Feb. 1, 1938. H. W. AUGUSTADT 2,106,785

ELECTRIC FILTER

Filed May 23, 1936

FIG. 1

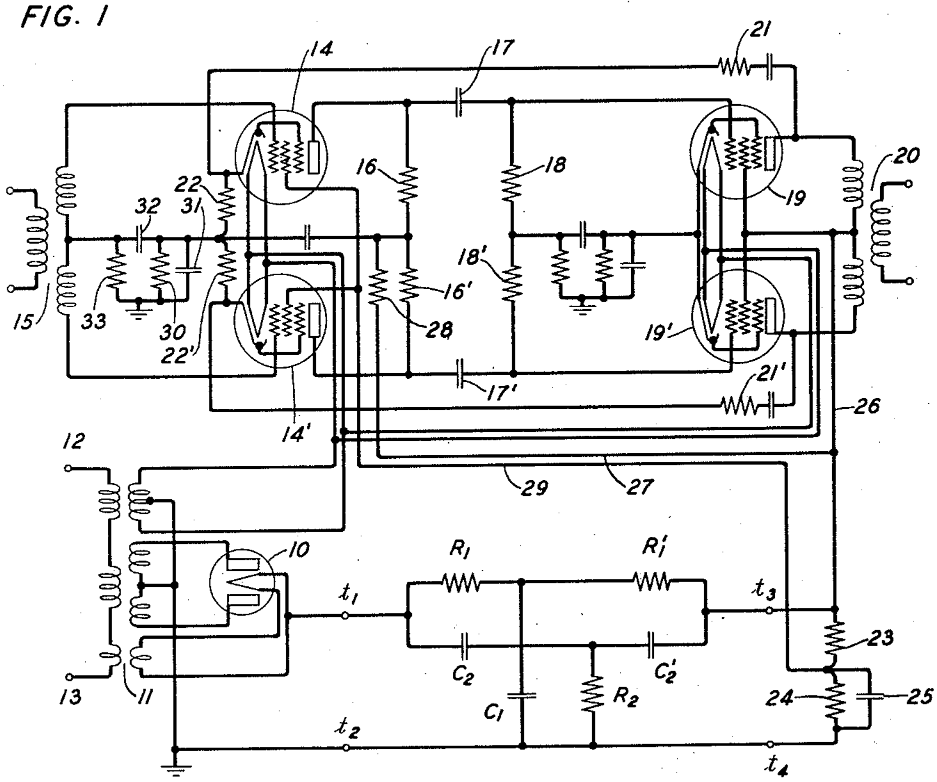


FIG. 2

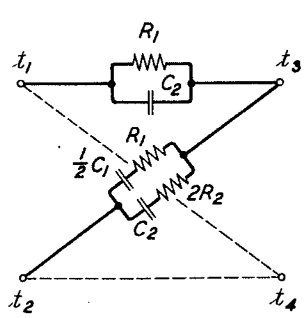
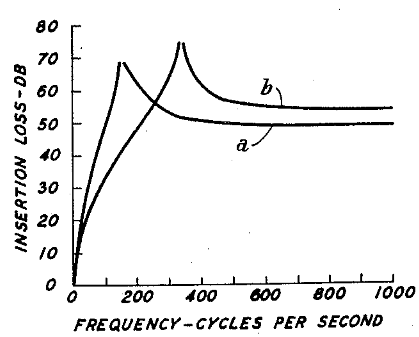


FIG. 3



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ELECTRIC FILTER

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7 Claims. (Cl. 178—44)

This invention relates to electrical filters and more particularly to filters for smoothing out fluctuations of a direct current.

An object of the invention is to reduce the cost and simplify the construction of current supply filters for amplifiers and other space discharge devices designed for energization from alternating current systems. Another object is to provide an enhanced degree of suppression of ripple currents in particular ranges of frequencies in the output of an alternating current rectifier. A further object is the provision of power supply circuits of aperiodic character which will be free from troublesome transients during operation.

An important application of the invention is found in current supply systems for vacuum tube apparatus, the energizing currents and voltages for which are obtained by rectification of alternating current from a power distribution network. The rectified current in such systems contains various harmonically related alternating components, the most important of which lie in the frequency range from 120 to 1000 cycles per second. To provide adequate suppression of the low frequency ripples with filters of the type heretofore commonly used, it has been necessary to employ choke coils of very large inductance and usually having windings of rather high resistance. Not only are such coils costly to manufacture and uneconomical of space and weight, but they also absorb a considerable portion of the rectified voltage and, with their associated condensers, tend to give rise to harmful voltage transients.

These difficulties are avoided in the filters of the invention by the use of a selective network comprising only resistance and capacity elements. The circuit configuration of the network is such as to permit the proportioning of the elements for the substantially complete suppression of currents of any selected frequency and, at the same time, to provide a large degree of attenuation over a relatively wide adjacent frequency range. By appropriate choice of the frequency at which complete suppression occurs, adequate attenuation of all of the noise producing ripples of a rectified current can be secured with a relatively small loss of the rectified voltage. If desired, the frequency of complete suppression may be made the same as that of the most troublesome ripple component, but experience has shown that this is not necessary although it is generally desirable to keep this frequency in the range from about 150 to 350 cycles per second when the power is obtained from a 60 cycle system.

The nature of the invention will be more fully understood from the following detailed description and from the accompanying drawing, of which:

Fig. 1 shows a filter network in accordance with the invention connected in the current supply circuits of a vacuum tube amplifier;

Fig. 2 is a schematic illustrating the theory of the invention; and

Fig. 3 illustrates the performance of the filters of the invention.

Referring to Fig. 1, the filter network comprises the circuits included between the terminals t_1 t_2 and t_3 t_4. It consists of two T-networks, one comprising series resistances R_1 and R_1' and shunt capacity C_1, and the other comprising series capacities C_2 and C_2' and shunt resistance R_2. The two networks are connected to common input terminals t_1 and t_2 and to common output terminals t_3 and t_4 thereby providing a pair of parallel transmission paths. Network $R_1R_1'C_1$ is a filter of the low-pass type which transmits direct currents and low frequency alternating currents with relatively small loss and attenuates high frequency currents. Network $C_2C_2'R_2$ is a high-pass filter which provides a high attenuation to low frequency currents. The two, in combination, provide a band elimination filter which may be proportioned to substantially suppress the transmission of alternating currents in any selected frequency range and to effect the complete suppression of a selected frequency in that range.

In the figure, the filter is shown connected in the power supply circuits of an audio-frequency amplifier, the plate current for which is obtained by the rectification of an alternating current. The amplifier and the rectifier are of known types and will be described only briefly. The rectifier system comprises a full-wave rectifier 10 of the vacuum tube or gas discharge type coupled through supply transformer 11 to power input terminals 12 and 13. The transformer includes additional secondary windings for cathode heating purposes in accordance with common practice. The amplifier comprises two stages of push-pull amplification with resistance-capacity coupling and is provided with stabilizing feedback circuits in accordance with the principles described by H. S. Black in an article entitled "Stabilized feed-back amplifiers", Bell System Technical Journal, vol. XIII, No. 1, January 1934.

The first stage of the amplifier comprises two suppressor grid pentode tubes 14 and 14', the signal input to which is supplied through transformer 15. Coupling to the second stage is effected through a resistance-capacity network comprising plate supply resistances 16 and 16', coupling condensers 17 and 17' and grid resistances 18 and 18'. The second stage comprises two suppressor grid pentode tubes 19 and 19' and balanced output transformer 20. The stabilizing feedback is transmitted from the plates of the second stage tubes through resistances 21 and 21' to cathode resistors 22 and 22' in the input circuits of the first stage, each side of the push-pull system being separately stabilized.

The energizing potentials for the anodes and screens of the vacuum tubes are taken from a potential divider comprising resistances 23 and 24 and condenser 25 connected across the output terminals of the supply filter. The anodes and screens of the second stage are supplied with the full rectified voltage through conductor 26 and the anodes of the first stage with a reduced potential through lead 27 and resistor 28. The screens of the first stage are connected through lead 29 to the high voltage side of resistor 24. The steady bias of the grids of the first amplifier stage is furnished by the fall of potential in resistor 30 which carries the steady plate current of that stage. A filter comprising capacities 31 and 32 and resistor 33 prevents plate current fluctuation from affecting the steady grid bias. A similar arrangement is provided for polarizing the grids of the second stage tubes.

The amplifier described above is representative of a type having high gain and stability suitable for use in sound reproducing systems, and the like, where the highest degree of fidelity is required. In such systems, extraneous noises must be avoided, consequently, the requirements on the current supply filters are of the most severe character.

The filters of the invention operate to remove the noise producing fluctuations of the energizing current through the balancing of the output currents from the two parallel transmission paths provided by the low-pass and the high-pass component networks. At very low frequencies most of the current is transmitted through the low-pass network $R_1R_1'C_1$ and such part as traverses the high-pass network $C_2C_2'R_2$ arrives at the output terminals in reversed phase. As the frequency increases, the output currents tend to become nearly equal in magnitude without substantial change in their relative phases, with the result that each substantially neutralizes the other in the output. By giving the elements suitable values, complete neutralization of the output currents may be secured at some selected frequency together with a high degree of suppression over a wide range including the selected frequency. Usually, the strongest component of the ripples in the rectified current is that corresponding to the second harmonic of the supply frequency, but it may frequently be the case that certain of the higher harmonic components are about equally effective in producing noise because of greater sensitivity of the ear at these frequencies. I have found that the most effective noise reduction is achieved by selecting the frequency of complete suppression some where in the range from about 150 to 350 cycles per second.

The design relationships of the filter elements to effect suppression of a given frequency may be developed as follows:

It will be assumed that the network is of symmetrical configuration such that R_1 and R_1' are equal and also C_2 and C_2'. While other relationships may be given, these do not materially alter the properties of the filter and the symmetrical arrangement is one that will usually be preferred in practice. Under this condition, the symmetrical lattice equivalent to the network is readily obtained by standard methods. This is illustrated in Fig. 2 in which, for simplicity, only one of each of the equal pairs of branches is shown. The line branch impedances each consist of a parallel connection of resistance R_1 and capacity C_2 and the lattice branches each comprise two parallel impedances, one consisting of resistance R_1 in series with capacity $\frac{1}{2}C_1$ and the other consisting of resistance $2R_2$ in series with capacity C_2. The condition for complete suppression of the output current is that the admittance of the line branches of the equivalent lattice should be equal to the admittance of the lattice branches, in which case the circuit becomes a balanced bridge.

In terms of the element values, the foregoing condition is expressed by the equation:

$$\frac{1}{R_1}+j\omega C_2=\frac{1}{R_1+\frac{2}{j\omega C_1}}+\frac{1}{2R_2+\frac{1}{j\omega C_2}} \qquad (1)$$

Since each side of Equation (1) contains a real part and an imaginary part, two conditions are implied, one corresponding to the equality of the real parts and the other to the equality of the imaginary parts. Upon simplification, these conditions are found to be:

$$R_1C_1=4R_2C_2 \qquad (2)$$

and

$$\omega^2R_1^2C_1C_2=2 \qquad (3)$$

where ω denotes 2π times frequency.

If the frequency of complete suppression be assigned, there remain four variables, R_1 C_1 R_2, and C_2 with only two equations relating to them. This leaves a considerable latitude in the design and permits variations to meet additional practical requirements. For example, since the series resistances determine the amount of the rectified voltage absorbed in the filter, their value may be chosen with respect to the direct current resistance of the load so as to limit the voltage loss to a predetermined value. In addition, one or the other of the capacities C_1 and C_2 may be fixed arbitrarily at some convenient value available in commercial condensers or the resistance R_2 may be assigned in accordance with a desired high frequency attenuation. In the latter connection it is to be observed that when the frequency is high enough to make the impedances of the several capacities negligibly small, the filter becomes equivalent to a simple resistance shunt of magnitude equal to the resistance of R_1 R_1' and R_2 all in parallel. With the series resistances fixed from other considerations, the high frequency attenuation may be controlled by adjusting the value of the shunt resistance R_2.

In an amplifier system corresponding to that illustrated in Fig. 1, the output load on the filter had an impedance of approximately 12,000 ohms and the internal impedance of the rectifier was approximately 300 ohms. A filter suitable for use between these impedances has the following constants:

R_1=250 ohms
C_1=2 microfarads
R_2=7.8 ohms
C_2=16 microfarads

The insertion loss characteristic for this filter is shown by curve *a* of Fig. 3. The attenuation peak occurs at 160 cycles per second and the attenuation is well above 45 decibels over the frequency range from 100 to 1000 cycles per second. The total series resistance of 500 ohms is less than the direct current resistance of choke coils commonly used in rectifier filters. The sixteen microfarad capacity of the condenser C_2 is well within the range of small sized electrolytic condensers. The loss characteristic of an alternative filter having an attenuation peak at 325 cycles per second is illustrated by curve *b* of Fig. 3. The constants for this filter were:

R_1=100 ohms
C_1=4 microfarads
R_2=8 ohms
C_2=12 microfarads

As the frequency of complete suppression is increased, the value of the series resistances may be reduced with a consequent reduction of the voltage loss in the filter. Alternatively, the capacity of condensers C_2 and C_2' may be diminished or the condenser capacity and resistance value may be reduced together. Some sacrifice of attenuation at the lower frequencies results, but this is not serious so long as the suppression frequency does not exceed about 350 cycles per second. It is generally desirable to have the shunt resistance R_2 of the high-pass section quite low in order that the attenuation level may be kept high as the frequency increases. I have found values in the range from 5 to 10 ohms to be suitable for this purpose. With values between these limits, the attenuation falls off very slowly above the suppression range and may easily be maintained at a level of 40 decibels or greater throughout the whole audio-frequency range.

What is claimed is:

1. An electrical filter comprising a pair of symmetrical T-networks connected in separate paths between a pair of common input terminals and a pair of common output terminals, one of said networks consisting of two series resistances and a shunt capacity, and the other of said networks consisting of two series capacities and a shunt resistance, said capacities and resistances being proportioned to provide maximum attenuation in the filter at a preassigned frequency.

2. An electrical wave filter comprising two T-networks connected in separate paths between a pair of common input terminals and a pair of common output terminals, one of said networks having series branches containing only substantially pure resistances and a shunt branch containing only capacitive impedance, and the other of said networks having series branches containing only capacitive impedance and a shunt branch consisting of a resistive impedance, said capacities and resistances being proportioned to provide maximum attenuation in the filter at a preassigned frequency.

3. In combination, a rectifier for alternating currents, a load impedance, and an electric filter network connected between the output terminals of said rectifier and the terminals of said impedance, said network comprising two parallel transmission paths, a low-pass wave filter in one of said paths, and a high-pass wave filter in the other of said paths, said low-pass and high-pass filters being proportioned relatively to each other whereby their output currents neutralize each other at a frequency in the range between the frequencies of the second and sixth harmonics of the alternating current supplied to said rectifier.

4. A system in accordance with claim 3 in which the said low-pass and high-pass filters contain resistance elements and reactance elements of only one kind.

5. In combination, an alternating current rectifier, a load, and an electric filter network connected between the output terminals of said rectifier and the terminals of said load, said network comprising two parallel transmission paths, a low-pass filter comprising only capacity and resistance elements connected in one of said paths, and a high-pass filter comprising only capacity and resistance elements connected in the other of said paths, said low-pass and high-pass filters being proportioned relatively to each other whereby their output currents neutralize each other at a frequency in the range between the second and sixth harmonics of the alternating current supplied to said rectifier.

6. A combination, in accordance with claim 5, in which the said low-pass filter is a T-network of two series resistances and a shunt capacity and the said high-pass filter is a T-network of two series capacities and a shunt resistance.

7. In combination, a source of fluctuating direct current, a load, a low-pass filter comprising only capacity and resistance elements connected between said source and said load, a transmission path paralleling said filter, and a high pass filter comprising only capacity and resistance elements included in said transmission path, the capacities and resistances of said filters being proportioned to provide substantial suppression of current fluctuations of a preassigned frequency.

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