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TAPERED FILTER FOR ALTERNATING CURRENTS OF VARYING FREQUENCY

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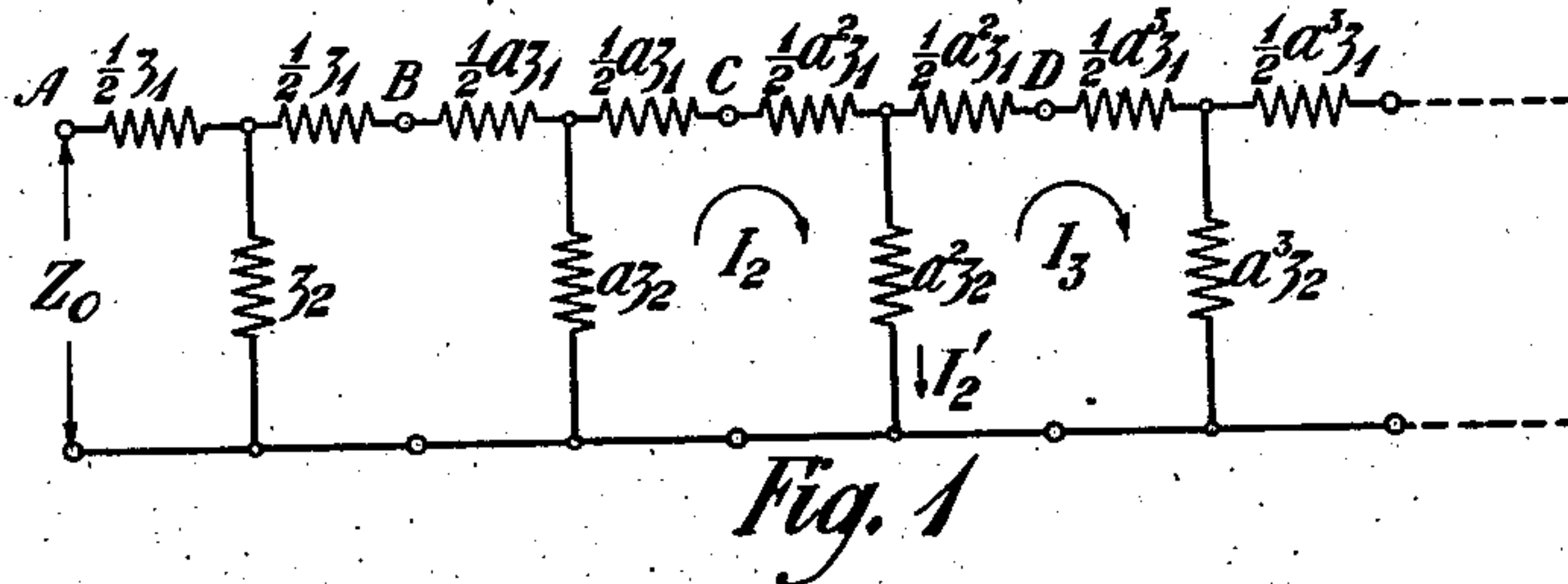


Fig. 1

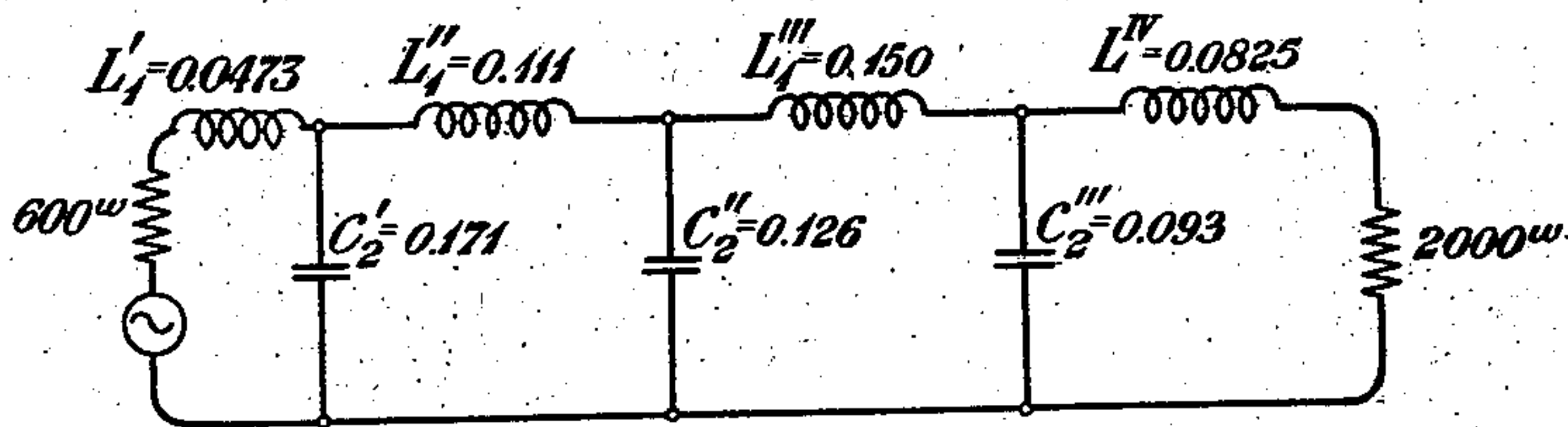


Fig. 2

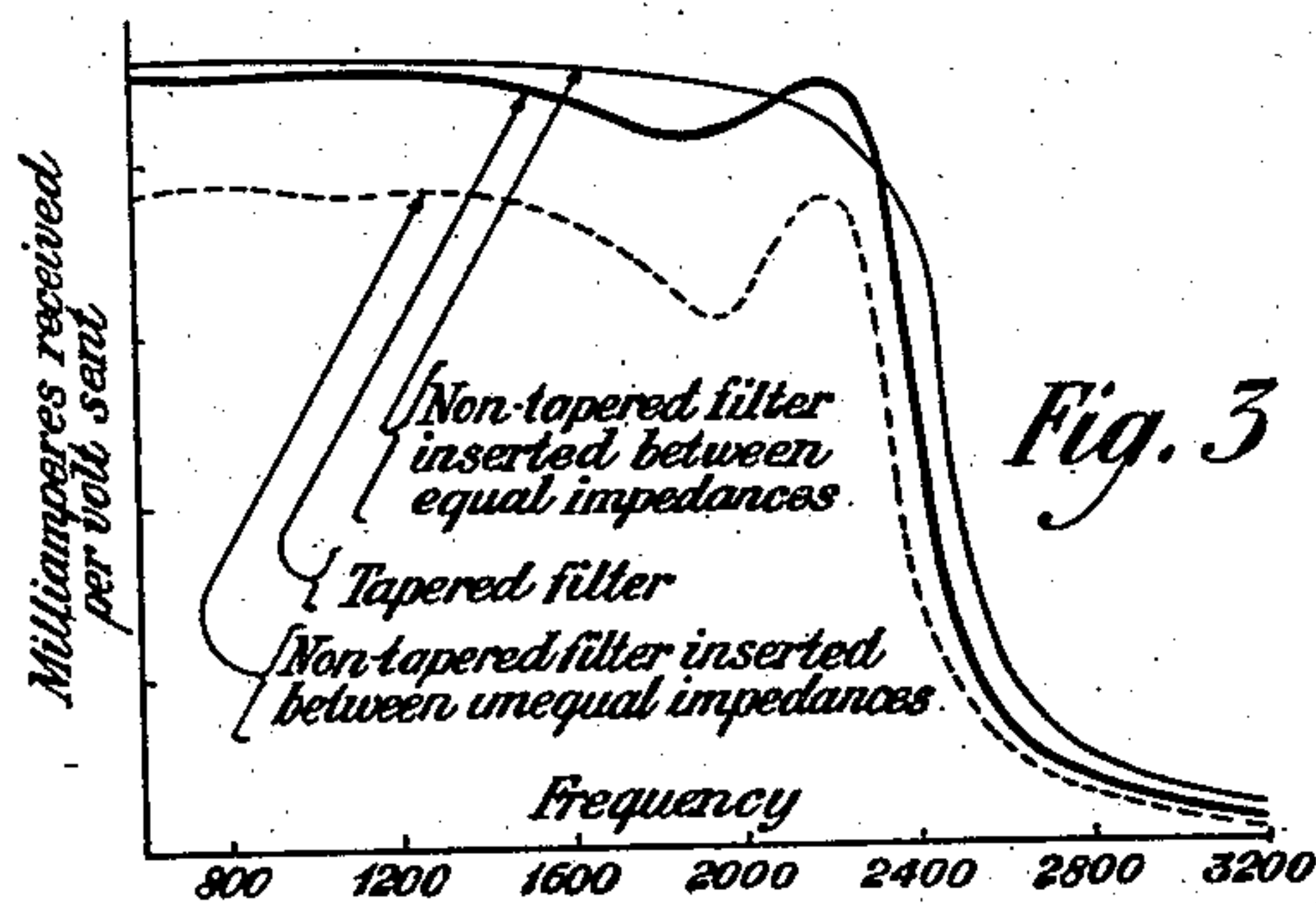


Fig. 3

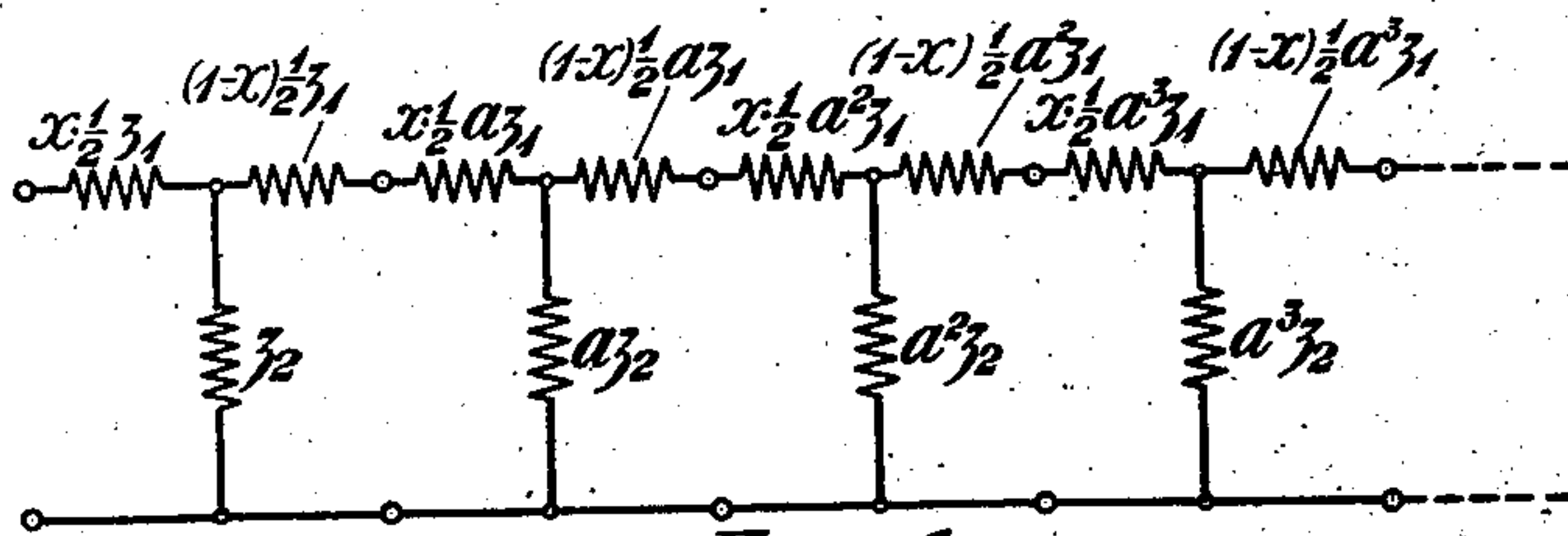


Fig. 4

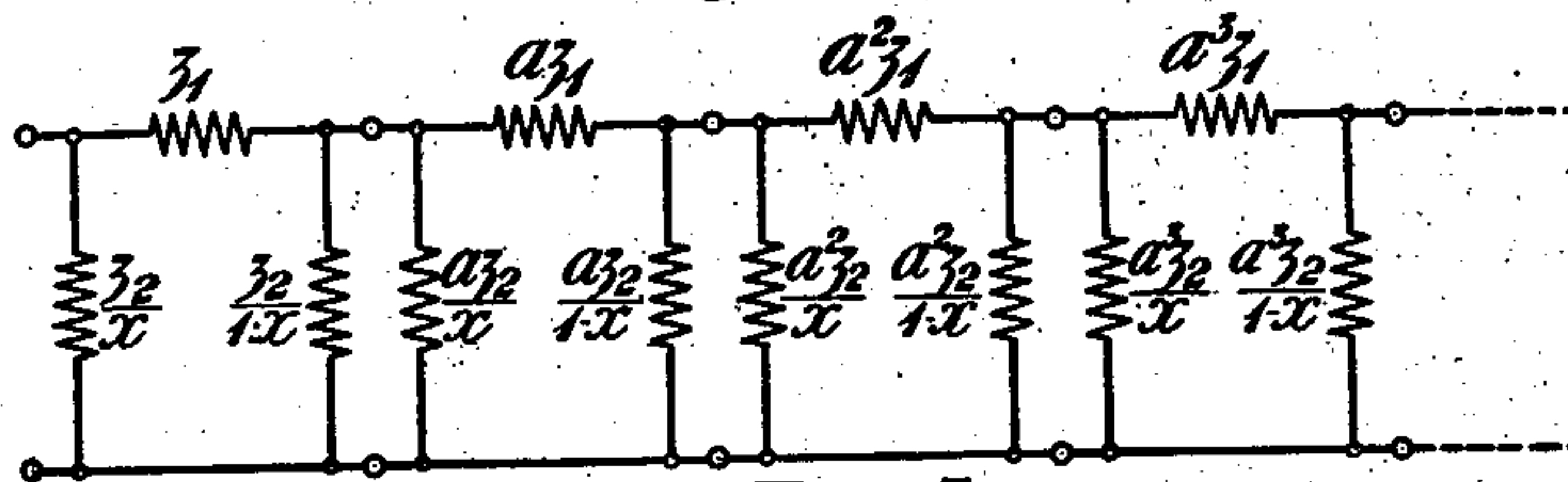


Fig. 5

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TAPERED FILTER FOR ALTERNATING CURRENTS OF VARYING FREQUENCY.

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By the term "wave-filter" I refer to a network of recurrent sections formed alike or according to some law of progressive change, and adapted freely to transmit currents of frequencies within a certain range and to shunt out currents within a different frequency range.

The principal object of my invention is to provide such a filter of tapering characteristic impedance. Another object of my invention is to provide a filter adapted to be interposed without serious reflection loss or irregularity between lines or apparatus of different characteristic impedance. Still another object is to provide a filter of this type, all sections of which shall have the same free transmission ranges and which shall have a definite and unvarying propagation constant throughout its length.

In the following specification I have disclosed a limited number of specific embodiments of the invention, which I shall now proceed to describe with the understanding that the definition of the invention is given in the appended claims.

Referring to the drawings, Figure 1 is a diagram illustrating a filter embodying my invention. Fig. 2 is a diagram of a more specific example. Fig. 3 is a diagram showing characteristic curves for the filter of Fig. 2. Figs. 4 and 5 are diagrams showing modifications.

It is known how to make filters of recurrent sections, all alike, each section comprising series impedance or impedances and shunt impedance or impedances. Fig. 1 can be looked upon as a filter of this type, provided the constant " a " appearing in the legends is taken equal to 1. With this understanding, it will be seen that the series impedances are each z_1 and the shunt impedances z_2 . The theory of such a filter is commonly developed on the assumption that there is an infinite number of sections. The results obtained for the infinite filter apply to a filter having only a finite number of sections, provided the proper terminal impedance is employed. The impedances z_1 and z_2 are made with as little dissipative loss as practicable, and for most purposes

this loss can be disregarded, and z_1 and z_2 can be looked upon as pure reactances. The filter of Fig. 1 has mid-series termination at the left, that is, the initial series impedance is only half that of the succeeding series impedances. The shunt impedances are equal.

The foregoing discussion of Fig. 1 is on the express assumption that the constant a is equal to 1. My improvement involves making a different from 1. Assuming that the first mid-series section extending from A to B is as given in Fig. 1, I form the next mid-series section from B to C by multiplying each of the component impedance elements by a . In the next section from C to D these elements are multiplied by a^2 , and so on. This defines the structure of my improved filter. The conditions that determine the value to be given to a will be discussed later.

My improved filter has the following properties:

1. Its critical or cut-off frequencies are definite and the same, no matter what value is given to a ; accordingly the same as for the non-tapered filter, corresponding to $a=1$.

2. The characteristic impedance from successive points of junction of the sections is increased from section to section by the factor a , assuming $a>1$, or decreased in this ratio if $a<1$.

3. The propagation constant is identical for all filter sections, both in the free transmission and attenuated frequency range.

Having the foregoing properties, it will be seen that my improved filter may be introduced between two lines or apparatus of different characteristic impedance, the filter being designed so that its characteristic impedance from section to section is graded between the two extreme values of impedance. My tapered filter then serves in all respects as an ordinary filter, and in addition it obviates the disadvantage of large reflection loss that would be had with an ordinary non-tapered filter. In the free transmission ranges of a filter the currents are displaced from section to section by a phase angle which varies from 0° at the one

limiting frequency to 180° at the other limiting frequency of each transmitted frequency band. In general, therefore, the reflected currents at successive junction points of the tapered filter are not in phase, so that to a great extent these reflections annul one another. Perhaps this point may be made clearer by considering that the sum of a number of vectors of equal length and random direction will be decidedly less than if they all had the same direction.

That the characteristic impedance of my improved filter varies in geometrical ratio from section to section with the factor a may be shown by the following considerations. Whatever the impedance Z_0 at A, if each individual component impedance element of the whole network be multiplied by a , the resultant impedance will be aZ_0 . But now

the filter viewed from A will be identical with what it was before when looking to the right from B, for it is assumed always that the filter has an infinite number of sections. Hence the characteristic impedance at B for the filter as given in Fig. 1 must be aZ_0 . By similar reasoning it may be shown that at C the characteristic impedance must be a^2Z_0 , and so on.

I will now proceed to obtain a formula for the input characteristic impedance Z_0 . From Kirchhoff's laws we get the equation

$$Z_0 = \frac{1}{2}z_1 + \frac{1}{\frac{1}{z_2} + \frac{1}{\frac{1}{2}z_1 + aZ_0}} \quad (1)$$

The solution of this gives

$$Z_0 = \frac{1}{2a} \left[(a-1) \left(\frac{z_1}{2} + z_2 \right) + \sqrt{(1+a)^2 \left(\frac{z_1^2}{4} + z_1 z_2 \right) + (a-1)^2 z_2^2} \right] \quad (2)$$

Knowing the impedance at the input end Z_0 , the impedance at any junction point of the filter sections may be determined at once by the formula

$$z_n = a^n Z_0 \quad (3)$$

where $n=0$ at the input end A, 1 at B, 2 at C, and so on.

That the propagation constant is the same at all points A, B, C, D, etc., may be shown as follows. By definition of the propagation constant Γ

$$e^{-\Gamma} = \frac{I_{n+1}}{I_n} \quad (4)$$

where the currents in the series elements of the successive n th and $(n+1)$ th meshes are represented by I_n and I_{n+1} . Let the current in the intermediate shunt impedance element be I'_n . Then we have the equations

$$I_n - I_{n+1} + I'_n = 0$$

and

$$I'_n \cdot a^n z_2 = I_{n+1} \left(\frac{1}{2} a^n z_1 + a^{n+1} Z_0 \right)$$

From these two equations we obtain the solution

$$e^{-\Gamma} = \frac{I_{n+1}}{I_n} = \frac{z_2}{\frac{1}{2} z_1 + z_2 + a Z_0} \quad (5)$$

Thus the value of the current ratio in successive sections of the filter is seen to be independent of n , showing that Γ has the same value, whatever the value of n that is taken. This proves the constancy of the propagation constant throughout the length of the filter.

In the ordinary filter to which the filter of Fig. 1 reduces when $a=1$, if we represent

the propagation constant by Γ_0 , we have the equation

$$\cosh \Gamma_0 = \frac{1}{2} \cdot \frac{z_1}{z_2} + 1 \quad (6)$$

Using this value, it is easily possible to derive from equation (5) the equations,

$$\cosh \Gamma = \cosh \Gamma_0 + \frac{a-1}{a+1} \sinh \Gamma \quad (7)$$

and

$$\cosh \Gamma = \cosh \Gamma_0 + \frac{a-1}{2} \cdot \frac{Z_0}{Z_2} \quad (8)$$

From equations (7) and (8), the propagation constant of the tapered filter can easily be compared with that of the non-tapered filter. In order to keep reflection effects between successive sections small, a value of a should be taken differing only slightly from 1.

It will be seen that my improved filter involves making the characteristic impedance vary in geometrical ratio from section to section. I have tried other laws for the progression of value of the characteristic impedance and I find that the law disclosed in this specification gives a unique result. Under other laws, a value of the propagation constant is obtained that can not be freed from n , which defines the position of the section in the filter.

In Fig. 2 I have illustrated a simple low-pass filter of three sections designed for a specific purpose and embodying the tapering construction heretofore disclosed in this specification. The filter of Fig. 2 is intended to make connection between a low impedance line of 600 ohms and another line

having an impedance of 2000 ohms. The critical or cut-off frequency of the filter is to be 2,500, and the maximum transmission is desired at a frequency of 800 cycles. With three sections there will be four points of discontinuity: hence we have for the determination of α , the equations $Z_0=600$, $\alpha^4 Z_0=2,000$, from which α is readily computed to be 1.35. I shall not take space here to give the steps by which the values of z_1 and z_2 are determined as they are practically the same as in the case of the non-tapered filter having the characteristic impedance Z_0 . In the actual construction of the filter the two series impedances shown separately on either side of a junction point such as B in Fig. 1 will be consolidated and in the case of the low-pass filter of Fig. 2 their combination in a single coil is shown. The resultant inductance values of the coils appear as legends on Fig. 2. The shunt impedances vary by the factor $\alpha=1.35$; and accordingly the capacities of the condensers C_2' , C_2'' and C_2''' vary inversely by the same factor.

In Fig. 3 the heavy line shows, plotted against frequency, the current received over the tapered filter per volt applied at the sending end. The diagram shows how the filter cuts off at a frequency of 2,500. For comparison I have shown, in the light, continuous line, the corresponding characteristic that might be obtained with a non-tapered filter inserted between two lines of equal impedance, that is when there are no reflection losses, and in the dotted line I have shown the characteristic for the non-tapered filter inserted between a 600-ohm line and a 2000-ohm line. The number of sections in Fig. 2 is rather small; for a larger number of sections the transmission characteristic of the tapered filter would be improved.

The foregoing discussion is based on "mid-series" sections and filter termination, but the same geometrical law of progression is equally applicable for other sections and filter terminations. Thus a filter may

be terminated at α -series section and all the sections may be divided accordingly. This is illustrated in Fig. 4. It will be seen that the filter of Fig. 1 is a special case of Fig. 4, with $\alpha=1$ in Fig. 1.

Instead of α -series and mid-series sections one may have α -shunt sections. In this case α times the shunt admittance is considered to belong to the section that follows and the remainder to the section that precedes. To make this clear on Fig. 5 the shunt impedances have been replaced by pairs of impedances with appropriate legends. By making $\alpha=1$, we have the special case of mid-shunt sections and termination.

I claim:

1. The method of reducing the total reflection loss in a sectional alternating current filter between lines or apparatus of different characteristic impedance, which consists in partially reflecting the currents at each successive section of the filter, whereby the vector sum of the partial reflections will be less than the total reflection would be if the impedance irregularity were all at one place.

2. The method of reducing reflection losses in a filter interposed between lines or apparatus of different characteristic impedance, which consists in dividing up the reflection at different points in different phase throughout the filter, and thereby largely neutralizing the reflection effects.

3. In the operation of a filter of recurrent section type, the method of filtering alternating currents of a certain frequency range from a circuit of one impedance value to a circuit of another impedance value, which consists in producing partial reflection effects at the respective sections due to corresponding differences of impedance between them.

In testimony whereof, I have signed my name to this specification this 18th day of February, 1921.

EGINHARD DIETZE.