Nov. 16, 1937. H. S. BLACK 2,098,950
VACUUM TUBE CIRCUIT
Filed Sept. 25, 1934

FIG. 1

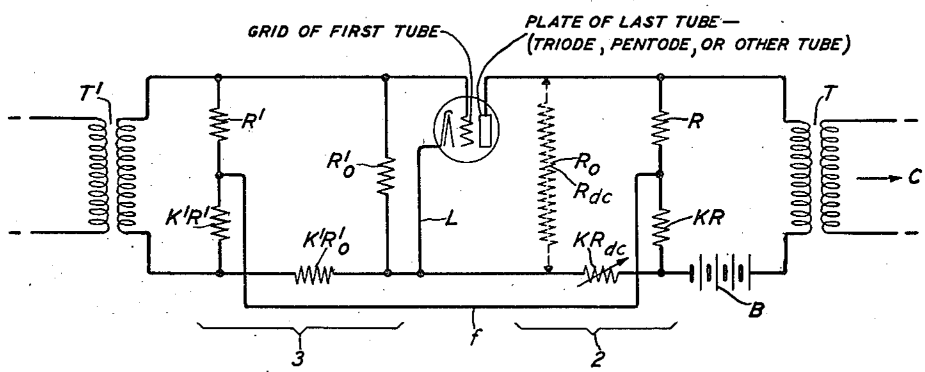


FIG. 2

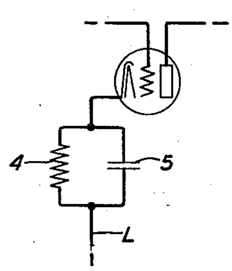


FIG. 3

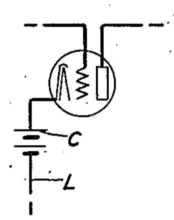


FIG. 4

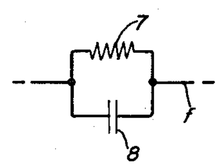
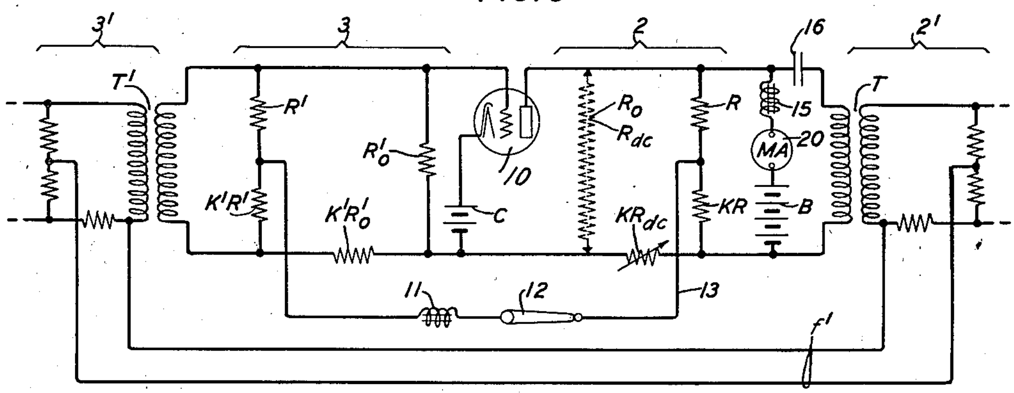


FIG. 5



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VACUUM TUBE CIRCUIT

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Application September 25, 1934, Serial No. 745,420

12 Claims. (Cl. 179—171)

This application is a continuation in part of my copending applications, Serial No. 606,871 filed April 22, 1932, for Wave translation system and Serial No. 663,317 filed March 29, 1933, for Wave translation systems.

This invention relates to wave translating systems, particularly systems involving electric space discharge devices as, for example, wave amplifying vacuum tube devices.

An object of the invention is to control transmission properties of such systems as, for instance, to control impedance relations, modulations, wave reflection, cross-talk, transmission efficiency, space currents, gain-frequency relations or singing tendencies involved in such systems.

A feature of the invention relates to effecting such control by feed-back in the system. If desired, the feed-back may be negative feed-back or feed-back that reduces gain, such feed-back increasing stability of operation and reducing distortion as pointed out in the above mentioned copending applications and in my article on Stabilized Feed-back Amplifiers published in Electrical Engineering, January 1934, pages 114–120 and in the January 1934 issue of The Bell System Technical Journal, pages 1–18.

It is also an object of the invention to facilitate application of feed-back in systems such as those referred to above.

A further object of the invention is to stabilize space current of electric space discharge devices as, for example, wave amplifying vacuum tube devices.

In one specific aspect the invention is a feed-back amplifier with conjugate relation of plate current supply source and feed-back path, so that the grid to which alternating potential is fed back will not receive undesired unidirectional potential, notwithstanding omission of the stopping condenser usually employed in the feed-back path to prevent the undesired application of unidirectional potential to the grid. It is often advantageous to avoid use of the stopping condenser since its use may give rise to troublesome phase shift problems at low frequencies because of its impedance and at high frequencies because of its capacity to ground.

The amplifier may be, for example, a negative feed-back amplifier. The loop transfer constant, (i. e. the transfer constant for propagation once around the feed-back loop) may be so large that unity is negligible in comparison, in which case the feed-back divides the amplification and modulation produced by the amplifier by approximately the loop transfer constant, as pointed out in the above mentioned publications and copending applications. The unidirectional plate potential for the last stage may be supplied by a source of voltage included in one diagonal of a bridge network which has the feed-back path in its other diagonal and the bridge may be balanced for direct current so that unidirectional potential from the plate potential supply source is suppressed from the feed-back path and consequently from the grid to which the alternating potential feed-back is applied. The plate-cathode path in the last tube of the amplifier may be in one ratio or balancing arm of the bridge, the outgoing load circuit may be in the diagonal with the plate current supply source, and the load circuit may include an amplifier output transformer matching the output impedance of the amplifier and the load impedance.

The direct current plate-cathode impedance in the tube may differ widely from the alternating current value for example, being approximately twice the alternating current value in usual triodes and of the order of one-tenth of the alternating current value in the case of usual power pentodes. In such cases, the bridge will be unbalanced for alternating current and feed-back will change the amplifier output impedance.

As disclosed in the above mentioned copending application, Serial No. 663,317, the negative feed-back tends to make the amplifier output impedance independent of the impedance value of the bridge arm containing the space discharge path, i. e., the R_0 arm, and changes the amplifier output impedance to render it less different from the value it would have if the bridge were rebalanced by adjustment of the impedance of the R_0 arm. As disclosed in that application, if the negative feed-back is made large, its impedance stabilizing effect is powerful, or in other words, when unity is made negligibly small in comparsion to the loop transfer constant, the amplifier output impedance can be made to approach or approximately equal the value it would have if the bridge were balanced by adjustment of the R_0 arm, and to become substantially independent of the impedance of that arm. Thus, as disclosed in that application, the output transformer ratio can be given the value proper for matching the amplifier output impedance and the load impedance.

In the case of the triodes, the tube then ordinarily will work not into a matching impedance but into an impedance approximately twice as great (or equal to its direct current impedance) which has been found a favorable condition of operation, for example, for reducing modulation.

In the case of the power pentodes, it is ordinarily desirable that the tube work into an impedance only a fraction, for instance a fifth or a sixth, of its matching impedance, and moreover, when the bridge is adjusted for the direct current balance, the feed-back ordinarily lowers the amplifier output impedance by approximately the ratio of the alternating current and direct current impedances of the tube or of the bridge arm containing the space discharge path. Consequently, in the case, for instance, of cable carrier or open wire carrier systems with the amplifier output transformer required to match the amplifier output impedance to a 140 ohm line or a 600 ohm line, respectively, the use of the direct current bridge balance with the power pentode does not necessitate an impracticable or inconvenient transformer ratio, even though the impedance match is required over a wide frequency band.

With the space current supply source in the load diagonal of the bridge, ordinarily the source is very efficiently used, nearly all of its voltage being applied across the plate and cathode and but little of its energy being dissipated in the bridge impedances other than the plate-cathode impedance in the tube.

By unbalancing the bridge for direct current and controlling the degree of unbalance, the transmission of unidirectional voltage from plate current supply source to grid through the feed-back path of the amplifier can be controlled as may be desired. For example, the direct current impedance of a triode in general increases with hours of use of the cathode, and, if desired, the space current decrease that would result can be avoided by having negative bias of the grid decrease in response to unbalancing of the bridge for direct current by the increase of the direct current impedance of the tube as referred to more in detail hereinafter.

If desired, the space current compensation thus effected by the unbalance can be measured, for example as indicated hereinafter, for determining when the tube is in such condition that it should be retired from service.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 of the accompanying drawing shows schematically a vacuum tube amplifier circuit embodying a form of the invention;

Figs. 2 and 3 show examples of grid biasing means that may be used in connection with the circuit of Fig. 1;

Fig. 4 shows means suitable for connection in the feed-back path of the amplifier of Fig. 1 for preventing application of undesired grid bias by suppressing transmission through that path of unidirectional voltage resulting from variation of space discharge path impedance for direct current; and

Fig. 5 shows a modification of the circuit of Fig. 1.

For any given frequency, the impedance of a network between any two points is considered the ratio that a voltage applied across the points from an external network would bear to the internetwork current.

The amplifier of Fig. 1 comprises one or more stages of vacuum tubes, as for example, three stages. It has a feed-back path *f*. An output bridge **2** connects the final stage to the feed-back path and to amplifier output transformer T. An input bridge **3** connects the first stage to amplifier input transformer T' and to the feed-back path. The feed-back path is in one diagonal of the input bridge and in one diagonal of the output bridge. In the input bridge the other diagonal includes the input transformer, and in the output bridge the other diagonal includes the output transformer or load and the plate current supply source B, which may be any suitable source of unidirectional voltage.

The input and output transformers may connect the amplifier in a cable carrier telephone or other circuit, the amplifier then being used for example for simultaneously amplifying a plurality of telephone messages, all transmitted together over the cable carrier circuit from multiplex carrier transmitting apparatus (not shown). Transformer T may be considered part of the receiving circuit or load, the amplifier output impedance being considered the impedance facing the primary or high impedance winding of transformer T.

The amplifier may be of the general type of those shown for example in Figs. 5, 56 and 57 of the above mentioned copending application, Serial No. 606,871 and Fig. 2 of the above mentioned publications, each of those amplifiers having a feed-back path connected between output and input bridges. The feed-back may be negative feed-back, and the amount of feed-back may be large. the absolute or scalar value of the loop transfer constant being, for example, of the order of 50 or 100 in the utilized frequency range, as in the case of the negative feed-back amplifier of Fig. 57 or Fig. 2 just mentioned.

The arms of the output bridge and their direct current impedance values for a balanced condition of the bridge for direct curent are represented by R_{dc}, KR_{dc}, R and KR, R_{dc} being the arm including the space discharge path of the tube (or tubes) of the final stage of the amplifier. The alternating current impedance of this arm is designated R_o. The arms of the input bridge, and alternating current impedance values for alternating current balance of the bridge, are represented by R'_o, $K'R'_o$, R' and K'R'. The bridge arms may be resistances or any suitable impedances. Ordinarily it is desirable, for avoiding undue loss in transmission to the load, that, as regards alternating current impedances, KR_{dc} be small and R large compared to the load impedance; and consequently the impedance into which the tube works is not materially different from the load impedance or high side impedance of the output transformer.

It is usual to employ a stopping condenser in the feed-back path. The use of the stopping condenser may give rise to troublesome phase-shift problems, and can be avoided, in accordance with the invention, by balancing the output bridge for direct current, so source B can not apply unidirectional potential to the grid through *f*, notwithstanding omission of the stopping condenser from path *f* so that there is a conductive connection from source B to the grid through *f*. While undesired application of unidirectional voltage from the space current supply source to the grid through the feed-back path might, in some cases, be avoided by employing a transformer in the feed-back path, connection of a transformer in the feed-back path is often objectionable, for example as producing troublesome singing tendency in the amplifier, either within the utilized frequency range or outside of that range. The suppression of transmission of unidirectional voltage from the space current supply source to the grid through the feed-back path by balancing the output bridge for direct current in accordance with the invention, is useful also in cases in which a phase reversal is introduced in the feed-back, without a transformer, for example by reversing the feed-back leads as in E. Peterson Patent No. 1,955,327, issued April 24, 1934. The reversal of the feed-back leads may be desirable, for example, due to the number of stages in the amplifier being even, or because of the phase-frequency characteristic of the feed-back loop.

The tube (or tubes) of the final stage of the amplifier may be of any suitable type, as for example a heater type triode or power pentode. If the tube be a triode, R_{dc} ordinarily is approximately 2 R_o. If the tube be a power pentode, its D. C. impendance R_{dc} may be, for example, a tenth of its alternating current impedance R_o. In either case, if each of the arms R, KR and KR_{dc} of the output bridge has its alternating current impedance equal to its direct current impedance, the bridge, when balanced for direct current, will be unbalanced for alternating current.

Nevertheless, the amplifier output impedance then can be matched to the load impedance by making the primary-to-secondary impedance ratio of the transformer

$$(1+K)\left(\frac{RR_{dc}}{R+R_{dc}}\right):c,$$

where c is the impedance of the cable or circuit facing the secondary winding. As indicated above, though K is small, doubling the alternating current impedance of the KR_{dc} arm will approximately double the amplifier output impedance, and reducing the alternating current impedance of the KR_{dc} arm 90 per cent will reduce the amplifier output impedance approximately 90 per cent.

If desired negative grid bias for any of the tubes of the amplifier of Fig. 1 may be supplied by the usual bias resistor and by-pass condenser in the cathode lead common to the external cathode-grid circuit of the tube (or tubes) whose grid structure is to be biased and an appropriate one (or appropriate ones) of the external cathode-anode circuits of the tubes. For example, as indicated by Fig. 2, the bias may be supplied by resistor **4** and by-pass condenser **5** connected in cathode lead L. By making condenser **5** of large capacity, alternating current feed-back from resistor **4** is reduced. The impedance of the resistor and condenser will be included in R_o and R_{dc}, since they are in the bridge arm with the space discharge path.

If desired negative grid bias for any of the tubes of the amplifier of Fig. 1 may be supplied by the usual grid-bias battery connected at a suitable place in the external circuit between the cathode and grid of the tube, as for example, battery C in the cathode lead L as indicated by Fig. 3.

If, due to variation in R_{dc}, a unidirectional voltage is applied to the feed-back path in the circuit of Fig. 1, and for any reason it is desired not to feed back direct current, then a direct current filter, (i. e. a filter offering high attenuation to all very low frequencies) may be used in the feed-back path f to suppress this voltage, as indicated for example by Fig. 4, showing a filter comprising high resistance **7** and by-pass condenser **8** connected in parallel to each other in series in the feed-back path f.

In the circuit of Fig. 1, instead of balancing the output bridge for direct current, it can be so unbalanced as to supply unidirectional grid biasing voltage through f. For example, increasing the impedance of the KR_{dc} arm above the value required for direct current balance of the bridge, or reducing the impedance of the KR arm below the value required for direct current balance, produces negative biasing potential on the grid. This bias method can automatically compensate for changes in R_{dc}. For example, if R_{dc} increases due to the usual increase of tube resistance with the number of hours the tube has been in use, the negative bias is automatically reduced. This assumes that if the grid to which the direct current from the output bridge is applied is a grid of a stage other than the last stage, the interstage couplings will transmit the direct current so that it will be propagated to the grid structure of the last stage.

Fig. 5 shows a modification of the circuit of Fig. 1 in which a tube **10** has input and output bridges connecting it between input and output transformers, as in Fig. 1, but a choke coil **11** and switch **12**, adapted for testing tube **10** as described below, are included in series in path **13** which is in the bridge diagonals opposite those that include the transformers. The choke coil prevents feed-back of alternating current through **13**. If desired, an alternating current feed-back path can be provided. For example, a feed-back path f' can be connected to produce negative feed-back from a bridge network **2'** on the secondary or low impedance side of the output transformer to a bridge network **3'** on the primary or low impedance side of the input transformer. This feed-back through bridges outside of the amplifier input and output transformers is disclosed in Figs. 38 and 73, for example, of the above mentioned copending application Serial No. 606,871. If desired, either or both of the bridges **2'** and **3'** can be omitted, the feed-back voltage for transmission through f' being obtained, for example, from across the low impedance winding of the output transformer and applied, for example, across the low impedance winding of the input transformer, as disclosed in Fig. 69, for example, of the copending application just mentioned.

In Fig. 5 the battery B is shown in shunt to the primary winding of transformer T, instead of in series with it as in Fig. 1. The usual alternating current choke **15** and direct current stopping condenser **16** prevent the battery from shunting alternating current around the winding or transmitting direct current through the winding. A milliammeter **20** is provided for reading the direct current space current. It is shown in the bridge diagonal that includes the B battery, since the current flowing from the battery through R and KR is negligibly small. However, if desired the milliammeter may be connected, for example, in the KR_{dc} arm.

In normal operation, battery C may provide the normal negative grid bias required, switch **12** may be closed, and the bridge **2** may be balanced for direct current, substantially no grid bias voltage being supplied from battery B through path **13**. Then as R_{dc} tends to increase with long use of the tube, the resulting tendency to unbalance of the bridge tends to apply positive potential to the grid from battery B through path **13**, thus tending to lower the negative potential of the grid so as to maintain the tube impedance and space current constant. To tell whether the tube has deteriorated to such extent that it should be retired from service, switch **12** can be opened and the resulting change in the milliammeter reading observed.

What is claimed is:

1. A space discharge device having a space current supply source and feed-back path, and circuits connecting the source and the path in conjugate relation to each other with respect only to steady unidirectional voltage and supplying a current from the source to the device and a current from the device to the path.

2. A wave translating device having a space discharge path and a space current supply source and having a circuit connected from output to input, and means connecting said source and circuit in a bridge network whose degree of balance for direct current differs from that for alternating current and controls transmission of steady unidirectional voltage from the space current supply source through said circuit to the input.

3. A space discharge device having a space discharge path, a space current supply source connected to said discharge path and a feed-back path connected to said discharge path, and a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source to the feed-back path, said bridge circuit having said space discharge path as a balancing arm of the bridge circuit and having said space current supply source and said feed-back path in diagonals of the bridge circuit that are conjugate at balance of the bridge circuit.

4. A space discharge device having a space discharge path, a space current supply source connected to said discharge path and a feed-back path connected to said discharge path, and a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source to the feed-back path, said bridge circuit having said space discharge path in a balancing arm of the bridge circuit and having said space current supply source and said feed-back path in diagonals of the bridge circuit that are conjugate at balance of the bridge circuit, and having a load circuit for said device in the branch that includes said space current supply source.

5. A space discharge device having a space discharge path, a space current supply source and a grid bias circuit all in a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source to the grid bias circuit and one of whose balancing arms includes said space discharge path and has substantially different impedance for alternating current than for direct current.

6. A space discharge device having an anode, a cathode and space discharge control means, a source of space current therefor, a circuit for supplying biasing potential to said control means, and means connecting said biasing circuit, said space current source and the anode-cathode space discharge path of said device in a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from said space current source to said biasing circuit, with the space discharge path a balancing arm of the bridge circuit and the space current source and the biasing circuit in diagonals of the bridge circuit that are conjugate at balance of the bridge circuit.

7. A space discharge device having a space discharge path, a space current supply source and a grid bias circuit all in a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source to the grid bias circuit and one of whose balancing arms includes said space discharge path, said grid bias circuit comprising a choke coil and a switch in series therein.

8. A wave translating device having a space discharge path and a space current supply source and having a circuit connected from output to input, and means connecting said source and circuit in a bridge network whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source through said circuit to the input, the impedance of a balancing arm of the bridge network being determined principally by said space discharge path.

9. The method of operating a retroactive space discharge device having space current supply source and a feed-back path in a bridge circuit, which comprises determining the impedance of one of the bridge balancing arms principally by the impedance of the space path of the device, and controlling the transmission of steady unidirectional voltage from the space current supply source to the feed-back path by control of degree of balance of the bridge circuit for direct current.

10. The method of operating a space discharge device having a space discharge path, a space current supply source and a grid biasing circuit all in a bridge circuit, which comprises controlling the transmission of steady unidirectional voltage from the space current supply source to the grid biasing circuit by control of degree of balance of the bridge circuit for direct current and maintaining the impedance of one of the bridge balancing means different for alternating current than for direct current.

11. A wave translating device having a space discharge path and a space current supply source and having a feed-back path providing negative feed-back of alternating voltage with the transfer constant for propagation once around the feed-back loop large compared to unity, and a bridge circuit whose degree of balance for direct current controls transmission of steady unidirectional voltage from the space current supply source to the feed-back path, said bridge circuit having said space discharge path in a balancing arm of the bridge circuit and having said space current supply source and said feed-back path in diagonals of the bridge circuit that are conjugate at balance of the bridge circuit.

12. A circuit comprising a wave translating device having a space discharge path and a space discharge control grid, a space current source for supplying space current to said path, means for supplying to said grid steady unidirectional biasing potential variable in response to changes in impedance of said space discharge path and substantially zero when said impedance has its normal value, means operable for rendering said first mentioned means ineffective without interrupting said space current, and means for measuring said space current.

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