

Aug. 29, 1944.

S. T. MEYERS

2,356,867

NEGATIVE RESISTANCE LOADING

Filed Aug. 14, 1942

4 Sheets-Sheet 1

FIG. 1

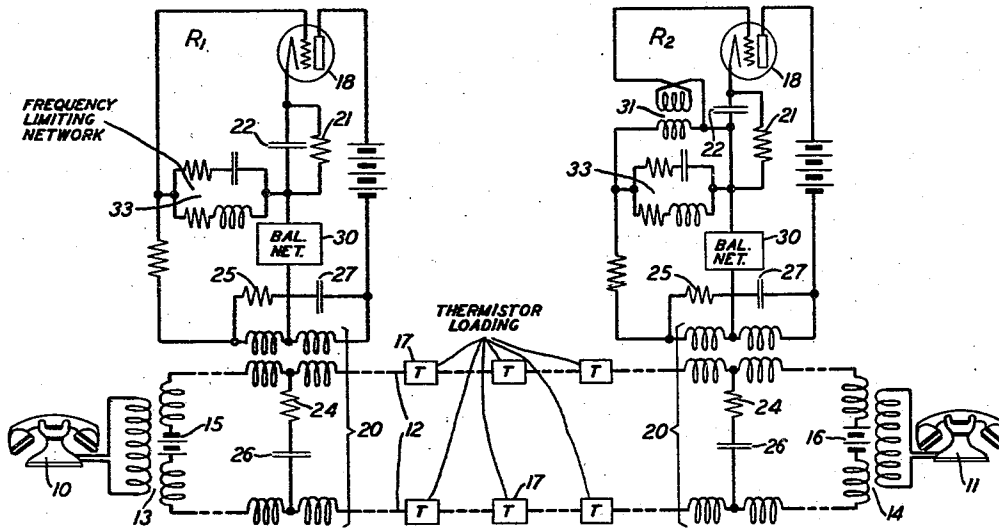
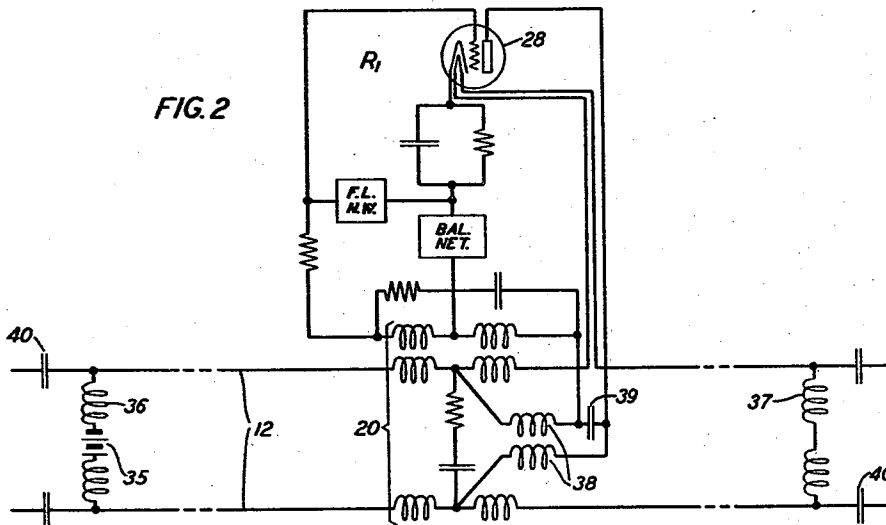


FIG. 2



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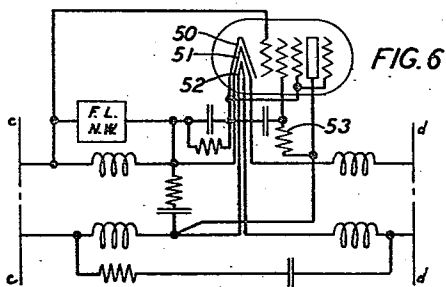
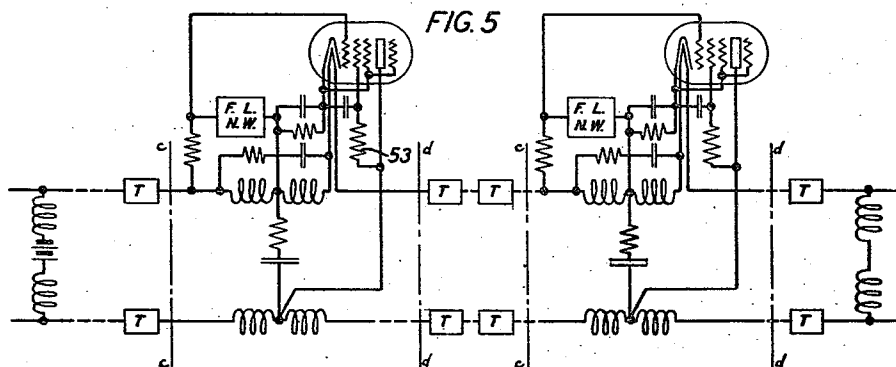
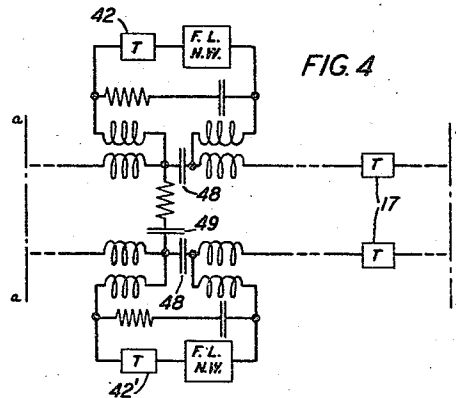
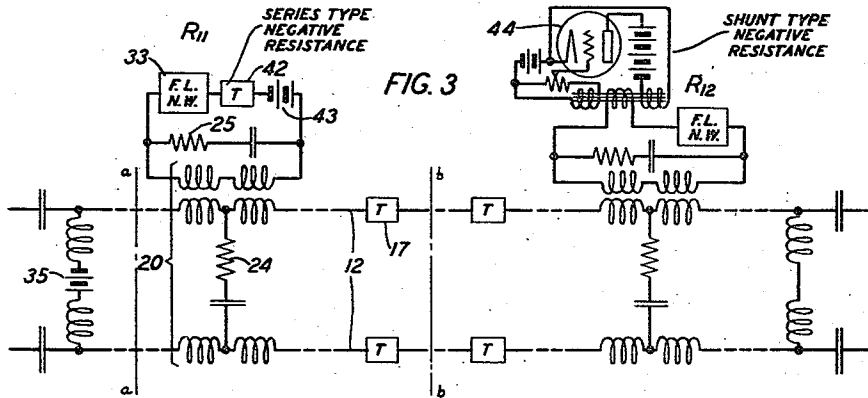
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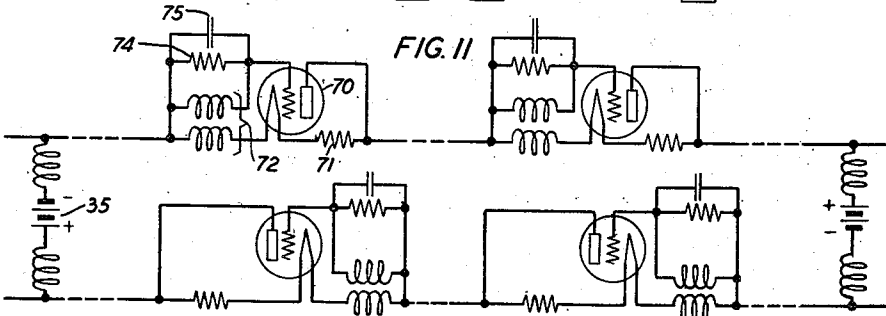
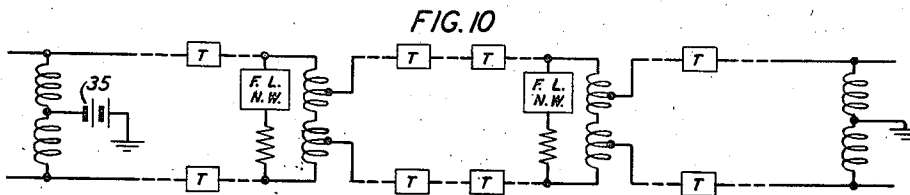
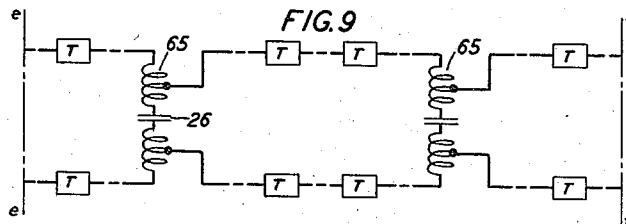
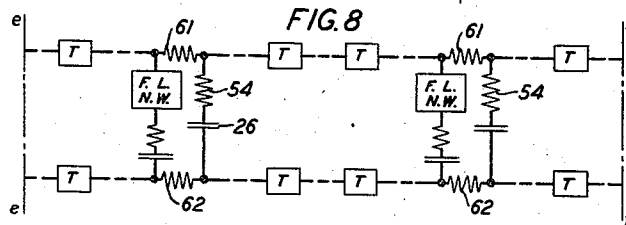
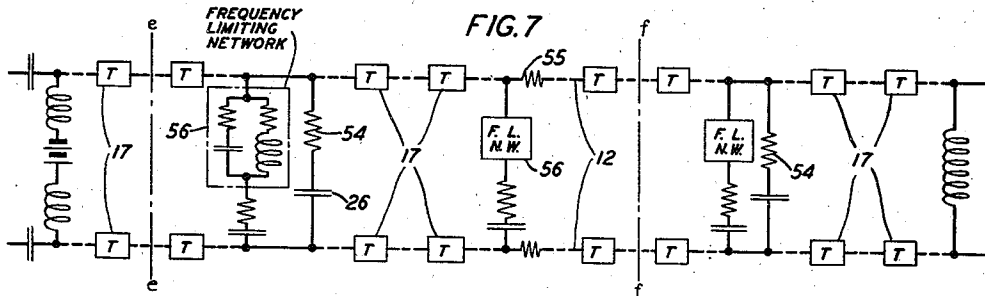
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4 Sheets-Sheet 3



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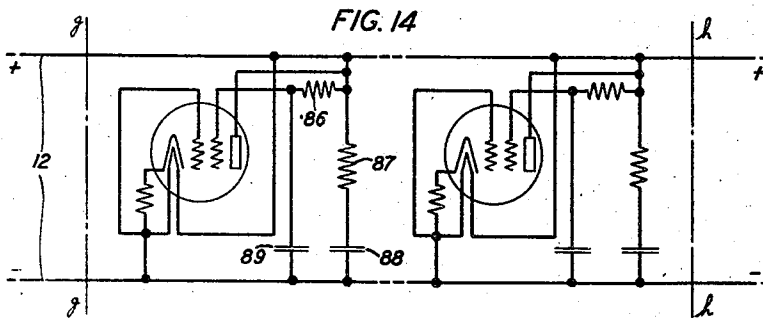
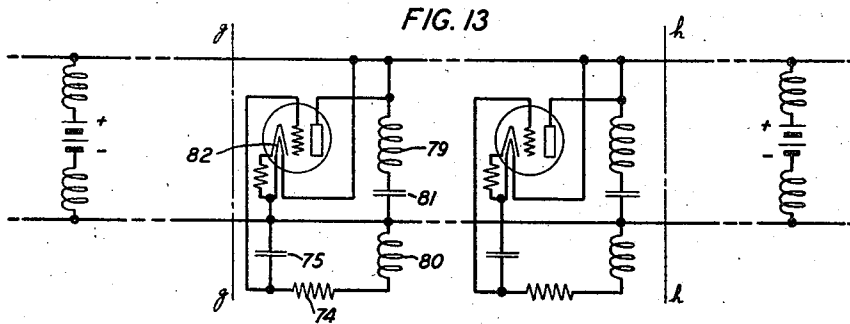
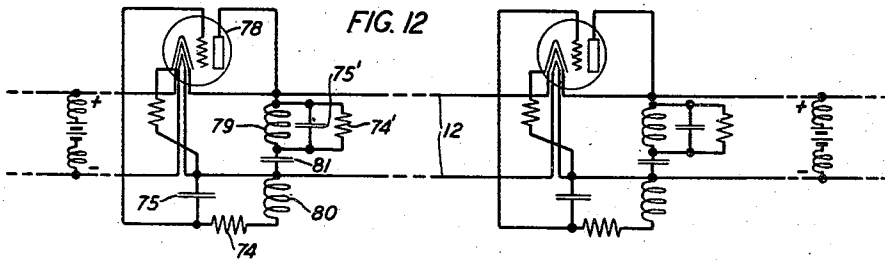
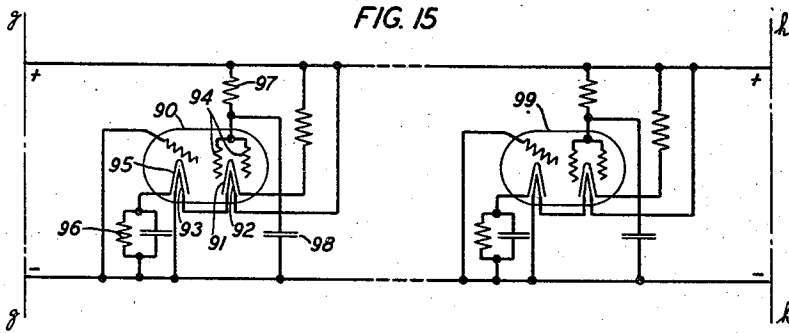
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NEGATIVE RESISTANCE LOADING

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4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,356,867

NEGATIVE RESISTANCE LOADING

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Application August 14, 1942, Serial No. 454,796

19 Claims. (Cl. 179—80)

The present invention relates to improvements in the transmission of electrical waves over lines for telephony or similar purposes.

More particularly, the invention relates to the use of negative feedback for stabilizing the transmission characteristics of a transmission line with respect to such variables as change of attenuation due to temperature, moisture or other causes. The gain necessary to the negative feedback may be provided by negative resistances or repeaters or partly by both. Since the stabilizing effect of the negative feedback is greater, the greater the amount of the feedback, it is desirable to use a large amount of negative feedback so that provision must be made for introducing a correspondingly high gain.

The use of a large feedback ratio to secure maximum benefits therefrom leads to a tendency toward self-oscillation or singing around the feedback loop and one of the features of the present invention has to do with permitting the use of a high degree of feedback without singing.

In order to stabilize the line by use of negative feedback, the line itself must be included in the feedback loop. This can be done by providing successive loops along the line and including successive lengths of the line in the successive feedback loops. A limitation is placed upon the length of line that may be included in a feedback loop for a given feedback ratio by the maximum permissible phase shift that may be used before a singing condition is produced, since the phase shift increases with distance along the line and a singing condition is reached when the phase shift around the loop is zero for any frequency provided also that the net numerical gain for that frequency is positive when taken once around the complete loop. If, therefore, the gain is all introduced at one point in each feedback loop, as by the use of repeaters, for example, a limitation is placed on the maximum permissible spacing of the gain devices, for a given feedback ratio, by the magnitude of the phase shift occurring within the length of line included between two gain devices.

In accordance with the present invention, part or all of the gain in a system using negative feedback for improving line transmission is obtained by negative resistance loading.

One effect of negative resistance loading is to reduce the phase shift per line section. Negative resistance loading can therefore be used to produce a more favorable phase shift characteristic as regards singing tendency and permit a wider spacing of repeaters.

Since the phase shift increases toward higher frequencies the zero phase shift condition is reached first at some high frequency usually above the useful transmission range. What would be desired, therefore, would be a large negative feedback over the useful band and a reduction of the gain with increasing frequency to a less than zero value (a loss) before the frequency is reached at which the phase shift is zero. This part of the problem is similar to that encountered in the design of stabilized feedback amplifiers. It is found that loss varying with frequency can be introduced to modify the gain cut-off and Bode has shown in his Patent 2,123,178, July 12, 1938, how to control the attenuation and phase shift characteristics around the feedback loop so as to permit use of large feedback in the useful band and reduce the gain toward high frequencies at such a rate as to reach negative value before the phase shift becomes zero.

By use of negative resistance loading according to this invention the phase shift of the line itself is decreased so that the zero phase point is moved to a higher frequency. This permits the use of larger feedback at the top frequency of the useful band and by using networks to cut off the gain of the repeaters or negative resistances or both, the singing point can be avoided. The nature and objects of the invention will become more apparent from the following detailed description of illustrative embodiments shown in the accompanying drawings.

In the drawings:

Figs. 1, 2, 3, 5, 7, 10 and 11 each show schematic circuit diagrams of transmission lines including devices for producing gain and negative feedback in accordance with the present invention;

Fig. 4 shows a modified circuit that may be substituted for the portion of Fig. 3 between the broken lines *a-a* and *b-b*;

Fig. 6 shows a modified circuit that may be substituted in Fig. 5 between each pair of broken lines *c-c* and *d-d*;

Figs. 8 and 9 each show a different modified circuit that may be substituted in Fig. 7 between the broken lines *e-e* and *f-f* and repeated along the line;

Figs. 12 and 13 show portions of lines with shunt negative resistance loading which may be used in place of series negative resistance loading of the previous figures; and

Figs. 14 and 15 show alternative modified types

of circuit that may be substituted in Fig. 13 between the broken lines $g-g$ and $h-h$.

Referring to Fig. 1 the telephone 10 and 11 are shown arranged for communication with each other over the line 12. The subscribers' lines are shown coupled to the line 12 through the medium of repeating coils 13 and 14 which may, for example, be located at a central office or exchange point. Line 12 may be a long toll line or other transmission line and is provided with a number of repeater points, two of which are shown at R_1 , R_2 . The line 12 is also provided with negative resistance loading, the negative resistances shown being thermistors of suitable type for developing negative resistance in the line conductors when supplied with direct current from the terminal sources 15 and 16 inserted between the line windings in the repeating coils 13 and 14, respectively. The use of thermistors for line loading is disclosed and claimed in an application of P. G. Edwards, Serial No. 440,550, filed April 25, 1942, and an application of R. K. Bullington, Serial No. 440,549, filed April 25, 1942, and the thermistors shown in Fig. 1 at 17, together with the manner of inclusion in the line, the spacing, etc., may be in accordance with the disclosures of the said applications.

Repeater R_1 is shown as comprising an amplifier tube 18 having its grid circuit and plate circuit associated with the line 12 by means of the hybrid coil 20 comprising coupled windings in both sides of the line. Grid bias resistor 21 and by-pass condenser 22 are provided in the cathode lead. The hybrid coils are designed so that over the desired frequency band the line input is conjugate to the line output. This is accomplished by properly proportioning the resistances 24 and 25. Condensers 28 and 27 are stopping condensers and are of large capacity.

This description of the repeater R_1 suffices also for the repeater R_2 , the difference between the two repeaters being the addition of a transformer 31 in the grid circuit of repeater R_2 to reverse the polarity of transmission through this repeater. The balancing networks are proportioned to balance the impedance of the thermistor loaded line making the output of the amplifier tube in each case conjugate to the input so that feedback does not take place locally around the repeater tube circuit.

The repeaters R_1 and R_2 are arranged so that for a given polarity of voltage applied to the input terminals of the repeaters the voltage returned to both the input and output of the plate circuits will have opposite polarities in adjacent repeaters. In this way a voltage originating in one repeater and traversing the thermistor loaded line section and the other repeater will be returned to the first repeater in phase opposition to the originating voltage. In this way a negative feedback path including the line section is provided.

Included in each repeater circuit is a frequency limiting network 33 comprising a suitable combination of resistances and reactances that will cause the repeaters to lose gain above the transmission band to an amount where the transmission is less than unity for any frequency for which the phase shift is zero. These frequency limiting networks 33 may be designed in relation to the rest of the circuit in accordance with the principles stated in the patent to Bode supra.

It is contemplated that in an actual installation a number of repeaters of the R_1 and R_2 types would be spaced at equal intervals along the line alternating as to type and introducing alternately

series and shunt negative resistance in the line. As noted above, the maximum permissible spacing between such repeaters is increased by the use of the negative resistance loading in the line for a given feedback ratio. Moreover, the frequency limiting network 33 reduce the gain at high frequencies where singing is most liable to occur. The spacing of R_1 and R_2 would be governed by the amount of feedback desired at the top frequency of the desired band. With optimum design of networks 33 the greater the feedback the shorter the spacing.

Fig. 2 shows the repeater R_1 of Fig. 1 arranged for battery supply over the line conductors 12. It will be obvious from the showing of this one repeater how repeater R_2 and other repeaters could be similarly energized. The tube 28 is similar to 18 except that a heater type cathode is shown, although a filamentary cathode could be used in this circuit also, if desired. The energy supply is from the battery 35 connected between the halves of retard coil 36 and the heater for the cathode of the tube 28 is included in series with the upper line conductor 12, the direct current path being completed through the retard coil 37 and lower side of line 12. The plate supply is taken from across the line between center points of line windings of hybrid coil 20 and the battery current is fed through a filter comprising choke coils 38 and shunt condenser 39. Series condensers 40 may be used to divide the line into sections as regards the direct current circuit. The circuit is otherwise the same as in Fig. 1.

Fig. 3 shows a similar type of system in which repeaters of alternate series and shunt negative resistance characteristics are provided in the line at spaced intervals and in which negative resistance loading is included between the repeaters. The first repeater R_{11} in Fig. 3 makes use of a series type negative resistance in the form of a thermistor 42 for introducing a series negative resistance into the line 12. The hybrid coil 20, resistances 24 and 25 and frequency limiting networks 33 may be as in Fig. 1. Energy for the negative resistance device 42 is supplied from battery 43.

A shunt negative resistance required by the repeater R_{12} is shown in the form of a vacuum tube 44 having its input and output inductively coupled with a coupling coefficient less than necessary to produce self-sustained oscillations. The directions of the windings and the adjustments are such that the tube 44 introduces a negative resistance of the shunt type into the line 12. This type of circuit is the same as that disclosed in Crisson Patent 1,776,310, September 23, 1930, Fig. 3. The general mode of operation of the circuit of Fig. 3 is similar to that of Fig. 1 in that a voltage originating in one repeater and traversing the line to the other repeater is returned to the first repeater in phase opposition to the originating voltage. In this way the total gain of the circuit is reduced by negative feedback and the advantages of improvement in stability against transmission changes in the line are obtained as in the case of Fig. 1.

Fig. 4 shows how line current from battery 35 (Fig. 3) provides energizing current for the thermistor 42. Stopping condensers 48 and 49 are used to block the direct current path except in series over each side of the line and through the thermistor. Also in Fig. 4 a symmetrical circuit is used by providing a second thermistor 42' for the opposite side of the line.

Fig. 5 shows the use of high internal im-

pedance tubes, such as pentodes, connected to be supplied with energy over the line as in Fig. 2. Here, however, the plate circuits deliver their power across the line at the center of line coil rather than in series with line as in the case of Fig. 2. The resistances 53 are so large as not to furnish objectionable shunting effects across the line for the signals. The by-pass condenser to the cathode furnishes together with the screen resistance 53 a filter to prevent the screen from reacting on the transmission properties of the tube.

In order not to unbalance the line by including the heaters in series on one side of the line the arrangement of Fig. 6 can be used in which a tube having a cathode 50 is provided with two heaters 51 and 52 connected in series on respective sides of the line. The circuit is otherwise the same as in Fig. 5.

Fig. 7 shows a system in which all of the gain is provided by the negative resistance loading devices 17 inserted at periodic intervals in the line conductors 12. At given intervals along the line shunt resistances 54, 54 alternate with series resistances 55, etc. Reflections of respectively opposite sign are produced from the series and shunt resistances so that a voltage starting anywhere in the feedback loop between two reflection points will traverse the loop and come back to the same point in phase opposition. The negative resistance devices 17 could be designed so that by themselves they produce a net gain in the line. This may be done, for example, as shown in the disclosure of the Bullington application cited. The reflections then produce the negative feedback in the manner just described. Frequency limiting networks 56 are provided similarly to the frequency limiting networks 33 of the previous figures to assist in providing a cut-off, such as to enable a greater degree of negative feedback to be used in the band with stability against singing. The magnitudes of the reflections can be controlled by proportioning the reflecting resistances 54 and 55 in relation to the line impedance, the greater the impedance irregularity, the greater being the amount of reflection. The spacing of the reflection points is determined in part by the phase shift occurring between reflection points and with special reference to singing tendency.

A variation of this method is shown in Fig. 8 in which inequality ratio pads are used to provide the reflections. In this case the reflections at each end of a negative feedback section are of opposite sign because the low impedance side of the pad is at one end of the section and the high impedance side of a pad at the other end. The pads are shown as comprising series resistances 61, 62 and shunt resistances 54.

A somewhat similar effect is secured in the circuit of Fig. 9 by the use of repeating coils or auto-transformers for producing impedance irregularities at the ends of the negative feedback sections. These auto-transformers are shown at 65, 65. At the left end of the complete negative feedback section shown the line conductors are tapped into intermediate points of the coils whereas at the opposite end of the same section the line conductors are connected to the extreme outer terminals. This is repeated from section to section so that reflections of opposite sign are produced at opposite ends of a feedback section.

Fig. 10 shows a circuit differing from Fig. 9 merely in the manner of supply of the energizing current over the line by using a phantom or simplex type of connection for the battery 35. 75

This allows the stopping condensers at various points along the line in Fig. 9 to be omitted. This mode of supply of the energizing current is applicable also to circuits of Figs. 7 and 8.

Instead of thermistors for negative resistance loading in many of the previous cases, vacuum tube circuits giving series type negative resistance characteristics may be used, one example being shown in Fig. 11. The type of negative resistance disclosed is similar, in general, to that shown in Fig. 4 of the Crisson patent given above and comprises a tube 70 having its filament connected in series in the line to be energized by current from battery 35 and its plate voltage derived from series resistor 71. The coupling for developing negative resistance is provided by the coupled windings 72, one in series in the line conductor and the other in the grid circuit. The resistance 74 furnishes a termination for the transformer, while the capacity 75 causes the local feedback to diminish with increasing frequency giving the unit as a whole a positive reactance component in series with the negative resistance, increasing with increase of frequency. Negative resistances of this type are shown included in both sides of the line and in the Fig. 1 type of system these would be included between repeater points, while in the Fig. 7 type of system these negative resistances would provide all of the gain of the system. Although Fig. 11 shows filamentary type tubes, heater type tubes are equally applicable.

Equalizers or impedance networks (not shown) may be associated with the thermistors 17 (or tubes 70) as disclosed in the Bullington application referred to.

In each of the foregoing examples the loading within a line section comprised series type negative resistances. In some cases the stray longitudinal currents over the line are comparatively large and difficult to avoid. Such currents might interfere with the operation of series type negative loading units.

Figs. 12 to 15 show examples of the use of negative shunt type resistances for loading a line. In order to be able to supply power to a number of units of this type along the line, such units should have high voltage with low current consumption as against the high current with low voltage consumption used for series loading. Referring first to Fig. 12, the tubes 78 are shown having their plates connected to the upper conductor of the line 12 and their cathodes connected to the lower conductor. The current is supplied from suitable terminal sources between the line conductors. The tubes have inductances 79 and 80 coupled together and connected, respectively, in their plate and grid circuits to provide positive feedback in such fashion as to develop a negative resistance of the shunt type in shunt across the line. A stopping condenser is shown at 81 and the coil winding 80 is provided with a terminating resistance 74 and condenser 75 which operate as described in connection with similar elements of Fig. 11. Instead of or in addition to elements 74 and 75 the resistance 74' and capacity 75' may be associated with the winding 79. A similar type of unit is used for each loading unit along the line. Longitudinal currents which traverse both sides of the line in parallel will affect only the heaters. The cathode circuit will be unaffected if the heaters are running at high enough temperature. The negative impedance derived in the grid cathode plate circuit will, therefore, be substantially independent of longitudinal currents. It is noted that in this case

also two heaters are used in each tube, connected in respective sides of the line to preserve a balanced line circuit. In the shunt type impedance, to make the unit completely independent of longitudinal currents a special construction of vacuum tube could be used in which the heater is a high voltage, low current heater so that the current drain along the line will be small and the voltage across the line maintained at sufficient amplitude to supply satisfactory operation of the circuits. In such cases the heaters can be connected across a line.

Such a circuit is shown in Fig. 13 which is similar to the circuit of Fig. 12 except for the use of high voltage, low current heaters 82 connected in shunt across the line.

The auto-transformers 79, 80 of Fig. 13 may be omitted if as in Fig. 14 screen grid tubes are used to provide a negative shunt type impedance in the plate circuit. The control grids are directly connected to the cathode through a grid bias resistor while the screen grids are connected through resistance 86 to the plate and to the positive side of the line 12. The impedances 87 and 88 associated with the plate circuit can be proportioned to give the proper value of negative resistance and positive reactance components necessary to load the line. The by-pass condenser 89 and the resistance 86 serve as filter circuits for the screen grid.

Fig. 15 shows shunt type negative resistance loading employing a special type of tube 90 operating as a shunt negative resistance in the general manner of a dynatron but with increased negative resistance effect. The negative resistance effect is due in the dynatron to secondary electron emission from the positive plate to the screen grid. In tube 90 this effect is heightened by making the positive plate 91 a good emitter of electrons, and by heating it. Heater 92 for the anode is connected across the line in series with cathode heater 93, these being high voltage low current heaters. Since the anode 91 is hot it emits electrons readily to the screen grid 94 when the screen is at about the same potential as or only slightly positive with respect to the anode 91. The flow of electrons from the plate thus caused is in opposition to the flow of electrons from the cathode through the screen to the plate. This causes the plate current in this region to decrease as the plate voltage increases causing a negative slope in the plate current-voltage characteristic. When the screen draws current due to the application between it and the cathode 95 of direct current potential from the line there is a large enough supply of electrons from the hot anode to considerably increase the influence of the screen potential on the plate current to produce a wider range of operating voltages over which the plate will have a negative resistance characteristic. The parallel resistance capacity at 96 in the cathode lead produces negative feedback of the signal frequencies with unequal feedback over the signal frequency band, the feedback having an amplitude and phase characteristic which modifies the value of negative plate resistance in such a way as to produce the necessary over-all negative resistance positive reactance characteristic required for a shunt loading unit. This capacity and resistance may be proportioned to suit a particular frequency range and line characteristic. The condenser resistance unit in the screen circuit, at 97, 98, serves as a filter to prevent the screen from reacting on the transmission of the circuit over the desired band. Tube 99

and its connections may be the same as in the case of tube 80 and their number and spacing along the line will be such as to provide the desired loading as in the previous figures.

The invention is not to be construed or limited to the specific circuits that have been disclosed herein for illustration, but its scope is defined in the claims.

What is claimed is:

1. A transmission line having inserted therein at spaced intervals means giving a gain to signal waves transmitted over said line, circuit means for producing negative feedback around a path including the gain producing means and said line, and negative resistance devices inserted in the line at intervals between said respective gain producing means, for improving the gain-phase characteristics of said feedback path.

2. In a transmission line, means at stated intervals along the line for reflecting waves back from one means to the next with a phase reversal such that a wave originating at one such means and traversing the line to the next means is returned in part to the first means in opposite phase to the originating wave, and negative resistance devices in the line at spaced points between the adjacent means.

3. In a transmission line, means dividing the line into a succession of negative feedback sections, each section including gain producing means consisting in part of equally spaced negative resistances along the line section.

4. In a transmission line, means dividing the line into a succession of negative feedback sections, each section comprising means at the remote end for reflecting waves back over the section in phase opposition to forwardly transmitted waves and including a plurality of negative resistance devices spaced at intervals along the line section.

5. In a transmission line, repeaters at intervals dividing the line into repeater sections, means at a given repeater for amplifying waves received over the line from the next preceding repeater and reintroducing the amplified waves into both the succeeding and preceding repeater sections in such phase relation that the part of the waves introduced into the preceding repeater section is sent back to the next preceding repeater in a phase opposite to that with which the waves were applied to said preceding repeater, whereby negative feedback loops are formed between adjacent repeaters and including intervening line sections, and means for improving the phase margins around the feedback loops comprising negative resistances inserted at points along the line within each repeater section.

6. The combination according to claim 5, including a frequency limiting network in each repeater for reducing the frequency band of the waves amplified by the repeater to increase the gain-phase margin against singing.

7. In a transmission line, for transmitting waves comprised in a band of frequencies, periodically spaced negative resistance devices along the line at fractional wave-lengths of the highest transmitted frequency, means to energize said negative resistance devices to cause them to reduce the line attenuation, amplifying devices included in said line at spaced intervals longer than the spacing of said negative resistance devices, and means to feed a part of the amplified output waves of each amplifying device back over the line to the next preceding amplifying

device in phase opposition to the waves in the input of the latter device.

8. The combination according to claim 7 in which said negative resistance devices are thermistors having a frequency response characteristic covering said band of frequencies.

9. In a transmission line, negative resistance repeaters at spaced points along said line, alternate repeaters producing series type negative resistance and intervening repeaters producing shunt type negative resistance, and a plurality of negative resistance elements inserted in the line between successive repeaters, the spacing of the repeaters being such that the waves amplified in each repeater are fed back to it in opposite phase from the next succeeding repeater.

10. In a transmission line, negative resistance loading inserted therein at spaced points, said loading introducing a gain in excess of the line loss for waves transmitted over the line, and impedance means at points of greater spacing in the line for producing reflections, the spacing between said impedance means being such that the waves reflected back to any point in the line arrive in phase opposition to the original wave at said point whereby negative feedback over the line is produced.

11. The combination of claim 10 with frequency limiting networks associated with the impedance means for preventing singing at frequencies at which the phase shift between original and reflected waves tends to become zero.

12. In a transmission line, negative resistance loading units inserted in the line at loading intervals to annul attenuation in the line for signals, each loading unit comprising a space discharge device having cathode, anode and control elements and a feedback coupling between the anode-cathode and cathode-control-element circuits of each device of such sense as to produce a negative resistance effect in the line, and a frequency dependent impedance included in the circuit of each such unit to give the unit a gain characteristic which falls rapidly to zero for frequencies higher than the frequencies essential to the transmission of said signals.

13. The combination of claim 12 in which each

of said loading units develops in the line a series type negative resistance in series with the line.

14. The combination of claim 12 in which each of said loading units develops a shunt type negative resistance in shunt relation to said line.

15. In a transmission line, means dividing the line into a succession of negative feedback sections, each section including gain producing means consisting in part of equally spaced shunt-type negative resistance devices along the line section bridged across the line.

16. The combination according to claim 15 in which said shunt-type negative resistance devices comprise vacuum tubes with positive feedback couplings between their plate and grid circuits and with their cathodes and plates connected to opposite line conductors.

17. The combination according to claim 15 in which said shunt-type negative resistance devices each comprise a vacuum tube including a screen grid and anode both connected to the positive side of the line and a grid and cathode both connected to the negative side of the line, and a resistance and capacity in series connected across the line and proportioned to cause said vacuum tube to develop a negative resistance and positive reactance in bridge of the line.

18. The combination according to claim 15 in which said shunt-type negative resistance devices each comprise a dynatron tube having its anode and screen grid connected to the positive side of the line and its control grid and cathode connected to the negative side of the line and having a negative feedback circuit between its anode and control grid for modifying the value of negative resistance to produce a positive reactance component of impedance together with a negative resistance, across the line.

19. The combination with a transmission line of negative resistance loading units bridged across said line at loading intervals along the line, each unit comprising a shunt-type negative resistance device and a network connected thereto having a frequency-dependent impedance for causing the unit to develop a negative resistance and positive reactance in bridge of the line.

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