of the cathode lead.

It is thus seen that G may be expressed as

$$G=\omega^2 C_{15}L'_{16}g_m \qquad (14)$$

where L'_{16} is a fictitious cathode lead inductance that would account for the total input conductance of the tube, having a value

$$L'_{16}=\frac{G}{\omega^2 C_{15}g_m} \qquad (15)$$

Therefore, for measured values of the left-hand member of Equation 14, there can be calculated the correct value of L_{16} for use in Equation 12 to obtain neutralization of the input conductance of the tube. This value will give exact compensation for any frequency but for only one value of transconductance of the tube, due to the fact that F does vary slightly with transconductance. However, a moderate degree of neutralization is provided over a reasonable range of variation of transconductance of tube 10.

From Equation 15 there may be derived the equation:

$$L'_{16}C_{15}=\frac{G}{\omega^2 g_m} \qquad (16)$$

If, in Equation 12, L'_{16} is substituted for L_{16},

$$L'_{16}C_{15}=L_{20}C_{21} \qquad (17)$$

Therefore, from Equations 16 and 17

$$L_{20}C_{21}=\frac{G}{\omega^2 g_m} \qquad (18)$$

That is to say, when both the screen and output circuits are returned for signal frequencies to a common terminal, such as ground, the means for neutralizing the positive conductance between the cathode terminal and control-electrode terminal of the vacuum tube 10 comprises the connection including inductance 20 between the cathode and common terminal and capacitance means 21 between the terminal of the control electrode and the common terminal for a given value of angular frequency ω and transconductance g_m of the vacuum tube 10, the product of inductance 20 and capacitance 21 being made equal to the quotient of the positive conductance G divided by the product of the square of the angular frequency, ω^2, and the transconductance g_m.

The circuit of Fig. 3 differs from that of Fig. 1 only in that a cathode resistor 24 has been added. Similar circuit elements have been given identical reference numerals in the two figures. Such a cathode resistor has been utilized in prior art arrangements to stabilize the input capacitance of a vacuum tube. Since the correct value of resistor 24 to provide stabilization for input capacitance of the stage of Fig. 3 does not completely eliminate input conductance, inductance 20, which must be proportioned in accordance with the principles outlined above, is also provided. The circuit is then effective to reduce the conductance of the input circuit of the stage to a very low value at high values of transconductance and to stabilize the input capacitance over the entire range of transconductance variation.

The circuit of Fig. 4 is also essentially similar to that of Fig. 1 and similar circuit elements have been given identical reference numerals. The circuit of Fig. 4 differs from that of Fig. 1 in that provision is made for applying a different control bias to the control electrode and the suppressor-grid electrode of vacuum tube 10. The ratio of the applied biases is such as to vary the transconductance of vacuum tube 10 over a desired range and to maintain the input capacitance of the system substantially constant over the range of variation of transconductance of vacuum tube 10, in accordance with the principles outlined in detail in the copending application of John F. Farrington, Serial No. 165,611, filed September 25, 1937. While the screen grid of vacuum tube 10 of Fig. 4 is bypassed to the cathode by condenser 23 as in the circuit of Fig. 1, the by-pass condenser 22 for the anode circuit may be coupled either to the common terminal between inductances 16 and 20 through a switch 22' as shown, or to a tap on inductance 20, by operation of the switch 22' to its lower position.

In considering the operation of the circuit of Fig. 4, it will be seen that the transconductance of vacuum tube 10 can be varied over a given range while maintaining the input capacitance substantially constant by means of a proper proportionment of the bias potentials applied to the control grid and suppressor grid of tube 10. However, with such a bias-control system, the input conductance of the stage tends to increase appreciably as the biases of tube 10 are increased. In order to compensate for such a variation of the conductance of the input circuit, it is, therefore, necessary to provide a current through inductance 20, the effect of which is complementary to that of the effective inductance 16 over the range of variation of the biases of tube 10. The screen-grid current, under the dual-bias variation, has the desired characteristic, and the circuit constants may, therefore, be proportioned, in accordance with the principles outlined above, to provide a relatively constant conductance in the input circuit of vacuum tube 10 over the range of grid-anode transconductance while simultaneously maintaining the input capacitance relatively constant.

With some tubes, the control-electrode screen-

electrode transconductance increases more rapidly than the input conductance with increasing bias voltages. Therefore, in order to provide the desired complementary characteristic, the anode current may be caused to flow through a portion of inductance 20. This circuit arrangement is provided by the operation of switch 22' to its lower position.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen circuit being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having a positive conductance therebetween, a condenser connected between the terminal of said control electrode and said common terminal, and an added inductance connected between said cathode terminal and said common terminal, the reactive constants of said condenser and said added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control-electrode terminal through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

2. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen and output circuits being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, an added inductance element connected between the external terminal of said cathode and said common terminal, and a condenser connected between the external terminal of said control electrode and said common terminal, said cathode and control electrode having capacitance therebetween, said cathode terminal and control-electrode terminal having a positive conductance therebetween which may be substantially simulated by an inductance in said cathode lead, the ratio of the capacitance of said condenser to the capacitance between said control electrode and cathode being equal substantially to the ratio of the simulated inductance to the inductance of said added inductance element.

3. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen and output circuits being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control electrode having a capacitance therebetween and said cathode lead comprising appreciable inherent inductance, said capacitance and said inductance being effective to produce positive conductance between said control-electrode and cathode terminals during normal operation of said stage, a condenser connected between said control-electrode terminal and said common terminal, and an added inductance connected between said cathode terminal and said common terminal, the reactive constants of said condenser and said added inductance being so proportioned with respect to those of said inherent inductance and said capacitance that the voltage developed across said added inductance and coupled to said control-electrode terminal through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

4. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen and output circuits being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control-electrode terminals having a positive conductance therebetween due to transit time of electrons during normal operation of said stage, a condenser connected between said control-electrode terminal and said common terminal, and an added inductance connected between said cathode terminal and said common terminal, the reactive constants of said condenser and said added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control-electrode terminal through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

5. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen and output circuits being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having therebetween a positive conductance which may be simulated by an inductance in said cathode lead during normal operation of said stage, a condenser connected between said control-electrode terminal and said common terminal, said condenser being effective with said capacitance to tune said input circuit within the range of operating frequencies of said stage, and an added inductance connected between said cathode terminal and said common terminal, the reactive constants of said condenser and said added inductance being so proportioned with respect to those of said simulated inductance and said capacitance that the voltage developed across said added inductance and coupled to said control-electrode terminal through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

6. An ultra-high-frequency signal-translating

stage comprising a vacuum tube of the screen-grid type operable over a given range of transconductance and having input, output, and screen circuits, said screen circuit being returned for signal frequencies to a common terminal, said vacuum-tube input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control electrode having a capacitance therebetween and said cathode terminal and said control-electrode terminal having therebetween a positive conductance, a condenser connected between said control-electrode terminal and said common terminal, an added inductance element connected between said cathode terminal and said common terminal, and means for maintaining said capacitance substantially uniform over said range of transconductance, the reactive constants of said added condenser and added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control electrode through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

7. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type operable over a given range of transconductance and having input, output, and screen circuits, said screen and output circuits being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having therebetween a positive conductance, a condenser connected between said control-electrode terminal and said common terminal, and means including an added inductance and a resistor connected between said cathode terminal and said common terminal, said resistor being proportioned to maintain said capacitance substantially uniform over said range of transconductance and the reactive constants of said condenser and said added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control-electrode terminal through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

8. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen circuit being returned for signal frequencies to a common terminal, said vacuum-tube input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, an additional electrode in said vacuum tube, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having therebetween a positive conductance, means for applying simultaneously adjustable biases to said control electrode and said additional electrode relatively proportioned to vary the transconductance of said tube and maintain said capacitance substantially constant over the range of transconductance variation, a condenser connected between said control-electrode terminal and said common terminal, and means including an added inductance connected between said cathode terminal and said common terminal, the reactive constants of said condenser and said added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control electrode through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

9. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen circuit being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal, and a control electrode having an external terminal, said output circuit comprising an anode, a screen electrode in said vacuum tube, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having a positive conductance therebetween, means for applying simultaneously adjustable biases to said control electrode and an additional electrode in said tube relatively proportioned to vary the transconductance of said tube while maintaining said capacitance substantially constant over the range of variation of said transconductance, a condenser connected between said control electrode terminal and said common terminal, and an added inductance connected between said cathode terminal and said common terminal and including an intermediate terminal connected to said anode, said added inductance being coupled between said cathode terminal and said control-electrode terminal through said condenser, the reactive constants of said condenser and said added inductance being so proportioned that the voltage developed across said added inductance and coupled to said control electrode through said condenser effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

10. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen circuit being returned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal and a control electrode having an external terminal, said cathode and control electrode having capacitance therebetween and said cathode terminal and said control-electrode terminal having positive conductance therebetween, capacitance means between said control-electrode terminal and said common terminal, and a connection including inductance between said cathode and said common terminal, the reactive constants of said capacitance means and said inductance being so proportioned that the voltage developed across said inductance and coupled to said control electrode through said capacitance means effectively reflects a negative conductance between said cathode and control-electrode terminals which neutralizes a substantial portion of said positive conductance.

11. An ultra-high-frequency signal-translating stage comprising a vacuum tube of the screen-grid type having input, output, and screen circuits, said screen and output circuits being re-

turned for signal frequencies to a common terminal, said input circuit comprising a cathode, a cathode lead having an external terminal and a control electrode having an external terminal, said cathode terminal and control-electrode terminal having a predetermined positive conductance therebetween at a given value of angular frequency and transconductance of said vacuum tube, and means for neutralizing said positive conductance comprising a connection including inductance between said cathode and said common terminal, and capacitance means between the terminal of said control electrode and said common terminal, the product of said inductance and capacitance being equal to the quotient of said positive conductance divided by the product of the square of said angular frequency and said transconductance.

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