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CONDUCTOR LOADING SYSTEM

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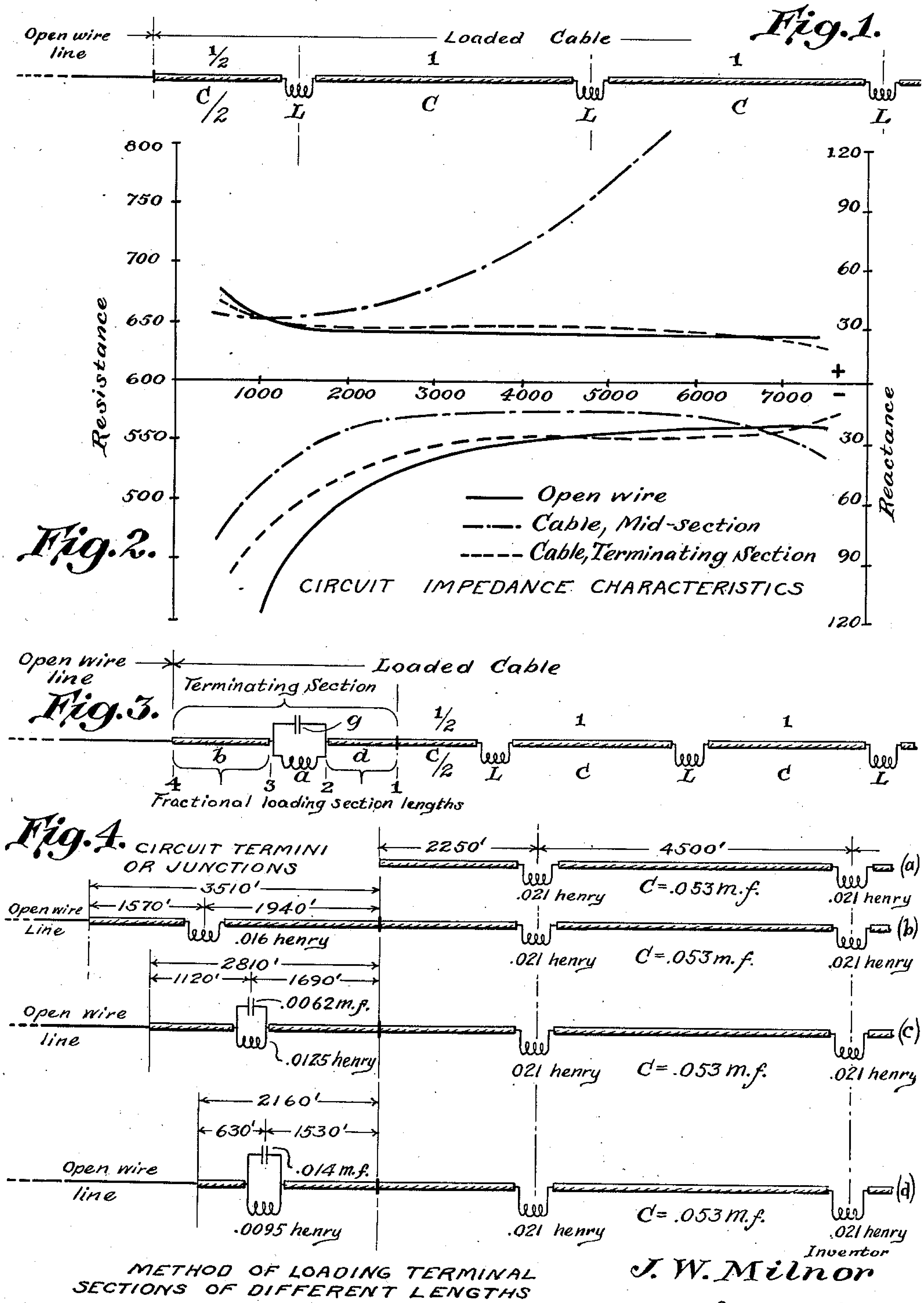

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CONDUCTOR LOADING SYSTEM

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5 Claims. (Cl. 178—45)

This invention relates to loading systems for land line cables used for the transmission of telephone and higher frequency signals and particularly to a system for terminating loaded land line cables so that the resistance and reactance of the loaded cable are substantially constant through the useful range of frequencies and correspond in value to the resistance and reactance of ordinary open wire circuits.

As is well known, cable circuits are loaded in order to reduce attenuation of the high frequency signals and to provide a uniform attenuation over the useful frequency range. This loading is usually in the form of inductance coils inserted at regularly spaced distances, the values of the coils and the distances between coils being determined by the characteristics of the cable and the frequency range which it is desired to transmit. It is necessary, of course, to connect such loaded cable circuits with terminal apparatus having fixed impedance characteristics and also to unloaded open wire lines, in which the impedance is substantially a pure resistance with a small negative angle. At these terminal and junction points it is important to avoid severe impedance discontinuities because of the objectionable reflections which would otherwise occur. To meet this situation it is common to adopt the impedance characteristics of open wire lines as the standard and to design the terminal apparatus and loading systems to provide an impedance equal to that of the open wire lines.

The resistance of open wire lines has the approximate value

$$\sqrt{L/C}$$

in the frequency range where loading is effective and where L and C refer to the inductance and capacity respectively per unit length of line. A system of loading designed for associated cable conductors should have this same nominal value of

$$\sqrt{L/C}$$

for the resistance component and an equivalent reactance.

The principal objective of my invention is to provide a loading system having a combination of terminating elements for a loaded cable such that the impedance looking into the cable will have the above specified characteristics. Another object of my invention is to combine with a mid-section termination of a loaded cable, such additional elements as will produce a substantial coincidence of impedance characteristics looking into the loaded cable and the impedance characteristics of an open wire line over a wide frequency range. These and other objects of my invention will become apparent upon consideration of a number of examples of practice according to the invention.

In the accompanying drawing, Figure 1 is a diagram of a loaded cable terminating in mid-section and connected to an open wire line; Fig. 2 is a diagram showing the impedance characteristics looking into the loaded cable together with the impedance characteristics of an open wire line; Fig. 3 is a diagram of a loaded cable shown in Fig. 1, but having the mid-section termination supplemented in accordance with my invention by additional terminal elements, e. g.: in a combination of four elements; namely, fractional cable sections b and d and the fractional loading coil a in parallel with a condenser g; and Fig. 4 shows detailed diagrams illustrating the principles involved in the practice of my invention.

For the purpose of explaining the principles involved in the termination of loaded cables according to my invention, as illustrated in Fig. 3, I shall first show how the impedance looking into the loaded cable is derived and how the values of the quantities b, d, a, and g, in terms of the unit values of L and C, per loading section are determined. Several combinations of values are developed herein, the final choice of any particular condition depending upon the fractional length of cable conveniently available at the end of the loaded section and also the values of the coils that are available.

Referring to Fig. 3, b and d are fractional loading section lengths and g is a condenser, all expressed as fractions of full section lengths, and a is a fractional loading coil. An expression for the impedance looking into a long loaded cable as measured at (1) is:

$$Z_1=\sqrt{L/C}\Big/\sqrt{1-\frac{\omega^2LC}{4}}$$

If L and C be each taken as unity, this expression becomes

$$Z_1=\frac{1}{\sqrt{1-\omega^2/4}}$$

The impedance measured at the point (2) is

$$Z_2=\frac{\frac{1}{j\omega d}\cdot\frac{1}{\sqrt{1-\omega^2/4}}}{\frac{1}{j\omega d}+\frac{1}{\sqrt{1-\omega^2/4}}}$$

Multiplying the numerator and the denominator by

$$j\omega d\sqrt{1-\omega^2/4},$$

this becomes:

$$Z_2=\frac{1}{j\omega d+\sqrt{1-\omega^2/4}}$$

The impedance of the parallel combination of coil a and condenser g is:

$$Z_x=\frac{j\omega a}{1-\omega^2 ag}$$

and the impedance at point (3) then becomes:

$$Z_3=\frac{j\omega a}{1-\omega^2 ag}+\frac{1}{j\omega d+\sqrt{1-\omega^2/4}}$$

The impedance at point (4) is:

The foregoing table gives a range of coil sizes which may be used to load terminal lengths $(b+d)$ of cable ranging from .4 to .73 of a section length. Below these values the element b approaches zero, while above them the element g becomes negative and the relations no longer apply.

In order to show the practical application of the invention under different conditions, I have given in Fig. 4, several examples of terminating sections. In this case a full length section is 4500 feet and the full sized coil is 21 millihenries. It is apparent that within the range of values indicated in the table it is possible to accommodate a large variety of fortuitous lengths of terminating sections.

$$Z_4=\frac{\dfrac{1}{j\omega b}\cdot\dfrac{j\omega a(j\omega d+\sqrt{1-\omega^2/4})+1-\omega^2 ag}{(1-\omega^2 ag)(j\omega d+\sqrt{1-\omega^2/4})}}{\dfrac{1}{j\omega b}+\dfrac{j\omega a(j\omega d+\sqrt{1-\omega^2/4})+1-\omega^2 ag}{(1-\omega^2 ag)(j\omega d+\sqrt{1-\omega^2/4})}}=\frac{1+j\omega a\sqrt{1-\omega^2/4}-\omega^2 ad-\omega^2 ag}{(1-\omega^2 ag-\omega^2 ab)\sqrt{1-\omega^2/4}+j\omega(b+d)-j\omega^3(adg+abd+abg)}$$

Making $s=j\omega$, the foregoing becomes:

$$Z_4=\frac{1+sa\sqrt{1+s^2/4}+s^2(ad+ag)}{[1+s^2(ab+ag)]\sqrt{1+s^2/4}+s(b+d)+s^3(abd+adg+abg)}$$

It is desired that Z_4 shall be equal to the nominal impedance of the loaded line for all values of s, i. e.

$$Z_4=\sqrt{L/C}$$

With L and C each equal to unity this expression becomes:—

$$Z_4=1, \text{ or}$$

$$[1+s^2(ab+ag)]\sqrt{1+s^2/4}+s(b+d)+s^3(abd+adg+abg)=1+sa\sqrt{1+s^2/4}+s^2(ad+ag)$$

Expanding the radical:

$$\sqrt{1+s^2/4}:—$$

$$\sqrt{1+s^2/4}=1+s^2/8-s^4/128+s^6/1024\ \ldots,$$

and substituting in the preceding expression—

$$1+s(b+d)+s^2[1/8+a(b+g)]+s^3a(bc+dg+bg)+s^4[a/8(b+g)-1/128]+s^6[1/1024-a/128(b+g)]=1+sa+s^2a(d+g)+s^3a/8-s^5a/128$$

Equating the algebraic sum of the coefficients of like powers of s to zero from the first three powers.

From s coefficients, $a=b+d$ (1)

s^2 coefficients, $d-b=1/8a$ (2)

s^3 coefficients, $db+dg+bg=1/8$ (3)

From these equations the values of b, d, and g, in terms of a are found to be

$$b=\frac{8a^2-1}{16a}$$

$$d=\frac{8a^2+1}{16a}$$

$$g=\frac{1}{8a}+\frac{1}{256a^3}-\frac{a}{4}$$

If we assume various values of a, and solve for values of b, d, and g corresponding to a range of coil sizes a, we have:

a	b	d	g
0.40	0.0437	0.356	0.273
.45	.089	.367	.211
.50	.125	.375	.156
.55	.161	.388	.113
.60	.196	.404	.076
.65	.229	.421	.044
.73	.276	.446	.000

The impedance characteristics of a standard No. 9 copper open wire line including both the resistance and reactance components are shown in Fig. 2. On this figure there are also included the impedance characteristics of a section of a loaded cable terminated in a terminating section, as illustrated in Fig. 4 (c), using the following values:

a=.597L=.0125 henry
b=.25 unit length=1120′
d=.37 unit length=1690′
g=.118C=.0062 mf.

where C=.053 mf. and L=.021 henry per section length of 4500′. These curves take into account coil and line resistance. These additional factors have required small modifications in the cable lengths and coil sizes from the values originally determined.

The terminating sections herein described would be used for terminating all sections of loaded cable at office terminals, open wire junctions, or patching points. These sections would not normally be used other than at such locations although two of them back to back may be used for loading short sections of cable.

It is, of course, possible to extend the apparent length of cable by means of building-out condensers or cable according to well understood practices. While I have indicated schematically single conductors, for the purpose of description, it is to be understood that the indicated inductance is divided between the two wires of the pair of conductors, or the four wires of a phantom circuit in accordance with common practice.

In the foregoing description, I have disclosed a method of terminating sections of loaded cable in a three or four element combination and which provides a resistance component that is substantially constant with respect to frequency and approximately equivalent to that of the standard open wire line. At the same time the reactance characteristic is considerably improved over that of the half-section termination. This system has the further advantage that with a small selection of fractional coils available, it is possible to terminate cables having various fractional lengths and yet obtain satisfactory impedance characteristics. Cables so terminated can thus be joined to open wire sections without impedance discontinuities or may be connected at terminals to apparatus comprising substantially pure resistance.

I claim:—

1. A signaling system comprising a loaded transmission line consisting of unit length cable sections and unit inductance loading coils inserted at regular intervals between said sections in series with the conductors of the cable sections and a terminating system comprising, in order, a fractional cable section, a fractional loading coil, and a second fractional cable section.

2. A terminating system for a loaded line as in claim 1, comprising a fractional cable section, a fractional loading coil shunted by a condenser and a fractional cable section.

3. The combination of a signaling system comprising a loaded transmission line consisting of unit length cable sections and unit inductance loading coils inserted at regular intervals between said sections in series with the conductors of the cable sections, said loaded line terminating in a mid-section of a unit length cable section, and a terminating system comprising, in order, a fractional cable section smaller than a half section, followed by a fractional coil and a second fractional cable section.

4. A transmission line comprising in sequence along its length, conductor cable sections of normal shunt capacity C, and alternate coils of normal inductance value L, an unloaded open wire line having the ratio of its inductance to its shunt capacity per unit length equal to L/C, and a terminating section for the loaded cable portion connecting the loaded and unloaded line portions, comprising a cable section of one-half unit length, and a network comprising two fractional cable section elements, and an inductance element and a capacity element connected in parallel with each other, said elements being assigned such values as to cause the impedance characteristics looking into the cable to be substantially equal to the impedance characteristics of the open wire line over a predetermined range of frequencies.

5. In a system for the transmission of telephone and higher frequency signals, comprising a transmission line having in sequence along its length, alternate inductance loading coils and cable conductor sections and ending in a mid-section, a termination system for connecting said line to terminal apparatus or to an unloaded open wire line comprising an inductance element and a capacity element connected in parallel to each other and two fractional cable section elements, each said elements having a value less than the normal value of that element in the transmission line, such values being assigned as to cause the impedance characteristics looking into the cable to be substantially equivalent to those of the open wire line over the transmitted range of frequencies.

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