March 10, 1936.

E. B. FERRELL

2,033,136

WAVE TRANSLATION SYSTEM

Filed Jan. 25, 1934

FIG. 1

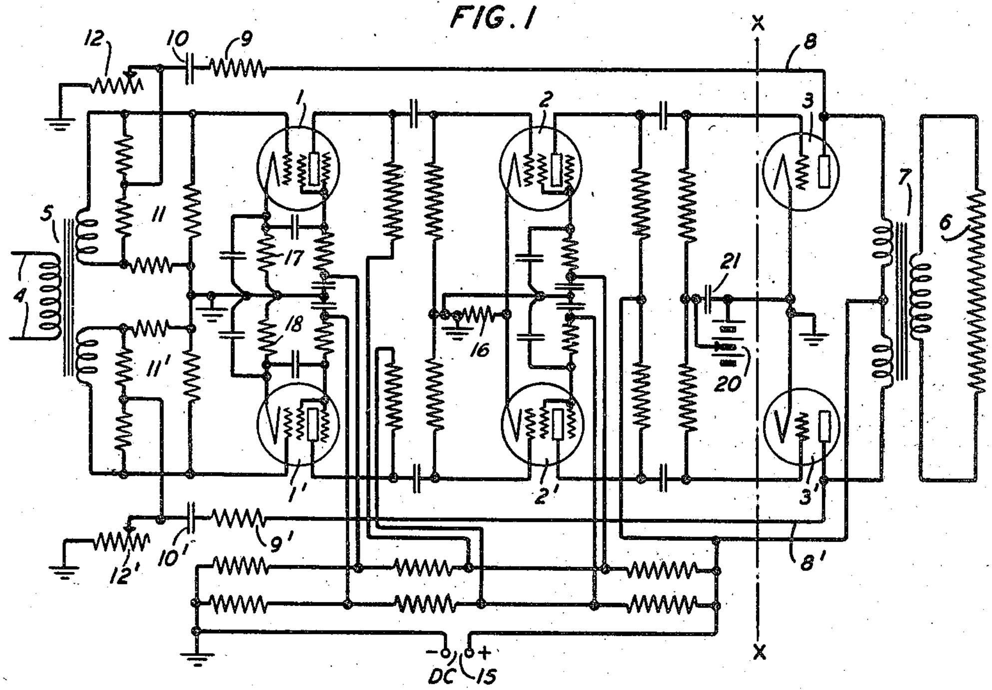


FIG. 2

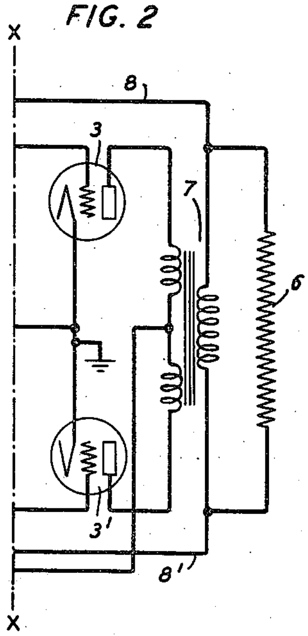
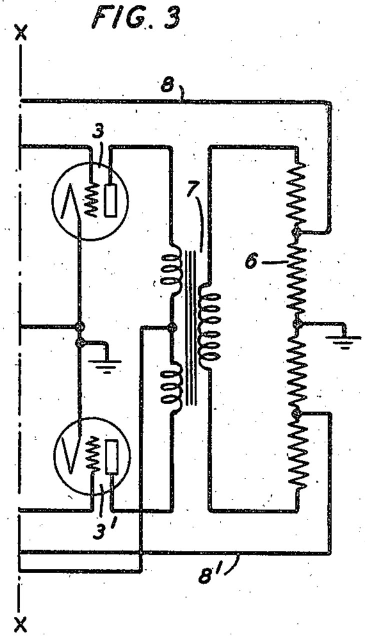


FIG. 3



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WAVE TRANSLATION SYSTEM

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13 Claims. (Cl. 179—171)

This invention relates to wave translation, and especially to retroaction or feedback in wave translating systems, as for example, in systems involving vacuum tube amplifiers.

An object of the invention is to obtain high efficiency and low distortion in such systems.

In one specific aspect the invention is a class B amplifier with negative feedback, or a negative feedback amplifier operating with steady grid potential just sufficient to extinguish or to nearly extinguish plate current in the absence of alternating grid excitation, or operating with input potential that varies sufficiently to cause interruptions of plate current. In this aspect the invention may be an amplifier of the general type, disclosed for example, in the copending application of H. S. Black, Serial No. 606,871, filed April 22, 1932, for Wave translation systems, the paper on Stabilized Feed-Back Amplifiers by H. S. Black in Electrical Engineering, January, 1934, pages 114 to 120, H. Nyquist Patent 1,915,440, June 27, 1933, British Patent 317,005, or British Patent 371,887, in which waves including waves of the frequency range of the fundamental or applied waves, are so fed from the output to the input of the amplifier as to reduce their output amplitude and render modulation or distortion generated in the amplifier less than without feedback. It has been found that, by this negative feedback and the above mentioned operation of the amplifier as a class B amplifier or operation with the interruptions of plate current, an important improvement can be obtained in efficiency, without entailing increase of harmonics or other distortion products.

The invention, in its aspect referred to above, may be a push-pull amplifier if desired, i. e., a duplex amplifier circuit with the input voltage applied to the balanced input circuits in phase opposition and the energy from the balanced output circuits combined cumulatively for odd order voltage components and differentially for even order voltage components. It has been found that the push-pull or balanced operation can increase the permissible negative grid bias and yield important increases in efficiency and in distortion reduction. If desired, the waves to be fed back from the amplifier output to the amplifier input may be derived from the combined energy of the balanced output circuits, so that the balancing action reduces the feedback of even order products of modulation. The balancing before feedback has been found effective in reducing modulation. Such balancing prevents passage of direct current around the feedback loop.

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

Fig. 1 shows an example of a push-pull, negative feedback amplifier embodying the aspect of the invention referred to above; and

Figs. 2 and 3 show modifications of the amplifier of Fig. 1.

The amplifier of Fig. 1 is shown by way of example as a three-stage amplifier with screen grid tubes 1 and 1′ in the first stage and 2 and 2′ in the second stage. Tubes 3 and 3′ in the third stage are operated as a class B amplifier stage (i. e. operated with their steady grid potential just sufficient to extinguish or to nearly extinguish their plate current in the absence of input from the preceding stage) or are operated with their grids driven by the excitation voltage to voltages beyond the cut-off voltage, i. e., the voltage just sufficient to cut off the plate current. Thus, the plate current of each of the tubes 3 and 3′ flows in pulses and becomes zero at times during operation of the amplifier, the duration of the periods for which the space current of the tube is zero depending upon the duration of the swings of the exciting voltage below the value which, when added to the value of any steady or biasing voltage employed, gives a grid voltage equal to the cut-off voltage. The amplifier of Fig. 1 is suitable for various purposes. For example, it may be employed as a speech amplifier, or amplifier of audio-frequency waves of a frequency band including the speech frequency range, the last stage serving as a power amplifier. The incoming circuit 4 then may be, for instance, a source of waves of speech frequencies, connected to input transformer 5; and outgoing circuit 6 connected to output transformer 7 may be any suitable load circuit for utilizing the amplifier wave of the speech or audio frequency band. As a further example, the amplifier of Fig. 1 may be employed, if desired, as an amplifier for carrier waves of one or more channels, and the incoming circuit 4 then may be, for instance, a source of carrier waves of one or more speech channels with or without associated carrier frequencies, the outgoing circuit 6 being any suitable load or work circuit. The coupling between the stages of the amplifier is shown as of the resistance-capacity type, which facilitates control of the phase of the feedback voltage and therefore is often desirable provided the class B or last stage does not draw appreciable grid current. In Fig. 1, waves are fed from the output of the amplifier to its input through a path extending from across the primary winding of the output transformer 7 through conductors 8 and 8', resistances 9 and 9' and stopping condensers 10 and 10' to input bridge networks 11 and 11'. Adjustable resistors 12 and 12' across this feedback path control the amount of feedback. The input bridges render this feedback path and the incoming circuit 4 conjugate to each other, preventing the feedback from affecting the input impedance of the amplifier, as pointed out in the above mentioned copending application or the above mentioned British Patent 371,887, or the above mentioned paper by H. S. Black. Plate and screen potentials for the tubes of the amplifier may be supplied, for example, from potentiometers shown connected across a voltage source 15, which may be a direct current generator, a rectifier or other suitable voltage source. The stopping condensers 10 and 10' not only prevents the grids of tubes 3 and 3' from being affected by the steady potentials that the plates of those tubes assume in the absence of waves incoming from circuit 4, but moreover prevent passage of the direct current component of the output wave of the amplifier around the feedback loop. The push-pull or balancing action of the amplifier also prevents this direct current component from passing around the feedback loop. The loop gain of the amplifier or gain in a single trip around the loop may be large compared to unity, for producing large reduction of distortion by the negative feedback; and the gain of the forwardly transmitting portion of the amplifier, i. e., the gain of the amplifier from the grids of the first stage to the fictitious plate generator of the space paths of the last stage may be large compared to unity, for providing large overall amplifier gain nothwithstanding the large reduction of distortion and gain by the large amount of negative feedback.

The class B stage or last stage of the amplifier may be any one of several types. For example, in one type of tube a comparatively high μ is used and the tube is operated near cut-off with zero grid bias, grid biasing battery 20 and its bypass condenser 21 shown in Fig. 1 being omitted. In a second type a tube of low μ is used and a large bias provided, for example, by battery 20 by-passed by condenser 21, is required to bring it to cut-off. The first type has the advantage of requiring no extra equipment to supply bias. This is important in low power sets where the other tubes of the amplifier can be biased by means of resistors such as 16, 17 and 18 between cathode and ground and thus all bias supply equipment avoided. However, with this first type the grid goes positive for half the cycle and thus throws a heavy and distorting load on the previous stage. In high power installations this load may become quite serious because of the size of driver stage required. It is then desirable to use in the last stage a low μ tube of such characteristics that its full rated power output can be obtained without driving the grid positive. In high power sets, the saving effected by reducing the required power output of the driving stage will usually more than offset the added expense of the bias supply. Compromise can be made between these two types of tube for use in the last stage, but then the tube requires a biasing voltage as well as a large amount of driving power to drive its grid positive.

If the tube is operated near cut-off, plate current will flow for a little more than half of each cycle.

To facilitate obtaining a good compromise between low distortion and low stand-by power consumption, it is often desirable to choose a value of grid bias that allows some idle current to flow, rather than to choose a value of grid bias that extinguishes the plate current in the absence of grid excitation voltage.

Figs. 2 and 3 show modifications of the circuit of Fig. 1 as regards the manner of obtaining the voltage to be fed back. Fig. 1 shows shunt feedback from the primary winding of the output transformer 7; Fig. 2 shows shunt feedback from the secondary winding of the transformer; and Fig. 3 shows series feedback from the load on the secondary winding of the transformer, the feedback voltage being proportional to the load current. The broken line X—X in Figs. 1, 2 and 3 indicates that the systems of these three figures are the same except as regards the portions shown to the right of that line. However, the stopping condensers such as 10 and 10' may be omitted when the voltage to be fed back is obtained as in Fig. 2 or Fig. 3, since the output transformer 7 does not transmit direct current from its primary winding to its secondary winding.

In each of the three figures, the voltage to be fed back is obtained from the combined outputs of the two sides of the push-pull or balanced system, so that the balancing action reduces the feedback of even order products of modulation, and prevents the direct current component of the output from passing around the feedback loop.

What is claimed is:

1. A wave translating system comprising an electric space discharge device having anode, cathode and discharge control means, means for supplying anode potential for said device, means for normally biasing said control means to a potential of algebraic value at least as high as the critical value at which anode current extinction takes place, a source of input waves for said device of amplitude such that anode current of said device is extinguished during an appreciable portion of their negative swing, and means for producing negative feedback in said device and normally rendering its loops gain large compared to unity for fundamental wave components.

2. A wave translating system comprising an electric space discharge device, means for producing space current in said device, means normally providing for said device space current reducing effect substantially just sufficient to reduce space current of the device to zero value, and means for producing negative feedback in said device.

3. A wave translating system comprising an electric space discharge device having anode, cathode and discharge control means, means for producing anode current in said device, means for normally biasing said control means to a potential substantially just sufficient to reduce anode current of said device to zero value, and means for producing feedback in said device of waves that reduce the magnitude of its output waves below their value without feedback.

4. A wave translating system comprising an electric space discharge device having anode, cathode and grid structure, means for producing negative feedback in said device and normally rendering its loop gain large compared to unity for fundamental wave components, and means for biasing said grid structure to a potential substantially just sufficient to reduce space current of said device to zero value.

5. A wave translating system comprising an

electric space discharge device, a source of input waves therefor, means for causing space current of said device to be zero during an appreciable portion of the negative swing of the waves from said source but finite in the absence of said waves, and means for producing feedback in said device of waves that reduce the magniture of its output waves below their value without feedback.

6. A wave translating system comprising an electric space discharge device having anode, cathode and grid structure, a source of input waves for said device, means for producing negative feedback in said device, and means for normally biasing said grid structure to a potential that causes anode current of said device to be finite in the absence of said waves but to be extinguished during a considerable portion of the negative swing of the waves from said source.

7. A wave translating system comprising an electric space discharge device having anode, cathode and discharge control means, means for supplying anode potential for said device, means for normally biasing said control means to a negative potential of numerical value at least as low as that at which anode current extinction takes place, a source of input waves for said device of amplitude such that anode current of said device is extinguished during a considerable portion of their negative swing, and means for producing negative feedback in said device of waves to the exclusion of direct current.

8. A wave translating system comprising an electric space discharge device having anode, cathode and grid structure, means for supplying anode potential for said device, means for normally biasing said grid structure to a negative potential of numerical value at least as low as that at which anode current extinction takes place, a source of input waves for said device of amplitude such that anode current of said device is extinguished during a considerable portion of their negative swing, means cooperating with said device to form a closed feedback loop for producing negative feedback in said system, and means in said loop for preventing passage of direct current around the loop.

9. A wave translating system comprising a wave source, a load, electric space discharge devices in push-pull connection, with their input and their output connected respectively with said source and said load for transmission through the devices from the source to the load, means for interrupting space current of each of said devices during a considerable portion of the negative swing of the waves from said source with respect to the device, and means for producing in said devices negative feedback of waves that reduce distortion in said transmission, and that are derived from the combined push-pull output of said system, whereby even-order components of the output waves of said devices are reduced by the balancing action of the push-pull connection before being fed back.

10. A wave translating system comprising a wave source, a load, electric space discharge devices in push-pull connection, with their input and their output connected respectively with said source and said load for transmission through the devices from the source to the load, means for interrupting space current of each of said devices during a considerable portion of the negative swing of the waves from said source with respect to the device, and means for producing negative feedback in said devices of waves that reduce distortion in said transmission caused by space current interruptions.

11. A wave translating system comprising a wave source, a load, electric space discharge devices in push-pull connection, with their input and their output connected respectively with said source and said load for transmission through the devices from the source to the load, means for causing space current of each of said devices to be zero during a considerable portion of the negative swing of the waves from said source with respect to the device but finite in the absence of said waves, and means for producing negative feedback in said devices of waves that reduce distortion in said transmission.

12. In an amplifier operated in accordance with so-called class "B" operation, in which such control-electrode potential is used that the space current is finite in the absence of waves to be amplified but is interrupted for the order of half the period of the waves being amplified, means for improving the operation comprising means feeding back a portion of the output waves in gain-reducing phase and in sufficient amount to reduce the distortion below the distortion level without feed-back.

13. In combination, an amplifier, comprising space discharge devices in push-pull relation, operated in accordance with so-called class "B" operation in which such control-electrode potential is used for each of the devices that the space current of the device is interrupted during a considerable portion of the negative swing of the waves to be amplified, and means for improving operation of the amplifier comprising connections for feeding back a portion of the output waves in gain-reducing phase and in amount sufficient to reduce the distortion below the distortion level without feed-back.

ENOCH B. FERRELL.