

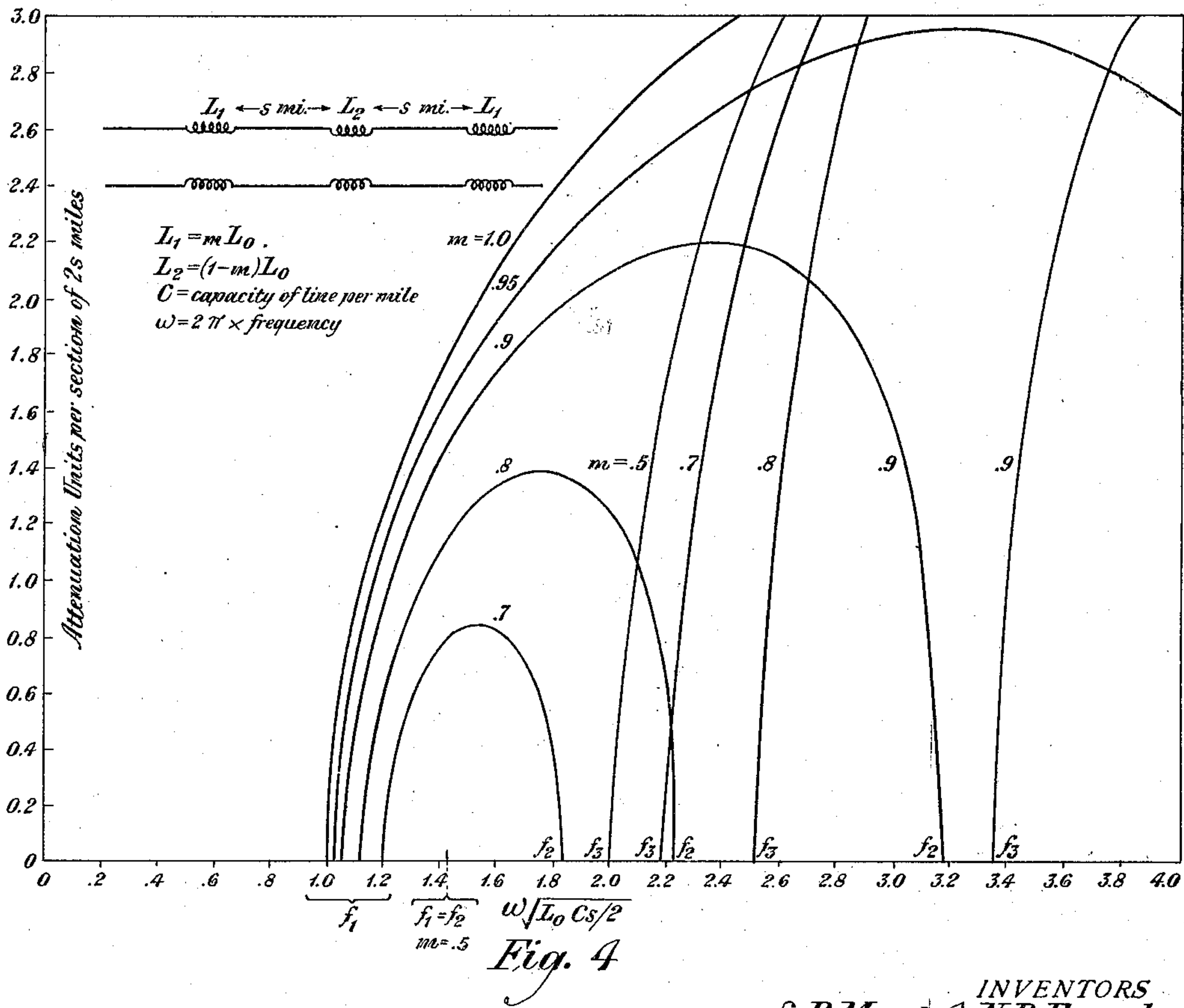
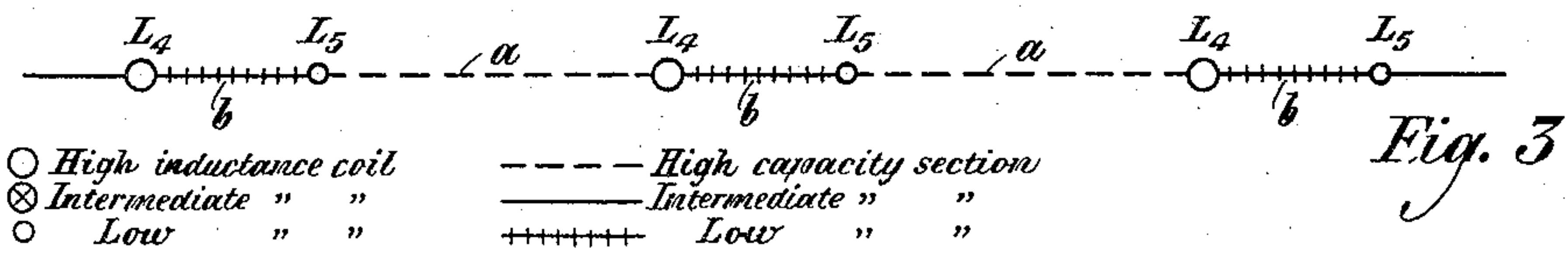
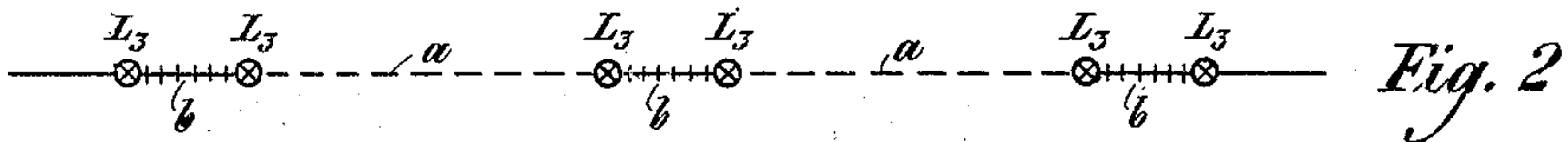
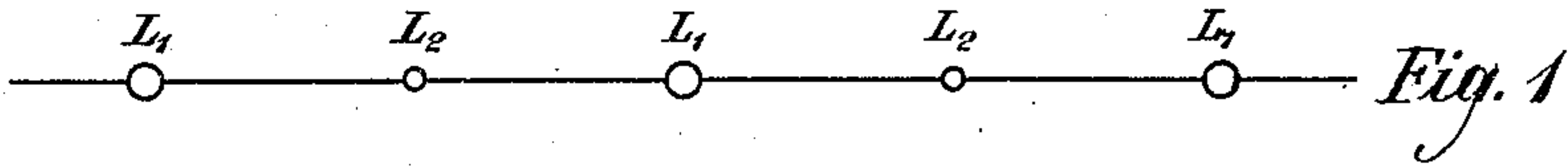
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LOADING SYSTEM

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LOADING SYSTEM

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This invention relates to compound loading systems and particularly to a system of that type having its elements so proportioned as to provide a plurality of signaling channels, each representing a band of frequencies separated from each other.

The copending application of N. R. French, Serial No. 68,692, filed November 12, 1925, which issued as Patent No. 1,741,926 on Dec. 31, 1929 discloses a compound system of loading characterized by the fact that each loading coil has an inductance value different from that of the coils connected with the same circuit at adjacent loading points thereon, the alternate coils having the same inductance value. By means of such a system of loading it is possible to give to a loaded cable circuit the same impedance and the same critical frequency as possessed by a loaded open-wire line connected with the cable circuit. In such a system no impedance irregularity exists at the junction point between the open wire and the cable, and furthermore, the system permits spacing of the coils so that they may be spliced into the cable at the same loading points at which the loading coils are connected with the trunk circuits which are made up entirely of cable conductors.

It has been found that by proper proportioning of the various factors involved in a system of compound loading the system may be made to have two bands of transmission separated by a band of suppression, the width of the latter being controllable.

Our invention resides in a compound system of loading which is so proportioned as to have two distinct bands of transmission whose separation may be varied within limits.

This invention will be clearly understood from the following description when read in connection with the attached drawing, in which Figures 1, 2 and 3 illustrate schematically various types of compound loading, and Fig. 4 is a graph which serves to show how

the bands of transmission and suppression may be varied.

In Fig. 1, L_1 represents a loading coil of relatively large inductance and L_2 a coil of smaller inductance. As indicated in the figure these coils alternate throughout the length of the loaded conductor. The arrangement shown in Fig. 1 represents the loading upon a cable circuit having uniformly distributed capacity throughout. The distance between adjacent loading coils is likewise the same throughout the length of the cable.

It has been found that in the simple loading systems, such as are common at the present time, in which coils of substantially equal inductance are connected with the cable circuit at equal distances apart, the resulting loaded circuit has only one transmitting range from zero to the critical frequency. This critical frequency depends only on the inductance and the spacing of the loading coils. This simple loading also represents a limiting case of compound loading where the total inductance of a loading section is concentrated in each alternate loading coil, which result is obtained by reducing to zero the inductance of the coil between adjacent alternate coils.

The nature of our invention will be apparent if we assume that a small part of the inductance of a simple loading system is taken from the loading coil at each end of the loading section and placed at the center, keeping the total inductance per compound loading section the same. It will be found that,

(1) An additional transmitting band will be introduced above the original critical frequency.

(2) The width of this secondary transmitting band and its position in the frequency spectrum can be expressed as a function of the ratio of inductance of the lower inductance coil and the adjacent higher induc-

tance coil. It is convenient to use the mid-frequency of the secondary transmitting band as a definition of the position of this band in the frequency spectrum.

(3) The amount of attenuation of the suppression band (the non-transmitting band between the primary and secondary transmitting bands), depends also on the ratio of the coil inductances.

(4) The width of the voice-frequency band will be increased slightly.

Assuming that more inductance is taken from the large coil and added to the adjacent low inductance coil, the total remaining the same, the four items mentioned above will be modified as follows:

(1) The additional band mentioned above will remain.

(2) Its width will be increased and its mid-frequency lowered.

(3) The attenuation in the suppression band will be smaller.

(4) The width of the voice-frequency band will be increased further.

If this process of removing inductance from one coil and adding it to the other is continued until the inductance of both coils is the same, the compound loaded circuit will reduce to a simple loaded circuit with coils having half the inductance and half the spacing of the original simple system. The characteristics of such a system would be as follows:

(1) The secondary transmitting band will remain until the inductance of the two coils becomes equal whereupon it will merge with the primary transmitting band.

(2) Its width will continue to increase and its mid-frequency will become lower until it merges with the primary band.

(3) The attenuation of the suppression band will continue to diminish and will finally become zero when the secondary transmission band becomes confluent with the primary transmitting band; that is, the suppression band disappears.

(4) The primary transmitting band becomes confluent with the secondary band and this combined band has a width twice that of the original transmitting band.

It will be seen from the above that the width and mid-frequency of the secondary transmitting channel can be controlled by merely varying the inductances of the two loading coils used in the compound system. However, it should be noted that if the ratio of inductances of the two coils is varied, the primary critical frequency of the circuit will also vary. For a given loading coil spacing, any two of the three factors, primary band width, secondary band width or nominal impedance, may be fixed but not all three; for example, if it is desired to apply compound loading to a line so as to obtain a voice fre-

quency channel of a certain width and also to obtain a certain nominal line impedance, it is not possible to regulate the secondary band since certain values of coil inductance and spacing are required to give the correct primary band width and nominal impedance.

The foregoing description shows the application of the invention to a system employing unequal inductances equally spaced along conductors of uniform capacity. The invention may also be applied to the arrangement shown in Fig. 2 which represents a loading system having coils of equal inductance values and adjacent loading sections of unequal capacities. In this figure the coils L_3 have inductance values intermediate to those described in connection with Fig. 1. The sections of the cable designated a have high capacity and those designated b have low capacity.

This system behaves exactly the same as that shown in Fig. 1, if it is assumed that instead of having loading sections with constant capacities and variable coil inductance ratios (as in Fig. 1), the system has loading sections of constant inductance and variable capacity ratio. Comparing this system with that of Fig. 1 on the same basis:

(1) Starting with zero capacity of the cable section b between the two coils in a compound loading section (equivalent to a simple loading system with two equal loading coils at the end of each section) and increasing the capacity in the same manner as the inductance in Figure 1, the secondary transmitting band will be introduced as soon as capacity is inserted between the two coils. The band will remain until the capacities between the coils are equal, in which case the compound loading becomes simple loading again.

(2) The width of the secondary band will increase and its mid-frequency decrease until the band becomes confluent with the primary band.

(3) The attenuation of the suppression band will become successively smaller until the secondary band merges with the primary band.

(4) The width of the primary transmitting channel will increase until it merges with the secondary channel, its width then being twice the original value.

The arrangement shown in Fig. 3 represents a loading system in which the adjacent coils having unequal inductance and the adjacent loading sections have unequal capacities. The coils of unequal inductances are designated L_4 and L_5 , and the sections of unequal capacities are designated a and b , section a being of larger capacity than section b .

It will have been noted from the description of Fig. 2 that the secondary transmitting band is widest when the inductances of

the two loading coils are equal and when the spacings are equal. Hence, starting with this as the extreme case, varying either the ratio of the inductances or capacities, or both, will cause the width of the band to decrease. As its width decreases, its mid-frequency will increase and the attenuation of the suppression band will become larger and the width of the voice-frequency channel will decrease until it reaches approximately one-half its original value.

The method of obtaining a plurality of channels of transmission by means of compound loading of a signaling circuit and the manner of controlling the width of the band of suppression separating the transmission bands will now be described. The description of the method will be limited to the system of loading shown schematically in Fig. 1 inasmuch as this system is of the greatest practical importance.

The method consists of alternating inductance loads of unequal values, the ratio $m/(1-m)$ of the inductance units L_1 and L_2 to be determined by the desired location of the critical frequencies f_1 , f_2 and f_3 , in accordance with the proportion

$$f_1:f_2:f_3 = \sqrt{1-m} : \sqrt{m} : 1.$$

The lower band, the usual one, extends from 0 to f_1 , assuming that $m \geq .5$, while a comparatively narrow additional transmitting band is introduced from f_2 to f_3 . The suppression band extends from f_1 to f_2 .

The line under consideration is a smooth (non-loaded) cable of propagation constant γ per mile and of characteristic impedance Z_0 , with negligible distributed inductance and with loading inductance L_1 and L_2 of impedances Z_1 and Z_2 , respectively, alternating at intervals of s miles as shown on the accompanying drawing. A complete section (including the loading impedance z_1+z_2) is then $2s$ miles long. Such a system has, in general, three critical frequencies exclusive of zero, which divide the frequency range as follows. If L_1 is the larger inductance, the lowest or principal critical frequency f_1 is that of a line with impedance loads Z_1 at intervals of $2s$ miles. There is then an attenuating band above this frequency and extending to the critical frequency f_2 , which is that of a line with loads of impedance Z_2 at intervals of $2s$ miles. The additional transmitting band extends from f_2 to the third critical frequency f_3 , which depends upon both loads. The region from f_3 to ∞ is an attenuating band.

The disposition of the transmitting and attenuating bands will be clear on reference to Fig. 4 of the accompanying drawing. Thus, when any inductance L_2 is introduced, a narrow transmitting band results. The position of this band on the frequency scale be-

comes lower and its width somewhat wider as L_2 is increased, until, when L_2 is equal in value to L_1 , the secondary band is confluent with the principal band. (The point of confluence is indicated by the cross on Fig. 4.)

It is evident from the figure that when the total loading inductance per section is kept constant, an additional effect of transferring some of the load to the mid-point of the section is to raise the principal critical frequency of the line somewhat. If, however, the original load is maintained and additional inductance of a smaller amount introduced at the mid-points, the original critical frequency remains unchanged.

Method of design

The critical frequencies of the system, as stated above, are in the proportion,

$$f_1:f_2:f_3 = \sqrt{1-m} : \sqrt{m} : 1 \quad (1)$$

where

$$Z_1 = i\omega L_1 = i\omega m L_0$$

$$Z_2 = i\omega L_2 = i\omega (1-m) L_0$$

$$f_1 = \frac{1}{\pi \sqrt{2mL_0Cs}} \text{ or } \omega_1 = \frac{1}{\sqrt{m}} \omega_0 \quad (2)$$

$$\omega_0 = \sqrt{2/L_0Cs}$$

$$1 \geq m \geq 0.5$$

The percentage band width W , defined below, is then

$$W = \frac{f_3 - f_2}{(f_3 + f_2)/2} = 2 \frac{1 - \sqrt{m}}{1 + \sqrt{m}} \quad (3)$$

It will be observed from Equations (1) and (2) that there are only two arbitrary constants (m and ω_0) so that only two of the critical frequencies may be arbitrarily fixed or the ratio of any two determines the relative value of the third. In fact, the factor m determines the relative disposition of the transmitting bands (as shown in Fig. 4) while, with it, the factor ω_0 fixes them absolutely. Equations (1) and (2) (or (2) and (3)) do not completely determine the loading design, however, for only the product $2L_0Cs$ is fixed by them. The separate values of total inductance L_0 and total capacity $2Cs$ per section will be determined by practical considerations other than the location of the critical frequencies. Some examples of the application of the formulæ follow.

Example 1

Given

$$f_1 = 4000$$

$$f_2 = 8000$$

Then

$$m = .8$$

and

$$f_3 = 8940$$

giving a signaling channel 940 cycles wide.

It will be observed from the drawing that the attenuation between the two transmitting bands in this case reaches about 1.4 units per sections of 2s miles.

Example 2

Required, a secondary channel of 10 per cent band width with mid-frequency at 20,000 cycles.

From (3)

$$m = 0.819$$

and from (1) since

$$f_3 = 21,000$$

$$f_1 = 8,950$$

Example 3

Required, a 5 per cent band width with principal critical frequency at 4,000 cycles.

From (3)

$$m = .904$$

and from (1) the mid-channel frequency is

$$\frac{f_2 + f_3}{2} = \frac{1}{2} \frac{1 + \sqrt{m}}{\sqrt{1 - m}} f_1 = 12,600.$$

The channel is then 630 cycles wide and might be utilized as a telegraph or picture-transmission channel. An 800-cycle channel with mid-frequency at 10,000 cycles ($m = .852$) is obtainable on a line with principal cut-off at 4,000 cycles and would be superior to the preceding for picture transmission.

Example 4

Required:

$$f_3 - f_2 = 800$$

$$f_1 = 2,000$$

Then from (1), putting $(f_3 - f_2)/f_1 = r$

$$m = \left(\frac{1 - r^2}{1 + r^2} \right)^2 = .525$$

$$f_2 = 2,100$$

This is a case of a very narrow attenuating band due to a comparatively slight difference between the loads. From formulæ (24) below, however, it follows that the attenuation reaches .1 unit per section. As the cut-off is sharp, this would be a quite distinct attenuating band.

Derivation of formulæ

The above conclusions are based upon the derivation of the critical frequencies from the formula for the propagation constant Γ of a 2s mile section of the system. The constant Γ is most easily derived by obtaining the difference equation of the voltages as follows:

The voltage V_q in the qth section is expressible as

$$V_q = M \exp(-q\Gamma) + N \exp(q\Gamma) \quad (4)$$

Here M and N are arbitrary constants determined by the terminal conditions.

If the typical section is made up of two networks A and a (as the present line may be regarded) whose one and two point admittances are denoted by A_{11} , A_{22} , A_{12} , A_{21} and a_{11} , a_{22} , a_{12} , a_{21} , respectively, the following relations hold between the currents and voltages at the junctions of the networks. I_q and V_q will denote the current and voltage at the junction of the qth and $(q+1)$ th sections, while i_q and v_q denote the current and voltage respectively at the junction point of the two networks within the qth section. The currents I_q and i_q at each of the two kinds of junction points are expressed first in terms of the admittances of network A and then of network a . Thus,

$$I_q = A_{11}V_q - A_{21}V_{q+1} = a_{12}V_q - a_{22}V_q \quad (5)$$

and

$$i_{q+1} = A_{12}V_q - A_{22}V_{q+1} = a_{11}V_{q+1} - A_{21}V_{q+1} \quad (6)$$

In the present instance the network a represents the smooth line of length s miles and characteristics γ , k terminated by an impedance Z_1 and the network A represents the smooth line of length s miles and characteristics γ , k terminated by the impedance Z_2 . Hence the admittances are given by the expressions

$$a_{11} = (k \cosh \gamma s + Z_1 \sinh \gamma s) / k D_1$$

$$a_{12} = a_{21} = 1/D_1$$

$$a_{22} = \cosh \gamma s / D_1$$

$$A_{11} = (k \cosh \gamma s + Z_2 \sinh \gamma s) / k D_2$$

$$A_{12} = A_{21} = 1/D_2$$

$$A_{22} = \cosh \gamma s / D_2$$

$$D_1 = k \sinh \gamma s + Z_1 \cosh \gamma s$$

$$D_2 = k \sinh \gamma s + Z_2 \cosh \gamma s$$

These follow from the usual expression for the current (I_x) in response to unit voltage at any point, x , on a transmission line having known impedances Z_s and Z_R at the sending and receiving ends respectively.

Briefly I_x may be derived as follows: writing the general expressions (see Fleming "Propagation of electric currents," Equations (19) and (20), 3rd edition) for the potential and current at all points, x , of the smooth cable of lengths s miles,

$$V_x = A \exp(-\gamma x) + B \exp(\gamma x)$$

$$I_x = \frac{1}{k} (A \exp(-\gamma x) - B \exp(\gamma x))$$

the two terminal conditions

$$V_o = 1 - Z_s I_o$$

and

$$V_s = Z_R I_s$$

determine the arbitrary constants A and B .

Substituting these values in I_x above gives the required equation

$$I_x = \frac{1}{k} \frac{k \cosh \gamma(s-x) + Z_R \sinh \gamma(s-x)}{(Z_R + Z_S) \cosh \gamma s + \left(k + \frac{Z_R Z_S}{k}\right) \sinh \gamma s} \quad (6)$$

Since $a_{12} = a_{21}$ and $A_{12} = A_{21}$, on substituting the value of v_q obtained from Equation (6) in Equation (5), the latter becomes

$$V_q - 1 - u V_q + V_{q+1} = 0 \quad (8)$$

where

$$u = \frac{(A_{11} + a_{22})(a_{11} + A_{22}) - a_{12}^2 - A_{12}^2}{a_{12} A_{12}} \quad (9)$$

Then writing the expression for V_q in terms of Γ (Equation 4) in the difference Equation (8) of the voltages, gives

$$\cosh \Gamma = u/2 \quad (10)$$

On substituting the values given by Equa-

tive. Consequently, letting L and C represent the inductance and capacity, respectively, of the smooth line per mile,

$$\gamma = i\omega\sqrt{LC} \quad (13)$$

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

where

$$\omega = 2\pi X \text{ frequency} \quad (13)$$

Furthermore, it is assumed that L is quite small as compared to the loading inductance and so small, absolutely, that,

$$\begin{aligned} \cos \omega\sqrt{LC}s &= 1 \\ \sin \omega\sqrt{LC}s &= \omega\sqrt{LC}s \end{aligned} \quad (14)$$

Now in the transmitting range α is zero, so that from (12),

$$\cosh \frac{\Gamma}{2} = \cos \frac{\beta}{2} \quad (15)$$

Substituting this and Equations (13) and (14) in (11) gives

$$\cos^2 \frac{\beta}{2} = \left(1 - \frac{\omega^2 m L_o C s}{2}\right) \left(1 - \frac{\omega^2 (1-m) L_o C s}{2}\right) \quad (15)$$

tion (7) for the admittances and simplifying, Equation (10) becomes

where L_o is the total loading inductance per section

$$\cosh \Gamma = 2 \cosh^2 \gamma s - 1 + \frac{Z_1 Z_2}{2k^2} \sinh^2 \gamma s + \frac{Z_1 + Z_2}{k} \sinh \gamma s \cosh \gamma s \quad \text{and}$$

$$(L_o = L_1 + L_2), \quad 0.5 \leq m \leq 1, \quad (16)$$

or

$$\begin{aligned} Z_1 &= i\omega m L_o \\ Z_2 &= i\omega (1-m) L_o \end{aligned}$$

$$\cosh \Gamma/2 = \sqrt{\left(\cosh \gamma s + \frac{Z_1}{2k} \sinh \gamma s\right) \left(\cosh \gamma s + \frac{Z_2}{2k} \sinh \gamma s\right)} \quad (11)$$

This is the required formula for the propagation constant Γ .

Since the limiting values of $\cos \beta/2$ are -1 and $+1$, it is evident that

Representing by α the attenuation and by β the phase change per section, gives

$$0 \leq \cos^2 \frac{\beta}{2} \leq 1 \quad (17)$$

and

$$\Gamma = \alpha + i\beta$$

and the critical frequencies $f_c = \omega_c/2\pi$ are determined by the equations

$$\left(1 - \frac{\omega_c^2 m L_o C s}{2}\right) \left(1 - \frac{\omega_c^2 (1-m) L_o C s}{2}\right) = 1 \quad (18)$$

and

$$\left(1 - \frac{\omega_c^2 m L_o C s}{2}\right) \left(1 - \frac{\omega_c^2 (1-m) L_o C s}{2}\right) = 0 \quad (19)$$

$$\cosh \frac{\Gamma}{2} = \cosh \frac{\alpha}{2} \cos \frac{\beta}{2} + i \sinh \frac{\alpha}{2} \sin \frac{\beta}{2} \quad (12)$$

To locate the critical frequencies, it is assumed, as usual, that the line is non-dissipa-

Equation (19) gives the two values $f_c = f_1$ or f_2 where

$$f_1 = \frac{1}{\pi \sqrt{2mL_oCs}} \text{ or } \omega_1 = \frac{1}{\sqrt{m}} \omega_o \quad (20)$$

$$f_2 = \frac{1}{\pi \sqrt{2(1-m)L_oCs}} \text{ or } \omega_2 = \frac{1}{\sqrt{1-m}} \omega_o \quad (21)$$

where

$$\omega_o = \sqrt{2/L_oCs}$$

and Equation (18) gives the two additional values

$$f_c = 0 \text{ or } f_3 \quad (22)$$

where

$$f_3 = \frac{1}{\pi \sqrt{2m(1-m)L_oCs}} \text{ or } \omega_3 = \frac{1}{\sqrt{m(1-m)}} \omega_o \quad (23)$$

Hence there are two ranges of frequency in which $\cos^2 \frac{\beta}{2}$ as determined by Equation (15) takes all values from 0 to unity, namely $0 \leq f \leq f_1$, and $f_2 \leq f \leq f_3$. If $m < 0.5$, f_1 and f_2 are simply interchanged.) These are, of course, the ranges of free transmission ($\alpha = 0$), while the range between f_1 and f_2 is an attenuating band. It has been remarked above that f_1 and f_2 are the critical frequencies which would exist if one or the other of the loads were omitted and the remaining load retained only its allotted part of the inductance.

The limiting values $m=1$ and $m=0$ reduce the system to the ordinary loaded line with inductance units L_o at intervals of $2s$ miles, for when $m=1$,

$$f_2 = f_3 = \infty$$

and

$$f_1 = \frac{1}{\pi \sqrt{2L_oCs}}$$

and when

$$m=0$$

$$f_1 = f_3 = \infty$$

and

$$f_2 = \frac{1}{\pi \sqrt{2L_oCs}}$$

In the special case $m=0.5$, making $Z_1 = Z_2 = i\omega_o.5L_o$, the system becomes a line loaded at intervals of s miles with inductance $0.5 L_o$ and

$$f_1 = f_2 = \frac{L}{\pi \sqrt{L_oCs}}$$

$$f_3 = \frac{1}{\pi \sqrt{.5L_oCs}}$$

This value of f_3 is the known critical frequency for such a system and since f_1 and f_2 are coincident they are eliminated as critical frequencies in this case, or, in other words, the attenuating band between them is infinitesimal.

To summarize, if the inductance L_o is all in the load Z_1 , i. e., $m=1$, the known critical frequency is given by f_1 , the others f_2 and f_3 being at infinity, or there is simply a transmitting band from zero to f_1 and an attenuating band from f_1 to infinity. Putting a small part of the load at the mid-point of the section, i. e., making $m > .5$ and < 1 , moves f_1 to a slightly higher frequency and makes f_2 and f_3 finite, introducing a narrow transmitting band between the latter two. As Z_1 is continuously decreased and Z_2 increased, f_1 becomes continuously higher and both f_2 and f_3 become continuously lower, the band be-

tween them increasing somewhat in breadth until, when

$$Z_1 = Z_2 \text{ or } m = 0.5, f_1 = f_2 = f_3 / \sqrt{2}$$

and the two transmitting bands are confluent. Fig. 4 illustrates the locations of the critical frequencies for different divisions of the total load of a compound system between the two adjacent loading points. In the limiting case above discussed, where $m=0.5$ [i. e., $L_1 = L_2$] the intermediate suppression band vanishes at a point on the frequency spectrum indicated in Fig. 4, corresponding to an abscissa value of 1.414.

With regard to the magnitude of the attenuation, we return to Equation (11). In accordance with the assumption that the line is non-dissipative, $\cosh^2 \Gamma/2$ is real as found above. Then, when α is not zero, it must follow that

$$\sin \frac{\beta}{2} \cos \frac{\beta}{2} = 0$$

or

$$\beta = \pm n\pi$$

$$n = 1, 2, 3, \dots$$

In the band between f_1 and f_2

$$1 - \frac{\omega^2 m L_o C s}{2} < 0$$

$$1 - \frac{\omega^2 (1-m) L_o C s}{2} > 0$$

Hence $\cosh \Gamma/2$ is pure imaginary, n is odd (by Equation (12)) and

$$\alpha = 2 \sinh^{-1} \sqrt{-(1 - \omega^2/\omega_1^2)(1 - \omega^2/\omega_2^2)} \quad (24)$$

$$= 2 \cosh^{-1} \frac{\omega}{2} \sqrt{L_o C s} \text{ when } m=0$$

On the other hand, in the band above f_3 , since

$$1 - \frac{\omega^2 m L_o C s}{2} < 0$$

and

$$1 - \frac{\omega^2 (1-m) L_o C s}{2} < 0$$

n is even and

$$\alpha = 2 \cosh^{-1} \sqrt{(1 - \omega^2/\omega_1^2)(1 - \omega^2/\omega_2^2)} \quad (25)$$

From (24) when $m=0$ or 1 , the slope $d\alpha/d\omega$ of the attenuation is

$$\frac{d\alpha}{d\omega} = \infty \text{ when } f=f_1 \text{ or } f_2$$

and

$$=0 \text{ when } 1-\omega^2 m(1-m) L_o C s=0.$$

The maximum value α_m of the attenuation in the lower band, occurring at the frequency f_m , is then

$$\alpha_m = 2 \sinh^{-1} [\pm (1-2m)] \quad (26)$$

$$=0 \text{ when } m=.5$$

and

$$f_m^2 = f_1 f_2 / 2 \sqrt{m(1-m)} = f_3^2 / 2 \quad (27)$$

In the upper attenuating band, from Equation (25) when $m=0$ or 1 ,

$$\frac{d\alpha}{d\omega} = \infty \text{ when } f=f_2$$

$$=0 \text{ when } f=f_1$$

and

$$\alpha_m = \infty$$

When $m=0$ or 1 , $f_2 = \infty$ and this band does not exist.

In summarization of what has been said before, as the coil inductance values or the loading section capacity values of a compound loading system are varied to raise the position of the secondary transmitting band in the frequency spectrum, the width of the primary transmitting band is decreased and the width of the intermediate suppression band is increased. From the opposite point of view, as the elements of a compound loading system are varied to increase the width of the secondary transmitting band, the width of the suppression band diminishes. The design problem therefore involves compromise depending upon the intended purpose of the primary and secondary transmitting channels.

While of course they may be used for various purposes the primary channel would ordinarily be preferred for speech transmission while the secondary channel could be used for carrier telegraph or for picture transmission.

It should be noted that a plurality of secondary signaling channels may be obtained by increasing the complexity of the compound loading beyond that described hereinbefore. The unique attenuation characteristics of compound loading result from the superposition of two simple systems having a definite regularity in the staggering of the coils belonging to the two simple loading systems. By superposing with regular periodicity three or more simple loading systems, the number of secondary transmitting channels may be materially increased.

What is claimed is:

1. A compound loaded transmission system consisting, in effect, of two simple load-

ing systems, one superimposed on the other, the said compound system comprising a line having inductance coils so connected therein that the total line current flows through all of them, the adjacent coils differing in inductance values but the alternate coils being of the same value, the relative separation of the coils being the same throughout the system and the said values being so chosen that the compound system will be characterized by two distinct, non-overlapping bands of transmission separated by a band of suppression.

2. A loaded transmission system characterized by two bands of transmission separated by a band of suppression, the said system employing coils of unequal inductance values L_1 and L_2 alternately connected and equally spaced throughout said system, the values of inductance of the coils being so chosen that

$$\frac{L_1}{L_2} = \frac{m}{1-m}$$

where m is greater than .5 and less than 1.

3. In a loaded transmission system the combination with a line of uniformly distributed capacity, of a plurality of loading coils, of inductances L_1 and L_2 connected therein, the coils L_1 being different in value from L_2 and being alternately spaced with respect to L_2 , the distance between adjacent coils being the same throughout the transmission system, the inductance values being so chosen that

$$\frac{L_1}{L_2} = \frac{m}{1-m}$$

where m is greater than .5 and less than 1.

4. A compound loaded transmission system characterized by two bands of transmitted frequencies, separated by a band of suppressed frequencies, said system consisting of one simple loading system superposed on another simple loading system, the inductance of a coil of one system differing from that of a coil of the other system, with the loading coils of both systems occurring at regular spaced intervals, the said coils being so connected that the total line current flows through all of them.

5. A compound loaded transmission system characterized by two bands of transmitted frequencies, separated by a band of suppressed frequencies, said compound system consisting of one simple loading system superposed on another simple loading system, the coils of both systems being equally spaced and having inductance values of such magnitude and of proper ratio to produce transmission bands of desired width and position in the frequency spectrum, the said coils being so connected that the total line current flows through all of them.

6. A compound loaded transmission system characterized by two bands of transmit-

ted frequencies, separated by a band of suppressed frequencies, said compound system consisting of one simple loading system superposed on another simple loading system, the inductance of the loading coils of the two
5 systems being different and the relative spacing of the coils being symmetrical throughout the compound system, whereby the widths of the transmission bands and their position in the frequency spectrum may be controlled,
10 the said coils being so connected that the total line current flows through all of them.

In testimony whereof, we have signed our names to this specification this 17th day of August, 1926.

15 SALLIE P. MEAD.
NORMAN R. FRENCH.

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