Aug. 12, 1930. T. E. SHEA 1,772,558

LOADING SYSTEM

Filed June 13, 1927

FIG. 1.

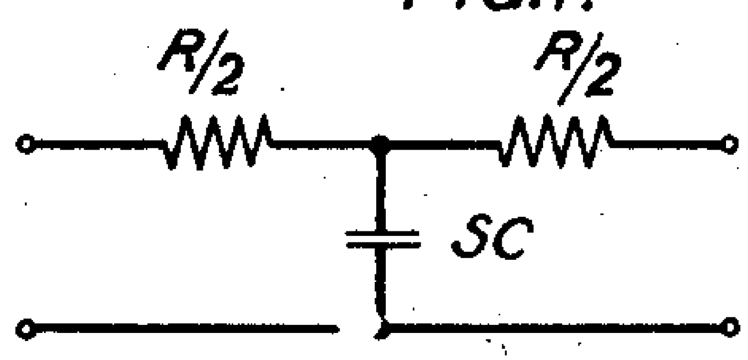


FIG. 2.

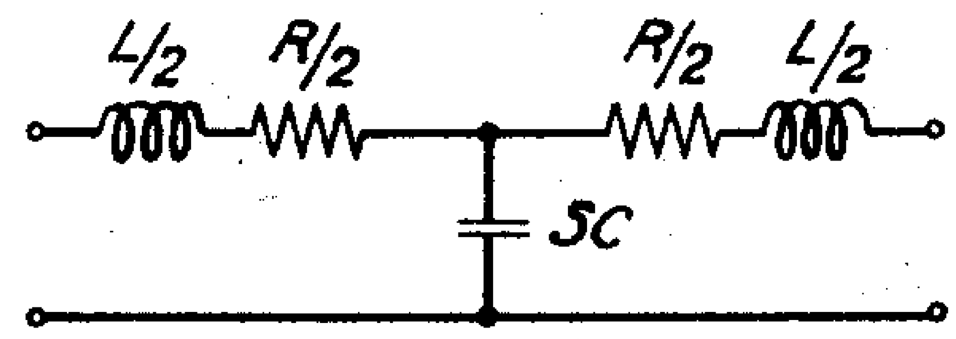


FIG. 3.

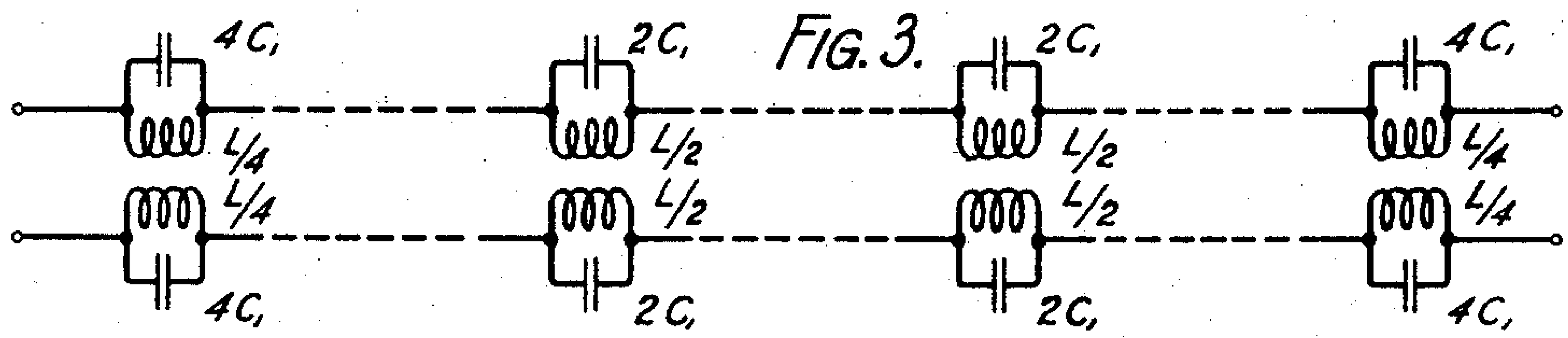


FIG. 4.

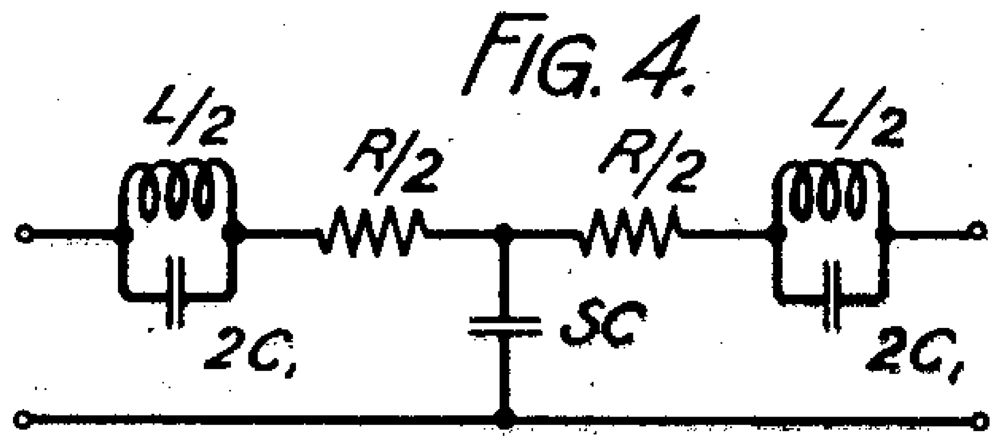


FIG 5.

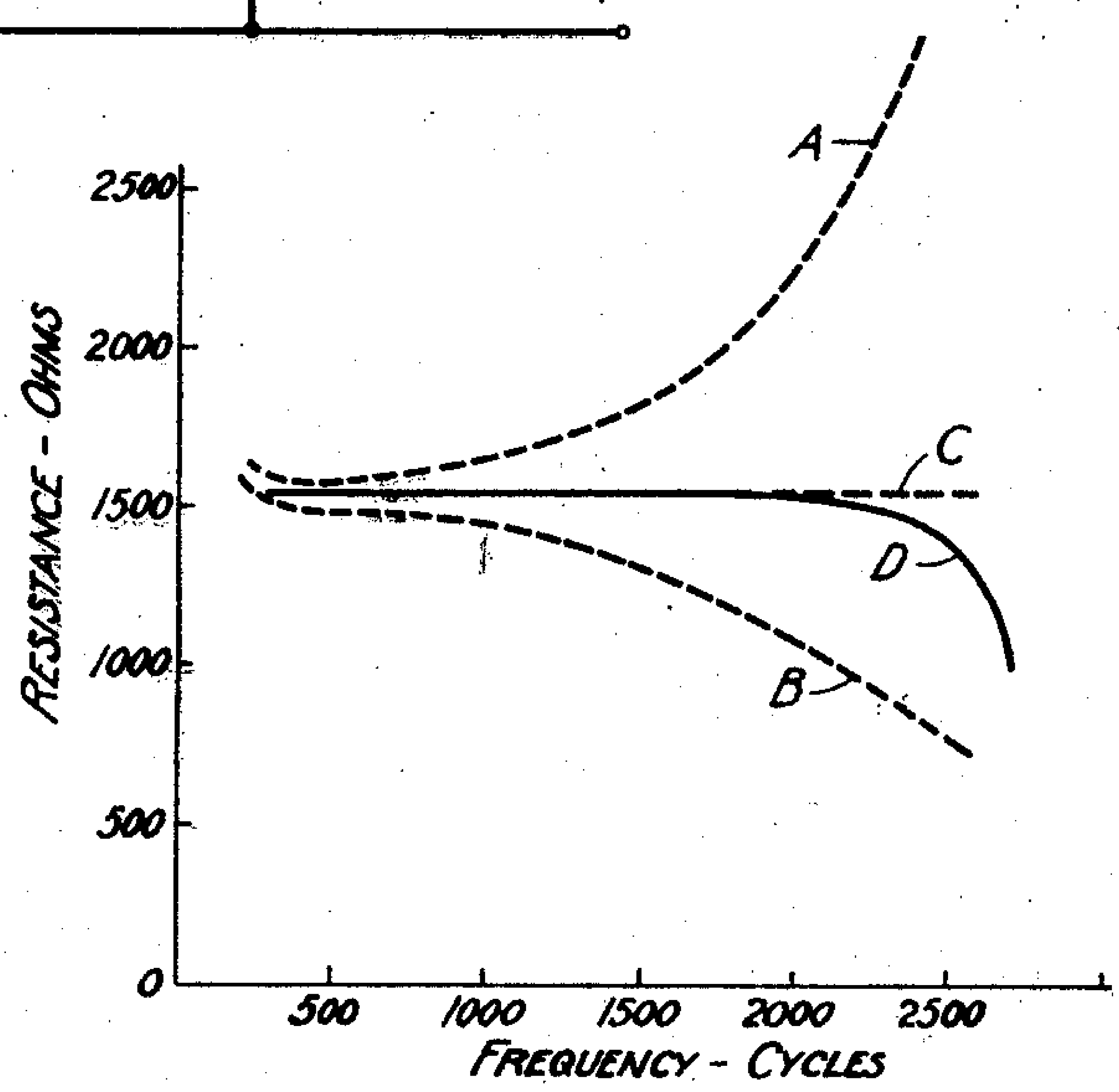
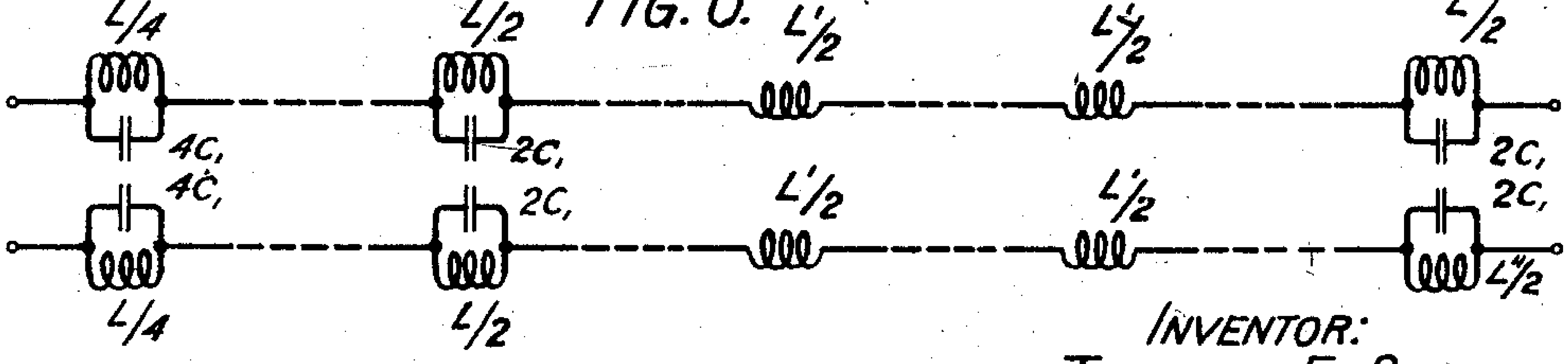


FIG. 6.



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UNITED STATES PATENT OFFICE

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LOADING SYSTEM

Application filed June 13, 1927. Serial No. 198,459.

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

It is well known that the ordinary loaded line has an impedance characteristic which is a practically pure resistance but which varies 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 of line is joined to an ordinary loaded line considerable reflection losses are introduced. In order to avoid such losses and also to simplfy the impedance balancing arrangements 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 line 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.

This invention will be better understood by reference to the following detailed description taken in connection with the accompanying drawing 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; and

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

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

$$f_c = \frac{1}{\pi\sqrt{LSC}} \quad (1)$$

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

$$Z_L=\sqrt{\frac{L}{SC}}\sqrt{1-\left(\frac{f}{f_c}\right)^2} \quad (2)$$

and

$$Z_{L'}=\sqrt{\frac{L}{SC}}\frac{1}{\sqrt{1-\left(\frac{f}{f_c}\right)^2}} \quad (3)$$

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

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

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

$$Z_o=\sqrt{\frac{L}{SC}} \quad (5)$$

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

$$Z_L=Z_o\sqrt{1-\left(\frac{f}{f_c}\right)^2}\quad\frac{1}{1-\left(\frac{f}{f\infty}\right)^2} \quad (6)$$

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

$$f\infty=\frac{1}{2\pi\sqrt{LC_1}} \quad (7)$$

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

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

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 networks in accordance with the invention are substituted for the ordinary type of loading, and the same values 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 impedance 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 the 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.

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. A wave transmission system comprising a plurality of sections of line, inductive means for periodically loading one of said sections in accordance with the Pupin system, and loading networks each comprising inductance and capacity elements connected in parallel with one another for periodically loading another of said sections for substantially the same range of frequencies.

2. A wave transmission system comprising intermediate and terminal sections of line, inductive means for periodically loading said intermediate section according to the Pupin method, and loading networks each comprising inductance and capacity elements connected in parallel with each other for periodically loading one of said terminal sections for substantially the same range of frequencies.

3. A wave transmission system according to the next preceding claim and a loading network for terminating said terminal section and comprising inductance and capacity elements connected in parallel with each other and each having an impedance which is a fraction of the impedance of the corresponding element of said other loading networks.

4. A wave transmission system comprising intermediate and terminal sections of line, inductive means for periodically loading said intermediate section according to the Pupin method, and loading networks each comprising inductance and capacity elements connected in parallel with each other for periodically loading one of said terminal sections for substantially the same range of frequencies, said elements being so proportioned as to give said terminal section substantially the same cut-off frequency as said intermediate section and the impedance of the elements of the terminating network being substantially one-half the impedance of the corresponding elements of the other networks.

5. A method of loading a transmission line,

for waves of a plurality of frequencies, which consists in inserting at regular intervals along the line and in series therewith, networks comprising inductance and capacitance in parallel with each other, and assigning to said networks such values as to cause said networks to become anti-resonant at a frequency which is substantially greater than loading cut-off frequency and greater than any frequency to be transmitted by said line, whereby the line is given a substantially constant impedance throughout a large portion of the transmission frequency range.

6. A method of loading a transmission line for waves of a plurality of frequencies, which consists of inserting at regular intervals along the line and in series therewith, networks comprising inductance and capacitance in parallel with each other, and assigning to said networks such values as to make said networks anti-resonant at a frequency which is substantially 25% greater than the loading cut-off frequency, whereby the line is given a substantially constant impedance throughout a large portion of the transmission frequency range.

7. A loading system comprising line conductors and loading units connected in series with each of said conductors for loading said conductors for waves of a plurality of frequencies, each unit including an inductance and a capacity element of such values as to cause the units to become anti-resonant at a frequency which is substantially greater than the loading cut-off frequency and greater than any frequency to be transmitted over said line conductors whereby the line is given a substantially constant impedance throughout a large portion of the transmission frequency range.

8. A loading system comprising a pair of line conductors and loading units connected in series with each of said conductors for loading said conductors for waves of a plurality of frequencies, said units being disposed at regular intervals along the conductors, each unit including an inductance and a capacity element of such values as to cause the units to become anti-resonant at a frequency which is substantially greater than the loading cut-off frequency and greater than any frequency to be transmitted over said line conductors, whereby the line is given a substantially constant impedance throughout a large portion of the transmission range.

9. A wave transmission system comprising a line, a plurality of loading networks periodically distributed along said line for loading said line for waves of a plurality of frequencies, each of said networks comprising an inductance element and a capacity element connected in parallel with each other, and assigned such values as to cause the units to become anti-resonant at a frequency which is substantially greater than the loading cut-off frequency and greater than any frequency to be transmitted over said line, and a terminating loading network comprising an inductance element and a capacity element connected in parallel with each other, the impedance of each of the elements of said terminating network being the same fraction of the impedance of the corresponding elements of the other loading networks, whereby the line is given a substantially constant impedance throughout a large portion of the transmission frequency range.

10. A wave transmission system according to the next preceding claim in which the impedance of each element of the terminating loading network is substantially one-half of the impedance of the corresponding elements of the other loading networks.

11. A loading system arranged in sections, each of which comprises line conductors and loading units connected in series with said conductors, each unit including an inductance and a capacity element of such values as to give each section a maximum value of attenuation at a frequency above the cut-off frequency and a substantial amount of attenuation for all frequencies higher than the frequency of maximum attenuation throughout a wide range of frequencies.

12. A loading system comprising line conductors and networks for loading said conductors for a band of telephone frequencies, connected in series with each of said conductors, each network including an inductance and a capacity element of such values as to cause the networks to become anti-resonant at a frequency which is substantially greater than the loading cut-off frequency and above the telephone frequency range, whereby the line is given a substantially constant impedance throughout a large portion of said band.

13. A loading system comprising a transmission line and recurrent networks inserted at regular intervals along said line and in series therewith to load said line for a plurality of frequencies to be transmitted, said networks comprising the sole loading elements in said line, each network comprising elements including an inductance and a capacitance in parallel with each other of such values as to cause the network to become anti-resonant at a frequency which is substantially greater than the loading cut-off frequency, each network having the same combination of elements and with the same values as every other network in the line, whereby the line is given a substantially constant impedance throughout a large portion of the transmission range.

In witness whereof, I hereunto subscribe my name this 10th day of June, A. D. 1927.

TIMOTHY E. SHEA.