

Jan. 2, 1940.

H. A. WHEELER

2,185,389

FEEDBACK AMPLIFIER FILTER

Filed May 9, 1938

2 Sheets-Sheet 1

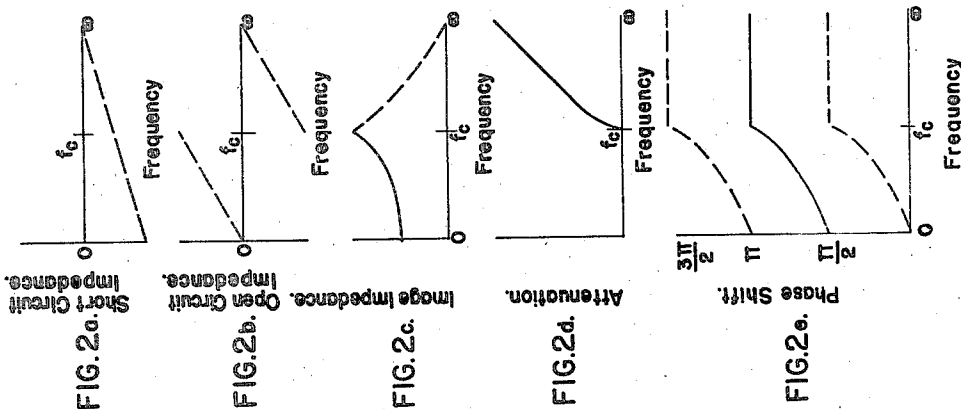
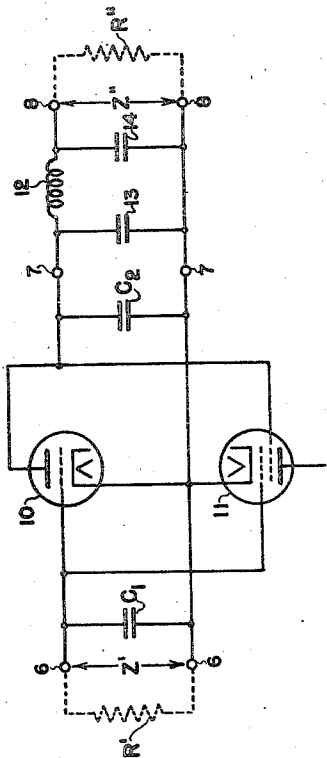


FIG. 1.



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2 Sheets-Sheet 2

FIG. 4.

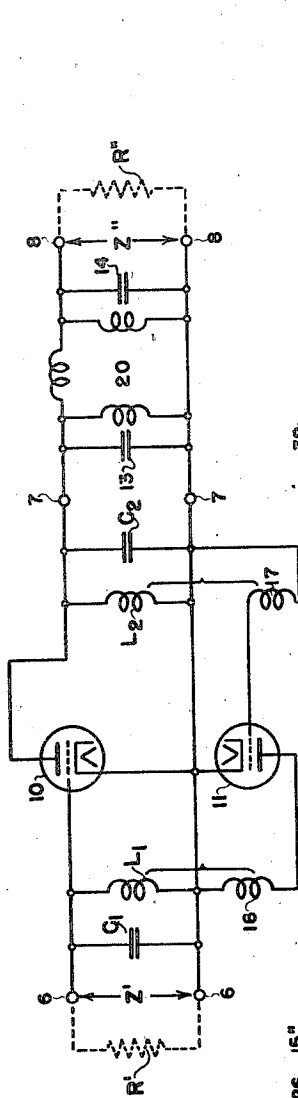


FIG. 5.

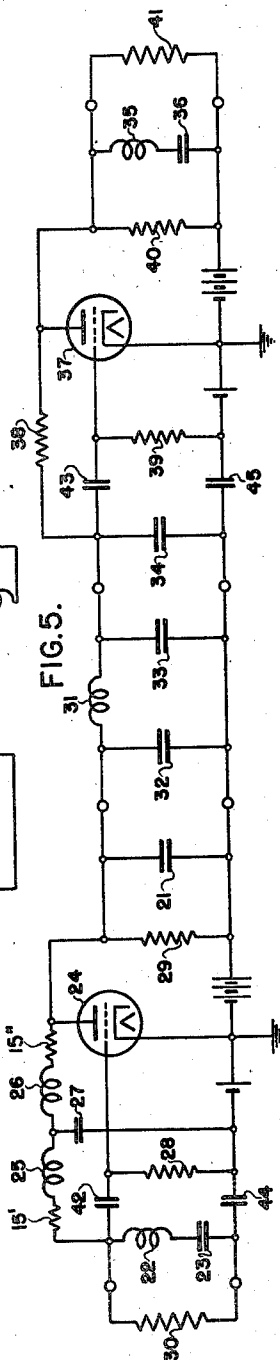
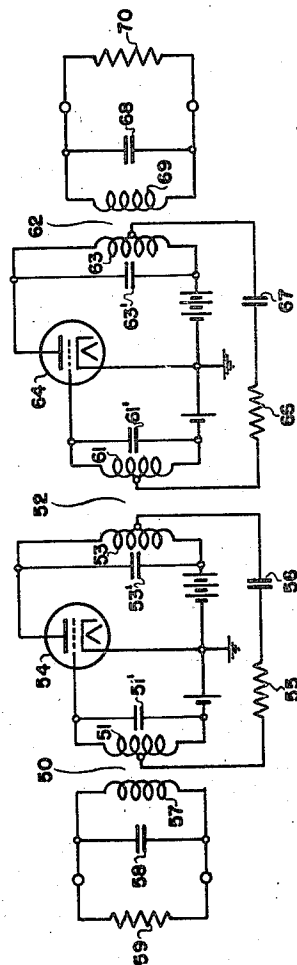


FIG. 6.



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2,185,389

FEEDBACK AMPLIFIER FILTER

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Application May 9, 1938, Serial No. 206,718

17 Claims. (Cl. 179-171)

This invention relates to signal-translating vacuum-tube stages and particularly to such stages of a type comprising a feedback circuit in which the filter properties of the stage are utilized to incorporate the stage as one of a series of confluent filter networks. Specifically the invention comprises a network in which the image impedance characteristics of the feedback stage are matched in the confluent series of networks with the image impedance characteristics of other similar stages or with the image impedance characteristics of conventional filter sections.

Vacuum-tube stages comprising feed-back circuits have been utilized for various purposes. For example, in modulated-carrier signal-translating systems, stages comprising a pair of terminal circuits and a vacuum-tube coupling means coupling the terminal circuits in one direction, together with an additional coupling means coupling the circuits in the opposite direction, have been utilized as band-pass selectors in the intermediate-frequency channel of superheterodyne signal receivers. In prior art circuit arrangements utilizing an amplifier stage with feedback, the terminal circuits of the stage have been individually loaded or damped by terminal resistances to provide suitable damping for the stage. As thus terminated, the feedback stages of the prior art have had the required damping within the feedback stages themselves and have been loosely coupled to adjacent similar stages or to other circuits. If such arrangements are utilized for passing a wide band of frequencies, the width of the pass band is limited by the inherent capacitances of the tubes and the circuit elements. Also, the gain of an amplifier comprising such a stage is materially decreased by the elements provided for individually damping the terminal circuits of the stage.

It is an object of the invention to provide a feedback vacuum-tube amplifier and filter having a relatively large amplification and passing a wide band of frequencies.

It is another object of the invention to provide a confluent filter network comprising a filter section including a vacuum-tube coupling in one direction and an additional coupling in the other direction, the stage being matched with adjacent sections of the network on an image impedance basis.

It is a further object of the invention to provide a confluent filter network comprising an active filter section, as contrasted with a passive filter section, at least one terminal circuit of

which is matched with an adjacent section of the network on an image impedance basis.

In accordance with the invention, there is provided a filter section comprising a vacuum-tube coupling in one direction and an additional coupling in the other direction, at least one terminal circuit of the stage being matched on an image impedance basis with an adjacent terminal circuit of an adjacent filter section to which the stage is coupled in a confluent network.

In one embodiment of the invention, a filter section comprises a vacuum-tube amplifier stage including terminal circuits, a vacuum-tube coupling means coupling the terminal circuits in the forward direction, and a second vacuum-tube coupling means coupling the terminal circuits in the backward direction. The input and output terminals of the stage are individually coupled to circuits having constant- k image impedances. The terminal circuits of the filter section and the relative transconductances of the vacuum tubes utilized in the stage are so proportioned that the image impedance at each pair of terminals closely matches the constant- k image impedance of the adjacent filter section to which it is directly coupled. This manner of coupling the amplifier stage to adjacent filter sections obviates the necessity of individually loading or damping each of the terminal circuits of the stage, since the loading or damping of the entire network is adequately secured at the input and output terminals of the system as a whole. The filter properties of the feedback stage of the invention make it possible to insert additional filter sections between the stages for any purpose for which they are useful. Added sections may be inserted for securing more attenuation outside the pass band, for securing phase correction within the band, or for both purposes.

In a preferred embodiment of the invention, the vacuum-tube stage comprises terminal circuits coupled in the forward direction by a vacuum-tube transconductance coupling means and coupled in the backward direction by passive conductance or resistance coupling means. A phase-shifting circuit may be associated with the backward coupling means, the amount of phase shift being proportioned to effect regeneration just sufficient to compensate, at the cutoff frequency, for the losses caused by the self-conductance or other dissipation in the terminal circuits and coupling means of the stage. The result is to maintain the sharpness of cutoff which would be obtained in a filter if the filter had no inherent dissipation.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Fig. 1 of the drawings is a simplified circuit diagram of a low-pass amplifier filter of the invention, an image impedance of the vacuum-tube feedback section of which is matched with that of an adjacent circuit to form a confluent series of sections; Figs. 2a-2e, inclusive, are graphs illustrating certain theoretical characteristics of the feed-back stage of Fig. 1; Fig. 3 is a simplified circuit diagram of a feedback filter similar to that of Fig. 1 except that a conductance feedback circuit is provided in the feedback section of the network; Fig. 4 is a circuit diagram of a band-pass amplifier filter corresponding in type to the low-pass filter of Fig. 1; Figs. 5 and 6 are circuit diagrams of different types of confluent amplifier filters of the invention, each comprising two feedback sections.

Referring now more particularly to Fig. 1, there is shown a vacuum-tube amplifier stage comprising one of a confluent series of filter sections. The stage comprises input terminals 6, 6 and output terminals 7, 7 across which are coupled, respectively, condensers C_1 and C_2 , forming shunt arms of the stage. The terminal circuits are coupled in the forward direction by a unidirectional coupling means primarily trans-conductive, such as a vacuum tube 10 and are coupled with opposite polarity in the backward direction by a vacuum tube 11. Sources of operating potentials (not shown) and other electrodes such as screen grids, if desired, are provided for tubes 10 and 11 in a conventional manner. The image impedance of the circuit between the input terminals 6, 6 is indicated by Z' . Vacuum tube 11 is so connected as to have effectively a positive transconductance in contrast to the ordinary negative transconductance of a vacuum tube; that is, the output circuit of vacuum tube 11 is taken from a screen circuit. This manner of utilizing a vacuum tube to procure positive transconductance is more fully explained in United States Letters Patent 1,997,665, granted April 16, 1935, on the application of Harold A. Wheeler. The output terminals 7, 7 of the amplifier stage are connected to a constant- k filter section comprising series inductance arm 12 and shunt condenser arms 13 and 14. Condensers 13 and 14 have approximately the same value of capacitance as condenser C_2 . The output terminals 8, 8 of the series of networks shown may be coupled, with image impedance matching, to any other network. The image impedance at the output terminals 8, 8 is indicated by Z'' , the image impedance termination of the output circuit being represented by resistor R'' .

The operation of the filter network described may be explained with reference to Figs. 2a-2e, inclusive, which represent certain theoretical characteristics of the feedback amplifier filter section of Fig. 1, each of the figures having frequency as the abscissae. Thus, Fig. 2a represents the impedance of the feedback amplifier filter section of Fig. 1 on either side, with the other side on short circuit; Fig. 2b shows the corresponding open circuit impedance; Fig. 2c shows the corresponding image impedance; Fig. 2d shows the attenuation; while the full line curve of Fig. 2e shows the filter phase shift of

the feedback amplifier filter section. The upper and lower dotted-line curves of Fig. 2e show the actual phase shift for a stage having, respectively, negative and positive forward transconductance. It will be understood that the characteristic curves of Figs. 2a-2c, inclusive, are equally applicable at either the input terminals 6, 6 or the output terminals 7, 7.

Thus it is seen that the feedback amplifier filter section has input and output image impedances which exactly conform to constant- k mid-shunt image impedances. The system may, therefore, be connected in a confluent series of networks on an image impedance basis with other similar amplifier stages or with filter sections having the constant- k form of image impedance. The low-pass amplifier filter stage shown has a cutoff frequency:

$$\omega_c = \sqrt{\frac{-g_{12}g_{21}}{C_1C_2}} = \frac{1}{\sqrt{LC_2}} \quad (1)$$

where

L = one-half the inductance of winding 12;
 g_{12} = the transconductance of vacuum tube 10;
 g_{21} = the transconductance of vacuum tube 11.

Resistor R' , representing the image impedance of both circuits connected at the terminals 6, 6, and resistor R'' , representing the image impedance of both circuits connected at the terminals 8, 8, or terminating resistors to match such image impedances, have the values:

$$R' = \frac{1}{\sqrt{-g_{12}g_{21}}} \sqrt{\frac{C_2}{C_1}} \quad (2)$$

$$R'' = \frac{1}{\sqrt{-g_{12}g_{21}}} \sqrt{\frac{C_1}{C_2}} \quad (3)$$

The respective image impedances for any frequency ω are:

$$Z' = \frac{R'}{\sqrt{1 - (\omega/\omega_c)^2}} \quad (4)$$

$$Z'' = \frac{R''}{\sqrt{1 - (\omega/\omega_c)^2}} \quad (5)$$

The image impedance ratio of the network shown is:

$$\frac{R''}{R'} = \frac{Z''}{Z'} = \frac{C_1}{C_2} \quad (6)$$

Ordinarily this image impedance ratio is unity in a low-pass filter network. However, due to the fact that the amplifier filter section of the invention is an active section, the image impedance ratio of the circuit of Fig. 1 can have any desired value. The gain of the amplifier filter section of Fig. 1, which is the voltage ratio when connected between equal impedances, is:

$$\frac{E_2}{E_1} = \frac{g_{12}}{g_{21}}$$

Ordinarily the phase shift of a filter section varies over a range of 180 degrees over the pass band. It will be seen from the phase-frequency curves of Fig. 2e that the phase of the low-pass active filter section of Fig. 1 varies over a range of 90 degrees over the pass band.

It will be understood that the transconductance of an ordinary vacuum tube is negative as regards its coupling effect. The transconductance symbols in the above formulae are evaluated on the basis of positive transconductance coupling. Thus, in an actual circuit, one of the transconductances has a positive value and the other a negative value, the negative value cancelling the minus sign appearing before their product in the formulae. Utilizing a screen-grid circuit as an output circuit, as in the case of tube 11 in

Fig. 1, is one way of securing a negative transconductance. Other means for accomplishing this are two conventional tubes coupled in cascade in the normal manner, or a phase-reversing transformer utilized with a normal tube having a negative transconductance. Preferably the tubes utilized in the filter networks of the invention have a very small anode conductance, which is a property of high- μ tubes, such as screen-grid tubes or high- μ triodes. If the amplifier filter section is designed for operation at very high frequencies, the tubes must be shielded against internal capacitive coupling and in such cases the use of screen-grid tubes is essential.

The circuit of Fig. 3 is, in general, similar to the circuit of Fig. 1 and similar circuit elements have been given identical reference numerals. In the circuit of Fig. 3 the coupling provided by vacuum tube 11 of Fig. 1, of opposite polarity to the coupling of vacuum tube 10, has been replaced by a primarily conductive coupling. This conductive coupling is obtained by means of a resistor 15 connected directly between the anode and the grid of vacuum tube 10. If the conductance G_3 of the feedback circuit comprising resistor 15 is much less than the transconductance g_m of vacuum tube 10, the operation of the circuit of Fig. 3 is in all respects similar to that of the circuit of Fig. 1. The amplifier filter section of Fig. 3 has the characteristic of a mid-shunt constant- k image impedance across each of condensers C_1 and C_2 similar to that across corresponding elements in the circuit of Fig. 1. The following additional equations express the effective transconductances in the circuit of Fig. 3:

$$-g_{12} = g_m - G_3 \quad (7)$$

$$g_{21} = G_3 \quad (8)$$

In Fig. 4 there is shown a band-pass filter amplifier section of the invention connected in a confluent network with image impedance matching. The circuit is generally similar to the circuit of the low-pass filter of Fig. 1 and similar circuit elements have been given identical reference numerals. In addition to the circuit elements of Fig. 1, Fig. 4 comprises an inductance L_1 connected in parallel with condenser C_1 , and an inductance L_2 connected in parallel with condenser C_2 . The positive transconductance in the feedback circuit of Fig. 4 is obtained by vacuum tube 11 connected in the normal manner together with proper polarity of the mutual inductances of the transformers provided by windings 16 and 17 coupled to inductances L_1 and L_2 , respectively. The inductance element 12 of the constant- k section of the circuit of Fig. 1 has been replaced in Fig. 4 by inductance network 20, the reactive constants of which effectively provide inductance elements for a band-pass modified constant- k filter section comprising shunt condensers 13 and 14. The operation of the circuit of Fig. 4 may be understood from the description of the operation of the circuit of Fig. 1 given above. The following equations define the characteristics of the amplifier filter section of Fig. 4:

$$\omega_2 = \sqrt{\omega_1 \omega_3} = \frac{1}{\sqrt{C_1 L_1}} = \frac{1}{\sqrt{C_2 L_2}} \quad (9)$$

$$\omega_3 - \omega_1 = \frac{1}{C_1 R'} = \frac{1}{C_2 R''} \quad (10)$$

where ω_2 = mean frequency of the band;
 ω_1 = lower cutoff frequency of the band;
 ω_3 = upper cutoff frequency of the band.

In Fig. 5 there is shown a confluent series of filter sections coupled with image impedance matching and comprising two amplifier filter sections in accordance with the invention. The first amplifier filter section comprises a shunt reactive arm including a series-connected inductance 22 and condenser 23 and a second shunt reactance arm comprising a condenser 21. These shunt reactance arms are coupled in the forward direction by the vacuum tube 24 and are coupled in the backward direction with opposite polarity by a conductance coupling with the addition of series inductances 25 and 26, resistor 15 being replaced by resistors 15', 15''. A condenser 27 is connected from the junction between inductances 25 and 26 and the low-potential terminal of condenser 23. Grid-leak resistor 28 is provided for vacuum tube 24, while the resistance of its load circuit is represented by resistor 29. Across the input terminals of the circuit of Fig. 5 is connected a resistor 30 matching the image impedance between the terminals and which is nearly constant over the pass band. Coupled to the output circuit of the first amplifier filter section of Fig. 5 is a constant- k low-pass filter section comprising series inductance arm 31 and shunt arms consisting of condensers 32 and 33, the value of each of which is equal to that of condenser 21. The second amplifier filter section of the circuit of Fig. 5 comprises a shunt capacitance arm consisting of a condenser 34 and a shunt arm including a series-connected inductance 35 and condenser 36. The shunt arm comprising condenser 34 and the shunt arm comprising series-connected inductance 35 and condenser 36 are coupled in the forward direction by vacuum tube 37 and are coupled in the backward direction with opposite polarity by a resistor 38. A grid leak 39 is provided for vacuum tube 37, while resistor 40 represents the resistance in the output circuit of vacuum tube 37. Across the output terminals of the confluent network of Fig. 5 is connected a resistor 41 matching its image impedance. Operating potentials are provided for the vacuum tubes in a conventional manner, while blocking condensers 42, 43, 44, and 45 are provided to confine direct currents to their proper channels.

In considering the operation of the circuit of Fig. 5, it will be seen that the conductance elements 15', 15'' provide a feedback coupling from the output circuit of vacuum tube 24 to the input circuit thereof. Inductances 25, 26 and condenser 27 are proportioned to shift the phase of the feedback coupling slightly to provide regeneration in the amplifier filter section just sufficient to compensate, at the cutoff frequency, for the losses caused by the feedback conductance of resistors 15', 15'' and the dissipation in the terminal circuits of the stage. The result is that the sharpness of cutoff is maintained just as if the filter had no dissipation. Inductance element 22 provided in the shunt reactance arm of the input circuit of vacuum tube 24 completes an m -derived termination having an image impedance which matches the constant resistance 30. Inductance 35 is provided for the same reason in series with condenser 36; that is, to complete an m -derived termination for the output circuit of the amplifier filter section comprising tube 37 which more closely matches the impedance of the load, represented by resistor 41, over the pass band of the system.

In Fig. 6 there is shown another embodiment of the invention comprising two amplifier filter sections of the invention coupled in cascade in a

confluent band-pass filter network. Thus, the first amplifier filter section of Fig. 6 comprises a shunt reactance arm including the secondary winding 51 of transformer 50 and a shunt reactance arm comprising the primary winding 53 of transformer 52. Winding 51 is coupled in a forward direction to winding 53 by a vacuum tube 54 and is coupled in the backward direction with opposite polarity by a circuit comprising series-connected resistor 55 and condenser 56. The electrode capacitances of tube 54, represented by condensers 51' and 53', are effective to tune the transformer windings to which the electrodes are coupled. The primary winding 57 of transformer 50 is tuned by a shunt condenser 58 across which is coupled a resistance element 59 representing the impedance of the preceding circuit to which the input circuit of Fig. 6 is coupled. The circuit of the second amplifier filter section of Fig. 6 is in all respects similar to the first amplifier filter section described above, and comprises a vacuum tube 64 coupling the secondary winding 61 of transformer 62 in the forward direction to the primary winding 63 of transformer 62, and a feedback circuit coupling windings 61 and 63 in the backward direction with opposite polarity comprising a series-connected resistor 66 and blocking condenser 67. A shunt condenser 68 is connected across the secondary winding 69 of transformer 62 to which is coupled resistance 70 representing the impedance of the succeeding circuit to which the output terminals of the filter network are coupled. The inherent input and output capacitances of vacuum tube 64 are represented respectively by condensers 61' and 63'.

The operation of each amplifier filter section of Fig. 6 is similar to the operation of the circuit of Fig. 3, rendering a further description thereof unnecessary. The feedback circuits of Fig. 6 are tapped down on their respective transformer windings in order that a lower value of resistance may be utilized in the feedback circuits and for the purpose of reducing the capacitive coupling associated with the resistance elements. It will be seen that the circuit of Fig. 6 provides a means for coupling two vacuum-tube amplifier filter sections in cascade, there being minimum dissipation within the filter stages. The circuit of each of the amplifier filters of Fig. 6 is similar to that of Fig. 4 in that each relates to a band-pass filter. However, the feedback coupling paths of the amplifier filters of Fig. 6 are similar to the conductance coupling including resistor 15 of the low-pass filter of Fig. 3. The damping necessary to provide proper terminal impedances for the amplifier filter sections is secured mainly by resistors 59 and 70 at the ends of the confluent network.

The coefficient of coupling k between windings 53 and 61 of transformer 52 is much less than would be required to couple conventional vacuum-tube amplifier stages. If $\Delta\omega$ is the width of the pass band and ω_0 is the mean frequency of the pass band, the required coupling is,

$$k = \Delta\omega / 2\omega_0$$

where $\Delta\omega < \omega_0$. This is half that required without feedback in the adjacent stages.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore,

aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A wave filter network comprising a first filter section having a predetermined image impedance at one end and an active second filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms primarily transconductive in the direction of coupling, and means coupling said arms with opposite polarity in the other direction, whereby said second filter section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, said coupling means being so proportioned with respect to the reactive constants of said arms that the image impedance of said second filter section matches the image impedance of said first section at their junction.

2. A wave filter network comprising a first filter section having a predetermined image impedance at one end and an active second filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms primarily transconductive in the direction of coupling, coupling means primarily conductive coupling said arms with opposite polarity in the other direction, whereby said second filter section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that the image impedance of said second filter section matches the image impedance of said first section at their junction.

3. A wave filter network comprising a first filter section having a predetermined image impedance at one end and a second active filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms primarily transconductive in the direction of coupling, coupling means primarily transconductive coupling said arms with opposite polarity in the other direction, whereby said second section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that said image impedance of said second filter section matches said image impedance of said first filter section at their junction.

4. A low-pass filter network comprising a first filter section having a predetermined image impedance at one end and a second active filter section comprising input and output pairs of terminals, a shunt reactance arm individual to and coupled to each of said pairs of terminals and comprising shunt capacitance, said reactance arms having coupling means between said arms primarily transconductive in the direction of coupling, means coupling said arms with opposite polarity in the opposite direction, whereby said

second section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that said image impedance of said second filter section matches the image impedance of said first filter section at their junction.

5. A band-pass filter network comprising a first filter section having a predetermined image impedance at one end and an active second filter section comprising input and output pairs of terminals, a parallel-resonant shunt arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms primarily transconductive in the direction of coupling, means coupling with opposite polarity said arms in the other direction, whereby said second section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that the image impedance of said second filter section matches the image impedance of said first section at their junction.

6. A low-pass filter network comprising a first filter section having a mid-shunt constant- k image impedance at one end and an active second filter section comprising input and output pairs of terminals, a shunt reactance arm including capacitance individual to and coupled to each of said pairs of terminals, unidirectional coupling means in one direction between said arms primarily transconductive in the direction of coupling, means coupling said arms with opposite polarity in the other direction, whereby said second filter section has a predetermined pass band and constant- k mid-shunt image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that said image impedance of said second filter section matches the image impedance of said first filter section at their junction, said second filter section having a phase shift which varies over a range of 90 degrees over the pass band of said network.

7. A wave filter network comprising a first filter section having a mid-shunt constant- k impedance at one end and an active second filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms primarily transconductive in the direction of coupling, means coupling said arms with opposite polarity in the other direction, whereby said second filter section has a predetermined pass band and a mid-shunt constant- k image impedance across each of said pairs of terminals, one of said pairs of terminals being coupled to said end of said first filter section, said coupling means being so proportioned with respect to the reactive constants of said arms that the image impedance of said second filter section matches the image impedance of said first filter section at their junction and said image impedances of said second section have a constant ratio substantially different from unity.

8. A low-pass filter network comprising a filter

network including a first filter section having a predetermined image impedance at one end and an active second filter section comprising input and output pairs of terminals, a shunt reactance arm individual to and coupled to each of said pairs of terminals and having substantial capacitances C_1 and C_2 , unidirectional coupling means between said arms in one direction consisting primarily of transconductance g_{12} in the direction of coupling, unidirectional coupling means of opposite polarity between said arms in the other direction consisting primarily of transconductance g_{21} , whereby said second filter section has a cutoff frequency

$$\omega_c = \sqrt{\frac{g_{12}g_{21}}{C_1C_2}}$$

and whereby said second section has a constant- k mid-shunt image impedance across one of said pairs of terminals, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that said image impedance of said second filter section matches the image impedance of said first filter section at their junction.

9. In a wave filter network, an active filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means between said arms in one direction primarily transconductive in the direction of coupling, coupling means of opposite polarity between said arms in the other direction, an m -derived termination for said filter section comprising one of said arms, whereby said filter section has a predetermined cutoff frequency and a predetermined constant image impedance across one of said pairs of terminals over said band, and a constant resistance circuit connected across said one of said pairs of terminals.

10. In a wave filter network, an active filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, directional coupling means in one direction between said arms primarily transconductive in the direction of coupling, and coupling means primarily conductive coupling said arms with opposite polarity in the other direction, an m -derived termination for said filter section comprising one of said arms, whereby said filter section has a predetermined cutoff frequency and a predetermined constant image impedance across one of said pairs of terminals over said band, and a constant resistance circuit connected across said one of said pairs of terminals.

11. In a low-pass filter network, an active filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, directional coupling means in one direction between said arms primarily transconductive in the direction of coupling, and means coupling said arms with opposite polarity in the other direction, one of said arms consisting of a series-connected inductance and condenser, whereby said section has a predetermined cutoff frequency and a substantially constant resistive image impedance across the pair of terminals to which said one of said arms is coupled, and a constant resistance circuit connected across said last-mentioned pair of terminals.

12. An active filter section comprising input and output pairs of terminals, a reactance arm

individual to and coupled to each of said pairs of terminals, directive coupling means in one direction between said arms primarily transconductive in the direction of coupling, and coupling means primarily conductive coupling said arms in the other direction with opposite polarity, phase-shifting means included in said conductive coupling means effective to provide regeneration at a cutoff frequency of said section just sufficient to compensate for dissipation in said section, whereby said section has a predetermined pass band and a predetermined image impedance across one of said pairs of terminals.

13. An active filter section comprising input and output pairs of terminals, a reactance arm individual to and coupled to each of said pairs of terminals, unidirectional coupling means in one direction between said arms primarily transconductive in the direction of coupling, and coupling means primarily conductive coupling said arms with opposite polarity in the other direction, phase-shifting means comprising inductance in series with said conductive coupling means and capacitance in shunt therewith effective to provide regeneration at the cutoff frequency of said section just sufficient to compensate for dissipation in said section, whereby said section has a predetermined cutoff frequency and a predetermined image impedance across one of said pairs of terminals.

14. A band-pass filter comprising a plurality of coupled filter sections with image impedance matching at their junctions, each of two of said sections comprising a transformer having primary and secondary windings, transconductive coupling means comprising a vacuum tube having inherent input and output capacitances coupling the secondary winding of one of said transformers with the primary winding of the other of said transformers, coupling means of opposite polarity in the other direction between said two last-mentioned windings, the coupling effect of said coupling means being proportioned with respect to the reactive constants of said transformers to provide constant- k mid-shunt image impedances across said capacitances and a predetermined pass band for said filter, said image impedances matching the image impedances of adjoining ones of said sections.

15. A band-pass filter comprising a plurality of coupled filter sections with image impedance matching at their junctions, each of two of said sections comprising a transformer having primary and secondary windings, transconductive coupling means comprising a vacuum tube having inherent input and output capacitances coupling the secondary winding of one of said transformers with the primary winding of the other of said transformers, coupling means of oppo-

site polarity in the other direction between said two last-mentioned windings, said coupling means comprising a resistor coupled between points of said two last-mentioned windings, the coupling effect of said coupling means being proportioned with respect to the reactive constants of said transformers to provide constant- k mid-shunt image impedances across said capacitances and a predetermined pass band for said filter, said image impedances matching the image impedances of adjoining ones of said sections.

16. A band-pass filter comprising a plurality of coupled filter sections with image impedance matching at their junctions and including two similar sections, two shunt reactance arms for each of said sections, a transformer having primary and secondary windings individually comprising one of said arms in each of said sections, transconductive coupling means comprising a vacuum tube in each of said sections coupling its respective arms, coupling means between said arms in each of said sections coupling said arms with opposite polarity in the other direction, the coupling effect of said coupling means being proportioned with respect to the reactive constants of said similar sections to provide constant- k mid-shunt image impedances and a predetermined pass band for said similar sections, said image impedances matching the image impedances of adjoining ones of said sections, said transformer having a coefficient of coupling $k = \Delta\omega/2\omega_0$, where $\Delta\omega$ is the width of the pass band of said similar sections and ω_0 is the mean frequency of said similar sections, $\Delta\omega$ being substantially less than ω_0 .

17. A wide band filter network comprising a first filter section having a predetermined image impedance at one end and an active filter section comprising input and output pairs of terminals, two capacitive shunt arms coupled to said terminals and having unidirectional coupling means between said arms primarily transconductive in the direction of coupling, said coupling means comprising a vacuum tube having input and output capacitances, one of said capacitances of said tube comprising the capacitance of a full-shunt element of said filter network, and means coupling said arms with opposite polarity in the other direction, whereby said section has a predetermined pass band and a predetermined image impedance across said one of said arms, said one of said pairs of terminals being coupled to said end of said first filter section, and said coupling means being so proportioned with respect to the reactive constants of said arms that the image impedance of said second filter section matches the image impedance of said first filter section at their junction.

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