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P. G. EDWARDS

2,360,940

NEGATIVE RESISTANCE LOADING

Filed April 25, 1942

FIG. 1

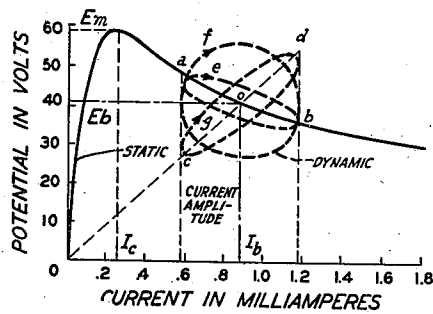


FIG. 2

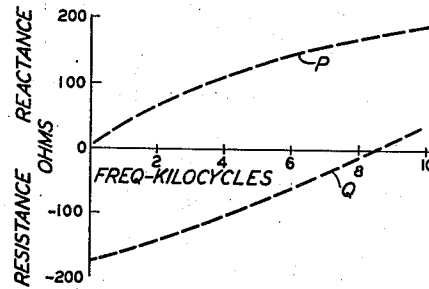


FIG. 4

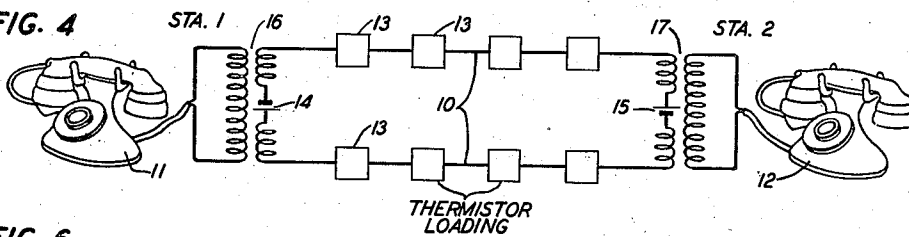


FIG. 6

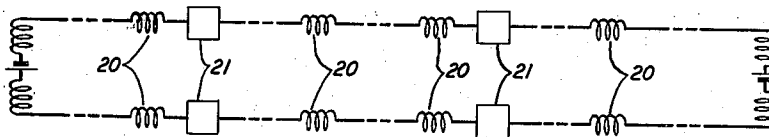


FIG. 7

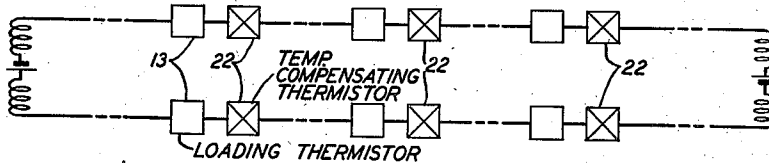


FIG. 5

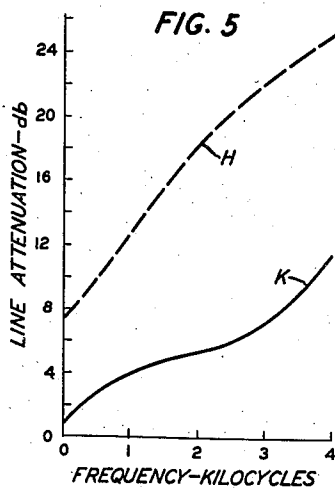
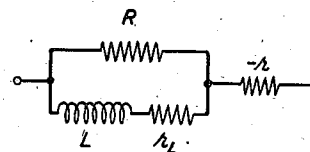


FIG. 3



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NEGATIVE RESISTANCE LOADING

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Application April 25, 1942, Serial No. 440,550

14 Claims. (Cl. 178—45)

The present invention relates to transmission of signal waves of a band of frequencies over a transmission line and more especially to a novel type of line loading that will facilitate such transmission.

It has heretofore been suggested to insert negative resistance elements in a line at intervals to offset the positive line resistance, and to supply energy to the negative resistances by sending current over the line. Such prior proposals have not proved practical because of the difficulty of maintaining stability of the system against self-oscillation and because of the difficulty of providing negative resistance devices having reliable characteristics and practical values of negative resistance at the frequencies concerned.

In accordance with the present invention a line is loaded with negative resistance elements capable of developing a practical value of negative resistance with a practical value of energizing line current and such elements possess an inherent impedance-frequency characteristic of such shape as to equalize to a considerable extent the line characteristic. A suitable device having these capabilities, for use in accordance with this invention, is an element having a high temperature coefficient of resistance and a temperature response rapid enough to follow the highest frequency in the transmitted wave band, associated with the line in such manner as to introduce a negative impedance effect therein. Devices making use of their temperature coefficient of resistance to give variable impedance are termed thermistors.

In accordance with the invention, thermistors are inserted at intervals in a transmission line to provide negative impedance loading.

The nature and objects of the invention will appear more fully from the following detailed description in connection with the drawing, in which:

Figs. 1 and 2 are graphs showing thermistor characteristics;

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

Fig. 4 is a simple schematic diagram of a telephone line with thermistor loading according to one form of the invention;

Fig. 5 shows transmission characteristics to be referred to;

Fig. 6 is a diagram showing the application of thermistor loading to a coil loaded line; and

Fig. 7 is a diagram showing thermistor loading of a line together with thermistors for com-

pensating for the effect of temperature variation of the line.

A thermistor, as already stated, is a resistance or impedance element or device which changes its resistance as a result of a change in its temperature. All thermistors have a frequency response characteristic to a greater or lesser degree. A thermistor in the form of a fine filament mounted to permit of rapid heat dissipation has a relatively high frequency of response because it can heat and cool quickly and therefore its resistance can vary quickly. A massive block of the resistance material has a slower dissipation rate and a lower response frequency, and if in addition to being itself massive it is heat insulated to different degrees, its sluggishness of response can be still further increased. When used as transmission elements for signaling, for example in speech transmission, the thermistors must be of very small mass and suitably mounted to permit their temperature to vary at the signaling or speech frequency in order that the resistance can vary at the signaling or speech frequency. It will be understood that the heating may result from the flow of the signal current through the thermistor element, the RI^2 loss causing the temperature to change with consequent change in resistance. The heating current in certain applications can be put through a heating coil separate from the thermistor element itself but mounted in heat transfer relation to the thermistor element. However, where the thermistor is to have a fairly high frequency response characteristic the heating current is put through the resistor whose temperature coefficient is being made use of to vary the resistance.

For purposes of securing negative resistance effects the thermistor may have a negative temperature coefficient of resistance and a suitable bias current applied to develop the negative resistance characteristic.

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. 1.

Dynamically, the alternating current resistance is negative in the region beyond the voltage maximum E_m for sufficiently low frequencies. Fig. 1

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 *aob* 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. The reactance and resistance curves *P* and *Q* for one type of thermistor are shown for illustration in Fig. 2. The resistance curve *Q* displayed a negative resistance at frequencies below about 8 kilocycles and positive resistance for higher frequencies. The reactance curve *P* will be recognized as inductive in nature.

This behavior may be translated, with a good degree of approximation, into the behavior of an electrical network of the type shown in Fig. 3, consisting of a positive resistance R , a negative resistance $-r$, an inductance L and a positive resistance r_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 assuming $|-r| > |r_L|$ since the relatively large resistance R is mostly shunted out by the branch L , r_L . 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 putting R directly in series with $-r$ and the device exhibits a positive resistance since $|R| > |-r|$.

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.

Referring to Fig. 4, the telephone line 10 interconnects station 1 with station 2 for two-way communication. At or connected to station 1 is a subscriber's set 11, and a similar set 12 is at or connected to station 2. Stations 1 and 2 may be exchanges in which the lines leading to sets 11 and 12 terminate on switchboards or switches. (The cord circuits or equivalents are not shown.) The thermistors are inserted in series in the line 10 at 13, 13, etc. spaced at regular intervals at about the frequency of ordinary loading coils, such as π loading units per wave-length of the highest frequency to be transmitted, or they may be more frequently spaced. It is desirable to include them in both sides of the line to provide symmetry. Bias current is supplied to the ther-

mistors from batteries 14, 15 connected at the middle of repeating coil windings 16, 17.

In Fig. 5 the curve H indicates the shape of line loss vs. frequency typical of a non-loaded telephone line of known type, such as a 19-gauge copper pair paper insulated, embodied in a lead-sheathed multipair cable. The loss increases with frequency over the speech frequency band, assumed to extend up to 3 or 4 kilocycles top frequency. Curve K shows the general shape of characteristic obtainable by thermistor-loading such a line in accordance with the foregoing description of Fig. 1, with thermistors of the type and construction referred to. It is seen that the loss is reduced and at the same time the transmission characteristic is flattened throughout the band (up to say 3 kilocycles). This indicates, of course, that the thermistor gain frequency characteristic provides equalization of the loss frequency characteristic over this band.

Stability against self-oscillation is obtained by not canceling all of the line resistance but leaving a residual positive resistance. The fact that thermistors lose their negative resistance property and become positive resistances at high frequency is of great advantage in preventing the development of self-sustained oscillations since they are usually most troublesome at high frequencies where the phase may become favorable. The gradual loss of gain with increase in frequency is an insurance against transients or other high frequency energy building up into sustained oscillations. Reference to the impedance network of Fig. 3 shows that the thermistors have a resistance cut-off effect which is an inherent property dependent upon the thermistor construction rather than on externally associated impedances. This sets the thermistors apart from prior art negative resistances, particularly for line loading purposes.

Thermistor loading can be applied to coil loading and the two loading effects are then superposed on each other. The thermistor loading units can be located at the same loading points as the coils or they may have a different location or different spacing. Specifically it may be desirable to provide a thermistor load at less frequent intervals than the coils. This is illustrated in Fig. 6 where the usual loading coils are shown at 20 and thermistor loading at 21. Supposing for illustration that the coil loading reduces the line loss at some frequency in the band from 1 decibel per mile to .35 decibel per mile, the thermistor loading may reduce the line loss from the value of .35 decibel to some value like .2 decibel per mile at such frequency. The inductance effect (time of response) of the thermistors in such a case can be less than if the thermistor loading alone were employed to give the total reduction in line loss indicated in the illustrative example. This means for one thing that the frequency of response of the thermistors can be made higher and the cut-off frequency is higher and may be above the cut-off frequency which the coil loading itself gives.

Since the negative resistance effect of a thermistor is determined by its temperature, as one factor, thermistor loading units are subject to ambient temperature variations. Variations in transmission characteristic of the line due to temperature variations in the copper conductors and in the thermistor load units can be compensated for by use of other thermistor units inserted into the line conductors at intervals.

Such units should have sluggish response characteristics to ambient temperature and should be sufficiently massive to remain substantially unaffected by the bias, signaling or other line currents. Such compensating thermistors are indicated in Fig. 7 at 22. They may be inserted at each loading point or at less frequent intervals but should occur at a rate of π units per wave-length at the highest signal frequency to avoid impedance irregularities in the line. These units may be in accordance with the disclosure in my prior application for patent Serial No. 410,149, filed September 9, 1941, except as their temperature resistance characteristic may need to be modified in order to compensate for the resultant variations of the line conductors plus thermistor loading units instead of the line conductors alone.

The invention is not to be construed as limited to the details disclosed, these being considered as illustrative, since its scope is defined in the claims which follow.

What is claimed is:

1. The combination with a transmission line for signal currents comprised in a band of frequencies, of a plurality of loading units inserted therein at intervals along its length for lowering the attenuation of said line for said currents, each such unit comprising an impedance element having a negative temperature coefficient of resistance, said element having a frequency of temperature response above the highest frequency to be transmitted over said line, and means to bias said elements sufficiently to cause them to present a negative resistance to signal currents transmitted over said line.

2. The combination with a transmission line having an attenuation increasing with frequency over a given transmission frequency band, of a plurality of loading units inserted therein at intervals along its length for reducing the attenuation of said line for waves in said band, each such unit comprising an impedance element having a negative temperature coefficient of resistance, the frequency-temperature response characteristic of which varies in inverse manner to the frequency-attenuation characteristic of the line over at least a significant portion of the range of frequencies transmitted over said line, and means to bias said elements sufficiently to cause them to introduce a negative resistance effect into said line to reduce the attenuation of the line, said negative resistance varying in magnitude with frequency in a manner to compensate in part the increase in line attenuation with frequency.

3. A loading unit for a transmission line for signals in a given frequency range comprising an impedance element having a negative temperature coefficient of resistance, and means to bias said element to cause it to introduce negative resistance in series with the line, said element having a temperature response at signal variations within said range, said response varying with frequency and becoming relatively insensitive at frequencies above the range to be transmitted.

4. The combination with a transmission line for the transmission of signal currents, of loading units inserted therein at intervals along its length, each such unit comprising an impedance element having a negative temperature coefficient of resistance and having a temperature sensitivity great enough to have its temperature and resist-

ance sensibly varied at signal frequencies by the flow of the signal currents through it, and means to bias said elements sufficiently to cause them to present a negative resistance to the signal currents transmitted over said line.

5. The combination recited in claim 4 in which said signals occupy a certain frequency band, and said line has unequal attenuation over the signal frequency band, each of said loading units having a temperature response time that is variable over the said band, causing the unit to develop a numerically decreasing negative resistance value with increase of frequency to provide inherent equalization of the line attenuation over said band.

6. The combination with a transmission line for the transmission of currents occupying a band of frequencies, of loading units inserted therein at intervals, each unit comprising an impedance element whose resistance varies in response to variation in its temperature, means to vary the temperature and, therefore, the resistance of said units at frequencies within said band by the transmitted currents, and means to bias said elements sufficiently to cause them to present a negative resistance to the transmitted currents, said elements each having a temperature frequency sensitivity which decreases rapidly above the band.

7. As a loading unit for a transmission line for transmitting currents occupying a band of frequencies, an impedance unit having, when suitably biased, a negative resistance in said band, and a positive resistance at all high frequencies beginning just above the band, said unit comprising an impedance having a negative temperature coefficient of resistance constructed to be temperature responsive to transmitted currents having frequencies in said band.

8. The combination with a transmission line for currents of a band of frequencies, of loading units inserted therein at periodic intervals, each comprising an impedance element having a negative temperature coefficient of resistance and a temperature-response frequency characteristic such that its resistance variations follow current variations at frequencies in the band but are unable to follow current variations at frequencies above the band, and means to bias said elements sufficiently to present a negative resistance at frequencies at which their resistance can follow the current variations.

9. A wave transmission line for the transmission of waves within a given frequency range including periodically spaced thermistors, said thermistors being temperature responsive at frequencies throughout the range of frequencies transmitted over said line to introduce a negative resistance effect into the line when energized by low frequency or zero frequency current, and means for supplying such energizing current to said thermistors.

10. A wave transmission line for the transmission of speech or other signal currents, including periodically spaced negative resistance elements, and means to energize said elements to cause them to introduce in the line negative resistance at the speech or signal frequencies, said elements possessing a resistance-frequency characteristic such that their negative resistance becomes numerically smaller with increasing frequency and changes to positive resistance at a frequency slightly above the highest signal frequency transmitted.

11. A telephone line having a higher velocity of transmission at speech frequencies than a coil-loaded line, said line having negative resistance periodic loading for introducing negative resistance in the line at speech frequencies, said negative resistance loading having a frequency-resistance characteristic such that the negative resistance decreases in magnitude with increasing frequency and changes to positive resistance at a frequency above the transmitted band.

12. A telephone line including high-speed thermistors in series in the line conductors, means to energize said thermistors to cause them to introduce negative resistance into said line in the speech frequency range, and sluggish thermistors inserted at intervals in said line unresponsive to the speech currents traversing the line but responsive to ambient temperature variations to compensate for the resistance variations of the line conductors with changes of temperature.

13. A telephone line including in series therein at loading intervals high-speed thermistors having a temperature-frequency response range covering essential speech frequencies, and means to energize said thermistors to condition them for developing negative resistance effects at speech frequencies.

14. A telephone line including in series therein at loading intervals high-speed thermistors having a temperature-frequency response characteristic covering essential speech frequencies, and means to supply said thermistors with energizing current to condition them to introduce negative resistance effects at speech frequencies, the response frequency characteristic sloping over the voice range in such manner as to compensate in part for the attenuation characteristic of said line.

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