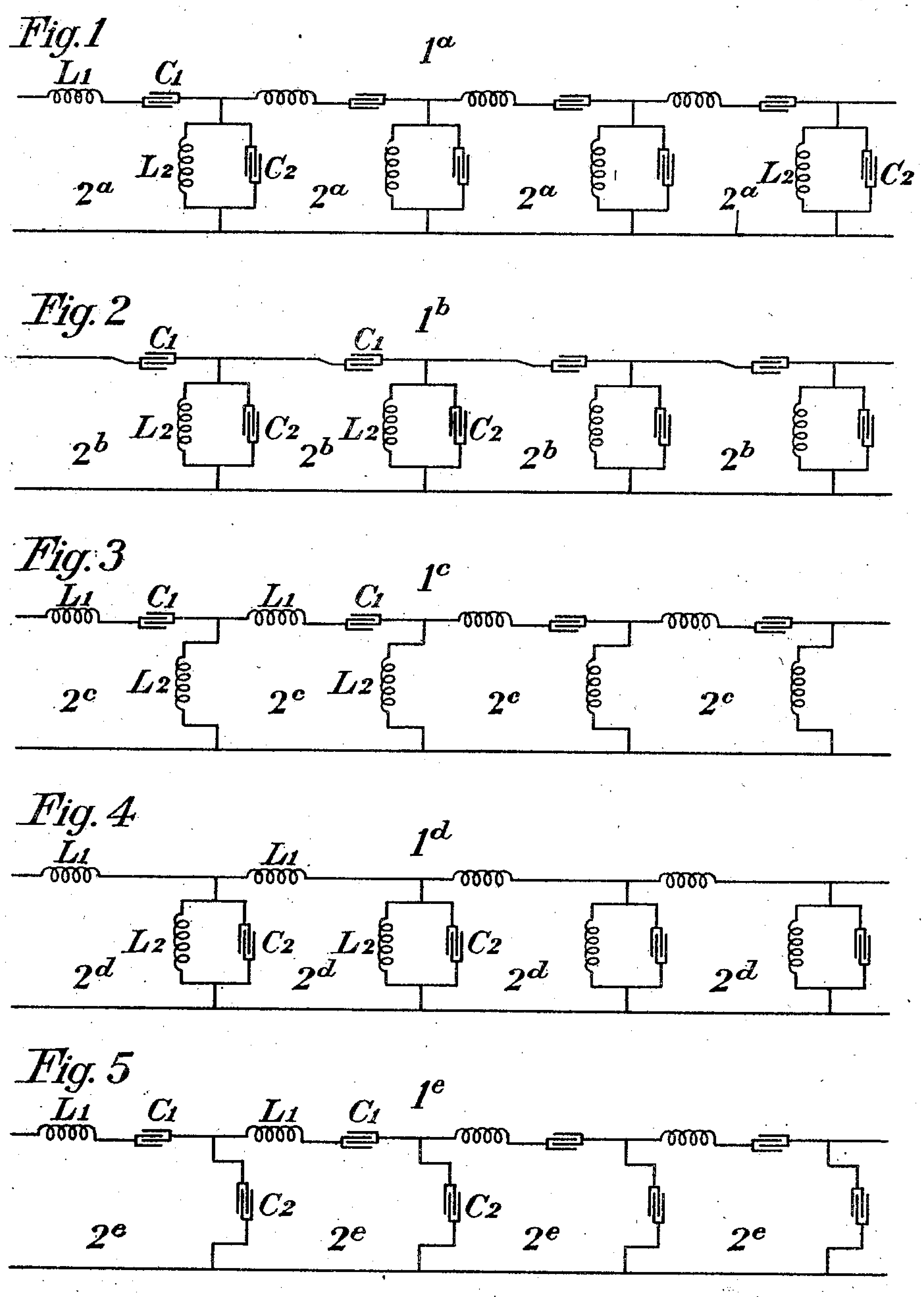
G. A. CAMPBELL.

ELECTRICAL RECEIVING, TRANSLATING, OR REPEATING CIRCUIT.

APPLICATION FILED JUNE 5, 1916.

1,227,114. Patented May 22, 1917.

3 SHEETS—SHEET 1.



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3 SHEETS—SHEET 2.

Fig. 6

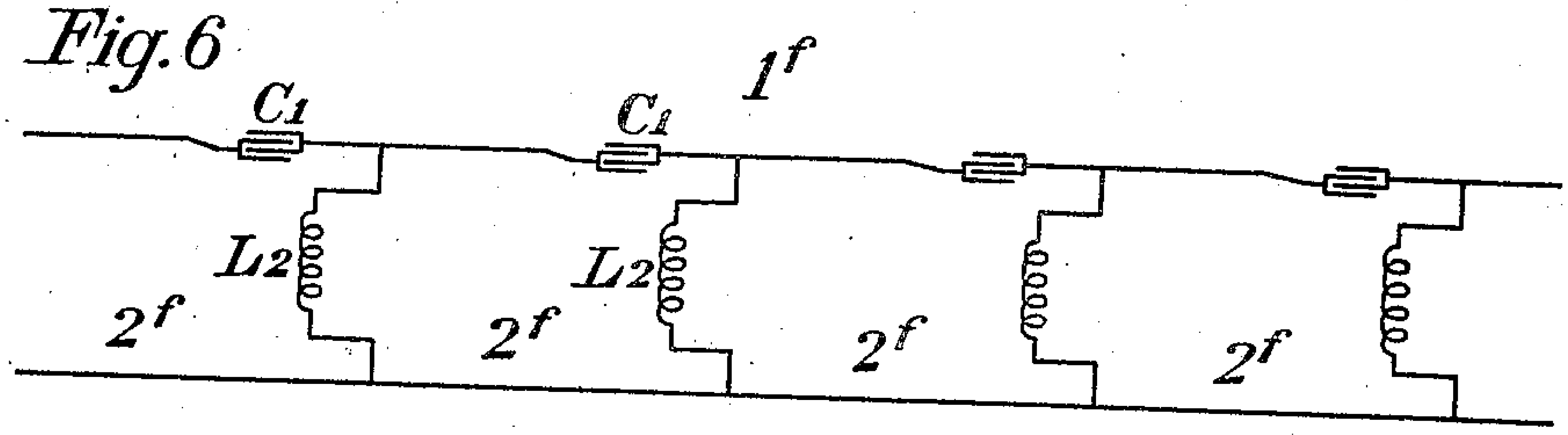
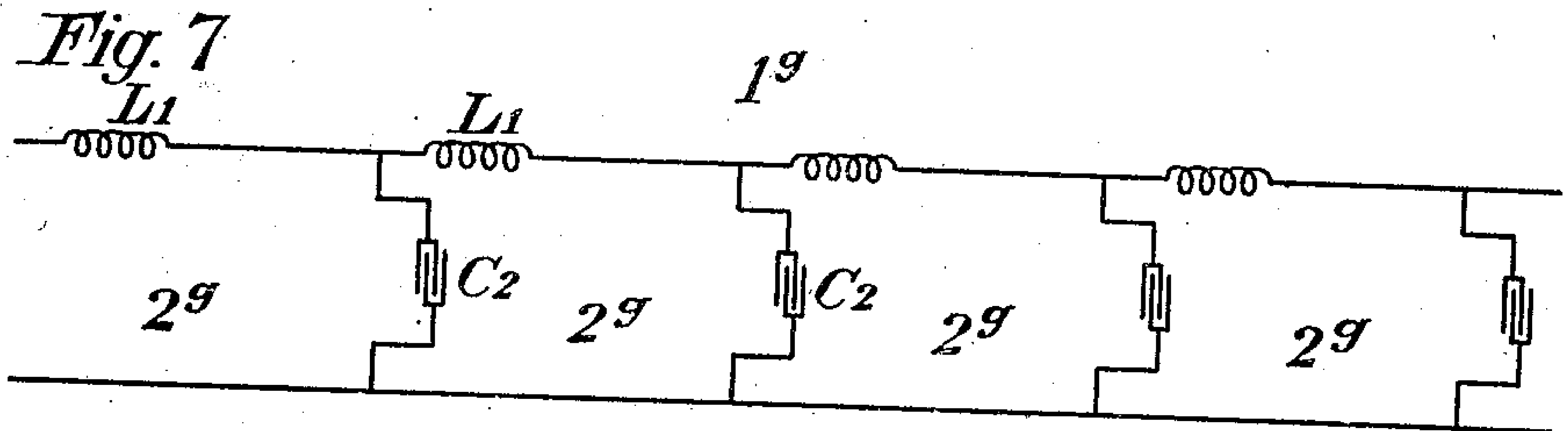


Fig. 7



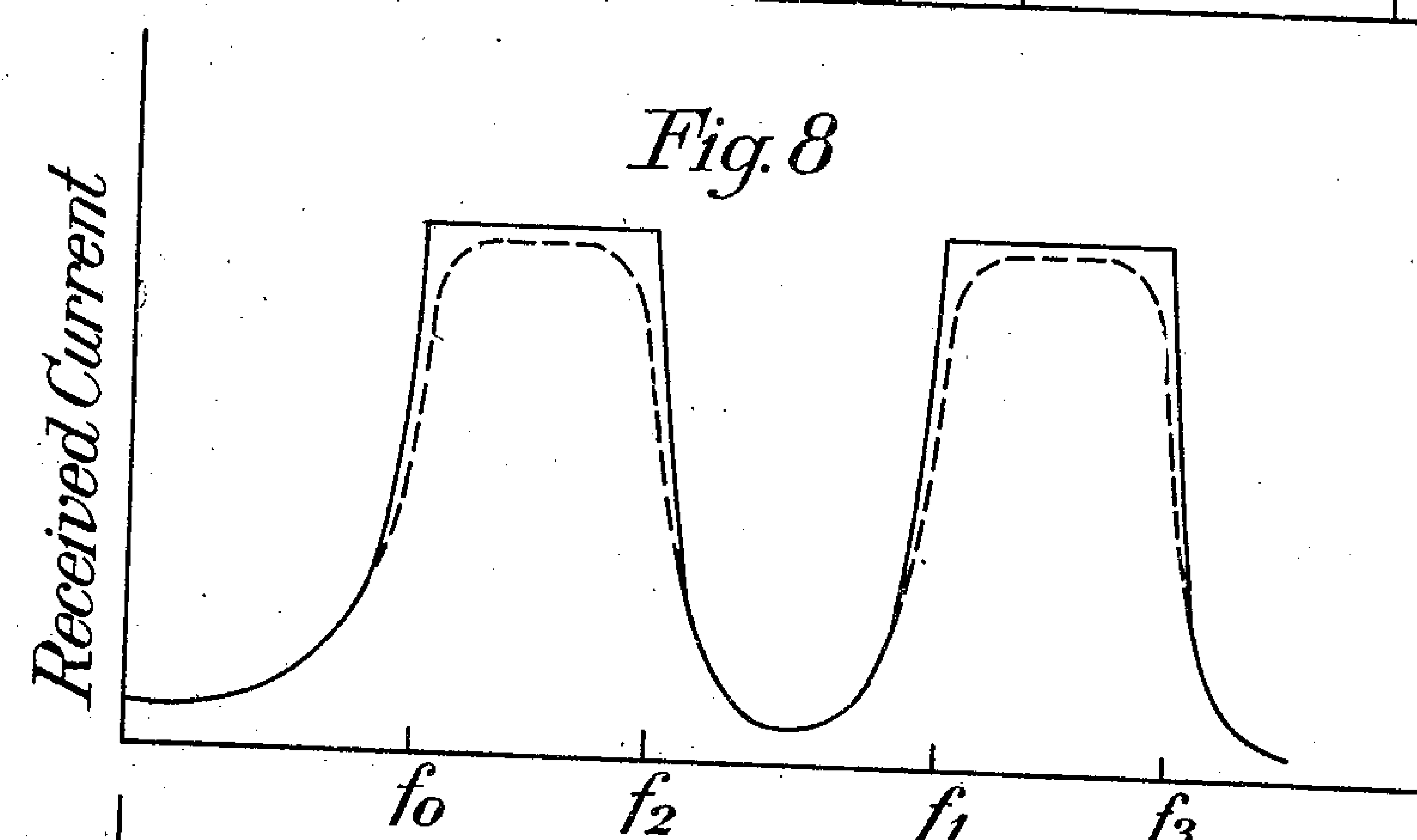


Fig. 8

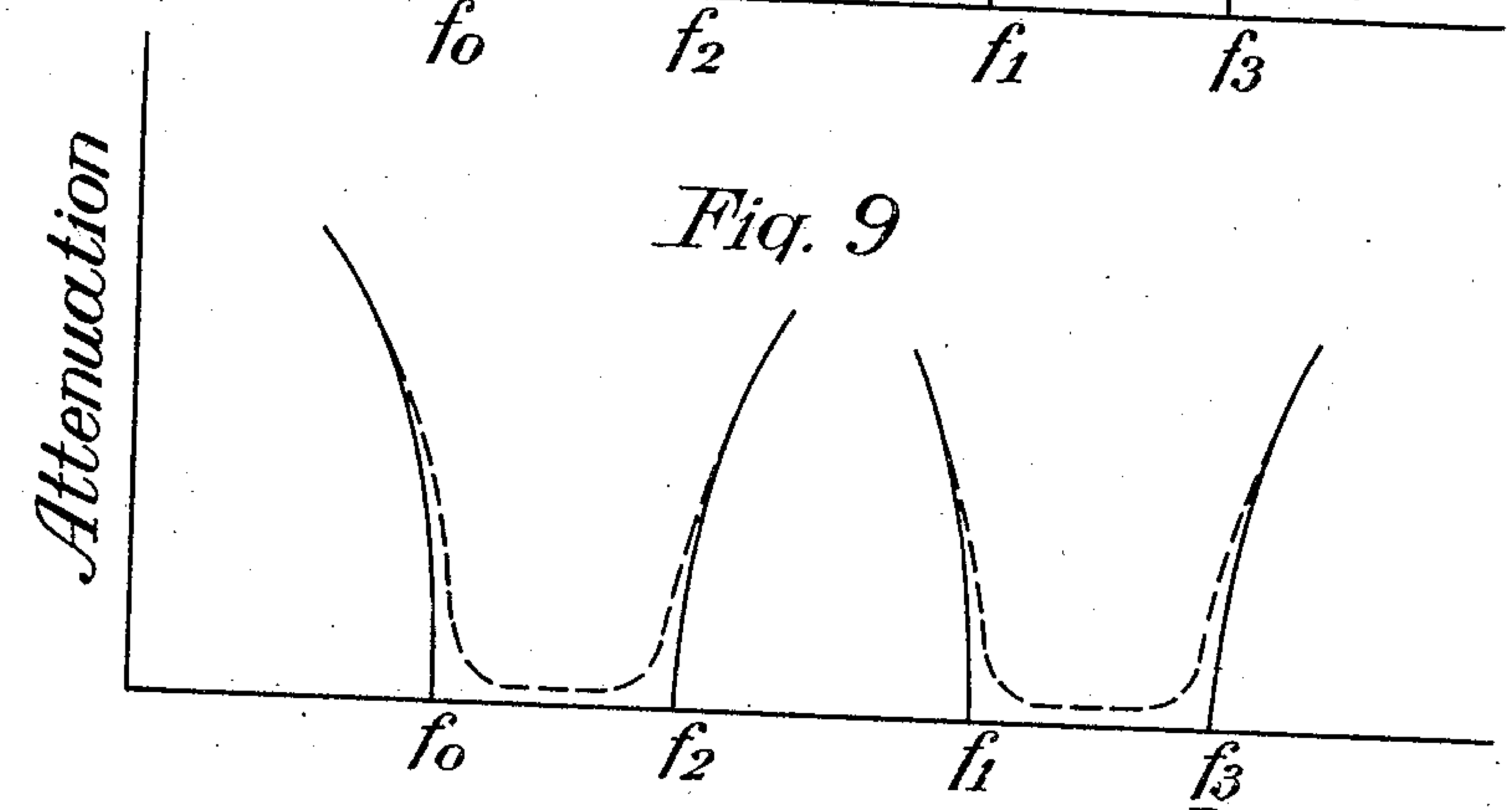


Fig. 9

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3 SHEETS—SHEET 3.

Fig. 10

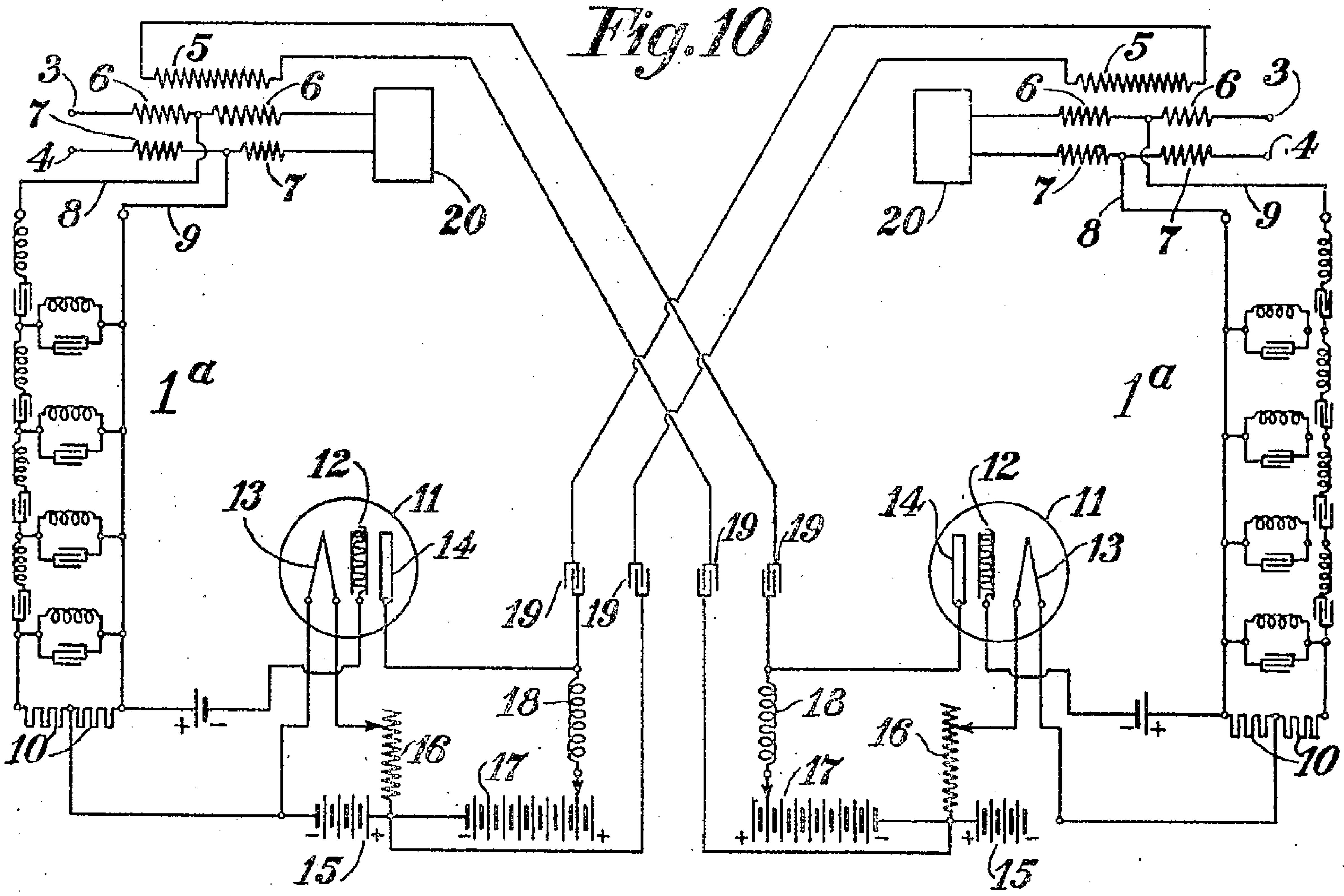
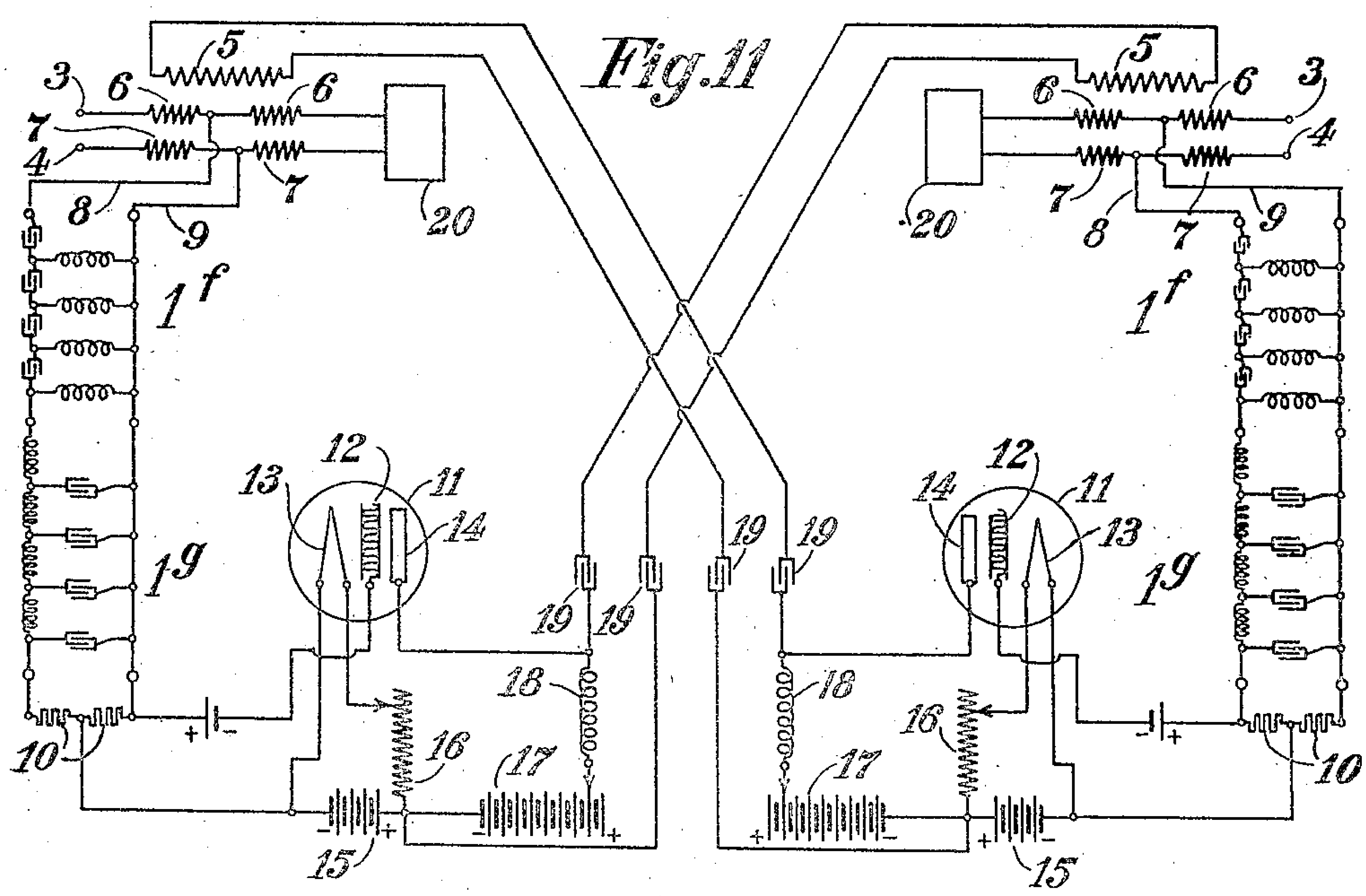


Fig. 11



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UNITED STATES PATENT OFFICE.

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ELECTRICAL RECEIVING, TRANSLATING, OR REPEATING CIRCUIT.

1,227,114. Specification of Letters Patent. Patented May 22, 1917.

Original application filed July 15, 1915, Serial No. 40,057. Divided and this application filed June 5, 1916. Serial No. 101,845.

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 Electrical Receiving, Translating, or Repeating Circuits, of which the following is a specification.

This invention relates to electric wave filters and more particularly to the combination of electric wave filters and electrical receiving, translating or repeating devices. Its object is to protect such electrical receiving, translating or repeating device from currents of all frequencies lying outside a preassigned range or ranges of frequency and to transmit thereto without appreciable diminution currents of all frequencies lying within said range or ranges of frequency. The object of my invention is attained by inserting between a signaling circuit, such as a telephone line, and the receiving, translating or repeating device an electric wave filter or the serial combination of a plurality of wave filters adapted to transmit with small or negligible attenuation currents of all frequencies lying within a preassigned range or ranges of frequency while attenuating and approximately extinguishing currents of all frequencies lying outside the limits of said preassigned range or ranges. The wave filter which I prefer to use is not claimed in this application, but constitutes the subject matter of my co-pending application, Serial No. 40,057, filed July 15th, 1915, of which this application is a division.

My invention, though it may find expression in many embodiments has, common to all, the broad idea of the combination of a translating device, such, for example, as a repeater, and 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 said translating device currents of all frequencies lying within specified or preassigned limits or ranges while attenuating and substantially extinguishing currents of all frequencies lying outside such limits.

My invention in one or more of its embodiments in signaling circuits has important applications in connection with wireless telegraphy, wireless telephony, multiplex high frequency wire telephony, composited telegraph and telephone lines; in fact broadly in connection with any signaling system employing translating devices wherein it is highly important that means be provided for selecting a range or band of frequencies necessary for the transmission of intelligence while at the same time excluding from the repeater 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 wave-filter which is a component element of my invention; Figs. 2, 3, 4, 5, 6 and 7 are diagrams illustrating different forms of wave-filters adapted for combination with repeaters; 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 form of wave-filter, 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 electro-magnetic 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 or frequencies.

The fundamental principles underlying the wave-filter and the manner of applying the same so as to provide a structure adapted for embodiment in this 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 and attenuation attending transmission of periodic currents, are so involved as to make desirable the use of mathematical formulæ in elucidating the laws governing the electro-magnetic 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 embodied as a component element in this invention.

For the purpose of deriving the mathematical formulæ pertaining to the theory of the wave-filter, 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 and by their aid the electrical constants of the wave filter may be determined. From said fundamental equations, simplified formulæ for different structural embodiments of the wave-filter 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 $C_2=0$; 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 the other band to infinity by making $C_2=0$;

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

(*e*) Relegating the other 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:

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

$$\frac{C_1}{C_2}=\frac{1}{4}\left[\left(\frac{f_3}{f_1}\right)^2-1\right] \qquad (II^e)$$

(f) Making $L_1=C_2=0$, 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.

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; $C_1=(5.14)\ 10^{-7}=0.514$ microfarad; and $C_2=0.254$ 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.

In the light of the foregoing description of the wave-filter my invention as illustrated in Figs. 10 and 11 will now be described. Referring to Fig. 10 there is shown a two-way two-repeater circuit employing vacuum tube repeaters in combination with wave-filters of the type shown in Fig. 1. It is to be understood that the wave-filters 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.

I claim:

1. The combination with a signaling circuit and a repeater therefor, of a wave filter inserted in circuit between said signaling circuit and said repeater for transmitting, with practically uniformly negligible attenuation, between said signaling circuit and repeater, sinusoidal currents of all frequencies between an upper pre-assigned limiting frequency and a lower pre-assigned limiting frequency of a predetermined range of frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said range.

2. The combination with a telephone line and a repeater therefor, of a wave filter inserted in circuit between said line and said repeater for transmitting, with practically negligible attenuation, between said line and repeater, sinusoidal currents of all frequencies between the upper and lower limits of the frequencies necessary for the telephonic transmission of intelligible speech, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said limits.

3. The combination with a transmission line, of an artificial line, a repeater, and a

wave-filter adapted to transmit with negligible attenuation a definite range of frequencies inserted in circuit between said line and said repeater for prescribing the range of frequencies to be transmitted by said repeater, substantially as described.

4. The combination with a transmission line, of a repeater normally capable of transmitting currents of all frequencies, a wave-filter for limiting to a definite range frequencies amplified by said repeater, and an artificial line simulating the impedance characteristics of said transmission line only over said limited range of frequencies, substantially as described.

5. The combination with a telephone line, of a vacuum tube repeater, a wave-filter for limiting the range of frequencies transmitted by said repeater, and an artificial line simulating the impedance characteristics of said telephone line only over said limited range of frequencies, substantially as described.

6. The combination with a telephone line and a telephone repeater therefor, of an electric wave-filter inserted in circuit between said line and the input side of said repeater, said filter consisting of a connecting line having lumped inpedance in series with said connecting line and lumped impedance in shunt across said connecting line, said impedances having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies necessary for telephonic transmission of intelligible speech, the values of said series and shunt impedances being so proportioned that said connecting line transmits with practically negligible attenuation, from the telephone line to the repeater, sinusoidal currents of all frequencies within said range of frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said range.

7. The combination with a telephone line and a vacuum tube repeater coöperating therewith, of an electric wave-filter inserted in circuit between said line and the input side of said repeater, said filter consisting of a connecting line 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 said connecting line and the other in shunt across said connecting 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 necessary for telephonic transmission of intelligible speech, the values of said capacity and inductance elements being so proportioned that said connecting line transmits with practically negligible attenuation, from the telephone line to said vacuum repeater, sinusoidal currents of all fraquencies within said range of frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said range.

8. The combination with a signaling circuit and a translating device therefor, of a wave filter inserted in circuit between said signaling circuit and said translating device, said filter including impedances having values depending upon the upper limiting frequency and the lower limiting frequency of a prescribed range of frequencies, the values of said impedances being so proportioned that said filter transmits with practically uniformly negligible attenuation, between said signaling circuit and translating device, sinusoidal currents of all frequencies within said range of frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said range.

9. In combination with a telephone line, a repeater normally capable of transmitting all frequencies with equal efficiency, a wave filtering apparatus to limit the range of frequencies to be transmitted from the line to the repeater, and a balancing network capable of balancing the telephone line for frequencies within the range so limited but incapable of balancing the line for frequencies outside such limitation but within the normally effective range of the amplifier.

10. The combination with a transmission line and a repeater therefor, of a wave filter inserted in circuit between said line and said repeater, said filter consisting of a connecting line having lumped impedances in series with said connecting line and lumped impedance in shunt across said connecting line, said impedances having values dependent upon the upper limiting frequency and the lower limiting frequency of a prescribed range of frequencies, the values of said series and shunt impedances being so proportioned that said connecting line transmits with practically negligible attenuation, between said line and repeater, sinusoidal currents of all frequencies within said range of frequencies, while attenuating and approximately extinguishing currents of neighboring frequencies lying outside of said range.

In testimony whereof, I have signed my name to this specification in the presence of two subscribing witnesses, this 25th day of May 1916.

GEORGE A. CAMPBELL.

Witnesses:

R. S. SUTLIFFE,

RALPH W. WOLF.