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RADIO TRANSMITTER

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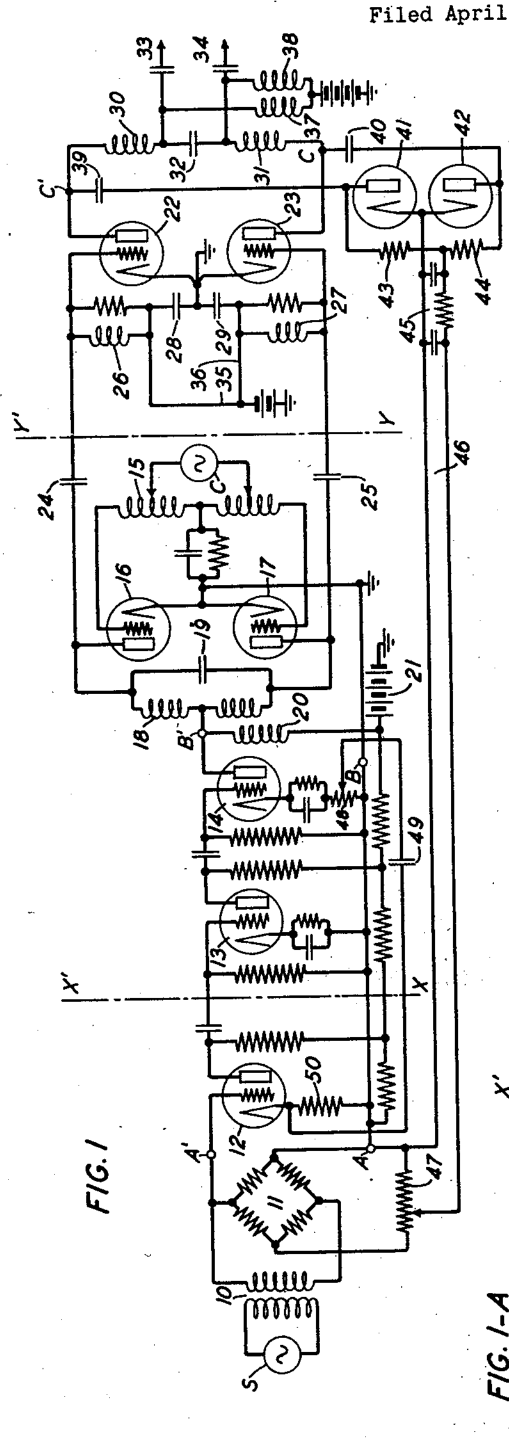

FIG. 1

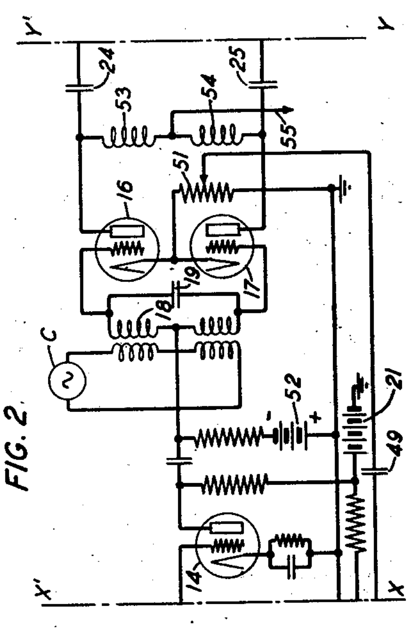

FIG. 2

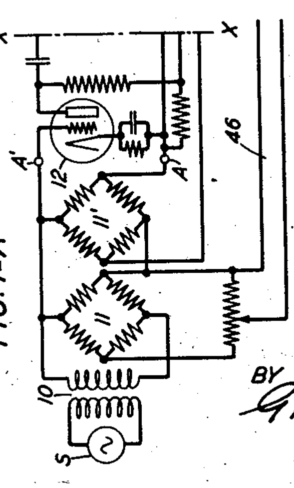

FIG. 1-A

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RADIO TRANSMITTER

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5 Claims. (Cl. 179—171.5)

This invention relates to the use of reverse feedback in radio transmitters and has for its principal objects to improve the stability against singing of transmitters employing reverse feedback; to facilitate the use of strong reverse feedbacks; and to provide for more effective reduction of signal distortion and noise producing disturbances by means of reverse feedback.

The distortion of speech signals in a radio transmitter occurs principally in those vacuum tubes in the system which are operated at relatively high energy levels and which are therefore likely to be loaded to their maximum capacity. The modulator tubes are frequently the most important source of distortion, particularly where modulation is performed at a high power level. This is as might be expected since the process of modulation requires the use of a device that is non-linear in its characteristics. Another important source of distortion is the output stage of the high frequency power amplifier, that is, the final stage of the transmitter. The distortion produced here affects both the wave form of the carrier oscillations and the envelope of their amplitudes. Only the latter effect is important since the distortion of the carrier wave form does not affect the signal after detection.

The stability of a feedback system against singing is dependent upon the characteristics of the closed loop formed by the amplifiers and the feedback path. When the transmission around this loop is such that the voltage arriving through the feedback path is in phase with the resultant voltage impressed on the input of the amplifiers, singing will occur unless the feedback voltage is sufficiently attenuated. Where a large number of amplifier stages is included in the loop, as is usually the case in a radio telephone transmitter of any considerable power, the phase of the feedback voltage changes very rapidly with frequency and at frequencies not far removed from the operating range is likely to reach the coincident value that gives rise to instability. A major problem in the application of feedback to radio transmitters is, therefore, that of so organizing the elements of the feedback path as to provide for strong feedback at the operating frequencies and to diminish the feedback at frequencies removed therefrom at such a rate as to insure adequate reduction of its magnitude before the frequency of phase coincidence is reached. The problem is made more difficult by the fact that the phase shift of the feedback is itself dependent upon the rate at which its magnitude diminishes.

In accordance with the present invention two reverse feedback paths are provided in a radio transmitter, one extending from the output circuit of the modulator or modulating amplifier to the signal input circuit and the other extending from the output circuit of the complete transmitter through a linear detector to the signal input circuit. The two feedback paths are thus connected respectively to the principal points at which distortion occurs and the relative amounts of feedback in each path may be apportioned in accordance with the amounts of noise and distortion originating at the two sources.

Preferably the feedback in the outer or overall loop is made to predominate, the feedback in the inner loop being utilized to secure additional suppression of the modulator distortion and to diminish the effective phase shift of the total resultant feedback as hereinafter described.

The nature of the invention will be more fully understood from the following detailed description together with the accompanying drawing, of which:

Figs. 1 and 1A show the application of the invention to a radio telephone transmitter; and

Fig. 2 illustrates a modified form of the invention.

Referring to Fig. 1, speech current source S supplies signal voltage oscillations through transformer **10** and differential bridge **11** to a three stage signal amplifier comprising vacuum tubes **12**, **13** and **14** which are coupled in tandem by means of series condensers and shunt resistances. A high frequency source C supplies carrier frequency oscillations through an autotransformer **15** to the grids of a duplex modulator comprising vacuum tubes **16** and **17**. The output circuit of the modulator includes a parallel circuit, coil **18** and condenser **19**, which is tuned to the frequency of the carrier wave. The modulator is of the well-known constant current type. The plates of signal amplifier tube **14** and modulator tubes **16** and **17** are connected together through a midpoint tap in coil **18** and are supplied with direct current through a common high inductance choke coil **20** from a direct current source **21**.

A second output circuit extends from the plates of the modulator tubes to the input of a push-pull power amplifier comprising vacuum tubes **22** and **23**. This output circuit includes series condensers **24** and **25**, radio frequency choke coils **26** and **27**, and by-pass condensers **28** and **29**. The input voltages of tubes **22** and **23** are derived from the potentials across choke coils **26** and **27**. The output circuit of the power amplifier is a tuned circuit comprising coils **30** and **31** and condenser **32**. A transmission line **33**, **34**, which may lead to an antenna, is connected across condenser **32** through suitable blocking condensers.

Plate current is supplied to the power amplifier tubes through choke coils **37** and **38** and suitable grid bias voltages through leads **35** and **36**. The grids of the speech amplifier tubes are self-biased by means of resistors included in the cathode leads as shown. The cathode heating circuits of the several tubes have been omitted for the sake of clarity.

The over-all feedback path is connected to the output circuit of the power amplifier through condensers 39 and 40 which are preferably of very small capacity and insulated to withstand the high radio frequency voltages. Full wave rectification of the modulated carrier wave is effected in a linear rectifier comprising diodes 41 and 42 and shunt resistors 43 and 44. The detected signal is impressed on a feedback line 46 through a resistance capacity filter 45 and is applied to the input of the signal amplifier through an adjustable potentiometer 47 and balanced differential bridge 11. The desired polarity of the feedback can be insured by poling the connection of line 46 to the rectifier output.

The internal feedback path extends from an adjustable tap in resistance 48 in the cathode lead of tube 14, through blocking condenser 49 to the cathode of tube 12 and cathode lead resistance 50.

Resistance 48 carries not only the direct current of the plate circuit of tube 14 but also a superimposed alternating current corresponding to the signal frequency variations of the current in this tube and modulator tubes 16 and 17. It is to be noted that as the plate current in tube 14 increases, the plate current in tubes 16 and 17 diminishes and vice versa, the two-plate current circuits together forming a single series path for the signal frequency variations. Because of this the current variations in resistance 48 correspond very closely to the envelope variations of the modulated wave and reproduce any distortion of the signal that may appear in the envelope variations. The feedback voltage is impressed upon resistor 50 which is included also in the grid circuit of tube 14 and is thereby transmitted to the vacuum tube grid.

The connection of the over-all feedback path to the input of the signal amplifier through the bridge 11 makes this feedback path conjugate to the signal source S. The high impedance of the grid circuit of tube 12 effectively separates the two feedback paths and prevents direct feedback from the transmitter output to the modulator which might otherwise take place through the two feedback paths in series. Complete conjugacy of the two feedback paths can be obtained by means of the double bridge input circuit illustrated in Fig. 1A, which represents an alternative arrangement of the system of Fig. 1 to the left of the line XX'. In this alternative, the conductor of the internal feedback path is connected to the corner of the second bridge 11' instead of to the cathode of the amplifier tube 12 as in Fig. 1.

The cooperative action of the two feedback paths will now be explained.

It is well known that the stability of a simple feedback amplifier and the distortion reducing effect of the feedback are dependent upon the net amplification experienced by a voltage or current oscillation in the course of a single traverse of the closed loop and upon the variation of this vector quantity with frequency. The net loop amplification is usually denoted by $\mu\beta$, where μ defines the vector amplification in the amplifier portion of the loop and β the transfer factor for the feedback path. The effect of the feedback is to diminish the effective amplification of the system in proportion to the quantity $(1-\mu\beta)$ and to reduce distortion and noise by substantially the same amount. The output level may be restored to its original value by an appropriate increase in the amplifier input voltage without losing the benefits of the distortion and noise reduction.

The action of the two feedbacks in the system of Fig. 1 may be analyzed as follows:

Let μ_1 denote the voltage amplification of the speech amplifiers from input terminals AA' to output terminals BB' and let $\mu_1\beta_1$ denote the net voltage amplification in the closed loop including these amplifiers and the local feedback path. Also, let μ_2 denote the voltage amplification from terminals BB' to terminals CC' in the high frequency system and let β_2 denote the voltage transfer factor between CC' and AA' for transmission through the over-all feedback path. The quantities μ_2 and β_2 refer to the signal variations, that is, μ_2 denotes the amplification of the signal modulation or the envelope variation of the carrier wave and β_2 the transfer factor relating the rectified signal voltage delivered to AA' to the signal modulations at CC'. For the over-all loop, in the absence of any feedback in the inner loop, the net voltage amplification is equal to $\mu_1\mu_2\beta_2$.

Since the action of the feedback in the inner loop including the speech amplifiers is to reduce the effective amplification of that portion of the system to the value

$$\frac{\mu_1}{1-\mu_1\beta_1} \qquad (1)$$

it readily follows that the additional effect of the over-all feedback is to reduce the total amplification of the system, to the effective value

$$\frac{\mu_1\mu_2}{1-\mu_1\beta_1}\cdot\frac{1}{1-\dfrac{\mu_1\mu_2\beta_2}{1-\mu_1\beta_1}}$$

or

$$\frac{\mu_1\mu_2}{1-(\mu_1\beta_1+\mu_1\mu_2\beta_2)} \qquad (2)$$

The stability of the system against singing is determined by the magnitude and frequency variations of the denominator of Expression 2, that is, by the vector sum of the two separate loop feedbacks $\mu_1\beta_1$ and $\mu_1\mu_2\beta_2$.

It is readily shown that a distortion or noise voltage which originates in the speech amplifier and which, in the absence of both feedbacks, would appear at terminals CC' as a modulation voltage ΔE_1 has its amplitude reduced to the effective value

$$\frac{\Delta E_1}{1-(\mu_1\beta_1+\mu_1\mu_2\beta_2)} \qquad (3)$$

Likewise, it may be shown that a distortion or noise voltage originating in the high frequency amplifier and contributing a modulation voltage ΔE_2 at terminals CC' in the absence of feedback is reduced by the action of the double feedback to the value

$$\frac{\Delta E_2(1-\mu_1\beta_1)}{1-(\mu_1\beta_1+\mu_1\mu_2\beta_2)} \qquad (4)$$

Comparing Expressions 2, 3, and 4 it is evident that noise or distortion originating in the speech amplifier is reduced by the feedback action to the same extent as the effective gain of the whole system is reduced, while noise or distortion originating in the high frequency portion of the system is reduced to a somewhat lesser extent. The difference corresponds to the reduction of gain of the speech amplifier effected by its local feedback.

If the over-all feedback $\mu_1\mu_2\beta_2$ is made as large as possible, consistent with stability requirements when the inner feedback is absent, a certain reduction of the noise and distortion originating at both the modulator and the power amplifier will result. The addition of the inner feedback provides a further suppression of distortion and noise originating in the modulator, but at some sacrifice of the degree of suppression of distortion originating in the power amplifier. In the carrying out of the invention, however, this sacrifice may be largely or completely offset by the use of an increased amount of feedback in the over-all loop. This is made possible by the increased stability of the system brought about by the use of the local feedback around the speech amplifier and the net result of the use of the two feedbacks is to considerably increase the suppression of the modulator distortion.

The manner in which the inner feedback operates to increase the stability is as follows: From the Expression 2 for the effective amplification of the system, it is seen that the stability is determined by the quantity

$$1-(\mu_1\beta_1+\mu_1\mu_2\beta_2) \qquad (5)$$

and that an unstable condition occurs if the phase angle of the vector $(\mu_1\beta_1+\mu_1\mu_2\beta_2)$ becomes zero while its magnitude is still greater than unity. Because of the larger number of amplifier stages and coupling networks included in the over-all feedback loop, the phase shift of the net amplification or feedback in this loop, $\mu_1\mu_2\beta_2$, varies more rapidly with frequency than does that of the net amplification, $\mu_1\beta_1$ for the inner feedback loop. For any given signal frequency, therefore, the phase shift of the total feedback $(\mu_1\beta_1+\mu_1\mu_2\beta_2)$ from the desired 180 degree value will be less than that of the over-all feedback $\mu_1\mu_2\beta_2$. By the use of resistance networks, as shown in Fig. 1, for coupling the speech amplifier stages, the phase shift of the inner feedback may be maintained at a low value for a range of signal frequencies several times as great as that required for speech transmission. The phase shift of the total feedback is thereby greatly reduced and a substantial increase in the over-all loop feedback is made possible without resulting instability.

The application of the invention to a radio transmitter employing a grid bias modulator is shown in Fig. 2. This figure shows the manner in which the system of Fig. 1 between the dotted lines XX' and YY' may be modified to provide for grid bias modulation. One stage of the speech frequency amplifier is dispensed with and the output of the final stage tube 14 is connected through a resistance network and tuned circuit 18—19 to the grids of the duplex modulator tubes 16 and 17. Plate current is supplied to the modulator tubes through chokes 53 and 54 from a direct current source connected to lead 55. The carrier source C is connected to the grids in push-pull relation through a transformer coupling to coil 18. The modulated output passes through tuning condensers 24 and 25 to the power amplifier as in Fig. 1.

The feedback from the modulator output extends from an adjustable contact on resistance 51 in the cathode lead of tubes 16 and 17 through blocking condenser 49 to the speech input circuit. The closed feedback loop includes three amplification stages, as in Fig. 1, the modulator tube itself functioning as the third audio stage and providing the desired number of phase reversals in the loop.

Part of the grid bias on the modulator tube is obtained from the fall of potential in resistance 51, but additional bias may be supplied by a suitable source, such as battery 52 in the grid leak circuit. If desired the modulator may be operated as a class B amplifier, that is, with the grid biased substantially to the cut-off point. In that case, the signal currents appear in resistor 51 as the modulations of amplified half period current pulses of the carrier frequency.

What is claimed is:

1. In a radio transmitter comprising a signal amplifier, a carrier wave source, a modulator, circuit connections for impresisng on said modulator waves from said source and amplified signal oscillations from said amplifier, and an amplifier for modulated carrier wave coupled to the output circuit of said modulator, a reverse feedback path extending from the output circuit of said carrier wave amplifier to the input circuit of said signal amplifier, and a second reverse feedback path extending between the input circuit of said signal amplifier and an intermediate point in the system at which amplified signal waves are present and at which the signal amplification is subject to distortion as the result of the action of said modulator.

2. In a radio transmitter comprising a signal amplifier, a carrier wave source, a space discharge modulator having a control grid, a cathode, and an anode, circuit connections for impressing waves from said source on said modulator grid circuit and amplified signal oscillations on said modulator anode circuit, and an amplifier for modulated carrier waves coupled to said modulator anode circuit, a reverse feedback path extending from the output circuit of said carrier wave amplifier to the input circuit of said signal amplifier and including a linear rectifier, and a second reverse feedback path extending from the output circuit of said signal amplifier to the input circuit thereof.

3. In a radio transmitter comprising in tandem relation a signal amplifier, a grid-bias modulator, and an amplifier for modulated waves, a reverse feedback path extending from the output circuit of said modulated wave amplifier to the input circuit of said signal amplifier and including a linear detector, and a second reverse feedback path extending from the output circuit of said modulator to the input circuit of said signal amplifier.

4. A system in accordance with claim 1 including circuit means in the input of said signal amplifier rendering the two feedback paths conjugate to each other whereby direct transmission from the first-mentioned feedback path to the modulator is prevented.

5. A system in accordance with claim 1 in which the said signal amplifier comprises a plurality of vacuum tubes coupled in tandem by resistance networks and in which the variation with frequency of the phase angle of the feedback loop constituted by said signal amplifier and said second feedback path is maintained small for a wide range of signal frequencies and whereby the feedback in said second feedback path compensates to a substantial extent the phase shift of the feedback from the output of said carrier amplifier.

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