

Dec. 5, 1939.

L. C. PETERSON

2,181,910

WAVE AMPLIFICATION

Filed Dec. 4, 1937

2 Sheets-Sheet 1

FIG. 1

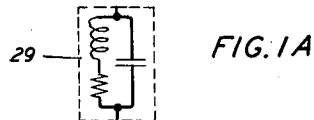
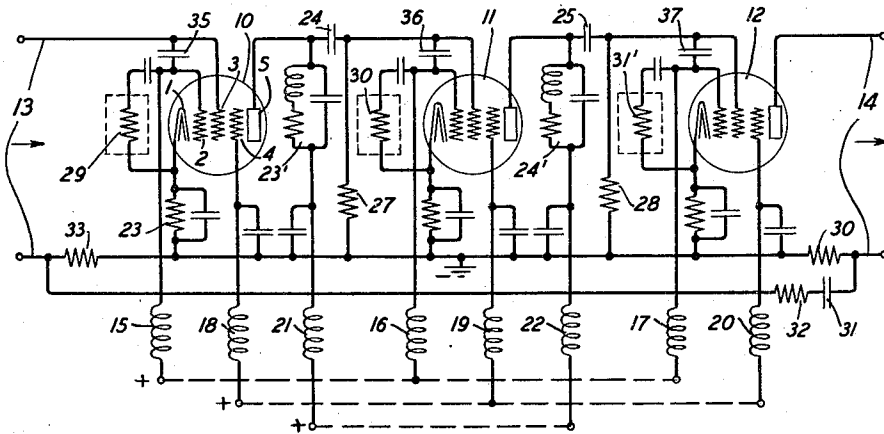
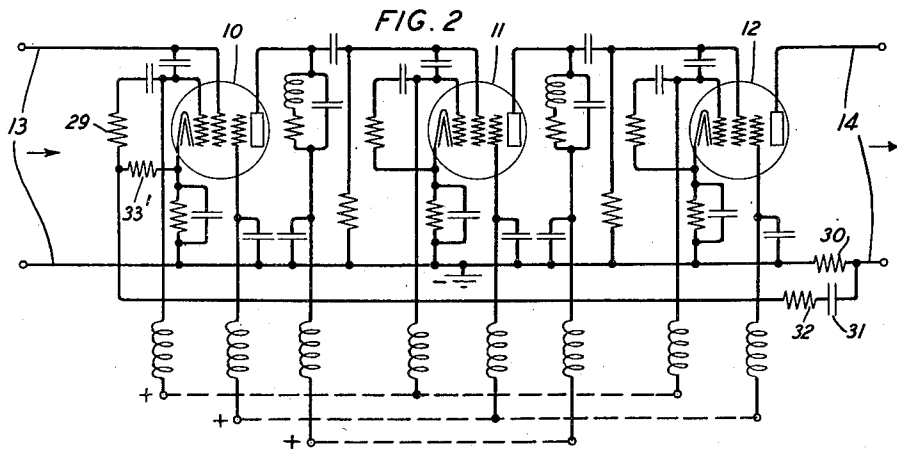


FIG. 2



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FIG. 3

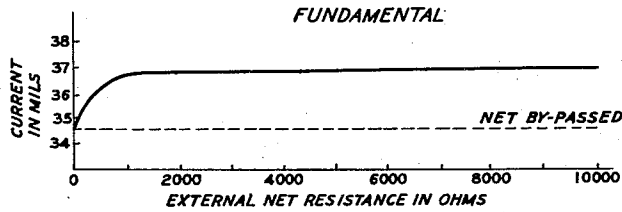


FIG. 4

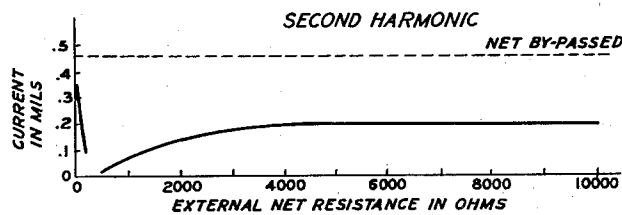
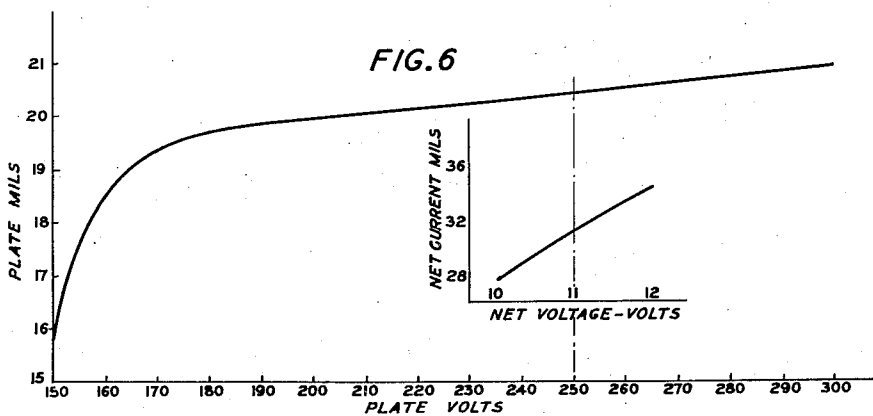
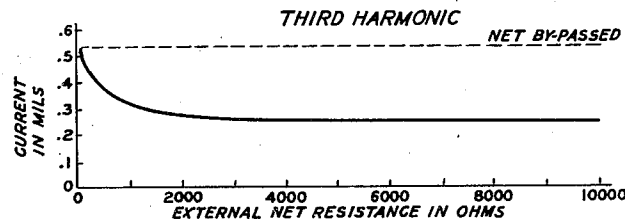


FIG. 5



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2,181,910

WAVE AMPLIFICATION

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Application December 4, 1937, Serial No. 178,058

7 Claims. (Cl. 179—171)

The present invention relates to wave translation circuits employing space discharge devices for repeating waves and more especially for amplifying waves while minimizing distortion.

The general object of the invention is an amplifier of particular construction for amplifying waves with a reduced amount of accompanying distortion.

More specifically the invention relates to amplifiers employing tubes with two grids—the usual negatively biased control grid and a positively biased space charge grid or net—with suitably constructed circuits for securing increased gain and reduced distortion.

Reduced distortion has more recently been associated with lowered gain in the so-called stabilized feedback amplifiers. With this invention, however, an increase in gain is accompanied, under certain circumstances to be outlined, with decreased distortion. An additional improvement in distortion ratio can, however, be realized, in accordance with the invention, by including amplifier stages of increased gain and lowered distortion in a circuit having over-all negative or gain-reducing feedback.

The various objects and features of the invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which Figs. 1, 1A and 2 show schematic circuit diagrams of typical amplifier circuits illustrative of the invention, and Figs. 3 to 6 show illustrative performance curves, as will presently be more fully described.

Referring first to Fig. 1, a three-stage amplifier is shown having amplifying stages 10, 11 and 12, each comprising a tube having a cathode 1, space charge grid or net 2, control grid 3, screen grid 4 and anode 5. The input is at 13 and output at 14. A common source is indicated (but not shown in detail) for supplying positive potential to the nets of all stages through connections including choke coils 15, 16 and 17. A common voltage source supplies screen grid voltage to all stages through choke coils 18, 19 and 20. Space current is supplied to stages 10 and 11 through choke coils 21 and 22, respectively, in series with coupling impedance networks 23' and 24'. By-pass condensers are shown between all of these supply connections and ground. The space current supply for tube 12 is assumed to be through the load to be connected in suitable manner at 14 but not actually shown. Negative bias for the control grids is furnished from bias resistors 23, etc., which have by-pass condensers

as usual. Interstage series coupling condensers are shown at 24 and 25; grid leaks at 27, 28 and alternating current net-to-cathode connections are shown at 29, 30 and 31' which, besides the stopping condensers, may comprise simple resistances as in Fig. 1 or reactances or complex networks of suitable type, one form being shown in Fig. 1A for illustration. An input circuit shown only in part extends through suitable input source or coupling at 13.

The circuit in Fig. 1 is shown as supplied with an over-all gain-reducing feedback path from an output circuit resistor 30 through stopping condenser 31 and resistor 32 to input resistor 33.

In accordance with a feature of this invention, a coupling impedance is connected between the control grid and space charge grid or net, comprising in Fig. 1 the condenser 35 of the first stage and corresponding condensers 36, 37 of later stages.

As pointed out in a copending application of K. C. Black Serial No. 86,778, filed June 23, 1936, a suitable impedance suitably coupled between the control grid and net increases the gain of an amplifier stage materially. The condensers 35, 36 and 37 shown in Fig. 1 serve to increase the gain in the manner taught by Black by increasing the control grid-to-cathode impedance due to the effect of negative transconductance from control grid to net, as referred to below. They also, by virtue of the resulting feedback between control grid and net, serve to reduce materially the shunt capacity across the input terminals.

I have discovered, in accordance with this invention, that under certain conditions it is possible to obtain, along with the increased gain and lowered shunt capacity as disclosed by Black, a material reduction in distortion. Thus, apparently, for the first time there are secured in one and the same circuit increased gain and increased purity of output.

These effects are dependent upon particular tube characteristics which applicant has found by test exist in certain available types of tube, such as Western Electric types 7575F and 291A and the RCA type 6A7. In each of these there is negative transconductance from control grid to net, taking the transconductance from control grid to anode as positive. Where the external impedance 29 between net and cathode is so high that the internal impedance between these elements is controlling, the transconductance of the amplifier stage is at maximum value and made up of two parts, first, that from control grid to anode and, second, the product of the transcon-

ductance from net to anode and the amplification factor from control grid to net. These are additive in their effects. While this completely determines the maximum gain obtainable, there is an additional factor determining the distortion.

As is well known, the anode current wave of a grid-controlled tube is not an exact replica of the input voltage wave but contains certain distortion products which can be expressed mathematically as terms in a power series. These terms first appear in the expression for the plate current; they are not present in the expression for the grid wave, which may, for example, be of simple sinusoidal form. Considering now that the net-cathode space path is also a current-carrying path in which the current is a function of the control grid voltage, it occurred to applicant that use might be made of the distortion products in the net current to oppose the distortion products in the anode current and reduce the magnitude of the latter. One possible explanation to account for this action is as follows. A convenient convention often used to account for plate current distortion in a triode is to assume first that the tube has a perfectly linear amplifying characteristic and then to assume the existence of a fictitious source of distortion voltage at some point in the circuit. This fictitious source may be assumed in the plate-cathode circuit or in the grid-cathode circuit, having due regard to magnitude and sign. With a proper shape and magnitude of distortion voltage such an ideal circuit would produce plate current containing the same signal and distortion components as occur in the case of an actual triode. Conversely, a fictitious source of distortion voltage, for example in the grid circuit of a triode, can neutralize or reduce the plate current distortion provided the shape, magnitude and sign of the fictitious voltage are properly chosen.

Now if we have a multigrid tube in which amplification is produced between voltage waves applied to the negative grid and the resulting voltage waves in the net circuit the distortion products in such current may be thought of as arising from a fictitious generator of distortion voltage situated between the cathode and net. But it is clear that variations in the net potential are repeated into the anode circuit in amplified form because of the transconductance factor from net-to-anode circuits. For example, in the simple case of second order distortion a second order type of fictitious voltage of proper magnitude and sign in the net circuit would neutralize or reduce second order plate current distortion. In order to neutralize or reduce some other type of plate current distortion the corresponding type of fictitious voltage must be assumed in the net circuit.

The warrant for assuming a fictitious distortion voltage in the net circuit is based in reality on the fact that the static characteristic of the net-cathode circuit is non-linear, and the kind of non-linearity determines the type of distortion. It follows then that if the non-linearity of the static characteristic of the net-cathode circuit is suitably related to the non-linearity of the static characteristic of the anode-cathode circuit the resulting distortions in the two circuits may be made to oppose each other. A necessary condition for this to happen is that the static characteristics of the plate circuit and of the net circuit have similar shape in the region of the operating point. Applicant has found that under

these conditions a material reduction in plate current distortion is realized.

For example, referring to the curves of Figs. 3, 4 and 5, which are mostly self-explanatory, it was found that when the net-to-cathode circuit was not short-circuited (by-passed) there was an increase in gain of the fundamental, accompanied by a reduction of both second harmonic and third harmonic components. For these curves the operating point corresponded to +11 volts on the net and +250 volts on the plate with an alternating current voltage swing no greater than the region indicated in Fig. 6 by the fragment of the net characteristic and the portion of the plate characteristic opposite which it is placed. That is, the signal applied to the control grid produced a voltage swing of ± 1 volt maximum value in the net voltage and a voltage swing of $\pm$ about 15 volts maximum in the plate voltage. Both characteristics had slight downward curvature throughout the operating range, hence were of the same general shape throughout the operating range.

For these curves, a single stage similar to one of the stages of Fig. 1 was employed, (without, of course, the external negative feedback path to 33). A fixed capacity of 98.2 micro-microfarads was used for condenser 35 and the plate load was 6000 ohms, the tube being Western Electric 7575F type. It will be noted that the curve in Fig. 4 indicates a minimum point for second harmonic corresponding to a value of external net impedance about half the internal net impedance. The curve is left broken in this region since its exact shape was not determined in the vicinity of the minimum point.

The circuit of Fig. 2 differs from the circuit of Fig. 1 only in the manner in which the overall external feedback path is connected. In Fig. 2 the feedback is brought to a point in the net circuit instead of in the control grid circuit.

It was pointed out above that it is advantageous to have the net-to-plate transconductance as large as possible for largest increase in gain, largest reduction in shunt capacity and largest improvement in distortion. When this condition holds, it is also advantageous to use the net for the negative feedback connection to enable large reduction in gain to be realized and at the same time (and in any case to) keep the feedback path independent of the input circuit, thereby avoiding the unfavorable impedance relations that might exist in some cases if the feedback path were connected directly to the control grid. The Fig. 2 type of connection also eliminates from the feedback path some parasitic elements such as shunt capacity of input transformer or other apparatus connected to the control grid.

One of the important advantages achieved by the invention is the reduction in distortion by the net-to-grid coupling already described. For a given gain and signal-to-distortion ratio in an amplifier such, for example, as is illustrated in Fig. 1 or Fig. 2, the reduction in distortion in individual stages eases the requirements placed on the characteristic of the amplifier as a whole, that is, on the gain and phase requirements of the amplifier-feedback loop. As is known, in broad band negative feedback amplifiers a singing tendency develops at high frequencies (generally much higher than the utilized range) due to the shunt impedances becoming predominantly capacitive. If the phase changes sign before the gain falls to zero as the upper limiting fre-

quency is approached, singing will be very likely, if not certain, to occur. The reduction of distortion in individual stages permits use of a smaller over-all negative feedback for a given distortion level and this is equivalent to raising the frequency at which the phase changes sign, making the amplifier less liable to develop singing. This margin in phase shift relaxes the design requirements of the amplifier-feedback loop.

10 This advantage is, of course, in addition to the advantages of increased gain and lowered shunt capacity already pointed out as resulting from the net-to-control grid coupling.

What is claimed is:

15 1. In combination, a space discharge device having a cathode, an anode and a control grid, means to impress signal voltages on the control grid, an anode-cathode circuit into which said signals are repeated with a certain amount of anode modulation, and means reducing such modulation comprising a net biased positive and connected to the cathode by an external impedance and having means to impress signal voltages on said net, the static characteristics of said net-cathode circuit and said anode-cathode circuit simulating each other sufficiently within the utilized range to reduce the amount of such modulation.

2. The combination according to claim 1 in which said means to impress signal voltages on said net comprises a coupling between said control grid and said net such as to increase the gain of the amplifier.

3. The combination according to claim 1 in which a feedback circuit is connected from a point on the output side of said discharge device to said net to feed back some of the output voltage in gain-reducing sense to reduce the modulation present in the anode-cathode circuit.

4. A multistage amplifier, each stage of which comprises the combination according to claim 1 and in which a negative feedback circuit is connected from the anode circuit of a later stage to

the net of a preceding stage, such feedback circuit reducing the gain of the amplifier and reducing the total modulation.

5. In an amplifier circuit, a space discharge device having a cathode, an anode, a control grid, a second grid, biased positive toward the cathode, said tube exhibiting gain from the second grid to the anode and from the control grid to the anode, and having negative transconductance from the control grid to the second grid, and means impressing signals on both of said grids, the static characteristics of the second grid-to-cathode path and of the anode-to-cathode path being of similar shape throughout the operating region whereby the modulation is lowered.

6. In an amplifying circuit, a space discharge device comprising a cathode, an anode, a control grid and a second grid biased positive toward the cathode, said tube having negative transconductance from the control grid to the second grid, means for increasing the gain of said amplifier comprising a coupling between said two grids, and means lowering the modulation in the output of said amplifier comprising means for producing static characteristics of similar shape for the anode-cathode circuit and for the second grid-to-cathode path in the region of the operating point whereby the modulation products set up in said second grid-to-cathode circuit reduce the magnitude of the modulation products in the anode-cathode circuit.

7. In an amplifier circuit having an input and an output, a space discharge device comprising a cathode, an anode, a control grid and a space charge grid, said control grid being connected to receive waves from said input, means to impress waves from said anode on said output, means to impress waves from said input on said space charge grid in such phase as to increase the gain of said circuit, and a gain-reducing feedback connection from said output to said space charge grid.

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