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2,397,625

THERMIONIC FEEDBACK AMPLIFIER

Filed Nov. 24, 1942

2 Sheets-Sheet 1

FIG. 1.

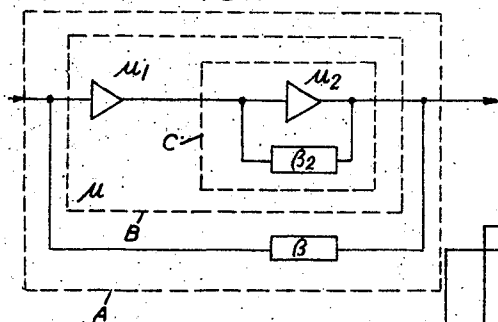
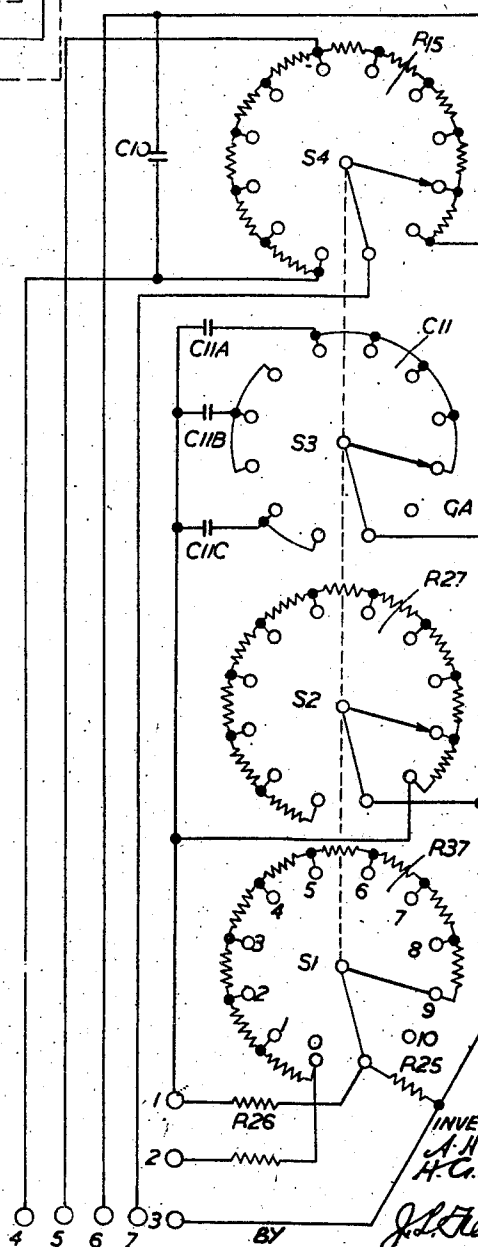


FIG. 3.



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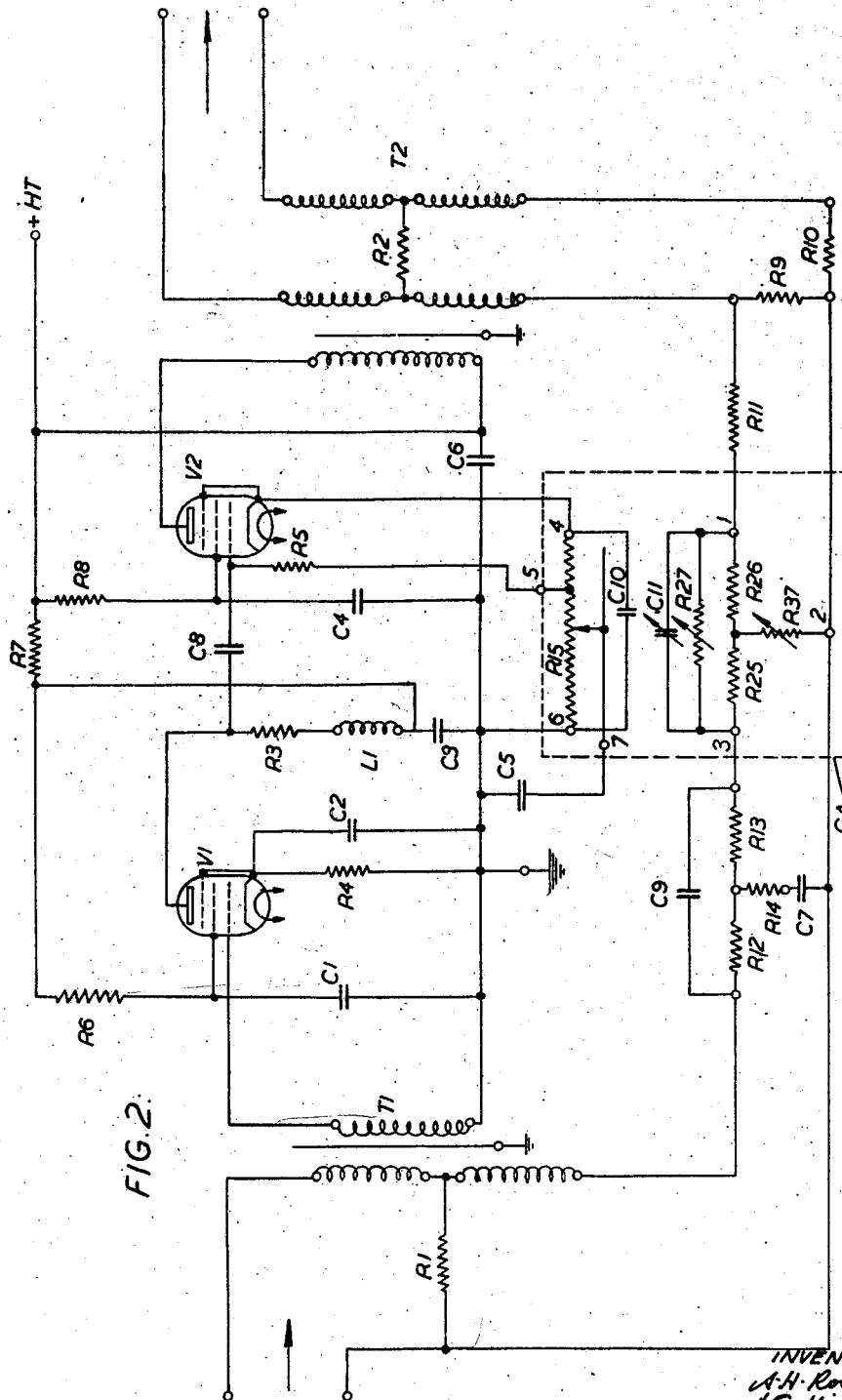
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2 Sheets-Sheet 2



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THERMIONIC FEED-BACK AMPLIFIER

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This invention relates to negative feedback amplifiers of the type in which the gain is adjusted by varying the loss in the feedback path.

Many amplifiers used in communication systems are required to have some means of controlling the gain. In feedback amplifiers this control may be entirely external to the amplifier, in which case its operation has no effect on the performance of the amplifier, or alternatively, it may operate in the feedback path. In this case the operation of the amplifier is affected and its performance will be improved when the gain is reduced by increasing the amount of energy fed back. The harmonic content of the output is reduced and the stability as affected by variation in the power supply, or the like, is improved.

It will usually be preferable, therefore, to control the gain by operating on the feedback path. Difficulties are, however, often encountered with instability as regards oscillation in amplifiers having a large amount of feedback, owing to the difficulty of maintaining the necessary high frequency correction as the gain is changed. Thus, if the correction is sufficient to prevent oscillation with the maximum amount of feedback, it usually affects the gain of the amplifier in the range of frequencies it is intended to transmit when the feedback is reduced to increase the gain. Alternatively, if the correction is such that the transmitted frequencies are unaffected when the feedback is a minimum, it proves insufficient to prevent self-oscillation with maximum feedback.

The present invention provides a means for overcoming these difficulties, whereby the advantage of decreased harmonic content which accrues from the reduction in gain by means of increased feedback may be retained, while stability as regards self-oscillation remains substantially the same for all gain settings.

The method of the invention consists essentially in providing the amplifier with two feedback paths, one of which embraces any number of stages including the last stage but excluding the first, and the other embraces all the stages. Means is provided in both feedback paths for adjusting the attenuation of each path, the separate means being coupled for simultaneous adjustment so that the gain of the forward path of the whole amplifier is changed at the same time as the loss in the over-all feedback path in such a way that the total feedback ($\mu\beta$) remains substantially constant.

According to the invention, there is provided a multi-stage negative feedback thermionic valve amplifier comprising an over-all feedback path

embracing all the stages and a local feedback path embracing any number of stages excluding the first and including the last, means being provided for simultaneously increasing the gain of the forward path comprising all the stages, and reducing the loss in the over-all feedback path, in such manner that the propagation round the over-all feedback loop remains substantially constant for all settings of the said means.

According to another aspect, the invention comprises a multi-stage negative feedback thermionic valve amplifier having an over-all feedback path, comprising means for simultaneously decreasing the gain of the forward amplifying path and decreasing the loss of the feedback path by substantially equal amounts in such manner that the harmonic distortion introduced by the amplifying path decreases as the gain is decreased.

According to a further aspect, the invention resides in a multi-stage negative feedback thermionic valve amplifier comprising a forward amplifying path which includes a local feedback path, and an over-all feedback path, each of the said feedback paths having a variable loss, means being provided for simultaneously adjusting the loss in each feedback path so that the over-all loop gain remains substantially constant in magnitude and phase.

The invention will be more clearly understood from the following detailed description of an embodiment, which refers to the accompanying drawings in which:

Fig. 1 shows a block schematic circuit diagram of the arrangement of an amplifier according to the invention;

Fig. 2 shows a detailed schematic circuit diagram of the amplifier; and

Fig. 3 shows a circuit diagram of the gain control means which operates simultaneously in both the feedback paths.

For convenience in describing the invention, the embodiment shown in Fig. 2 is a two-stage amplifier in which the local feedback path embraces the last stage only. The invention is however applicable to amplifiers with any larger number of stages, and the local feedback path may embrace any number of other stages besides the last, not including the first stage.

In accordance with the usual practice in considering feedback amplifiers, the circuit is regarded as comprising a forward amplifying path and a feedback path connected in a loop called the feedback loop; the voltage transfer ratio of the forward path is denoted by μ , and that of the feedback path is denoted by β ; the produce $\mu\beta$

represents the voltage transfer ratio or propagation constant corresponding to a transit once round the feedback loop. μ is greater than 1 and β is less than 1, and the product $\mu\beta$ is generally made very large compared with 1 in order to obtain the well known advantages of negative feedback. This product denotes what is called the total feedback, and the gain round the feedback loop is determined by $\log(\mu\beta)$. It is, however, not essential for the purposes of the invention that the product $\mu\beta$ should be very large.

It is well known that the effective gain of the amplifier when the feedback is operating is practically given by $1/\beta$ when $\mu\beta$ is large. The effective gain may therefore be reduced by increasing β , which increases the total feedback, provided the conditions of stability are always satisfied. However, as the total feedback is increased, the margin of stability tends to become progressively lowered, and it becomes very difficult to design a variable feedback path which gives adequate correction when the total feedback is large, and also freedom from distortion in the range of transmitted frequencies when the total feedback is small. According to the present invention, it is arranged so that when β is increased for the purpose of reducing the effective gain of the amplifier, the value of μ is at the same time decreased by increasing the feedback of energy in a local feedback path, in such manner that the product $\mu\beta$ remains practically constant in magnitude and phase.

This method not only allows a large variation of the effective amplifier gain to be made while at the same time maintaining the same margin of stability, but also it reduces the harmonic content of the output by virtue of the local feedback.

In Fig. 1, the outline A represents the amplifier comprising a forward amplifying path μ enclosed in the outline B, and a feedback path β . The forward amplifying path includes a number of stages denoted by μ_1 and other stages μ_2 enclosed in the outline C and provided with a local feedback path β_2 . In the following equations the harmonic distortion produced at the output of the μ_2 stages when neither the β nor the β_2 feedback paths are operating is denoted by D, and the harmonic distortion of the μ path as above defined, when the β feedback path is not operating, is denoted by d.

Then it follows that:

$$\mu = \mu_1 \mu_2 / (1 + \mu_2 \beta_2)$$

and,

$$d = D / (1 + \mu_2 \beta_2)$$

If μ_0 is the voltage transfer ratio corresponding to the effective gain of the complete amplifier A, then

$$\mu_0 = \mu / (1 + \mu\beta)$$

and the corresponding harmonic distortion will be

$$d_0 = d / (1 + \mu\beta) = D / (1 + \mu\beta) (1 + \mu_2 \beta_2)$$

If as is usually the case, $\mu\beta$ is large compared with 1, the effective gain of the amplifier is given by $1/\beta$, and accordingly β is varied in order to adjust the gain. As already explained, it is desirable to keep $\mu\beta$ substantially constant, and therefore μ must be simultaneously varied inversely as β .

When $\mu\beta$ is large compared with 1, also

$$d_0 = D / \mu\beta (1 + \mu_2 \beta_2)$$

and if $\mu\beta$ is kept constant by varying β_2 at the same time at β , the value of the harmonic content d_0 decreases as the effective gain is decreased. If $\mu_2 \beta_2$ is also large compared with 1, this decrease will be in exactly the same ratio as the decrease in μ ; otherwise it will be slightly less. These are the principles on which the invention is based.

The simultaneous variation of β and β_2 is preferably achieved by mechanically coupling the controls, though any other coupling arrangement may be used instead, if desired. The corresponding attenuating networks will be unavoidably made more complicated by the new requirement, and the degree of complication will depend upon the degree of constancy required for $\mu\beta$.

Fig. 2 shows the details of a practical embodiment of the invention in accordance with Fig. 1, comprising a two-stage amplifier.

The signals arriving from the line are applied to the input transformer T₁, which is a three-winding transformer or hybrid coil of a kind well known in the art. The signals reach the control grid of the first valve V₁, which may be of the pentode class.

After amplification in V₁, the signals are applied to the control grid of the second valve V₂, which may also be a pentode, and thence through a balanced output hybrid coil T₂ to the outgoing line.

The plate and screen grid of V₁ are respectively decoupled by resistance R₇ and condenser C₃, and by resistance R₆ and condenser C₁; and the screen grid of V₂ is decoupled by resistance R₈ and condenser C₄. The high tension supply for the plate of V₂ is fed through the high impedance winding of the hybrid coil T₂, a by-pass condenser C₅ being connected across the supply. The grid bias potential for V₁ is obtained by means of the cathode circuit resistance R₄ shunted by the condenser C₂, and the grid bias for V₂ is obtained from the potential drop across part of the cathode circuit resistance R₁₅ applied through the grid resistance R₆. The interstage coupling network comprises the inductance L₁ and the resistance R₃ in series with the plate circuit of V₁, and the condenser C₈ connecting the plate of V₁ and the grid of V₂.

A portion of the energy of the output signals is fed back through the over-all or β feedback path to the input of the amplifier. This path is connected between the two hybrid coils as shown so as to be conjugate respectively to the input and output lines at its ends, for which purpose the balancing resistances R₁ and R₂ are provided. This feedback path contains in order starting from T₂: an impedance changing network of three resistances R₉, R₁₀ and R₁₁, which is also used for making the connection between the balanced hybrid coil T₂ and the rest of the circuit, which is unbalanced; part of the gain control attenuator GA, comprising a variable bridged T type of attenuating network; and a fixed network of resistances R₁₂, R₁₃ and R₁₄ and condensers C₇ and C₉. The variable network comprises fixed series resistances R₂₅ and R₂₆ a variable shunt resistance R₃₇, and a variable bridge resistance R₂₇ shunted by a variable condenser C₁₁. All these variables are mechanically coupled. The fixed network is provided with the condensers C₇ and C₉ for the purpose of providing feedback loop correction at the lower and upper frequencies, respectively.

The local or β_2 feedback path for the valve V₂ comprises an adjustable resistance R₁₅ connected in series with the cathode, a variable portion of which is shunted by a small condenser C₅. This network is designed to give the desired magnitude

and phase of the feedback for the valve V_2 at all settings of the gain control attenuator in the β path, by arranging that the condenser C_5 shall substantially short-circuit (for the signal frequencies) a variable portion of R_{15} , the control of which is mechanically coupled to the controls of the other attenuator. As the effective value of R_{15} is progressively reduced, the effect of the small condenser C_5 in shunt with it decreases, so that both the phase and the magnitude of the β_2 feedback are simultaneously changed.

A further control over the phase shift at high frequencies is provided by the condenser C_{11} . This is varied at the same time as the network resistances, and enables a more desirable phase characteristic to be obtained. In practice it is found that only two or three different values of this condenser are necessary in the case, for example, of an attenuator giving ten 1 db steps. Obviously, any theoretically possible degree of correction may be obtained if the circuit is allowed to become sufficiently complicated.

Figure 3 shows the details of one form of the gain control attenuator GA of Fig. 2. The terminals of the attenuator are similarly numbered in both figures. It comprises four rotatable switches S_1 , S_2 , S_3 and S_4 , which are mechanically coupled, and each has eleven steps giving a range of attenuation of 0 to 10 db, for example. The first three rotors S_1 , S_2 , and S_3 , control the bridged T network in the β path, and respectively adjust R_{37} , R_{27} and C_{11} . The rotor S_4 controls the resistance R_{15} in the β_2 path. The steps of the switch S_1 have been marked with the corresponding relative effective amplifier gain in decibels in accordance with the above assumed range, and it will be noted that the gain will be reduced by turning the switch anti-clockwise.

The variable condenser C_{11} comprises three separate fixed condensers C_{11A} , C_{11B} and C_{11C} one of which is shunted across R_{27} as required, according to the position of the switch. As already explained, the capacities of these condensers are chosen to give a sufficient amount of phase correction at frequencies above the pass range of the amplifier for each setting of the gain control. The rotor S_4 is shunted by the fixed condenser C_{10} and when it is adjusted, it changes both the magnitude and the phase of the gain in the μ path.

The fixed series resistances of the bridged T network R_{25} and R_{26} are shown connected to the contact arm of the switch S_1 between terminals 1 and 3.

There is, of course, no reason to limit the attenuator to the precise example which has been described in connection with Fig. 3, which represents an actual case which has proved satisfactory in practice. It could obviously have other numbers of steps, and be designed to cover a different attenuation range, and any other known type of adjusting switch or arrangement could be used.

The invention is likewise not intended to be limited to the relatively simple networks which have been described used for the β and β_2 paths. The networks may be as complicated as desired, according to the stringency of the requirements which have to be met, and the details of the adjusting arrangements described in Fig. 3 will of course have to be designed accordingly. It will usually be found, however, that it is convenient to allow a small variation in the value of $\mu\beta$ from the theoretical constant value at the different gain settings in order to obtain some simplification of the networks. Thus, when it is stated that $\mu\beta$ is "substantially constant," it is to be understood to cover such deliberately allowed small variations.

Finally, the invention is not confined to the particular two-stage amplifier shown in Fig. 2. It is applicable to any negative feedback amplifier having two or more stages, and persons skilled in the art will know how to make the necessary modifications to adapt the invention to other types of feedback amplifier.

What is claimed is:

1. A multi-stage negative feedback vacuum tube amplifier including a balanced hybrid coil circuit coupled to the input end of said amplifier, a second balanced hybrid coil circuit coupled to the output end of said amplifier, a forward amplifying path from the input to said amplifier going through said amplifier to the output thereof, a resistance coupled negative feedback path from the output end of the amplifier going back to the input end of said amplifier, a second resistance coupled negative feedback path going from the output end of the amplifier back to the input of the second stage, and means for simultaneously adjusting the loss in each feedback path so that the over-all loop gain remains substantially constant in magnitude and phase.
2. The amplifier according to claim 1 wherein the first-named feedback path comprises a bridged T network including an adjustable bridge resistance, a variable condenser shunting said resistance, and a common control for adjusting said resistance and said condenser.
3. A two-stage vacuum amplifier comprising a pair of vacuum tubes having input and output circuits, means for cascading said tubes so that a two-stage amplifier having a forward amplifying path is provided, a negative feed back in the cathode circuit of the tube in the second stage, a negative feedback from the output of the second stage to the input of the first stage, and means for simultaneously adjusting the loss in each feedback path so that the over-all gain in the two-stage amplifier remains substantially constant in magnitude and phase.

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