Dec. 22, 1931. C. F. CHISHOLM 1,837,851

AMPLIFYING METHOD AND APPARATUS

Original Filed April 15, 1924 2 Sheets-Sheet 1

Fig 1

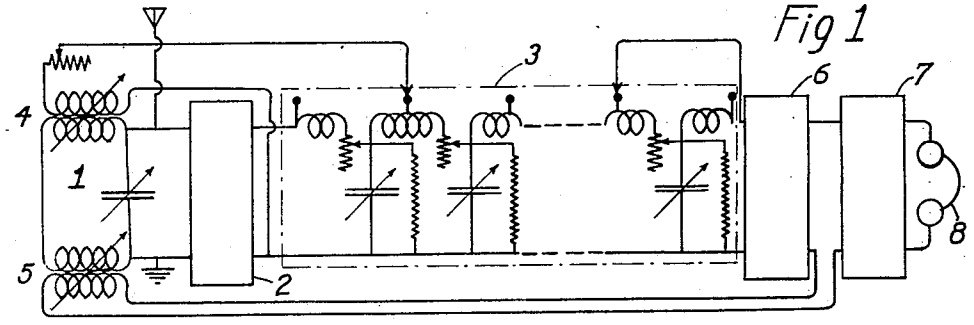


Fig 3

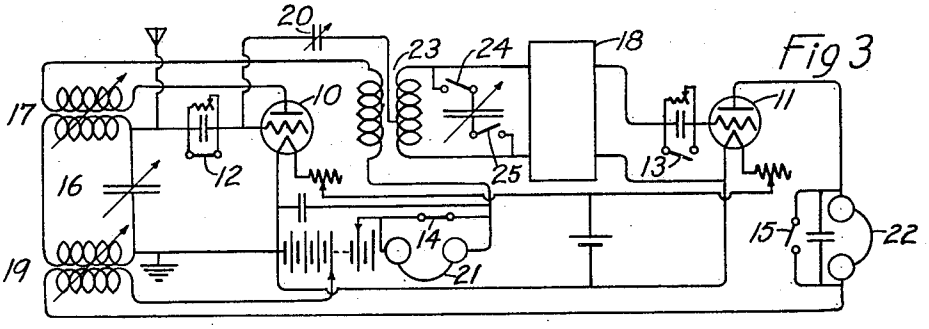
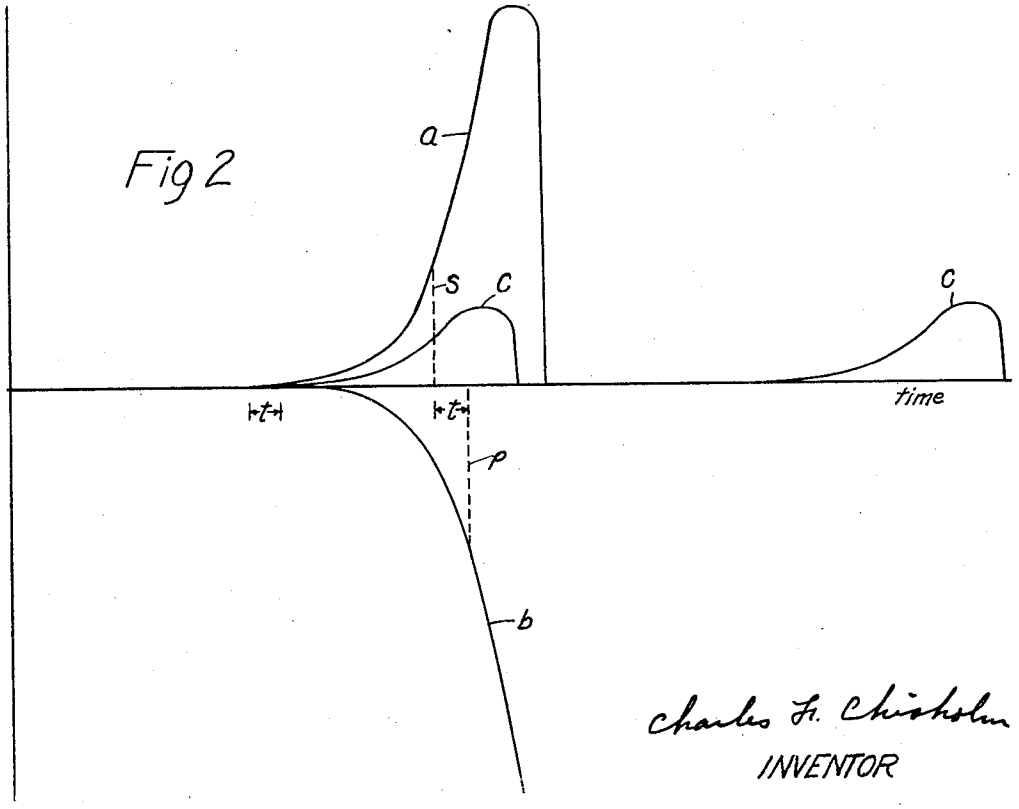


Fig 2



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Fig 4

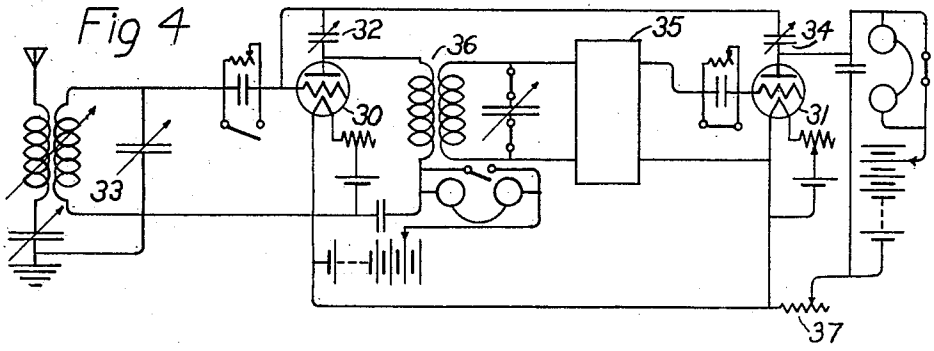
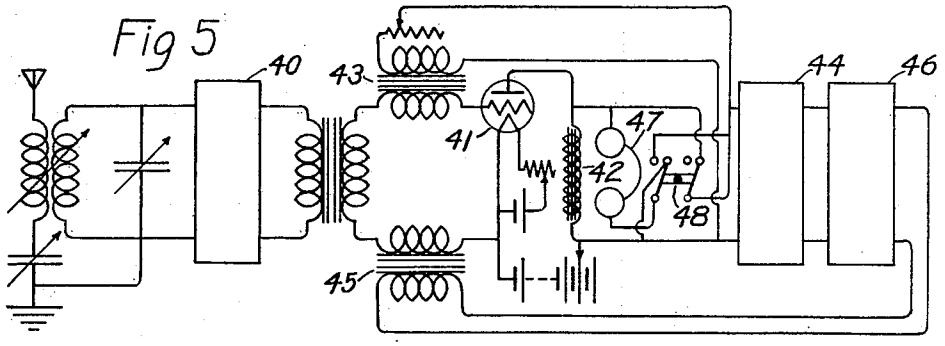


Fig 5



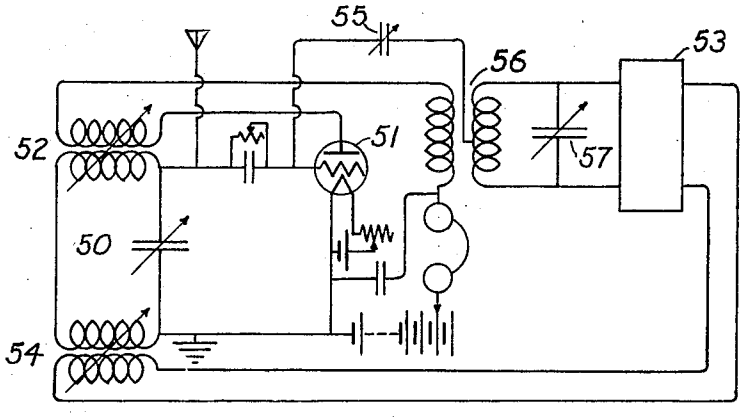


Fig 6

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1,837,851

UNITED STATES PATENT OFFICE

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AMPLIFYING METHOD AND APPARATUS

Application filed April 15, 1924, Serial No. 706,666. Renewed June 20, 1931.

This invention relates to amplifying methods and apparatus, and particularly to methods of and apparatus for amplifying impulses or the like a plurality of times with the same amplifying unit.

The general object of the invention is to provide a method of feeding back pulses from the output side to the input side of an amplifying device and arresting the amplification of each pulse after it has been fed back a limited number of times.

Another object of the invention is to provide a method of obtaining characteristic amplification with a so-called feedback amplifying device having a negative damping characteristic tending to cause sustained oscillation.

Other objects of the invention are to provide an improved method of and to provide an improved apparatus for preventing so-called feedback amplifying devices from going into sustained oscillation.

Other objects are to provide a method of and to provide an apparatus for passing pulses to be amplified, thru an amplifying device a plurality of times while limiting the ratio of the maximum value of an amplified pulse to the value of the original unamplified pulse.

Other and important objects of the invention are to provide an improved method of and to provide an improved apparatus for obtaining high amplification with a small number of amplifying units.

Among the specific objects of the invention are to provide a method of and to provide an apparatus for controlling feedback amplification by opposing the pulses or undulations fed back to effect regeneration by similar pulses or undulations retarded in time with respect to the regenerating pulses or undulations.

In accordance with the above and other objects of the invention, pulses to be amplified are passed thru an amplifying unit such as a three-electrode thermionic tube or the like, and at least a portion of each amplified pulse is returned to the input side of the amplifying unit and again passed thru and further amplified. In order to prevent this process from leading to sustained oscillation commonly known as "howling" or "singing", a portion of each amplified pulse is retarded in time by passing it thru a suitable phase retarding network, after which it may be further amplified and returned to the input side of the amplifying unit in a direction to oppose building up of sustained oscillation. For convenience the portion of the pulses fed back in a direction tending to produce sustained oscillation may be termed "feedback pulses", while the portion which opposes sustained oscillation (and which is retarded in time with respect to the feedback pulses) may be termed "counter-feedback" pulses. Similarly the path which returns the feedback pulses to the input side of the amplifying element may be termed a "feedback path" and the path which returns the counter-feedback pulses to the input side of the amplifying element may be termed a "counter-feedback path". By making the strength of each counter-feedback pulse greater by a sufficient amount than the strength of the feedback pulse which left the output side of the amplifying unit at the same time, sustained oscillation is prevented. However, on account of the retardation of the counter-feedback pulses after leaving the output side of the amplifying unit, a definite time interval elapses between the arrival of a feedback pulse at the input side of the amplifying unit and the arrival of the corresponding counter-feedback pulse. Thus, a feedback pulse on its first arrival at the input side of the amplifying unit is unopposed and produces corresponding amplification. At a later time the opposition by the counter-feedback pulses begins and since the counter-feedback pulses increase in strength more rapidly arithmetically than the feedback pulses, amplification is arrested after an incoming signal pulse or the like has been fed back a definite number of times; and under some circuit conditions the instantaneous value of the impulse may be brought to zero. This, however, is the starting condition and hence the process is immediately repeated. The result is that the effective value of each pulse as amplified is

limited to a definite multiple of the original unamplified pulse.

In the ordinary types of regenerative thermionic amplifiers the time required for a pulse to pass thru the thermionic element and be returned to the input side is practically negligible, and hence when the invention is applied to a radio telephone receiving set or the like, the building up of the pulses to a high instantaneous value may be made to take place at a superaudible rate and hence, even under circuit conditions where the instantaneous value of the pulse is reduced to zero upon arrest of amplification, the current when detected and fed to a sound reproducing device will cause a sound to be produced which is characteristic of the original unamplified pulse.

Both the feedback pulses and the counter-feedback pulses may be returned to the input of the amplifying unit by any suitable means and the counter-feedback pulses may be retarded by any suitable phase retarding network. If the time required to return the feedback pulses to the input of the amplifying device is too short for convenient adjustment and operation of the apparatus, it may be adjusted to a desired time of transmission by passing the feedback pulses thru a phase retarding network of such constants that it retards the propagation by a lesser amount than the network thru which the counter-feedback pulses are passed.

Figure 1 of the drawings shows schematically a radio receiving circuit in which feedback amplification in accordance with the present invention is carried out at radio frequency, inductive coupling being used to effect the feeding back.

Figure 2 shows curves plotted with time as abscissas to illustrate the principle of the present invention.

Figure 3 shows schematically an alternative form of the circuit shown in Figure 1.

Figure 4 shows schematically a radio receiving circuit in which feedback amplification in accordance with the present invention is carried out at radio frequency, capacity coupling being used to effect the feeding back.

Figure 5 shows schematically a radio receiving circuit in which amplification in accordance with the present invention is carried out at audio frequency.

Figure 6 shows schematically a radio receiving circuit embodying the present invention and employing only a single amplifying unit.

Referring to Fig. 1, an oscillatory circuit 1 is arranged to be excited by radio signals and to correspondingly energize an amplifying unit 2 which may be of any suitable type. By suitable means such as inductive coupling at 4 a portion of the output current of the amplifying unit 2 is fed back or made effective to reenforce the oscillations in circuit 1, as is well understood in the art. This current may be retarded in time somewhat by passing it thru a portion of a suitable phase retarding network 3. Another portion of the amplifying unit output current is further retarded in time by passage thru a greater portion of phase retarding network 3, after which it is impressed on the oscillatory circuit 1 by suitable means such as inductive coupling at 5 so connected that the voltage fed back to circuit 1 opposes the building up of oscillations therein.

The network 3 is shown as a variable length of artificial transmission line in which at least some of the constants are variable. This line should be designed and adjusted to have a suitable attenuation-frequency characteristic, and may be what is known in the art as a "distortionless" network, i. e., one which attenuates all frequencies equally. The mutual inductances 4 and 5 are so arranged relatively to each other that for a current pulse of given strength delivered by amplifying unit 2, inductance 5 feeds to circuit 1 a larger voltage than is fed by inductance 4. The voltage pulse fed to circuit 1 by inductance 5 is in a direction to oppose building up of oscillations, but due to the action of phase retarding network 3 this opposing pulse in circuit 1 is not set up until some definite time after a corresponding building up pulse has been fed back by inductance 4. In order to enable inductance 4 to feed back a relatively strong voltage without it being greater than the counter-feedback voltage fed back correspondingly (but at a later time) by mutual inductance 5, the current delivered to the primary of mutual inductance 5 may be independently amplified by a suitable amplifying unit 6.

By proper adjustment of the feedback and counter-feedback pulses an incoming signal impulse will in effect be passed thru amplifying unit 2 a definite limited number of times, thus being amplified by an amount which would be obtained by its passage thru a plurality of amplifying units in cascade. This action will be more clearly understood by referring to Fig. 2 which shows curves illustrating the voltages fed back to oscillatory circuit 1 by mutual inductances 4 and 5. Considering zero time to be at the instant a signal impulse is impressed on oscillatory circuit 1, the voltage fed back by mutual inductance 4 (or feedback voltage) builds up as illustrated by curve a, this voltage being shown as positive to indicate that it is cumulative with the incoming signal impulse. The voltage fed back thru mutual inductance 5 (or counter-feedback voltage) increases according to a law similar to that of the feedback voltage, but the curve is shifted to the right by an amount t which measures the time lag introduced by phase retarding net-

work 3. This voltage represented by curve *b* is plotted negatively to indicate that it is opposed to the voltage of the impressed signal pulse. A pulse delivered to the output of the amplifying unit 2 is fed back more strongly thru mutual inductance 5 than thru mutual inductance 4 which is illustrated in the curves by the condition that the absolute value of any ordinate *p* representing the counter-feedback voltage is equal to *ks*, where *s* is the absolute value of the ordinate of curve *a* which precedes ordinate *p* by time *t*, and *k* is a constant which is greater than unity. It is seen therefore that initially an incoming pulse is fed back and amplified unrestrained, but that if *k* has a suitable value, the counter-feedback voltage will overtake the feedback voltage after the signal impulse has passed thru the amplifying unit a definite number of times, thus arresting amplification and preventing the amplifying unit from going into sustained oscillation. Under some conditions the oscillation of circuit 1 may be killed completely for an instant when amplification is arrested by the counter-feedback voltage, as is indicated by curve *c* illustrating the resultant of curves *a* and *b*. This, however, places the circuit in the initial condition, and hence the resultant value of the voltage in the oscillatory circuit 1 again builds up in like manner as is indicated by the second hump of curve *c*.

A detector 7 and suitable translating device 8 are suitably associated with the amplifying circuit to be acted upon by amplified incoming signals, as by cascade connection to the amplifier 6. The constants of the circuit are given values which cause the humps of curve *c* to occur at a superaudible rate, and hence the translating device 8 gives a sound output corresponding to the incoming signals, but greatly increased in strength. By varying the values of the feedback and counter-feedback pulses and varying the time lag *t* the signal pulses may be passed thru the amplifying unit 2 a greater or lesser number of times before the arrest of amplification, and hence the effective amplification of the received signals may be varied accordingly.

The actual shape of the curves shown in Fig. 2 will vary with the degree of coupling at 4 and 5, the amplification factors of the amplifying unit 2 and the amplifier 6, the circuit losses etc., and hence the curves shown are not intended to show the actual values for any circuit, but are merely illustrative to make clear the principle on which the invention operates.

In the circuit shown in Fig. 3 there are two three-electrode thermionic elements 10 and 11, either of which may be operated as an amplifying unit while the other functions as a combined detecting and amplifying unit. Considering switches 12 and 14 closed and switches 13 and 15 open, the oscillatory circuit 16 is excited by incoming signals and correspondingly energizes amplifying unit 10, feedback pulses being returned to circuit 16 thru mutual inductance 17. A portion of the amplified pulses passes thru phase retarding network 18 after which this portion is further amplified by amplifying-detecting unit 11 and fed back to circuit 16 by mutual inductance 19 as counter-feedback pulses. The circuit operates in the manner of the circuit of Fig. 1. If desired a small condenser 20 connected to the secondary of transformer 23 may be used to eliminate feedback thru the capacity of the electrodes of element 10, thus leaving only the feedbacks thru inductances 17 and 19 to be dealt with in adjusting the circuit. Transformer 23 is of suitable type and may be tuned by closing switches 24 and 25.

By closing switch 13 and opening switch 12 thermionic element 11 becomes an amplifier, while element 10 serves as an amplifier and detector. By closing the switch in shunt of either translating device 21 or translating device 22, it is rendered inoperative and the other may be used to produce sound corresponding to the received signals.

In the form of apparatus shown in Fig. 4 either of the thermionic elements 30 or 31 may be used as an amplifying unit, while the other functions both as a detecting unit and as an amplifying unit. By means of a condenser 32 amplified undulations are fed back to the oscillatory circuit 33 as feedback pulses, and by means of another condenser 34 corresponding undulations which have been retarded in time by a phase retarding network 35 are fed back as counter-feedback pulses. If the undulations after passing thru transformer 36 (which may be tuned) and being retarded by phase retarding network 35 are not of a phase to oppose the initial oscillations, this condition can be brought about by reversing the connection of the secondary of the transformer 36 to the network 35 or by reversing the connection of the network to thermionic element 31, thus shifting the undulations delivered by thermionic element 31 thru an electrical angle of 180 degrees without affecting the time of propagation of the counter-feedback pulses from the thermionic element 30 back to oscillatory circuit 33. A variable impedance 37 may be used to adjust the external impedance of the output circuit of thermionic element 31 to the optimum value. The remaining features of this circuit are similar to corresponding features of the circuit of Fig. 3 and hence further description is believed to be unnecessary.

In the form of the invention shown in Fig. 5 received radio signals or the like are detected by a suitable detector 40 and then passed to an amplifier comprising thermionic element 41. The space current of thermionic

element 41 may be shunted thru an audio frequency choke 42, a portion of the undulations as amplified by element 41 being returned to the input circuit of the element as feedback pulses by suitable means such as a transformer 43, connected to aid the undulations delivered by the detector. A further portion of the undulations amplified by element 41, after being retarded in time by a phase retarding network 44, is returned to the input of element 41 as counter-feedback pulses by suitable means such as a transformer 45 connected to oppose the undulations delivered by detector 40. Transformer 45 feeds back a voltage larger than the voltage correspondingly fed back (but at an earlier time) by transformer 43, and the relative values of the feedback and counter-feedback voltages are such as to produce an action such as is represented by the curves of Fig. 2. Phase retarding network 44 attenuates the counter-feedback pulses somewhat and hence an independent amplifier 46 may be used to boost them in strength if desirable to aid in returning them with requisite strength to the input circuit of element 41. To convert the received signals into corresponding sound waves a translating device 47 is provided and by means of a switch 48 may be connected either in series with or in shunt of the a. c. output circuit of amplifying unit 41.

In the form of apparatus shown in Fig. 6 an oscillatory circuit 50 is arranged to be excited by incoming radio signals or the like, and to correspondingly energize a three-electrode thermionic element 51 connected to function both as a detecting unit and as an amplifying unit. A portion of the undulations amplified by element 51 are returned to oscillatory circuit 50 as feedback pulses by suitable means such as inductive coupling at 52, and a further portion of the amplified undulations are retarded in time by a phase retarding network 53 after which it is returned to oscillatory circuit 50 as counter-feedback pulses by suitable means such as inductive coupling at 54. The counter-feedback pulses not being independently amplified, the proper relationship between the strength of the feedback and counter-feedback pulses is obtained by adjustment of the mutual inductances 52 and 54. In order to eliminate the factor of feedback thru the capacity of the electrodes of the thermionic element, a small condenser 55 may be connected between the input circuit of element 50 and the secondary of transformer 56 interposed between the output circuit of element 51 and the phase retarding network 53. If desired transformer 56 may be tuned by a condenser 57.

The present invention has been disclosed as applied to radio receiving circuits, but it will be apparent to those skilled in the art that the method disclosed may be used for obtaining amplification in other relationships. It is therefore desired that the present disclosure be considered as illustrative and not in the limiting sense.

Having thus described my invention, what I claim is:

1. The method of amplifying electrical undulations which comprises strengthening undulations in the input circuit of an amplifying device with similar undulations, weakening the undulations in the input circuit with other undulations which are retarded in physical time with respect to said strengthening undulations, and increasing the strength of the weakening undulations.

2. The method of amplifying electrical impulses which comprises regenerative amplification of said impulses restrained by portions similar to those amplified but retarded in physical time with respect to the regenerating portions, said restraining portions being increased in strength to prevent singing of the amplifying device.

3. The method of preventing singing of a so-called regerenative amplifier which comprises opposing the regeneration with electrical undulations which are retarded in physical time with respect to the undulations fed back to effect regeneration and increasing the strength of the opposing undulations with sufficient rapidity to prevent singing of the amplifying device.

4. The method of amplifying electrical undulations which comprises passing said undulations through an amplifying device, feeding a portion of the amplified undulations back through the amplifying device to effect regeneration, retarding the propagation of another portion of the amplified undulations and feeding said retarded undulations back through the amplifying device to oppose regeneration.

5. The method of amplifying electrical undulations which comprises passing said undulations through an amplifying device, feeding a portion of the amplified undulations back through the amplifier to effect regeneration, retarding the propagation of another portion of the amplified undulations and feeding said retarded undulations back with greater strength than the companion portion of the undulations fed back to effect regeneration, said retarded undulations being fed back to the amplifying device to oppose regeneration.

6. In combination, an electrical amplifying device comprising an amplifying unit having an input and an output circuit, a feedback path from said output circuit to said input circuit to by-pass energy around the amplifying unit from the output circuit to the input circuit, and a counter-feedback path from said output circuit to said input circuit.

7. In combination, an electrical amplifying device having an input circuit and an

output circuit, a feedback path from said output circuit to said input circuit, a counter-feedback path from said output circuit to said input circuit, and means to retard in physical time the electrical energy passing over said counter-feedback path.

8. In combination, an electrical amplifying device comprising an amplifying unit having an input circuit and an output circuit, means to feed energy of one phase from said output circuit around said amplifying unit to said input circuit, means to feed energy of another phase from said output circuit around said amplifying unit to said input circuit, and means to independently amplify the energy fed by one of said means.

9. In combination, an amplifying device comprising an amplifying unit having an input side and an output side, means to feed energy of one phase from the output side around the amplifying unit to said input side, means to feed energy of another phase from the output side around the amplifying unit to said input side, and means to independently amplify the energy fed by one of said means.

10. In combination, an electrical amplifying device having an input circuit and an output circuit, said amplifying device inherently feeding back energy from the output circuit to the input circuit; means to neutralize the effect of the energy inherently fed back; a feedback path from said output circuit to said input circuit; a counter-feedback path from said output circuit to said input circuit; and means to retard in physical time the electrical energy passing over said counter-feedback path.

11. A signaling system comprising an amplifier, a pair of paths for conveying energy to the input side of the amplifier, means to apply electrical energy of substantially the same phase to each of said paths, and a delay circuit interposed in one of said paths.

12. A signaling system comprising an amplifier, a plurality of paths for conveying energy to the input side of the amplifier, means to apply electrical energy of substantially the same phase to each of said paths, and delay circuits of different times of transmission interposed in said paths, respectively.

13. A signaling system comprising an amplifier, a pair of paths for conveying energy to the input side of the amplifier, means to apply electrical energy of substantially the same phase to each of said paths, and a variable delay circuit interposed in one of said paths.

14. A signaling system comprising an amplifier, a plurality of paths for conveying energy to the input side of the amplifier, means to apply electrical energy of substantially the same phase to each of said paths, and variable delay circuits of different times of transmission interposed in said paths, respectively.

15. In combination, an electrical amplifying device comprising an amplifying unit having an input circuit and an output circuit, means to feed electrical energy of one phase and frequency band from said output circuit around said amplifying unit to said input circuit, and means to feed electrical energy of another phase but of substantially the same frequency band from said output circuit around said amplifying unit to said input circuit.

16. In combination, an electrical amplifying device having an input circuit and an output circuit, means to feed electrical energy of one phase and frequency band from said output circuit to said input circuit, means to feed electrical energy of another phase but of substantially the same frequency band from said output circuit to said input circuit, and a delay circuit interposed in the path of the energy fed by one of said means.

17. In combination, an electrical amplifying device comprising an amplifying unit having an input circuit and an output circuit, and means to feed energy of a plurality of phases but of substantially the same frequency band from said output circuit around said amplifying unit to said input circuit.

18. In combination, an electrical amplifying device having an input side and an output side, means to feed energy of one phase from the output side to the input side of the amplifying device, means to feed energy of another phase from the output side to the input side of the amplifying device, and a delay circuit interposed in the path of the energy fed by one of said means.

19. In combination, an amplifier unit, a detector unit connected to receive energy delivered by the amplifier unit, means to transmit energy from the output of the detector unit to the input of the amplifier unit to control the amplification, and a delay circuit operatively interposed in the energy path from the output of the amplifier unit back to the input of the amplifier unit.

20. In combination, an amplifier unit, a detector unit connected to be energized from the output of the amplifier unit, a delay circuit interposed between the amplifier unit and the detector unit, and a feedback connection from the detector unit to said amplifier unit to control the amplification.

21. In combination, an amplifier unit, a feedback path from the output circuit to the input circuit of the amplifier unit, a detector unit connected to receive energy delivered by the amplifier unit, means to transmit energy from the output of the detector unit to the input of the amplifier unit to control the amplification, and a delay circuit operatively interposed in the energy path from the out-

put of the amplifier unit back to the input of the amplifier unit.

22. In an electrical amplifying system, means for coordinating the transmission of energy over a pair of paths, said means comprising a delay circuit connected into one path to give a time of transmission which can be readily handled, and a delay circuit of different time of transmission connected into the other path.

23. In an electrical amplifying system, means for coordinating the transmission of energy over a pair of paths, said means comprising a delay circuit connected into one path to give a time of transmission which can be readily handled, and a variable delay circuit of longer time of transmission connected into the other path.

CHARLES F. CHISHOLM.