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H. K. KRIST

2,281,312

WAVE TRANSLATION

Filed Feb. 25, 1941

FIG. 1

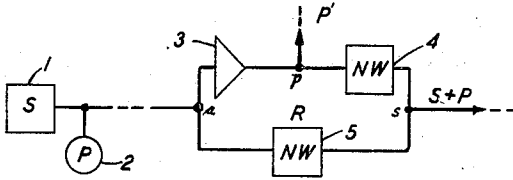


FIG. 2

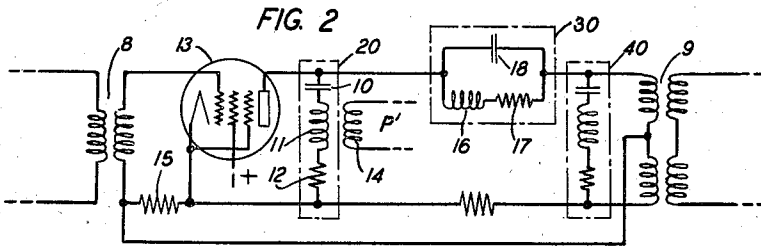


FIG. 3

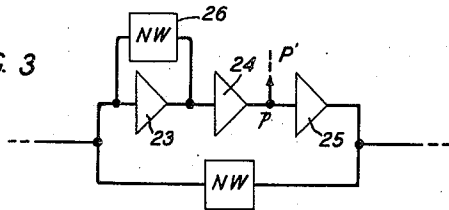


FIG. 4

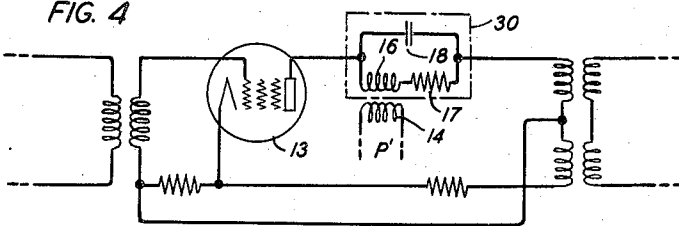
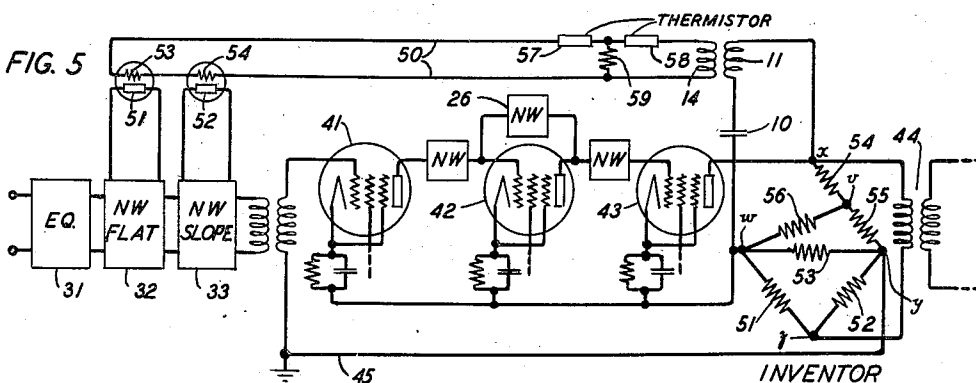


FIG. 5



INVENTOR
H. K. KRIST

BY

W. A. Ewing
ATTORNEY

UNITED STATES PATENT OFFICE

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WAVE TRANSLATION

Henry K. Krist, Mountain Lakes, N. Y., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

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7 Claims. (Cl. 178-44)

This invention relates to electric wave amplification and more particularly to electric wave amplifiers of the stabilized feedback type.

Heretofore in long distance signaling systems comprising signal repeaters spaced apart in a long transmission line, a pilot wave of fixed initial intensity has been transmitted at low level through the system concurrently with the signals and employed at the several repeaters for variably controlling the amplification or gain thereof to compensate for variations in the attenuation of the line and similar effects. In systems of this character the pilot wave is ordinarily diverted in part at the output of each repeater and separately amplified to an intensity sufficient to operate a repeater gain controlling device or the like. It is highly desirable that the diversion be so effected that the over-all gain of the repeater is substantially the same at the pilot wave frequency as at the signal frequencies, so that throughout the system the pilot wave accurately reflects the variations in transmission equivalent experienced by the signals.

A principal object of the present invention is to provide an improved repeater amplifier adapted for a system of the kind described and more particularly one of such character that the diverted pilot wave is amplified in relatively great degree within the repeater amplifier, enough so in fact that separate amplification of the diverted pilot may be omitted. Another and more general object is to provide an improved stabilized feedback amplifier adapted for the concurrent amplification and through transmission of signals and waves of non-signal frequency with partial diversion of the waves of non-signal frequency and relatively great amplification thereof.

Whereas it has been proposed heretofore, as disclosed in United States Patent 2,154,888 to H. S. Black dated April 18, 1939, to derive pilot current by applying a frequency selective shunt to the mu circuit of a stabilized feedback repeater amplifier, thereby reducing by feedback the effect of the shunting circuit on the over-all gain characteristics of the repeater, the present invention in one aspect involves appreciation and utilization of the fact that high loss at the pilot frequency may be so interposed in the mu circuit, either incidental to bridging the mu circuit or otherwise, that there is tremendously increased amplification of the pilot current without deleterious effect on the undistorted load carrying capacity or other significant characteristics of the amplifier.

In accordance with a feature of the invention the mu-beta or feedback loop of an amplifier is provided with electrically spaced output connections adapted respectively for signal and pilot frequencies or for other respectively different frequencies. In another aspect of the invention, a signal amplifier having a mu-beta loop is provided with a pilot current or like output circuit so connected that a portion of the loop that is effectively in the mu circuit for signal amplification, lies effectively in gain increasing relation in the beta circuit for pilot current amplification.

Another feature of the invention provides for transfer of the power load at the pilot frequency from the signal output stage to an anterior stage whereby the power load on a plurality of stages is more nearly equalized or otherwise more favorably apportioned.

The nature of the present invention and its various objects, features and advantages will appear more fully from a consideration of the following description of the embodiments illustrated in the accompanying drawing.

Fig. 1 illustrates diagrammatically a signal transmission system comprising a signal repeater in accordance with the invention;

Fig. 2 illustrates schematically the circuit details of an amplifier in accordance with Fig. 1;

Figs. 3 and 4 illustrate diagrammatically modifications of the Fig. 1 amplifier; and

Fig. 5 illustrates in fairly complete detail a repeater amplifier in accordance with the invention having special advantages and features that will be described hereinafter.

Referring now to Fig. 1 there is shown diagrammatically a signaling system in which signals from a source 1 and currents of non-signal frequency from a source 2 are transmitted through a wire line having at least one repeater R disposed therein. It may be convenient to think of the source 1 as the transmitting terminal circuits of a multiplex carrier telephone system delivering telephone signals occupying a plurality of carrier channels. Likewise, it is thought that the principles underlying the invention may be more readily grasped if it be supposed that source 2 delivers a single-frequency pilot wave that lies above, below or between the telephone channels. It will become apparent, however, that the invention is not limited in its application to the particular case assumed and that there may be, for example, a plurality of pilot frequencies or that the diverted non-signal frequency may be used to supply carrier current for demodulation at a receiving terminal.

The negative feedback repeater amplifier illustrated in Fig. 1 comprises a mu-beta loop having an input terminal *a* for the application of signal and pilot waves from the incoming line, and a corresponding output terminal *s* where the amplified signal and pilot waves are taken off for application to the following section of transmission line. The "normal" mu circuit of the amplifier comprises a single stage or multistage amplifier section 3 followed by a frequency selective device or network 4, the purpose of which will be explained. The corresponding normal beta circuit of the amplifier is illustrated as comprising network 5. The over-all gain *G* of an amplifier of the kind described is known to be

$$G = \frac{\mu}{1 - \mu\beta} \quad (1)$$

where μ represents the transmission equivalent of the mu portion of the loop and β the transmission equivalent of the beta portion. Assuming that at all frequencies of interest the vectorial product $\mu\beta$ is large compared with unity, the gain can be represented as

$$G = \frac{-1}{\beta} \quad (2)$$

The normal gain characteristic of the amplifier is therefore seen to be dependent substantially only on the characteristics of the beta circuit network 5, and the latter may be readily designed to provide constant gain over the frequency range or non-uniform gain proportioned, for example, to compensate for the attenuation-frequency characteristics of the transmission line.

Consider now that in the mu circuit at a point *p* between amplifier section 3 and output terminal *s* some frequency selective means is provided for diverting current of pilot frequency. In so far as the diverted pilot current is concerned the point *p* may be considered the output terminal of the amplifier, so that the mu circuit therefor consists of amplifier element 3, and the corresponding beta circuit now includes both networks 4 and 5. With respect to the pilot current diverted at point *p*, the net amplifier gain is measured by or proportional to whatever total loss is interposed in the beta circuit, that is, the loss at the pilot frequency associated with the pilot diverting means and networks 4 and 5. At the same time the over-all amplifier gain for through transmission of pilot and signals from *a* to *s* is substantially equal to the loss of network 5, which should be so proportioned that pilot and signals are amplified to substantially the same degree.

Circuit details of a simple form of repeater amplifier in accordance with Fig. 1 are shown schematically in Fig. 2. The normal input and output connections to the amplifier are made by transformers 8 and 9, respectively. In the mu circuit of the amplifier a single amplifying discharge device 13 is shown, although it will be apparent that it could be replaced by a plurality of stages in tandem. The normal beta circuit of the amplifier comprises a connection from a tap on the primary of the output transformer 9 to the secondary of input transformer 8, resistance 15 constituting the coupling impedance. Across the output terminals of amplifying device 13 there is disposed a shunt branch 20 comprising capacitance 10 and inductance 11 connected in series with each other and proportioned for resonance at the pilot frequency. The pilot output circuit *P'* comprises a coil 14 inductively coupled with inductance 11, and the effective re-

sistance of this circuit is represented schematically by a resistance 12 in series in the shunt branch 20.

In series between the shunt branch last described and output transformer 9 there is interposed a network 30 comprising an inductance 16 and resistance 17 disposed in series with each other and shunted by a capacitance 18. Inductance 16 and capacitance 18 are adjusted for anti-resonance at the pilot frequency, and the impedance presented and the loss introduced thereby are controlled by the magnitudes of resistance 17 and of reactance 16.

Now it will be seen that a certain amount of loss at the pilot frequency is interposed in the normal mu circuit at the point where the pilot is diverted, by virtue of the effective resistance of the pilot shunt 20 and associated output circuit, and that an indefinitely great amount of loss may be interposed immediately following this point by the series branch 30. Both of these losses are effective in reducing the amount of feedback at the pilot frequency, with respect to the diversion point *p* of Fig. 1, and both therefore contribute in proportion to their magnitudes to increased effective gain at the pilot frequency from input point *a* to output point *p*. With $\mu\beta$ large compared with unity the increase in gain so obtained is approximately equal to the loss introduced.

Whereas the mu circuit loss at the pilot frequency is provided in Fig. 2 by both the shunt branch 20 and by the series network 30, and either one alone would serve to some extent for that purpose, the combination of both together has other advantages and is especially useful where control of the circuit impedances is desired as will presently appear.

For maximum power output from an amplifier tube, the tube must work into the correct impedance, which depends on the type of tube and on the associated circuit conditions. In a typical example involving a pentode amplifier tube of 35,000 ohms plate impedance, the optimum load impedance was found to be about 3,000 ohms. With departure from the optimum load impedance, the power which it is possible to deliver to a load, with maximum grid voltage swing, is reduced due to current limitation or to voltage limitation of the particular vacuum tube circuit. In Fig. 2 output transformer 9 is accordingly so proportioned as to present the optimum load impedance, of 3,000 ohms for example, to pentode 13 throughout the signal frequency range.

If either network 20 or network 30 is alone interposed between the anode of tube 13 and output transformer 9, the impedance presented to the tube at the pilot frequency will thereby be changed from the optimum value available at output transformer 9. This change tends to reduce the total power diversion obtainable at the pilot frequency. In view of the fact that the power demanded from the tube at the pilot frequency is generally small compared with the signal power, an even more important effect of departure from optimum impedance is that the load-carrying capacity of the tube is reduced also at the signal frequency and accordingly less power can be delivered to output transformer 9. In other words, if a tube delivers power at two frequencies to two separate loads, the maximum power at one of the frequencies can be obtained only if the impedance at the other frequency is adjusted to its optimum value. From another

point of view it may be said that the presence of the pilot frequency changes the instantaneous operating point of the tube with respect to the superimposed signal frequencies and that this change in operating point should be made along the optimum load line at the pilot frequency. Expressed in a slightly different manner, the instantaneous voltage and current components of the frequencies may be considered as being additive so that each of the components should be capable of achieving maximum value.

With the aid of networks 20 and 30 in Fig. 2, optimum impedance can be presented to the pentode 13. Thus the impedance presented by the pilot diverter circuit P' to the pentode 13, and therefore also the power transmission into that circuit, is susceptible of adjustment. If network 30 is proportioned to have high series impedance at the pilot frequency, such for specific example as an impedance one hundred times the output impedance of the amplifier or 300,000 ohms, it will be apparent that at the pilot frequency the respective impedances of the shunt branch and the output transformer are effectively isolated from each other so that they may be independently adjusted to the most favorable values.

The output impedance at the pilot frequency presented by the amplifier to the outgoing line is normally rather uncritical. Moreover, the impedance modifying effect of networks 20 and 30 is substantially reduced by the negative feedback existing in the amplifier at the pilot frequency. If in any case the residual effect were considered objectionable, however, it could be eliminated by the use of an additional shunt branch 40, similar to shunt branch 20 and interposed between network 30 and output transformer 9.

In a particular case in practice substantially conforming with the typical example described with reference to Fig. 2, the virtual resistance 12 of the pilot output circuit P' was adjusted to 3,000 ohms whereby the shunt branch in conjunction with network 30 introduced a loss of 14 decibels into the feedback path. In this case the power delivered to the pilot output circuit P' was more than twenty times the pilot power delivered to the outgoing line, although this is by no means the limiting value of power multiplication that can be achieved if desired.

The arrangement described with reference to Fig. 2 has the additional important advantage of providing enhanced selectivity in the diversion of pilot power. In the first place the active plate impedance of the discharge device 13 is substantially reduced by feedback, resulting in a low impedance generator working into the pilot output circuit P' through the frequency selective combination 10-11. In the second place, added selectivity is obtained by virtue of the attenuation-frequency characteristic of network 30 which is effective in relatively reducing the amount of feedback at the pilot frequency.

Whereas in Fig. 1 the pilot power is indicated as being diverted at a point following the last stage of the amplifier element 3, advantages may be secured in particular cases by diverting the pilot power at a point anterior to the last stage. In an amplifier such as represented in Fig. 3 comprising three amplifying stages 23, 24, 25, the last stage may normally operate nearer to overload than the second stage. If in such case pilot power is to be diverted from the amplifier in accordance with the invention, the pilot diverter circuit P' may be connected at the output

of the second stage 24 thereby increasing the power load on that stage and providing increased power margin in the last stage. Although the diverted pilot power may be less when the connection is made anterior to the last stage, there may be more effective utilization of the power capacity of the several stages.

If, with respect to the normal amplifier a—s in Fig. 1, $\mu\beta$ is not so large that the loss at the pilot frequency introduced in the mu circuit can be ignored, then the gain-frequency characteristic of the normal amplifier may exhibit an abrupt variation in gain at the pilot frequency. This effect may be reduced or substantially eliminated by providing increased gain in the mu circuit of the normal amplifier. The increased gain at the pilot frequency may be obtained as indicated in Fig. 3 by providing positive feedback at the pilot frequency around one or more of the local stages. With the arrangement shown the increased gain is effective not only in the normal amplifier but also in the mu circuit of the pilot amplifier portion a—p.

It may not be necessary in all cases to operate the discharge device 13 into its optimum impedance at the pilot frequency, as for example where the maximum pilot power to be diverted through the shunt branch is very small compared to the load carrying capacity of the discharge device. In such cases the series network 30 can be omitted and the value of virtual resistance 12 reduced until the amount of power diversion for the pilot frequency is obtained. This can be readily accomplished inasmuch as the voltage across resistance 12 is maintained substantially independent of the magnitude of resistance 12 by virtue of the constant voltage type of feedback indicated in Fig. 2. Alternatively, the shunt branch can be omitted and the pilot output circuit P' coupled to the series network 30, as by inductive coupling to the inductance 16 thereof. The first of these alternatives is illustrated in Fig. 5 and the second in Fig. 4 which will now be described.

The circuit shown schematically in Fig. 4 is essentially of the same configuration as Fig. 2 except that the shunt branch is omitted and the pilot output circuit P' is inductively coupled by coil 14 to the inductance 16 comprising network 30. The effective resistance in the network, comprising the virtual resistance of the pilot output circuit P', is represented by resistance 17. Element 17 might in fact furnish the pilot frequency load directly without the coupling 14. The gain from the input of the amplifier to the pilot output circuit is enhanced by the loss at the pilot frequency in the mu circuit of the normal amplifier, introduced by network 30 and by the pilot output circuit P' connected thereto. As in preceding examples, the diverted pilot power may be many times as great as the pilot power delivered with the signals to the outgoing line.

In Fig. 5 applicant has shown in considerable detail a practical repeater amplifier illustrating one embodiment of the invention. The amplifier proper is preceded by an equalizer 31 which compensates for the nonuniform attenuation-frequency characteristic of the preceding line section, and by flat gain and slope control circuits 32 and 33, respectively. The latter are controlled by diverted pilot power in a manner and for a purpose to be described. The amplifier comprises three stages impedance-coupled in tandem relation and adapted to amplify with substantially constant gain over a frequency

range extending from 15 to 30 kilocycles, for example. The cathodes of the several amplifier pentodes 41, 42 and 43, are connected through respective grid biasing resistor-condenser combinations to one corner *w* of an output circuit bridge of which an opposite corner *y* is grounded and connected through a lead 45 to provide negative feedback to the first stage of the amplifier. The remaining corners *x* and *z* of the bridge are connected to the respective primary terminals of output transformer 44, and corner *x* is connected also to the anode of pentode 43.

In a particular case in practice where pentode 43 was of the Western Electric 311-A type and where output transformer 44 presented an impedance of 4,000 ohms across its primary winding, the resistor 51 connecting bridge corners *w* and *z* was 100 ohms, resistor 52 connecting corners *y* and *z* was 1,140 ohms and the resistor 53 connecting diagonally opposite corners *w* and *y* was 32 ohms. In lieu of a single resistor connecting points *x* and *y*, which would have to be of undesirably high resistance, three resistors arranged in the form of a T are employed instead. Two of these resistors 54 and 55 are connected in series with each other between points *x* and *y*, and in the example mentioned the first was 44,400 and the second 824 ohms. The third resistor 56 is connected between the junction *v* of the first two resistors and corner *w* of the bridge, and in the same example was 103 ohms.

The pilot diverting circuit in Fig. 5 comprises a capacitance 10 and inductance 11, connected in series with each other across bridge points *w* and *z*, and respectively corresponding with the like designated elements of Fig. 2. Coil 14 coupled to inductance 11 supplies pilot power to control circuit 50. Pilot power from circuit 50 is applied to heaters 53 and 54 which are respectively associated with thermistors 51 and 52. Thermistor 51 is connected to or constitutes an element of network 31 which is so arranged that as the resistance of the thermistor varies in response to changes in the pilot power in circuit 50, the loss it introduces into the circuit is changed uniformly over the frequency range to maintain the pilot power in circuit 50, and also at the output terminals of the repeater, substantially constant. Thermistor 52 is similarly associated with network 33 and the changes in its resistance accompanying changes in the pilot power are translated into changes in the slope of the attenuation-frequency characteristic of the repeater. The use of thermistors as described for regulating the flat gain and slope characteristics of a repeater under the control of a pilot wave is well known in the art and does not of itself constitute a part of the present invention.

Bearing in mind that the pilot output power and the diverted pilot power both vary over only a very slight range when the regulating system is properly adjusted, it would evidently be desirable if these slight changes could be translated into magnified changes in heating current supplied to the thermistors 51 and 52 so that a correspondingly wide range of resistance values could be utilized. This desirable object is secured in Fig. 5 by interposing in the pilot circuit 50 one or more directly heated thermistors 57, 58. The thermistors are so proportioned and so connected in the circuit that as the pilot current from coil 14 changes they change in resistance in such sense as to amplify the change in current appearing at thermistor heaters 53 and 54.

Thus, if a single thermistor having a negative temperature coefficient of resistance is disposed in series in circuit 50 an increase in the pilot voltage at coil 14 will cause a more than proportionate increase in the current flow inasmuch as with an increase in current the thermistor is heated, its temperature raised and its resistance lowered, thereby reducing the total amount of resistance in the circuit connected to coil 14. Where two such series thermistors are employed as in Fig. 5, a resistance 59 may be bridged across the circuit 50 from their junction so that the expanding or amplifying effect of the first thermistor is in turn augmented by the expanding effect of the second thermistor. Thermistors 51, 52, 57 and 58 may be provided with supplemental heating means to compensate for the effect of varying ambient temperature on their operating characteristics.

If desired, positive feedback may be provided at the pilot frequency to compensate for the effect described with reference to Fig. 3 and for this purpose a frequency selective network 26 may be connected as shown from the anode to the control grid of the second stage amplifier tube 41.

Although the present invention has been described with reference to certain specific embodiments and with emphasis on its application to pilot channel control of the transmission characteristics of a repeater, it will be evident to those skilled in the art that the invention is susceptible of various other embodiments and applications within the spirit and scope of the appended claims.

What is claimed is:

1. In a system for the pilot channel control of repeater gain, a repeater amplifier of the negative feedback type, means for applying signal and pilot currents to said amplifier for through transmission with substantially equal gain, means at a point in the mu circuit of said amplifier for diverting pilot current therefrom, and means in said mu circuit following said point introducing many times greater relative transmission loss for said pilot current than for said signal current.

2. An electric wave amplifier of the stabilized feedback type comprising a mu-beta loop, means for applying signals and currents of non-signal frequency to the input of said amplifier for amplification therein, output means for withdrawing concurrently the amplified signals and non-signal current, frequency selective means in the mu portion of said loop for diverting current of said non-signal frequency, a load circuit for the current so diverted, and impedance means in said mu portion following said frequency selective means, said impedance means introducing substantially greater impedance at said non-signal frequency than at the frequencies occupied by said signals.

3. In a system for the pilot channel control of repeater gain, a repeater amplifier of the negative feedback type, means for applying signal and pilot currents to said amplifier for through transmission with substantially equal gain, means at a point in the mu circuit of said amplifier for diverting pilot current therefrom, means in said mu circuit at or following said point introducing many times greater relative transmission loss for said pilot current than for said signal current, said diverting means comprising a tuned circuit shunted across said mu circuit and a load circuit connected thereto having an effective resistance at the frequency of said pilot current such that the greater part of

the pilot power available at said point is absorbed.

4. A system in accordance with claim 1 in which said pilot diverting means comprises a frequency selective circuit disposed in shunt across said mu circuit and in which said amplifier is of the constant voltage feedback type.

5. An electric wave amplifier, means for applying signal and alternating non-signal currents to the input of said amplifier, means for concurrently withdrawing the amplified signal and non-signal currents from the output of said amplifier, said amplifier being of the negative feedback type having a mu circuit and a beta circuit, means at a point in said mu circuit for selectively diverting said non-signal currents, the transmission equivalent of the portion of said mu circuit following said point being such that said non-signal currents are highly attenuated therein relative to said signal current.

6. An electric wave amplifier of the negative feedback type having a mu beta loop, means for

applying to the input of said amplifier signal and alternating non-signal currents, frequency selective means in the mu portion of said loop for diverting said non-signal currents, and a frequency selective transmission element in the mu portion following said diverting means, said last-mentioned element interposing relatively high loss at the frequency of said non-signal currents and relatively low loss at the frequency of said signal currents.

7. An amplifier of the negative feedback type comprising a mu-beta loop, means for applying message current and unmodulated alternating currents to the input of said amplifier, a frequency selective load circuit shunted across said mu circuit and tuned to admit said unmodulated currents, and frequency selective means interposed in said mu circuit following said shunt circuit and tuned to relatively impede said unmodulated currents.

HENRY K. KRIST.