Oct. 13, 1925. 1,557,036

H. W. ELSASSER

TERMINAL NETWORK FOR HIGH PASS WAVE FILTERS

Filed March 24, 1921

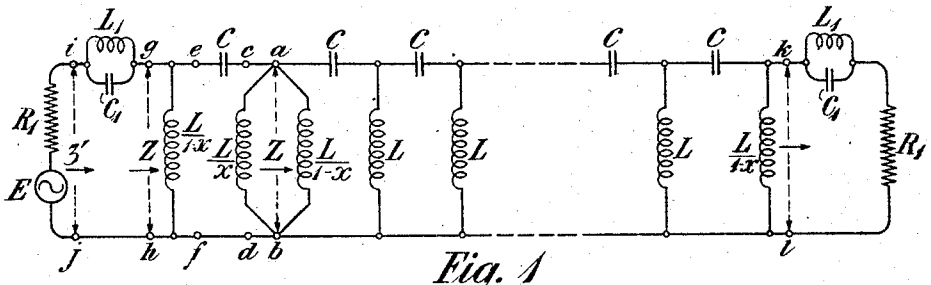


Fig. 1

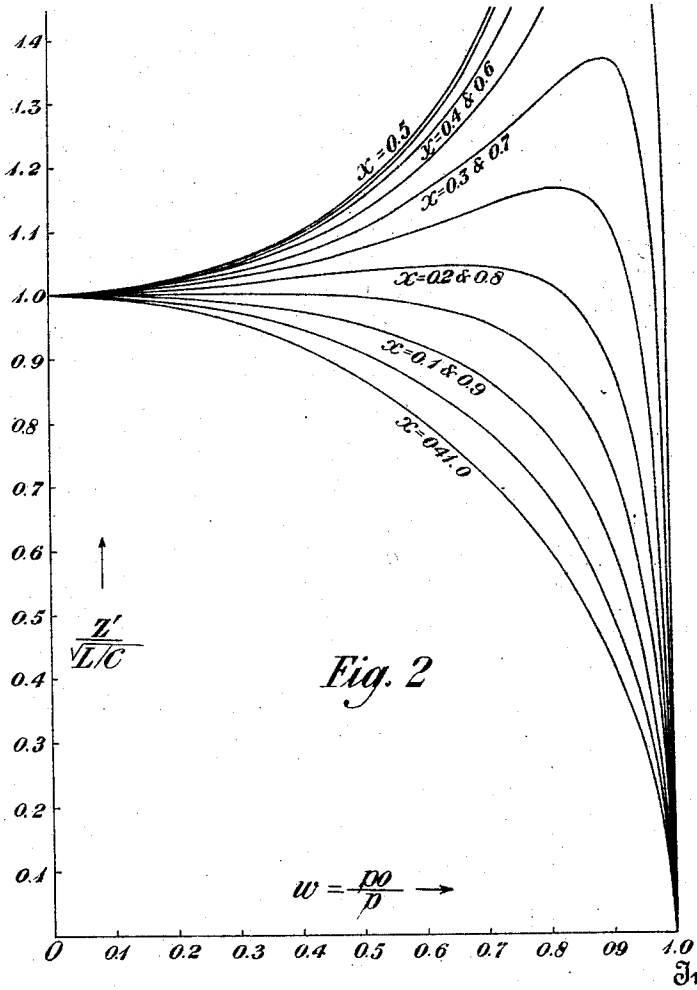


Fig. 2

Inventor

H. W. Elsasser

By his Attorney

Patented Oct. 13, 1925. 1,557,036

UNITED STATES PATENT OFFICE.

HENRY W. ELSASSER, OF NEW YORK, N. Y., ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TERMINAL NETWORK FOR HIGH-PASS WAVE FILTERS.

Application filed March 24, 1921. Serial No. 455,360.

To all whom it may concern:

Be it known that I, HENRY W. ELSASSER, residing at New York, in the county of New York and State of New York, have invented certain Improvements in Terminal Networks for High-Pass Wave Filters, of which the following is a specification.

The principal object of my invention is to provide a new and improved terminal network for a high-pass wave filter of the type having recurrent sections. Another object of my invention is to provide a high-pass wave filter and terminal impedance elements associated therewith, so that reflection losses and irregularities shall be avoided. Still another object is to provide a terminal network to simulate the iterative impedance of such a filter, so that it shall be equivalent to the ideal filter with an infinite number of recurrent sections. All these objects and other objects and advantages of my invention will become apparent on consideration of the specific example disclosed in the following specification, for which a diagram is given in Fig. 1 of the drawings, Fig. 2 shows certain curves that will be referred to in explaining the operation of the device of Fig. 1. The invention is defined in the appended claims.

Proceeding now to disclose the structure of the specific embodiment of the invention shown in Fig. 1, this shows a high-pass wave filter of known type, having like recurrent sections, with a series condenser C in each section and a shunt inductance L in each section. For such a filter the critical frequency is

$$\frac{p_o}{2\pi} = \frac{1}{4\pi\sqrt{LC}} \quad (1)$$

This means that the filter will transmit freely those frequencies lying above $p_o/2\pi$, but will attenuate frequencies below that limit.

For convenience in explaining the theory of the device, I have substituted for L at the left of the filter an equivalent pair of parallel inductance of value L/x and $L/(1-x)$. It will be seen that the impedance of the combination is the same as of the single inductance L.

To attain the objects of my invention, I make the last shunt element at each end of the filter to be $L/(1-x)$ instead of L. x may have different values, but the optimum value will be disclosed presently; it may be mentioned here that it is 0.2. In series with the filter at each end, I introduce the combination consisting of the elements L_1 and C_1 in parallel, having values such that

$$L_1 = \frac{0.5-x}{x(1-x)} L \text{ and } C_1 = \frac{1}{0.5-x} C \quad (2) \text{ and } (3)$$

At the drop end of the filter I close the circuit through a resistance

$$R_1 = \sqrt{L/C}$$

The translating device intended to receive the transmitted current may properly have this resistance and be represented by R_1, or it may have a resistance which is part of the resistance R_1, the remainder being made up by the insertion of additional resistance elements, or any equivalent multiple arrangement of elements may be involved, or a transformer may be interposed at the drop end having the proper ratio to give the effective resistance R_1.

Similarly the resistance R_1 at the sending end of the filter may be taken as the effective resistance of the transmitting device, and for best efficiency the filter will be designed to meet this resistance.

In accordance with the usual practice in developing the theory of wave filters, let us now assume that the elements C and L respectively in series and in shunt are repeated to the right an infinite number of times, but that at the left the apparatus is arranged as shown in Fig. 1. Let the impedance to the right across the points *ab* be represented by Z. Accordingly the impedance to the right across the points *cd* is

$$\frac{ip\frac{L}{x}Z}{ip\frac{L}{x}+Z}$$

and across *ef*, looking to the right, the impedance is

$$\frac{ipLZ}{ipL+xZ}+\frac{1}{ipC} \quad (4^a)$$

But the admittance across *ef* may evidently be expressed as

$$\frac{1}{Z}-\frac{1}{ip\frac{L}{1-x}} \quad (5)$$

where Z is the impedance across the points *gh* and is the same as across the points *ab*. Evidently the impedance (4ª) may be equated to the reciprocal of the admittance (5), and the solution of this equation for Z gives

$$Z=-\frac{pL\sqrt{p^2LC-1/4}}{x(1-x)-p^2LC}-\frac{i(0.5-x)pL}{x(1-x)-p^2LC} \quad (6)$$

Now consider the impedance across *ij*. First we will get the impedance of the parallel combination L_1C_1. This is easily shown to be

$$\frac{ipL_1}{1-p^2L_1C_1}$$

Substituting from equations 2 and 3 this becomes

$$i\frac{(0.5-x)pL}{x(1-x)-p^2LC} \quad (6^a)$$

which is evidently equal to the reactance term of equation 6, but opposite in sign. Accordingly for the impedance across *ij* we add this expression (6ª) to the right hand member of equation (6) and get

$$Z'=-\frac{pL\sqrt{p^2LC-1/4}}{x(1-x)-p^2LC} \quad (7)$$

This is evidently a pure resistance. Hence it will be seen that, by terminating the filter at the input end in the manner shown in Fig. 1, I have made the impedance of the combination equal to a pure resistance, leaving the parameter x as yet undetermined.

Notice that when $p=\infty$, equation 7 reduces to

$$Z'=\sqrt{L/C} \quad (8)$$

We shall find it convenient to divide both sides of equation 7 by $\sqrt{L/C}$, getting

$$\frac{Z'}{\sqrt{L/C}}=-\frac{p\sqrt{LC}\sqrt{p^2LC-1/4}}{x(1-x)-p^2LC} \quad (9)$$

To examine the variation of $\frac{Z'}{\sqrt{L/C}}$ over the frequency range, with various values of x, we notice that the frequency range extends from the value given in equation 1 to infinity. Accordingly, instead of plotting against p, we shall find it more convenient to keep our diagram within a finite range and plot against the ratio of the critical frequency $p_o/2\pi$ of the filter to the variable frequency $p/2\pi$. Let this ratio be represented by the character w. Thus equation 9 becomes

$$\frac{Z'}{\sqrt{L/C}}=\frac{\sqrt{1-w^2}}{1-4x(1-x)w^2} \quad (10)$$

The plot for this equation is given in Fig. 2 of the drawings, and we see at once that the impedance Z′ varies over the frequency range, approaching constancy as w approaches zero, that is, as p approaches ∞. The diagram Fig. 2 also shows that a value of x equal to 0.2 or 0.8 gives to Z′ about the most nearly constant value over the transmitting frequency range. Accordingly in the system shown in Fig. 1, where x appears, it will be understood that 0.2 is the optimum value. This is taken rather than 0.8, for the reason that the value 0.8 in equations 2 and 3 would give values that cannot be realized physically.

Assuming all the time to this point that the filter extends infinitely to the right, we have shown that, with the termination at the left, the impedance Z′ to the right is a pure resistance and is fairly constant over the greater part of the free transmitting range. It remains to discuss the effect of the termination of the finite filter at the drop end on the right.

From the expression (6ª) we know the impedance of the parallel combination L_1C_1 at the right of Fig. 1, and we also know the value of R_1 from equation 4. Accordingly, for the impedance across *kl* looking to the right, we have

$$\sqrt{\frac{L}{C}}+i\frac{(0.5-x)pL}{x(1-x)-p^2LC} \quad (11)$$

The part of the infinite filter that has been cut away at points *kl* and replaced by the combination C_1, L_1, R_1 evidently begins with a shunt inductance $\frac{L}{x}$. Thus it begins the same as at *ab* looking to the right, except that x and $1-x$ are interchanged. Hence we shall get the impedance across this discarded infinite extension of the filter by interchanging x and $1-x$ in equation 6, which thereupon becomes

$$Z''=-\frac{pL\sqrt{p^2LC-1/4}}{x(1-x)-p^2LC}+\frac{i(0.5-x)pL}{x(1-x)-p^2LC} \quad (12)$$

Comparing this result with equation (11) we see that the reactance terms are the same. Also, by comparison with equation 9 and consideration of Fig. 2, we see that the resistance term of equation 12 is given by the curves of Fig. 2 and that when, as under the conditions of equation 12, x=0.8, the resistance takes the optimum value as heretofore explained for x=0.2. To summarize briefly, the terminal network L_1, C_1, R_1 at the drop end simu-

lates the impedance of the infinite extension of the filter which it replaces; it simulates the reactance exactly and the resistance approximately. The actual finite filter is made to operate in a manner closely similar to the ideal infinite filter.

Thus I have shown how to terminate the high-pass filter to make it operate without reflection losses or irregularities. Occasions may arise when it is desired to provide a balancing network for a filter. It will be seen that my network to the right of *kl* simulates the filter, and therefore it could be used as a network to balance against the filter. A few actual filter sections C, L, might be interposed as part of the balancing network to improve the simulation.

I claim:

1. A high-pass wave-filter of the type having recurrent sections in combination with a terminal network comprising inductance and capacity in parallel and simulating the impedance of the corresponding infinite filter.

2. A high-pass filter having fractional shunt termination, in combination with a series reactance of approximately equaling the reactance of the corresponding infinite filter, and a series resistance approximating to the resistance of the infinite filter over the greater part of its free transmitting range.

3. In combination with a high-pass filter, a terminal network comprising inductance and capacity in multiple and resistance in series.

4. A high-pass filter of the type having recurrent sections in combination with a network in series therewith, said network having a reactance equal in absolute value to the reactance of the corresponding infinite filter, said reactance being obtained by means of inductance and capacity in parallel in said network.

5. A high-pass filter of the type having recurrent sections in combination with a network in series therewith, said network consisting of inductance and capacity in parallel, said inductance and capacity having the proper values to give the network a reactance equal and opposite to that of the filter at the corresponding termination.

6. A high-pass filter of the type having recurrent sections in combination with a network in series therewith, said network consisting of inductance and capacity in parallel and of values determined by equations (2) and (3) of the foregoing specification.

7. A high-pass filter of the type having recurrent sections, with a fractional shunt element at one end, in combination with a network in series at that end, said network consisting of inductance and capacity in parallel and of values determined by equations (2) and (3) of the specification and with the value 0.2 for the parameter x of those equations.

8. A high-pass wave-filter of the type having recurrent sections in combination with a terminal network closely simulating the reactance of the corresponding infinite filter for all frequencies, and approximately simulating its resistance over substantially all of the free transmitting range.

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

HENRY W. ELSASSER.