

Aug. 17, 1943.

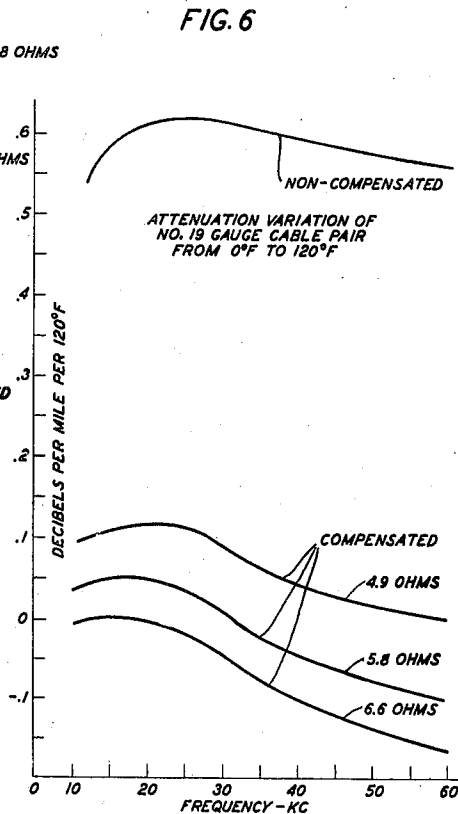
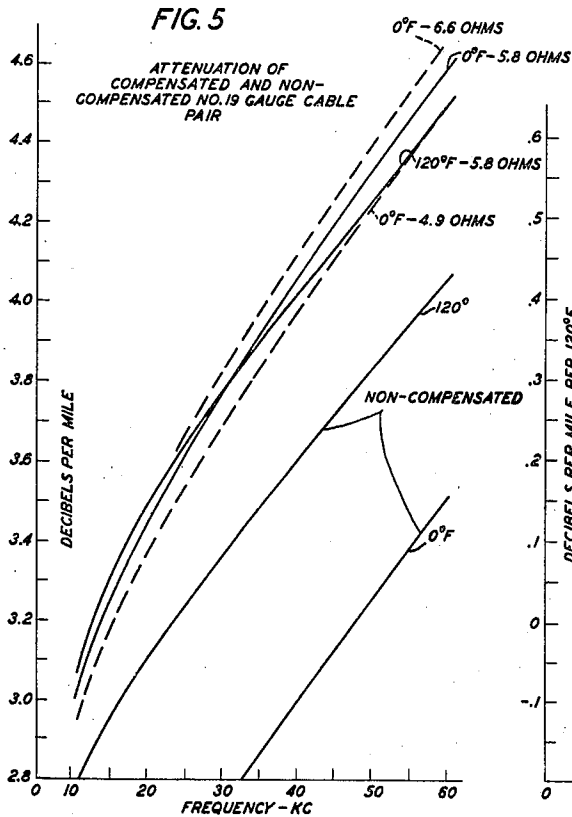
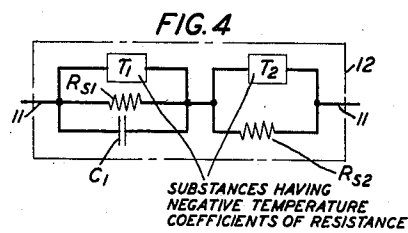
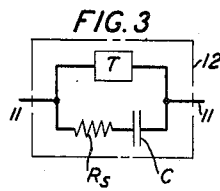
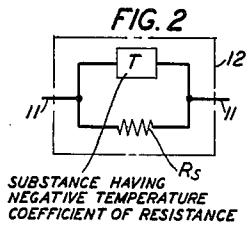
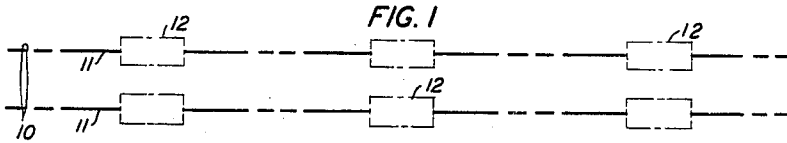
R. K. BULLINGTON

2,326,826

TRANSMISSION SYSTEM REGULATION

Filed Sept. 9, 1941

3 Sheets-Sheet 1



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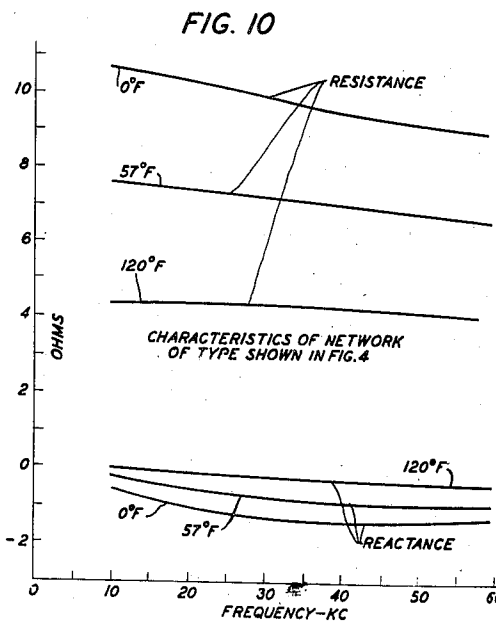
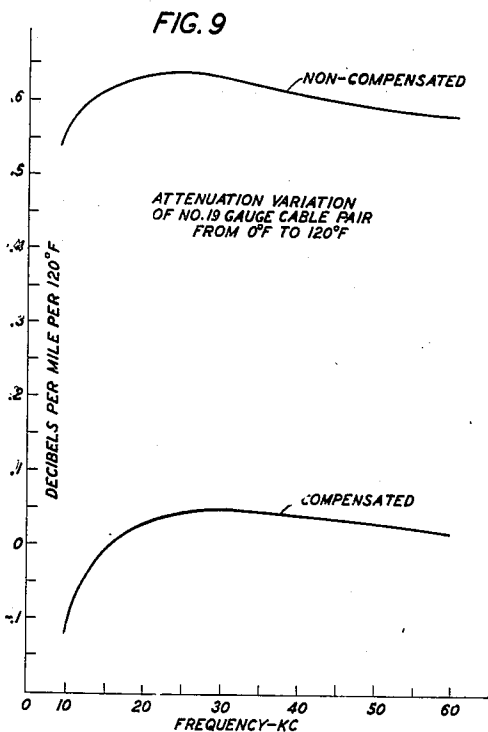
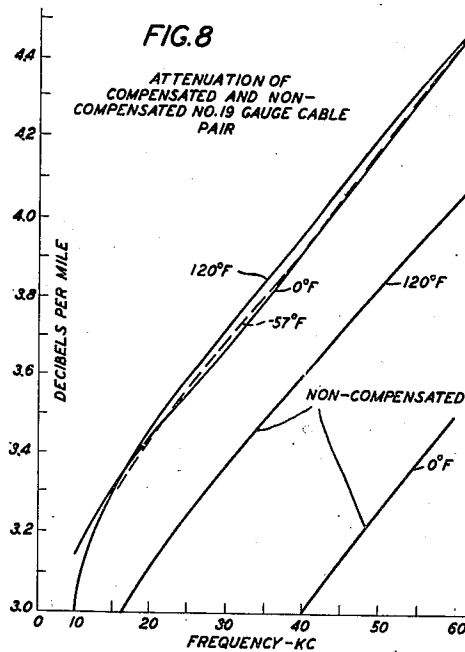
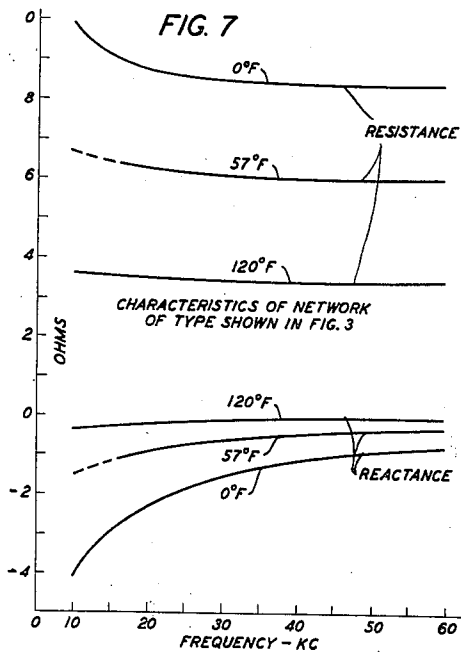
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TRANSMISSION SYSTEM REGULATION

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3 Sheets-Sheet 2



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TRANSMISSION SYSTEM REGULATION

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3 Sheets-Sheet 3

FIG. 11

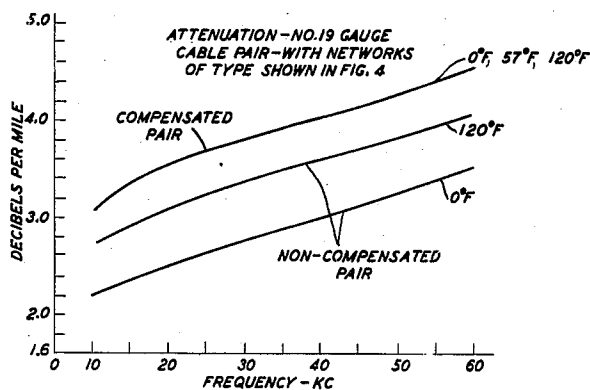


FIG. 12

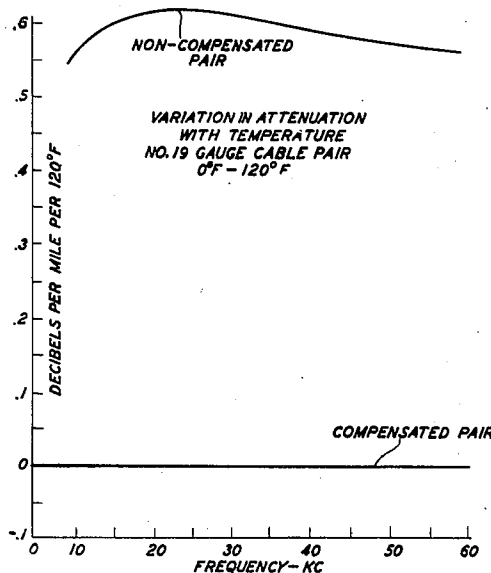


FIG. 13

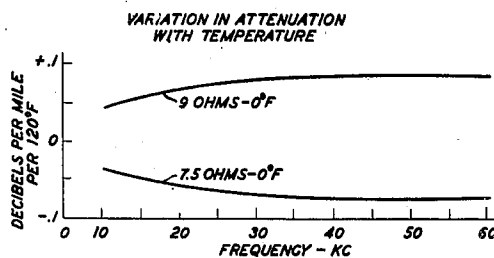


FIG. 14

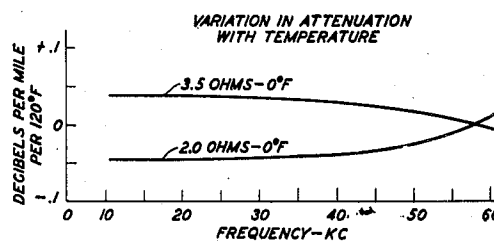
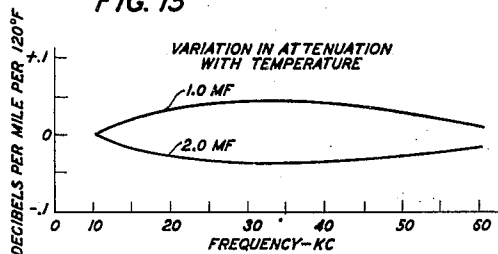


FIG. 15



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2,326,826

TRANSMISSION SYSTEM REGULATION

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Application September 9, 1941, Serial No. 410,133

6 Claims. (Cl. 178-44)

This invention relates to electric wave systems and, more particularly, to transmission lines and means for compensating for variations in attenuation and impedance thereof with temperature variations.

An object of the invention is to reduce the attenuation variation with temperature of a transmission path or line.

A further object is to reduce the impedance variation with temperature of a transmission path or line.

The transmission line may comprise a pair of telephone conductors or wires of the so-called open-wire type or may be included in a cable together with a plurality of other telephone pairs. The line may be of the non-loaded type and be intended to transmit a band of frequencies, for example, between 10 and 60 kilocycles per second. The ordinary telephone pair has a positive variation of resistance with temperature over the limited range embraced by atmospheric temperature. Line impedance variations with temperature in the above-noted frequency range are normally small. The changes in attenuation and impedance with temperature are due generally to changes in the effective high frequency resistance of the telephone pair, but variations in inductance, capacitance and leakance are contributing factors.

A feature of the invention comprises associating an impedance net work with a transmission line whose attenuation and impedance characteristic varies with variation in temperature, which network has a resistance component that decreases substantially linearly with frequency, a negative reactance component that increases in a negative direction substantially linearly with frequency, and in which both components decrease substantially linearly with temperature.

Another feature of the invention comprises compensating for attenuation and impedance change with temperature in a transmission line by inserting one or more impedance networks at spaced intervals in the line, the network comprising a temperature-dependent resistance element and a capacitive reactance element.

Still another feature comprises inserting one or more compensating units or networks in a transmission line to compensate for attenuation and impedance changes therein with temperature and in which each unit includes a plurality of temperature-dependent resistance elements.

In accordance with the invention, a transmission line adapted for transmitting a broad band of frequencies has inserted therein at intervals

determined by the highest frequency being transmitted, compensator units or impedance networks comprising one or more temperature-dependent resistance elements and a capacitive reactance element. In one embodiment, the network may comprise a temperature-dependent resistance element having a negative temperature coefficient of resistance with a series-connected resistance and capacity in shunt therewith. In another embodiment the compensator unit may comprise a plurality of impedance networks, for example, two, one of which comprises a network including a temperature-dependent resistance, a shunt resistance of low temperature coefficient and a capacity, and the other of which comprises a temperature-dependent resistance element having a negative temperature coefficient of resistance with a resistance element connected in shunt therewith. In each instance, the shunt resistance element is preferably of low temperature coefficient of resistance. In the more elaborate unit, the two temperature-dependent resistance elements may be chosen so as to be of different resistances at the various temperatures in the range of temperatures involved.

A more complete understanding of this invention will be obtained from the detailed description that follows hereinafter, read with reference to the appended drawings, wherein:

Fig. 1 shows a transmission path or line having compensator units inserted therein at spaced intervals to compensate for attenuation and impedance variations in the line with temperature;

Fig. 2 shows a compensator unit or network heretofore proposed for use in the arrangement of Fig. 1;

Fig. 3 shows a compensator unit or network in accordance with this invention;

Fig. 4 shows still another compensator unit or network in accordance with this invention;

Figs. 5 and 6 show attenuation and attenuation variation versus frequency characteristic curves for a non-compensated cable telephone pair, and the same telephone pair with compensator units of the type shown in Fig. 2 inserted therein;

Fig. 7 shows resistance and reactance versus frequency characteristic curves for a thermistor compensator unit of the type shown in Fig. 3;

Figs. 8 and 9 show attenuation and attenuation variation versus frequency characteristic curves for a non-compensated cable telephone pair, and the same telephone pair with compensator units of the type shown in Fig. 3 inserted therein;

Fig. 10 shows resistance and reactance versus

frequency characteristic curves for a thermistor compensator unit of the type shown in Fig. 4;

Figs. 11 and 12 show attenuation and attenuation variation versus frequency characteristic curves for a non-compensated cable telephone pair, and for the same telephone pair with compensator units of the type shown in Fig. 4 inserted therein; and

Figs. 13, 14 and 15 show curves evidencing the effect on variation in attenuation of independently varying the parameters of the unit or network of the type shown in Fig. 4.

With particular reference to Fig. 1, there is shown a transmission path or line 10 comprising a pair of telephone conductors or wires 11, 11 which may be of the so-called open-wire type, or be one telephone pair of many enclosed in a cable. In order to compensate for the change in the attenuation and impedance characteristics of the line with temperature change, suitable networks or compensator units 12 are inserted in the line at spaced intervals and, for purposes of symmetry, in each conductor.

In accordance with J. B. Johnson Patent 2,650,703 of August 11, 1936, these networks may take the form shown in Fig. 2 where the element T is a temperature-dependent resistance or thermistor, for example, of a material or substance having a negative temperature coefficient of resistance, for example, zinc oxide or silver sulphide, and the resistance R_s is of a material having a small or zero temperature coefficient of resistance.

In accordance with this invention, however, the compensator unit is of the types shown in Figs. 3 and 4. The unit of Fig. 3 comprises a thermistor T and a resistance R_s as in the arrangement of Fig. 2, but also includes a reactance element, specifically, a capacitance C in series with the resistance R_s . The unit of Fig. 4 is more complex in that it comprises a plurality, specifically, a pair, of impedance networks. One network comprises a thermistor T_1 , with a resistance R_{s1} and a capacitance C_1 each in shunt therewith, and the other comprises a thermistor T_2 with a resistance R_{s2} in shunt therewith. The elements T_1 and T_2 are of different resistances over the temperature range of interest, but in particular situations it may be desirable to have them of the same resistances over the temperature range involved.

As noted, it has already been proposed that temperature-dependent resistance units or thermistors, more particularly resistance units having a negative temperature coefficient of resistance, might be employed to reduce the variation in the attenuation of a cable telephone pair resulting from temperature changes inasmuch as this variation is due largely to the resistance change. There are various materials that evidence a negative temperature coefficient of resistance, e. g., zinc oxide, silver sulphide, a mixture of nickel, manganese and cobalt, and a mixture of nickel, manganese and copper, and in all of which the resistance decreases substantially exponentially with temperature, at least throughout the atmospheric temperature range. In order that the resistance may decrease linearly with increase in temperature, a unit or disc of the negative resistance material should be shunted with a resistance element that is of constant resistance or that varies linearly with temperature. By appropriate choice of the negative resistance element and of the shunting resistance, a combination network or unit can be obtained that

will give an approximately linear decrease in resistance for any desired change in resistance over a given temperature range.

When units or networks of the type described are inserted in a pair of telephone conductors or wires, for example, of the commonly employed 19 gauge wire, the probable range of temperature change, the varying characteristics of the telephone pair with such temperature change, and the effect of frequency or variation in frequency at a particular temperature, or with temperature change, must be considered. The spacing of the unit or network is determined primarily by the highest frequency that is to be transmitted. In order to avoid impedance irregularities, it is desirable to have at least two and, in particular situations, it may be more advantageous to have more than π compensating networks per wave-length at the maximum frequency. If the telephone pair is intended to be used for transmitting a band of frequencies between 10 kilocycles and 60 kilocycles, for example, and the expected or probable upper temperature will be of the order of 120° F. the controlling wave-length will be of the order of 2 miles. A spacing, therefore, of approximately 3,000 feet is a convenient one, and affords adequate margin from the impedance peak that would occur at 60 kilocycles if a theoretical maximum spacing of 1.015 miles were used.

As shown in the following table, the resistance of 19 gauge cable telephone pairs varies appreciably with frequency as well as with temperature, and, even if the inductance, capacitance and leakage of the cable telephone pair were to remain constant with temperature and frequency, complete compensation over a band of frequencies could not be obtained with a pure resistance unit.

TABLE I

Resistance (ohms) per 3,000 feet of 19-gauge cable telephone pair

Frequency kc. per sec.	Resistance at 0° F.	Resistance at 120° F.	Difference
10	42.3	55.2	12.9
25	46.1	58.1	12.0
40	51.4	62.9	11.5
60	57.2	68.5	11.3

The effect on attenuation with various pure resistance networks of the general type shown in Fig. 2, and inserted every 3,000 feet in a 19 gauge cable telephone pair, is shown by the curves of Fig. 5. If a network having a decrease in resistance of 5.8 ohms over the temperature range from 0° F. to 120° F. is employed, exact compensation can be obtained at approximately 31 kilocycles, but with a variation at other frequencies amounting to as much as one-tenth decibel per mile per 120° at 60 kilocycles. The 0° F. characteristics for networks in which the resistance change over the before-mentioned temperature range is of the order of 6.6 ohms and of 4.9 ohms are also shown. In the case of a resistance change of 6.6 ohms, compensation can be obtained at about 16 kilocycles, but with overcompensation at all higher frequencies. In the case of a resistance change of 4.9 ohms, complete compensation is obtainable at about 60 kilocycles, but with under-compensation at lower frequencies. Although only the 120° F. characteristic for a network having a resistance change of 5.8 ohms is shown, the same temperature characteristic of the other two net-

works will depart slightly from the one shown, but such deviation is not important in comparison with the change in the 0° F. characteristic. The decibel per mile per 120° F. characteristic for each of these cases, and for the non-compensated telephone pair, are shown in Fig. 6.

In order to reduce this variation in loss with temperature, it is desirable to add one or more reactive elements so that the characteristic of the compensating unit or network will vary with frequency as well as with temperature. Networks so modified are shown in Figs. 3 and 4 of which more detailed treatment will be given hereinafter. With reference to Fig. 2, it will be evident that the reactive elements may be included in the network in one of the following ways: (1) in series with the temperature-dependent resistance T ; (2) in series with the resistance R_s connected in shunt with the temperature-dependent resistance; (3) in parallel with both the resistances and (4) in series with both of the resistances.

Each of these arrangements has advantages and limitations, but, at this time, it is believed that the arrangement of Fig. 3, in which a condenser C is connected in series with the resistance shunting the temperature-dependent resistance, is one of the more satisfactory of the possible units or networks incorporating an additional element. With the arrangement of Fig. 3, the presence of the condenser results in a decreasing resistance characteristic with increasing frequency, as is shown desirable by Table I, and the highest reactive component will be at the low frequencies and low temperatures. The effect of inserting a compensating network of the type shown in Fig. 3 in a 19 gauge cable telephone pair every 3,000 feet, with the network comprising a temperature-dependent resistance of 20.6 ohms at 0° F. (4.2 ohms at 120° F.), a shunting resistance of 13.8 ohms at 0° F. (17.4 ohms at 120° F.), and a 1.2 microfarad condenser, is indicated by Fig. 8, the curves of which show the characteristics of such a telephone pair. The decibels per mile per 120° F. characteristics for the compensated and non-compensated telephone pair are shown by Fig. 9. The characteristic for the compensated line indicates that, in a 100 mile section, the maximum variation in the frequency range of about 12 kilocycles to 60 kilocycles is approximately ± 2.5 decibels, with the variation below 16 kilocycles in the opposite direction to the variation above 16 kilocycles. The resistance and reactance characteristics for the compensating unit for 0° F., 57° F. and 120° F. conditions are shown in Fig. 7.

It will be noted that the effect of the compensating unit on the decibels per mile per 120° F. characteristic is to reduce its magnitude by approximately the same amount at all frequencies. In other words, the compensating unit under consideration would provide essentially flat gain regulation. It will be noted, also, that the primary effect of a resistance change in the compensating unit is a translation of the decibels per mile per 120° F. characteristic with respect to the vertical axis, while the primary effect of the addition of the condenser is a counter-clockwise rotation of this characteristic. Thus, complete compensation at any one frequency and the slope of the residual twist variation (residual variation at 60 kilocycles compared to the residual variation at 10 kilocycles) can be controlled, but the shape of the decibels per mile per 120° F. characteristic remains essentially the same.

If a temperature-dependent resistance of a

material comprising oxides of nickel, manganese and cobalt, for example, as disclosed in E. F. Dearborn application Serial No. 280,692, filed June 23, 1939, for Resistance materials and method of making same, now Patent No. 2,274,592, dated Feb. 24, 1942, is employed, the maximum attenuation per mile may be increased somewhat. The use of a silver sulphide resistance element for the temperature-dependent resistance would increase the maximum attenuation by a smaller amount, but would not carry direct current satisfactorily and would be less stable. Another material that could be used for the temperature-dependent resistance is a composition of oxides of nickel, manganese and copper, such as is disclosed in E. F. Dearborn-G. L. Pearson application Serial No. 336,734, filed May 23, 1940, for Resistance composition and method of making it.

The desired result, of course, is to straighten the decibels per mile per 120° F. characteristic, along the zero axis. The addition of a second reactive element to the network would be a step in this direction as it would result in the provision of compensation at any three frequencies, that is, the pure resistance unit or network compensates at one frequency, and the unit with a condenser compensates at two frequencies. If a second reactive element is added to the compensating unit, care must be taken to avoid non-linearity with temperature.

To recapitulate at this point, the use of a single reactive element in conjunction with the compensating unit or network of the type shown in Fig. 2, that is, to give the network arrangement of Fig. 3, would provide compensation at at least two frequencies in the carrier frequency band. The use of two reactive elements would provide compensation at at least three points, but with bulges at intermediate frequencies. By using even more elements, the characteristic of a given cable telephone pair could be compensated with even greater accuracy. The optimum network would appear to be one whose resistance and reactance characteristics vary linearly with frequency as well as temperature. More specifically, the attenuation variations with temperature of a 19 gauge cable pair at all frequencies in the range of 10 to 60 kilocycles, may be compensated with sufficient accuracy from a practical standpoint if the compensating network has the following general characteristics: (1) a resistance component decreasing linearly with frequency; (2) a negative reactance component increasing in a negative direction linearly with frequency; and (3) both components decreasing linearly with temperature.

When only one temperature-dependent resistance is included in the compensating network, the optimum characteristics are obtainable only by using a large number of other resistance and reactive elements in the compensating unit or network. The inventor has determined, however, that a simple approximation of the optimum network is obtainable with the network or unit shown in Fig. 4, in which two temperature-dependent resistances T_1 , T_2 are included, one of the temperature-dependent resistances T_1 having a resistance of low temperature coefficient R_{s1} and a condenser C_1 each connected in shunt therewith, and the other temperature-dependent resistance T_2 having a resistance R_{s2} of low temperature coefficient connected in shunt with it. The first temperature-dependent resistance T_1 is preferably of low resistance, and is shunted by the resistance R_{s1} to provide approximate

linearity with temperature, and by the capacitance C_1 to obtain a decreasing resistance characteristic and an increasing negative reactance characteristic with frequency. The second temperature dependent resistance is of higher resistance than the first, that is, over the temperature range involved. The two temperature-dependent resistances may be of the same material and of different sizes, or of different materials, of the same or different sizes, to give the resistance values desired in the particular situation. By using the two temperature-dependent resistances, the major portion of the desired change can be obtained with temperature-dependent resistance T_2 and its associated shunt resistance, the characteristics of which are, of course, constant with frequency and can be made approximately linear with temperature. The temperature-dependent resistance T_1 of low resistance and its associated resistance and condenser provide the necessary variation with frequency, and because of the relatively low impedance of the latter combination, its inherent non-linearities are small. The characteristics of a typical network of the type shown in Fig. 4 are shown in Fig. 10 for 0° F., 57° F. and 120° F. Although the resistance and reactance characteristics as shown by the curves of Fig. 10 depart from linearity especially at the upper frequencies, these departures are in the opposite direction so far as the effect on attenuation is concerned and are more or less self-compensating. In this typical network, the combined resistance elements of T_1 and R_{s1} was of the order of 2.8 ohms at 0° F. and of 1.1 ohms at 120° F.; the combined resistance of elements T_2 and R_{s2} was of the order of 8.2 ohms at 0° F. and of 3.3 ohms at 120° F.; and the capacity C_1 was of the order of 1.4 microfarads.

As an example, by inserting the network of Fig. 4, having the characteristics shown by the curve of Fig. 10, in a 19 gauge cable telephone pair at 3,000 foot intervals, the values of attenuation shown in the following Table II are obtained.

TABLE II
Attenuation in decibels per mile of 19 gauge cable telephone pair

Frequency—kc. per sec.	10	16	25	40	60
TEL. PAIR COMPENSATED AT 3,000 FOOT INTERVALS					
0° F.	3.057	3.415	3.690	4.076	4.542
57° F.	3.415	3.702	4.078	4.531	5.000
120° F.	3.082	3.414	3.704	4.085	4.537
NON-COMPENSATED TEL. PAIR					
0° F.	2.196	2.403	2.631	3.013	3.521
120° F.	2.727	3.006	3.255	3.608	4.085

The attenuation for a non-compensated telephone pair is also listed. These data are plotted in Fig. 11. The characteristic impedance of the line is not changed appreciably by the addition of such a network at 3,000 foot intervals and the variations in impedance with temperature are reduced. For a spacing of one mile or more, there would be less than two compensating networks per wave-length, and the resulting impedance characteristic would not be as favorable. The decibels per mile per 120° F. characteristic for the non-compensated and compensated telephone pairs is shown by the curves of Fig. 12.

A better appreciation of the possibilities presented by the network of Fig. 4 is obtainable by considering the effect of varying in turn each of its various parameters. It is to be assumed, of course, that, when the resistivity of the temperature-dependent resistance is changed to another value, the shunting resistance is also changed so that the approximate linear characteristic with temperature is retained. The curves of Figs. 13, 14 and 15 were obtained with a network in which, initially, the condenser C_1 had a capacity of 1.4 microfarads, the temperature-dependent resistance R_1 combined with the resistance R_{s1} had a resistance of 2.8 ohms at 0° F. and a resistance of 1.1 ohms at 120° F. and the temperature-dependent resistance T_2 combined with the resistance R_{s2} had a resistance of 8.2 ohms at 0° F. and of 3.3 ohms at 120° F. If the constants of the network remain unchanged except that combination of the temperature-dependent resistance T_2 and the resistance R_{s2} is changed to one whose resistance at 0° F. is 9 ohms, or to one whose resistance at 0° F. is 7.5 ohms, the effect on the decibels per mile per 120° F. characteristic will be as shown in Fig. 12. The effect of substituting different values for the combination of the temperature-dependent resistance T_1 and the resistance R_{s1} is indicated by the curves of Fig. 14, for a combination whose resistance at 0° F. is 3.5 ohms and for a combination whose 0° F. resistance is equal to 2 ohms. When the compensating network is the same as that for the curves of Figs. 10, 11 and 12, but the capacity of the condenser C_1 is changed to one microfarad or to two microfarads, the effect of such change is indicated by the curves of Fig. 15. It is apparent, therefore, that by appropriate choice of these parameters, any expected cable telephone pair characteristic can be compensated with considerable accuracy.

Although this invention has been disclosed with reference to several specific embodiments, it is to be understood that it is not limited thereto but is of a scope embraced by the appended claims.

What is claimed is:

1. A transmission line whose attenuation and impedance characteristics vary with temperature, and means inserted in said line to compensate for said variations, said means comprising a plurality of networks spaced at regular intervals in said line, each of said networks comprising two resistances in series in said line and having negative temperature coefficients of resistance, shunted by resistances of small temperature coefficient, with a capacitance in shunt with one of said last-mentioned resistances.

2. In combination, a transmission line whose attenuation and impedance characteristics vary with temperature, and means inserted in said line to compensate for said variations, said means comprising a compensator unit including a pair of series-connected impedance networks, each network comprising a temperature-dependent resistance, a series-connected resistance of small temperature coefficient of resistance and a capacitance being connected in shunt with one of said temperature-dependent resistances, and a resistance of small temperature coefficient of resistance being connected in shunt with the second of said temperature-dependent resistances.

3. A transmission line whose attenuation and impedance characteristics vary with temperature, and means inserted in said line to compensate for said variation, said means comprising

ing a compensator unit including a pair of series-connected impedance networks, each network comprising a resistance having a high temperature coefficient of resistance, each of said networks including a resistance of small temperature coefficient of resistance and one of the networks including a reactance element, said line and said unit being subjected to the same variation in temperature but varying in resistance in opposite directions for a given temperature change.

4. In combination, a transmission line that varies in attenuation and impedance with temperature and means inserted in said line to compensate for such variations, said line and said means being subjected to the same range of temperatures, said means comprising an impedance network having a resistance component that decreases substantially linearly with frequency and a negative reactance component that increases in a negative direction substantially linearly with frequency, both components decreasing substantially linearly with temperature, the impedance network comprising two resistance elements having negative temperature coefficients of resistance, each of said elements being shunted by an individual resistance of low temperature co-

efficient of resistance, and one element being shunted by a capacitance.

5. In combination, a transmission line to be subjected to a wide range of atmospheric temperatures and to transmit a broad band of high frequency currents, said line being of a material having a positive temperature coefficient of resistance and increasing in resistance with rising frequency, and impedance units to compensate for variation in line resistance with variation in temperature and frequency, said units being inserted in series in said line at intervals and subjected to the same variation in temperature and frequency as the line, each unit comprising a pair of resistance networks changing in resistance in a direction opposite to that of the temperature change, one network including reactance means contributing a decreasing resistance and an increasing negative reactance characteristic with frequency to the unit.

6. The combination of claim 5 in which one of said networks is of higher resistance over the temperature range than the other and provides the major portion of the compensation for resistance change in the line with temperature change.

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