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H. S. BLACK

2,245,565

WAVE TRANSLATING SYSTEM

Filed May 27, 1938

FIG. 1

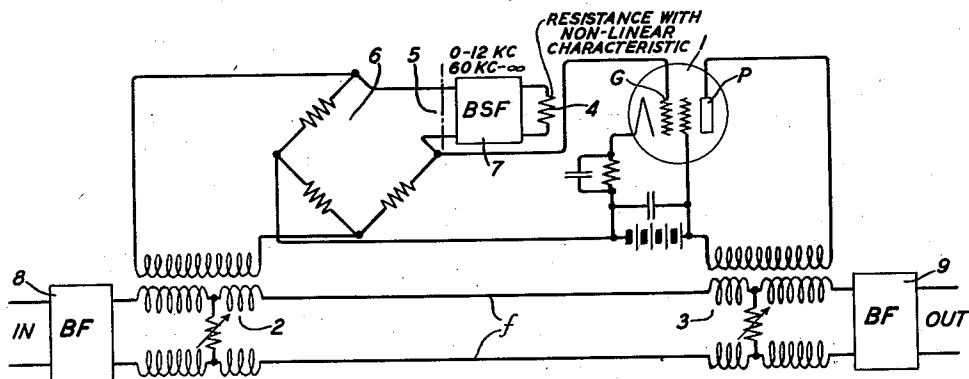


FIG. 1A

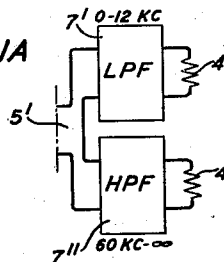
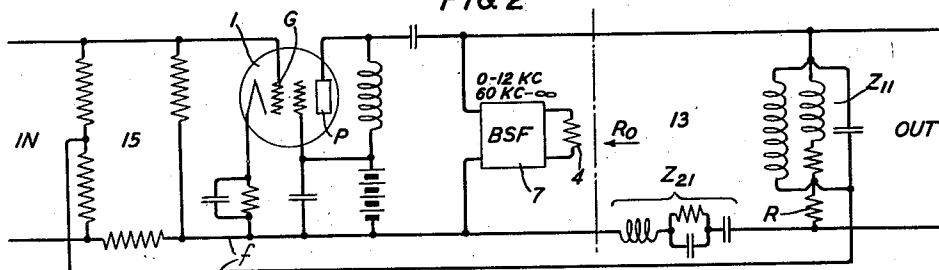


FIG. 2



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WAVE TRANSLATING SYSTEM

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Application May 27, 1938, Serial No. 210,333

11 Claims. (Cl. 179-171)

This invention relates to wave translation, as for example, electric wave amplification, and relates especially to retroactive or feedback systems, as for example, negative feedback amplifiers.

Objects of this invention are to control feedback and singing or production of self-sustained oscillations in such systems.

It is also an object to increase the amount of useful non-oscillatory feedback obtainable in such systems, as for example, the amount of negative feedback of utilized waves obtainable without undue degradation of the performance of the systems by incidental oscillatory feedback of unwanted waves.

In one specific aspect the invention is embodied in a broad band vacuum tube amplifier with large negative feedback. In this type of circuit, and in many other types of feedback circuits, prevention of singing is a major problem, but it is often relatively easy to insure that the frequency at which the circuit does sing is considerably beyond or outside the used frequency band. For example, in a 12-60 kilocycle amplifier the singing frequency may be about 1,000,000 cycles.

Ordinarily the chief objection to singing is that the tubes overload and hence the modulation is too great and in other respects the transmission of the amplifier is impaired. However, as pointed out in R. S. Caruthers Patent 2,066,333, January 5, 1937, the amplitude of sustained oscillations in an oscillator circuit can be limited to a value well below the overload point of the amplifying element, by an amplitude limiting device other than the amplifying element, and then the amplifying element can be used for amplifying not only the sustained oscillations generated in the oscillator circuit but also other waves.

Therefore, in the above-mentioned specific aspect of the present invention, in accordance with the invention, the amplifier is allowed to oscillate or sing around its negative feedback loop outside the used frequency band (since satisfying the requirements for preventing oscillation would be so difficult), but the amplitude of the unwanted oscillations circulating around that loop is limited to a value sufficiently small to avoid overloading the amplifier or reducing the gain of its amplifying element, for example, a value so minute as to avoid appreciably reducing the useful output capacity of the amplifier even though it is thus oscillating. Further, the element that limits the amplitude of the oscillations is so

associated with that loop, for example, through a band suppression filter whose attenuation range is the used frequency band, as to be not acted upon or not appreciably affected by the utilized waves or waves in the used frequency band that circulate around that loop. Therefore the amplitude limiting element does not prevent or interfere with the large negative feedback around that loop in that band. (Although, for any given feedback loop and frequency, positive feedback can be large with the feedback ratio less than unity, which is the value for sustaining oscillation, negative feedback cannot exceed 6 decibels unless the magnitude of the feedback ratio exceeds unity.) The maximum amplitude of the signal waves or waves of the used frequency band circulating around the loop may greatly exceed the amplitude of the oscillations, or on the other hand may, for instance where the amplifier is used for measuring purposes, be small (for example even smaller than the amplitude of the oscillations), with the negative feedback nevertheless large.

The amplitude limiting means or element may be a non-linear element of any suitable character, as for example, the "Thyrite", copper oxide rectifier, or space discharge device referred to in the above-mentioned Caruthers patent as exhibiting an overload or non-linear relation between current and voltage, or any suitable temperature dependent resistance of the general type that varies its resistance greatly in response to change of its temperature. Examples of such temperature-dependent resistors or so-called thermistors, which change the magnitude of their resistance enormously in response to temperature change, even when only heated by the current passing through them, are resistors of silver sulphide, uranium oxide, cobalt oxide or boron. The term non-linear resistance is used herein in the broad sense of resistance having a characteristic that is non-linear, and includes resistances, such for example as these thermistors, which nevertheless are linear in the sense that they introduce no material amount of deleterious modulation in the useful frequency range, because the time required to alter their temperature and, hence, resistance, is appreciable as compared to the more rapid changes in instantaneous current or voltage at any frequency falling within the useful band of frequencies of the amplifier.

The amplitude limiting element may be anywhere in the negative feedback loop. However, ordinarily it preferably is in the forward or

amplifying path, i. e., in the μ -circuit as this term is used in my Patent 2,102,671, December 21, 1937 and as near the output as convenient. Location in the μ -circuit is advantageous because then the over-all transmission in the pass-band of the amplifier will be least affected (by changes in amplitude of the input waves, for example), which is important especially if this transmission is being controlled precisely, for instance, within limits of .01 or .001 decibel; and location near the output ordinarily is advantageous because the smaller voltage at which limiting is desired the less readily the limiting is accomplished, in practice. If the gain of the μ -circuit is 120 decibels limiting in the output at 1 volt would be equivalent to limiting at .000001 volt at the input.

A feature of the invention is limitation of the amplitude of incidental, unwanted, self-sustained oscillations in a feedback system, as for example an amplifier with large negative feedback, to a value below the overload point of the system.

Another feature is accomplishing such limitation without thereby necessitating limitation of feedback of utilized waves in the system.

A further feature is reduction of the operating margin required against singing in a negative feedback system, as for example an amplifier with large negative feedback, or elimination of necessity for such margin.

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

Figs. 1 and 2 show two negative feedback amplifiers of the type referred to above; and

Fig. 1—A indicates a modification of the amplifier of Fig. 1.

The amplifier of Fig. 1 may be, for example, of the general type shown in Figs. 1, 6 and 7 of my copending application Serial No. 114,390, filed December 5, 1936, for Wave translation systems, now Patent No. 2,209,955, issued August 6, 1940. It comprises an amplifying path including an amplifying element or device having any desired number of cascaded vacuum tube stages, G and P designating the grid of the first tube and the plate of the last tube (in this figure and also in Fig. 2), and comprises a feedback path f . The amplifying path may be referred to as the μ -circuit and the feedback path may be referred to as the β -circuit, the significance of μ and β , as well as μ -circuit and β -circuit being as indicated in my above-mentioned Patent 2,102,671.

An input bridge transformer or hybrid coil 2 couples the incoming circuit and the feedback path f to the input end of the amplifying path; and an output hybrid coil 3 couples the output end of the amplifying path to the outgoing circuit and the feedback path. If desired, the amount of the negative feedback (in the used frequency range), or the gain reduction due to feedback, may be large. For example, $\mu\beta$ may be of the order of one or more times 10 decibels.

The amplifier may be designed to pass and amplify frequencies from 12 to 60 kilocycles for example, and when the feedback connection is made the amplifier may sing around the negative feedback loop at 1,000,000 cycles for instance. In this singing or oscillatory loop is included means for limiting the amplitude of the sustained oscillations to value below the overload point of the amplifying tubes or element. This means, as shown, comprises a non-linear resistance 4 in one arm 5 of a Wheatstone bridge network 6, such as the bridge of Fig. 3 of the above-mentioned

Caruthers patent, connected in the loop. The element 4 may be, for instance, a thermistor of any of the types mentioned above with negative temperature coefficient of resistance, or "Thyrite" or a copper oxide rectifier. As explained in the above-mentioned Caruthers patent, if the voltage input to the bridge network had a certain predetermined value the non-linear resistance would balance the bridge and the voltage output of the bridge network would be zero, and therefore (as also explained in the patent) the amplitude of the sustained oscillations at the input to the bridge is slightly below that predetermined critical value.

In Fig. 1 the element 4 is preceded by a band suppression network or filter 7 which attenuates or suppresses waves of the used frequency band, i. e., the 12 to 60 kilocycles band, but passes other frequencies, including the sing frequency or oscillation frequency of 1,000,000 cycles, so the amplifier sings weakly at this oscillation frequency. At this frequency the resistance of the element 4 determines the resistance of the bridge arm containing it, and, as explained in the Caruthers patent, by properly proportioning the resistance of element 4 and the resistances forming the other three ratio arms of the bridge, the bridge may be so unbalanced when the amplitude of the waves of oscillation frequency is below the critical value that as the amplitude of those waves increases the bridge approaches a condition of balance because of the change in resistance of the element 4 and finally the limiting point (i. e. the point where the magnitude of $\mu\beta$ or the feedback ratio is unity for the oscillation frequency) is reached as the result of the twofold action of the bridge and of the non-linear resistance of the element 4. As explained in the Caruthers patent, by adjusting the resistances of the ratio arms other than the arm containing element 4, the point of balance of the bridge may be controlled and thus the limit of amplitude of currents generated may be controlled. As indicated above, the amplitude of the sustained oscillations may thus be limited to a value sufficiently small to avoid overloading the amplifier or reducing the gain of its amplifying element, for example a value even so minute as to avoid appreciably the useful output capacity of the amplifier. As also indicated above, the filter 7 prevents the signal waves or waves of the used frequency band that circulate around the negative feedback loop from acting upon or appreciably affecting the element 4 in the same loop.

The impedance of filter 7 viewed from the bridge network 6 may be a low impedance outside the used frequency band. Whether it is high or low affects either the poling of the transformers or the bridge arm in which it is located. Accordingly, the filter 7 and amplitude limiting resistance 4 may preferably be in the arm 5 of the bridge network 6, as shown, rather than in the opposite arm, because when in the arm 5 they are in the μ -circuit of the amplifier.

The amplifier of Fig. 1 oscillates or sings weakly as described above at 1,000,000 cycles; and if there is a low frequency phase cross-over as for example, at 100 cycles (that is, if at a frequency below the used band, as for instance a frequency of 100 cycles, the phase shift around the feedback loop is zero and the gain around the loop exceeds zero decibel), the amplifier will oscillate weakly at both 1,000,000 cycles and 100 cycles at the same time if the bridge arm containing

the amplitude limiting element be changed, for example, as indicated in Fig. 1—A.

This Fig. 1—A shows the arm of the bridge corresponding to arm 5 of Fig. 1 as an arm 5' in which are connected two filters 7' and 7'' each feeding a non-linear resistance 4 such as that of Fig. 1. The filter 7' is a 0-12 kilocycle low-pass filter, transmitting to its associated element 4 waves of frequencies below the used frequency band and attenuating waves of other frequencies. The filter 7'' is a high-pass filter with cut-off at 60 kilocycles, transmitting to its associated element 4 waves of frequencies above the used frequency band and attenuating waves of other frequencies.

The invention comprehends application in which unwanted oscillations may, without objection, be permitted to fall within the used frequency band, as well as applications in which the unwanted oscillations are outside the used band. Also, the invention comprehends applications in which an oscillation frequency may lie in an unused frequency range between two used frequency bands, as in the case of a two-band amplifier for a single-amplifier type of repeater for a multiplex carrier telephone system.

If desired, filters may be used to connect the amplifier to its attached incoming and outgoing circuits, for excluding the weak oscillations of sing frequencies from those circuits. For example, filters indicated in Fig. 1 as band filters 8 and 9 may be low-pass filters having cut-off frequencies of 60 kilocycles to serve this purpose. The filters for this purpose may be of any suitable type, for instance 12-60 kilocycle band-pass filters, or high pass filters attenuating frequencies below 12 kilocycles in case the sing frequency is below instead of above the used frequency range of 12-60 kilocycles. Either the filter at the input or that at the output, or both, may be omitted, depending upon the specific application of the amplifier.

In the amplifier of Fig. 2 the band suppression filter 7 feeding the non-linear resistance 4 is shown across the plate circuit of the last tube and in the μ -circuit of the feedback amplifier. Then the input impedance of filter 7 viewed from the amplifier ordinarily is preferably made high for the used frequency band. The amplifier may be, for instance, a 12 to 60 kilocycle negative feedback amplifier similar to that of Fig. 1, and is shown by way of example with input bridge network 15 and output bridge equalizer network 13 like those of A. L. Stillwell Patent 1,993,758, March 12, 1935, instead of the input and output bridge transformers 2 and 3 of Fig. 1. The equalizer bridge comprises arms designated R_0 , Z_{21} , R and Z_{11} as in that patent, and functions as explained therein. The amplifier operates in the same general manner as that of Fig. 1 herein, the non-linear resistance limiting the amplitude of the oscillations of the sing frequency (for example 1,000,000 cycles) and the band suppression filter preventing the signal waves or waves of the used frequency band from acting upon or materially affecting the non-linear resistance, as brought out above. If desired or necessary for modulation reasons, the filter 7 feeding the amplitude limiting element 4 in Fig. 2 may be connected across the μ -circuit of the feedback amplifier at an earlier point than shown. The disadvantage of picking off the oscillating frequency whose amplitude is to be controlled earlier in the μ -circuit is that its energy level is weaker, the advantage is that the entire

pick-off circuit has more lenient requirements as regards non-linearity.

What is claimed is:

1. A wave translating system comprising a closed feedback loop, an active transducer included in said loop, means included in said loop for producing negative feedback around said loop of signal waves of a given frequency range, amplitude discriminating means for connection to said loop to limit the amplitude of waves passing around said loop, and frequency selective means for connecting said amplitude discriminating means to said loop, said frequency selective means having its attenuation for transmission from said loop to said amplitude discriminating means high throughout the signal frequency range, but low over a wide frequency range exclusive of the signal frequency range.

2. An amplifier comprising a forwardly transmitting path including a wave amplifying device and a feedback path forming with said first path a closed loop path producing such large negative feedback of waves of such a wide frequency band to be amplified by said amplifying device that said loop path produces as a consequence of the magnitude of said negative feedback and the width of said band self-sustaining oscillations around said loop path of a frequency above said band and simultaneously of a frequency below said band, a non-linear resistance, a frequency selective circuit connecting said resistance in said first path and having high attenuation for waves of said band and waves of said frequency below said band but relatively low attenuation for waves of said frequency above said band, a second non-linear resistance, and a second frequency selective circuit connecting the latter resistance in said first path and having high attenuation for waves of said band and waves of said frequency above said band but relatively low attenuation for waves of said frequency below said band.

3. A wave translating system comprising a source of signaling waves of a wide frequency band to be amplified and a wave amplifying circuit connected thereto for amplifying said waves, said circuit comprising an amplifying device and a feedback path forming therewith a feedback loop path having its loop propagation over said band such as to produce negative feedback of said signaling waves around said loop path, said loop path having its loop propagation at a given frequency such as to produce self-sustained oscillations at said frequency, and amplitude discriminative means non-linearly responsive to amplitude changes of impressed waves for limiting the amplitude of said oscillations to the exclusion of said signaling waves to a value sufficiently low to prevent said oscillations from materially reducing the load capacity of said system in amplifying said signaling waves.

4. A wave translating system comprising a source of signaling waves of a wide frequency range to be amplified and a wave amplifying circuit connected thereto for amplifying said waves, said circuit comprising an amplifying device and a feedback path forming therewith a feedback loop path having its loop propagation over said range such as to produce negative feedback of said signaling waves around said loop path, said loop path having its loop propagation at a plurality of frequencies such as to produce self-sustained oscillations at all of said frequencies simultaneously, and amplitude discriminative means non-linearly responsive to impressed volt-

age changes for limiting the amplitudes of said oscillations at said frequencies to the exclusion of said waves to values sufficiently low to prevent said oscillations from materially reducing the load capacity of said system in amplifying said waves.

5. An amplifier for signal waves comprising a forward amplifying path and a feedback path forming therewith a feedback loop which has its loop gain of greater order of magnitude than zero decibels over the signal frequency range and around which occurs such large negative feedback of said signal waves in said frequency range as to produce incidental singing around said loop at a frequency outside said range and means to prevent said singing from rendering said amplifier useless and thereby increase the maximum amount of said negative feedback that can be usefully employed as compared to the non-singing condition, said means including a non-linear resistance for connection in said forward path to limit the amplitude of waves of said singing frequency to an amplitude such that said singing is prevented from overloading the amplifier, and means selective to frequencies outside of said frequency range for connecting said resistance in said forward path and preventing waves in said range from affecting said resistance.

6. The method which comprises producing negative feedback of wanted waves around a closed loop path containing an amplifying element with the loop gain for said waves of so much greater order of magnitude than zero decibels over a frequency band so wide that self-sustaining feedback of other waves around said path is produced at a frequency outside of said band as a consequence of the magnitude of said band width and loop gain and producing a component of loop transmission varying non-linearly with amplitude of said other waves for maintaining the maximum amplitude of said other waves below the overload point of the amplifying element.

7. A wave amplifying device, means for supplying thereto signal waves of a wide frequency band, a feedback path forming therewith a loop path having the loop gain of so much greater order of magnitude than zero decibels over a frequency range of said signal waves extending so far upwardly from a frequency at which the loop phase shift is 180 degrees that self-sustaining feedback of oscillations around said loop path results at a frequency above said band, means in said loop path selective to frequencies including said oscillation frequency outside of said band and means responsive to the selected waves to produce a component of loop propagation varying non-linearly with amplitude variation of the selected waves for maintaining the amplitude of said oscillations below the overload value for said device.

8. A wave translating system comprising a source of signal waves of a wide frequency range, an amplifier connected thereto for amplifying said waves, means forming with said amplifier a closed feedback loop path producing negative feedback of said waves around said loop path with the loop gain over said range of larger order of magnitude than zero decibels, said loop path having the loop gain decrease so rapidly with change of frequency at one side of said range that before the decreasing loop gain reaches a value less than zero decibels, the loop phase shift

reaches zero degrees and causes self-sustaining feedback of oscillations of given frequency around said loop path, said given frequency having a higher order of frequency magnitude than the top frequency of said range, means in said loop path controllable for limiting the amplitude of said oscillations, and frequency selective means responsive to said oscillations for causing said controllable means to introduce in a portion of said loop path a transmission variation non-linear with respect to the amplitude variation of the selected oscillations and thereby limit the amplitude of said oscillations to a value below the overload value for the amplifier.

9. A wave amplifying device, means for supplying thereto a frequency band of signal waves, a feedback path for said device forming therewith a loop path producing negative feedback of said waves around said loop path with the loop gain of greater order of magnitude than zero decibels over said band, said loop gain over said band being so great that at a frequency outside of said band for which the loop phase shift equals zero the loop gain is at least as great as zero decibels, frequency selective means responsive to oscillations of substantially said frequency outside of said band in said loop path and means responsive to the selected waves to produce a component of loop propagation varying non-linearly with amplitude variation of the selected waves for limiting the amplitude of said oscillations to a value below the overload value for the amplifier.

10. A wave amplifying device having a feedback path forming therewith a closed loop path producing such large negative feedback of waves of a given frequency band to be amplified by said device that said loop path produces as an incident of said negative feedback self-sustaining feedback of oscillations around said loop path at a plurality of frequencies simultaneously, said oscillation frequencies being outside of said frequency band, means including a plurality of amplitude limiting devices, one for each of said frequencies, responsive to change of amplitude of impressed waves to introduce non-linearly proportional change in transmission efficiency in a portion of said loop path for limiting the amplitude of said oscillations at each of said frequencies to values below the overload value for said device and a plurality of frequency selectors, one for each of said amplitude limiting devices, each selector transmitting to its associated limiting device said oscillations of one of said frequencies to the exclusion of said oscillations of said other frequencies and said waves.

11. A wave amplifying device having a feedback path forming therewith a closed loop path producing negative feedback of waves of a used frequency band around said loop path, said negative feedback being so great that said loop path produces self-sustaining feedback of oscillations of frequency outside of said band around said loop path as an incident of said negative feedback, means in said loop path non-linearly responsive to impressed waves to provide amplitude discrimination for limiting the amplitude of said oscillations, and means comprising a band suppression filter attenuating waves of said utilized frequency band but having relatively low attenuation for waves of a wide frequency range above and below said band for excluding from said limiting means waves of said band.

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