

Dec. 5, 1939.

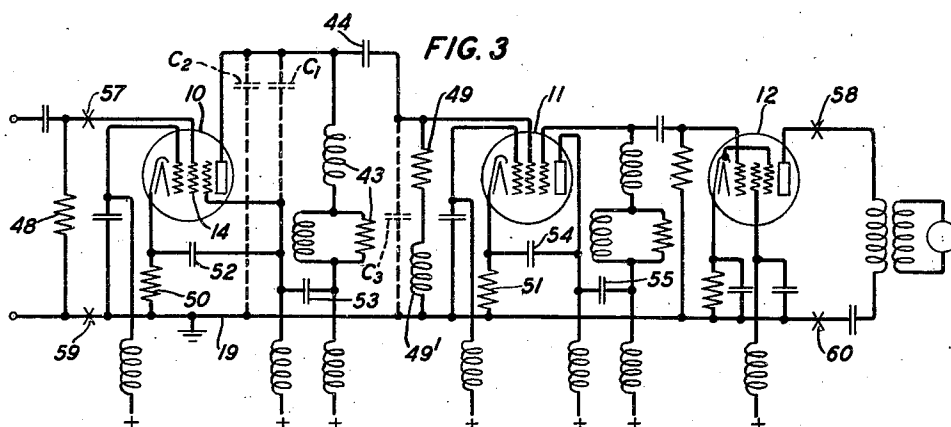
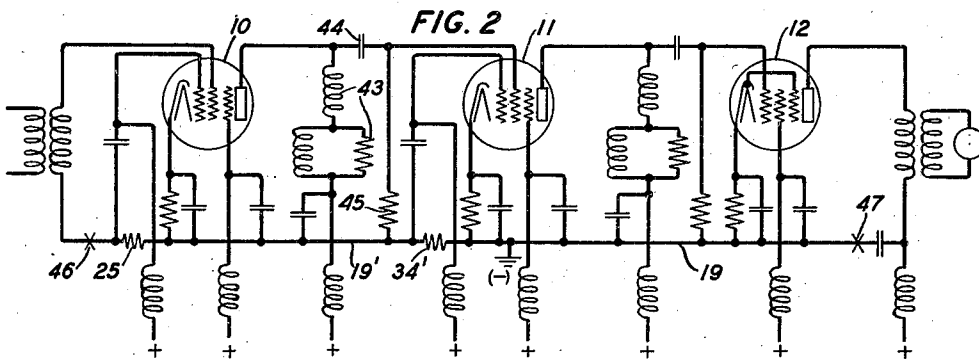
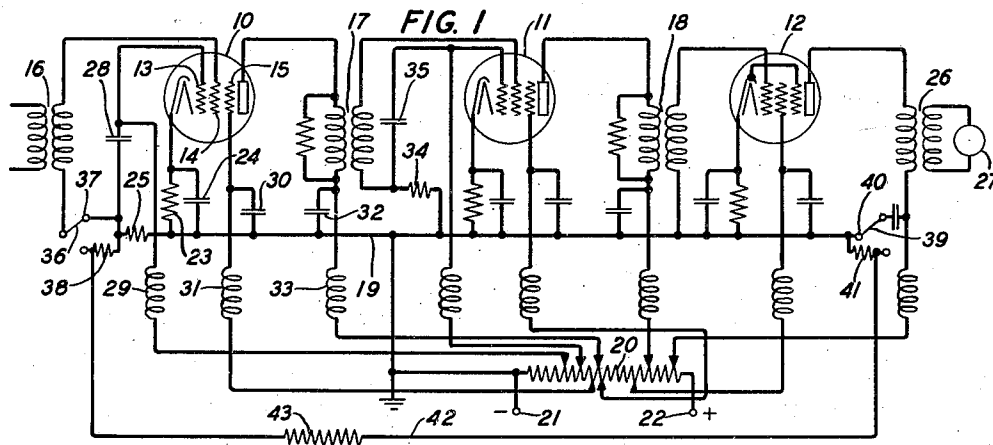
K. C. BLACK

2,181,865

MULTIGRID TUBE AMPLIFIER

Filed June 23, 1936

3 Sheets-Sheet 1



INVENTOR
K. C. BLACK
BY *E. V. Briggs*

ATTORNEY

Dec. 5, 1939.

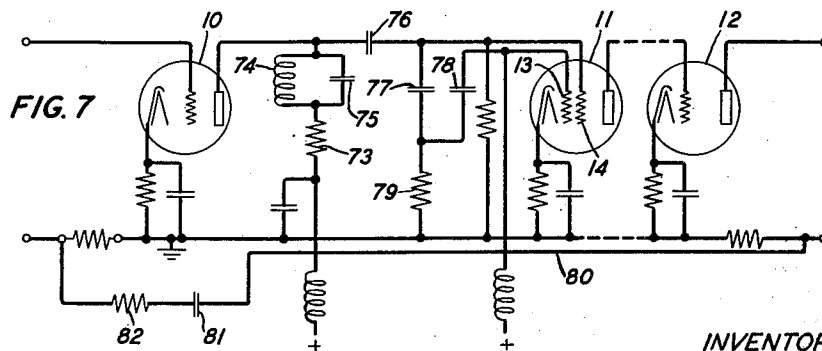
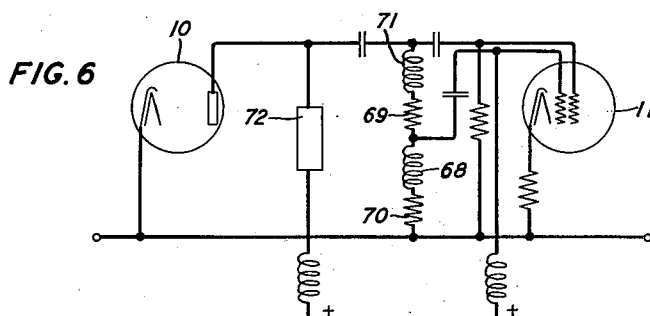
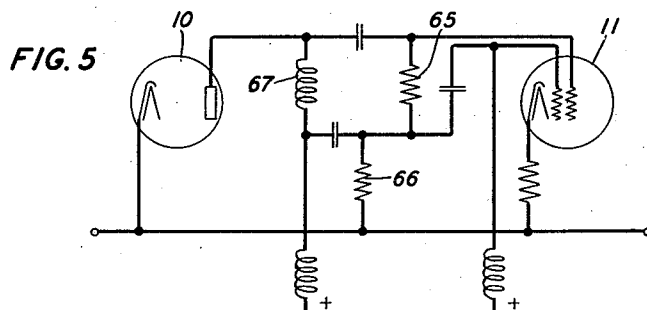
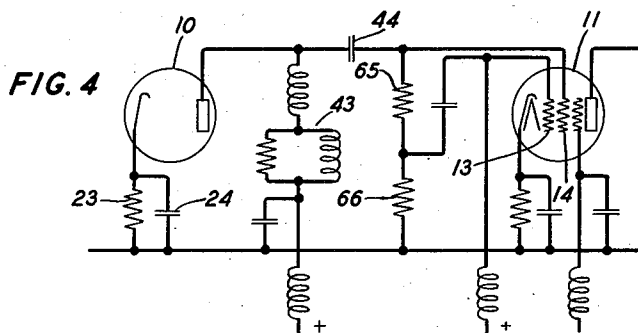
K. C. BLACK

2,181,865

MULTIGRID TUBE AMPLIFIER

Filed June 23, 1936

3 Sheets-Sheet 2



INVENTOR
K. C. BLACK
BY *E. V. Snigg*
ATTORNEY

Dec. 5, 1939.

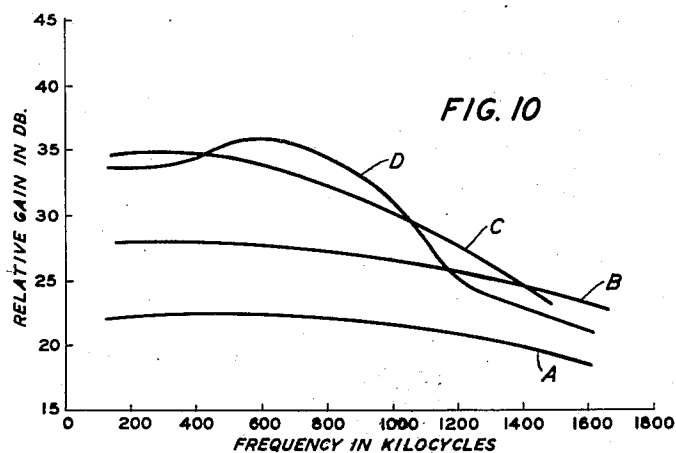
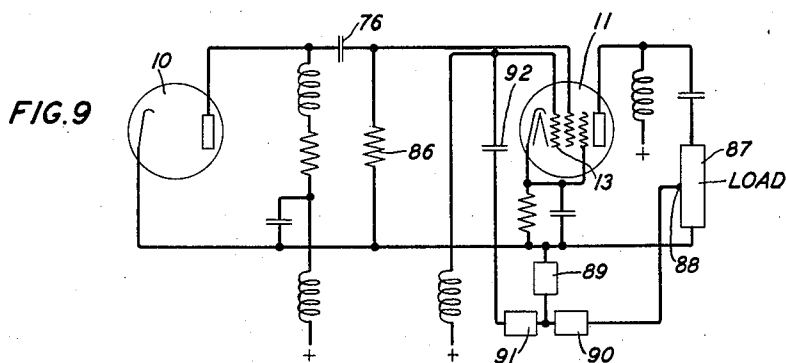
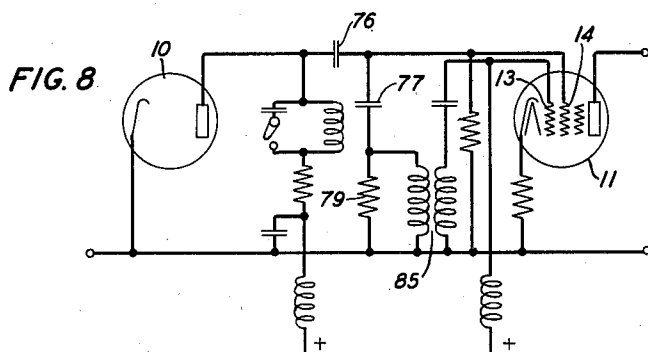
K. C. BLACK

2,181,865

MULTIGRID TUBE AMPLIFIER

Filed June 23, 1936

3 Sheets-Sheet 3



INVENTOR
K. C. BLACK
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

2,181,865

MULTIGRID TUBE AMPLIFIER

Knox C. Black, Mountain Lakes, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application June 23, 1936, Serial No. 86,778

12 Claims. (Cl. 179—171)

The present invention relates to a space discharge amplifier with circuit means for increasing the effective transconductance of the tube.

The invention has particular application to tubes having a plurality of grids, such for example as pentodes.

It has been shown that an increase in the effective transconductance of such tubes can be effected by means of a coupling between the control grid and the space charge grid, whereby the amount of gain obtainable from a given tube can be raised appreciably without incurring instability.

An object of the invention is to improve upon amplifiers using intercoupled grids or similar elements and to increase their range of usefulness.

A particular object is to provide multistage amplifiers of the general type indicated, suitable for use in broad frequency band transmission.

These and further objects, together with the various features of construction according to the invention, will be made more apparent from the detailed description to follow, taken in conjunction with the accompanying drawings in which:

Figs. 1 to 9 inclusive show various modifications of amplifier circuits with feedback to the net or space charge grid of a multi-grid tube for increasing the gain of the stage with stability of amplification, and Fig. 10 shows measured curves illustrative of the performance of certain of the circuits disclosed.

The transconductance of a tube is defined by

$$S = \frac{di_p}{de_g}$$

and is a measure of the effectiveness with which a change of grid voltage (de_g) produces a change in plate current (di_p). The effectiveness with which a change of grid voltage produces a change in plate voltage is given by the amplification constant of a tube, and the plate current produced by a given plate voltage varies in inverse ratio to the plate resistance. It is thus seen that transconductance is a function of the amplification factor and of the plate resistance, and varies in the same direction as the former and in opposite direction to the latter.

The transconductance of a tube can be increased by tube design within limits. If it is desired to obtain higher effective transconductance without altering the tube structure (as with tubes already in existence or with tubes representing the ultimate at present attainable by way of tube design) resort may be had to the circuit with which the tube is to be used. One

type of circuit already known for accomplishing the purpose comprises a simple resistance in series between the cathode and input transformer, with the space charge grid-cathode circuit also including this resistance, which therefore forms a coupling element between the control grid and space-charge grid circuits.

The result is a positive regenerative action within the tube, the space charge grid being at a positive potential to the cathode. This regenerative action effectively increases the amplification factor, hence the transconductance.

Frequently it is necessary or desirable to use high gain stages in cascade and to control the phase shift of the entire amplifier over a broad frequency band. Especially is this the case in amplifiers provided with a gain-reducing feedback.

The present invention is concerned with coupled-grid circuits that are improvements upon the simple series resistance type referred to as already known, and that, in some cases at least, are well adapted for connection in cascade to build up a multistage amplifier which may or may not be provided with a gain-reducing feedback.

Referring now to Fig. 1 of the drawings, a three-stage amplifier is shown comprising pentode tubes 10, 11 and 12 for amplifying waves between any suitable input circuit 16 and the output transformer 26 leading to a suitable load 27. Interstage coupling transformers 17 and 18 are used in this figure. Considering the first tube 10, the space charge grid 13 also called the "net", lies between the cathode and the control grid 14. The screen grid 15 lies between the control grid and the plate and may have any suitable construction as, for example, comprising portions on both sides of the anode for more complete shielding. The tube 11 may have a generally similar construction to the tube 10. Tube 12 is shown as an output power pentode of usual type.

Grid bias is indicated as being supplied in the case of each stage from a cathode resistor 23 with suitable bypass condenser 24. A common source of anode voltage, space charge grid voltage and screen grid voltage indicated by potentiometer 20 is bridged across terminals 21 and 22 of any suitable source, such as a battery or rectifier and filter. Potential for the space charge grid 13 is supplied through high frequency choke 23 with bypass through condenser 28 to a resistor 25; potential for the screen grid 15 is supplied through high frequency choke 31 with bypass through condenser 30 to the ground bus 19 and

plate voltage is supplied through high frequency choke 33 with bypass through condenser 32 to ground bus. Potentials for the elements of the other tubes may be similarly supplied. The connection of these various voltage supply leads to the potentiometer 20 as shown in Fig. 1 is purely conventional and in practice a number of potentiometers or other types of voltage dividing circuits might be used. Also, in any case, the various portions of the potentiometer resistance may be provided with suitable bypass condensers.

Coupling is provided in accordance with the invention between the grids 13 and 14 of the tube 10 by means of the resistor 25 which is common to the alternating current path between these two grids and the cathode, the alternating current path for the space charge grid 13 extending through capacity 28. In a similar manner resistance 34 affords the coupling between the corresponding grids of the tube 11, the connection to the space charge grid leading through capacity 35. The ground terminal of the coupling resistors 25 and 34 has substantially the same alternating current potential as the cathode on account of the negligibly low impedance of bypass condenser 24 around each cathode resistor.

By suitably proportioning the coupling resistances 25 and 34 and the voltage on the space charge grid, it is found that the gain of each of the stages containing tubes 10 and 11 may be increased in the order of ten decibels per stage without incurring objectionable instability. The circuit of the output pentode 12 is conventional.

While the circuit of Fig. 1 is not as well adapted as are some of the circuits of later figures, to the use of a gain reducing feedback, such a feedback, if used, might be effected through conductor 42 which becomes operative if the connecting wires 36 and 39 in this figure are severed from the uppermost contacts 37 and 40 respectively and are brought into engagement with the lower contacts shown on the terminals of the resistances 38 and 41, respectively. By proportioning the magnitude of resistances 38 and 41 and the amount of loss 43 indicated in the feedback connection 42 the amount of gain reduction can be controlled.

At very high frequencies or for very broad bands the presence of the interstage coupling transformers would become a limiting factor in the use of overall reverse feedback because of the phase shift which they introduce.

Fig. 2 differs from Fig. 1 mainly in the use of impedance couplings in place of transformer couplings. The external plate impedance of tube 10 of Fig. 2, indicated at 43, may comprise any suitable type of impedance network. The series coupling capacity is shown at 44 and the grid leak resistor for the control grid of the tube 11 is shown at 45. The coupling resistance 25 is used similarly to that of Fig. 1 and coupling resistance 34', except as hereinafter noted, acts similarly to resistance 34 of Fig. 1. It will be noted that in Fig. 2 the bus 19 is at ground potential whereas the bus 19' is off ground by the drop in the coupling resistance 34'.

From the standpoint of using a gain reducing feedback the circuit of Fig. 2, while possessing an advantage over that of Fig. 1 in that the interstage coupling networks introduce less phase shift, presents a slight complication in that the coupling resistance 34' is included between the points 46 and 47 between which a gain reducing feedback circuit would be connected, a condition

that would need to be taken into account in the design of an overall feedback for this amplifier.

Fig. 3 shows a multistage circuit comprising tubes 10 and 11 which, if desired, may be followed by an output tube similar to tube 12 of the previous figures. In this figure the coupling resistance between the control grid and the space charge grid is resistance 50 or 51 which also serves as the grid biasing resistance for the control grid 14 through leak resistor 48 or 49. It is desirable with this type of circuit to bypass the plate and screen grid circuit directly to the cathode as by condensers 52 and 53 in the case of tube 10 and condensers 54 and 55 in the case of tube 11. The reason for this is that feedback from plate or screen grid to cathode through resistance 50 or 51 would be degenerative if plate and screen currents were bypassed to ground in the conventional way, and would overbalance, or at any rate, partially annul the regenerative effect obtained between the control grid and space charge grid or net.

This type of connection gives a circuit with a common ground lead and with impedance coupling between stages, a condition not attainable with the two types of circuits previously described. In this circuit the plate to ground capacity C_2 and the plate to screen capacity C_1 , as well as the control grid to ground capacity C_3 of tube 11, should be kept to as low values as possible since they tend to give a degenerative action at the highest frequencies in the band because of the coupling resistor 50. One method of reducing the effect of capacity C_3 is to include inductance 49' in series with the leak resistor 49 or possibly in place of resistor 49 to resonate with the capacity C_3 . These capacities where present in substantial amounts limit the usefulness of this circuit at very high frequencies but large gains can be obtained at lower frequencies where these shunt capacities have a less marked effect.

The circuit of Fig. 3 lends itself well to the use of an overall gain reducing feedback of either the series or shunt type, because of the common ground connection. Such overall feedbacks may be connected, for example, between points 57 and 58 or by opening the circuit at points 59 and 60 and inserting resistances similar to 38 and 41 of Fig. 1.

The circuits described up to this point may appropriately be termed series resistance feedback circuits since the resistances serving as the feedback coupling are in series relation to the signal input source. Fig. 4 shows a type of shunt feedback circuit between the control grid and the space charge grid or net comprising resistances 65 and 66 connected between the control grid 14 and the cathode with a connection from a point between these two resistances to the net 13. This type of connection may therefore be designated shunt resistance feedback.

In Fig. 5 a shunt type of feedback comprising inductance and resistance is shown. In this circuit in addition to resistances 65 and 66 an inductance 67, which may be incorporated in the plate feed circuit is used.

Fig. 6 shows a somewhat similar circuit in which inductances 68 and 71 and resistances 69 and 70 are serially related in a shunt type of coupling circuit. Any suitable type of plate feed impedance represented by rectangle 72 may be used.

The capacity-coupled circuit of Fig. 7 represents a very effective type of connection for obtaining increased effective transconductance, and

has been found especially suited to broad band high frequency amplification. Since all stages have a common ground, this circuit is well adapted to use of an overall gain-reducing feedback which can be connected as indicated in Fig. 3 or in any other suitable manner. For example, the feedback may be made as shown by a connection 80 including series condenser 81 and resistance 82.

In Fig. 7, the anode branch of tube 10 is shown as including resistance 73, inductance 74 and capacity 75. Any other suitable type of impedance or network may be used at this point. Condenser 77 affords a coupling between the two grids of tube 11, and may be supplemented by resistance 79 which will ordinarily be quite high and may be infinite. In other words, the conductance of element 79 is negligibly small. The interstage coupling circuit between tubes 11 and 12 is not shown but may be as in Fig. 3 or of other suitable type.

It was found with a circuit of the Fig. 7 type that the grid to plate inherent capacity could be considerably reduced by the type of coupling used between the two grids, and this is favorable to large gain at very high frequencies where the capacity between grid and plate limits the gain.

The explanation which at the present time appears to account for the good characteristic at high frequencies is as follows. It is known that when the external plate impedance of a tube is resistive, the grid-to-plate capacity is, in effect, reflected into the grid circuit where it would appear as an apparent capacity between grid and cathode larger than the grid-to-plate capacity in the ratio (approximately) of the voltage ratio gain from grid to plate in the tube. The transconductance of grid-to-plate is opposite in sign to that from grid 14 to net 13, being taken as positive in the former case and negative in the latter. While there is (or may be) no gain from grid 14 to net 13, the effect of the transconductance between them apparently is effective in supplying a grid-to-cathode capacity negative in sign with respect to that effectively existing between these same two points as a result of the grid-to-plate capacity. The result is a partial annulment of the effect of the grid-to-plate capacity. The measured curves of Fig. 10 taken with this circuit show the material increase in gain at all frequencies over a wide band for stage 11 only, when the grid-to-grid coupling of the invention was used. Curve A is shown for comparison and represents the gain curve obtained with the best resistance-choke coil circuit design for a flat characteristic without the use of the grid-to-grid feedback through condenser 77 and resistance 79. Curves B and C were made with resistance 79 infinite and with increasing capacity in condenser 77, condenser 75 being omitted. Curve D shows the case with a still larger capacity at 77, with resistance 79 infinite and capacity 75 about half as large as capacity 77. Resistance 73 was increased for each curve B and C but was slightly smaller for curve D than for curve C. Resistor 79 was infinite in the case of each of the curves. Stages of this type can be connected in cascade (for example, by arranging the circuit elements of stage 10 similarly to those of stage 11), and when so connected have a common ground point. A common power supply (not shown) can be used for all stages in conventional manner. The phase shift in case an overall gain-reducing feedback connection is used is in general no worse than in

the case of amplifiers using the same type of interstage coupling but without the coupling between grids of the same tube.

The circuit of Fig. 8 represents one variant of the capacity type of grid-to-grid coupling, and its main difference with respect to the circuit of Fig. 7 is in the use of the transformer 85. Use of this transformer permits a voltage gain in the feedback from control grid 14 to net 13 and through coupling elements 77, 79 back to control grid, and permits a smaller condenser to be used at 77, an advantage particularly at high frequencies.

A somewhat different type of circuit employing feedback to the net is shown in Fig. 9 in which the feedback is taken from the output load 87 through a suitable network represented diagrammatically as comprising impedances 89, 90 and 91 and through blocking condenser 92 to the net 13. The connection to the load impedance may be made to include part or all of the load impedance between the cathode and point of connection 88. The network indicated as comprising impedances 89, 90 and 91 may vary widely as to design, to have any suitable relation between feedback voltage and frequency or any suitable phase shift characteristic. In particular, if the circuit is used as a stage in a reverse-feedback amplifier, excessive phase shift is to be avoided. By feeding back in this manner from the plate circuit impedance to the net an increase in gain is obtainable and the frequency or phase characteristic is subject to control by the design of the network 89, 90, 91.

The invention is not to be construed as limited to the types of circuits specifically chosen for illustration, but its scope is indicated by the appended claims.

What is claimed is:

1. In a cascaded amplifier having in each of a plurality of stages a tube having cathode, anode, control grid and space-charge grid elements, capacitive coupling impedance between said two grids in each of said stages and a resistive impedance between the space charge grid and cathode, the corresponding ends of said last impedances in said stages being at ground potential.
2. In a cascaded amplifier including in each of a plurality of stages a tube having cathode, anode, control grid and space charge grid elements, an alternating current connection from the said grids in each stage to the cathode including impedance in common whereby the grid-cathode circuits in the same stage are coupled, the cathode end of said grid-cathode circuits in each stage being at alternating current ground potential, and a suitable input wave coupling connected to the control grid and the cathode, said impedance in common to said alternating current grid-to-cathode circuits comprising a portion of an impedance connected across said input wave coupling.
3. In a cascaded amplifier including in each of a plurality of stages a tube having cathode, anode, control grid and space charge grid elements, all stages having their cathodes at the same alternating current potential, impedances connected in each stage between the cathode and each of the other recited elements of the tube, certain of said impedances affording a capacitive coupling between said two grids and a resistive impedance between the space charge grid and cathode.
4. A cascaded amplifier including in each of a plurality of stages a multigrid tube, a gain-

increasing regenerative coupling between a pair of grids in each of said tubes, and a gain-reducing feedback from the output side of the last to an input portion of the first of said stages.

5 5. In a plural stage amplifier, one stage comprising a multi-grid tube, a circuit connection from each of the grids to the cathode, said connections including a common impedance for coupling the grid-to-cathode circuits for increasing
10 the gain of the stage, and an over-all gain reducing feedback connection for said amplifier.

6. In an amplifier circuit, a space discharge tube having cathode, anode, control grid element and another grid, said other grid being between
15 the control grid and cathode and having a positive bias, an input circuit leading to the cathode and control grid, an impedance connected across said input circuit and a coupling from said other grid to a point on said impedance for increasing
20 the gain of the amplifier.

7. In an amplifier circuit, a stage of amplification comprising a space discharge tube having cathode, anode, control grid and a second grid, impedance between the second grid and cathode,
25 an incoming circuit leading up to the cathode and control grid, means for applying a negative bias to said control grid, a highly resistive circuit connected to the plate and cathode whereby the control-grid-to-plate capacity is in effect reflected
30 into the circuit from control grid to cathode and magnified, and means for reducing this effective capacity comprising a capacitive coupling of proper phase relation between said two grids to increase the gain of said stage, the impedance
35 between the second grid and cathode being resistive.

8. A broad band amplifier circuit comprising in one stage a space discharge tube having a pair of grids, means to bias one of said grids positive and
40 the other grid negative with respect to the cathode, and means for simultaneously reducing the effective grid-to-plate capacity and increasing the gain of said stage comprising a gain-increasing capacitive coupling between said two grids.

45 9. In combination a space discharge device having cathode, anode, control grid and space charge grid elements, means to apply positive

potential to said anode and space charge grid, an input circuit connected to said cathode and control grid, an output circuit connected to said cathode and anode, and means to improve the transmission property of said device comprising
5 an impedance providing capacitive coupling between said two grids, the effective external conductance between said space charge grid and cathode being negligibly small.

10. In an amplifier circuit for amplifying waves of a band of frequencies, a space discharge device
10 having cathode, anode, control grid and space charge grid elements, means making the anode and space charge grid each positive toward the cathode, an input circuit and an output circuit
15 therefor, the system having input shunt capacity, and means for increasing the gain of the circuit and simultaneously reducing the input shunt capacity comprising a capacitive reactance inter-coupling said grids, the effective external con-
20 ductance between said space charge grid and cathode being negligibly small throughout the frequency range of the waves being amplified.

11. In combination, a space discharge device having cathode, anode, control grid and space
25 charge grid elements, means supplying positive potential to said anode and space charge grid, an input circuit connected to said cathode and control grid, said input circuit having effective shunt capacity, and means to reduce the value
30 of said shunt capacity comprising a capacity connected between said grids, the effective external conductance between said space charge grid and cathode being negligibly small.

12. In combination, a space discharge device
35 having cathode, anode, control grid and space charge grid elements, means supplying positive potential to said anode and space charge grid, an input circuit connected to said cathode and control grid, and means for producing effective
40 negative capacity between said cathode and control grid comprising a capacity connected between said two grids, the effective external conductance between said space charge grid and cathode being negligibly small.
45

KNOX C. BLACK.