Aug. 9, 1927. 1,638,437

D. K. GANNETT ET AL

ELECTRICAL NETWORK

Filed April 27, 1920

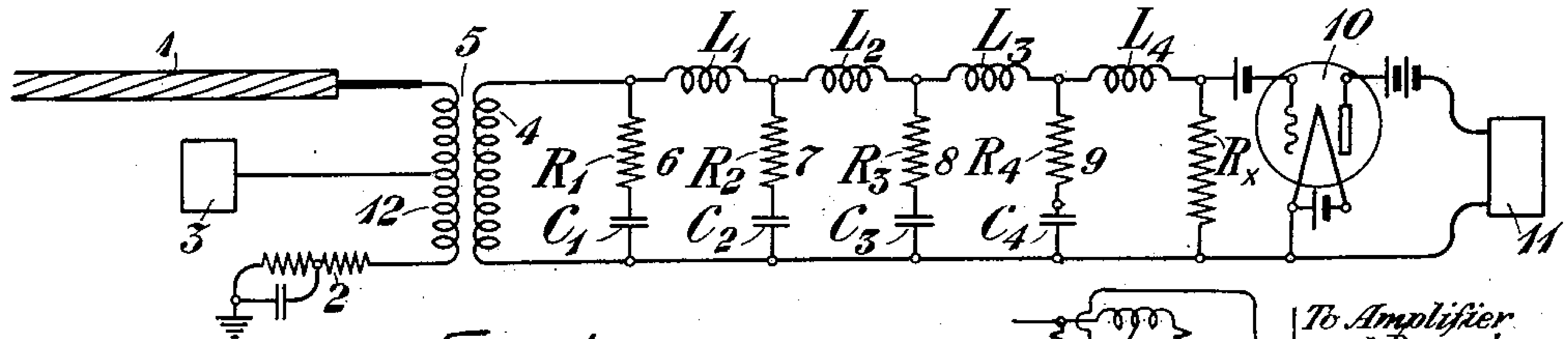


FIG. 1.

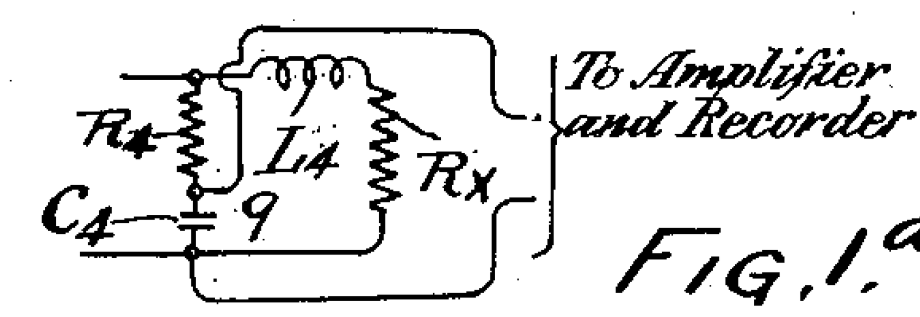


FIG. 1.ª

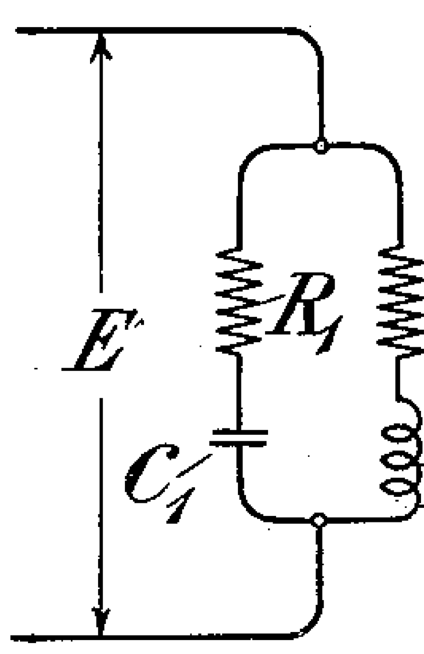


Fig. 2

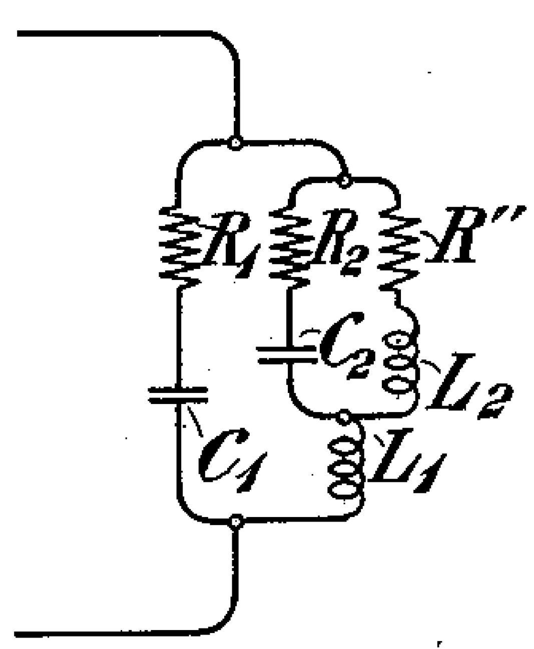


Fig. 2a

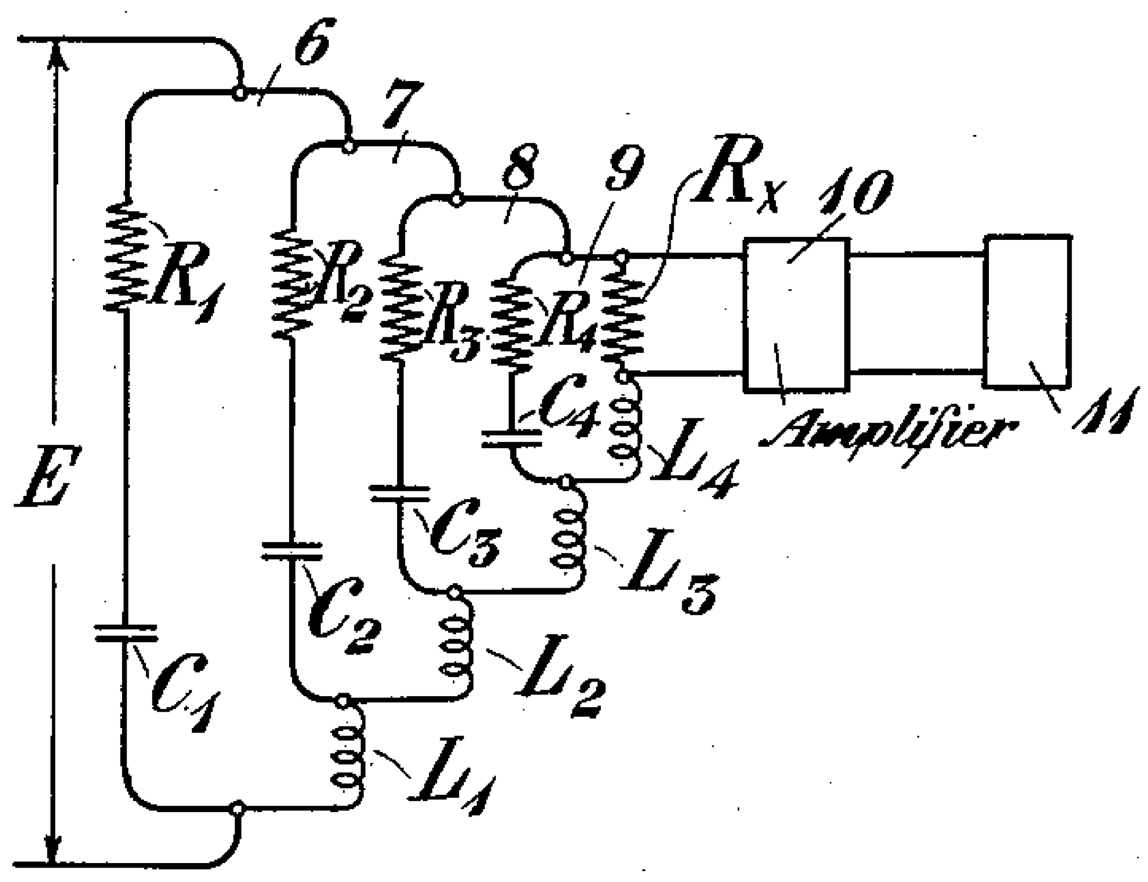


Fig. 3

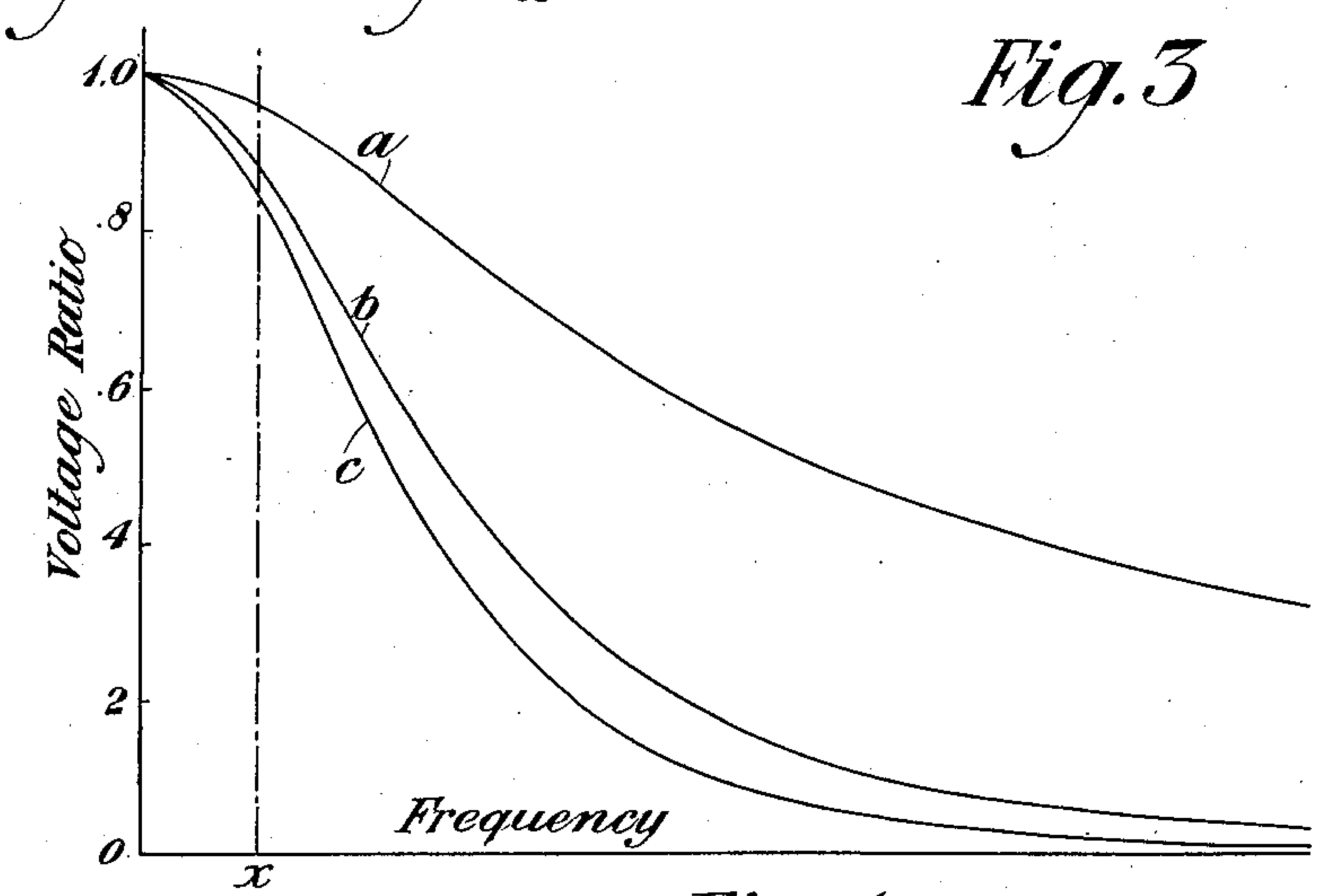
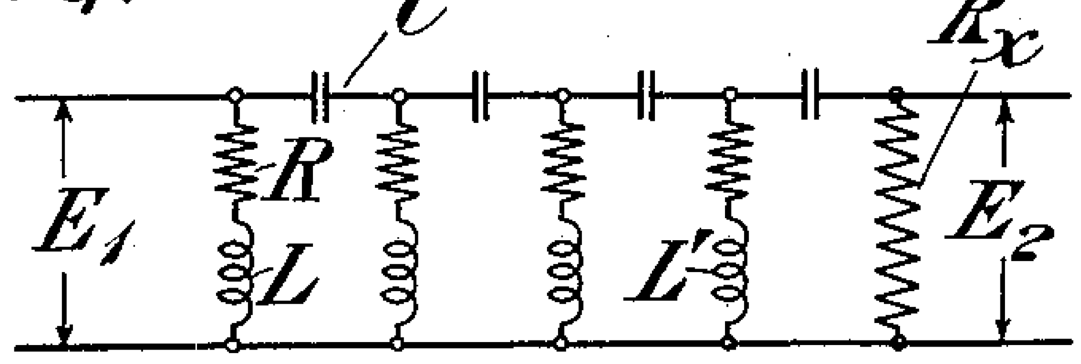


Fig. 4

FIG. 5.



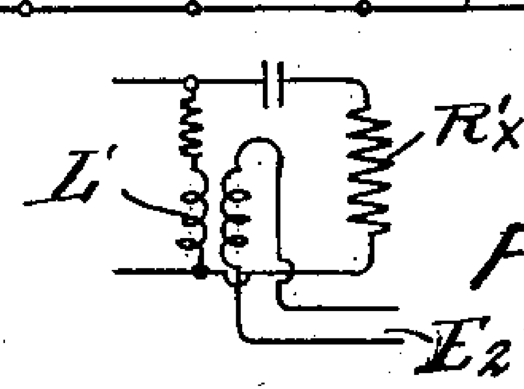


FIG. 5.ª

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UNITED STATES PATENT OFFICE.

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ELECTRICAL NETWORK.

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This invention relates to electrical networks, and especially to a type of aperiodic network which is adapted to modify the voltage wave impressed thereon in such manner that the wave at the output end of the said network closely approximates in form any desired integral or derivative of the impressed wave depending upon the type of network used.

Networks heretofore devised for approximating a required integral or derivative of an impressed voltage wave may be rendered free from undesirable interaction between the component parts only by the insertion of some form of unilateral device at suitable points, or by proportioning the constants of the successive networks so that the current transmitted therethrough becomes unduly diminished, or by greatly increasing the impedance of the circuits.

It is the object of the present invention to provide networks involving resistances, inductances and capacities combined so as to closely approximate any required integral or derivative of an impressed wave, which networks require no unilateral devices to prevent interaction between the parts and do not cause undue diminution of the transmitted current, or other undesirable results.

The integrating or differentiating networks of this invention are of the nature of low pass and high pass filters respectively. The integrating networks simulate the low pass type, being designed to transmit with slight attenuation a range of low frequencies and to attenuate greatly the frequencies above a certain critical frequency. In a converse manner, the differentiating networks transmit readily the upper range or band of frequencies and subject the lower frequencies to greater attenuation. It will be shown later that the integrating networks produce a wave that closely approximates a true integral of the impressed wave throughout the frequency range above the aforesaid critical frequency, and similarly the differentiating network approximates a true derivative of the impressed wave through the frequency range below the critical frequency, the said critical frequency depending on the time-constant of the circuit.

Such networks, especially of the integrating type, are found advantageous in submarine cable telegraphy, in order to screen the receiving apparatus of such cables from the effects of transient interference waves set up in said cable, and at the same time to freely transmit the signaling waves received over the said cable. This invention has accordingly been described in its relation to such type of telegraphy, but it is to be understood, however, that it is not so limited, but may be used in any type of circuit where it is desired to obtain any integral or derivative of a variable voltage wave.

This invention will be better understood from the following description when read in connection with the attached drawing, of which Fig. 1 shows the arrangement of the network for four successive integrations of an impressed voltage wave; Fig. 2 shows in detail one unit illustrating the basic principles involved; Fig. 2ª shows the first step in building up a network comprising more than one unit; Fig. 3 shows a method for combining these units in a network producing the fourth integral of the impressed wave; Fig. 4 shows graphically the first, third and fourth integrals, and Fig. 5 shows the arrangement of the elements to obtain, for example, the fourth derivative of an impressed variable voltage wave.

In Fig. 1, 1 represents a transmission line having large distortion and attenuation characteristics such as a submarine telegraph cable, which is connected to a winding 12 of the transformer 5, the other side of said winding being connected to an artificial line 2, adapted to balance the submarine cable. A transmitting device 3 which may be of any well known type is connected to the midpoint of winding 12. Bridged across the other winding 4 of the transformer 5 is an interference reduction network comprising four sub-networks 6, 7, 8 and 9, each of the said sub-networks comprising an inductance L in series with the line, a resistance R and a capacity C in series with the said resistance bridged across the line. Network 9 terminates in resistance R_x the value of which may be determined by equations hereinafter set forth. Across R_x is bridged the input side of a vacuum tube amplifier 10, which is adapted to impress the amplified wave upon a recording device 11. The same result would be obtained by bridging the input side of the amplifier across the condenser C_4 in the manner shown in Fig. 1ª.

Fig. 2, as stated, shows a single unit embodying the basic principles of this invention, comprising two parallel circuits, one of which has in series a resistance R_1 and a capacity C_1, and the other of which has in series a resistance R' equal to the resistance R, and in series therewith an inductance L_1. It will be shown later that the impedance of such circuit when its constants are properly proportioned is equal to the resistance in either branch at all frequencies. Accordingly, there may be substituted for the resistance R', another network similar to that shown in Fig. 2, which arrangement is illustrated clearly in Fig. 2^a.

Fig. 3 shows means for combining a plurality of sub-networks as shown in Fig. 2 so as to obtain, for example, at the output side of the said network the fourth integral of the impressed voltage wave. It will be seen that the network shown in Fig. 1 in connection with the terminal circuit of a submarine cable telegraph system is only a re-arrangement of the circuit shown in Fig. 3.

Fig. 4 shows graphically the relation between the ratio of the output voltage to the input voltage of the network and the frequency, when a network such as is shown in Figs. 1 and 3 is inserted in the circuit. The curves *a*, *b*, and *c* represent respectively the first, third and fourth integrals of the impressed voltage wave. It will be noted that the curves fall off sharply after passing a certain frequency value. Since the interference waves are of relatively high frequency compared with the signaling waves, they will be reduced in magnitude whereas the signaling frequency will pass through the network substantially unaffected thereby.

Fig. 5 shows the arrangement of the network to obtain for example, the fourth derivative of an impressed voltage wave. It comprises four sub-networks, each of which is made up of a capacity C in series with the line and a resistance R in series with an inductance L, connected across the line. Bridged across the last network is a resistance R_x' the value of which may be determined by equations hereinafter set forth. The network of Fig. 5 may be derived by extending the fundamental network shown in Fig. 2 by a process of substitution, in general, similar to the method of developing the integrating networks shown in Figs. 2, 2^a and 3, but differing therefrom in that each additional network replaces the resistance in the capacity branch instead of the resistance in the inductance branch of the preceding network. Each of these sub-networks produces a voltage wave which is the derivative of the wave impressed thereon. It will be seen, therefore, that any desired derivative may be obtained by connecting together in the manner shown, a number of sub-networks corresponding to the desired derivative. The same result may be obtained by an inductive coupling shown in Fig. 5^a across the inductance L', since the voltage wave across L' is the same as that across the resistance R_x'.

Having in mind the foregoing description of the circuits and the functions of the component parts, this invention will be more clearly understood from the following description of the manner in which the circuit operates when an impressed variable voltage wave, such as a transient interference wave is impressed across the winding 4 of the transformer 5.

Consider first the unit network shown in Fig. 2. If the two resistances therein represented by R_1 and R' are each equal to $\sqrt{\frac{L}{C}}$ and the inductance L is assumed to have zero resistance, the network as shown in the figure will have an impedance equal to the resistance $R_1=R'$ for all frequencies of the impressed wave. This will be seen from the following derivation of the impedance of the circuit:

$$Z=\frac{(R+j\omega L)\left(R+\frac{1}{j\omega C}\right)}{(R+j\omega L)+\left(R+\frac{1}{j\omega C}\right)}=\frac{R^2+\frac{L}{C}+j\left(R\omega L-\frac{R}{\omega C}\right)}{2R+j\left(\omega L-\frac{1}{\omega C}\right)}$$

in which $R=R_1=R'$; $\omega=2\pi\times$frequency and $j=\sqrt{-1}$. If $R^2=\frac{L}{C}$ or $C=\frac{1}{R_2}$, the above equation by substitution becomes

$$Z=\frac{R^2+R^2+j\left(R\omega L-\frac{R^3}{\omega L}\right)}{2R+j\left(\omega L-\frac{R^2}{\omega L}\right)}$$

$$Z=\frac{R\left[2R+j\left(\omega L-\frac{R^2}{\omega L}\right)\right]}{2R+j\left(\omega L-\frac{R^2}{\omega L}\right)}=R$$

Since, therefore, the impedance of the circuit represented in Fig. 2 is equivalent to R, we may substitute such a circuit for the resistance R' in the manner shown in Fig. 2^a. In this figure, the elements R_1, C_1 and L_1 are the same as the similarly designated parts of Fig. 2, but in place of the resistance R' we have substituted a circuit of equivalent impedance comprising a resistance R_2, a capacity C_2, an inductance L_2 and a resistance R''. This process may be carried further by substituting for R'' a third network, and by thus adding to the basic network the required number of sub-networks, we may provide a structure adapted to produce approximately the required integral of the impressed voltage wave.

Further consideration of the unit network shown in Fig. 2 in connection with the following description, will make clear the reason why the output voltage across the network closely approximates an integral of the impressed voltage wave.

Assuming a voltage E impressed across the network, the voltage drop e across the resistance R′ in terms of the impressed voltage is

$$e=\frac{R'}{R'+j\omega L_1}E \quad (1).$$

If the frequency is above a certain critical value, the voltage drop across the inductance L_1 is substantially E, and consequently the current through L_1 is related to the voltage E substantially in accordance with the following equation:

$$E=L_1.j\omega i=L_1\frac{di}{dt}$$

which, when rearranged in form, is

$$i=\frac{1}{L_1}\cdot\frac{E}{j\omega}=\frac{1}{L_1}\int E\,dt$$

If we multiply the preceding equation by R′, we obtain

$$iR'=e=\frac{R'}{j\omega L_1}E=\frac{R'}{L_1}\int E\,dt \quad (2).$$

It will be seen that equation 1 approaches in value equation 2 for those frequencies at which the voltage drop across the inductance L_1 is substantially equal to E, because at those frequencies $j\omega L_1$ becomes large relative to R′. Therefore, the network as shown in Fig. 2 may be said to approximately integrate the impressed voltage wave for frequencies above the critical frequency, and the approximation to an exact integral being proportional to the distance from the critical frequency.

In a similar manner, it may be shown that for frequencies below a limiting value, such that the impedance of the condenser C_1 is great compared with its resistance R_1, the current through the condenser and hence the voltage across the resistance approximates the first derivative of the voltage E. The limiting value of frequency below which this approximation approaches the actual condition is proportional to the reciprocal of the time constant of C_1 and R_1 and therefore may be made any required value.

Since, however, it is impracticable to obtain inductance coils having zero resistance, the values of the elements of the networks must be modified in order to apply this principle to a practical case. If R_L represents the resistance of one inductance coil, the conditions which must be satisfied are that

$$R_n=R_{n-1}-R_L$$

and

$$R_n=\sqrt{\frac{L_n}{C_n}}$$

in which the subscripts denote the number of the section of the network under consideration. Thus in the sub-network 7, the value of the resistance R_2 is

$$R_2=R_1-R_L.$$

Also, since R_2 differs from R_1 we must change the values of L_2 or C_2 so that

$$R_2=\sqrt{\frac{L_2}{C_2}}.$$

The value of the resistance R_x may be determined from the foregoing equations in the same manner in which the magnitude of the other resistance elements is obtained.

By means of the arrangements represented in Figs. 1 and 3, having inductances in series with a source of variable voltage waves and capacities with resistances in series bridged across the said source, the integral of the impressed wave corresponding to the number of sections of network may be obtained. That is to say, with a network having four sections, the impedance of which is equal to R at all frequencies, the voltage E_2 impressed across the input circuit of the amplifier 10 is represented by the equation

$$E_2=E_1\times\left(\frac{R}{R+jL\omega}\right)4$$

The result of the successive integrations is clearly shown by curves a, b, and c in Fig. 4, in which the ordinates represent the ratio of the output voltage E_2 to the input voltage E_1 across said network and the abscissæ represent frequency. It will be noted that the voltage values are greatly reduced beyond a certain critical frequency and that successive integrations tend to diminish the magnitude of the voltage values. Since transient interference waves in submarine cables have relatively higher frequencies than the impressed signaling waves, the amplitude of the signaling voltage is relatively unaffected by such a network as is shown in Fig. 1, provided the frequency of the signaling wave is kept below the critical frequency indicated by "x" upon the curves of Fig. 4. It will, therefore, be seen that this network tends to screen the receiving apparatus from the effects of a high frequency transient wave, and at the same time, to readily transmit to the said apparatus, the lower frequency signaling wave. This network, furthermore, does not require the insertion of a unilateral device between the component sub-networks since there is no interaction between the various parts.

Any desired derivative of an impressed variable voltage, E_1, may be obtained by a network of the required number of sections such as that shown in Fig. 5, in which the capacities are in series with the source of impressed voltage waves, and the inductances in series with resistances are bridged across the said source. With such an arrangement of the elements, the networks shown in Fig. 5 will be adapted to produce a voltage wave E_2 representing the derivative of the impressed voltage wave E_1. The value of the terminating resistance R_x' may be obtained in the same manner in which the value of the other resistances is obtained, viz, from the formula

$$R_n = R_{n-1} + R_L$$

Where R_n is any resistance, R_{n-1} is the value of the resistance of the preceding sub-network and R_L is the resistance of the inductance coils such as L, L′, etc. The relation between the voltages E_2 and E_1 may be represented by the equation

$$E_2 = E_1 \times \left(\frac{R}{R + \frac{1}{j\omega C}}\right)^4$$

It will be seen that by grouping together any desired number of unit networks having elements of the proper values, any desired integral or derivative of a variable voltage wave may be obtained. Furthermore, such network or group of networks furnish an interference reduction device which requires the use of no unilateral device between the component unit networks to prevent interaction therebetween. This network, as has been shown, does not appreciably affect the magnitude of the signaling voltage waves provided the frequency thereof is kept within certain limits. Also, since the impedance of the arrangement is equivalent to pure resistance, at all frequencies, such network may be correctly terminated by a resistance element.

Although this invention has been disclosed as embodied in a particular form, it is to be understood that it is not so limited but may be embodied in other and different forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In an electrical circuit, the combination of a network, means for impressing across one end thereof a variable voltage wave, a receiving apparatus connected across the other end thereof, the said network comprising a resistance in series with a capacity bridged across said circuit, an inductance in series with said circuit and a second resistance bridged across the input side of the said receiving apparatus, the values of the said elements being so proportioned that the impedance of the said network is equal to the resistance at all frequencies.

2. In an electrical circuit, the combination of a source of variable voltage waves, an aperiodic network adapted to be connected with the said source, a receiving apparatus adapted to be connected with the network, said network comprising a resistance in series with a capacity bridged across said source, an inductance in series with said source, and a second resistance bridged across the input side of the said receiving apparatus, the values of the elements being so proportioned that the impedance of the circuit at all frequencies is substantially pure resistance, whereby the integral of the impressed voltage wave may be impresed on the said receiving apparatus.

3. In an electrical circuit, the combination of a source of a variable voltage wave, of a network substantially aperiodic, and a receiving circuit connected therewith, the said network comprising a resistance and a capacity serially bridged across said source, an inductance in series therewith, and a second resistance bridged across the input side of the said receiving circuit, the elements being so proportioned as to produce a wave form which is substantially the integral of the impressed wave, and to impress said integral upon the receiving circuit.

4. In an electrical circuit, the combination with a source of a variable voltage wave, of an aperiodic network comprising a plurality of sub-networks each including a resistance and a capacity serially bridged across said source, an inductance in series with said source, and a resistance bridged across the last sub-network, the values of the elements in each of said sub-networks being so proportioned that the impedance of the said network is substantially pure resistance, and a receiving circuit adapted to receive the voltage wave impressed by said network.

5. In a signaling system, the combination with a transmission circuit of a terminal circuit comprising an aperiodic network made up of an inductance in series with said circuit, a resistance in series with a capacity bridged across said circuit, a receiving apparatus, the said network being so designed as to attenuate transient interference waves arriving over said transmission circuit, and to pass substantially unaffected the lower frequency signaling waves.

6. In an electrical signaling system, the combination with a transmission circuit of a terminal circuit comprising an aperiodic network made up of a group of sub-networks, each including an inductance in series with the circuit and a resistance in series with a capacity bridge across the circuit, the sub-networks being so related that the respective inductances are in series and

the respective resistances and capacity branches will be bridged in parallel across said terminal circuit, whereby the desired integral of any impressed transient wave may be obtained.

7. An electrical filter having a single cut-off point comprising a plurality of aperiodic networks, each having a series member consisting of reactance and a shunt member consisting of resistance in series with reactance.

8. An electrical filter having a single cut-off point comprising a plurality of aperiodic networks, each having a series member consisting of reactance and a shunt member consisting of resistance in series with reactance, the reactance in said shunt member being of opposite phase angle to the reactance in said series member.

In testimony whereof we have signed our names to this specification this 26th day of April 1920.

DANFORTH K. GANNETT.
MACLEAN KIRKWOOD.