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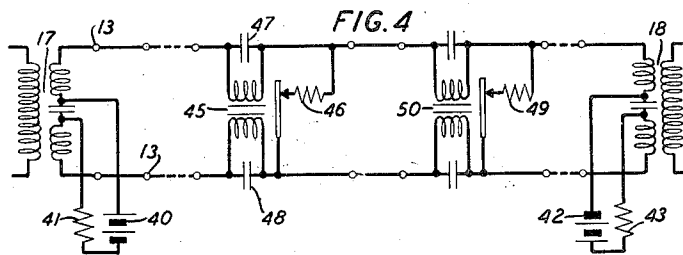
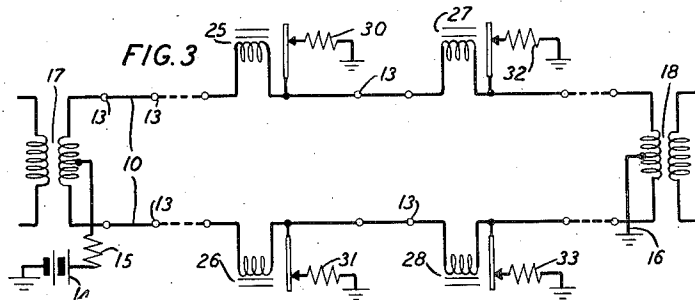
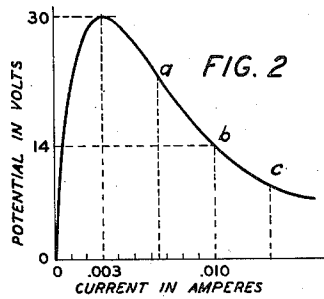
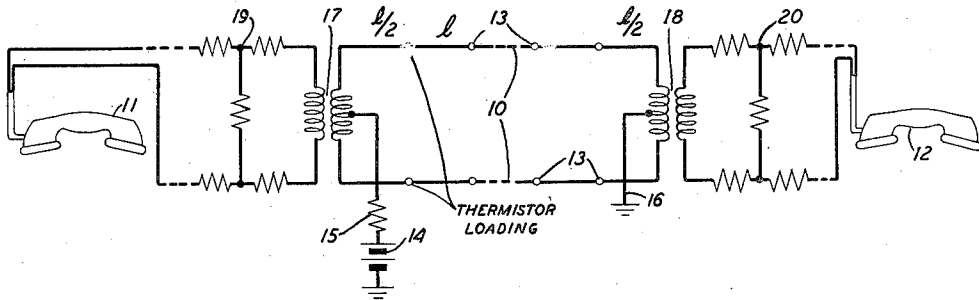
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2,361,160

LINE WITH NEGATIVE RESISTANCE LOADING

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FIG. 1



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LINE WITH NEGATIVE RESISTANCE
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5 Claims. (Cl. 178-45)

The present invention relates to the supply of power over a line to negative resistance devices associated with the line.

Negative resistances have been proposed for loading transmission lines to reduce the line attenuation for signal or other waves transmitted over the line. The negative resistance units operate over a drooping portion of their volt-ampere characteristic and it is necessary to supply them with energizing or bias current to bring them into the portion of the characteristic that has negative slope to enable them to develop a negative resistance. It is generally desirable to supply this bias current from a terminal point over the line conductor or conductors to a number of the loading units along the line.

In installations of this type a difficulty arises in starting the system into operation in that initially a relatively high voltage must be applied to the line to bring the negative resistance devices into the region of their characteristic that has a downward slope, after which the applied voltage must be reduced to hold the devices at the proper operating point on their characteristic and, as well, to avoid danger of harmful effects to the devices resulting from excessive current flow through them.

An object of this invention is to provide means for automatically insuring application to such a system of the proper starting voltage for initially bringing the devices into their intended operating range and for thereafter reducing the applied voltage to the proper operating value.

The nature of the invention and its various features and objects will be more readily apparent from the following detailed description of illustrative embodiments thereof, shown in the accompanying drawing.

Referring to the drawing:

Fig. 1 is a diagrammatic showing of a telephone line with negative resistance loading using thermistors as the negative resistance devices and embodying the invention in one form;

Fig. 2 is a diagram showing the volt-ampere characteristic of one of the loading devices of Fig. 1; and

Figs. 3 and 4 show other forms of embodiment of the invention in transmission circuits schematically shown.

Referring first to Fig. 1, the line 10 is shown connected (through the medium of exchanges with suitable switches, not shown) for two-way transmission between subscriber stations 11 and 12. The line is provided with negative resistance loading, the negative resistance loading units

being shown spaced along the line conductors at 13, 13, etc. with a spacing 7. Energizing current for the negative resistance loading units is supplied over the line conductors from a source 14 in series with an ohmic resistance 15 with a ground return from 16 at the opposite end of the line. Repeating coils are shown at 17 and 18 at opposite ends of the line, with terminal loss pads 19 and 20. The negative resistance devices may comprise vacuum tube circuits of suitable type for developing series type negative resistance or any other suitable types of devices capable of developing requisite negative resistance effects in the line, one specific type of device being a thermistor, such loading being more fully disclosed in an application of R. K. Bullington, Serial No. 440,549, filed April 25, 1942, to which reference is made for further detailed disclosure. The pads 19 and 20 are used to provide a suitable over-all loss which may be desirable for crosstalk suppression or other transmission control and their use also aids in preventing terminations using different types of subscribers' lines from causing the circuit to sing. The loaded line 10 may have a zero loss, negative loss or small loss per mile following the teachings of the Bullington disclosure.

Negative resistance devices have a volt-ampere characteristic of the general form given in Fig. 2, the curve as plotted in this figure being a typical characteristic of a thermistor such as would be suitable for the loading of telephone lines. As voltage increasing from zero is applied across such a thermistor (through a series resistance) the thermistor resistance is first positive and high so that very little current flows. When the applied voltage reaches 30 volts the current is 3 milliamperes. The characteristic bends over at about 30 volts, the slope becoming negative with increasing current, with consequent decrease in voltage drop as the current increases. At the 10-milliamperere point (b) the voltage drop has fallen to 14 volts. Since this point lies about midway of a considerable range of nearly constant slope between a and c, the point b is a suitable operating point and the bias voltage for operation about this point is, therefore, 14 volts. For purposes of illustration it will be assumed that each of the negative resistance devices 13 in the line 10 has a characteristic like that of Fig. 2, although it will be understood that widely different values might apply to different cases in practice. For further purposes of illustration, let it be assumed that the line in Fig. 1 comprises ten negative resistance loads in each conductor

with ten loading sections each having a line conductor resistance of 400 ohms, giving a total resistance of 4,000 ohms for each line conductor. The sum of the voltages at the loads required to start the ten thermistors is 10×30 or 300 volts while the voltage required to bias them to their working point is 10×14 or 140 volts. It is desirable with the type of regulation disclosed in Fig. 1 to make the voltage of battery 14 and resistance value of 15 such as to fulfill these two conditions. Calling R the value of resistance 15, and noting that the line current is .003 ampere when the starting voltage is 30 volts per load and is .010 ampere for the working condition, the voltage supplied by the battery in both conditions is

$$E = .003 R + .003 (4000) + 10 \times 30 \\ = .01 R + .01 (4000) + 10 \times 140$$

Solving for R,

$$R = 18,857 \text{ ohms}$$

Hence

$$E = 368.57 \text{ volts}$$

That is, a battery voltage at 14 of this voltage and a resistance at 15 of this resistance will just allow the required 30 volts per load to be developed for starting and will limit the steady current to .010 ampere and the steady voltage to 14 volts per load. For reliability of operation somewhat larger values of both E and R may be desirable, such that as the current increases, the drop through R increases somewhat faster than the rate of fall of potential in the negative resistance devices. For example, if the battery voltage is 380 and resistance R has a value of 20,000 ohms, the voltage put across each load at a current of .003 ampere is 30.8 volts while at .010 ampere it is 14 volts. In the working condition there is a voltage drop in R of 200 and a drop of 40 volts in the line resistance leaving $380 - 240 = 140$ volts to be applied to the loads. The foregoing calculation shows that if the line resistance were greater than the assumed value, R could be correspondingly smaller. In fact, the resistance 15 could be entirely absorbed in the line by using a sufficiently high line resistance.

Stability is another consideration in choosing the size of resistance R. A small increase in battery voltage tends to increase the line current and the increase in current through the positive resistances of the system produces a drop of potential in a direction to absorb the increase in battery voltage; but the effect of the assumed increase in current in the negative resistance devices is to give back a voltage rather than absorb voltage so that if the total amount given back in this way is greater than the amount absorbed, the net effect of the initial assumed increase in battery voltage is a further increase in the same direction. This is indicative of an unstable condition. It can be prevented by increasing the value of the positive resistance in the circuit. As an example, assuming the same circuit constants as given above, suppose that an increase of current from .010 to .011 ampere results in a decrease of terminal voltage across each thermistor of .5 volt. Then the decrease for ten thermistors is 5 volts. In order to provide an increase in voltage drop of 5 volts resulting from an increase in current amounting to .001 ampere, R must have such value that

$$.001 (R + 4000) = 5$$

or $R = 1000$ ohms. So long as R is in excess of 1,000 ohms, therefore, the system will be stable

as regards fluctuations in the power supply. Obviously, in this case if R has a value such as suggested previously for supplying the proper starting and bias voltages to the thermistors, the stability requirement is also met since the value of R is greatly in excess of the 1,000 ohms found from the assumed conditions.

Fig. 3 shows a type of loaded line circuit which permits the use of a lower voltage battery than in the case of the Fig. 1 type and which consumes less power. The system of Fig. 3 differs from the system of Fig. 1 in having relays 25, 26, 27, 28, etc. connected in circuit at suitable points along the line and in having resistors 30, 31, 32, 33, etc. connected to the line wires under control of these relays in a manner and for a purpose to be disclosed.

Assuming the same circuit constants for the line and loads as before, there would be a variety of possible values for the battery voltage and sizes of the resistances 15, and 30 to 33, but it is thought that the principle involved can best be illustrated by arbitrarily assuming a set of values and noting their effect. Suppose, therefore, that the voltage of battery 14 be taken as 250 volts and the values of resistances 15, 30 and 32 be taken at 3,500 ohms, 20,000 ohms and 10,000 ohms, respectively, resistance of 31 being equal to that of 30, and resistance of 33 being equal to that of 32. Confining attention at first to the left-hand portion of the circuit from the battery up to the point at which the first pair of resistors 30, 31 is located, in the starting condition in which the current must reach at least the value .003 ampere before the resistance of the thermistors begins to decrease, the drop of potential in 15 is $2 \times .003 \times 3,500 = 21$ volts, leaving an applied line voltage of $250 - 21 = 229$ volts. It will be assumed that the resistances 30 and 31 are located half way between the fifth and sixth thermistors counting from the left along the line. If the total resistance of either side of the line beyond resistances 30 (or 31) is 20,000 ohms, this in parallel with 30 (or 31) gives a resultant of 10,000 ohms through which the initial .003 ampere must flow for the starting condition. This requires 30 volts, so that the battery voltage available for the first five line sections is $229 - 30 = 199$ volts of which 6 volts are used in line drop ($5 \times 400 \times .003 = 6$ volts), leaving 193 volts as the starting voltage for the first five thermistors in each side of the line. Since this gives 38.6 volts per thermistor, this is ample under the assumption of 30 volts required starting voltage per thermistor.

The current will increase once the starting conditions have been met and a stable point will be reached at some value of current which for illustration will be taken as .008 ampere. The drop of potential across each thermistor for this value of current will be assumed to be 19.6 volts. The full battery voltage of 250 volts is, therefore, accounted for by the summation of:

.008 $\times$ 2 $\times$ 3,500 drop through R
+ .008 $\times$ 5 $\times$ 400 drop through five sections of line
+ .008 $\times$ 10,000 drop through total resistance to right of point of connection of 30, 31
+ 19.6 $\times$ 5 drop across five thermistors giving a total of 250 volts. In this way the first five sections are brought into operating condition with the application of no higher voltage than the assumed 250 volts.

Thermistors 6 and 7 are brought into operating condition by the drop existing across 30 (or

31) when the line current has reached the assumed value of .008 ampere as assumed. Resistors 32, 33, as stated, each has a value of 10,000 ohms and if the total resistance between the point of connection of each to the line and the ground at 16 is 10,000 ohms, the resistance of the parallel combination is 5,000 ohms, each side. Suppose that of the .0008 ampere flowing over the first five sections of line, at least as much as .005 is flowing through either resistor 30 or 31. The other .003 ampere will then take the path through line sections 6 and 7. The line drop of $400 \times .003 = 1.2$ volts per section will consume 2.4 volts and the assumed 5,000 ohms total, to the right of the point of connection of 32 or 33, will consume $.003 \times 5,000 = 15$ volts making a total resistance drop of 17.4 volts which, subtracted from the assumed available applied 100 volts from across resistor 30 or 31, leaves 82.6 volts or 41.3 volts per thermistor for starting thermistors 7 and 8. This is well above the required 30 volts per thermistor. Thermistors 6 and 7 will, therefore, be started.

Relays 25, 26 will each operate to attract its armature in response to a line current of about .008 ampere so that resistors 30 and 31 are removed from circuit when that value of line current is reached. The circuit for the first seven sections will now stabilize at, say, .0085 ampere and 17.74 volt drop across each thermistor. $[.0085 (2 \times 3,500 + 7 \times 400 + 5,000) + 7 \times 17.74 = 250 \text{ volts}]$ This current divides between resistor 32 or 33 and the total circuit resistance beyond that point. If .003 flows through the latter branch, the drop across 32 (or 33) will be about 55 volts which is sufficient to start thermistor 9. Relays 27 and 28 operate on a line current of about .008 ampere and remove resistors 32 and 33 from circuit. In similar manner to that described thermistor sections 9 and 10 are started, two further pairs of relays being required following relays 27 and 28 in order to allow sections 9 and 10 to be started and the last of the starting shunts to be removed. This example shows, therefore, how a ten-section line can be started with an available voltage of less than ten times the starting voltage of one thermistor.

Fig. 4 shows a similar starting circuit applied to a circuit comprising the two line conductors in series. Battery sections 40, 42 are connected at opposite ends of the line and are poled to be series aiding. They are connected through stabilizing resistances 41, 43 which as in the previous cases could be absorbed in the line as conductor resistance if desired. This voltage is applied across condensers inserted in the middle of the repeater coils 17, 18. In this case a single shunt 46 can be used at the first shunting point, connected across the line and arranged to be opened when the line circuit through the winding of relay 45 reaches sufficient strength. The talking currents are by-passed around the relay windings by condensers 47, 48. Other shunting points may be provided as necessary, one other shunting relay 50 being indicated, controlling shunt resistor 49. The operation of this circuit is similar in general to that described of Fig. 3.

The invention is not to be construed as limited to the specific circuit details or quantitative values that have been given since these are for purposes of illustration in order to provide a clearer understanding of how the invention may be applied to particular cases. The scope of the invention is defined in the claims.

What is claimed is:

1. In a transmission system, a line, negative resistance loading units connected at intervals along said line, said units each requiring a value of operating direct current bias voltage that is low relative to the starting voltage required to bring them into the negative resistance region of their characteristic, a source of direct current bias voltage at a point on said line for supplying bias current over said line to all of said units and means to apply to said line initially a sufficient large proportion of the voltage of said source to initiate the negative resistance condition in said units, said means being effective in response to the bias current flow on said line after the negative resistance condition in said units has been initiated to reduce the voltage applied to the line from said source to the magnitude required to provide each unit with said value of operating bias voltage.

2. In a transmission system, a line, negative resistance loading units connected at intervals along said line, said units requiring a value of operating direct current bias voltage that is low relative to the starting voltage required to bring them into the negative resistance region of their characteristic, a source of direct current bias voltage at a point on said line for supplying bias current over said line to said units, one or more shunt resistances initially connected to one or more points in said line between certain of said units remote from said source to provide relatively low return resistance for the bias current whereby a greater bias voltage is applied across certain of said units than across others for starting purposes, and means for removing said shunt resistances in response to current flow of given strength over said line.

3. In a transmission system, a line, negative resistance loading units inserted therein at periodic intervals, a source of bias current common to a plurality of said units, a path over said line in series with said units and said source for the flow of said bias current, a shunting resistance initially closed across said path at a point between certain of said units to permit application initially of a large enough voltage to the units included between said source and said shunting point to bring the latter units into their negative resistance condition whereby an increased bias current flows through them, and means operating in response to said increased current flow to remove said shunting resistance from across said path.

4. In combination, in a signaling system, a transmission line, thermistors included therein at periodic intervals, a source of bias current for biasing all of said thermistors to the negative resistance region of their volt-ampere characteristic whereby said thermistors introduce negative attenuation into said line for signal currents traversing said line, a path for said bias current extending from said source over said line and through said thermistors in series, shunt resistors initially connected across said path at spaced points along said line between different thermistors whereby initially the thermistors nearest said source receive the greatest bias voltage, the bias voltage so received being sufficient to bring the latter thermistors into their negative resistance condition thereby increasing the flow of bias current through the first shunt resistance sufficiently to bring a thermistor located beyond

said first shunt resistor into its negative resistance condition, and means to remove each of said shunt resistors in succession in response to increased bias current flow over the preceding line section.

5. In a thermistor loaded telephone line having thermistors inserted in the line at loading intervals to introduce negative resistance in the line for speech currents, the method of biasing all of said thermistors into their negative resistance region without having to provide excessively high biasing voltage in the bias current source, comprising initially shunting the bias current path over the line at one or more spaced points along the line to permit the ther-

mistors located in a section of line nearest the bias current source to receive high enough voltage to bias them into their negative resistance region resulting in an increased flow of bias current, using said increased flow of bias current to apply high enough voltage in the next succeeding line section to bias the thermistors located therein to their negative resistance condition, and removing one at a time said one or more shunting paths from the bias current path until all thermistors have been brought into their negative resistance condition and all initial shunting paths have been removed.

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