United States Patent

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[31] 16,806/1966

[54] **FILTER ARRANGEMENT**
5 Claims, 11 Drawing Figs.

[52] U.S. Cl. **333/24.1,** 333/73, 333/11
[51] Int. Cl. **H03h13/00,** H01p 5/12
[50] Field of Search .... 333/73 W, 24.1, 73

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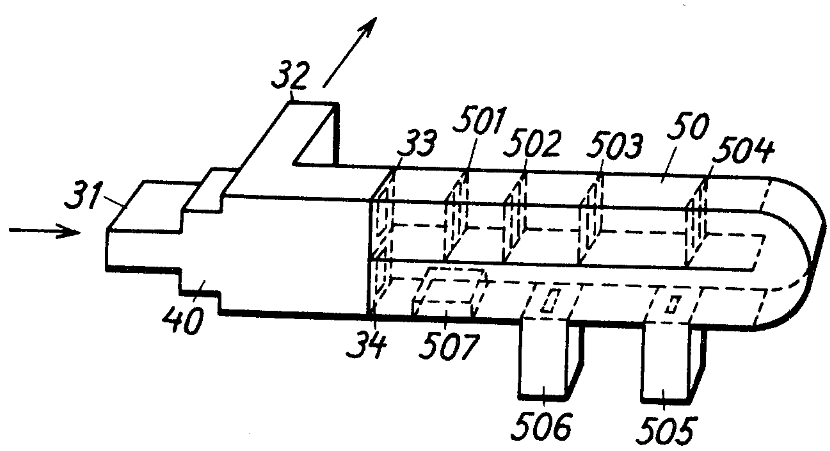
ABSTRACT: There is disclosed a filter comprising a power dividing circuit means including an input port adapted to receive signals, an output port adapted to transmit signals and two signal-transfer ports. Signals received by the input port are power divided and fed to the signal-transfer ports for transmission therefrom to a reactive circuit means which reflects the signals back to the signal-transfer ports. The reflected signals received by the signal-transfer ports pass through the power dividing circuit means to the output port and are geometrically added.

Various power dividing circuit means including differential transformers, magic T devices and 90° hybrid devices are disclosed. The reactive circuit means include, reciprocal and nonreciprocal phase shifters as well as waveguide elements having irises and tuning stubs.



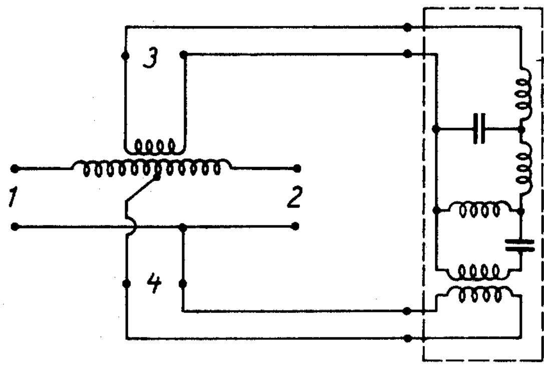


Fig. 1

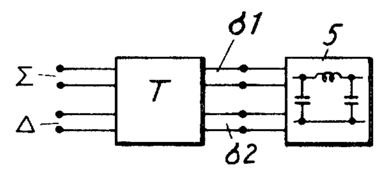


Fig. 2

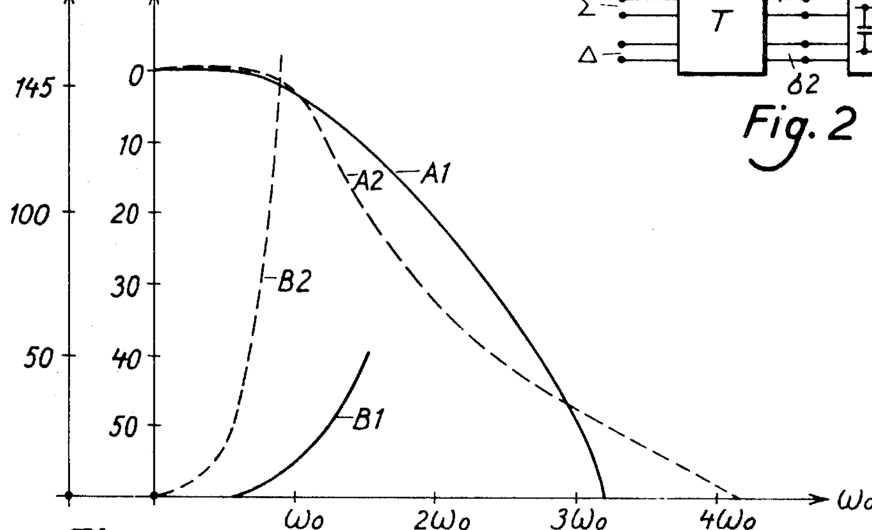


Fig. 3

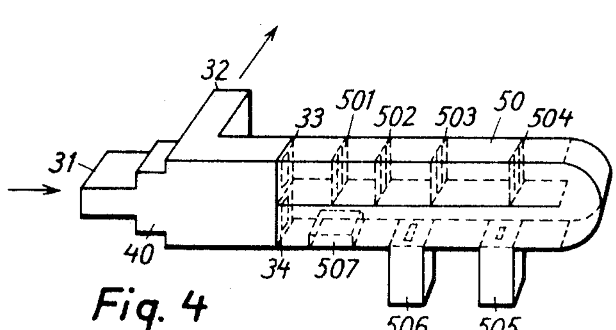
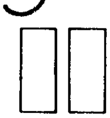


Fig. 4

Fig. 4a



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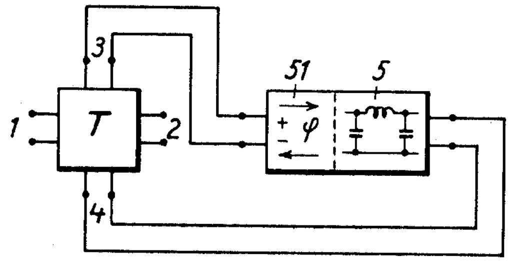

Fig.5

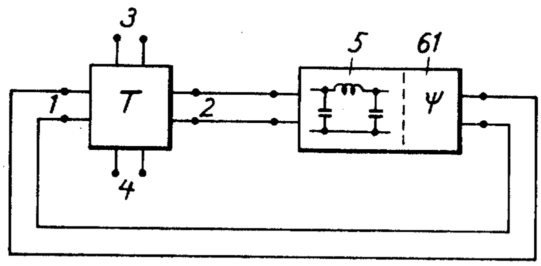

Fig.6

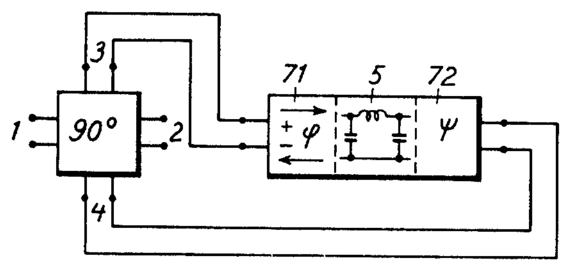

Fig.7

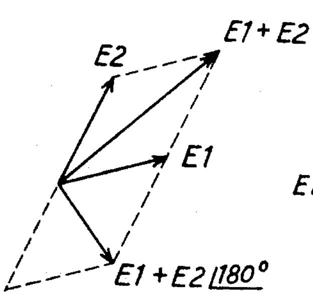

Fig.8

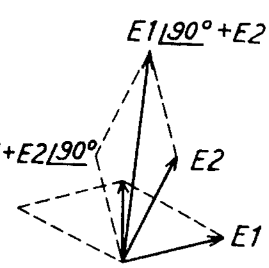

Fig.9

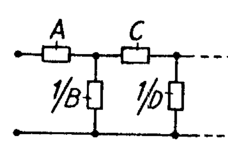

Fig.10

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FILTER ARRANGEMENT

The present invention relates to filters and more particularly to filters having attenuation and phase characteristics which are not simply realizable with conventional filters.

There are cases where it is necessary for filters to be substantially lossless and free of mutual inductances, and at the same time comprise a simple ladder network terminated at both ends by resistances. Such filters are restricted to certain types of amplitude and phase functions which restrictions can be mathematically formulated.

It is a general object of the invention to provide such filters which are subject to no such restrictions.

It is another object of the invention to provide filters having a great range of amplitude and phase characteristics which are simply realizable.

A further object of the invention is to provide filters which while being utilizable at both microwave and low frequencies have very good phase linearity, low time-delay distortion and flat attenuation characteristics within the desired passbands.

Briefly, the invention contemplates a filter or filter arrangement comprising a power dividing circuit means including two external signal-transfer ports and two sum signal-transfer ports and a reactive circuit means. One of the external signal-transfer ports of the power dividing circuit means is the input of the filter and is adapted to receive signals; the other of the external signal-transfer ports of the power dividing circuit means is the output of the filter and is adapted to transmit signals. The reactive circuit means is connected across the sum signal-transfer ports of the power dividing circuit whereby signals received by the reactive circuit means, via the sum signal-transfer ports of the power dividing circuit means, from one of the external signal-transfer ports is reflected by the reactive circuit means and transferred therefrom, via the sum signal-transfer ports of the power dividing circuit means, to the other of the external-signal transfer ports. By an external signal-transfer port is meant a port which connects to circuits external to the filter. By sum signal-transfer ports are meant ports of the power dividing circuit means which are connected to the reactive circuit means for transmitting signals thereto and receiving signals therefrom and wherein the signals received from the reactive circuit means are geometrically (vectorially) added by the power dividing circuit means.

The invention will now be more particularly described with reference to the accompanying drawings, where:

FIG. 1 shows schematically a low frequency filter arrangement employing a differential transformer for the power dividing circuit means;

FIG. 2 shows a filter arrangement with a magic T as the power dividing circuit means;

FIG. 3 shows amplitude functions and time delay distortions for a conventional filter as well as for a filter arrangement according to the invention;

FIG. 4 shows a filter arrangement for microwave frequencies;

FIG. 4*a* shows as an example a detail of FIG. 4;

FIG. 5 shows a modification of the filter arrangement according to FIG. 2;

FIG. 6 shows a further modification of the filter arrangement according to FIG. 2;

FIG. 7 shows a filter arrangement with a 90° hybrid;

FIG. 8 shows a vector diagram for a magic T;

FIG. 9 shows a vector diagram for a 90° hybrid, and

FIG. 10 shows a ladder network.

The filter arrangement schematically shown in FIG. 1 comprises a power dividing circuit means in the form of differential transformer 1–2–3–4 with the external signal-transfer ports 1,2 and sum signal-transfer ports 3,4. Of the external signal-transfer ports, port 1 represents the input of the filter arrangement and port 2 represents its output. The sum signal-transfer ports 3,4 and connected to a reactive circuit means or link 5 comprising reactive elements. The construction of this link is determined by the desired transfer function for the filter arrangement. The differential transformer works as a power dividing circuit and divides the power supplied to the port 1 between the two ports 3,4. The link 5 reflects to a large extent the signals supplied through the ports 3,4, and the differential transformer has the property of transmitting to the port 2 of the filter the geometric sum of the signals reflected from the link 5 to the ports 3,4.

The arrangement shown in FIG. 2 comprises a magic T as the power dividing circuit means, the ports Σ and Δ of which, represents the external signal-transfer parts and are the input and output respectively of the filter arrangement, while the link is connected to the sum signal-transfer ports δ_1 and δ_2.

The advantages obtained from the filter arrangements of the present invention are apparent from FIG. 3, where the curve A2 shows the amplitude characteristic and B2 the time delay distortion characteristic as a function of the relative frequency ω, for a conventional filter, while the corresponding curves A1 and B1 relate to similar characteristics of a filter arrangement designed according to the invention. The frequency is normalized with respect to the 3 db. bandwidth.

The filter arrangement shown in FIG. 4 is comprised of microwave elements and has a magic T 40 with four ports 31, 32, 33 and 34 as the power dividing circuit means. External signal-transfer port 31 represents the input (Σ) of the filter arrangement external signal-transfer port 32 represents the output (Δ) of the filter arrangement. The sum signal-transfer ports 33 (δ_1) and 34 (δ_2) are connected to a link 50 (a reactive circuit means). Link 50, in principle, represents a wave guide constructed in such a way that its two ends lie close to each other. The detailed construction of this link is also determined by the desired transfer function for the filter arrangement, according to a well known technique. As an example, the construction of this link will be described in a few words. It may be presumed that the filter arrangement is intended for a center frequency of 9 MHz, with a 3 db. bandwidth width of 17.4 MHz., and an impedance level corresponding to the impedance of a wave guide dimensioned 9 inches × ½ inch. In the upper branch of the link, connected to the port 33, there are four vertical walls 501, 502, 503 and 504 with vertical openings. Such a wall is shown in FIG. 4*a*. The widths of the vertical openings are 7.4; 3.0; 2.2 and 5.8 mm. respectively. The space between the walls 501, 502, 503 and 504 is 22.9 mm. 24.1 mm. and 23.5 mm. respectively. In the lower branch of the link connected to port 34, there are two matching devices (short-circuited waveguide sections) 505 and 506 respectively, the openings of which into the branch in the longitudinal direction are 4.6 mm. and 3.7 mm. respectively and in the latitudinal direction 18.0 mm. and 7 mm. respectively, and a $\lambda/4$-transformer 507. The space between the centers of the stubs 505 and 506 is 36.5 mm.

A nonreciprocal phase shifting element (not shown) can be connected between the magic T and the link 50. The phase shifting element can be for example a ferrite element under the influence of a magnetic field. By varying the nonreciprocal phase shift angle Φ, as for example by varying the current in a magnet winding or by displacing the ferrite element in the waveguide, the amplitude function of the filter arrangement may in some cases be affected while its phase function remains unaffected. This is interesting, particularly in so-called phase linear filters used, for example, in systems for transfer of frequency modulated signals. These filters may be constructed in such a way that a variation of the nonreciprocal phase shift changes the size of the frequency band within which the amplitude characteristic of the filter is flat without affecting the phase function of the filter.

The arrangement shown in FIG. 5 is comprised of a magic T and a link 5 consisting of a nonreciprocal phase shifter 51, having a phase shift of $+\Phi$ for signals in one direction and a phase shift of $-\Phi$ for signals in the opposite direction. The link 5 is constructed in such a way that its input impedance $Z(j\omega)$, starting from a region between the power dividing circuit (the T-circuit) and the link 5, for example at the sum signal port 3, is defined by the expression:

$$z(j\omega)=\frac{M_1+N_1}{M_2+N_2} \qquad (1)$$

when the transfer function $t(j\ \omega)$ of the filter arrangement is defined by the expression:

$$t(j\omega)=\frac{M_2-M_1+2\sqrt{|M_1M_2-N_1N_2|}\ \sin\ \varphi}{M_2+M_1+N_2+N_1} \qquad (2)$$

M_1 and M_2 being even functions of the angle frequency ω and N_1 and N_2 being odd functions of the angle frequency ω. If $\Phi=0$, the following expression may be obtained:

$$t(j\omega)=\frac{M_2-M_1}{M_2+M_1+N_2+N_1}$$

The arrangement shown in FIG. **6** is made up of a magic T and a link **5** consisting of a reciprocal phase shifter **61**, having the phase shift ψ for signals independent of the transmission direction of the signals. The link **5** is constructed in such a way that its input impedance $Z(j\ \omega)$ corresponds to the expression (1) above when the transfer function $t(j\ \omega)$ of the filter arrangement is defined by the expression:

$$t(j\omega)=\frac{(M_2-M_1)\cdot\ \cos\ \varphi+(N_2-N_1)\cdot\ \sin\ \varphi}{M_2+M_1+N_2+N_1} \qquad (3)$$

the conditions for M_1 M_2 N_1 N_2 being the same as before. In the microwave case the phase shifter **61** corresponds to a wave guide device of a certain length. $\psi=90°$ gives the length $\lambda/4$. The reciprocal phase shifter gives moreover the advantage of a certain freedom in the choice of the power dividing circuit. Thus a magic T in combination with a phase shifter $\psi=90°$ is equivalent to a 90° hybrid. If $\psi=0$, the following expression is obtained:

$$t(j\omega)=\frac{M_2-M_1}{M_2+M_1+N_2+N_1}$$

that is the case shown in FIG. **2**.

The arrangement shown in FIG. **7** has a 90° hybrid as a power dividing circuit means, and a reactive circuit means or link **5** consisting of a nonreciprocal phase shifter **71**, as well as a reciprocal phase shifter **72**. The link **5** is constructed in such a way that its input impedance $Z(j\ \omega)$ corresponds to the expression (1) above when the transfer function $t(j\ \omega)$ of the filter arrangement is defined by the expression:

$$t(j\omega)=\frac{(M_2-M_1)\cdot\sin\psi+(N_2-N_1)\cdot\cos\psi+2\sqrt{|M_1M_2-N_1N_2|}\cdot\sin\varphi}{M_2+M_1+N_2+N_1} \qquad (4)$$

If the 90° hybrid in FIG. **7** is replaced by a magic T, the link **5** must be constructed in such a way that its input impedance $z(j\ \omega)$ corresponds to the expression (1) above when the transfer function $t(j\ \omega)$ of the filter arrangement is to be:

$$t(j\omega)=\frac{(M_2-M_1)\cdot\cos\psi+(N_2-N_1)\cdot\sin\psi+2\sqrt{|M_1M_2-N_1N_2|}\sin\varphi}{M_2+M_1+V_2+N_1} \qquad (5)$$

The arrangements shown in FIGS. **2**, **4**, **5** and **6** all have a magic T, for which the vector diagram shown in FIG. **8** is used. Vectors E1 and E2 represent signals at the external signal-transfer ports and the two remaining vectors represent the signals at the internal signal-transfer ports of the magic T.

The arrangement shown in FIG. **7** has a 90° hybrid, for which the vector diagram is given in FIG. **9**. The vectors have the same significance as for FIG. **8**.

An example, utilizing the above expression (1) .... (5) will follow below.

Let it be supposed that for a certain case a filter with the following transfer function (t) is wanted, s having been made equal to $j\omega$,

$$t=\frac{0\cdot242\cdot s^4+42\cdot75\cdot s^2-945}{s^5+15s^4+420s^2+945+105s^3+945s}$$

This can be written

$$t=\frac{M_2-M_1}{M_2-M_1+N_2+N_1}$$

where

$$M_1=945-188\cdot62\omega^2+7{,}38\omega^4$$
$$M_2=-231\cdot38\omega^2+7{,}62\omega^4$$
$$N_1+N_2=j\omega^5-105j\omega^3+945j\omega.$$

Since only the sum N_1+N_2 is defined here, but not the relative size between N_1 and N_2, it can be easily realized that there is here a certain freedom of a choice. This choice is made so that the impedance Z may be written in the following way:

$$Z=\frac{M_1+N_1}{M_2+N_2}=A+\cfrac{1}{B+\cfrac{1}{C+\cfrac{1}{D+\cfrac{1}{E+F}}}}$$

where A, B, C ..... are terms of the type $C.\ \omega$ or $C.\ 1/\omega$ or C. This implies that it is possible to carry out a repeated division and inversion, and that the impedance may be realized in the form of a simple ladder network, see FIG. **10**. In the case described above the following values are obtained:

a. $A=0{,}135\omega$;
b. $B=0{,}317\omega$;
c. $C=0{,}41\omega$;
d. $D=34{,}2.\ 1/\omega$;
e. $E=0{,}488.\ 1/\omega$;
f. $F=0{,}21$.

I claim:

1. A filter arrangement comprising a power dividing circuit means including a single input port, a single output port and two sum signal-transfer ports wherein signals received by said input port are power divided and transmitted to each of said sum signal-transfer ports and signals received by said sum signal-transfer ports are geometrically added and transmitted to said single output port, and reactive circuit means for partially reflecting signals received thereby, said reactive circuit means being connected across said sum signal-transfer ports for partially transmitting signals between said sum-signal-transfer ports, and so dimensioned that only signals within a given single frequency range are transmitted to said single output port.

2. Filter arrangement according to claim **1**, characterized in that the power dividing circuit means comprises a 90° hybrid, and that the reactive circuit means comprises reactive elements, a nonreciprocal phase shifter having a phase shift Φ and a reciprocal phase shifter having a phase shift ψ, wherein the reactive circuit means is constructed in such a way that its input impedance, starting from a region between the power dividing circuit means and the reactive circuit means is defined by the expression:

$$Z(j\omega)=\frac{M_1+N_1}{M_2+N_2}$$

when the transfer function of the filter arrangement is defined by the expression:

$$t(j\omega)=\frac{\left[\begin{array}{r}(M_2-M_1)\cdot\sin\ \psi+(N_2-N_1)\psi\cdot\cos\\ +2\sqrt{|M_1M_2-N_1N_2|}\cdot\sin\ \varphi\end{array}\right]}{M_2+M_1+N_2+N_1}$$

M_1 and M_2 being even functions of ω and N_1 and N_2 being odd functions of the angle frequency ω.

3. The filter arrangement according to claim **2** wherein the quantity N_1 and N_2 are such that the input impedance is the impedance of a simple ladder network.

4. Filter arrangement according to claim 1, characterized in that the power dividing circuit means comprises a magic T, and that the reactive circuit means comprises reactive elements, a nonreciprocal phase shifter having a phase shift Φ and a reciprocal phase shifter have a phase shift ψ wherein the reactive elements and the phase shifters are constructed in such a way that the input impedance of the reactive circuit means, starting from a region between the power dividing circuit means and the reactive circuit means, is defined by the expression:

$$Z(j\omega)=\frac{M_1+N_1}{M_2+N_2}$$

when the transfer function of the filter arrangement is defined by the expression:

$$t(j\omega)=\frac{\left[\begin{array}{r}(M_2-M_1)\cdot\cos\psi+(N_2-N_1)\cdot\sin\psi\\ +2\cdot\sqrt{|M_1M_2-N_1N_2|}\cdot\sin\varphi\end{array}\right]}{M_2+M_1+N_2+N_1}$$

M_1 and M_2 being even functions of ω and N_1 and N_2 being odd functions of the angle frequency ω.

5. Filter arrangement according to claim 4 characterized in that the quantities N_1 and N_2 are such that the input impedance constitutes the impedance of a simple ladder network.