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2,373,624

NEGATIVE RESISTANCE LOADING

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FIG. 1

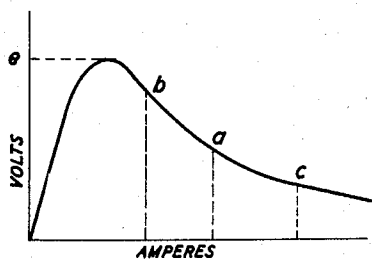


FIG. 2

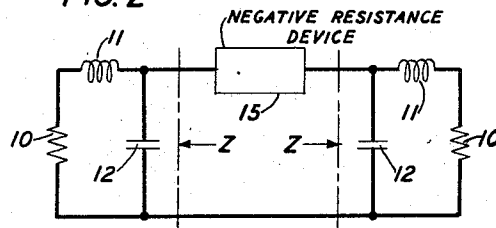


FIG. 3

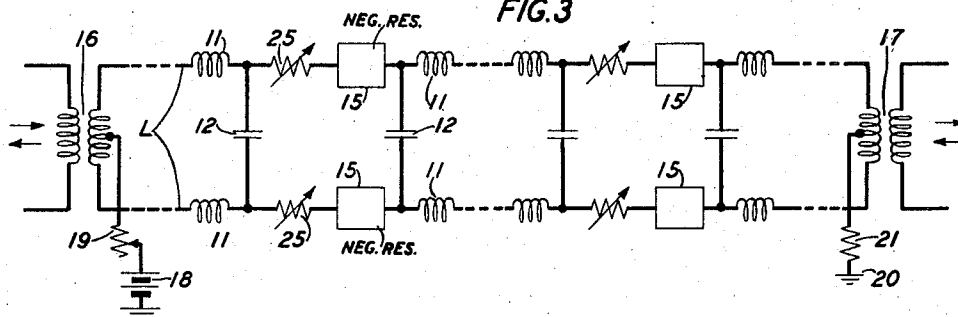


FIG. 4

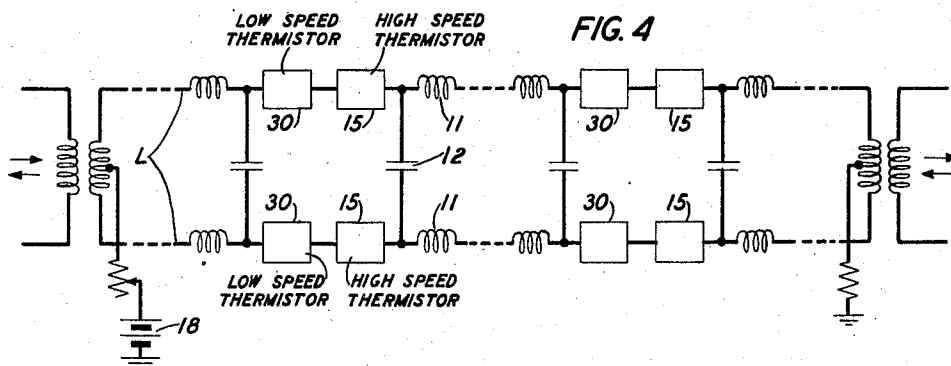
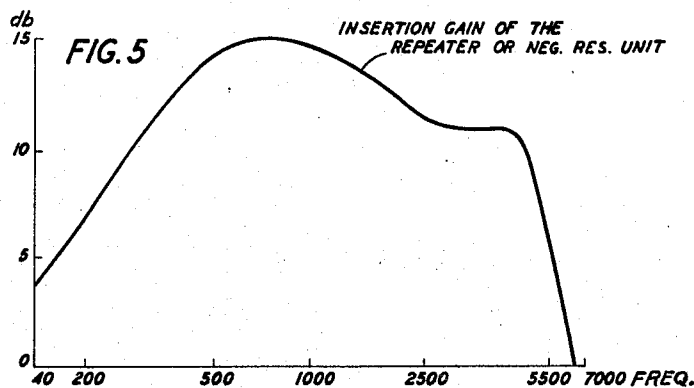


FIG. 5



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NEGATIVE RESISTANCE LOADING

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6 Claims. (Cl. 178-44)

The present invention relates to the use of negative resistances in telephone lines or other types of transmission lines for reducing the line attenuation in the frequency range employed for the transmission of the voice or other signal currents. One type of use would be in negative resistance repeaters, for example.

In a practically useful system employing negative resistances in lines, it is necessary to provide the proper amount of insertion gain, with a requisite gain-frequency characteristic. The circuit must also have stability or freedom from self-oscillation, commonly called singing. One difficulty in guarding against singing arises in turning the system on. If the energizing current is applied without enough series positive resistance in the circuit, the system will develop singing and the negative resistances may, moreover, be damaged by initial current surges.

An object of the present invention is to secure improved transmission by means of negative resistance devices.

A further object is to maintain stability in a negative resistance circuit or system under different operating conditions and specifically during starting.

The manner in which these objects are attained in practice will be fully set forth hereinafter. One feature, however, concerned with maintaining stability when starting the system into operation comprises the use of automatically variable series resistances which may take the form of thermistors heated by the energizing current for the negative resistance elements or repeaters and having a negative temperature coefficient of resistance so that their resistance is initially high but falls to a low value as the thermistors warm up to operating temperature.

The objects and features of the invention will now be more fully described with the aid of the attached drawing, in which:

Fig. 1 shows a volt-ampere characteristic of the general type suitable for the negative resistance repeater elements;

Fig. 2 shows in schematic form a negative resistance repeater element with terminating impedances;

Figs. 3 and 4 are schematic diagrams of a repeatered line in accordance with the invention; and

Fig. 5 is a curve showing the insertion gain of a negative resistance repeater according to this invention.

The curve given in Fig. 1 is the curve of a negative resistance device of the series type suitable

for use as a repeater element. As voltage is applied to the device beginning at zero and building up, the current increases slowly at first indicating high positive resistance. When the voltage has reached the value e the characteristic turns over and begins to slope in the negative direction. If the voltage is supplied from a battery through a large series resistance, it is found that the voltage drop across the negative resistance device becomes smaller as the current becomes larger over the range b, a, c . If the energizing current is held at a and an alternating voltage is applied between peak limits b and c , it is found that the current varies inversely as the applied voltage and for this reason the device is said to exhibit a negative resistance characteristic. Such a device offers negative resistance to the alternating component of the current although the resistance for direct current is, of course, always positive since voltage in the direction of the current is required to produce direct current flow through the device.

Many substances and devices may be made to exhibit a characteristic of the type shown in Fig. 1 including vacuum tube circuits of various types, certain crystals or contact resistances, and thermistors. While the invention contemplates the use of any suitable type of negative resistance device, the disclosure will, for illustrative purposes, assume that the type to be used is a thermistor. Thermistors are known which are capable of following temperature variations as rapid as several thousand cycles per second. They have the advantage of compactness, cheapness and ability of being made with any of a wide variety of characteristics and normal resistance value to suit all sorts of circuit requirements. One type of such device is disclosed in Patent 2,276,864 of G. L. Pearson, patented March 17, 1942. The use of such devices for negative resistance loading is disclosed and claimed in United States applications of P. G. Edwards Serial No. 440,550 and R. K. Bullington Serial No. 440,549, both filed April 25, 1942, which have now matured into patents, 2,360,932 and 2,360,940, respectively, both granted October 24, 1944.

Thermistors do not exhibit pure negative resistance but because of thermal lag their impedance has an inductive component which varies widely with the thermal properties of the device. By changing the physical dimensions and configuration to promote or retard heat dissipation and vary the thermal capacity, the reactive component of impedance can be varied over an enormous range. Expressed in the frequency to which

the device is thermally responsive, this may vary from a period of seconds or longer to a frequency of many kilocycles per second.

To obtain a flat gain with a thermistor over a given frequency band it is necessary to provide terminal impedances that are approximately the negative of the thermistor impedance over such band. To slope the gain, equalizers can be used. It is found that with the type of terminating impedance shown in Fig. 2 at Z, Z where the resistances 10, inductances 11 and capacities 12 are variable, practically any thermistor (15) could be matched closely. The energizing supply is not shown in this figure but could be a battery and series resistance.

In Fig. 3, the line L is provided at periodic intervals with repeaters of the type shown in Fig. 2. The negative resistance devices 15 may be of any suitable type but are assumed to be thermistors. The impedance elements 11 and 12 may be determined as to value by a circuit like that of Fig. 2 using variable elements. The resistance 10 is in this case provided by the line conductors.

Line L may be an open wire telephone line, for illustration. Typical constants for such a line per loop mile are:

$$\begin{aligned} R &= 10.4 \text{ ohms} \\ L &= 0.004 \text{ henry} \\ C &= 0.0078 \text{ microfarad} \\ G &= 0.8 \text{ micromhos} \\ \alpha &= 0.64 \text{ decibel} \end{aligned}$$

The characteristic impedance Z_0 would be 756 ohms. The negative resistance devices 15 could be spaced 20 miles apart, each pair of thermistors at one point (considered as a repeater) could have an insertion gain of the type shown in Fig. 5, having a value of about 13 decibels average over the speech band or from slightly in excess of 200 cycles to up to about 4 kilocycles.

The repeating coils at 16 and 17 could couple similar lengths of line L or could lead to terminal connections at telephone exchanges. Energizing current is supplied over the two sides of the line L in parallel from battery 18 through regulating resistance 19 to ground at 20. Assuming ten such repeating points in one battery span, the battery stations could be every 200 miles with not more than 160 volts applied between the line and ground when the thermistors are in their operating condition. During the starting condition when the drop across each thermistor must correspond to at least as high a value as represented at e in Fig. 1, the voltage between the line wires and ground must be higher. In the illustrative example given, the battery 18 might have a voltage of 600 and resistance 19 might have a maximum value of 500,000 ohms, while resistance 21 may have some small value such as 100 ohms. It is to be noted that the four inductances 11, 11 in any one repeater unit would in practice comprise a single coil with four windings on the same core.

A feature of the present invention comprises the use of protective resistances at 25, 25 for preventing injury to the thermistors and avoiding singing when the thermistors are cold and the energizing current is turned on. These resistors are illustrated in Fig. 3 as simply variable resistances associated with each thermistor to indicate that they may be of any suitable type having initially a high value of resistance which after a suitable time interval reduces to a low operating value. A form of variable resistance in accordance with this invention is a slow speed

thermistor and this is specifically shown in Fig. 4, this figure being in all other respects the same as Fig. 3.

The slow speed thermistors are shown at 30, 30. These slow speed thermistors may be of similar material to the negative resistance thermistors 15 or of other type but are sufficiently massive not to have their temperature changed at speech frequencies by the passage through them of speech currents. They, therefore, introduce only a positive resistance to speech currents of the same value as their direct current resistance. They are heated by the battery current and when cold their resistance may be, for example, 1,000 ohms apiece, while after their operating temperature has been reached the resistance may be only the order of 50 ohms. In one form these slow speed thermistors may comprise beads or small lumps of oxides of nickel manganese and cobalt or other suitable materials.

Assuming the direct current voltage drop through each thermistor under operating conditions to be 15 volts, and the energizing current .015 ampere, the drop in the two sides of the line in parallel at one repeater point is 15 volts so that the operating voltage for ten repeater sections or 200 miles is 150 volts (plus the drop in the line which amounts to only 8 volts).

Assuming for illustration that both the negative resistance thermistors and the protective thermistors have the same type of steady-state volt-ampere characteristic and that this is the type given in Fig. 1, on the initial application of the energizing current from battery 18 the high speed thermistors will almost instantaneously heat up to operating temperature, while the slow speed thermistors will heat up slowly and maintain a series resistance of the order of 1,000 ohms adjacent each negative resistance repeater device during the starting interval, this value falling in a few seconds or less to a small value such as 50 ohms. The total effect of these protective resistances adds to the other series resistance to give the requisite amount of series starting resistance. In the operating condition each negative resistance thermistor may have a negative resistance equal to -350 ohms or thereabouts.

The circuit must be kept stable not only while starting but at all other times. The transmission characteristic for free oscillations around any path through one or several negative resistance devices must be such that any voltage traversing such path returns to the place of beginning in such magnitude and phase as not to reinforce itself to give a larger resultant than the initial voltage. This same statement can also be put in another form. In general, the free oscillations in any linear system are of the form

$$I = Ae^{pt}$$

where p is, in general, a complex number having as components a real part, which is the damping factor, and an imaginary part, which is 2π times the frequency. For stability, the real parts of all the values of p must be negative. Explicit design criteria are given in the Bullington application referred to and this may be consulted for further disclosure.

The invention is not restricted to use on open wire lines nor limited to or by the specific instances or values or materials that have been given, since these are by way of illustrative examples. The scope of the invention is defined in the claims which follow.

What is claimed is:

1. A signal transmission line including periodically spaced negative resistance elements and means to energize said elements by current sent over the line in combination with periodically spaced means for introducing high series positive starting resistance and less high series positive operating resistance, said means each comprising a negative resistance device energized by the energizing current for said elements but having a response frequency confined to frequencies below the frequency range employed for signaling.

2. In a signal transmission line, periodically spaced negative resistance devices inserted in said line for lowering the attenuation of said line for said signals, means to energize said devices by current sent over the line conductors, and in series with said devices stabilizing resistance elements each having its resistance value lowered by the line current traversing it and having too long a response time to change its resistance value in response to said signals.

3. In a signal transmission line, periodically spaced negative resistance repeaters each comprising a negative resistance in each side of the line, a stabilizing resistance in each side of the line, an inductance in each side of the line at each side of said devices and a condenser bridged across the line on each side of said devices, and means to supply energizing current to said devices through the respective stabilizing resistances.

4. A repeater unit for a signal transmission line comprising a four-terminal network having in each side a thermistor whose temperature response frequency includes said signal frequency, said thermistor when suitably energized adapted to develop series negative resistance at the signal frequency, a building-out inductance on each side

of each thermistor in series with the respective thermistor, and a building-out capacity in bridge of said network on each side of said thermistors, said building-out inductances and capacities being proportioned in relation to said thermistors to provide impedance matching of said network to said transmission line.

5. In a signal transmission line, thermistors inserted in said line at periodic intervals each having a negative temperature coefficient of resistance and a temperature response frequency range including signaling frequencies, means to supply energizing current to said thermistors to bias them into the negative resistance operating region of their characteristics, and a stabilizing thermistor in series with each of said first-mentioned thermistors, said stabilizing thermistors having a negative temperature coefficient of resistance and proportioned to be heated by said energizing current to cause them when so heated to develop lower series resistance than when said energizing current is not flowing through them, said latter thermistors having too great a thermal lag to respond to signaling frequency current fluctuations.

6. In a transmission line for signaling currents of a certain frequency range, periodically spaced thermistors responsive to signaling frequency variations for introducing negative resistance in said line for the signals, means to send energizing current to said thermistors over said line, and stabilizing thermistors in series with said first thermistors and having volt-ampere characteristics similar to the volt-ampere characteristics of said first thermistors, said stabilizing thermistors having a response frequency range confined to frequencies below said signaling frequencies.

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