

Aug. 17, 1943.

L. G. ABRAHAM ET AL

2,326,742

ELECTRIC WAVE SYSTEM

Filed Sept. 9, 1941

4 Sheets-Sheet 1

FIG. 1

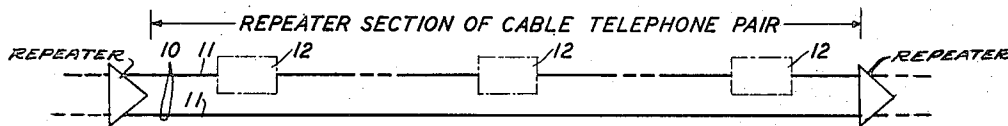


FIG. 2

SUBSTANCE HAVING NEGATIVE
TEMPERATURE COEFFICIENT
OF RESISTANCE

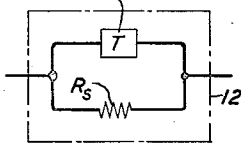


FIG. 3

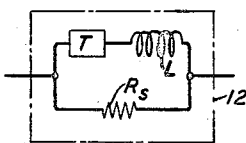


FIG. 4

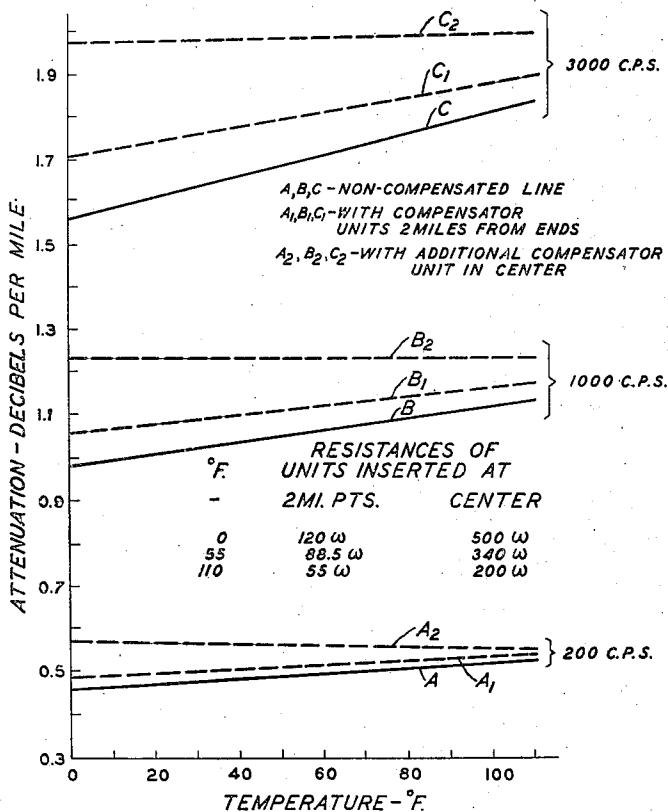
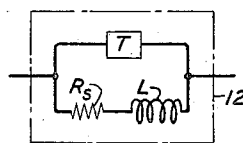


FIG. 5

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FIG. 6

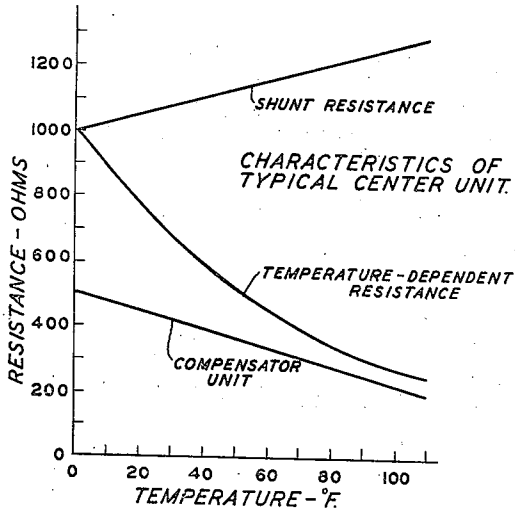


FIG. 7

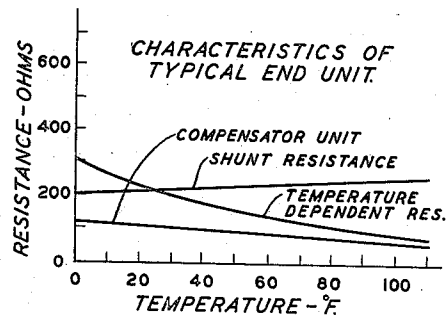
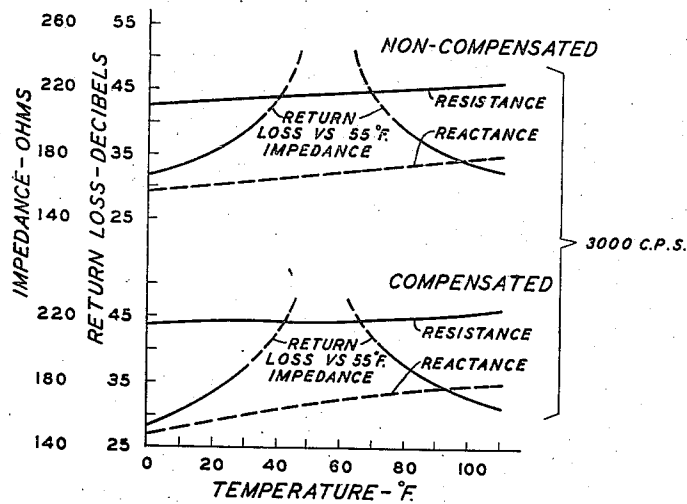


FIG. 8



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FIG. 9

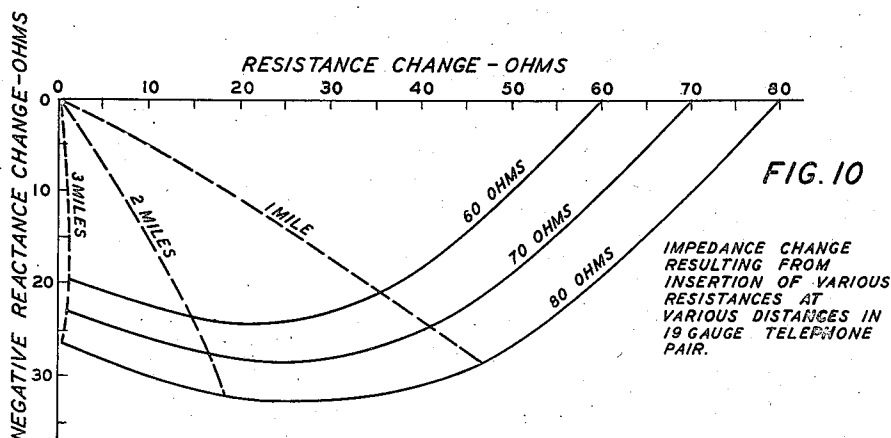
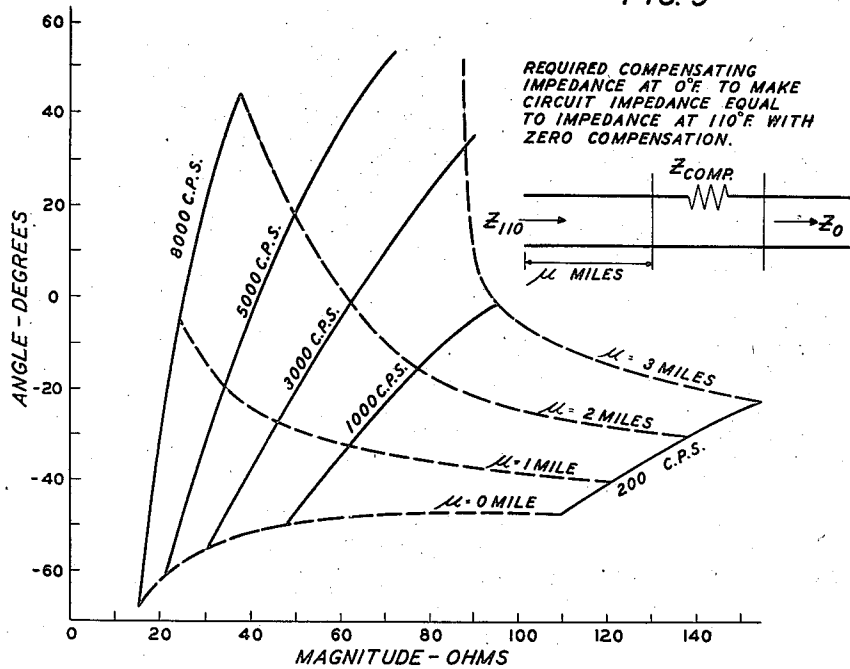


FIG. 10

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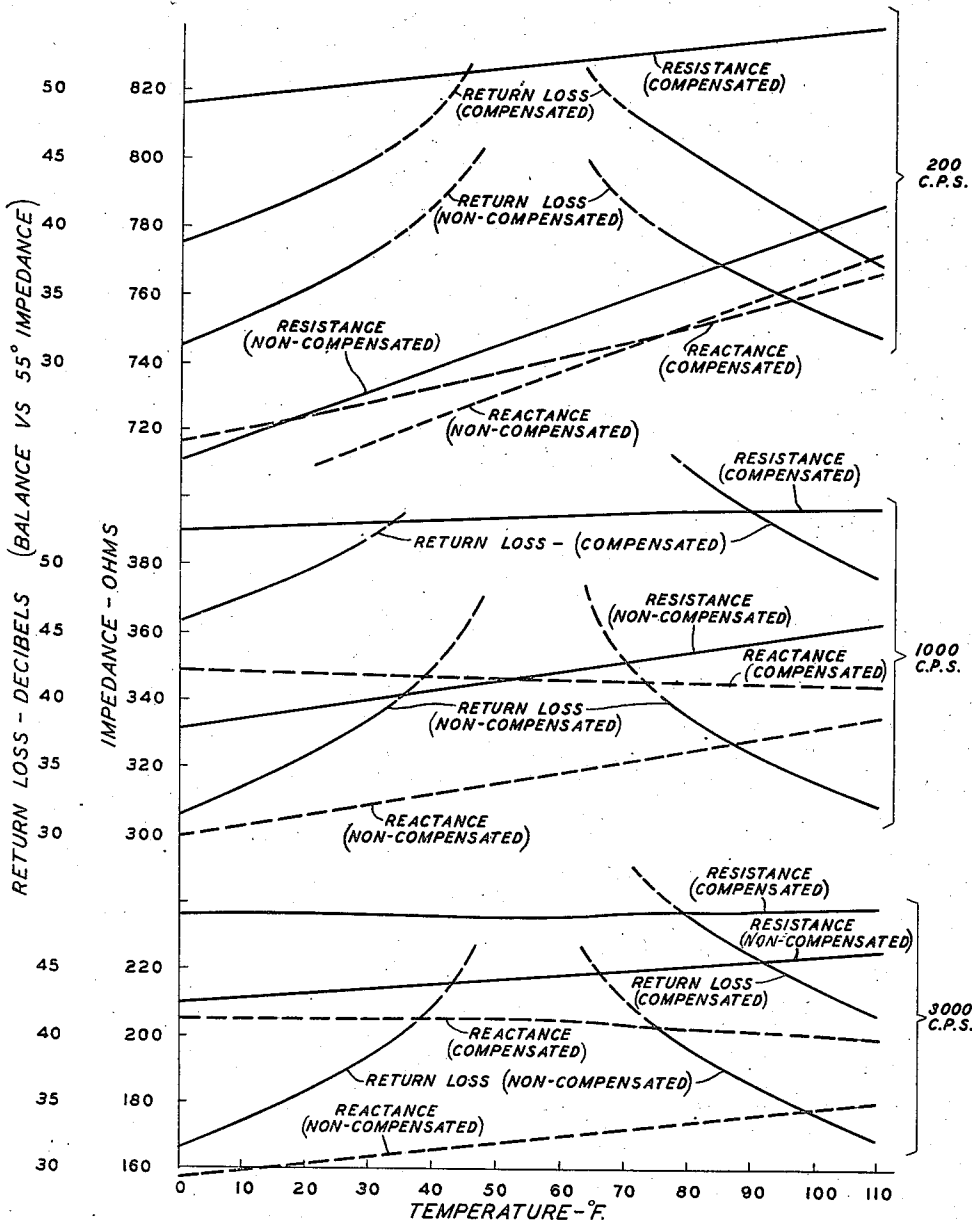
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FIG. 11

IMPEDANCE - TEMPERATURE COMPENSATION
19 GAUGE TELEPHONE CABLE PAIR



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2,326,742

ELECTRIC WAVE SYSTEM

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Application September 9, 1941, Serial No. 410,130

9 Claims. (Cl. 178-44)

This invention relates to electric wave systems and more particularly to compensation for the variations in the characteristics of a transmission path or line with variations in temperature.

An object of the invention is to compensate or correct for changes in the attenuation and impedance of a transmission line, for example, a pair of telephone conductors or wires of the so-called open wire or of the cable type.

A feature of the invention comprises inserting, at optimum spacings in the line, impedance networks or units that enable the desired compensation.

Another feature comprises inserting a plurality of attenuation and impedance variation compensating units in each repeater section of a long transmission line, one unit being located centrally and other units being located nearer each end of the repeater section than to the center thereof.

Still another feature comprises compensating for the attenuation variation with temperature of a transmission line by the provision of an appropriately proportioned compensator unit at about the center of a repeater section of the line, and compensating for attenuation and impedance variation with temperature by the provision of an appropriately proportioned compensator unit near each end of the repeater section.

An ordinary telephone pair or line has a positive variation in resistance with temperature over the limited range embraced by atmospheric temperatures. The inductance, capacitance and leakage are also affected by change in temperature, but to a much smaller degree than the resistance and attenuation. The impedance and variation in impedance are more dependent on frequency but are affected by temperature variation. In accordance with this invention, a transmission line subjected to variation in temperature over the range of atmospheric temperatures has compensator networks or units inserted therein at spaced intervals. In one embodiment, three units per repeater section may be provided in a non-loaded telephone pair, one substantially at the center of the section to compensate primarily for attenuation variation with temperature, and one near each end of the section to compensate for both attenuation and impedance variation. The compensator unit may comprise a temperature-

dependent resistance or thermistor having a negative temperature coefficient of resistance, and a resistance of zero or of low temperature coefficient of resistance connected in shunt with the thermistor. This unit may be proportioned so that it experiences a linear or other change in resistance with temperature. In a particular situation, it may be desirable to include a positive reactance element in series with the thermistor or the shunt resistance to compensate for capacitance change in the line with temperature change. In another embodiment, the compensating units may be spaced uniformly in a loaded telephone pair, one to each loading section.

A more complete understanding of the invention will be derived from the detailed description that follows, taken in conjunction with the appended drawings, wherein:

Fig. 1 shows a portion of a transmission line having inserted therein compensator units or networks to compensate or correct for attenuation and impedance variation in the line with temperature variation;

Fig. 2 shows one form the compensator unit may assume;

Figs. 3 and 4 show other configurations that the compensator unit may have;

Fig. 5 shows attenuation versus temperature curves at three frequencies for a cable telephone pair with and without compensation in accordance with this invention;

Figs. 6 and 7 show resistance versus temperature curves for the thermistor alone, the shunt resistance alone and the compensator unit, inserted at the center and near the ends of the compensated line;

Fig. 8 shows resistance and reactance and return loss characteristics of a telephone pair at 3000 C. P. S. with and without attenuation compensation at the center only of a repeater section;

Fig. 9 shows the effect on impedance changes in a telephone pair of inserting compensator units at various distances from the ends of a repeater section;

Fig. 10 shows the effect on the 0° F. impedance at one voice frequency of inserting various resistances at various distances from the end of a section of a telephone pair; and

Fig. 11 shows resistance, reactance and return

loss versus temperature characteristics for the line having the attenuation-temperature characteristics of Fig. 5, at three frequencies.

With reference to the drawings, Fig. 1, represents a transmission path or line 10 comprising a pair of telephone conductors or wires 11 of the so-called open wire type, or one pair of many pairs enclosed in a cable. Such a line will experience variations in its attenuation and impedance characteristics with variations in atmospheric temperature. A plurality of compensator units or networks 12 is inserted in the line, for example, in one conductor thereof, at spaced intervals. For reasons of symmetry, noise and cross-talk control, correspondingly located units or networks may be inserted in the other conductor also. One network is located substantially centrally in a repeater section, i. e., between repeater or amplifier points in the transmission path, and each of two other networks is located between the center unit and the end of a repeater section but nearer to the repeater point than to the center unit. In a repeater section of the order of twenty miles in length, the outer units may be of the order of two miles from the ends of the repeater section. The outer units compensate or correct for both attenuation and impedance changes in the characteristics of the line with temperature change thereof, and the center unit provides primarily supplemental compensation or correction for attenuation changes with temperature change. In a telephone pair that includes loading coils at spaced intervals, the compensator units may be located at uniform intervals, one to each loading section.

Fig. 2 shows one configuration that the network 12 may assume. It comprises a temperature-dependent resistance element or thermistor T, for example, of a substance or material having a negative temperature coefficient of resistance, with a resistance R_s of low or zero temperature coefficient of resistance connected in shunt therewith. The resistance T may consist of zinc oxide; silver sulphide; a mixture of the oxides of manganese, nickel and cobalt such as is disclosed in E. F. Dearborn United States Patent 2,274,592 issued February 24, 1942; or a mixture of the oxides of manganese, nickel and copper such as is disclosed in E. F. Dearborn-G. L. Pearson United States Patent 2,282,944 issued May 12, 1942. Such material, over the range of atmospheric temperatures, have a substantially exponential resistance-temperature characteristic. The shunting resistance R_s may be of a metal such as copper and is selected with respect to the particular thermistor T so that the two combined have a resistance-temperature characteristic decreasing substantially linearly with increase in temperature over the range of atmospheric temperatures to which the transmission line is expected to be subjected. In particular situations, the character of the compensation or correction desired may make advantageous the inclusion of one or more reactive elements in the compensator unit. Two such networks are shown in Figs. 3 and 4, that of Fig. 3 including a positive reactance element or inductance L in series with the thermistor, and that of Fig. 4 including the inductance L in series with the resistance R_s . With the network of Fig. 3, as the resistance of the thermistor decreases, the element L introduces an increasing inductive component in the line to compensate for the change in capacitance of the line with temperature. The

attenuation compensation or correction at the higher frequencies is materially improved with the network of Fig. 4 inserted in a line intended to transmit electric waves of frequencies up to, say, 20 kilocycles per second. Additional compensator networks or units embodying one or more reactance elements are disclosed and discussed in the copending application of P. G. Edwards, Serial No. 410,149, filed September 9, 1941, and still others in the copending application of R. K. Bullington, Serial No. 410,136, filed September 9, 1941.

A better understanding of the invention may be obtained in the light of the following specific embodiment. Consider the following situation. It is desired to compensate or correct substantially for the attenuation and impedance change with temperature change in a repeater section of a transmission line approximately twenty miles in length and comprising a telephone pair of 19-gauge, .062 microfarad per mile, 1.117 millihenries per mile, copper wire. The attenuation (in decibels per mile) versus temperature (in degrees Fahrenheit) characteristic of such a line at three typical frequencies (200, 1000 and 3000 cycles per second) is shown by the curves A, B, C of Fig. 5. The curves A₁, B₁, C₁ and A₂, B₂, C₂ show the effect on the attenuation-temperature characteristic of the line of inserting compensator networks therein in accordance with invention. Each network would be of the configuration shown in Fig. 2 and comprise a thermistor of nickel-manganese-cobalt oxides and a shunt resistance of say, copper. The unit or network inserted at the center of the line is proportioned to have a resistance-temperature characteristic such that it decreases in resistance substantially linearly from about 500 ohms to about 200 ohms over the temperature range of 0° F. to 110° F. Each unit inserted approximately two miles from the end of the line section is proportioned to have a resistance-temperature characteristic such that it decreases in resistance substantially linearly from about 120 ohms to about 55 ohms over the same temperature range. Curves A₁, B₁ and C₁ show the attenuation-temperature characteristic for the repeater section when the compensator units are inserted only near the ends of the section; curves A₂, B₂ and C₂ show the supplemental attenuation compensation effect of adding the center compensator unit, resulting in a substantially flat attenuation-temperature characteristic at the three typical frequencies.

The resistance versus temperature characteristics of the thermistor and of the shunt resistance of the center unit are shown in Fig. 6 as is the center unit's resistance versus temperature characteristic; and similar curves for the end compensator units are shown in Fig. 7.

Fig. 8 shows the resistance and reactance of the transmission line at 3000 cycles per second with and without attenuation compensation at the center only of a repeater section. The characteristics for return loss versus 55° F. impedance of the line are also shown. The compensator unit was similar to that specified hereinabove for the center unit in the illustrative example. As indicated by Fig. 8 a single compensator unit at the center of the section does not compensate for changes in impedance. The effect on impedance changes of providing compensator units at various distances from the ends of the repeater section is shown by the curves of Fig. 9. That figure shows the results of a generalized computation of the required impedance A_z at μ miles

to compensate for the change in impedance due to temperature change from 0° F. to 110° F. In other words, a series impedance Δz at μ miles makes the input impedance of the line at 0° F. equal to the input impedance of the line at 110° F. without the series impedance. It can be shown that

$$\Delta z = Z_{0(t)} \frac{\left[\frac{Z_{0(110)} - 1}{Z_{0(t)}} - 1 \right] [1 + \tanh \mu P(t)]}{\left[1 - \frac{Z_{0(110)}}{Z_{0(t)}} \tanh \mu P(t) \right]} \quad (1)$$

where

- Δz = added impedance at temperature t
 μ = miles from the end of the section to the point where Δz is inserted
 $P(t)$ = Propagation of one mile of the telephone pair at temperature t
 $Z_{0(110)}$ = characteristic impedance of cable at 110° F.
 $Z_{0(t)}$ = characteristic impedance of cable at temperature t
 t = some temperature less than 110° F. at which it is desired to equate impedance to that of 110° F. ($t=0$)

when $\mu=0$, the equation reduces to

$$\Delta z = Z_{0(110)} - Z_{0(t)}$$

Fig. 9 indicates that a resistance of the order of 65 ohms at a distance of two miles from the terminal of the repeater section will make the 3000 cycles per second input impedance at 0° F. equal that at 110° F. without added resistance. This does not perfectly compensate for other frequencies. To maintain the compensator unit of simple character, i. e., to employ only resistance changes, the effect on the change in impedance of adding various resistances at various distances, bearing in mind the importance of the 3000 cycles per second frequency from a voice frequency repeater standpoint, should be considered. It can be shown that

$$Z_{\Delta} = \Delta \frac{1 - \tanh \mu P}{1 + \tanh \mu P + \frac{(\Delta)}{Z_0} \tanh \mu P} \quad (2)$$

where

- Z_{Δ} = change in input impedance due to Δ
 Δ = added resistance
 μ = miles from the end of the section to the point where Δ is inserted
 Z_0 = characteristic impedance of the telephone pair
 P = propagation of the telephone pair

The relation of Equation 2 holds at any temperature assuming that P and Z_0 are for that temperature, and can be applied, also, to determine the effect of nearby resistances for impedance compensation, or of attenuation compensator units at the center of the section. Fig. 10 shows the modification of the 0° F. impedance at 3000 cycles per second caused by the insertion of 60, 70 and 80 ohms at 0, 1, 2, or 3 miles. The effect changes from pure resistance change at zero mile to substantially pure reactance change at three miles.

The curves of Fig. 11 show the resistance, reactance, and return loss versus temperature characteristics for the line having the attenuation-temperature characteristics of Fig. 5, at 200, 1000 and 3000 cycles per second. The resistance and reactance versus temperature characteristics are seen to be substantially flat over the temperature range of 0°-110° F.

To recapitulate in part and also to afford a further understanding of our invention, the following statements may be made. In a non-loaded telephone pair, if a series impedance is added at the terminal, it will modify the terminal impedance by algebraic addition of the resistance and reactance components. As the added series impedance is moved farther away from the terminal, the modifying effect becomes less because of the shunting due to the intervening cable, so that at a distance of, say, 6 to 10 miles, the modification of the terminal impedance is much smaller. The change in attenuation is approximately the same for a given added series impedance regardless of the location in the line. An arrangement is feasible, then, where added impedance near the end of the cable modify both impedance and attenuation, and added impedances near the middle of the cable modify attenuation primarily, and both impedance and attenuation changes with temperature normally occurring may be substantially canceled or compensated for by the added impedances.

A study of the impedance required to cause a desired change in the original terminal impedance shows that for various distances of for example 0, 1, 2, 3 etc. miles out from the terminal impedances, added series impedances Z_0, Z_1, Z_2, Z_3 , etc. can be found which will cause the desired modification at the terminal. At certain critical distances these impedances are resistances, even though the resulting terminal changes are reactive in character. The ideal impedance and impedance changes are of course different for different frequencies.

Since the same added impedance applies to all frequencies, attention is centered on the most critical frequency or frequencies, and the effect of the optimum impedance for this frequency or frequencies is determined for other frequencies of interest. Also, it is desirable to keep the added impedance to a minimum of complexity consistent with the desired results as, for example, pure resistance only.

If for a given frequency, say 3000 cycles, investigations are made of the effect of various amounts of resistance added in series with a non-loaded telephone pair at various distances, it will be found that a pure resistance of about 65 ohms at a distance of 2 miles from the terminal will cause the required impedance change to compensate for the change in impedance of the line at 3000 cycles, 0° F. to 110° F., and that the required change and the resulting compensation are substantially proportional, so that, if it is assumed that the added resistance is 0 ohms at 110° F. and 65 ohms at 0° F., and changes proportionally for intermediate temperatures, satisfactory 3000 cycle compensation will result.

At other frequencies, it will be found that the same resistance required to compensate 3000 cycle temperature impedance changes will provide a good degree of compensation at 1000 cycles and slightly inferior degree of compensation at 200 cycles. It would, of course, be possible to provide separate units for a better degree of compensation at all frequencies, or a more complex unit involving reactances which would match the required compensation changes for several frequencies at several temperatures.

The fact that practical compensating resistances cannot become zero at 110° F. means that the compensated loss and the compensated impedance will be higher than for an ideal compensating resistance.

Now, if the attenuation changes produced by a compensator unit near each terminal are determined, it will be found that insufficient attenuation compensation is provided, and the additional attenuation compensation can be added at or near the middle of the cable section without seriously modifying the impedance compensation already obtained. In fact, it is possible to arrive at a design in which the effect of the center compensation on the terminal impedance is taken into account. The general procedure is to add algebraically the impedance compensation caused by the terminal and central units.

In the case of a loaded telephone pair, as indicated in the copending application noted above in the name of P. G. Edwards, Serial No. 410,149, the location in the loading section, the frequency with which the compensating units are provided, and the accuracy of spacing are all important considerations. The compensating units should be regularly spaced, and one loading section or a multiple thereof apart. End sections may or may not be compensated depending on their length. Half sections, for example, might have half compensation.

Where the location in the section is unsymmetrical, as for example, at the 0.2-0.8 point, and this spacing is preserved throughout the repeater section, the impedances as seen from the two ends would be somewhat different at low frequencies. This condition can be obviated by making the two halves of the line alike. For example, with half section termination, it may be desirable to place a half section compensator in the end section and 0.2 from the first loading coil, with subsequent compensators at intervals of one loading section up to the center of the repeater section. If this is done from either end, generally speaking the terminal compensated impedances will be alike since the effect on the terminal impedance diminishes as the distance of the compensator unit from the terminal increases. At the center, one of two conditions will prevail: for an even number of sections the two compensators near the center will be 0.4 section apart; for an odd number of sections the center compensator may be placed in the center of the center section.

The intervals at which the compensator units are provided is governed by the smoothness required in the line impedance. For one compensator per loading section, the impedance is smooth throughout the range to cutoff. For one compensator per two loading sections, there is an impedance irregularity at 0.7 of the cutoff frequency, and so on, the fewer the compensator units the greater the impedance irregularity with more and more of the useful frequency range affected.

The effect of varying the location of the compensator units from the theoretical location is like that caused by varying the location of loading coils from the theoretical in that it reduces the return loss which can be obtained because of impedance irregularities, but the effect is not as severe since at most frequencies resistance has little effect on impedance. At low frequency, where the effect is appreciable, the line tends to be transparent and the location is not critical.

Because of the modification of the low frequency impedance by the compensator units, it is advantageous to modify the balancing networks employed to balance the compensated lines in connection with the use of telephone repeaters. A simple way to do this is to add to

the regular network a compensating series element made up of resistance and capacitance in shunt to cause the same change in the network impedance from say 200 cycles to 1000 cycles as the line compensator units cause in the line impedance.

While this invention has been disclosed as embodied in certain specific forms which are deemed desirable, it is understood that it is capable of embodiment in many and other widely varied forms without departing from the spirit of the invention as defined by the appended claims.

What is claimed is:

1. In combination, a transmission line that varies in attenuation and impedance with variations in temperature, and means inserted in a section of said line to compensate for said variations in said section, said means comprising an impedance unit, nearer each end of the section than the center thereof, and an impedance unit at substantially the center of said section compensating primarily for attenuation variation in said section, each of said units being subjected to the same temperature variation as said line and including a resistance element that varies in resistance in a direction opposite to the variation in resistance of said line with temperature variation.

2. In combination, a transmission line that varies in attenuation and impedance with variations in temperature, a pair of repeaters in said line at spaced intervals along said line, and means inserted in said line intermediate said repeaters to compensate for said variations, said means comprising three impedance units variable in impedance with temperature variation and subject to the same temperature variation as the line, one of said units being located at a point in said line approximately equally distant from each of said repeaters, and each of the other units being located at a point in the line unequally distant from the two repeaters.

3. The combination of claim 2 in which said one unit compensates primarily for attenuation change in the line between the repeaters, and said other two units compensate substantially entirely for the impedance variation in the line between said repeaters.

4. In combination, a transmission line that varies in attenuation and impedance with temperature variations and being of a material having a positive temperature coefficient of resistance, impedance means inserted in said line to compensate for said impedance change, and additional impedance means inserted at another point in said line to compensate primarily for attenuation change in said line, said impedance means being subjected to the same temperature variations as said line and each including a resistance element having a negative temperature coefficient of resistance.

5. In combination, a transmission path comprising a section of a transmission line that varies in attenuation and impedance with variation in temperature, a substantially pure resistance inserted in said section nearer to one end than to the center thereof to provide compensation for said impedance variation, and an additional substantially pure resistance inserted at another point in said section to provide compensation for said attenuation variation, each of said resistances being variable in resistance with temperature variation and subject to the same temperature variation as the line.

6. In combination, a transmission path comprising a section of a transmission line that varies in attenuation and impedance with variation in temperature, a substantially pure resistance inserted in said section to provide compensation for said impedance variation, and another substantially pure resistance inserted at another point in said section to provide compensation for said attenuation variation, each of said resistances being variable in resistance with temperature variation and subject to the same temperature variation as the line.

7. In combination, a transmission path comprising a section of transmission line that varies in attenuation and impedance with temperature, and a plurality of attenuation and impedance variation compensator units inserted in said section and being variable in impedance with temperature and subject to the same temperature

variation as the line, one of said units being located in the central portion of said section and another unit being located nearer to one end of said section than to the center thereof, the centrally located unit being of a different resistance over the expected temperature range than the end unit.

8. The combination of claim 7 in which said centrally located unit is of a higher resistance over the expected temperature range than the end unit.

9. The combination of claim 7 in which said centrally located unit provides compensation primarily for attenuation variations and the end unit provides compensation for attenuation and impedance variations.

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