Jan. 12, 1943. R. LEE 2,308,013

FILTER CIRCUIT

Filed July 12, 1940

Fig. 1.

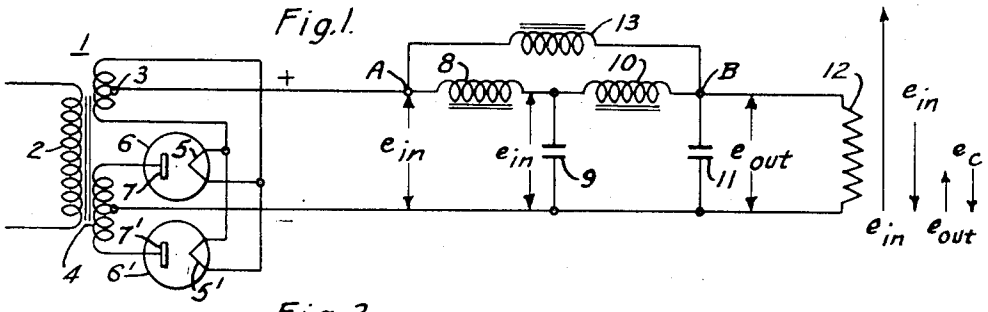


Fig. 2.

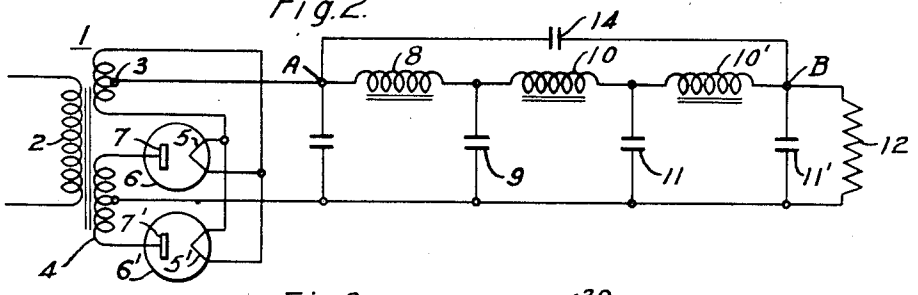


Fig. 3.

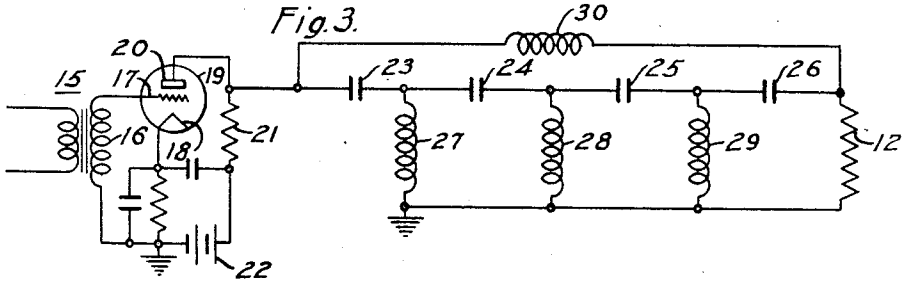


Fig. 4.

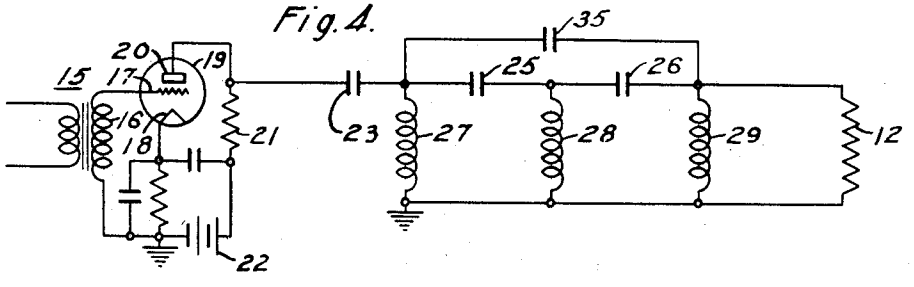
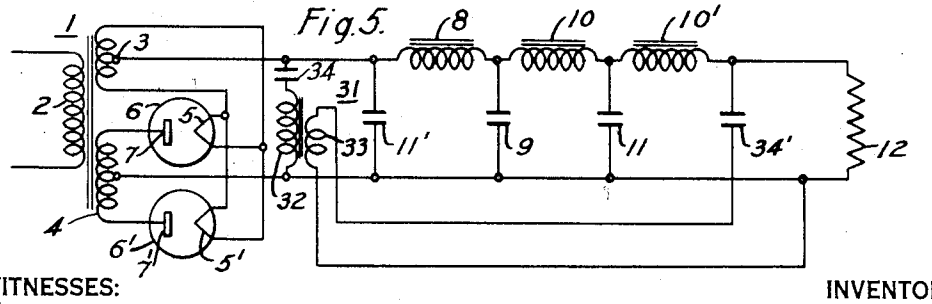


Fig. 5.



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FILTER CIRCUIT

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6 Claims. (Cl. 178—44)

This invention relates to electrical filter circuits and is applicable to various types of filters of either the high, low or band-pass variety.

Filter circuits in general comprise reactive elements in series-parallel combinations connected in cascaded sections. Each section may have an inductance in series connection with respect to the terminals of the filter and a capacitor in shunt relation therewith, or vice versa, depending upon whether the filter is used to attenuate all frequencies above or below a definite cutoff point. Each section of the filter will provide a definite insertion loss at the operating frequency, and, in connecting the sections in cascade, each section contributes to the overall filtering effect. If it is desired to obtain a certain required attenuation, several sections must be employed. In general practice, for example, in filtering the alternating current component of a rectified alternating current source, two or three filter sections are usually cascaded. However, when extremely pure direct current is needed, additional sections need to be added to obtain the required output from the filter. Increasing the number of sections will, of course, increase the cost of the equipment and also the size of the physical assembly.

A particular feature of this invention is that the cumulative attenuation effect of a filter may be greatly increased, by simple means whereby a voltage is introduced into the filter output or a portion thereof which is equal in magnitude but opposite in phase to the voltage component present in the output portion of the filter.

Another feature of this invention is that by a simple expedient the filtering effect can be increased to such an extent as to enable the elimination of one or more sections of a filter and yet retain the same attenuation as would be without elimination of such sections.

Another advantage resulting from the application of this invention to filter circuits is found in the simplicity of the means employed which requires only the use of a single additional component, such as an inductive or a capacitive reactance to provide an overall filtering effect which otherwise would need additional sections of filters each including two or more reactive elements.

Other features and advantages will be apparent from the description of this invention, pointed out in particularity by the appended claims and taken in connection with the accompanying drawing in which:

Figure 1 shows a filter circuit commonly employed for rectified alternating current power supply systems incorporating the voltage cancelling feature in accordance with this invention;

Fig. 2 is a similar circuit illustrating a three-section filter network with a capacity feed for voltage cancellation;

Fig. 3 shows the application of the invention to a high-pass filter;

Fig. 4 shows a modification thereof also in connection with a high-pass filter; and

Fig. 5 illustrates the modification of the invention applied to a three-section low-pass filter employing shunt type feed of cancellation voltage.

Prior to referring to the figures, certain principles of operation of filters and observable facts may be mentioned for a better understanding of this invention. The filters illustrated in Figures 1, 2 and 5 in connection with rectifier circuits are the so-called low-pass filters and as such are designed to pass currents of frequencies below a critical frequency, and thereby to reduce substantially the amplitude of currents of all frequencies above this critical frequency. The critical frequency in full wave rectifier systems is usually twice the frequency of the power supply line and is referred to as the ripple which is to be eliminated from the output of the system. A ripple filter consists usually of a series arm impedance in the form of a self-inductance or choke coil and a shunt impedance which is always one or more capacitors. The object of the filter is to reduce the ripple, that is, the alternating current component present in the rectified output of the tubes and pass freely the direct current obtained by rectification.

It is an observable fact that the phase relation of voltages in the attenuating band of frequencies for which the filter is designed is such that a complete phase reversal occurs of the voltage between the output terminals of each section. The magnitude of the voltage in each section depends upon the insertion loss produced by the particular section. Taking Fig. 1 as an example to illustrate this phenomenon, we may indicate the input to the filter as e_{in} and the voltage in the mid-section of the filter as e_m, and that at the output as e_{out}. Assuming that there is a 4:1 attenuation per section, we may refer to the vectors which represent the magnitude and direction of the voltages and it is seen that e_{in} has considerable magnitude in one direction, and that e_m is of a lesser magnitude, which equals the ratio of insertion loss provided by the section but in an opposite direction; whereas at the output of the filter the vector e_{out} shows again a reversal

of direction and a corresponding reduction in magnitude. Obviously, if a voltage, let it be designated by e_c, could be introduced at the point e_{out} of equal value but of opposite phase as shown by the vector e_m, the voltage component in the output of the filter could be completely eliminated. This is the principle of operation of this invention and it will be seen that this cancellation voltage can be derived in a simple manner and applied effectively to the filter.

Considering Figure 1, the source of operating voltage is shown as a rectifier circuit comprising a power transformer 1 having a primary winding 2 and secondary windings 3 and 4. The primary winding is to be connected to a suitable alternating current supply source, whereas the secondary winding 3 supplies energy to the filaments 5 and 5' of rectifier tubes 6 and 6'. The secondary winding 4 connects to the plates 7 and 7' of the respective tubes. The output of the rectifier is derived between the center taps of each of the secondary windings. The positive side of the system is identified by the conductor connected to the secondary winding 3, and the negative side to that of the secondary winding 4. In series with the positive conductor is the inductance 8 which is followed by a capacitor 9 connected in parallel with the output line. The inductance 8 and the capacitor 9 form the first section of the filter. Several other sections may similarly be added and, by way of example, Fig. 1 includes another section comprising inductance 10 and capacity 11. The work circuit or load which is to be supplied from the filter is represented by the resistor 12. The description so far illustrates a conventional low-pass filter widely of the choke input type used in the art for rectifier type power supplies, and in other applications requiring filtering of certain frequencies. A capacity-type filter may also be used without altering the result as far as the invention herein described is considered. The figures are chosen merely to illustrate various types of filters and the invention can easily be applied to all types of and combinations of filters. The filtering effect, as stated before, depends on the insertion loss presented by each filter section, and heretofore in order to increase the overall insertion loss, it was necessary to insert additional sections. However, in order to increase the filtering effect in accordance with this invention, a branch circuit is connected to the filter in the form of an inductance 13 between points marked A and B, that is, between the input and output portions of the system. The voltage component in the output will then be cancelled out by applying a voltage derived from the input of the system by means of the inductance in conjunction with the terminal capacitor of the filter, the inductance being so chosen as to fulfill two requirements, namely, that, aside from a phase reversal, its impedance shall effect a suitable reduction in magnitude of the voltage derived from the input. Both the above requirements are obtained by the fact that the branch circuit is connected to a point where the voltage is in equal phase with the voltage to be cancelled and by the fact that the reactor is so chosen as to coperate with the capacitance portion in the output of the filter. In other words, the self-inductance 13 is so chosen that in conjunction with the capacitor 11 it attenuates the voltage derived from the input by an amount equal to that obtained by the two sections of the filter whose reactances are 8 and 10. At the same time, the self-inductance 13 and the capacitor 11 form a single filter section. Therefore, the voltage applied by them is opposite in phase to the voltage appearing in the output. Referring to the voltage vectors, it is seen that the input to the branch circuit will be that of e_{in} and the output e_c will be identical in direction with the voltage e_m appearing in the mid-section of the filter, and of a magnitude equal to that produced by the attenuation effect of two sections of the filter.

It is seen now that by the addition of a single filter element herein shown as an inductance, the attenuation effect of several filter sections may be obtained. Considering the same ratios of attenuation, namely, 4:1, in a conventional filter system, an additional section consisting of an inductance and capacity arm would effect only an attenuation of ¼ of e_{out}, and another section added on attenuation of ¼ of the latter, etc. Several sections would have to be cascaded to approach the result achieved by the circiut of this invention, which requires only one element of these additional sections to effect substantially complete cancellation of the residual alternating component.

It is to be observed that the phase reversals occurring in each section must always be considered when choosing voltage-feed cancellation. As seen in Fig. 2, in which identical component elements of Fig. 1 are designated with like reference characters, the filter is of the capacity-input type and includes also an additional section which is the third arm composed of the series reactor 10' and shunt capacity 11'. In order to connect a cancellation branch circuit, an element of negative reactance characteristics must be chosen, and therefore a condenser 14 is connected between points A and B. The reason for this is that due to the additional section the direction of the output voltage vector was submitted to another reversal and will be in the same direction as that of e_m. To obtain this direction from a point in the system at which the voltage magnitude is of opposite phase, a condenser is required. A positive reactance in this case would apply a voltage equal in magnitude and equal in phase, thereby increasing the alternating component in the output of the system.

The choice and connection of the branch circuit is a simple matter when careful consideration is given to the phase relationship and voltage magnitudes in the various sections of the filter system. In low-pass filters when the connection is derived from the input, an even number of filter sections will require an inductive reactance for compensation, whereas when there are an odd number of sections a capacitive reactance must be used. The branch circuit need not take the voltage from the input of the system, as this voltage may be derived from some other filter section. Attention must be given, of course, to the phase relations so that the reactive component, having either positive or negative reactance characteristics, should introduce a voltage in opposite phase to that which is desired to be cancelled.

Referring to Figs. 3 and 4, a high-pass filter is illustrated in which the source of the operating frequencies is shown, by way of example, to be the output circuit of an amplifying tube. The input to the vacuum tube may be coupled to a source of frequencies by means of a transformer 15, the secondary winding 16 of which connects between grid 17 and cathode 18 of the tube 19. The output of the tube between anode 20 and cathode 18 includes the load resistance 21 and a

suitable potential source shown here by the battery 22.

The filter comprises a chain of series capacitors 23, 24, 25 and 26 and shunt inductances 27, 28 and 29 between the output circuit of the vacuum tube and the work or load circuit which is shown as the resistor 12. The choice as to the type of branch circuit is governed here also by the number of filter sections provided that the same type of filter is considered. That is whether the high-pass filter has R or T sections. An odd number of T sections, as shown in Fig. 3, requires an inductive branch circuit whereas an even number of R sections as shown in Fig. 4 requires a capacitive branch circuit. In general, whether a capacitive or an inductive forward-feed is used will depend upon the terminal reactance of the filter. When this is capacitive, as shown in Fig. 3, the branch circuit will have to be inductive and when the terminal reactance is inductive, as shown in Fig. 4, the branch circuit will be capacitive.

In the modification shown in Fig. 4 the filter is identical with the one shown in Fig. 3 except that there are an odd number of stages; consequently, the branch circuit comprises the capacitor 35.

Fig. 5 illustrates another modification of the invention operating on the principle of cancellation of voltage components. In the figure previously described, the branch circuits may be termed as being of the "series-feed" type in that the reactances employed formed a series impedance with respect to the reactance with which it cooperated in producing the cancellation effect. The modification in Fig. 5 may be termed the "shunt-feed" in that the branch circuit is in shunt with the input terminals of the filter and also in shunt with the output portion. By way of illustration, a low-pass filter of the type shown in Fig. 2 was chosen, and the reference characters used are identical with like parts of the system illustrated in Figs. 1 and 2. Here, the branch circuit comprises a transformer 31, the primary winding 32 of which, in series with the blocking condenser 34, is fed from the output of the rectifier and the secondary winding 33 is effectively in shunt with the output of the filter including also a direct current blocking condenser 34' in series with one of the conductors connected to the secondary winding 33. The turn-ratio of the transformer is so chosen that the voltage output thereof will equal in magnitude the ripple voltage present in the output of the filter. The connection of the secondary winding is of such polarity as to introduce this voltage in phase opposition to the ripple voltage present in the output.

In a practical arrangement of the circuit shown in Fig. 1 the reactors 8 and 10 had a value of one henry, the capacitors 9 and 11 were 4.5 microfarads, and the load resistance was 2000 ohms. The branch circuit inductance 13 was two henrys. Before connecting the branch circuit the ripple voltage output was measured and had a value of 42.5 volts. By connecting the inductance 13 into the circuit as shown in Fig. 1 the ripple voltage across the load resistance 12 dropped from 42.5 to 6 volts which is roughly a 7:1 reduction, or a 17 db. attenuation. The relative values of the elements will, of course, influence the performance of the filter and a more careful choice of constants would result in an even higher overall attenuation. It is to be noted, however, that to obtain a ripple of 6 volts under similar circuit conditions in the conventional manner by addition of filter sections, three additional reactors similar in value to that of 8 or 10 and three additional capacitors of the same value as 9 and 11 would have to be added.

I claim as my invention:

1. A filter circuit comprising a source of rectified alternating current, a self-inductance in series and a capacitance in parallel between terminals constituting one section of said filter, another self-inductance in series with said first mentioned inductance, and another capacity in parallel between output terminals constituting the second section of said filter, a work circuit connected to said filter, and means for applying a voltage of predetermined magnitude between output terminals of said filter and of opposite phase to the ripple voltage appearing thereacross, comprising an inductive reactance connected in parallel with said self-inductances.

2. A filter circuit comprising a source of rectified alternating current, a self-inductance in series and a capacitance in parallel between terminals constituting one section of said filter, another self-inductance in series with said first mentioned inductance, and another capacity in parallel between output terminals constituting the second section of said filter, a third section similar to said other sections connected thereto, a work circuit connected to said filter, and means for applying a voltage of predetermined magnitude between output terminals of said filter and of opposite phase to the ripple voltage appearing thereacross, comprising a capacitive reactance connected in parallel with said three self-inductances.

3. In a filter circuit comprising a plurality of reactances in series and parallel relationship between input and output terminals constituting an attenuation network at the operating frequency, means for increasing the overall attenuation of said filter comprising a transformer of a predetermined voltage ratio having its primary winding effectively in shunt between input terminals and its secondary winding effectively in shunt between output terminals, said secondary winding being connected in such phase relation as to apply a voltage in phase opposition to the output of said filter at the operating frequency, and the voltage ratio of said transformer being so chosen that said voltage applied is of equal magnitude to the voltage component present in the output of said filter at the operating frequency thereof.

4. An electrical filter system comprising a plurality of successive sections in a line, each section comprising a reactance of one sign in series with the line followed by a reactance of the opposite sign in shunt with the line, and a reactance shunting the terminals on one side of the line of a plurality of the first-mentioned sections whereby fluctuations in a voltage impressed upon one end of said filter will be reduced at the other end of said filter.

5. An electrical filter system comprising a plurality of successive sections in a line, each section comprising a reactance of one sign in series with the line followed by a reactance of the opposite sign in shunt with the line, and a reactance of the sign first mentioned shunting two points on the first-mentioned reactances which have voltages relative to the opposite side of the line which are substantially identical in phase whereby fluctuations in a voltage impressed upon one end of said filter will be reduced at the other end of said filter.

6. An electrical filter system comprising a plurality of successive sections in a line, each section comprising a reactance of one sign in series with the line followed by a reactance of the opposite sign in shunt with the line, and a reactance of said opposite sign connected between two points on the first-mentioned reactances which have voltages relative to the opposite side of the line which are substantially 180 degrees different in phase whereby fluctuations in a voltage impressed upon one end of said filter will be reduced at the other end of said filter.

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