Dec. 8, 1925.

1,564,201

J. R. CARSON ET AL

LOADING SYSTEM

Filed June 4, 1921

Fig. 1

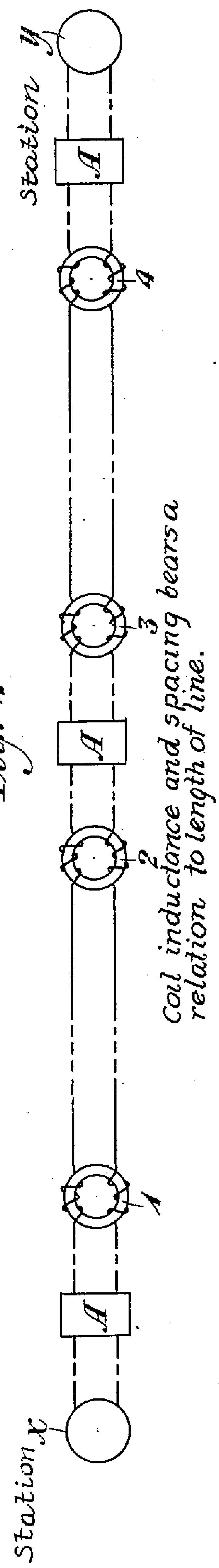
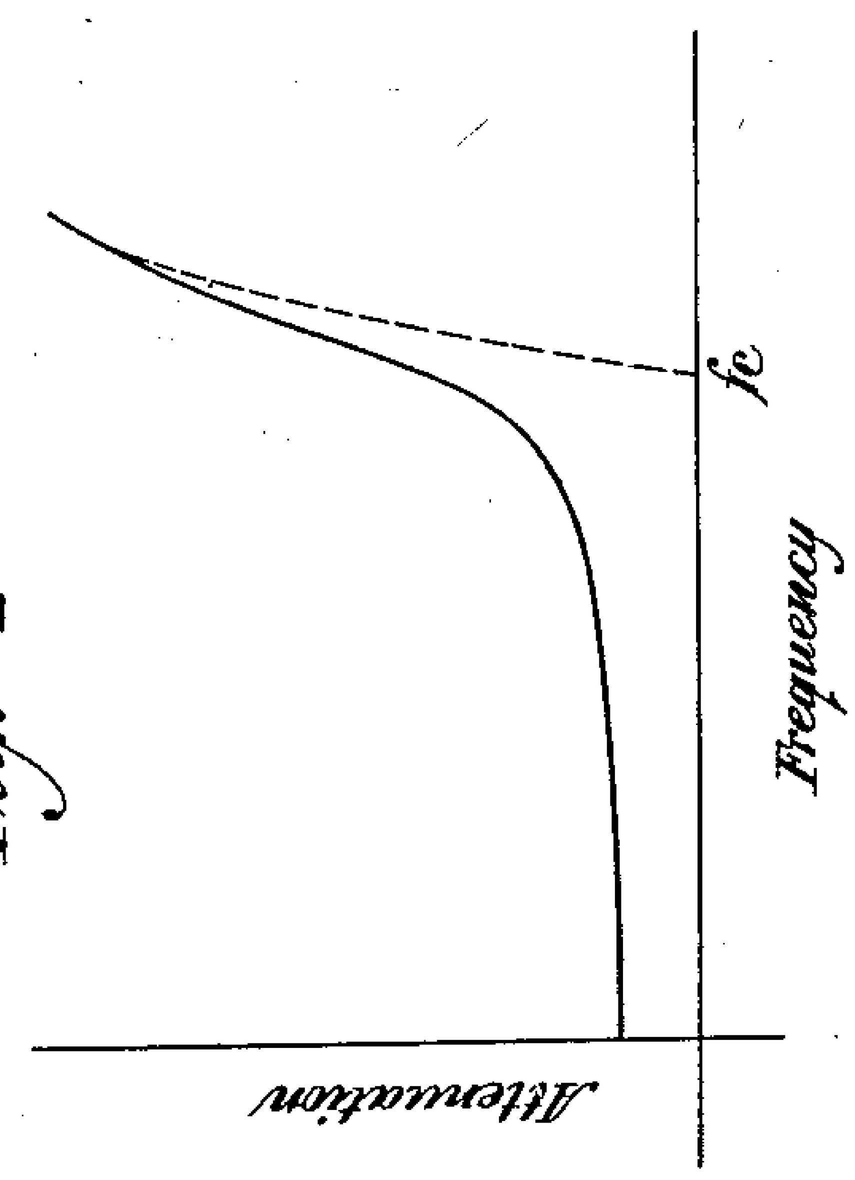


Fig. 2



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By their Attorney

G. E. Folk

Patented Dec. 8, 1925. **1,564,201**

UNITED STATES PATENT OFFICE.

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LOADING SYSTEM.

Application filed June 4, 1921. Serial No. 474,878.

To all whom it may concern:

Be it known that we, John R. Carson, Alva B. Clark, and John Mills, residing at Harmon, Brooklyn, and Wyoming, in the counties of Westchester, Kings, and Essex and States of New York, New York, and New Jersey, respectively, have invented certain Improvements in Loading Systems, of which the following is a specification.

This invention relates to loaded lines for the transmission of telephonic currents and the like. The object of the invention is to provide a system of loading applicable especially to long lines, which will improve the quality of transmission.

The Pupin-Campbell system of loading, as originally conceived and hitherto practiced, has as its main object the reduction of attenuation, thereby increasing the possible range of the telephonic transmission of speech. With the advent of the efficient telephone repeater, mere reduction of the attenuation by loading ceased to have its former fundamental importance, while at the same time, the possible length of lines for telephonic communication was much increased. These considerations made it necessary to give more serious attention to the question of the quality of the transmission and the received speech, because in long lines various factors combine to impair the quality. Three of these factors which require particular attention are, first, equal attenuation for currents of the various frequencies within the telephone range, second, the time of transmission of the speech impulses, and third, the transient distortion. All three of these factors tending to impair the quality of the received speech are affected injuriously by the system of loading as now practiced.

As to the requirement for equal attenuation, it will be clear from a moment's consideration that the received currents which represent telephonically transmitted speech must be a faithful copy of the corresponding currents which enter the transmission system at the sending end, if the system is not to distort the speech. In practice, we are concerned only with the currents of those frequencies which go to make up speech, which, for practical purposes, may be taken as lying between 200 and 2500 cycles per second. If these frequencies are transmitted over the line with equal attenuation, the system may be said to be distortionless from the steady-state standpoint. In actual systems, however, this requirement alone is insufficient to insure good quality and as the length of the circuit is increased, it is found that the time of transmission and the transient distortion play increasingly important rôles.

With respect to the effect of the time of transmission, it has been found that when the time is increased, due, for example, to the lengthening of the line beyond a certain point, reflected currents produce serious effect upon the quality of the received speech and also serious auditory and psychological effects upon the speaker, who hears his own words return to him as an echo. This particular difficulty may be minimized by increasing the losses in the circuit or by reducing the time of transmission. The losses, however, must be kept below a certain point to meet commercial requirements.

With respect to the part played by transient distortion, the currents, after arriving at the distant end of the line, require an appreciable time to build up, and under certain conditions never build up, to anything remotely resembling the transmitted current in the short interval during which the latter exists. The effect produces, or may produce, serious impairment in the quality and intelligibility of the received speech even when the line is so designed that the steady-state attenuation of all currents within the speech range is substantially constant, and, therefore, the system is, from the steady-state standpoint, substantially distortionless.

For relatively short lines, the evil effect of the ordinary loading upon these three factors affecting the quality of transmission may be disregarded because the effects are relatively inappreciable, but as the range of telephonic transmission is increased, a point is reached where the impairment of quality becomes so serious as to materially reduce the commercial efficiency of the circuits.

The present invention proposes to overcome the difficulties above described by properly relating the loading to the length of the line. Generally speaking, the value of the inductance for each loading section should be proportioned inversely with respect to the length of the line. Length of line, in the sense here used, refers, of course, to electrical length, which is ordinarily approximately the same as geographical length, but the criterion is rather the degree of the echo effect produced by the line or the transient distortion of the signal currents.

In the accompanying drawing, Figure 1 illustrates a line to which the present invention is applicable; Fig. 2 is a curve representing the frequency-attenuation characteristic of a loaded line.

In Fig. 1, X represents one terminal of the line and Y another terminal. Loading coils are indicated diagrammatically at 1, 2, 3 and 4. On long lines of the character to which the invention is particularly applicable, amplifiers will be used as indicated at A.

For any given loading of a line there is a frequency above which the currents are attenuated by the loading per se; that is to say, the presence of the loading coils themselves introduces attenuation. This effect is illustrated in Fig. 2, where the dotted line represents attenuation due to loading alone in an ideal transmission line, and the full line the actual attenuation, taking into account the resistance of the line. The frequency at which the attenuating effect of the loading coils becomes marked is called the critical frequency and is denoted on the drawing by f_c.

In order that the invention may be defined with sufficient clearness that one skilled in the art may readily practice the same, the manner of proportioning the loading and the principles upon which the invention is based will be set forth. Let L be the total inductance of the line (including loading coils); R the total resistance; C the total capacity, and n the number of loading sections. Then the critical frequency f_c is given by

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

And the attenuation of the line (except at very low frequencies) by

$$A = \frac{R}{2}\sqrt{\frac{C}{L}}\,\frac{(1+p) - \frac{2}{3}\left(\frac{f}{f_c}\right)^3}{(1+p)\sqrt{1-\left(\frac{f}{f_c}\right)^2}} \quad (2)$$

where p is the ratio of the resistance of the load coils to the resistance of the line, and leakage is neglected. For these formulæ see G. A. Campbell's paper on Loaded lines, Phil. Mag., March, 1903.

The time of transmission t_1 is given by

$$t_1 = \sqrt{LC} \quad (3)$$

If t_2 denote the time required for a current of frequency f to build up to its proximate steady-state after arriving at the end of the line, it may be shown theoretically that

$$t_2 = t_1\left(\frac{1}{\sqrt{1-\left(\frac{f}{f_c}\right)^2}} - 1\right) \quad (4)$$

If f_m is the maximum frequency which it is necessary to transmit, then in terms of t_1 and t_2 the foregoing formulæ give

$$f_c^2 = f_m^2\frac{(t_2+t_1)^2}{(t_2+t_1)^2 - t_1^2} \quad (5)$$

$$n = \pi t_1 f_c \quad (6)$$

$$L = \frac{t_1^2}{C} \quad (7)$$

L′ = inductance of load coil

$$= \frac{L}{n} \quad (8)$$

neglecting the distributed inductance of the line.

It will be observed that formulæ 5–8 completely determine the loading design (inductance and spacing of load coils) in terms of t_1, t_2 and C which is determined by the length of the circuit and the wire gauge and spacing. Now as stated previously the time of transmission t_1 and the building up time t_2 must not exceed certain experimentally determined values for a prescribed standard of quality. Letting T_1 and T_2 denote these values, the requirements of the prescribed standard of quality are satisfied if:

$$f_c^2 \geqq f_m^2\frac{(T_2+T_1)^2}{(T_2+T_1)^2 - T_1^2} \quad \text{I}$$

$$n \geqq \pi T_1 f_c \quad \text{II}$$

$$L \leqq \frac{T_1^2}{C} \quad \text{III}$$

Examples of the application of these formulæ now follow. As the requirements for good transmission, T_1, have been taken as 0.05 sec. and T_2 as 0.005, values which it has been experimentally determined insure good quality as regards echo and transient effects.

Example 1.

1150 miles #19 Ga. Cable

$C = 0.7\text{x}10^{-4}$ farads

$T_1 = 0.05$

$T_2 = 0.005$

$f_m = 2300$

$$L \leqq \frac{(0.05)^2}{0.7\text{x}10^{-4}} = 36 \text{ henrys}$$

$$f_c^2 \geqq (2300)^2\,\frac{3.025}{.525}$$

$$f_c = (2.40)(2300) = 5520$$

$n = 867$

The inductance per loading coil should not exceed 41 mh. The spacing of loading coils should not exceed 1.3 miles.

Example 2.

115 miles #19 Ga. Cable
$C=0.7\times10^{-5}$ farads $T_2=0.005$
$f_m=2300$

In this circuit, since the capacity is only $\frac{1}{10}$ that of the preceding example, it is possible to have a total inductance of 360 henrys instead of 36 and still keep t_1 less than its upper limit 0.05 seconds. Such a value is unnecessary for transmission purposes; instead we may tentatively take $L=\frac{4}{10}$ (36) which makes the equivalent distributed inductance 4 times that of the 1150 mile system. This gives

$$t_1=\sqrt{LC}=0.01$$

Then from the design formulæ it follows at once that

$$f_c \geqq 3090;\ n \geqq 97$$

and the loading coil spacing must not exceed 1.18 miles and the load coil inductance must not exceed 148 mh.

In the foregoing examples no consideration has been given to the question of the variation of attenuation ΔA over the speech range. From equation (2) ΔA may be written as:

$$\Delta A=\frac{\pi f_c RC}{2n}\left(\frac{1-\frac{2}{3}\dfrac{\left(\frac{f_m}{f_c}\right)^2}{1+p}}{\sqrt{1-\left(\frac{f_m}{f_c}\right)^2}}-1\right) \quad \text{IV}$$

which diminishes in general as the cut-off frequency is increased. Hence, if it required that ΔA shall not exceed a prescribed value this requirement may set a still higher limit to the cut-off frequency f_c. The appropriate design procedure is to determine the loading design and f_c from formulæ I, II, III and then calculate ΔA from IV. If the attenuation variation thus computed falls within the prescribed limit, the design is satisfactory; otherwise the cut-off frequency must be increased and the loading design recalculated from formulæ I, II and III. As an example of this appropriate procedure, assume that in system of example #1, the requirements regarding allowable attenuation variation make it necessary to increase the cut-off frequency f_c to 6000 cycles per second. The design of the system may then be modified in either of the following 2 ways:

(1) If we keep the total inductance constant it follows from equation (1) that the number of load coils must be increased in the ratio 6000/5520=1.09 which means that the spacing must not exceed (1.3) (.92)=1.19 miles and the inductance per load must not exceed (41) (.92)=38 mh.

(2) If we keep the spacing constant, the total inductance must be decreased in accordance with equation (1) in the ratio $(5520/6000)^2$ or .85. Hence the inductance per coil with 1.3 miles spacing must not exceed (41) (.85)=35 mh.

To summarize the foregoing there is disclosed a loading system and a method of design thereof with reference to the length of the system and the resistance and capacity of the wires, such that transmission over the circuit satisfies preassigned quality requirements as regards (1) variation of attenuation over the telephonic range; (2) echo effects, and (3) transient distortion.

What we claim is:

1. The method of improving the signal transmitting properties of a periodically loaded line, which consists in reducing the inductance of the line per unit of length throughout the line as the length of the line is increased.

2. The method of improving the signal transmitting properties of a periodically loaded line, which consists in reducing the inductance per unit of length throughout the line as the echo effect upon the line increases.

3. The method of improving the signal transmitting properties of a periodically loaded line, which consists in increasing the speed of wave transmission over the line as a whole as the transient distortion of the signals increases.

4. The method of improving the signal transmitting properties of a periodically loaded line, which consists in proportioning the loading of the line in an inverse relation to the length of the line so that the time of transmission of signal waves shall not exceed a predetermined value sufficiently small to avoid echo effects.

5. The method of improving the signal transmitting properties of a periodically loaded line, which consists in so relating the loading inversely to the length of the transmission line that the time required for a signal impulse to build up at the receiving end shall not exceed the time during which the impulse persists by more than an amount determined to be consistent with echo qualities.

6. The method of improving the signal transmitting properties of a periodically loaded line which consists in reducing the loading of the line, as compared to that of a line of different length, in inverse proportion to the length, to such a point that the cut-off frequency is substantially greater than the highest frequency necessary to transmit speech, whereby the variation in attenuation of all necessary frequencies is within predetermined limits.

7. In a signal transmitting system, a transmitting line of such length that the time of transmission of a signal impulse becomes a factor effecting signal quality at the receiving end, and loading coils connected at intervals in said line whose inductance and spacing bear a definite relation to the length of the line such that the total time of transmission is reduced below that producing substantial echo effects and transient distortion.

8. A signal transmitting line in which the number of loading sections is equal to or greater than

$$\pi T_1\left(f_m{}^2\frac{(T_2+T_1)^2}{(T_2+T_1)^2-T_1{}^2}\right)^{\frac{1}{2}}$$

and the inductance of each section is equal to or less than $\frac{T_1{}^2}{nC}$, where T_1 and T_2 represent respectively the limiting values for the time of transmission and time of building up of the signal, consistent with good signal quality, and f_m represents the maximum frequency which it is necessary to transmit, n is the number of loading sections, and C the capacity of the line.

9. A signal transmitting line in which the number of loading sections is equal to or greater than

$$\pi T_1\left(f_m{}^2\frac{(T_2+T_1)^2}{(T_2+T_1)^2-T_1{}^2}\right)^{\frac{1}{2}}$$

and the inductance of each section is equal to or less than $\frac{T_1{}^2}{nC}$, where T_1 and T_2 represent respectively the limiting values for the time of transmission and time of building up of the signal, consistent with good signal quality, and f_m represents the maximum frequency which it is necessary to transmit, n is the number of loading sections, and C the capacity of the line, and in which the cut-off frequency of the line is sufficiently high so that all frequencies of f_m and under are transmitted with substantially equal attenuation.

10. A long loaded transmission line comprising loading coils periodically spaced and amplifiers, in which the loading coils are of such inductance and spacing that the cut-off frequency exceeds twice the highest frequency necessary for telephonic transmission of speech.

In testimony whereof, we have signed our names to this specification this 31st day of May, 1921.

JOHN R. CARSON.
ALVA B. CLARK.

In testimony whereof, I have signed my name to this specification this 1st day of June, 1921.

JOHN MILLS.