May 13, 1941. C. E. STRONG 2,241,892

THERMIONIC AMPLIFIER

Filed Feb. 23, 1938 2 Sheets-Sheet 1

Fig. 1.

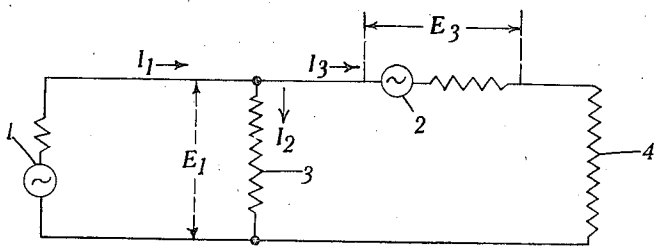
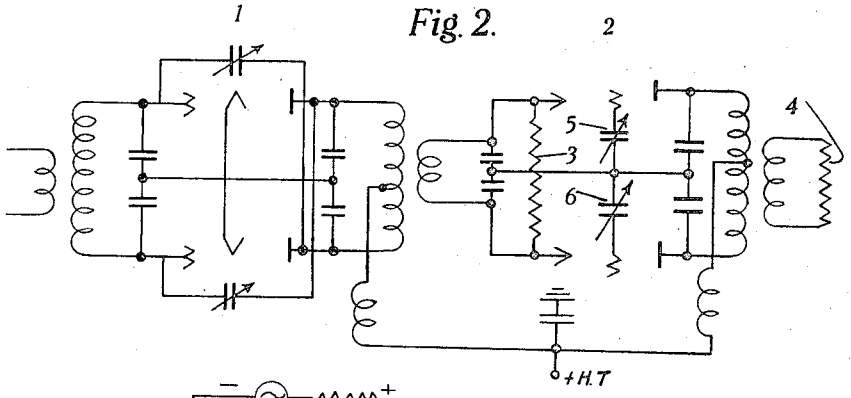


Fig. 2.



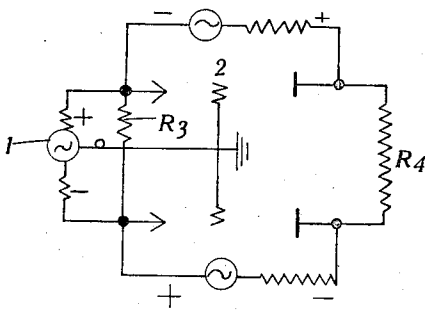


Fig. 3.

INVENTOR
C. E. STRONG
BY E. O. Thinney
ATTORNEY

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THERMIONIC AMPLIFIER

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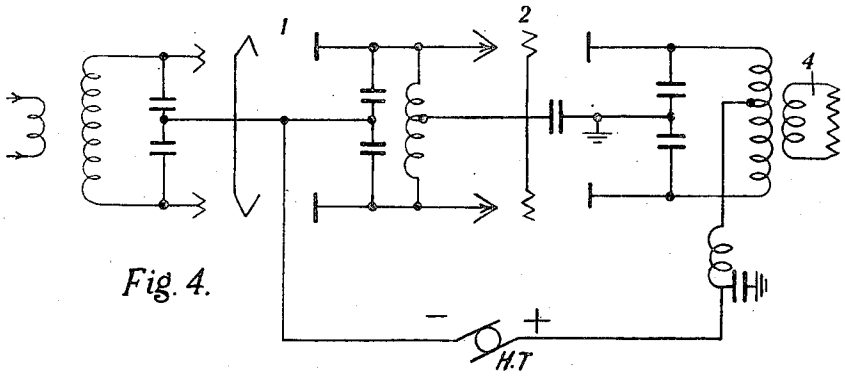


Fig. 4.

Fig. 5.

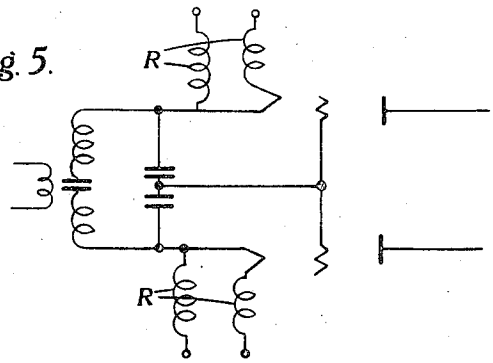
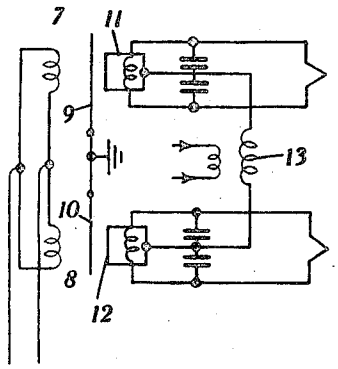


Fig. 6.



INVENTOR
C.E. STRONG

BY

ATTORNEY

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UNITED STATES PATENT OFFICE

2,241,892

THERMIONIC AMPLIFIER

Charles Eric Strong, London, England, assignor to International Standard Electric Corporation, New York, N. Y.

Application February 23, 1938, Serial No. 192,083
In Great Britain March 8, 1937

5 Claims. (Cl. 179—171)

This invention relates to a thermionic valve amplifying system particularly adapted to power amplification at high frequencies.

An object of the invention is to improve the efficiency and stability of such amplifiers.

In its simplest form the invention comprises a driving amplifier and a driven amplifier operating in series feeding power into a common load resistance and so associated that the driven amplifier is excited from the output voltage of the driving amplifier.

Similarly the system may comprise a plurality of amplifiers operating in series each of these except the first being excited by the output voltage of the preceding amplifiers.

The system is, to a certain extent, analogous to the operation of alternators in series, the field of the first alternator being excited from an external source, but the fields of the remaining alternators being excited from voltages set up in the system.

The invention will be fully understood from the following detailed description and the accompanying drawings in which—

Fig. 1 is a diagram used to explain the underlying principle of the invention;

Fig. 2 is a schematic diagram showing a practical embodiment of the invention;

Fig. 3 is a diagram used in explaining Fig. 2;

Fig. 4 shows a modified form of Fig. 2; and

Figs. 5 and 6 show methods of feeding the valve filaments with heating current.

The case of two amplifiers operated in accordance with this invention is analogous to an arrangement of two alternators operating in series as shown in Figure 1 in which 1 is an alternator whose field is excited from an external source, 2 is an alternator in series with 1 whose field circuit 3 is excited from the terminal voltage of alternator 1 and 4 is a load resistance into which both alternators feed power.

In such an arrangement if we know the terminal voltage of alternator 2 and the power delivered by it, and if we know also the voltage across the field circuit of alternator 2 and the power absorbed in that circuit, then the power which must be furnished by alternator 1, and the total power delivered into the load resistance 4 and the value of the load resistance 4 are all determined and may be calculated as follows.

Let the known quantities be defined as follows:

P_3=power delivered by alternator 2.
E_3=terminal voltage of alternator 2.
E_1=voltage across field circuit of alternator 2.
P_2=power dissipated in the field circuit of alternator 2.

Then if P_1 is the power delivered by alternator 1, P_4 the total power delivered into the load resistance 4 and R_4 the value of the load resistance; and if L_1, L_2, and L_3 are currents as shown in Figure 1, we have:

$$I_1=\frac{P_1}{E_1}$$

$$I_2=\frac{P_2}{E_1}$$

$$I_3=\frac{P_3}{E_3}$$

but

$$I_1=I_2+I_3$$

$$\therefore \frac{P_1}{E_1}=\frac{P_2}{E_1}+\frac{P_3}{E_3}$$

$$\therefore P_1=P_2+P_3\frac{E_1}{E_3} \quad \text{---------- 1}$$

also

$$P_4=P_1-P_2+P_3$$

$$=P_2+P_3\cdot\frac{E_1}{E_3}-P_2+P_3$$

$$=P_3\left(1+\frac{E_1}{E_3}\right) \quad \text{---------- 2}$$

and

$$R_4=\frac{P_4}{I_3^2}$$

$$=\frac{P_3\left(1+\frac{E_1}{E_3}\right)}{\left(\frac{P_3}{E_3}\right)^2}$$

$$=\frac{E_3^2}{P_3}\left(1+\frac{E_1}{E_3}\right) \quad \text{----------3}$$

According to this invention two high frequency amplifiers can be operated in series in a manner similar to that which has been described for the case of alternators in which case the grid to filament input circuit of the second or driven amplifier takes a similar place in the system to the field circuit of alternator 2. In an amplifying system so constituted the relations between the terminal voltages and the powers as determined for the analogous alternator case must be provided for.

One manner in which the basic idea of this invention, that is operating thermionic amplifiers in series and exciting one from the output of another in the chain, can be practically applied is illustrated in Figure 2.

In this figure 1 is a push pull high frequency amplifier of well known form and 2 is a push pull amplifier in which, for the purpose of putting this amplifier in series with the first, the "drive" is applied from filament to filament, the grids being effectively grounded for high frequency.

The input circuit resistance of amplifier 2 is represented by resistance 3, and the output circuit load resistance for both amplifiers is represented by resistance 4.

Amplifier 1 is shown as a neutralised push pull amplifier of the classical type for the purpose of simplicity, but it could according to this invention also be an inverted amplifier operating in series with one or more other driving amplifiers.

In order to make it clear that amplifier 2 is working in series with amplifier 1 reference is made to Figure 3 in which amplifier 1 is represented by a generator delivering the same voltage and power and generators are shown in amplifier 2 between the filaments and plates representing the sources of filament to plate circuit E. M. F. which are brought into action when voltages are applied on the input side between the filaments and grids. The output circuit of amplifier 2 is represented for clarity by the resistance R_4 which is the equivalent plate to plate load resistance of the output circuit when tuned.

As is well known, when the driving voltage is in such phase as to cause the grid to be positive with respect to the filament, then the plate circuit E. M. F. is in such phase as to make the plate negative with respect to the filament. Or to put it otherwise, if the grid is maintained at zero potential and the filament is driven positive with respect to zero, then the plate becomes positive with respect to filament, and, therefore, still more positive with respect to zero. In short, the plate circuit E. M. F. is in series and in phase with the driving voltage and, therefore, both amplifiers feed power in series into R_4. Also amplifier 1 feeds power into the input resistance R_3. The power delivered into the load R_4 is the sum of the powers delivered by the two alternators less the power dissipated in the driving circuit resistance R_3.

As an example, let it be assumed that both amplifiers work with a D. C. plate voltage of 12,000 and that it is required to draw power from the amplifiers at high efficiency. In order that the efficiency should be high, the high frequency plate swing on each amplifier must have a peak value only slightly less than the value of the D. C. voltage; therefore, having specified the D. C. voltage, the terminal voltage E_3 of amplifier 2 is determined. The value across the push pull circuit from plate to plate might be

$$10{,}500+10{,}500 \text{ peak}=15{,}000 \text{ v. R. M. S.}$$

Suppose also we know that the valves in amplifier 2 are such that with this plate swing they can deliver 50 kw. and that they require a drive voltage from filament to filament of 5,000 v. R. M. S. and further that the loss in the drive circuit under that voltage is 5 kw., then with these values given we can determine the power P_1 which is required from amplifier 1 and the power P_4 delivered into the load and the resistance R_4 of the load as follows:

Given

$P_3=50$ kw.
$E_3=15{,}000$ v. E. M. S.
$E_1=5{,}000$ v. E. M. S.
$P_2=5$ kw.

then

$$P_1=P_2+P_3\frac{E_1}{E_3}$$

$$=5+50\cdot\frac{5{,}000}{15{,}000}$$

$$=21.6 \text{ kw.}$$

and

$$P_4=P_3\left(1+\frac{E_1}{E_3}\right)$$

$$=50\left(1+\frac{5{,}000}{15{,}000}\right)$$

$$=66.6 \text{ kw.}$$

and

$$R_4=\frac{E_3^2}{P_3}\left(1+\frac{E_1}{E_3}\right)$$

$$=\frac{15{,}000^2}{50{,}000}\left(1+\frac{5{,}000}{15{,}000}\right)$$

$$=6{,}000 \text{ ohms.}$$

It is clear from the above that amplifier 1 must deliver much more power than is required to drive amplifier 2, but the extra power is directly transferred to the output load and usefully employed there.

In many practical cases it is very advantageous to be able to take power from the driving stage and use it to augment the power delivered by the final stage. Such is the case when it is desired to obtain the highest possible output on short or ultra-short waves without resort to the operation of amplifiers in parallel. The power which can be obtained from a single amplifier is restricted by reason of the fact that a limitation is imposed on the size of the valves which can be usefully employed by excess of interelectrode capacity. If that limitation is reached, then the system described allows for a further increase in a manner much more convenient in practice than by the addition of a parallel amplifier.

The efficiency of this system expressed as the ratio of the output power to the input power to the plates of the two stages is theoretically no greater than the efficiency similarly expressed for two normal amplifiers, but in practice if the stability is comparable in both cases, then this system will generally have improved efficiency because in the normal case it would in general be necessary to incorporate a damping resistance across the grids of the driven stage absorbing power which in the new system would be transferred to the output load resistance.

Also this system is stabilised by inherent reverse feed back and the other known advantages of reverse feed back are obtained such for example as reduction of noise introduced from the filaments if heated by alternating current, provided the second amplifier is not driven to full saturation and provided the driving amplifier has not perfect regulation. This will be seen by considering the fact that an increase of the load current through R_4 would, in view of the second condition given above, cause a drop in the terminal voltage of the first amplifier, and, this under the first condition specified, would result in a drop in the terminal voltage of the second amplifier both tending to oppose the initial rise of output current.

In addition to the advantages which have been claimed, the system has other advantages which are incidental to the use of an inverted amplifier as a convenient practical way of operating the amplifiers in series. These incidental advantages may be summed up as follows:—In the first place there is the important advantage of lesser output circuit minimum plate to plate capacity. Balancing condensers are not required to neutralise the plate to grid capacity since the grids are at ground potential and form a screen

between the input and output circuits. Leaving stray capacity out of account, the plate to plate output circuit capacity is equal to one half of the plate to grid capacity of one valve. This is to be compared with double this value for the case of the classical neutralised amplifier. Consequently, larger valves can be used before the limits imposed by excessive capacity are reached and a higher maximum output power can be obtained on this account in addition to the increase previously mentioned due to output from the driving amplifier.

Secondly, there is very much greater freedom from tendencies to parasitic oscillations as a result of the elimination of large plate to grid balancing condensers which with the unavoidable inductance of their connecting leads form ultra-short wave oscillatory circuits. This advantage is of particular importance in the case of high power short wave or ultra-short wave transmission, because as the size of valves is increased with resulting increase of interelectrode capacity the resonant frequency of balancing condenser circuits becomes nearer and nearer to the frequency of operation with the result that selective damping becomes less and less practicable.

Thirdly the elimination of the plate to grid balancing condensers is very advantageous in transmitters designed to operate on a number of spot frequencies with facilities for rapid frequency selection, because it would be difficult to arrange that the balancing condensers would not have to be accurately adjusted for each frequency and difficult also to provide for automatic adjustment as part of the wave change system. As will be pointed out, in a practical inverted amplifier a certain adjustment varying with frequency is required but the necessary accuracy is of a much lower order than that involved in the bridge balance, especially in this case in view of the existence of reverse feed back in the system under consideration.

It might be required to modulate the output of an amplifying system such as has been described in this invention for the purpose of telegraph, telephone or television transmission. The system lends itself both to grid and plate modulation. For the former both of the amplifiers would be adjusted with an efficiency of the order of 30% and the first amplifier would be driven with modulated wave, or alternatively, would be modulated by grid voltage variation. For plate modulation both amplifiers would be caused to operate at high efficiency, and modulating voltages would be applied to the plates of both simultaneously.

The reason for modulating both stages simultaneously for the case of plate modulation lies in the fact that both amplifiers are delivering power into the load.

When both amplifiers are plate modulated, it is clear that the drive on the second amplifier is modulated. This is advantageous since it avoids the necessity of having such a large drive on the second amplifier for the carrier condition as would suffice also for the peaks of up-modulation with consequent high grid dissipation for the carrier condition.

In practice it is found that a complication is introduced into the inverted amplifier on account of the unavoidable inductance in the connections between the grids and ground due partly to the inductance of the grid leads inside the valves, and partly to the inductance of leads outside the valves. This inductance is a coupling impedance between the input and output circuits giving reaction which may not be desired. The difficulty can be overcome by inserting condensers (5 and 6 in Figure 2) to tune out the inductance of the grid connections. The value of these condensers has to be charged when the frequency is altered, but the adjustment is not critical.

In the arrangement shown in Figure 2 the D. C. plate voltage is fed to the two amplifiers in parallel although the amplifiers are in series for high frequency. Under certain conditions it might be convenient to feed the D. C. plate voltage also in series as indicated in Figure 4.

Since the filaments of an inverted amplifier have a high frequency voltage on them compared to ground, the filament heating current must be supplied through circuits having a high impedance to the high frequency voltages. One method consists in feeding the filament current through reactors R having high impedance to the working frequency as shown in Figure 5. This method has the disadvantage that reactors having a suitable impedance for one working frequency might not be suitable for another.

A better method which has given excellent results is to heat the filaments by alternating current supplied through special shielded transformers having low capacity between the secondary and a grounded shield between the windings. The secondary is enclosed in a copper case having a determined capacity to the ground shield, this capacity then forming part of the tuning capacity of the amplifier input circuit. This arrangement is illustrated in Figure 6 in which 7 and 8 are shielded filament transformers, 9 and 10 being earth shields and 11 and 12 shields surrounding the secondary windings. 13 is the input circuit high frequency tuning coil which forms an anti-resonant circuit with the capacities between 9 and 11 and between 10 and 12 together with any other parallel capacity there may be across the circuit from filament to filament. This system has the great advantage that the circuit is tuned for new frequencies by the normal procedure of changing the coil 13.

What is claimed is:

1. A thermionic valve amplifying system comprising a driving amplifier having a cathode, an anode and a grid, a driven amplifier having a cathode, an anode and a grid, means to connect the cathode-anode discharge paths of the amplifiers so that they feed power in series to a common output load circuit with respect to signal voltages, connections for exciting the driven amplifier from the output voltage of the driving amplifier while maintaining the grid of the driven amplifier at a base signal potential, a source of signal modulating voltage, and connections from said source to the anodes of both stages for modulating the power output of the amplifier.

2. A system according to claim 1 in which the grid of at least the driven amplifier is provided with circuit connections for maintaining it at ground potential as regards high frequency voltages, and circuit connections are also provided for applying the exciting voltage to the cathode of the driven stage to vary its high frequency potential with respect to ground.

3. A thermionic valve system according to claim 1 in which each stage comprises a pair of tubes arranged in push-pull relation and circuit connections are provided for maintaining the grid of at least the driven stage at ground po-

tential with respect to high frequency voltages, and circuit connections for applying the excitation to the cathodes of the driven stage to vary correspondingly their high frequency potential with respect to ground.

4. A system according to claim 1 in which the cathodes are provided with a source of heating current, and said source is connected to the cathodes through reactances having a high impedance to the signal frequency of the system.

5. A system according to claim 1 in which the cathodes for the amplifiers are provided with a source of heating current and connections from said source to the filaments, said connections including transformers having grounded shields between their primary and secondary windings, the secondary windings of each transformer being enclosed in a metal box having a predetermined capacity to said shields and circuit connections for utilizing said capacity as part of the tuning capacity of the input circuit of the amplifiers.

CHARLES ERIC STRONG.