G. A. CAMPBELL.
ELECTRIC WAVE FILTER.
APPLICATION FILED JULY 15, 1915.

1,227,113.

Patented May 22, 1917.

3 SHEETS—SHEET 1.

Fig. 1

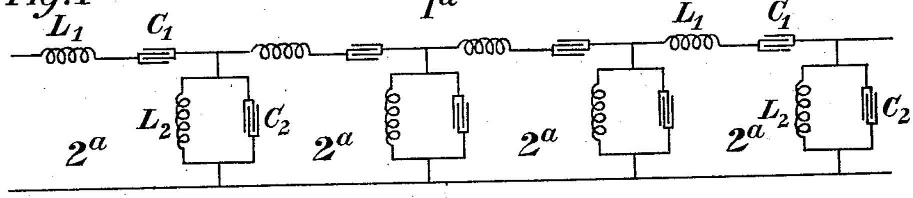


Fig. 2

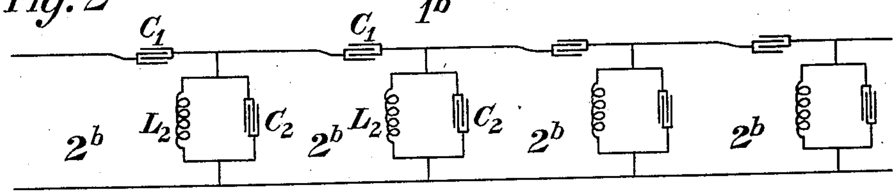


Fig. 3

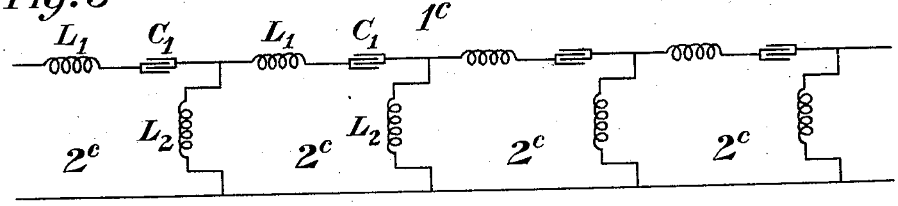


Fig. 4

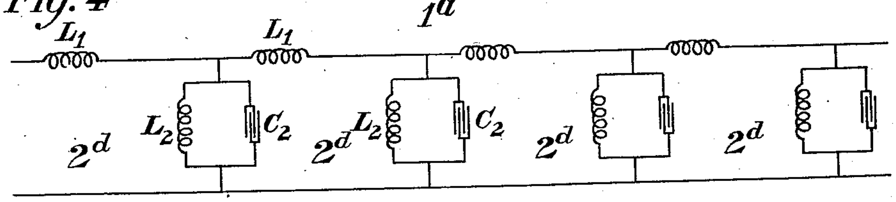
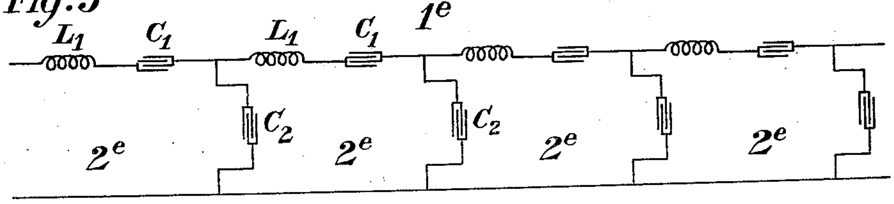


Fig. 5



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3 SHEETS—SHEET 2.

Fig. 6

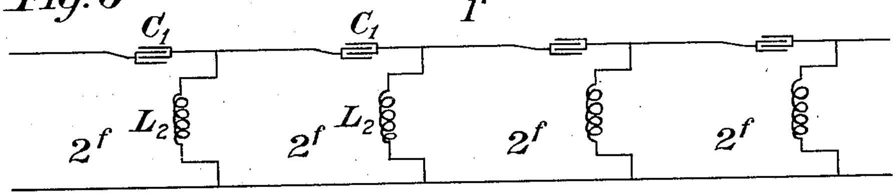


Fig. 7

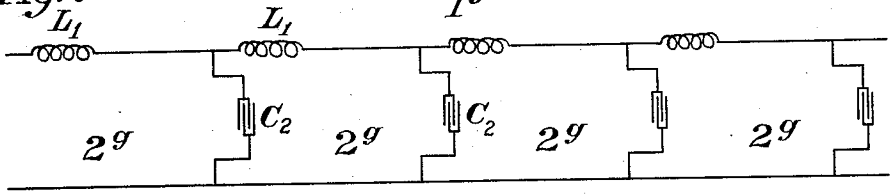


Fig. 8

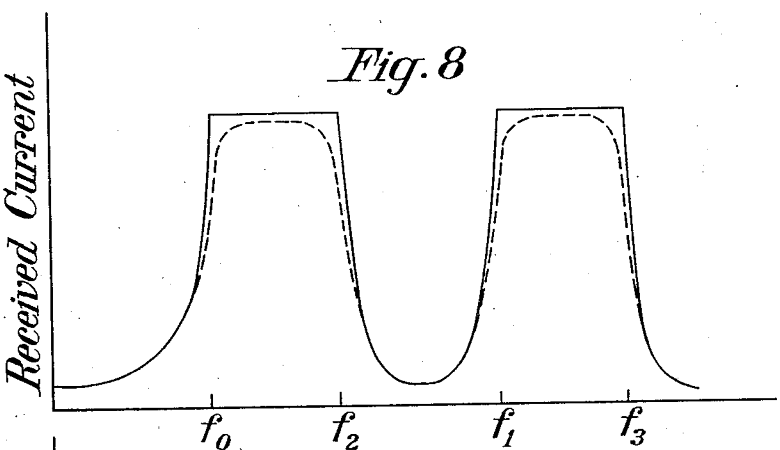
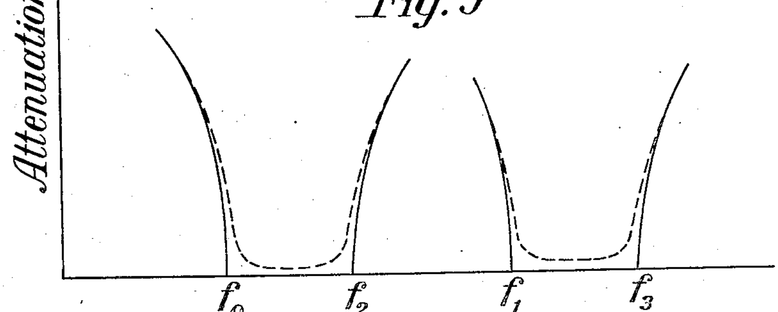


Fig. 9



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3 SHEETS—SHEET 3.

Fig. 10

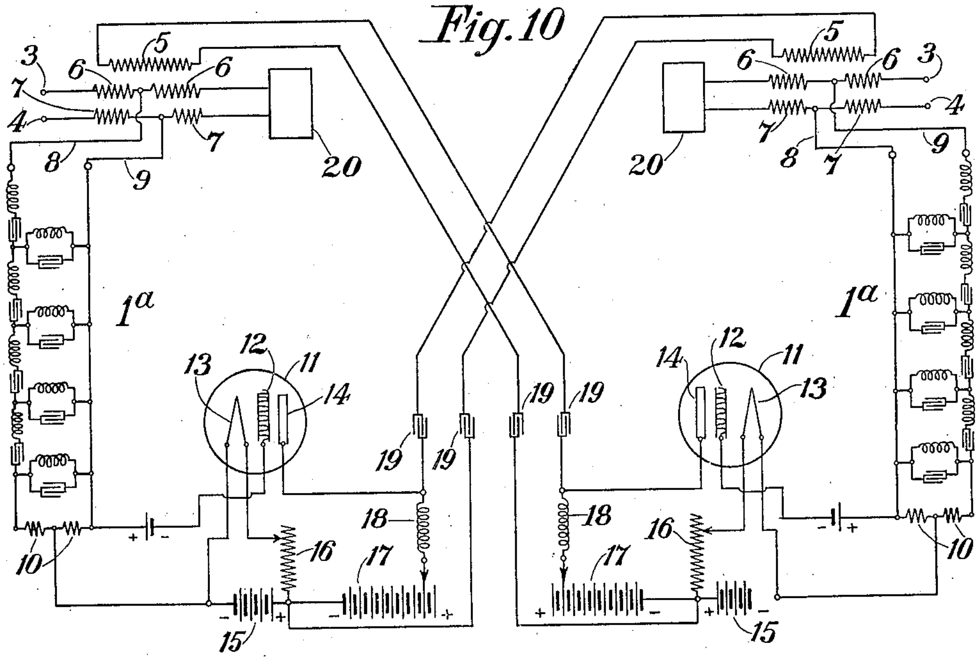
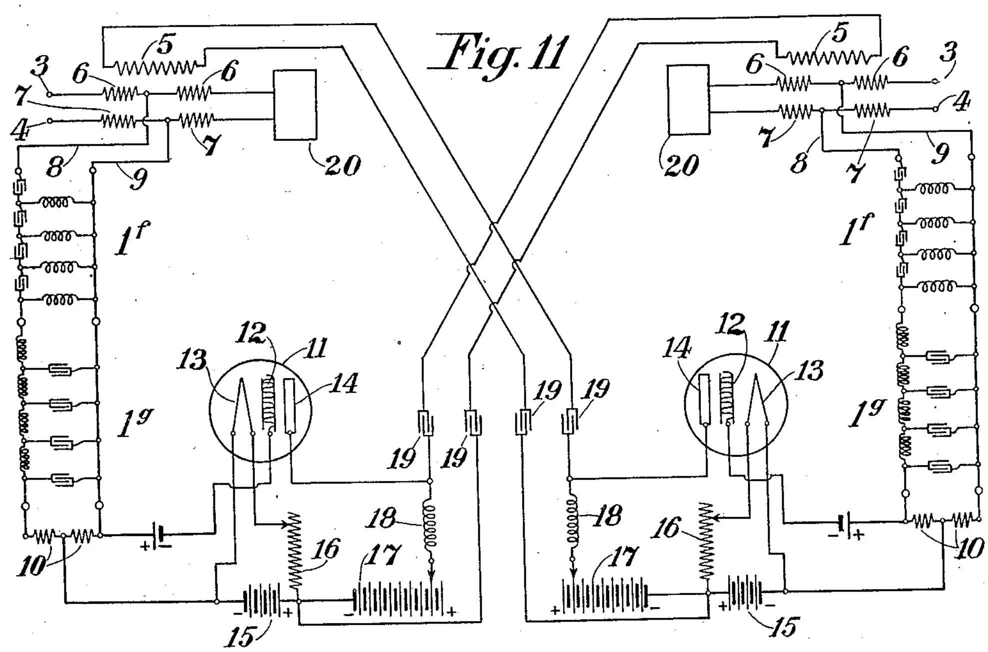


Fig. 11



Inventor:
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UNITED STATES PATENT OFFICE.

GEORGE A. CAMPBELL, OF MONTCLAIR, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

ELECTRIC WAVE-FILTER.

1,227,113. Specification of Letters Patent. Patented May 22, 1917.

Application filed July 15, 1915. Serial No. 40,057.

To all whom it may concern:

Be it known that I, George A. Campbell, residing at Montclair, in the county of Essex and State of New Jersey, have invented certain Improvements in Electric Wave-Filters, of which the following is a specification.

This invention relates to an electric wave-filter and more particularly to a wave-filter adapted to transmit with small or negligible attenuation sinusoidal currents of all frequencies lying within a range or ranges of preassigned limiting frequencies while attenuating and approximately extinguishing sinusoidal currents of frequencies lying outside the limits of the preassigned range or ranges.

My invention, though it may find expression in many embodiments, has common to all the broad idea of a wave-filter in the nature of a connecting line having an impedance element or elements in series with the line and an impedance element or elements in shunt across the line, the values of the impedance elements being so proportioned that the structure will transmit, with small or negligible attenuation, from a source of electromagnetic energy to an electrical receiving, translating or repeating device, sinusoidal currents of all frequencies lying within specified and preassigned limits or ranges while attenuating and sensibly extinguishing currents of all frequencies lying outside such limits.

My invention in one or more of its embodiments has important applications in connection with wireless telegraphy, wireless telephony, multiplex high frequency wire telephony, composite telegraph and telephone lines, and in particular with telephone repeater circuits, wherein it is highly important that means be provided for selecting a range or band of frequencies, such as, for instance, the range or band of frequencies necessary for intelligible telephonic transmission of speech, while at the same time excluding from the receiving or translating device currents of all other frequencies.

My invention is illustrated in the accompanying drawings in which Figure 1 is a diagram illustrating the broad form of my invention from which all specific embodiments may be derived by assigning proper values to the electrical constants of the structure; Figs. 2, 3, 4, 5, 6 and 7 are diagrams illustrating different embodiments of my invention; Figs. 8 and 9 show curves illustrating the characteristic performance of the wave-filter; and Figs. 10 and 11 are diagrams showing my invention embodied in telephone repeater circuits.

Like reference characters refer to like parts throughout the several figures of the drawings.

Referring to Figs. 1 to 7 inclusive, each wave-filter 1^a, 1^b, 1^c, 1^d, 1^e, 1^f, 1^g is composed of a plurality of identical sections 2^a, 2^b, 2^c, 2^d, 2^e, 2^f, 2^g, respectively, each including lumped impedance in series with the line and lumped impedance in shunt across the line. Said impedance may be provided by condensers, C_1, C_2 or by inductance coils L_1, L_2 or by a suitable combination of both, there being at least, for each section of the wave-filter, an inductance element in series with the line and a capacity element in shunt across the line or vice versa. Thus in Fig. 1 showing the preferred embodiment of the invention, there are, for each section, both a condenser C_1 and an inductance coil L_1 in series with the line and a condenser C_2 and an inductance coil L_2 in parallel in shunt across the line. In said figures, as well as in the other figures of the drawing, the reference characters C_1 and C_2 are used to designate similar elements, that is condensers, the subscript 1 affixed to the reference letter indicating that the element is in series with the line and the subscript 2 indicating that the element is in shunt across the line. In like manner the reference characters L_1 and L_2 are used to indicate inductance coils in series with the line and in shunt across the line, respectively.

In Figs. 2 to 7 inclusive, said impedance elements for each section are included as follows:—in Fig. 2 there is a condenser in series with the line and a condenser and an inductance coil in parallel in shunt across the line; in Fig. 3, a condenser and an inductance coil in series with the line and an inductance coil in shunt across the line; in Fig. 4, an inductance coil in series with the line and a condenser and an inductance coil in parallel in shunt across the line; in Fig. 5, a condenser and an inductance coil in series with the line and a condenser in shunt across the line; in Fig. 6, a condenser in series with the line and an inductance coil in shunt across the line; and, in Fig. 7, an inductance coil in series with the line and a condenser in shunt across the line. Said Figs. 1 to 7 inclusive, merely show typical forms of the invention and are not intended to illustrate all of the possible modifications thereof.

By assigning suitable values to the condensers C_1, C_2 and the inductance coils L_1, L_2 in said Figs. 1 to 7 inclusive, the structure, if inserted as a connecting line between a source of electromagnetic energy and an electrical receiving, translating or repeating device, will transmit to the latter sinusoidal currents lying within preassigned ranges or bands and will at the same time effectively protect the receiving, translating or repeating device from currents of frequencies lying outside the preassigned ranges of frequencies.

The fundamental principles underlying my invention and the manner of applying the same so as to provide a structure embodying the invention will now be set forth.

It is a well known fact that, in a uniform transmission line containing uniformly distributed resistance, inductance and capacity, the attenuation of current along the line is a phenomenon which is caused by resistance dissipation and becomes zero when the resistance becomes zero. In a periodic structure, however, containing lumped series impedance and lumped shunt impedance, high attenuation may exist even when the resistance is practically zero. This attenuation is due not to resistance dissipation but to involved reactions among the impedance units of the structure. The reactions and interactions, taking place in the structure and determining the character of the attenuation attending transmission of periodic currents, are so involved as to make desirable the use of mathematical formula in elucidating the laws governing the electromagnetic phenomena taking place in the structure and in particular in laying down rules of design whereby any one, skilled in the art, may construct the electric wave-filter of this invention.

For the purpose of deriving the mathematical formulæ pertaining to the theory of my invention, assume a structure consisting of a series of sections, each section having an impedance Z_1 in series with the line, and an impedance Z_2 in shunt across the line. Letting J_n denote the circuital current flowing in the nth section of the structure, J_{n-1} the current flowing in the $(n-1)$st section, and J_{n+1} the current flowing in the $(n+1)$st section, and applying Kirchhoff's law to said currents and circuits, it follows that:—

$$Z_1J_n + Z_2(J_n - J_{n+1}) + Z_2(J_n - J_{n-1}) = 0.$$

By various rearrangements this equation may be written as,

$$\frac{J_{n+1}}{J_n} + \frac{J_{n-1}}{J_n} = \frac{Z_1}{Z_2} + 2$$

The last foregoing equation is a difference equation and, under the principles of the calculus of finite differences, the ratio of

$$\frac{J_{n+1}}{J_n}$$

is equal to the ratio of

$$\frac{J_n}{J_{n-1}},$$

the equality of said ratio holding for propagation in either direction. If this ratio is set equal to ϵ^{Γ} without specifying the value of Γ, it follows that for propagation in either direction:

$$\frac{J_{n-1}}{J_n} = \epsilon^{\Gamma} \text{ and } \frac{J_{n-1}}{J_n} = \epsilon^{-\Gamma} \quad (1)$$

In the foregoing equations, ϵ denotes the base of Naperian logarithms, and Γ denotes the propagation constant of the structure. The value of Γ is, so far, unknown but may be determined by substitution of the above values of

$$\frac{J_{n+1}}{J_n}$$

and

$$\frac{J_{n-1}}{J_n}$$

in the above difference equation, whence,

$$\epsilon^{\Gamma} + \epsilon^{-\Gamma} = \frac{Z_1}{Z_2} + 2$$

or,

$$\cosh \Gamma = \frac{1}{2}\left(\frac{Z_1}{Z_2}\right) + 1 \quad (2)$$

Referring to equation (1), if Γ is not a pure imaginary, the current value is diminished or attenuated in transmission from the nth section to the $(n+1)$st section. If Γ is a pure imaginary, the absolute values of J_n and $J_{(n+1)}$ are equal, and hence the current suffers no attenuation in transmission from section to section but only a change of phase. The condition, then, for unattenuated transmission is that Γ shall be a pure imaginary. It may be shown from equation (2) that the condition for unattenuated transmission is that

$$\frac{1}{2}\left(\frac{Z_1}{Z_2}\right)+1 \text{ shall lie between } \pm 1. \quad (3)$$

Hence the limiting values of the frequency for free transmission are given by:—

$$\left.\begin{array}{l}\frac{Z_1}{Z_2}=0\\ Z_1=-4Z_2\end{array}\right\} \quad (4)$$

For the structure shown in Fig. 1, it is evident that the series impedance

$$Z_1=\frac{1-L_1C_1p^2}{ipC_1};$$

and the shunt impedance

$$Z_2=\frac{iL_2p}{1-L_2C_2p^2}.$$

In these formulæ p is $2\pi f$ where f is the frequency in cycles per second, and i is the imaginary quantity

$$\sqrt{-1}.$$

Referring to the expressions for Z_1 and Z_2 above given, it is evident that equations (4) have as the variable or unknown the value of p. There are four roots or four values of p which will satisfy said equations (4), which roots will be denoted by the symbols p_0, p_1, p_2 and p_3. Said roots have the following values:—

$$p_3=\frac{1}{\sqrt{2L_1C_2}}\sqrt{4+\frac{L_1}{L_2}+\frac{C_2}{C_1}+\sqrt{\left(4+\frac{L_1}{L_2}+\frac{C_2}{C_1}\right)^2-4\frac{L_1C_2}{L_2C_1}}} \quad (5)$$

$$p_0=\frac{1}{\sqrt{2L_1C_2}}\sqrt{4+\frac{L_1}{L_2}+\frac{C_2}{C_1}-\sqrt{\left(4+\frac{L_1}{L_2}+\frac{C_2}{C_1}\right)^2-4\frac{L_1C_2}{L_2C_1}}} \quad (6)$$

$$p_1=\frac{1}{\sqrt{L_1C_1}} \quad (7)$$

$$p_2=\frac{1}{\sqrt{L_2C_2}} \quad (8)$$

It will be observed that these four limiting values of p or $2\pi f$ are in geometrical proportion, and that:—

$$\frac{p_3}{p_1}=\frac{p_2}{p_0} \quad (9)$$

An examination of equations (4) to (9) inclusive shows that the unattenuated frequencies lie in two distinct, continuous bands or ranges. If $p_1>p_2$, the frequencies of unattenuated transmission lie between $p_{3/2\pi}$ and $p_{1/2\pi}$ for the upper band and between $p_{2/2\pi}$ and $p_{0/2\pi}$ for the lower band. If, on the contrary, $p_1<p_2$, the frequencies for the upper band lie between $p_{3/2\pi}$ and $p_{2/2\pi}$, and for the lower band between $p_{1/2\pi}$ and $p_{0/2\pi}$.

Equations (5) to (9) inclusive are fundamental to my invention and by their aid the electrical constants of the wave-filter of my invention may be determined. From said fundamental equations, simplified formulæ for different structural embodiments of the invention may be derived, as will hereinafter be pointed out.

Referring to the drawings, Figs. 8 and 9 show the character of transmission through the structure illustrated in Fig. 1. In said Figs. 8 and 9, f_0, f_2, f_1, f_3, represent frequencies corresponding to p_0, p_2, p_1, p_3, respectively. In Fig. 8, the ordinates are received currents while the abscissæ are frequencies. Fig. 9 has as its ordinates attenuation values per section and as abscissæ frequencies. The full line curves refer to the ideal structure in which the resistance of the impedance units is quite negligible, while the broken line curves show the departure from the ideal case due to resistance in the structure. In any case the resistances are made sufficiently small to be practically negligible.

It is not always desirable to transmit two bands of frequencies, and as a further refinement, my invention also contemplates a wave-filter which will transmit freely all frequencies lying within a single band of specified limits. As will hereinafter be more fully set forth, the structures shown in Figs. 2 to 7 inclusive will function as a single band wave-filter, and the structure shown in Fig. 1 may be made to so function.

Reference to Fig. 8 and to equations (5), (6), (7) and (8), shows clearly that if the two bands of free transmission are made to coalesce or merge into one by setting $f_1=f_2$, or if one of the bands is pushed out or relegated either to infinity or to zero, there remains one single band of free transmission for finite frequencies. The first form of single band wave-filter is attained by making $f_1=f_2$ or $L_1C_1=L_2C_2$. This form will be referred to as a filter having coalescent or confluent bands.

The second method of realizing a single band wave-filter is attained by relegating the upper band to infinity or the lower band to zero. Reference to equations (5), (6), (7) and (8), shows that one band is relegated to infinity if L_1 or $C_1=0$; while the other band is relegated to zero if L_2 or $C_1=\infty$. Obviously, from the foregoing, the single band may also be attained by making $L_1=C_2=0$, or by making $L_2=C_1=\infty$. It will be understood, of course, that an infinite inductance or a zero capacity are equivalent to an infinite impedance, and, hence, a circuit through the same may be regarded as replaced by an open circuit; on the other hand a zero inductance or an infinite capacity are equivalent to a zero impedance, and, hence, they may be regarded as in effect short circuited.

It thus appears that there are, in general, seven ways of reducing the double band wave-filter to a single band wave-filter, namely:

(*a*) Making the two broad bands coalescent or confluent by setting $L_1C_1=L_2C_2$;

(*b*) Relegating one band to infinity by making $L_1=0$;

(*c*) Relegating one band to infinity by making $C_2=0$;

(*d*) Relegating one band to zero by making $C_1=\infty$;

(*e*) Relegating one band to zero by making $L_2=\infty$.

(*f*) Making $L_1=C_2=0$ and thereby transmitting freely all frequencies above a specified value;

(*g*) Making $L_2=C_1=\infty$ and thereby transmitting all frequencies below a specified value.

Design formulæ will now be given by applying which any one skilled in the art may construct a wave-filter which will freely transmit a definite, preassigned band or definite, preassigned bands of frequencies while attenuating all frequencies lying outside these bands.

Considering first the general form of the double band wave-filter, let it be required to design a filter which shall freely transmit all frequencies lying between the limiting frequencies f_3 and f_1 and also between f_2 and f_0 with the provision that

$$f_3>f_1>f_2>f_0$$

and

$$\frac{f_3}{f_1}=\frac{f_2}{f_0}.$$

The formulæ determining the relations obtaining among the electrical constants are deducible from equations (5), (6), (7) and (8), and are as follows:—

$$L_1C_1=\left(\frac{1}{2\pi f_1}\right)^2 \qquad \text{(I)}$$

$$L_2C_2=\left(\frac{1}{2\pi f_2}\right)^2 \qquad \text{(II)}$$

$$\frac{L_2}{L_1}=\frac{1}{4}\left(\frac{f_1}{f_0}\right)^2\left[1-\left(\frac{f_0}{f_1}\right)^2\right]\left[1-\left(\frac{f_0}{f_2}\right)^2\right] \qquad \text{(III)}$$

or

$$\frac{L_2}{L_1}=\frac{1}{4}\left(\frac{f_1}{f_3}\right)^2\left[1-\left(\frac{f_3}{f_1}\right)^2\right]\left[1-\left(\frac{f_3}{f_2}\right)^2\right] \qquad \text{(IV)}$$

Formulæ III and IV are equivalent. A structure so designed or proportioned that its electrical constants satisfy formulæ (I), (II) and (III), or (I), (II) and (IV), complies with the above stated requirements for freely transmitting frequencies lying between f_3 and f_1, constituting one band and between f_2 and f_0, constituting the second band, while attenuating and sensibly extinguishing currents of all frequencies lying outside these bands.

The rules of design of the single band wave-filter will now be considered, the different cases, hereinbefore stated, being treated in order.

(*a*) Confluent bands, in which case $L_1C_1=L_2C_2$. This form is shown in Fig. 1, it being understood that the structure shown in said figure may be made to function as a single band wave-filter by making $L_1C_1=L_2C_2$, that is by causing the two bands to coalesce. If the frequencies to be freely transmitted are to lie between the upper limiting frequency f_3 and the lower limiting frequencies f_0, the design formulæ are:

$$L_1C_1=L_2C_2=\left(\frac{1}{2\pi f_3}\right)\left(\frac{1}{2\pi f_0}\right) \qquad \text{(I}^a\text{)}$$

$$\frac{L_2}{L_1}=\frac{1}{4}\left(\frac{f_0}{f_3}\right)\left(\frac{f_3}{f_0}-1\right)^2 \qquad \text{(II}^a\text{)}$$

(*b*) Relegating one band to infinity by making $L_1=0$ in which case the structure of the wave-filter assumes the form shown in Fig. 2. If the limiting frequencies of free transmission are f_2 (upper limit) and f_0 (lower limit), the design equations for this form are:—

$$L_2C_2=\left(\frac{1}{2\pi f_2}\right)^2 \qquad \text{(I}^b\text{)}$$

$$\frac{C_1}{C_2}=\frac{1}{4}\left[\left(\frac{f_2}{f_0}\right)^2-1\right] \qquad \text{(II}^b\text{)}$$

(*c*) Relegating one band to infinity by making $C_2=0$, in which case the structure of the wave-filter assumes the form shown in Fig. 3. If the limiting frequencies of free transmission are f_1 (upper limit) and f_0

(lower limit) the design formulæ for this form are:—

$$L_1C_1=\left(\frac{1}{2\pi f_1}\right)^2 \qquad (I^c)$$

$$\frac{L_2}{L_1}=\frac{1}{4}\left[\left(\frac{f_1}{f_0}\right)^2-1\right] \qquad (II^c)$$

(d) Relegating one band to zero by making $C_1=\infty$, in which case the wave-filter is of the form shown in Fig. 4. Let the limiting frequencies be f_3 and f_2 and the design formulæ are:

$$L_2C_2=\left(\frac{1}{2\pi f_2}\right)^2 \qquad (I^d)$$

$$\frac{L_2}{L_1}=\frac{1}{4}\left[\left(\frac{f_3}{f_2}\right)^2-1\right] \qquad (II^d)$$

(e) Relegating one band to zero by making $L_2=\infty$, in which case the wave-filter assumes the form shown in Fig. 5. Let the limiting frequencies of free transmission be f_3 and f_1 and the design formulæ are:—

$$L_1C_1=\left(\frac{1}{2\pi f_1}\right)^2 \qquad (I^e)$$

$$\frac{C_1}{C_2}=\frac{1}{4}\left[\left(\frac{f_3}{f_1}\right)-1\right] \qquad (II^e)$$

(f) Making $L_2=C_2=0$, in which case the wave-filter assumes the form shown in Fig. 6 and freely transmits all frequencies above a definite inferior limit. If the inferior limit is specified as f_0, the design formula is:

$$L_2C_1=\frac{1}{4}\left(\frac{1}{2\pi f_0}\right)^2 \qquad (I^f)$$

(g) Making $L_2=C_1=\infty$, in which case the wave-filter assumes the form shown in Fig. 7 and freely transmits all frequencies below a specified superior limit. If the superior limiting frequency is specified as f_3, the design formula is:

$$L_1C_2=4\left(\frac{1}{2\pi f_3}\right)^2 \qquad (I^g)$$

It will be observed from the foregoing design formulæ that there is always one impedance element whose value is a matter of choice. The value of this element may be determined from convenience of design or may be made to satisfy some other specified requirement, such as, for instance, that the line shall have a definite impedance at a particular frequency. It is further evident that the particular form of single band wave-filter is a matter of choice and the selection of any particular form may be left to the requirements of a particular design.

It will further be understood that the number of sections of the wave-filter will depend on the degree to which it is desired to extinguish the currents to be filtered out. If the number of sections is doubled the ratio of the current of any particular frequency entering the filter to the current of that frequency leaving the filter is approximately squared.

It should be clearly understood that my invention differs fundamentally both in structure and function from loaded transmission line systems. In transmission lines in which loading coils may advantageously be inserted, the attenuation is excessive and the sole purpose and object of loading is to reduce the attenuation which normally exists in the unloaded line. Moreover said organizations are strictly dependent for their utility upon the proper spacing of the loading elements such as inductance coils or condensers with reference to the electrical wave length of the line. In the present invention, however, the line in which the impedance elements are inserted is so short that normally the attenuation is absolutely negligible, that is, there is no observable attenuation except when the impedance elements are inserted in accordance with my invention. When, however, the impedance elements are so inserted, the normally non-attenuating line sharply attenuates currents of preassigned frequencies while freely transmitting currents of other frequencies. My invention is therefore not concerned with the spacing of the impedance elements with reference to the electrical wave length since said entire line is so short as normally to extend over only a minute fraction of a wave length, but is directed to the proper proportioning of said impedance elements. In brief my invention is directed to introducing in a line normally of negligible attenuation, impedance elements so proportioned as to render said line attenuating for certain specified or preassigned ranges of frequencies.

As an example of the application of the foregoing design formulæ, let it be required to design a filter which shall transmit all frequencies lying between 200 and 2000 cycles per second. Any one of the forms shown in Figs. 1, 2, 3, 4, 5 may be employed or the two forms shown in Figs. 6 and 7 connected in series. Let it be assumed that convenience or other considerations lead to the selection of the type of wave-filter shown in Fig. 1. Applying design formulæ (I^a) and (II^a), applicable to this type of single band wave-filter, and substituting therein for f_0 and f_3 the above assigned values 200 and 2000, respectively:

$$L_1C_1=L_2C_2=\left(\frac{1}{2\pi 2000}\right)\left(\frac{1}{2\pi 200}\right)=(.635)\ 10^{-7}$$

and

$$\frac{L_2}{L_1}=\frac{1}{4}\left(\frac{200}{2000}\right)\left(\frac{2000}{200}-1\right)^2=2.025$$

Therefore the above stated requirements are satisfied if

$$L_1C_1=L_2C_2=(.635)\,10^{-7}$$

and

$$\frac{L_2}{L_1}=2.025.$$

As has been hereinbefore stated, one of the constants L_1, C_1, L_2, C_2 is arbitrary. Let it be assumed that convenience or other considerations dictate a value of 1 henry for L_2. The values of the several impedance elements are then as follows: $L_2=1$ henry; $L_1=0.494$ henry; $C_1=(1.29)\,10^{-7}=0.129$ microfarad; and $C_2=0.0635$ microfarad.

Therefore the wave-filter shown in Fig. 1 having its impedance elements of the values above derived will transmit freely currents of all frequencies lying between 200 and 2000 cycles per second. The attenuation constant per section at a frequency of 2200 cycles per second, for example, is found from equation (2) by computation to be .98. Hence, from equation (1), the ratio of currents in adjacent sections is 2.67 approximately, and if five sections are employed the current of 2200 cycles in the 5th section is less than 2% of its value in the first section, while currents of frequency lying between 200 and 2000 cycles per second are practically unattenuated.

Fig. 10 shows my invention, as embodied in the type shown in Fig. 1, employed in combination with vacuum tube repeater circuits. It is to be understood that the embodiments of my invention shown in Figs. 2, 3, 4 and 5 might be equally well employed. In said Fig. 10, a two-way two-repeater set consisting of two symmetrical halves is shown, and hence the same parts in the two halves of the set are designated by the same reference characters. The terminals 3, 4 and 3, 4 connect the repeater set in series with the through telephone line (not shown). At each end of the set are the secondary windings 6, 6 and 7, 7 of a repeating coil, of which the windings 5 constitute the primaries. Across the middle of the windings 6, 6 and 7, 7 are connected the conductors 8, 9 which lead to the filters 1^a. The other end of each filter is closed by a non-inductive resistance 10. The vacuum tube repeaters 11 are of a well-known type comprising a grid 12, filament 13, and plate 14. The input side of the repeater 11 is shown as bridged across half of the non-inductive resistance 10. The battery 15 heats the filament 13 through the adjustable resistance 16. Across the filament 13 and plate 14 is bridged the battery 17 in series with the high inductance coil 18. The function of the coil 18 is to allow the passage of direct current, but to prevent the passage of alternating current of telephonic frequencies. In parallel with the battery 17 and inductance coil 18, the repeater coil primary 5 is connected through the condensers 19, 19 whose function is to prevent the passage of direct current through the winding 5. Artificial lines 20, 20, which may be of a well-known construction, are provided, said artificial lines having substantially the same impedance as the telephone line over the range of telephonic frequencies. Said artificial lines are provided in order that inductive effects from the output side of one repeater 11, impressed through the coil 5, shall not create any difference of potential between the conductors 8 and 9. This condition is necessary in order that the output side of one repeater shall not impress disturbances on the input side of the other repeater, and thus cause sustained interaction or "singing" between the repeaters 11, 11. The function of the filters 1^a, 1^a is to prevent currents other than those necessary for the telephonic transmission of intelligible speech from being transmitted from the telephone line to the input side of the repeaters 11, 11.

The repeater set shown in Fig. 11 is the same as that shown in Fig. 10 except as to the form of the wave-filter. In said Fig. 11, the wave-filter structure consists of a low frequency wave-filter 1^f and a high frequency wave-filter 1^g of the types shown in Figs. 6 and 7, respectively, connected in series. The advantage of this latter structure over that shown in Fig. 10 is that the low frequency wave-filter 1^f may be omitted from the circuit when conditions are such as not to require the protection of the repeater from low frequency disturbances.

It is well known that high frequency induction or inductive disturbances militate seriously against the satisfactory operation of telephone repeaters, particularly of the vacuum tube type, such as are shown in Figs. 10 and 11. It is also well known that low frequency disturbances, such as those due to superposed or composited telegraphic impulses are equally objectionable. My invention prevents either high frequency or low frequency disturbances from affecting the repeater by inserting wave-filters between the telephone lines and the repeaters, as shown, for example, in Figs. 10 and 11. In this particular case, said wave-filters are designed to transmit all frequencies lying within the limiting frequencies, say between 200 and 2200 cycles per second, necessary for intelligible telephonic transmission of speech, while extinguishing currents of all frequencies lying above 2200 and below 200 cycles per second.

A further advantage attending the employment of the wave filter with the repeater circuits lies in the fact that the balancing artificial line need simulate the impedance characteristics of the telephone lines only over the limited range of frequencies necessary for intelligible telephonic transmission of speech, which permits of a more simple, efficient, and economical artificial line.

The invention which consists in the coöperative combination of the wave filter of my invention with a repeater, as illustrated in Figs. 10 and 11, is not embodied in the appended claims, but forms the subject matter of my co-pending application, Serial No. 101,845, filed June 5, 1916.

I claim:—

1. An electric wave-filter consisting of a connecting line of negligible attenuation containing lumped impedance in series with the line and lumped impedance in shunt across the line, said impedances having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said series and shunt impedances being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies, while attenuating and approximately extinguishing currents neighboring frequencies lying outside of said limiting frequencies.

2. An electric wave-filter consisting of a connecting line of negligible attenuation composed of a plurality of sections, each section including a capacity element and an inductance element, one of said elements of each section being in series with the line and the other in shunt across the line, said capacity and inductance elements having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said capacity and inductance elements being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said limiting frequencies.

3. An electric wave-filter consisting of a connecting line of negligible attenuation containing lumped capacity in series with the line and lumped inductance in shunt across the line, said capacity and said inductance having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said capacity and inductance being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said limiting frequencies.

4. An electric wave-filter consisting of a line composed of a plurality of sections, each section including a condenser and an inductance coil in series with the line, and an inductance coil in shunt across the line, said condensers and inductance coils having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said condensers and said inductance coils being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said limiting frequencies.

5. An electric wave-filter consisting of a line composed of a plurality of sections, each section including a condenser in series with the line and an inductance coil and a condenser in parallel in shunt across the line, said condensers and inductance coils having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said condensers and said coils being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said limiting frequencies.

6. An electric wave-filter consisting of a line composed of a plurality of sections, each section having a condenser and an inductance coil in series with the line and a condenser and an inductance coil in parallel in shunt across the line, said condensers and inductance coils having precomputed values

dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation, the values of said condensers and said coils being so proportioned that the structure transmits with practically negligible attenuation sinusoidal currents of all frequencies lying between said two limiting frequencies while attenuating and approximately extinguishing neighboring frequencies lying outside of said limiting frequencies.

In testimony whereof, I have signed my name to this specification in the presence of two subscribing witnesses, this ninth day of July 1915.

GEORGE A. CAMPBELL.

Witnesses:
GEORGE E. FOLK,
JOHN R. CARSON.

Certificate of Correction.

It is hereby certified that in Letters Patent No. 1,227,113, granted May 22, 1917, upon the application of George A. Campbell, of Montclair, New Jersey, for an improvement in "Electric-Wave Filters," an error appears in the printed specification requiring correction as follows: Page 5, below line 25, for formula (II°)—

$$\frac{C_1}{C_2}=\frac{1}{4}\left[\left(\frac{f_2}{f_1}\right)-1\right] \text{ read } \frac{C_1}{C_2}=\frac{1}{4}\left[\left(\frac{f_2}{f_1}\right)^2-1\right]$$

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 9th day of October, A. D., 1923.

[SEAL.]

WM. A. KINNAN,
Acting Commissioner of Patents.