Aug. 8, 1933. T. E. SHEA 1,921,431

LOADING SYSTEM

Filed Aug. 11, 1930 2 Sheets-Sheet 1

FIG. 1

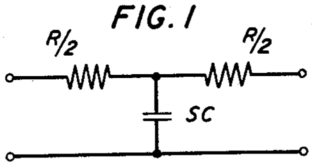

FIG. 2

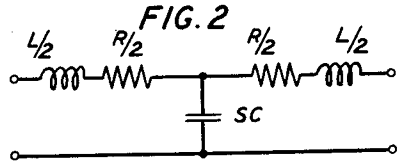

FIG. 3

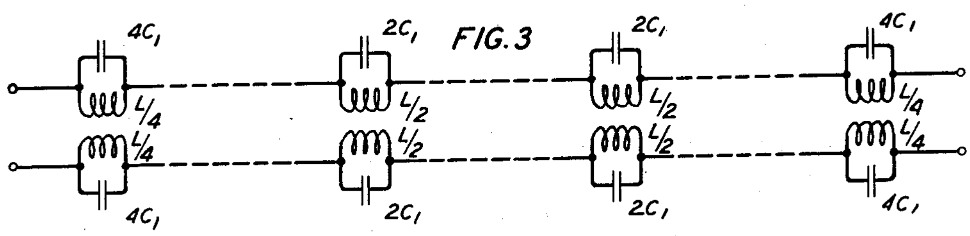

FIG. 4

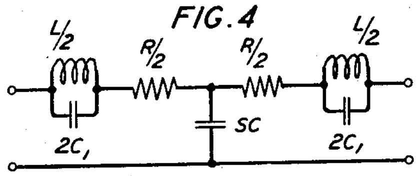

FIG. 5

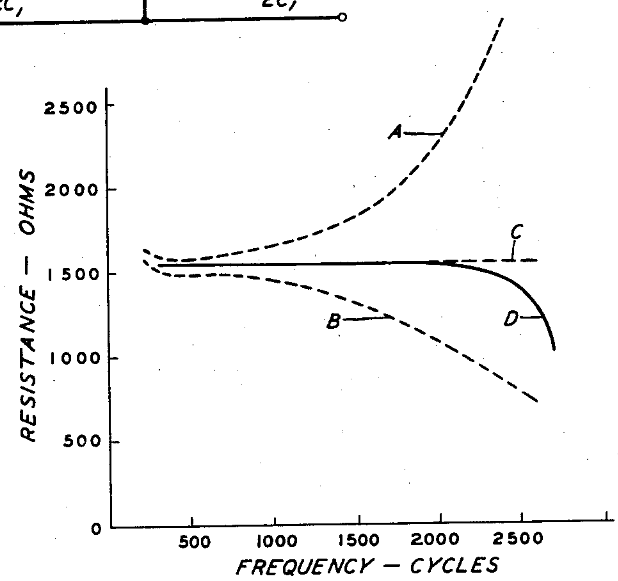

FIG. 6

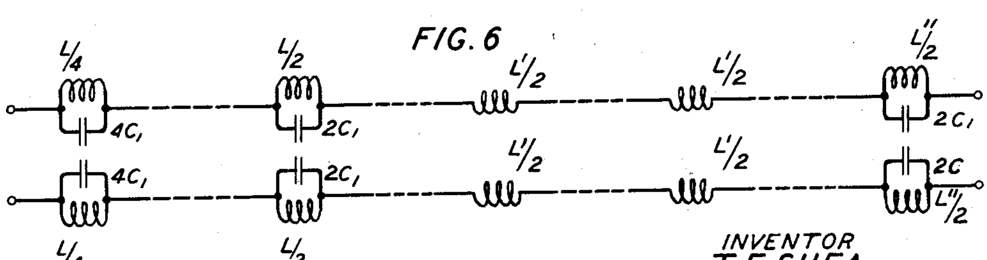

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FIG. 7

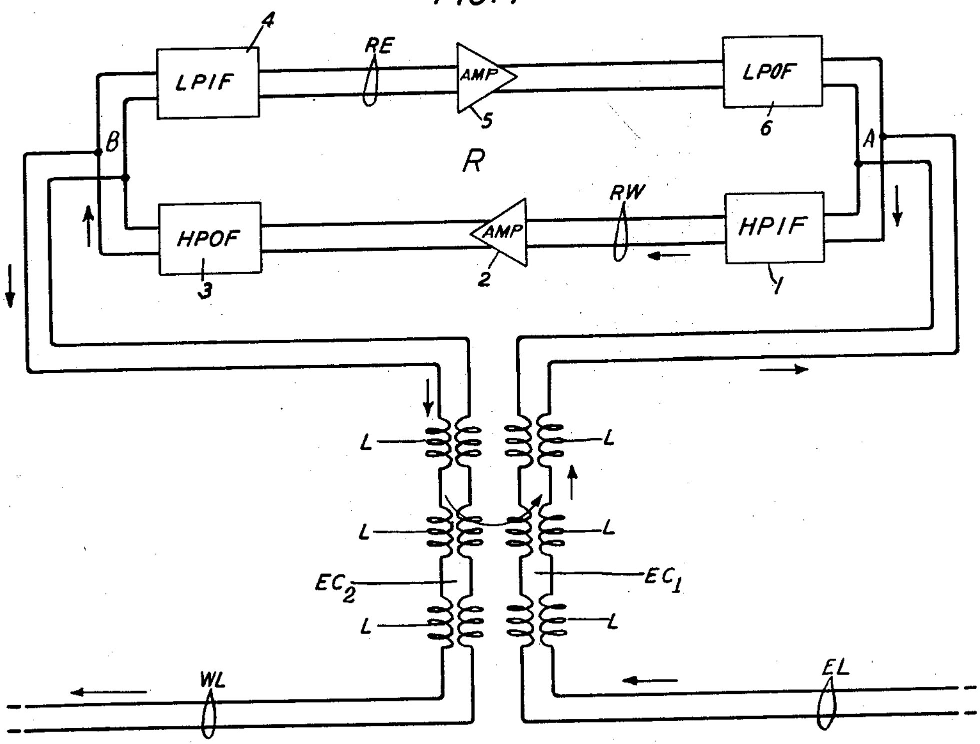
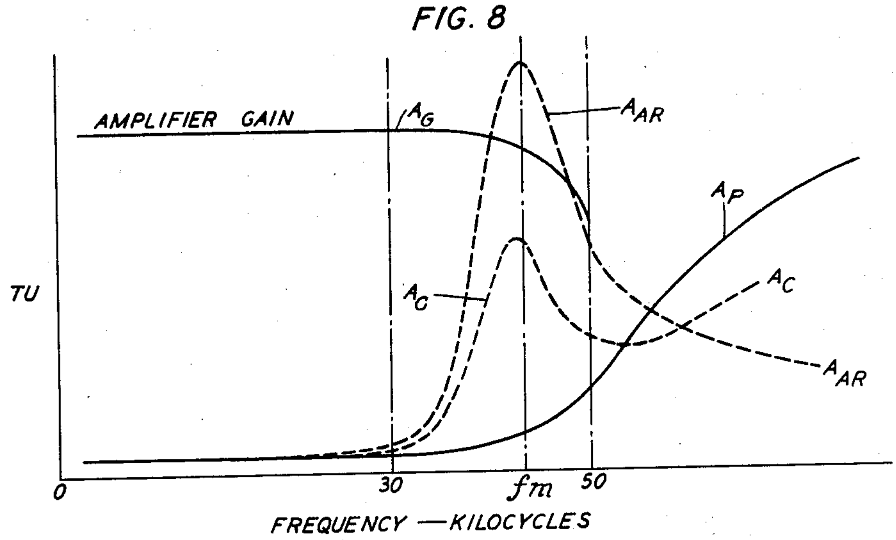


FIG. 8



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UNITED STATES PATENT OFFICE

1,921,431

LOADING SYSTEM

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Application August 11, 1930. Serial No. 474,331

7 Claims. (Cl. 178—45)

This invention relates to loading systems for telephone lines and the like, and has for an object to improve the transmission and impedance characteristics of loaded lines.

This application is a continuation in part of the co-pending U. S. application of T. E. Shea, Serial No. 198,459, filed June 13, 1927, now Patent No. 1,772,558 issued August 12, 1930.

It is well known that the ordinary loaded line has an impedance characteristic which is a practically pure resistance but which varies quite considerably with frequency. This variation is particularly marked in the case of loaded cable circuits. On the other hand the impedance of unloaded open-wire lines is practically independent of frequency so that when an unloaded open-wire line is joined to an ordinary loaded line considerable reflection loses are introduced. In order to avoid such losses and also to simplify the impedance balancing arrangement at repeaters, it is desirable that the loaded line should have an impedance which is resistive and practically constant with frequency.

In one specific embodiment this invention comprises an open-wire line or cable periodically loaded by means of loading units comprising inductance coils and condensers connected in parallel with each other in each side of the line. These loading units may be distributed along the lines at approximately the same distances apart as are the loading coils in lines loaded by the Pupin method. When terminated mid-coil such a system has a characteristic impedance which is a substantially constant resistance throughout the transmission range.

In a modified form this invention comprises a composite loaded system in which the section or sections at each terminal are loaded according to the method of this invention as above described while the intermediate sections are loaded according to the ordinary method, i. e., the Pupin method. It is possible to use this combination, because for frequencies in the transmission range the mid-section characteristic impedance of a line loaded with the loading units of this invention is substantially equal to the mid-section characteristic impedance of a line loaded in the usual manner.

In certain types of circuits, the loading networks of the invention may be utilized for providing the improved characteristics mentioned above and in addition for reducing or preventing undesired cross-talk and distortion effects due to electrostatic or electromagnetic induction between adjacent portions of the circuits. One application of this is in connection with loaded office entrance cable connecting a carrier repeater to an open-wire line. Where the output and input cable pairs of the entrance cable are in close proximity, as is usually the case, and the usual coil loading is applied, the electrostatic and electromagnetic induction between the adjacent pairs at high frequencies may be such as to produce circulating currents tending to cause regeneration and singing. If the loading networks of the invention are substituted for the usual loading coils in the entrance cable, the sharply rising attenuation characteristics of the former above the loading cut-off frequency may be utilized for reducing the flow of the undesired circulating current to an amount which will be ineffective to cause singing and regenerative effects in the repeater.

This invention will be better understood by reference to the following detailed description taken in connection with the accompanying drawings in which:

Fig. 1 shows a network substantially equivalent to a section of a cable or line in which the distributed series resistance and shunt capacity of the line are represented by equivalent lumped impedances.

Fig. 2 illustrates the equivalent network of Fig. 1 combined with the usual type of loading coils and terminated mid-coil;

Fig. 3 shows schematically a portion of a transmission line loaded with the loading units of this invention;

Fig. 4 shows a network equivalent to a single mid-coil terminated section of the system of Fig. 3;

Fig. 5 shows the impedance-frequency characteristics of cables loaded in the ordinary manner and in accordance with the present invention;

Fig. 6 shows schematically a composite type of loaded line of this invention;

Fig. 7 illustrates diagrammatically the usual arrangement of office entrance cable associating two sections of an open-wire line with a two-way amplifying repeater; and,

Fig. 8 shows curves illustrating the application of the invention to a system such as shown in Fig. 7.

If a section of cable or open-wire line in which the series resistance and shunt capacity are the controlling factors, be represented by the equivalent T network shown in Fig. 1, where R is the total series resistance of the section and S and C are respectively the length of the cable section and the capacity for each unit of length, so that the product SC is the total capacity, such a section loaded in the usual manner may be represented by the network shown in Fig. 2, where L is the total inductance of the loading coil. In this case, as is well known, the cut-off frequency of the loaded section is approximately given by

$$f_c=\frac{1}{\Pi\sqrt{LSC}} \qquad (1)$$

The two most common methods of terminating such loaded sections are, respectively, mid-section and mid-coil. In the case of the mid-section termination, the first loading coil is located at a distance equivalent to one-half of the length of a regular loading section from the beginning of the line. Mid-coil termination is obtained by installing at the beginning of the line, a coil having one-half of the inductance of the regular coils, the first full coil being installed at the end of the first complete loading section. The network of Fig. 2 represents a mid-coil terminated section. For cables loaded mid-coil and mid-section respectively the characteristic impedances in the transmission range are given approximately by

$$\Xi_L=\sqrt{\frac{L}{SC}}\ \sqrt{1-\frac{(f)^2}{(f_c)}} \qquad (2)$$

and

$$\Xi_L{}^1=\sqrt{\frac{L}{SC}}\ \frac{1}{\sqrt{1-\frac{(f)^2}{(f_c)}}} \qquad (3)$$

From which it is seen that for mid-coil and mid-section terminations the characteristic impedance is approximately a pure resistance, which varies with the frequencies as a function of the ratio of the frequency to the cut-off frequency.

Referring to Fig. 5 curve B represents the impedance-frequency characteristic of a cable loaded in the ordinary manner (Pupin method) with mid-coil termination, and as shown, the impedance decreases with increasing frequency, approaching zero at the cut-off frequency which for this case is about 2800 cycles per second. Curve A shows the impedance-frequency characteristic for the same type of cable with mid-section termination, and, as shown, in this case the impedance increases with increasing frequency, approaching infinity at the cut-off frequency. Curve C is the impedance-frequency characteristic of a non-loaded open-wire line of approximately the same nominal impedance. It is therefore obvious that if the ordinary type of loading is employed and the loaded cable having either termination is joined directly to a non-loaded open-wire line, large reflections will occur at the junction due to this difference in the impedances.

Fig. 3, shows a line or cable loaded in accordance with the method of this invention in which anti-resonant networks, each of which consists of an inductance coil connected in parallel with a condenser, replace the ordinary type of loading coils. Fig. 4 shows a T type network equivalent to a single mid-coil terminated section of the system of Fig. 3. This type of loading unit, like the usual type, has a low pass characteristic, and its cut-off frequency is approximately

$$f_c=\frac{1}{\Pi\sqrt{L(SC+4C_1)}} \qquad (4)$$

Its nominal impedance is the same as for lines loaded in the usual manner

$$\Xi_0=\sqrt{\frac{L}{SC}} \qquad (5)$$

and is independent of the capacity of the series condensers. The characteristic impedance of a cable terminated at mid-section with this type loading is, for a given nominal impedance and given cut-off frequency, very nearly the same as that of the usual type of loaded line, given by formula (3). While the variation of impedance, taken mid-section, throughout the frequency band is unaltered, this, as hereinafter explained, is advantageous rather than otherwise since it allows a cable of composite loading to be formed. The characteristic impedance of a cable terminated at mid-load (mid-coil) with the anti-resonant type of loading is, however, affected by the series condensers and is approximately

$$\Xi_L=Z_o\sqrt{1-\frac{(f)^2}{(f_c)}}\ \frac{1}{1-\frac{(f)^2}{(f\infty)}} \qquad (6)$$

where $f\infty$, the anti-resonant frequency of the loading network, is

$$f\infty=\frac{1}{2\Pi\sqrt{LC_1}} \qquad (7)$$

Except where this anti-resonant frequency is very close in value to the cut-off frequency, the effect will be to make the characteristic impedance very uniform throughout the transmission band.

Comparing formulæ (6) and (2), it is seen that for the two types of loading the mid-load impedance differs by the factor

$$\frac{1}{1-\frac{(f)^2}{(f\infty)}}$$

and that this factor may be varied over a wide range by a suitable choice of $f\infty$, that is, by a suitable choice of capacity for the condensers.

In Fig. 5 curve D shows the impedance frequency characteristic for a loaded line of the type shown in Fig. 3 in which the anti-resonant frequency is 1.25 times the cut-off frequency, that is,

$$f\infty=1.25f_c$$

For a fixed value of loading coil inductance in each anti-resonant network and fixed spacing of such networks, the cut-off frequency is somewhat lower than for the ordinary type of loading, as can be seen by comparing equation (4) with equation (1), the amount of reduction of the cut-off frequency depending on the choice of anti-resonant frequency of the loading networks. Throughout the effective transmission range the anti-resonant type of loading gives attenuation and phase characteristics which are nearly the same as for the ordinary type of loading, except at frequencies near the cut-off frequency. The difference in transmission characteristics may be roughly expressed by saying that the cut-off frequency is somewhat reduced as compared with the ordinary type loading, although this effect may be minimized or prevented by reducing the loading spacing.

The attenuation and phase characteristics are not always controlling, however, and in certain cases it may be desirable, in an effort to obtain uniform impedance characteristics to sacrifice to some extent the obtaining of good attenuation and phase characteristics. This is particularly true when toll entrance cable or submarine cable must be joined to open-wire lines without causing reflections at the junction points. For example, in a case in which an entrance cable is used to connect a repeater to an open-wire line, the repeater having a cut-off frequency of about 2600 cycles per second and the nominal cut-off frequency of the cable being fixed at 7200 cycles per second, only 36% of the transmission range is used. The impedance of the cable loaded in the usual manner, as shown by curves A and B in Fig. 5 will still be considerably different from that of the open-wire line, as shown by curve C. However, if the anti-resonant network in accordance with the invention is substituted for the ordinary type of loading, and the same value of loading coil inductance and the same spacing are chosen as in the case of ordinary loading sections and the condensers are chosen of such capacity that

$$f_\infty = 1.5 f_c$$

the cut-off frequency of the cable would be 5400 cycles and the impedance of the cable would be practically the same as that of the open-wire line throughout the entire effective transmission range. Also the attenuation and phase shift characteristics would be practically identical with those of the cable loaded in the ordinary manner.

Fig. 6 shows a composite type of loaded line in which some of the sections are loaded with anti-resonant networks and some are loaded in the ordinary manner. This arrangement is possible because the mid-section characteristic impedence with either type of loading may be made very closely the same by choosing the same cut-off frequencies and nominal impedances. The particular advantage of this type of composite loaded line is that the uniform impedance characteristics are desired primarily at the ends of the cable span, that is, at repeater and terminal points. By loading a few sections at either end of the cable span with anti-resonant type of network the terminal impedance of the span of cable may be made to closely approximate a constant value so that it may be connected to terminal or repeater apparatus without reflection losses.

There may conceivably be cases where the attenuation characteristic of the line above the cut-off frequency is important in excluding interfering frequencies induced from extraneous sources, and inasmuch as the anti-resonant network has an attenuation characteristic which rises sharply above the cut-off frequency, as in the case of the corresponding type of low pass filter, this proposed type of loading may be of considerable value from this standpoint. Furthermore, the sections of this type when inserted in the cable, may have different frequencies of anti-resonance, so that the attenuation is maintained high for some distance above the cut-off frequency.

Fig. 7 illustrates diagramatically the usual arrangement of office entrance cable associating an open-wire line with a carrier telephone repeater in a multiplex signal transmission system. The two-way repeater R may be for example of the type disclosed in U. S. Patent 1,413,357, to P. A. Raibourn, issued April 18, 1922. It comprises two one-way repeating channels RW and RE adapted to repeat signaling currents between a west section WL and an east section EL of an open-wire line through entrance cable pairs EC_1 and EC_2.

The signaling currents received at the repeater R over the cable pair EC_1 from line section EL are amplified in the channel RW and the amplified currents are delivered to the line section WL over the cable pair EC_2. Similarly the signaling currents received at the repeater R over the cable pair EC_2 from the line section WL are amplified in the channel RE and delivered to line section EL over cable pair EC_1.

The currents incoming at the repeater from the line section EL are of higher frequencies than those incoming thereat from the line section WL. Accordingly, the respective repeating channels are provided with frequency discriminating filters which direct the incoming currents to the proper channels. The repeating channel RW includes a high pass input filter 1, a one-way amplifying device 2 and a high pass output filter 3. The repeating channel RE includes the low pass input filter 4, the one-way amplifying device 5 and the low pass output filter 6. The directional filters 1 and 3 are designed to transmit currents of the upper group of frequencies to be repeated by the amplifying device 2 and to suppress from transmission currents of lower frequencies, while the directional filters 4 and 6 are designed to transmit currents of the lower group of frequencies to be repeated by the amplifying device 5 and to suppress from transmission currents of higher frequencies. The filters may be of the type disclosed in U. S. Patent No. 1,227,113 to Campbell, issued May 22, 1917.

The repeating paths RE and RW may contain other apparatus than that shown, for example, attenuation equalizers for compensating for unequal attenuation of the transmitted currents of different frequencies.

As the carrier repeater R ordinarily would be located at some distance from the main pole leads of the open-wire line, it is the usual practice to bring in the input and output wires of the repeater through entrance cable which is ordinarily loaded periodically with Pupin loading coils L, as indicated in the drawings, to reduce the attenuation to a minimum. This coil loading is usually designed to have a cut-off at a frequency which is well above the frequencies in the signaling range to be transmitted, in order to prevent reflections. For a range of signaling frequencies up to 30 K. C. the cut-off frequency would be 50 K. C., for example. On the other hand, in order to secure a flat amplifier characteristic for the range of signaling frequencies up to 30 K. C. it may be necessary to transmit fairly efficiently frequencies for a considerable distance above 30 K. C.

If the two entrance cable pairs EC_1 and EC_2 are in close proximity, as would commonly be the case, some electrostatic or electromagnetic induction will take place between them so that there will be a tendency for currents leaving the repeater at a high level to cross over to the opposite pair and reenter the repeater at a lower level. In this way there is a tendency towards regeneration or singing, due to the fact that a circuit may be formed by one side of the repeater, portions of the entrance cable pairs, and the leakage path therebetween.

For the current which travels through the low pass side of the repeater, that is, the channel RE, there is little to worry about from the standpoint of circulating currents due to electrostatic or electromagnetic induction, as the entrance cable pairs would be ordinarily well transposed with respect to each other. At high frequencies, however, the transpositions become less effective and the electrostatic and electromagnetic induction becomes greater. Consequently, it is the current which travels through the high pass side of the repeater, that is, the channel RW (which will be high frequency current) which may be troublesome.

The path of these high frequency circulatory currents may be traced as follows. They will pass as indicated by the arrows from the east line section EL through the cable pair EC_1 to the junction point A of the repeater and thence to the repeating channel RW. In the repeating channel RW these currents will pass through the high pass input filter 1, and after being amplified by the amplifying device 2 will be passed through the high pass output filter 3 to the point B of the repeater. From the point B these currents will pass through the loaded entrance cable pair EC_2 to the west line section WL, and in passing therethrough, will induce a corresponding high frequency current in the adjacent entrance cable pair EC_1, which will pass, as indicated by the arrow, into the repeater at the junction point A, and will be amplified therein. It may be readily seen that such regenerative and singing effects under certain conditions may be such as to prevent proper operation of the system.

The high pass side of the repeater will be effective in transmitting currents to a much higher frequency generally than the maximum conversational frequency. This maximum conversational frequency might be 30 K. C. and the repeater might be efficient up to a frequency in the vicinity of 50 K. C. It would be possible to prevent currents of greater frequencies than 30 K. C. from flowing through this part of the repeater by inserting therein a separate low pass electrical filter. However, the same result may be accomplished by changing the type of loading and giving the entrance cable through which the circulating currents flow the sort of characteristics that a low pass electrical filter would have. In other words, for circulating currents of frequencies between the maximum conversational frequency and the maximum frequency of transmission of the repeater, attenuations may be introduced to circulating currents at any point or points along their path. It may be introduced by a low pass electrical filter cutting off at a frequency of about 30 K. C., or it may be introduced by the use of properly designed loading networks in the entrance cable pairs.

If the loading networks of the invention either the anti-resonant type shown in Fig. 3 or the composite type shown in Fig. 6, are substituted for the coil loading networks L in the system of Fig. 7, the sharply rising attenuation characteristic of these networks above the loading cut-off frequency may be utilized to introduce considerable attenuation in transmitted frequencies in the range between 30 K. C. and 50 K. C., that is, in the range occupied by the harmful circulating currents.

Some of the induction causing circulating currents will take place in each section of the loaded cable, and, for the induction taking place in any particular section, the attenuation to which that particular portion of the circulating currents will be subjected, is that of one circuit of the entrance cable from the repeater down to the point where induction takes place plus the attenuation taking place in the induction process plus the attenuation in the corresponding portion of the entrance cable between the second point of induction and the opposite side of the repeater. For those elements of the circulating currents which are caused by induction at points remote from the repeater, the attenuation will therefore be high; for those elements for which induction takes place at a point close to the repeater the attenuation will be low. On the average, the elements of circulating current will be subjected to a considerable amount of attenuation and consequently the circulating currents will be smaller with the anti-resonant type of loading or the composite type of loading of the invention than with the Pupin type of loading, and the tendency toward regeneration or singing will be minimized.

The advantages which may be obtained by the use of loading networks of the invention in the system of Fig. 7 will be clearer from an examination of the characteristic curves of Fig. 8. In Fig. 8, the curve A_G represents the frequency gain characteristic of the amplifying device 2 in the amplifying path RW. As indicated, it may have a fairly flat gain characteristic over a frequency range extending from the lowest speech frequencies up to a frequency of about 50 K. C. Therefore, the amplifier transmits some distance beyond the maximum conversational frequency of say 30 K. C. The reason for this is generally inherent in amplifier and transformer design. The curve A_P represents the attenuation frequency characteristic for the loading networks L in the system of Fig. 7 corresponding to the well known Pupin loading coils, this characteristic being similar to that of a low pass electrical filter of corresponding structure. The curve designated A_{AR} represents the attenuation frequency characteristic of the anti-resonant loading network, such as shown in Fig. 3, where the frequency of maximum attenuation corresponding to f_m is selected by design. The curve A_C represents a combination of the anti-resonant and the Pupin type of loading, such as shown in Fig. 6, and gives an intermediate characteristic. Because this composite loading network maintains a fairly large attenuation at all frequencies a substantial distance above the minimum conversational frequency it would often be used in preference to the anti-resonant type of network as shown in Fig. 3. It may be seen from the curves of Fig. 8 that the characteristics A_C and A_{AR} rise sharply for frequencies immediately above 30 K. C. while the characteristic A_P representing the Pupin type of loading rises much more gradually above 30 K. C. It may be seen therefore, that either of the loading networks of the invention may be advantageously used in place of the Pupin type loading network in the entrance cable in the system of Fig. 7 to minimize cross-talk effects as well as to obtain additional advantages from the standpoint of impedance constancy explained above.

In loading phantom circuits and side circuits in phantomed systems with the anti-resonant type of loading network the condensers forming a part of the loading network in the side circuit produce no effect as far as the phantom circuit is concerned, and similarly those used in the phantom circuit produce no effect on the side circuits.

What is claimed is:

1. In a wave transmission system, two adjacent two-way transmission paths, means for impressing on said paths signal waves of one frequency range to be transmitted in one direction thereover, and signal waves of a different frequency range to be transmitted in the opposite direction thereover, an amplifier for repeating the waves of said one frequency range over said paths in said one direction while substantially excluding transmission of waves of said other frequency range, a second amplifier for repeating the waves of said other frequency range over said paths in said opposite direction while substantially excluding transmission of waves of said one frequency range, and means for periodically loading said paths so as to obtain substantially uniform, low attenuation in the transmitted waves of all frequencies in said ranges while producing high attenuation in transmitted waves of frequencies at least immediately above the highest frequency in said ranges and thereby effectively reducing undesired interchange of high frequency energy by induction between said adjacent paths.

2. In a wave transmission system, two adjacent two-way transmission paths so arranged that there will be substantially no interchange of low frequency energy by induction therebetween, means for impressing on said paths, waves of one frequency range to be transmitted in one direction thereover, and waves of a different frequency range to be transmitted thereover in the opposite direction, two amplifiers for respectively repeating waves of a different one of the two frequency ranges over said paths to the substantial exclusion of waves of the other frequency range, and means for periodically loading said two-way paths to obtain substantially uniform low attenuation in transmitted waves of all frequencies in both ranges while producing high attenuation in wave frequencies at least immediately above the highest frequency in said ranges.

3. The system of claim 1 and in which said loading means consists of a plurality of loading units connected in series in said paths, each comprising inductance and capacitance in parallel and having an attenuation characteristic which rises sharply above the loading cut-off frequency.

4. The system of claim 1 and in which said loading means comprises a plurality of loading units connected in series with said paths and having sharply increasing attenuating properties in the frequency range above the loading cut-off frequency.

5. The system of claim 1 and in which said loading means consists of a plurality of loading units connected periodically in series along said paths, each of said loading units comprising parallel inductance and capacitance of such values as to make the unit anti-resonant at a frequency substantially greater than the loading cut-off frequency, and to make the unit have a high attenuation for frequencies above the loading cut-off frequency.

6. In combination, two sections of an open-wire line and a two-way repeater interconnecting said sections, means for impressing on said line signal waves of one frequency range to be transmitted thereover in one direction, and signal waves of a different frequency range to be transmitted thereover in the opposite direction, said repeater comprising amplifying means for repeating respectively waves of each frequency range between said line sections to the substantial exclusion of waves of the other frequency range, two two-way cable pairs respectively connecting said line sections to said repeater and in such close proximity as to allow interchange of high frequency energy therebetween and means for periodically loading said cable pairs to obtain substantially uniform low attenuation in transmitted waves of all frequencies in both ranges while producing high attenuation in transmitted waves of substantially all frequencies above said ranges.

7. In combination, two sections of an open-wire line and a two-way repeater interconnecting said sections, means for impressing on said line signal waves of one frequency range to be transmitted thereover in one direction, and signal waves of a different frequency range to be transmitted thereover in the opposite direction, said repeater comprising amplifying means for repeating respectively waves of each frequency range between said line sections to the substantial exclusion of waves of the other frequency range, two adjacent two-way transmission paths respectively connecting said line sections to said repeater, and arranged so that there is substantially no interchange of low frequency wave energy by induction between said paths, and means for periodically loading said paths to obtain substantially uniform low attenuation in transmitted waves of all frequencies in both ranges while producing high attenuation in transmitted waves of substantially all frequencies above said ranges.

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