

Oct. 24, 1944.

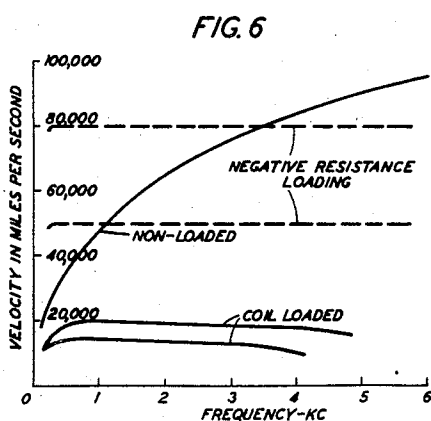
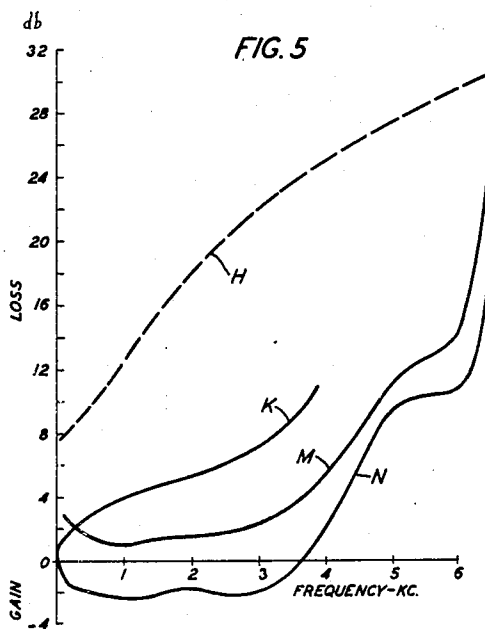
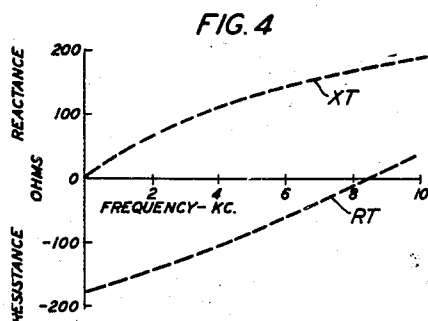
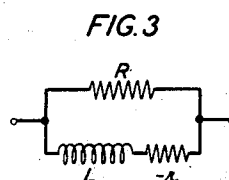
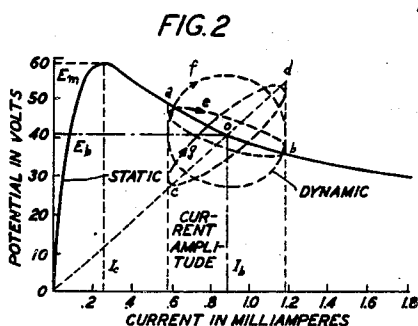
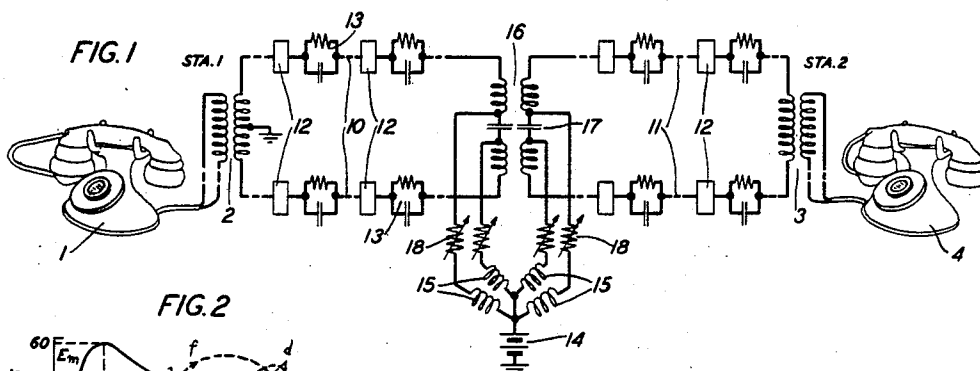
R. K. BULLINGTON

2,360,932

NEGATIVE RESISTANCE LOADING

Filed April 25, 1942

2 Sheets-Sheet 1



INVENTOR
R. K. BULLINGTON
BY *H. A. Burgess*
ATTORNEY

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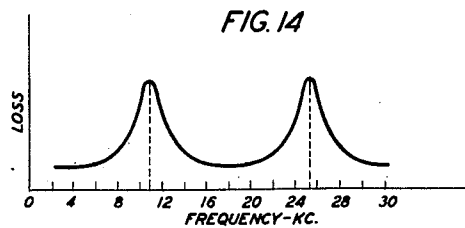
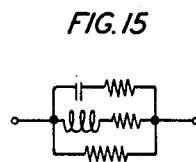
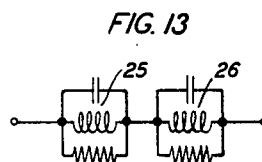
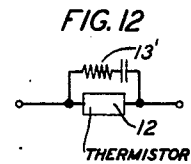
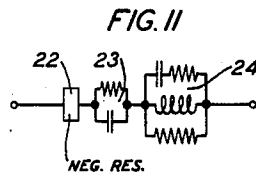
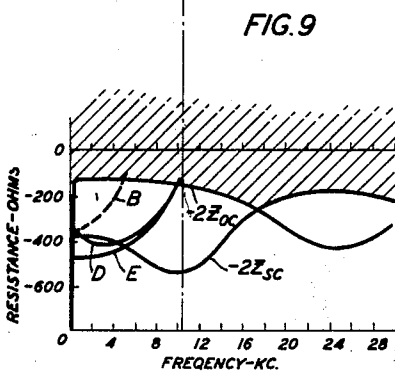
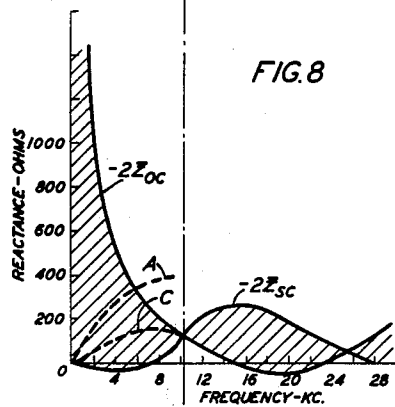
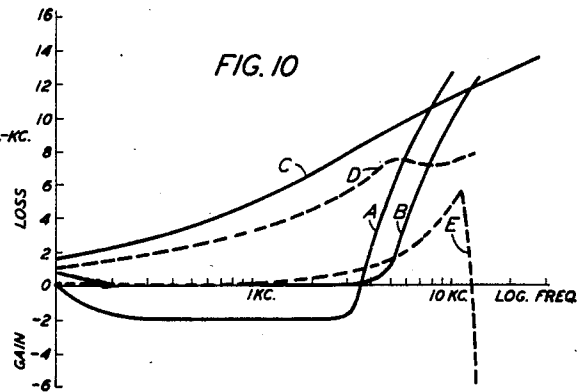
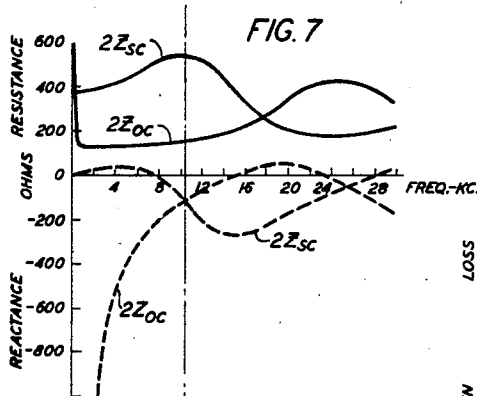
R. K. BULLINGTON

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NEGATIVE RESISTANCE LOADING

Filed April 25, 1942

2 Sheets-Sheet 2



INVENTOR
R. K. BULLINGTON
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

2,360,932

NEGATIVE RESISTANCE LOADING

Robert K. Bullington, Forest Hills, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 25, 1942, Serial No. 440,549

22 Claims. (Cl. 178-45)

The present invention relates to wave transmission over lines and more particularly to the use of negative resistance loading to improve the transmission characteristics of lines.

It has been proposed heretofore to insert negative resistance loading units in a transmission line at periodic intervals in order to reduce the line attenuation, and to supply the energizing current, necessary for developing the negative resistance effect, over the line conductors to the various loading units.

Such prior proposals have not proved practical because of the difficulty of providing loading elements having practical values of negative resistance or sufficient stability to secure satisfactory transmission. This has been due in part to attempts to use loading elements whose negative resistance characteristics did not exhibit a cut-off effect at higher frequencies, thus resulting inevitably in a singing tendency at some high frequency at which the spacing exceeds the maximum permissible fraction of a wave-length. In other words, such loading units continue to introduce negative resistance with increasing frequency until a frequency is reached at which the phase shift per section becomes 180 degrees, resulting in instability as regards singing tendency.

In accordance with the present invention, negative resistance loading is used of a type having a cut-off effect and in a manner to secure very low, substantially uniform, attenuation in the transmission band with high stability.

The invention also permits the securing of high and constant velocity of transmission over a broad band.

Other advantages, as well as the nature and objects of the invention, will appear more fully from the following detailed description in connection with the drawings, in which:

Fig. 1 is a simplified sketch in schematic form of a telephone circuit with negative resistance loading according to the invention;

Figs. 2, 4, 5, 6, 7, 8, 9, 10 and 14 show graphs to be referred to in the description to follow;

Fig. 3 is an impedance network diagram showing the electrical equivalent of a thermistor; and

Figs. 11, 12, 13 and 15 show different types of network configuration that may be used in the practice of the invention.

Periodic loading of lines with inductance coils has long been in use as a means of reducing the line attenuation over a transmission frequency range from near zero to some upper limiting frequency such as the top frequency of the essen-

tial speech band or in some cases higher frequencies. Formulas have been developed relating the general design factors to the line dimensions. It is found, for example, that the spacing should be uniform and such as to give a minimum of two coils per wave-length at the cut-off frequency, the general practice being to use a closer spacing than this minimum in order to approach more closely to a smooth line to provide a better image impedance at the terminals. Coil loading is capable of giving a low and practically uniform attenuation over the band, but a disadvantage has been that the velocity is reduced to a marked degree and the velocity is not constant, especially as the cut-off frequency is approached. Since the velocity is lowered, the wave-length is shortened so that the spacing factor is shorter in proportion to the reduction in velocity. Since coil loading does not reduce the resistance of the circuit but actually increases it to an extent, the problem of instability leading to a singing condition does not arise.

Negative resistance loading reduces the attenuation by canceling positive resistance in the line. It can result, as more fully disclosed later on, in higher transmission velocity at low frequencies, and more nearly uniform velocity over the band, than in the case of non-loaded lines or coil loaded lines. The wave-length and, therefore, the length of loading section is longer than in the case of coil loading. Where the reduction in positive resistance is sufficient to materially reduce the attenuation, difficulty arises in maintaining the circuit stable, unless the phase shifts are properly controlled. This instability may result even though the net resistance (series resistance of the non-loaded line in combination with the negative resistance of the loading unit) is positive; also a stable net gain (less than zero attenuation) may be obtained under certain conditions even though the net resistance is positive. Criteria are given hereinafter for stability requirements with negative resistance loading.

The present invention employs for the loading unit an elemental circuit which inherently possesses a cut-off whereby the unit is capable of developing a negative resistance effect over a band of frequencies but this effect decreases to zero at some frequency at or above the upper edge of the band and becomes a positive impedance at all higher frequencies. This type of characteristic is favorable to stability since the design can be such as to allow the resistance to become positive before the phase shift, with increasing frequency, reaches 180 degrees per loading sec-

tion. The invention further includes in or associates with such loading unit, impedance elements to control the shape of transmission characteristic to give improved transmission and where necessary increased stability.

A feature of the invention is the use in a negative resistance loading unit of an element having a negative temperature coefficient of resistance, so constructed as to be variably heated by the signal currents passing over the line, with a steady bias current to enable the element to exhibit a negative resistance effect in the line. Such devices are commonly referred to in the art as thermistors. Thermistors as constructed in the art can be made to have various time constants depending upon their physical dimensions and heat dissipating properties. For loading uses in telephone transmission it is necessary that the thermistors be able to respond to frequencies up to at least 2 or 3 kilocycles per second and preferably higher frequencies, while for carrier telephony they must respond to several times 3 or 4 kilocycles per second.

The use of negative resistances, specifically thermistors, for line loading is disclosed and claimed in an application for patent of P. G. Edwards, Serial No. 440,550, filed April 25, 1942. The present invention is concerned with securing improved transmission by means of thermistor loading or other negative resistance loading, and particularly in obtaining such characteristics as low attenuation with satisfactory stability, and high, constant velocity.

Referring to Fig. 1, the telephone set 1, at or connectable to station 1, is shown as communicating over a toll trunk 10; 11, with distant telephone set 4 at or connectable to station 2. Stations 1 and 2 may be telephone exchanges at which the subscribers' lines leading to sets 1 and 4 appear on switchboards or switch terminals. Repeating coils 2 and 3 are inserted between the local lines and the toll trunk. (The cord circuits or equivalents are not shown.)

Negative resistance loading elements 12, 12, etc., are inserted in the toll lines at periodic intervals. An equalizer network 13 is shown connected to each loading element 12. Current for energizing the negative resistance elements is supplied over the line sections 10, 11 from battery 14, this current flowing over each side of the line section to ground at the mid-point of the distant repeating coil 2 or 3. Inductances 15 are inserted in series with the battery leads to offer high impedance to talking currents. The battery is applied to the line sections at the mid-points of the repeating coil 16, across the terminals of condensers 17 which are inserted between the two halves of each winding and complete the talking current paths. Regulating resistances 18 are provided to enable control of the magnitude of the energizing or bias current. In practice the networks 13 may be spaced farther apart than the loading units, if desired.

The negative resistance used for the loading element may be of any suitable or known type such as a vacuum tube circuit but is specifically disclosed herein as a thermistor, that is, an impedance whose resistance changes as a result of a change in its temperature due to the heating effect of the telephone currents or other signaling currents that are being transmitted. If a pure negative resistance is used impedance elements are associated with it to give the loading unit a cut-off effect as will be more fully described.

Thermistors suitable for use with this invention have a non-linear static voltage current characteristic. If a negative resistance temperature coefficient thermistor of this type is subjected to a direct current of increasing magnitude, the voltage drop across it is found to increase to a maximum and then decrease. In other words, the device has a declining voltage-current characteristic. The static voltage-current curve of a typical thermistor is shown in Fig. 2.

Dynamically, the alternating current resistance is negative in the region beyond the voltage maximum E_m for sufficiently low frequencies. Fig. 2 also indicates the dynamic characteristics. If a direct current of value I_b greater than I_c (that current corresponding to E_m) be applied to the thermistor, a superposed alternating current of frequency approaching zero will trace out a curve aoa approximating the static characteristic. If the superposed current has a very high frequency, the thermal lag of the thermistor will prevent any change in temperature, and hence in resistance, from taking place. The voltage current trace therefore will be along the ohmic resistance line cod . At intermediate frequencies the superimposed current will produce traces as shown at e, f and g in the order of increasing frequency. At low frequencies the effective alternating current resistance is negative, at high frequencies it is positive and at intermediate frequencies it may be either positive or negative; thus for some critical frequency it becomes equal to zero. This latter is the maximum frequency at which amplification can occur.

This behaviour may be translated, with a good degree of approximation, into the behaviour of an electrical network of the type shown in Fig. 3, consisting of a positive resistance R , a negative resistance $-r$, and an inductance L associated in the manner shown. If a direct current voltage is applied across the terminals of such a network, its total resistance is negative since the relatively large resistance R is effectively shunted out by the branch $L, -r$. If a low frequency is applied and the frequency is gradually increased, the impedance of the L branch increases with increase in frequency so that the total negative resistance is decreased and a corresponding phase angle is introduced. At frequencies above the temperature response of the thermistor, the L branch becomes an open circuit leaving R as the only branch effectively in the circuit.

A thermally sensitive resistor suitable for use in loading a telephone line, for example, in accordance with the present invention, may consist of a semiconductive material such as uranium oxide, a mixture of nickel and manganese oxides and boron or similar substances or mixtures, and they may be constructed in the manner disclosed in United States Letters Patent 2,276,864 of Gerald L. Pearson granted March 17, 1942, to which reference is made for a complete disclosure of the device itself.

In case a negative resistance other than a thermistor is used, it should have associated with it whatever reactance and resistance elements are needed to impart to it a cut-off characteristic at some frequency above the band, as already stated. Thermistors inherently possess such a cut-off because they lose their negative resistance effect and become loss elements at frequencies too high for the temperature variations to follow. A pure negative resistance at all frequencies or a thermistor whose negative resistance extends

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beyond the desired frequency range may be made to have a cut-off characteristic by connecting in series with it a positive resistance in parallel with an inductance. More generally, a network as shown in Fig. 15 may be used to insure the desired cut-off and to provide suitable characteristics over the transmission band. In particular cases some elements in Fig. 15 may be eliminated.

The measured reactance and resistance characteristic of one thermistor used by applicant are given in Fig. 4 by way of example. It will be noted that this thermistor exhibited a negative resistance characteristic over the band from zero to about 8 kilocycles and positive resistance for higher frequencies.

When negative resistances or thermistors of the types described are used to load a transmission line, as in Fig. 1 for example, they are given a spacing in accordance with general loading practice, the maximum permissible spacing being two loading units per wave-length at the highest frequency transmitted. In one case used by applicant the thermistors were spaced 24,000 feet in a 19 gauge cable pair, as in Fig. 1. Closer spacing results in a closer approach to a smooth line, in transmission characteristic, as already stated. As compared with coil loading, negative resistance loading is capable of giving higher velocity and a more nearly constant velocity over the transmission band. Negative resistance loading can also give a lower attenuation, even less than zero attenuation, but certain requirements as to stability must be met as will be pointed out hereinafter. While a spacing factor of two loads per wave-length is desirable from the standpoint of economy in the number of loading units required, a closer spacing for a given band width simplifies the impedance matching at the terminals and increases the stability margin.

As pointed out in the Edwards application referred to, a line loaded with thermistors can give lower and more uniform attenuation over the band than the same line with no loading. Singing difficulties are avoided by using negative resistance numerically sufficiently smaller at all frequencies (including zero) than the positive resistance of the line to result in positive attenuation at all frequencies.

In Fig. 5, the upper curve H is the attenuation frequency curve of a non-loaded cable pair. Curve K indicates the type of characteristic that can be obtained with thermistor loading without the equalizers 13 of Fig. 1 and with the negative resistance numerically smaller at all frequencies, including zero, than the positive resistance of the line. Curves M and N show characteristics such as may be obtained in accordance with the present invention, as by using equalizers in addition to thermistor or negative resistance loading and by observing the stability requirements given hereinafter. Curve M was obtained with a direct current on the line of 14 milliamperes and curve N was obtained with 13 milliamperes energizing current on the line. The variation in current required to shift the curve in this way can be obtained by varying the resistances 18 of Fig. 1. It will be noted that curves M and N indicate a more uniform attenuation over the band, from zero up to about 3 kilocycles, than curve K and in the case of curve N the attenuation is actually negative over most of the band, meaning that a net gain is obtained in this case.

The velocity characteristics with frequency for a non-loaded line, a thermistor loaded line, and a coil loaded line are given in Fig. 6. The velocity

of the thermistor loaded line is higher and more uniform than that of the coil loaded line, and at low frequencies, at least, it is higher than that of the non-loaded line.

Any system is stable under transient conditions if it is stable under steady state conditions at all frequencies from zero to infinity. A loaded line is stable at all frequencies provided the resistive components of its mid-series and mid-shunt impedances are positive at all frequencies. Another way of saying this is that if the line is cut at a point of symmetry (where the impedance looking one way is equal to the impedance looking in the opposite direction) and its impedance as seen from that point is such that the resistive component is positive at all frequencies, the line is stable.

For any thermistor there is a frequency above which the effective resistance is always positive due to the inability of the thermal response to follow the alternating current. Above this frequency the network is always positive, hence is stable. Consequently the frequency range to be explored in stability considerations is reduced to that range within which the thermistor resistance is negative.

As an illustrative example, reference is made to the thermistor characteristics plotted in Fig. 4 and the open and short-circuit impedance characteristics for a line section shown in Fig. 7, where Z_{sc} refers to the impedance of the cable alone as seen from the loading point looking toward a short circuit at mid-section, and Z_{oc} refers to the impedance of the cable alone as seen from the loading point looking toward an open circuit at mid-section.

It can be shown, as in K. S. Johnson's "Transmission Circuits for Telephone Communication" (D. Van Nostrand Company, New York, New York, 1927 pp. 154-155) that the mid-load impedance

$$Z_K = \sqrt{(Z_o \tanh P/2 + \frac{1}{2}Z_c)(Z_o \coth P/2 + \frac{1}{2}Z_c)} \quad (1)$$

and the mid-section impedance

$$Z'_K = Z_o \coth P/2 \sqrt{\frac{2Z_o \tanh P/2 + Z_c}{2Z_o \coth P/2 + Z_c}} \quad (2)$$

where

Z_o is characteristic impedance of non-loaded line, P is propagation constant per loading section of the non-loaded line, and Z_c is impedance of the series loading unit.

However,

$$\begin{aligned} Z_{sc} &= Z_o \tanh P/2 \\ Z_{oc} &= Z_o \coth P/2 \end{aligned} \quad (3)$$

Therefore,

$$Z_K = \frac{1}{2} \sqrt{(2Z_{sc} + Z_c)(2Z_{oc} + Z_c)} = \frac{1}{2} \sqrt{Z_A Z_B} \quad (4)$$

$$Z'_K = Z_{oc} \sqrt{\frac{2Z_{sc} + Z_c}{2Z_{oc} + Z_c}} = Z_{oc} \sqrt{\frac{Z_A}{Z_B}} \quad (5)$$

The propagation constant $P' = \alpha' + j\beta'$ per section of loaded line can be obtained from one of the following equations:

$$\sinh \frac{P'}{2} = \sqrt{\frac{Z_A}{2Z_{oc} - 2Z_{sc}}} = \sqrt{\frac{Z_A}{Z_B - Z_A}} \quad (6)$$

$$\cosh P' = \frac{Z_B + Z_A}{Z_B - Z_A} = \frac{Z_c + Z_{sc} + Z_{oc}}{Z_{oc} - Z_{sc}} \quad (7)$$

Solving for Z_c

$$Z_c = -Z_{sc}(1 + \cosh P') - Z_{oc}(1 - \cosh P') \quad (8)$$

Thus for any desired propagation constant P'

the required value for Z_c can be obtained from Equation 8. For zero attenuation ($\alpha'=0$), $\cosh P'=\cos \beta'$ and

$$Z_c = -Z_{sc}(1 + \cos \beta') - Z_{oc}(1 - \cos \beta') \quad (9)$$

$$\beta' = \frac{2\pi f}{V}$$

V' =velocity of propagation of loaded line.

Three particular solutions that can be obtained from Equation 9 are shown in the following table:

β'	$\cos \beta'$	Z_c
Degrees		
0	1	$-2Z_{sc}$
90	0	$-(Z_{sc} + Z_{oc})$
180	-1	$-2Z_{oc}$

The criteria for stability in circuits embodying negative impedances are disclosed in United States Patent 2,099,769, issued to Harry Nyquist on November 23, 1937, wherein it is demonstrated that:

- (1) A series circuit is stable when a plot of the real versus the imaginary parts of the total impedance in the series loop does not enclose the origin.
- (2) A plot of the product of two impedance factors does not enclose the origin providing the plot of each of the two impedance factors taken separately does not enclose the origin.

The criteria for stability of a series loaded line, therefore, can be determined by inspection from plots of Z_A and Z_B ; if neither locus encloses the origin the line is stable. In general but not necessarily, this means that the resistive components of Z_A and Z_B should be positive whenever the reactance component is zero, but may be negative for other values of reactance.

The reactance component of $2Z_{sc}$ at direct current is zero and for low frequencies it becomes inductive (Fig. 7). The reactance of the thermistor at direct current is also zero and for low frequencies it becomes inductive. It is concluded then that the negative resistance introduced by the loading unit at zero frequency must not be numerically greater than the positive resistance of the line section if instability is to be avoided, for then the loss would be less than zero in a circuit of zero reactance.

Also, considering first only the Z_{sc} reactance, over at least that low frequency region where both this reactance and the load reactance are inductive, the circuit indicated by Z_A is stable even with a net negative resistance since the phase cannot be zero.

The reactance component of $2Z_{sc}$ changes sign in the neighborhood of 8 kilocycles for the particular line and spacing plotted in this figure, becoming capacitive from there on over a wide frequency range. The thermistor reactance component is increasingly inductive in the frequency region where the reactance of $2Z_{sc}$ turns capacitive, so that the net effect of the two together is to raise the frequency at which the resultant reactance value reaches zero. In order to avoid singing it is necessary that the net resistance of the loading unit plus line section shall become positive before this frequency is reached.

Considering only Z_A , the following requirements result:

- (a) At zero frequency, the negative resistance of the loading unit should be smaller in magnitude than the direct current resistance per loading section of the non-loaded transmission line.
- (b) At frequencies other than zero, the negative resistance of a loading unit may have any value providing the reactance values are properly controlled.

Turning now to the other factor Z_B , the value of Z_{oc} at zero frequency is large, being the direct current resistance of the insulation between the wires. Above zero frequency, the reactance component of Z_{oc} is very large at a fraction of a cycle per second, decreases in magnitude with increasing frequency, and reaches zero at about 16 kilocycles for the line plotted in Fig. 7. This reactance is capacitive, so that the effect of the series inductive reactance of the thermistor loading is to bring the total reactance to zero at a frequency lower than 16 kilocycles. It is necessary, therefore, that the resistance of the loading unit plus the resistive component of $2Z_{oc}$ assume a positive value with increasing frequency before this frequency of zero reactance is reached. At lower frequencies, the negative resistance of a loading unit may have any value not exceeding the insulation resistance at zero frequency.

From the foregoing reasoning it is apparent that the frequency at which the thermistor resistance changes from negative to positive should lie near and preferably below the lower of the two upper frequencies discussed.

It can be shown that to obtain a low or zero attenuation the reactive components of Z_A and Z_B must be opposite in sign and the resistive component of Z_A must be negative. For a loading unit with negative resistance and sufficient inductive reactance, Z_A gives the obvious limiting value of negative resistance at zero frequency, and Z_B gives the usual spacing requirement of two or more loading units per wave-length. These two requirements could have been obtained or inferred from well-known loading theory, but in addition, the method disclosed herein results in the following conclusions:

- (1) In the frequency band between the two frequencies for which the phase shift per loading section is zero degrees and 180 degrees, respectively, the impedance of a loading unit may have any desired value. Consequently, a loading unit can be designed to give any particular attenuation characteristic, positive, zero or negative, and any possible velocity characteristic.
- (2) To insure stability, the negative resistance of the loading unit at the frequency for which the phase shift is 180 degrees must not only be less in magnitude than the series resistance of the conductors, but also be less in magnitude than the resistive component of the impedance $2Z_{oc}$.

In order to get a better picture of what the thermistor characteristics can be while meeting the requirements for stability, curves representing the inverse of the curves for open and short-circuit impedance of the line section have been plotted in Figs. 8 and 9. The area between the two reactance curves in Fig. 8 has been cross-hatched and the area between the zero axis and

the resistance curves in Fig. 9, whichever is nearer the zero axis, has been cross-hatched as well as all the positive area above the zero axis. The general rules for stability may be stated with reference to these curves, namely, that (1) the resistance component of the thermistor impedance can have any value positive or negative as long as the reactance component is inside the shaded area between the reactance curves (Fig. 8), and (2) the reactance component of the thermistor impedance can have any value as long as the resistance component is positive or no more negative than shown by the shaded area on the resistance plot (Fig. 9).

It follows that at the frequencies at which the two reactance curves cross, the resistance component must lie in the shaded area (Fig. 9). Assuming for illustration that a thermistor has a reactance characteristic A which begins at zero and crosses the boundary curve $-2Z_{oc}$, Fig. 8, at 6 kilocycles, the resistance curve must have a value at zero frequency numerically smaller than approximately -380 ohms, the direct current resistance value of the $-2Z_{sc}$ resistance curve, and it must pass into the shaded region (Fig. 9) at a lower frequency than 6 kilocycles. Hence it may have some such form as B. If the thermistor has such a reactance curve as C, its resistance characteristic could have (among other shapes) a form such as curve D, this in turn being the resultant of the curve (assumed) of the thermistor proper E and an equalizer curve introducing the necessary loss at direct current and diminishing loss at higher frequencies. The important relations to consider, therefore, are (1) the direct current resistance of the thermistor with respect to the direct current resistance component of $-2Z_{sc}$, and (2) the thermistor resistance at the frequency at which the thermistor reactance crosses from inside to outside the shaded area bounded by the reactance curves. As to (1) if the direct current resistance of the thermistor is numerically larger than the direct current resistance component of $-2Z_{sc}$, series resistance shunted by capacity (equalizer 13) can be used to reduce the direct current negative resistance to the desired value as illustrated by the curves D and E. As to (2), the thermistor resistance must become numerically less than the resistance component of $-2Z_{oc}$ at a lower frequency than that at which the thermistor reactance passes outside the shaded area between the reactance curves. At all frequencies between these two critical frequencies, the resistance of the thermistor can have theoretically any value and this permits a design to give a net circuit gain with uniform attenuation and velocity characteristics over a large part of the band without instability.

Fig. 10 is similar to Fig. 5 but is plotted on a logarithmic frequency scale and shows additional characteristics for comparison. Curves A and B are of the same general type as curves M and N of Fig. 5. They show characteristics obtainable with loading units each comprising either the thermistor 12 and network 13 of Fig. 1 or a pure negative resistance plus networks of the type shown in Fig. 11. In this latter figure, element 22 may be any suitable series negative resistance, such as those known in the art using vacuum tubes in suitable circuit connections. One such circuit is shown in R. C. Mathes Patent 2,236,690, April 1, 1941, arranged to introduce series negative resistance, network 23 may be similar to the networks 13 previously referred to, while network

24 may be of such type as to give the loading unit a cut-off effect by causing the negative resistance to diminish with increasing frequency and turn positive at some frequency above the upper edge of the band.

Curve C of Fig. 10 is similar to curve H of Fig. 5. Curve D represents the approximate minimum loss that can be obtained with pure negative resistance loading and still keep the line stable. Curve E is the characteristic for pure negative resistance loading where the negative resistance equals the direct current resistance of the line. Singing occurs for this particular case at about 13 kilocycles. (With the scale used in this figure it appears as though curve E coincided with the horizontal axis from 1 kilocycle to zero but as a matter of fact the curve does not actually reach zero until the frequency is reduced to zero.)

Instead of the series networks 13 of Fig. 1, shunt networks of the type shown at 13' in Fig. 12 may be used, if desired. These provide no shunting action at direct current and very little at frequencies close to zero but increasing shunting effect with increasing frequency. They, therefore, operate to increase the sharpness of the cut-off of the thermistor.

It was pointed out above that the resistance component of the loading impedance should be inside the shaded area of Fig. 9 at the cross-over points of the reactance curves of Fig. 8 (10.3 kilocycles, 25.3 kilocycles, etc.) if the line is to be stable. Fig. 13 shows a multisection network that may be used in series with the networks 13 of Fig. 1, that may be designed to have a loss characteristic as generally indicated in Fig. 14 with peak loss at 10.3 kilocycles, 25.3 kilocycles etc., such that the resistive component of the loading impedance will lie in the shaded area of Fig. 9 at these cross-over frequencies. This is accomplished by anti-resonating the successive sections 25, 26 at these cross-over frequencies so as to introduce maximum loss at those frequencies. The sharpness of the loss peaks may be controlled by the amount of resistance used in these network sections. The network may comprise more than the two sections indicated. Between these cross-over frequencies the network introduces only small loss (ideally zero loss) so as to permit efficient transmission over these intermediate bands.

What is claimed is:

1. A telephone line including periodically spaced loading units having negative resistance properties sufficient to give the line an over-all attenuation of substantially zero value throughout at least a substantial portion of the speech frequency band and including means rendering the line stable against self-oscillation, said last means comprising frequency-dependent impedance included in said loading units for causing the resistance of the units to change from negative to positive resistance, with increasing frequencies, at or near the upper edge of the speech band.

2. A telephone line including periodically spaced loading units having negative resistance properties sufficient to give the line an over-all negative attenuation throughout at least a substantial part of the speech frequency band and including means rendering the line stable against self-oscillation, said last means comprising frequency-dependent impedance included in said loading units for causing the resistance of the units to change from negative to positive resist-

ance, with increasing frequencies, at or near the upper edge of the speech band.

3. A telephone line according to claim 1 in which said loading units include frequency-dependent impedances for shaping the attenuation characteristic of the line to approximate a constant value over the speech band.

4. A telephone line according to claim 2 in which said loading units include frequency-dependent impedances for shaping the attenuation characteristic of the line to approximate a constant value over the speech band.

5. A telephone line including periodically spaced loading units having negative resistance properties sufficient to materially lower the overall line attenuation, said units each having a frequency-dependent impedance increasing with increasing frequency for maintaining said line stable against self-oscillation, said line having a velocity of propagation in excess of that of the line without said loading, over at least the lower portion of the speech band.

6. A telephone line according to claim 5 having a constant velocity of propagation throughout at least the speech band.

7. A signal wave transmission line including periodically spaced loading units, each introducing negative resistance into said line, and impedance networks connected in circuit with at least certain of said loading units and comprising parallel resistance and capacitive reactance in series in the line for increasing the stability of the line against self-oscillation.

8. A signal wave transmission line including periodically spaced negative resistance loading units for materially reducing the over-all attenuation, and networks connected in series in the line at intervals for preventing instability of the line at any frequency for which the phase shift per loading section is 180 degrees or multiple thereof.

9. A signal wave transmission line according to claim 8 and including networks at periodic intervals each comprising parallel resistance and capacity.

10. A signal wave transmission line having inserted in series therein at periodic intervals lumped impedances, each comprising in combination elements electrically equivalent to a negative resistance and in series therewith a network of three parallel branches, one branch consisting of resistance, another branch consisting of inductance and resistance in series and the third branch consisting of capacity and resistance in series, the value of said negative resistance being sufficient to materially lower the over-all attenuation of the line and the remaining components of the lumped impedance combination stabilizing the line against self-oscillation.

11. A signal wave transmission line including thermistors inserted therein at periodic intervals, direct current supply means for said thermistors to cause them to introduce a negative resistance effect into the line, and a network connected in parallel to each thermistor and consisting of capacity and resistance in series.

12. In combination, a transmission line for transmitting waves comprised in a band of frequencies, negative resistance devices inserted in said line at periodic intervals to cancel at least in part the positive resistance of the line, said devices having a negative resistance value decreasing with increasing frequency over said band and an equalizer connected to each of said devices to insert positive resistance in the line in progres-

sive amount over said band with decreasing frequency, said devices and equalizers providing a resultant line loss that is high at zero frequency and at frequencies above the band and low and substantially uniform throughout most of the band.

13. The combination with a transmission line for transmitting waves comprised in a band of frequencies of periodic loading units inserted in said line comprising elements having negative resistance dependent upon negative temperature coefficient of resistance, such elements capable of having their temperature instantaneously varied by the transmitted currents, bias means for said elements, and an equalizer connected in circuit with each such loading element, the attenuation frequency characteristic of the loading elements plus equalizers substantially complementing the attenuation frequency characteristic of the line throughout the transmitted frequency band, resulting in substantially flat transmission characteristic throughout the transmitted band.

14. In a transmission system for signals occupying a band of frequencies, a line, negative resistance devices inserted therein at uniform loading intervals, means to energize said negative resistance devices to enable them to introduce a negative resistance into said line numerically greater than the positive resistance of the line over a considerable portion of said frequency band, means imparting to said devices a resistance cut-off characteristic such that at some frequency above the band their resistance becomes positive, and impedance means in circuit with said devices for adding positive resistance at zero frequency.

15. In a signaling system, a line for transmitting said signals, thermistors inserted in said line at periodic intervals, energy supply means for said thermistors for enabling them to introduce negative resistance into said line, and networks comprising parallel resistance and capacity connected in series with said thermistors for increasing the stability of the line against self-oscillation.

16. In a signaling system for signals occupying a band of frequencies, a line for the transmission of said signals, thermistors inserted in said line at fractional wave-length intervals of the highest frequency of transmission, energy supply means for said thermistors to cause them to introduce negative resistance into the line of great enough magnitude to create a tendency to instability under operating conditions, and means to stabilize the system comprising means to introduce loss selectively at zero frequency and at and above the lowest frequency at which the thermistor reactance component approaches in value twice the reactance component of half a loading section as seen from the loading point when said half section is either open-circuited or short-circuited at its opposite end.

17. A signal wave transmission line including periodic negative resistance loading and including impedance means for making the net negative resistance numerically less than the resistance component of $2Z_{sc}$ at zero frequency and numerically less than the resistance component of $2Z_{oc}$ at any frequency at which the phase shift is 180 degrees per loading section.

18. A periodically loaded line having series loading units of impedance Z_c in which the reactive component of the quantity $2Z_{sc} + Z_c$ is opposite in sign to that of the quantity $2Z_{oc} + Z_c$ in the transmission band and in which the re-

sistive component of the quantity $2Z_{oc} + Z_c$ is negative over the range of frequencies transmitted, Z_{sc} and Z_{oc} being the impedances of the loading section when, respectively, short-circuited and open-circuited at its mid-point.

19. A multiband loaded line comprising periodically spaced negative resistance loading elements and, in series therewith, networks made up of tandem connected sections introducing damped anti-resonant impedance into the line at spaced frequencies at which the phase shift per loading section is a multiple of 180 degrees, said networks preventing instability at such frequencies and permitting the negative resistance loading to produce low attenuation over the intermediate frequency ranges.

20. A periodically loaded transmission line for the transmission of signals comprised in a band of frequencies, the loading elements therein introducing negative resistance into the line sufficient to provide an over-all zero attenuation over at least a part of said band and impedance means included in said elements for giving the line positive attenuation at all frequencies at

which an over-all zero attenuation would result in instability.

21. A periodically loaded transmission line for the transmission of signals comprised in a band of frequencies, the loading elements therein introducing negative resistance into the line sufficient to provide an over-all negative attenuation over at least a part of said band and impedance means included in said elements for giving the line positive attenuation at all frequencies at which an over-all negative attenuation would result in instability.

22. In a telephone line a plurality of high-speed thermistors connected in the line at loading intervals, said thermistors having negative temperature coefficient of resistance and being capable of temperature response at speech frequencies, means to supply bias current of the right magnitude to bias them into their negative resistance range, from a common source of bias current, and means to control the magnitude of the negative resistance comprising a variable resistance in series with said common source and said thermistors.

ROBERT K. BULLINGTON.