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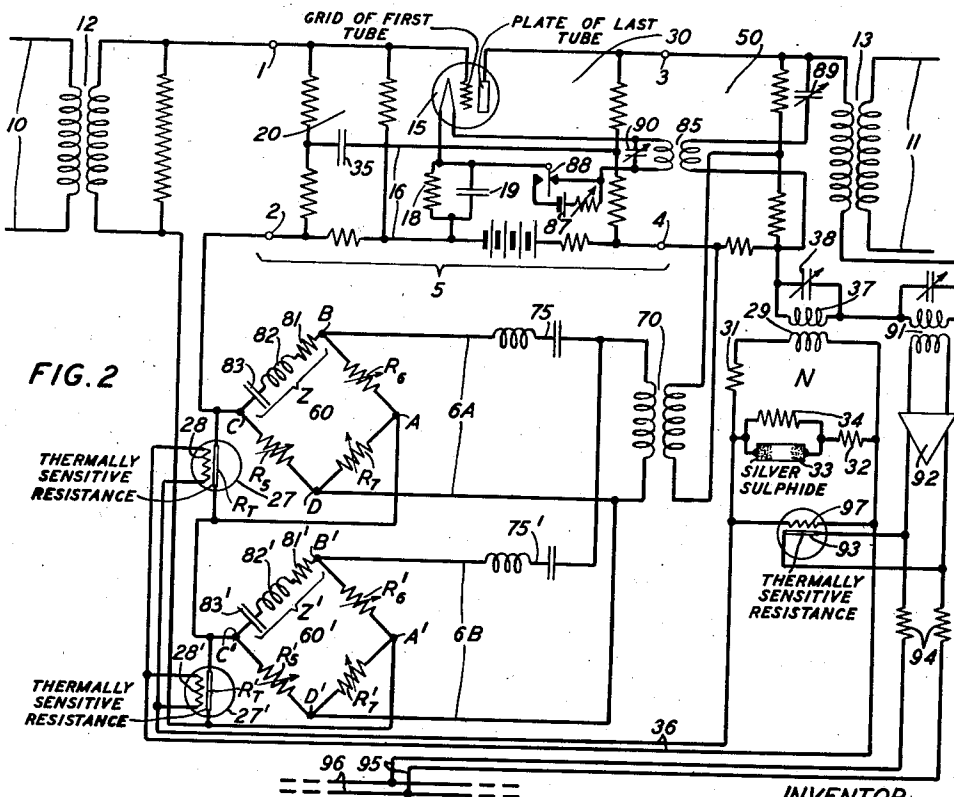
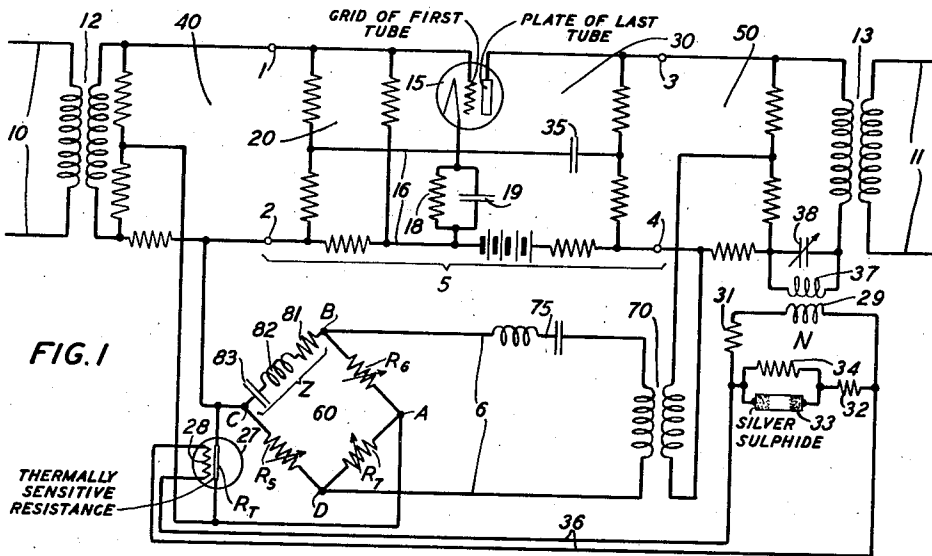
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2,258,128

WAVE TRANSLATING SYSTEM

Filed Dec. 20, 1938

2 Sheets-Sheet 1



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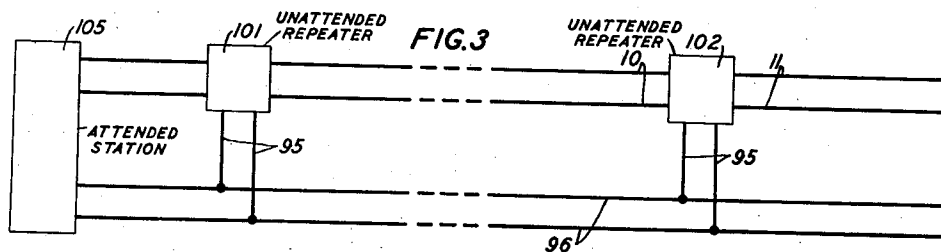
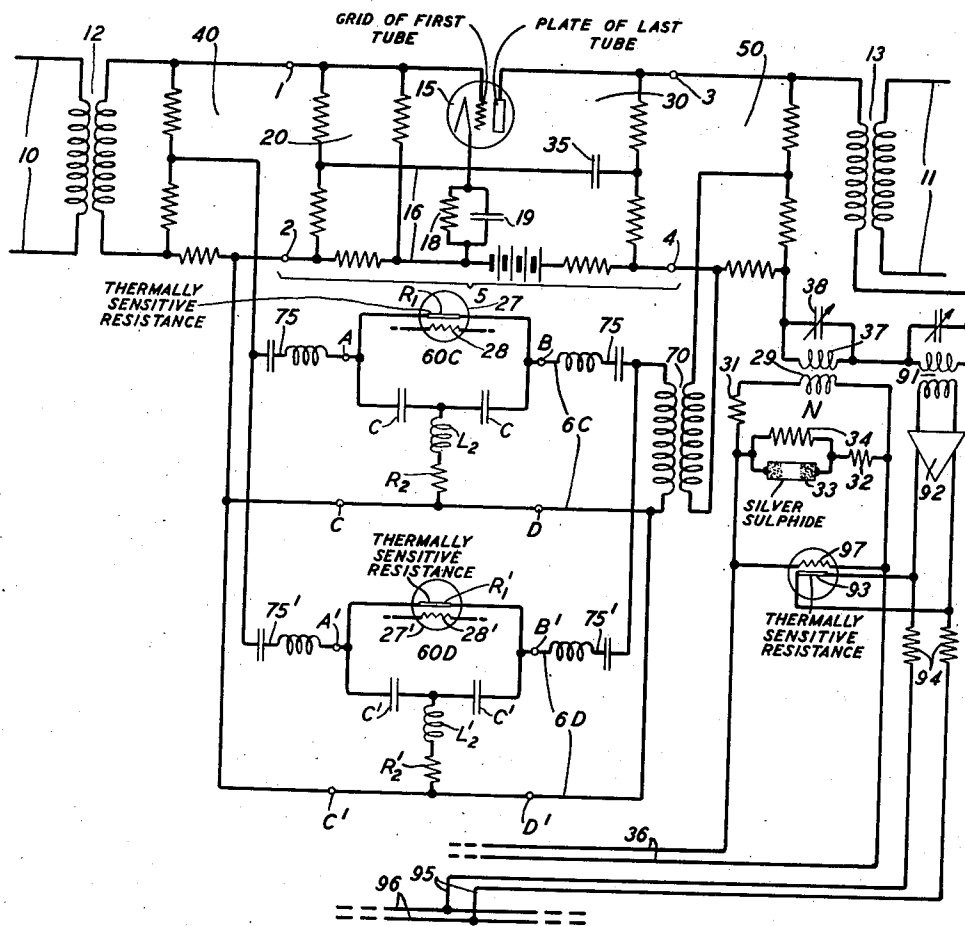
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2 Sheets-Sheet 2

FIG. 4



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2,258,128

WAVE TRANSLATING SYSTEM

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10 Claims. (Cl. 250—36)

This invention relates to wave translating systems, as for example, oscillators and oscillator-amplifiers.

An oscillator may be regarded as an amplifier plus a retroactive coupling or oscillation circuit whose critical phase angle determines the oscillation frequency (the free response of the system being an expanding wave and the amplitude of the oscillations being limited by non-linearity of the amplifying device or some other element of the system). In adding a retroactive coupling or oscillation circuit of critical phase frequency characteristic to an amplifier to form an oscillator, the optimum phase shift for the amplifier is the negative of the phase shift of the oscillation circuit at its critical frequency, at which its frequency stabilizing effect is a maximum. For example, with the usual bridge or other types of coupling circuit having phase shift 180 degrees at the critical frequency, an amplifier phase shift of 180 degrees enables the coupling circuit to operate at its critical frequency, at which its frequency stabilizing effect is a maximum; and such a system will not oscillate at all if the phase angle of the amplifier is in the first or fourth quadrants.

An object of the invention is to facilitate obtaining the optimum phase shift in an amplifier or driving circuit for an oscillator or wave generator.

In one specific aspect the invention is an oscillator in which the optimum amplifier phase shift for the oscillation frequency is obtained by negative feedback in the amplifier at that frequency. For example, the oscillator may be of the general type (disclosed, for instance, in L. A. Meacham Patent 2,163,403, or in the paper by L. A. Meacham on "The Bridge Stabilized Oscillator," Proceedings of the Institute of Radio Engineers, October 1938), whose frequency determining circuit coupling the amplifier output terminals to the amplifier input terminals is a bridge network with 180 degrees phase shift at the desired oscillation frequency, and in accordance with the invention the amplifier may include a negative feedback path conjugate to the coupling circuit to render the amplifier phase shift 180 degrees at that frequency. For instance, with the amount of negative feedback in the amplifier sufficient, for example of the order of upwards of twenty decibels, the amplifier phase shift can be made substantially 180 degrees by making the phase shift of the feedback path substantially zero; for, as explained in my Patent 2,102,671, the phase shift of an

amplifier with large negative feedback approaches 180 degrees minus that of the feedback path, for example the phase shift of such an amplifier approaching 180 degrees if the phase shift of the feedback path is zero.

For best frequency stability it is desirable not only to operate with the mean value of the phase shift of the bridge network or coupling circuit and the mean value of the phase shift of the amplifier near to 180 degrees (in order to minimize the effect upon the oscillator frequency of any change in the amplifier gain or phase shift or a change in a bridge resistance), but also to keep the phase variations of the amplifier and the gain variations of the amplifier as small as possible, and, moreover, to have the amplifier gain high (the higher the gain, the higher the frequency stability, other things being equal). Fixing the amplifier phase shift at 180 degrees by a large value of negative feedback facilitates obtaining all of these desirable operating conditions. It reduces the amplifier phase shift variations; and it gives flexibility as to the number of amplifier stages (and interstage circuits) available and thus facilitates giving the amplifier (as well as the amplifying element or device of the amplifier) high gain while maintaining the 180 degree phase shift of the amplifier.

If desired, the amplitude of the oscillations may be limited to and stabilized at a value below the overload value for the amplifying element. This may be done, for instance, by having an amplitude stabilizing element in the oscillation-producing coupling circuit in the general manner disclosed in R. S. Caruthers Patent 2,066,333, January 5, 1937, and the Meacham patent and paper mentioned above. For example, the amplitude stabilizing element may vary its impedance, in response to variations of the oscillation amplitude, so as to vary the attenuation of the coupling circuit in such manner as to maintain the gain for propagation once around the oscillator loop zero decibels at an oscillation amplitude that is below the overload value for the amplifying element and is substantially constant at the amplifier output, and thus maintain the oscillation amplitude substantially constant at the amplifier output. Further, the amplitude of the oscillations may thus be limited to a value far below the overload value for the amplifying element, and the amplifier, while being used with the coupling circuit to generate the oscillations, may at the same time be used as a broad band amplifier for amplifying waves supplied by an incoming circuit and transmitting the amplified

waves to an outgoing circuit, for example in the general fashion disclosed in the Caruthers patent.

If desired the oscillator, or the oscillator-amplifier, may have a plurality of oscillation or frequency determining circuits coupling the amplifier output terminals to its input terminals, each coupling circuit having a suitable amplitude stabilizing element for limiting the oscillation amplitude as indicated above, so that the system produces oscillations of a plurality of frequencies, which need not be related to each other but, as long as they differ substantially from the frequencies to be amplified by the system, may have any desired values, even values that are close to frequencies to be amplified.

The amplitude stabilizing element may be of any suitable type. For example, it may be the "Thyrite," copper oxide rectifier, or space discharge device referred to in the Caruthers patent as exhibiting an overload or non-linear relation between instantaneous values of current and voltage; or it may be variable with its temperature in response to change in magnitude of the current traversing it. In accordance with the invention, the amplitude stabilizing element may preferably be a so-called thermister, or temperature dependent, non-linear resistance element of the general type that varies the magnitude of its resistance enormously in response to change of its temperature, so as to exhibit a non-linear relation of current to voltage when heated by the current passing through it. For example, the non-linear element may be a resistance of silver sulphide, uranium oxide, cobalt oxide, or boron, with its operating and restoring times (i. e., the times required for it to heat and cool) less than the times required for the oscillations to build up and decay, a sufficient condition to insure against any tendency for the oscillations to build up in spurts when the system is switched or keyed to the condition for oscillation production, yet with the time required to alter the thermister temperature (and hence to alter the thermister resistance) large compared to the time required for execution of changes in instantaneous current or voltage at any frequency falling within the useful range of frequencies of the amplifier or the oscillator, thus avoiding production of deleterious modulation by the amplitude limiting or amplitude stabilizing element.

Other objects and features of the invention will be apparent from the following description and claims.

Fig. 1 is a circuit diagram of a self-oscillating feedback amplifier, or wave generating and wave amplifying system embodying one form of the invention;

Fig. 2 is a circuit diagram of a modification of the self-oscillating amplifier of Fig. 1 which produces oscillations of a plurality of frequencies;

Fig. 3 is a schematic circuit diagram of a system including the amplifier of Fig. 2; and

Fig. 4 is a circuit diagram of a modification of the amplifier of Fig. 2.

The system of Fig. 1 comprises an amplifier 5 having input terminals 1 and 2 and output terminals 3 and 4, and comprises a coupling circuit 6 coupling the amplifier output and input circuits for generating sustained oscillations of given frequency, and also comprises an incoming circuit 10 with input transformer 12 for supplying the amplifier with waves to be amplified and an outgoing circuit or load circuit 11 with output trans-

former 13 for utilizing the amplified waves and the generated oscillations.

The waves to be amplified may be, for example, a wide frequency band of signal waves. For instance, these waves may be speech modulated carrier waves of a number of carrier telephone channels of a multiplex carrier telephone system.

The frequency of the generated oscillations, so long as it differs substantially from the frequencies of the waves to be amplified, may have any desired value. The generated oscillations or waves may be utilized for any desired purposes, a few examples being given hereinafter.

The amplifier 5 comprises an amplifying path including an amplifying element or device 15 and a feedback path 16 connecting the output and input circuits of the amplifier for producing negative feedback in the amplifier.

The device 15 may be, for example, a vacuum tube amplifying device having a single vacuum tube stage or any desired number of cascaded stages of triodes, pentodes, or other suitable vacuum tubes, as indicated by the legends applied to the grid and plate shown in the drawing. Grid biasing potential may be supplied in any suitable manner, as indicated, for example, by a resistor 18 in the cathode lead which is traversed by plate current and which is by-passed for alternating current by condenser 19. The grid bias for the tube or tubes of the amplifier preferably is sufficiently large to prevent flow of grid current during normal operation of the system.

An input bridge 20 connects the terminals 1 and 2 to the input of the amplifying device and connects the feedback path 16 to the input of the amplifying device, giving conjugacy between the feedback path 16 and the circuits attached to the amplifier at its input terminals 1 and 2, i. e., the incoming circuit 10 of the system and the oscillator coupling circuit 6.

An output bridge 30 connects output of the amplifying device to the terminals 3 and 4 and connects the output of the amplifying device to the feedback path 16, giving conjugacy between the feedback path 16 and the circuits attached to the amplifier at its output terminals 3 and 4, i. e., the outgoing or load circuit 11 and the oscillator coupling circuit 6.

The feedback path 16 includes a stopping condenser 35 of negligible reactance for the frequencies of the waves to be amplified and the oscillations to be generated.

An input bridge 40 connects the incoming circuit 10 to the amplifier input terminals 1 and 2 and connects the oscillator coupling circuit 6 to the amplifier input terminals 1 and 2, giving conjugacy between the oscillator coupling circuit 6 and the incoming circuit 10.

An output bridge 50 connects the amplifier output terminals 3 and 4 to the outgoing circuit 11 and connects the amplifier output terminals 3 and 4 to the oscillator coupling circuit 6, giving conjugacy between the oscillator coupling circuit 6 and the load circuit 11.

The oscillator coupling circuit 6 comprises a frequency stabilizing bridge network 60, amplitude limiting or amplitude stabilizing means R_T , a transformer 70 which prevents short-circuiting of one of the arms of bridge 60, and a frequency selective network 75. The network 75 may be a circuit tuned to the frequency of the oscillations to be generated, and serves to prevent transmission from bridge 50 to amplitude limiter R_T of waves of other frequencies, espe-

cially the signal waves supplied by line 10 to amplifier 5.

The transformer 70 may be a unity ratio broad band transformer of close coupled high efficiency type with its phase shift inherently small, for example within one or two degrees over its broad band, including the frequencies at and near the desired oscillator frequency.

The bridge 60 comprises resistance arms R_5 , R_6 and R_7 and an impedance arm Z shown as resistance 81, inductance 82 and capacity 83 in series, the resistance of inductance 82 being considered as included in resistance 81. Inductance 82 and capacity 83 resonate at the desired oscillator frequency. Resistances R_5 , R_6 , R_7 and 81 preferably have approximately equal values, so that at the resonance frequency the bridge 60 is balanced except for a slight resistive unbalance.

The amplitude stabilizing element R_T may be an impedance variable in magnitude with the strength of the current traversing it. For example, it may be a "Thyrite" element or copper oxide rectifier or space discharge device exhibiting an overload or non-linear characteristic as referred to above. Preferably, it is a temperature dependent non-linear resistance, for example a thermister unit of silver sulphide, uranium oxide, cobalt oxide or boron, varying its impedance in response to variations of the oscillation amplitude, so as to vary the attenuation of the coupling circuit in such manner as to maintain the oscillation amplitude at the amplifier output substantially constant at a value below the overload value for the amplifier, as indicated above. The thermister may have its operating and restoring times less than the times required for the oscillations to build up and decay, yet sufficient to avoid production of deleterious modulation, as indicated above. Such condition is readily obtainable in the system shown, for two reasons. One reason is that, with the frequency determining circuit in the bridge as shown and with high amplification in the amplifier, the frequency selective bridge circuit is equivalent to a series-resonant circuit of very high effective "Q" connected across the coupling circuit 6. (In general, the narrower the pass band or frequency band of response of the path through the amplifier and coupling circuit, the longer are the times taken for the oscillations to build up and decay. In the system shown, these times tend to increase as the gain of the amplifier is increased. Moreover, they can be increased by reducing the resistances of bridge 60, reducing the impedances viewed from the bridge toward 70 and toward R_T , and increasing the inductance 82.) The second reason is that the operate and release times of the thermister can be made to approach equality and also can be varied through very wide limits by the mechanical and thermal design of the thermister units. For example, the release time is a measure of the heat loss of the thermister and in a well designed assembly will be largely controlled by the mass of the unit and its heat loss, which is largely due to heat conduction along its two lead wires. If the operate time is materially shorter than the release time (it is never longer) additional mass can be placed in thermal but not electrical contact with the surface of the thermister. This lengthens the operate time and shortens the release time and can be continued until the two are almost equal with some attendant loss in sensitivity. The smaller the mass of the thermister, the shorter the operate and release times. Units

have been constructed to operate and release in $\frac{1}{40,000}$ of a second.

Any objectionable effects of changes in ambient temperature of the thermister can be obviated in any suitable manner. For example, the thermister may be enclosed in a heat insulated chamber 27. Where heat insulation surrounding the thermister is sufficiently far from the thermister, such insulation merely has the effect of housing the thermister in a heat insulated room. Thus, placing the thermister in an insulated chamber, such as 27, sufficiently large with regard to the thermister unit itself and the power it dissipates, greatly reduces the effect upon the thermister of fluctuations in room temperature and also materially reduces its slow temperature changes, yet does not materially effect its relative times of heating and cooling.

Where required by the desired precision of operation of the thermister, objectionable effects of room temperature variations can be obviated by maintaining the heat insulated chamber 27 at a fixed temperature, in excess of the highest room temperature. For example, in the general manner disclosed in my Patent No. 2,209,955, August 6, 1940, for Wave translation system, this can be accomplished by a chamber heating element 28 supplied with heating current from a power source through regulating network N and conductors 36. This network has a series resistance arm 31 and a shunt arm comprising a resistance 32 in series with two parallel resistances 33 and 34, resistance 33 being a resistance with a negative temperature coefficient, as for example, a silver sulphide thermister. The constants of the network depend upon the thermal and other properties of the particular unit 33. With the temperature of the chamber 27 elevated above the highest room temperature by the chamber heating element 28, if the room temperature rises the resistance of the unit 33 falls sufficiently to reduce the heating current in the element 28 so that the temperature of the chamber 27 is held constant. The source should be a constant voltage or current source, preferably as nearly constant as practicable. In accordance with the invention it can comprise a coil 29 inductively coupled to a coil 37 tuned to the oscillation frequency by condenser 38, so that the oscillations generated by the system supply the power for network N and heater 28. Since the power required for this purpose can be made trivial, these oscillations are especially well adapted for this purpose as they are of more nearly constant magnitude than even a well-regulated ordinary power supply.

In operation of the system, waves to be amplified are transmitted from circuit 10 through bridge 40 to the amplifier terminals 1 and 2, the amplifier input impedance viewed to the right from terminals 1 and 2 being determined by three of the four arms of the bridge 40. The waves amplified by the negative feedback amplifier 5 pass from the amplifier output terminals 3 and 4 through bridge 50 to the load circuit 11, being excluded from the oscillator coupling by the tuned circuit 75. The amplifier output impedance viewed to the left from terminals 3 and 4 is determined by three arms of bridge 50.

Regardless of whether waves are thus being supplied from line 10 for amplification, the system can generate oscillations stabilized as to frequency and amplitude, oscillations from the amplifier output terminals 3 and 4 being transmitted through bridge 50, transformer 70 and tuned cir-

cuit 75 and impressed across one pair of the diagonally opposite corners B and D of the bridge 60, and the unbalance potential, appearing across the other pair A and C, being transmitted through the circuit comprising thermister R_T and bridge 40 to the amplifier input terminals 1 and 2. Assuming that at the oscillation frequency the phase shift of the amplifier 5 is 180 degrees and the phase shift through transformer 70 is negligibly small, or that the phase shift through the portion of the oscillator loop external to the bridge 60 is 180 degrees, the requisite phase shift through the coupling circuit 6 for the production of oscillations may be obtained by polling the connections of transformer 70, or by interchanging the connections of the corners of bridge 60.

The bridge 60 is kept as nearly in exact balance as practicable, but in order that the circuit may oscillate a slight unbalance is required, which, however, can be very slight provided the gain of amplifier 5 is high. Accordingly, one of the resistances of the bridge may have a value slightly different from the others. For example, resistance R₇ may be slightly greater or less than each of the other three resistances (according to whether the greater or the lesser value is required to give the phase shift through the bridge the proper sign for production of oscillations), so that the attenuation through the coupling circuit 6 including the bridge 60 and the thermister R_T is just equal to the gain of the amplifier 5.

This attenuation is controlled by the thermister in response to change in the oscillation amplitude. When oscillations are initiated, the thermister is cold and its resistance is large. Thus the attenuation produced by the thermister in transmission through the circuit 6 is small and oscillation amplitude increases rapidly. As the oscillating current traversing the thermister heats it, its resistance decreases, approaching the value for which the loss through the coupling 6 equals the gain through the amplifier 5, and reaching that value when the oscillation amplitude is well below the overload value for amplifier 5. Should the gain of the amplifier then change, an extremely small consequent change in the amplitude of the oscillations at the amplifier output changes the temperature of the thermister sufficiently and in proper sense to so change the attenuation of the circuit 6 as to render the loss in the circuit 6 equal to the gain in amplifier 5. This automatic adjustment stabilizes the oscillation amplitude at the amplifier output.

The frequency control exerted by the bridge 60 depends upon the fact that at the actual oscillation frequency the phase shift of the amplifier 5 must be equal and opposite to that through the circuit 6, as explained, for example, in the above-mentioned Meacham patent and paper. The phase angle between the input and output voltages of the bridge 60 is dependent on the resistance unbalance of the bridge. When the degree of resistance unbalance is small this phase angle is very strongly variable with the reactance of the frequency selective branch at frequencies close to resonance. A relatively large phase shift produced by elements external to the bridge 60 can therefore be compensated by the phase shift in the bridge itself resulting from an extremely small departure of the frequency from the resonance value. The operation of the bridge in a nearly balanced condition, therefore, increases the stability of the oscillation frequency. When the amplifier 5 changes its phase shift for some rea-

son, even by an amount far in excess of what would be anticipated in practice, an extremely small consequent change in the phase angle (between the voltage and the current) of the impedance Z included in bridge 60 suffices to change the phase of circuit 6 sufficiently and in proper sense to maintain the phase of circuit 6 equal and opposite to that of amplifier 5. That is, the tuned circuit comprising inductance 82 and capacity 83 still operates very close to resonance in spite of the exaggerated change in the amplifier phase shift. The greater the amplifier gain (with other conditions unchanged), the greater is the frequency stabilizing effect of the bridge 60.

The amount of negative feedback through the path 16 may be large for the frequencies supplied to the amplifier 5 from circuit 10 and also for the oscillation frequency and any harmonics thereof that it is desired to suppress by the feedback. For example, the reduction in gain of amplifier 5 effected by that feedback may be of the order of one or many more times ten decibels for those frequencies. This feedback can greatly facilitate obtaining the optimum amplifier phase shift for production of the stabilized oscillation frequency. For example, the amplifier 5 may be a high gain amplifier with a plurality of interstage coupling circuits, for amplifying a broad band of waves supplied from circuit 10, as well as waves of the oscillation frequency, the phase shift through the amplifier 5 without the negative feedback through path 16 being substantially different from 180 degrees at the desired oscillator frequency; and the negative feedback path 16 may have zero phase shift at that frequency, to make the amplifier phase shift with the negative feedback 180 degrees from terminals 1 and 2 to terminals 3 and 4.

Regardless of whether the phase shift of the portion of the oscillator loop external to the amplifier 5 is 180 degrees at the desired oscillator frequency, the phase shift of the amplifier can be made the negative of the phase shift of that portion of the oscillator loop at that frequency by making the feedback path 16 with its phase shift 180 degrees different from the phase shift of that portion of the oscillator loop at that frequency and producing sufficient negative feedback in the amplifier 5 at that frequency by the path 16.

For example, if it is desired to take into account phase shift of transformer 70, a duplicate of the transformer can be connected in path 16 and the phase shift of path 16 as so modified can be made equal to that of transformer 70, at the desired oscillator frequency. Then, with path 16 producing sufficient negative feedback in the amplifier 5 at that frequency, the amplifier phase shift will be the negative of (180 degrees plus the phase shift of transformer 70).

The negative feedback through path 16 is advantageous for suppressing harmonics of the oscillation frequency that may be generated in the amplifier, due for instance to non-linearity of the characteristic of an amplifying element. The selectivity of the tuned rejector circuit 75 prevents these harmonics from being suppressed by negative feedback through the coupling circuit 6. Need for circuit 75 in the self-oscillating amplifier arises from the use of a frequency determining circuit such as 60 of bridge or balancing type or type which has its selectivity effectively enhanced by the amplification of amplifier 5; for in case it is permissible to use, instead, a frequency determining circuit giving a lower effect-

tive "Q," for instance a parallel-tuned circuit connected in shunt to thermister 75 in the general fashion in which a tuned frequency determining circuit is shown connected across the oscillator coupling circuit in the above-mentioned Caruthers patent, the circuit 75 then ordinarily can be omitted. Bridges 20 and 30, assuming $\mu\beta \gg 1$, provide excellent impedances for the fourth arm of bridges 40 and 50 and as a result the amplitude and frequency of the oscillations will be to a very high degree independent of the impedances that may be connected to 10 and 11. In a similar manner the over-all amplification from 10 to 11 is independent of coupling circuit 6.

The cathodes of the amplifier may be heated in any suitable manner, for example, in the manner shown and described hereinafter for the amplifier of Fig. 2, if desired.

Omitting the amplitude limiting element R_r and the tuned circuit 75 (for example by opening a switch, not shown, connected in series with element R_r and closing a switch, not shown, across 75) and adjusting the bridge 60 to resistance balance at the resonance frequency of impedance Z, the system becomes a highly selective amplifier, transmitting from line 10 to line 11 waves of that frequency to the exclusion of other frequencies. The repetition of the feedback process, provided by the conjugate feedback paths, then enhances the gain stability and the frequency selectivity of the amplifier. It is not necessary that the bridge 60 be in exact resistance balance at the frequency of peak gain of the selective amplifier. An improvement in gain stability of the amplifier with circuit constants can be realized in the region of peak gain with the bridge adjusted to give a small amount of negative or positive feedback at the frequency of peak gain, as for example 4 or 5 decibels of negative feedback or one-half decibel of positive feedback.

Fig. 2 indicates one way in which the system of Fig. 1 can be modified or extended to provide a self-oscillating amplifier generating oscillations at a plurality of frequencies, which need not be harmonically related but can be independent frequencies, and can lie close to the frequency band supplied from circuit 10 if desired. For each oscillation frequency the oscillations are stabilized as to frequency and amplitude, in the manner indicated in the description above of Fig. 1. The self-oscillating amplifier of Fig. 2 is similar to that of Fig. 1 but has a plurality of coupling circuits 6A and 6B, each comprising elements structurally and functionally similar to those of the coupling circuit 6 of Fig. 1, the frequency determining circuits in bridge arms Z and Z' of the coupling circuits 6A and 6B, respectively, being tuned to the desired oscillation frequencies. Portions of the coupling circuits may be common, the bridge 50 and transformer 70 being so shown. However, the coupling circuit 6A has its individual frequency stabilizing circuit 60, rejector circuit 75 and amplitude stabilizing thermister R_r corresponding to those of Fig. 1, and the coupling circuit 6B has respectively corresponding individual frequency stabilizing circuit 60', rejector circuit 75' and amplitude stabilizing thermister R_r'. The circuit 75' is tuned to the resonance frequency of inductance 82' and capacity 83'. Portions of coupling circuit 6B respectively corresponding to portions of coupling circuit 6 are designated by the same reference characters primed. The bridge 40 shown in Fig. 1 is dispensed with in the system of Fig. 2, the coupling

circuits 6A and 6B being shown in series with the incoming circuit 10.

The oscillation frequencies may lie as close to the frequency band of the waves supplied by circuit 10 as is permitted by the ability of the rejector circuits 75 and 75' to prevent those waves from unduly interfering with the amplitude stabilizing functions of the thermisters R_r and R_r'. Any desired number of coupling circuits such as 6A and 6B may be employed, to give oscillations of various frequencies stabilized as to frequency and amplitude.

When the self-oscillating amplifier is an amplifier of an unattended repeater for a cable containing lines 10 and 11, it is economical to transmit the power for the amplifier over the cable. It is desirable to transmit direct current instead of alternating current because the line loss is less, direct current does not interfere into other circuits, more power can be transmitted for a given allowable line voltage, and a storage battery can serve as a standby without switching. The B battery voltage can readily be transmitted because this voltage is high and the plate current low. Even small tubes are available whose filament power consumption is less than the plate power, for example, a pentode having a filamentary cathode with a plate current of 5 milliamperes at 300 volts=1.5 watts and a filament power of .1 watt. The tube or tubes of amplifier 5 may be of such type. The output of the last tube can be adjusted to something in excess of the amount of power required to heat the tube cathodes, (while reserving adequate load carrying capacity of the amplifier for the waves from circuit 10), and oscillations of the required amount of power for heating the amplifier filaments can be abstracted by a selective circuit, such for example, as tuned transformer 85 across the amplifier output transformer, and supplied to the amplifier filaments for heating them as indicated in the drawing. For starting the oscillations, it suffices to preheat the filaments with a battery 87 and then operate switch 88 (in less time than the filament would require to cool), to connect the filaments to the low voltage side of the transformer, (which can be an inexpensive one when the oscillation frequency is high). The amplifier will then work under its own B battery power as long as the requirement is met that this power be not interrupted. (This is a practical requirement, met by present B battery plants in order to avoid producing telegraph hits on existing voice and carrier systems.) With the oscillations thus heating the amplifier filaments, the amplifier is still capable of delivering considerable undistorted power, when operated class A. Condensers 89 and 90 are shown for tuning the windings of transformer 85. In case the amplifier has filaments requiring different voltages, these may be supplied from different secondary windings that may be provided on transformer 85, if desired.

In Fig. 2 the heaters 28 and 28' for the amplitude-limiting thermisters are indicated by way of example as operated in parallel with each other from the same tuned transformer 37, 29, network N and conductors 36. The condenser 38 can then tune the transformer to one of the oscillation frequencies generated by the system, for example one other than that used for filament heating. These same conductors 36 can supply the oscillations to similar heaters for other thermisters that may be used for other purposes in operation of the self-oscillating amplifier, as for

instance for the purpose of enabling the amplifier to effect self-testing of its modulation. For example, two weak (compared to the full output of the amplifier) oscillations can be produced by the oscillator and maintained at two closely spaced frequencies outside of the band of the amplifier and preferably above so as not to reach the next repeater. Their difference frequency will also be a low frequency not transmitted by the output transformer and also not subject to much feedback. In this way the difference frequency current will be a measure of the modulation without feedback. It can be selected by a tuned transformer 91 having a primary winding in series with the output transformer and if in excess of tolerable limits will be caused, through an amplifier 92 if desired, to vary the resistance of a sensitive thermister 93, by passage through the thermister. This thermister, in series with resistances 94, is bridged, by means of conductors 95, across a fine gauge wire pair 96 to transmit this information back to an attended station. This thermister 93 may be one such as the thermister R_T , for example of silver sulphide, and may have a heater 97 (like the heater 23 of thermister R_T), supplied with oscillations from conductors 36 for maintaining the ambient temperature of the thermister fixed at a value in excess of the highest room temperature, to obviate objectionable effects of room temperature variations upon the operation of the thermister. Amplifier 92, if used, may be of any suitable type. If of thermionic type, it may have its cathodes heated, for example, from a tuned secondary winding that may be added to transformer 85 for the purpose, in the fashion indicated for the filaments of amplifier 5.

Fig. 3 shows repeaters 101 and 102 connecting line sections such as 10 and 11. Each of these repeaters contains an amplifier such as that of Fig. 2. Fig. 3 shows the conductors 95 that connect the pair of conductors 96 with the thermister 93 in the amplifier, and shows the pair 96 extending back to an attended station or terminal 105. At this station, measurement or indication of the resistance viewed when looking into the pair 96 can indicate when an amplifier has triggered off its thermister 93, and the location of the amplifiers that may have thus operated their thermisters. The thermisters operate in the manner disclosed for example in my above-mentioned Patent No. 2,209,955, August 6, 1940; and the resistance measurement and location of the faulty repeater may be effected manually or automatically in any suitable manner, as for example in the general fashion of impedance measurements and fault locations for long cable or other circuits.

Fig. 4 shows a self-oscillating amplifier like that of Fig. 2 except that the filament heating circuit (which may be like that of Fig. 2) is omitted for simplicity, the bridge 40 is included (as in Fig. 1), and coupling circuits 6C and 6D which correspond respectively to circuits 6A and 6B of Fig. 2 have frequency stabilizing and amplitude stabilizing circuits 60C and 60D that are somewhat different from those of the coupling circuits 6A and 6B and that are connected to bridge 40 in parallel with each other. The circuit 60C is a frequency selective bridged T network of the type shown in Fig. 8 of the above-mentioned Meacham patent. The T network comprises equal series branches of capacity C, the shunt branch consists of an inductance L_2 and a

resistance R_2 in series, and the bridging impedance is a variable resistor R_1 which is an amplitude control element for limiting and stabilizing the amplitude of the oscillations produced by the feedback through the coupling circuit 6C. As pointed out in the Meacham patent just mentioned, R_1 should be somewhat greater than $4R_2$ and for control purposes should have a negative temperature coefficient. The oscillation frequency lies very close to the value determined by the product $2L_2C$. Stability of the oscillation frequency is obtained by making the difference between R_1 and $4R_2$ very small, that is, by making the attenuation of the circuit 60C very great at the oscillation frequency, and is enhanced by making the capacity C small and the inductance L_2 large. The resistor R_1 may be, for example, a thermister of the type of the thermister R_T of Fig. 1, with its operate and release times, or heating and cooling times, preferably adjusted as described above for thermister R_T .

The rejecting circuits 75 of Fig. 4 correspond to the rejecting circuit 75 of Figs. 1 and 2, and are tuned to the oscillation frequency determined by the circuit 60C.

The coupling circuit 60D is like the circuit 60C except adjusted to produce a different oscillation frequency. Portions of circuit 60D respectively corresponding to portions of circuit 60C are designated by the same reference characters primed. Any desired number of coupling circuits such as 6C and 6D may be employed, to give oscillations of various frequencies stabilized as to frequency and amplitude.

What is claimed is:

1. A wave translating system comprising an amplifying device and conjugate feedback paths therefor, one forming with said device an amplifier having negative feedback that renders the phase shift of said amplifier substantially 180 degrees at a given frequency and another forming with said amplifier a circuit producing self-sustained oscillations of said frequency.

2. An oscillator comprising an amplifier having input terminals and output terminals and having a retroactive coupling circuit for producing sustained oscillations of given frequency connected between said output terminals and said input terminals, said coupling circuit including a frequency stabilizing bridge network with 180 degrees phase shift at said given frequency, and said amplifier including a feedback path and balancing circuits rendering said path conjugate to said coupling circuit and thereby preventing said coupling circuit from affecting the amplifier phase shift, said path having substantially zero phase shift at said given frequency and producing sufficient negative feedback in said amplifier to render the amplifier phase shift 180 degrees at said given frequency.

3. A wave translating system comprising an amplifier having input terminals and output terminals, a wave source for supplying to said amplifier waves to be amplified thereby, a load circuit for receiving from said amplifier said waves amplified thereby, a plurality of selective circuits each having frequency determining means tuned to a different frequency connected between said output terminals and said input terminals for causing said amplifier to generate self-sustained oscillations of said different frequencies, and amplitude limiting means in each of said selective circuits for limiting the amplitudes of said oscillations to values below the overload value for said amplifier, said amplifier

comprising a wave amplifying device and a feedback path therefor, said feedback path having substantially zero phase shift for each of said oscillation frequencies and producing sufficient negative feedback in said amplifier at each of said oscillation frequencies to render the phase shift from said input terminals to said output terminals substantially 180 degrees at each of said oscillation frequencies.

4. A wave generating and wave amplifying system comprising an amplifier with input terminals and output terminals, a source of waves to be amplified thereby and a load circuit therefor, a plurality of selective circuits connected between said output terminals and said input terminals for causing said amplifier to generate sustained oscillations of chosen different frequencies, each of said selective circuits including a Wheatstone bridge in reactive balance at one of said frequencies and having in one of the bridge arms a resonant impedance tuned to the one frequency, amplitude limiting means individual to each of said selective circuits for limiting the amplitudes of said oscillations to values below the overload value for said amplifier, each of said selective circuits including in series therein between said output terminals and its amplitude limiting means a series-tuned resonant at the same frequency as its resonant bridge arm impedance for preventing operation of its amplitude limiting means by waves of other frequencies, said amplifier comprising a wave amplifying device and a feedback path therefor, said feedback path having substantially zero phase shift for each of said oscillation frequencies and producing sufficient negative feedback in said amplifier at each of said oscillation frequencies to render the phase shift from said input terminals to said output terminals substantially 180 degrees at each of said oscillation frequencies.

5. An oscillator comprising a wave amplifying device having a feedback circuit forming therewith a closed loop producing self-sustaining feedback of oscillations around said loop and amplitude limiting means in said loop for limiting the amplitude of said oscillations to a value below the overload value for said amplifying device, said amplitude limiting means comprising a thermally sensitive resistance element traversed by said oscillations and varying its temperature and consequently its resistance in response to variations of the oscillation amplitude to maintain substantial constancy of the amplitude, and said resistance element having its mass sufficiently small to render its operating and restoring times required for heating and cooling less than the times required for said oscillations to build up and decay yet having its mass sufficiently large to render its operating and restoring times large compared to the period of said oscillations.

6. The combination with an oscillation generator, of means comprising a thermally sensitive resistance responsive to the generated oscillations to stabilize the amplitude of the oscillations, a temperature control resistor associated with said thermally sensitive resistance for maintaining a constant ambient temperature therefor, and means for supplying energy of the oscillations to said control resistor for heating said control resistor.

7. In combination, a space discharge tube hav-

ing an input circuit and an output circuit, a feedback coupling for causing said tube to act as a generator of sustained oscillations, a thermally sensitive resistance connected to said tube to stabilize the amplitude of the generated oscillations at a value below that corresponding to the limit of the load-carrying capacity of the tube, whereby a portion of the load-carrying capacity is left unused in the production of the oscillations, means to impress waves, independently of the oscillations being generated, upon said input circuit to be amplified by said tube and utilized in said output circuit, a temperature control resistor associated with said thermally sensitive resistance for maintaining a fixed ambient temperature therefor, and means for supplying energy of the oscillations to said control resistor for heating said control resistor.

8. A wave translating system comprising a wave amplifying device, an incoming circuit for supplying thereto waves to be selectively amplified by said system, an outgoing circuit for said device for utilizing the selectively amplified waves, a feedback circuit for said device comprising a network having a frequency selective transmission characteristic providing minimum feedback substantially at the frequency to be amplified by said system but strong degenerative feedback at frequencies removed therefrom, a feedback circuit included in said amplifying device for producing negative feedback therein, and means rendering said feedback circuits conjugate to each other.

9. A wave translating system for selectively amplifying waves of a given frequency to the exclusion of waves of other frequencies, comprising a wave amplifying device, an incoming circuit for supplying thereto waves to be amplified by said system, an outgoing circuit for said device for utilizing the amplified waves, a coupling circuit for feeding waves from the output circuit of said device to the input circuit of said device, a network including in said coupling circuit having a maximum attenuation substantially at said given frequency and relatively low attenuation at other frequencies and having its phase shift abruptly change 180 degrees in the neighborhood of said given frequency, a feedback circuit included in said amplifying device for producing negative feedback therein, and means rendering said feedback circuit and said coupling circuit conjugate to each other.

10. A wave translating system for selectively amplifying waves of a given frequency comprising a wave amplifying device, an incoming circuit for supplying thereto waves to be amplified by said system, an outgoing circuit for said device for utilizing the amplified waves, a coupling circuit for feeding waves from the output circuit of said device to the input circuit of said device, a Wheatstone bridge network included in said coupling circuit and having in one arm an impedance resonant substantially at said give frequency, said bridge network being adjusted for a maximum attenuation substantially at said given frequency and relatively low attenuation at other frequencies, a feedback circuit included in said amplifying device for producing negative feedback therein, means rendering said feedback circuits conjugate to each other, and means rendering said coupling circuit and said outgoing circuit conjugate to each other.

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