July 1, 1941. H. A. WHEELER 2,247,898

BAND-PASS FILTER INCLUDING TRAP CIRCUIT

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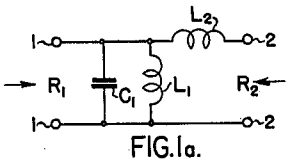


FIG.1a.

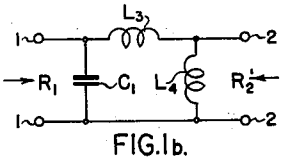


FIG.1b.

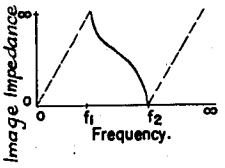


FIG.1c.

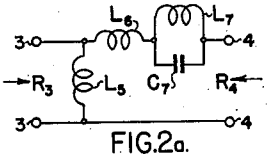


FIG.2a.

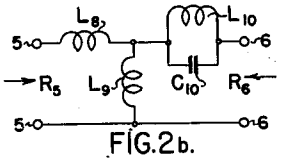


FIG.2b.

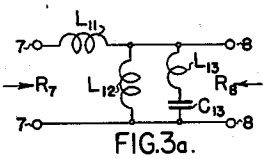


FIG.3a.

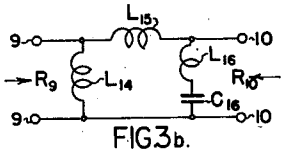


FIG.3b.

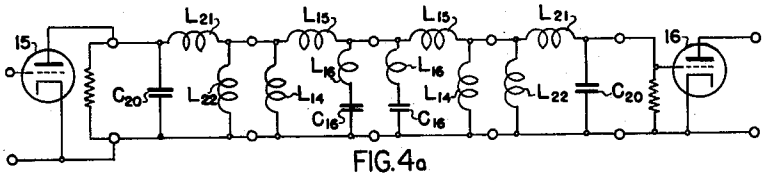


FIG.4a

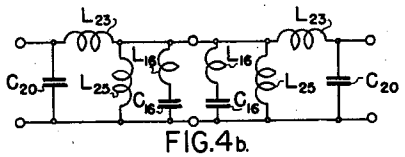


FIG.4b.

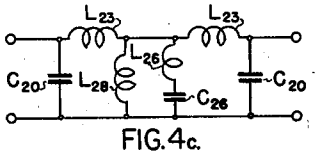


FIG.4c.

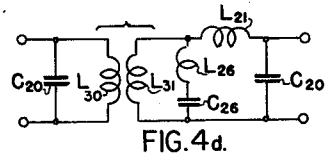


FIG.4d.

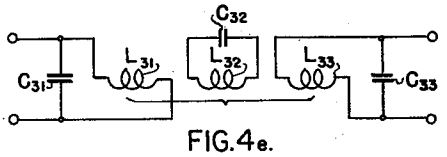


FIG.4e.

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BAND-PASS FILTER INCLUDING TRAP CIRCUIT

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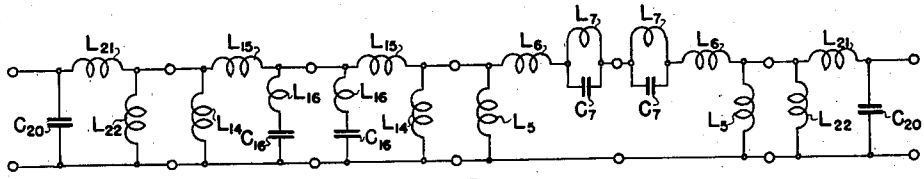


FIG. 5a.

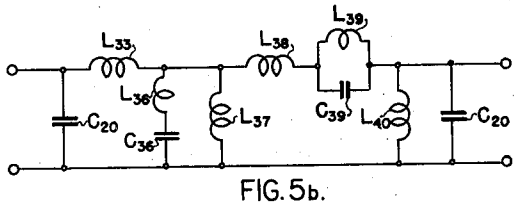


FIG. 5b.

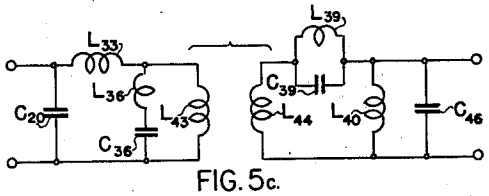


FIG. 5c.

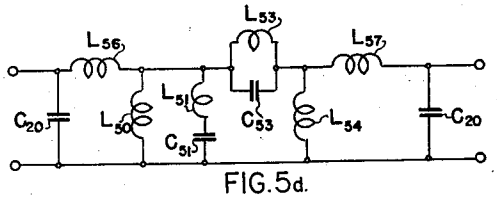


FIG. 5d.

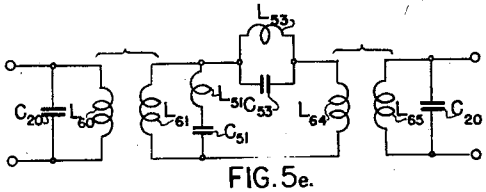


FIG. 5e.

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Patented July 1, 1941 2,247,898

UNITED STATES PATENT OFFICE

2,247,898

BAND-PASS FILTER, INCLUDING TRAP CIRCUIT

Harold A. Wheeler, Great Neck, N. Y., assignor to Hazeltine Corporation, a corporation of Delaware

Application September 29, 1939, Serial No. 297,081

19 Claims. (Cl. 178—44)

This invention relates to band-pass filters including filter sections having trap circuits therein and having an image impedance at a pair of terminals which has opposite extreme values at the upper and lower cutoff frequencies of the pass band. While the filters of the invention are of general application, they are of particular utility in effecting an impedance transformation between two pairs of terminals while providing traps for frequencies just outside of a desired continuous pass band.

A double-tuned transformer is a commonly used form of band-pass filter section. Such a transformer circuit may be regarded as two half-sections joined together, each comprising a shunt- and a series-reactance arm. Each of these half-sections comprises at their junction a pair of terminals across which the image impedance has opposite extreme values at the upper and lower cutoff frequencies of the pass band, which form of image impedance is not matched with the more familiar constant-k type of band-pass image impedance. However, such filter half-sections have many uses and are of particular utility because of their extreme simplicity and their image-impedance transforming properties between their two pairs of terminals. Band-pass filters utilizing only half-sections of the type under discussion, or such half-sections in combination with other known filter sections, have the disadvantage that, for some purposes, sufficient attenuation at frequencies just above and below the pass band is not secured with a minimum number of circuit elements. This is true, even if the other known filter sections are of types including trap circuits to provide maximum attenuation at particular frequencies outside the pass band. Some attempts to design simple filters with traps have yielded filters with spurious pass bands in addition to the desired pass band, and such spurious bands are usually undesirable.

It is an object of the present invention, therefore, to provide an improved impedance-transforming band-pass filter half-section which includes a trap for frequencies outside the pass band.

It is another object of the invention to provide an improved band-pass filter half-section which passes only a single continuous band and which includes a trap circuit for frequencies outside the pass band.

It is another object of the invention to provide an improved band-pass filter section for passing a single band of frequencies and which includes a trap circuit for frequencies above the pass band and a trap circuit for frequencies below the pass band.

It is still another object of the invention to provide a band-pass filter network for passing a single continuous band of frequencies which includes one or more trap circuits for frequencies outside of the pass band and which tolerates maximum shunt capacitance across one or both pairs of terminals.

In accordance with one feature of the invention, a band-pass filter half-section having input and output pairs of terminals effectively comprises series- and shunt-reactance arms of which at least each of two includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies within the pass band; that is, all such portions individually have the same variation of reactance with frequency over the pass band and effectively provide either only inductive or only capacitive reactance at frequencies within the pass band. A trap circuit is included in one of the reactance arms which is adjacent to one of the pairs of terminals and comprises the only other reactance of the half-section. The trap circuit is resonant at a frequency outside of the pass band and is so connected to present reactance of the kind opposite to that of the said portions at frequencies within the pass band, whereby the image impedance at the other pair of terminals is caused to present opposite extreme values at the upper and lower cutoff frequencies of the pass band.

In accordance with another feature of the invention, a band-pass filter section has input and output pairs of terminals and effectively comprises, series- and shunt-reactance arms at least each of three of which includes a portion of the same reactance-frequency characteristic and of a given kind at frequencies in the pass band; the filter section also includes a trap circuit in one of its reactance arms which is connected between two of the said three reactance arms and which comprises the only other reactance of the filter section. The trap circuit is resonant at a frequency outside of the pass band and presents reactance of the kind opposite to that of the above-mentioned portions at frequencies in the pass band, whereby the image impedance at both pairs of terminals is caused to have opposite extreme values at the upper and lower frequencies of the pass band.

In accordance with another feature of the invention, a confluent band-pass filter effectively comprises a series of filter half-sections with image-impedance matching at their junctions, each of two adjacent ones of said half-sections having both series- and shunt-reactance arms of which each of two of the reactance arms adjacent to their junction includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies in the pass band. The filter of this embodiment also includes a trap circuit in each

of the said two adjacent half-sections which is removed from their junction by at least one of the said adjacent reactance arms and which comprises the only other reactance of the half-section. One of the trap circuits comprises a shunt arm of series-connected capacitance and inductance resonant at a frequency on one side of the pass band, and the other of the trap circuits comprises a series arm having parallel-connected capacitance and inductance resonant at a frequency on the other side of the pass band. The matched image impedance at the above-mentioned junction therefore has opposite extreme values at the upper and lower cutoff frequencies of the pass band and unlike trap circuits are provided in the two adjacent half-sections.

In accordance with still another feature of the invention, a band-pass filter comprises two resonant circuits each having an inductor coupled therewith by mutual inductance, a series circuit including the said inductors and a trap circuit with parallel-connected capacitance and inductance resonant at a frequency below the pass band, and a second trap circuit connected in parallel with one of the above-mentioned inductors and including series-connected capacitance and inductance resonant at a frequency above the pass band. The filter is preferably proportioned to pass a continuous band of frequencies and to secure maximum attenuation at frequencies above and below the pass band.

It is seen, therefore, that, while some arrangements of the prior art utilize both a band-pass filter circuit and one or more trap circuits for frequencies outside the pass band of the filter, such prior art arrangements are subject to the disadvantage that they require more than the minimum number of circuit elements or the filter properties of the filter are disturbed by the addition of the trap circuit. In the latter case, the filter may be caused to have one or more spurious pass bands other than the desired pass band. The invention, however, provides a most simple band-pass filter which effectively includes the required number of trap circuits with filtering properties undisturbed by the inclusion of the traps. Substantially only one single continuous band of frequencies is passed by the filter circuits of the invention.

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.

Each of Figs. 1*a* and 1*b* of the drawings represents a filter half-section which is equivalent to one-half of a double-tuned transformer circuit and which is utilized to explain the principles of operation of the present invention; Fig. 1*c* is a graph of the image-impedance characteristic at one pair of terminals of each of the circuits of Figs. 1*a* and 1*b*, which characteristic is similar to the image-impedance characteristic at one pair of terminals of each of the filter half-sections of the invention; each of Figs. 2*a* and 2*b* is a circuit diagram of a band-pass filter half-section of the invention comprising a trap circuit for frequencies below the pass band; each of Figs. 3*a* and 3*b* represents a band-pass filter half-section of the invention comprising a trap circuit for frequencies above the pass band; Fig. 4*a* is a circuit diagram of a band-pass filter in accordance with the invention which is utilized to couple two vacuum tubes in cascade and which comprises a trap circuit for frequencies above the pass band of the system; Figs. 4*b*–4*e*, inclusive, represent equivalent modifications of the circuit of Fig. 4*a*; Fig. 5*a* is a circuit diagram of a band-pass filter in accordance with the invention which comprises a trap circuit for frequencies above the pass band and a trap circuit for frequencies below the pass band; each of Figs. 5*b* to 5*e*, inc., represents an equivalent modification of the circuit of Fig. 5*a*.

Referring now more particularly to Fig. 1*a* of the drawings, there is shown a filter half-section comprising a shunt reactance arm including parallel-connected inductance L_1 and capacitance C_1 and a series-reactance arm including inductance L_2. The filter half-section of Fig. 1*a* is a known electrical equivalent of one-half a filter whole-section comprising a conventional double-tuned transformer. The filter comprises one pair of input terminals **1**, **1** across which appears the image impedance of nominal value R_1 and another pair of input terminals **2**, **2** across which appears the image impedance R_2. The conventional double-tuned transformer circuit may also be divided in a known manner into two filter half-sections of the form shown in Fig. 1*b*, each of which includes a shunt-reactance arm comprising capacitance C_1 across terminals **1**, **1**, a series-reactance arm comprising inductance L_3, and a shunt-reactance arm comprising inductance L_4 connected across terminals **2**, **2**. Each of the following equations is applicable to one or both of the circuits of Figs. 1*a* and 1*b*:

$$Z_1=R_1,\ Z_2=R_2 \text{ and } Z_2'=R_2',\ \text{at } f_m=\sqrt{f_2 f_3} \quad (1)$$

$$L_1=\frac{1}{\omega_2^2 C_1} \quad (2)$$

$$L_2=\frac{1}{(\omega_3^2-\omega_2^2)C_1} \quad (3)$$

$$L_3=\frac{1}{\omega_3^2 C_1} \quad (4)$$

$$L_4=\frac{\omega_3^2-\omega_2^2}{\omega_2^2\omega_3^2 C_1} \quad (5)$$

$$R_1=\frac{1}{(\omega_3-\omega_2)C_1} \quad (6)$$

$$R_2=R_1\frac{\omega_3}{\omega_2+\omega_3} \quad (7)$$

$$R_2'=R_1\frac{(\omega_3-\omega_2)^2(\omega_3+\omega_2)}{\omega_3^3} \quad (8)$$

where

f_2=lower cutoff frequency;
f_3=upper cutoff frequency;
Z_1=image impedance at terminals **1**, **1**;
Z_2=image impedance at terminals **2**, **2** of Fig. 1*a*;
Z_2'=image impedance at terminals **2**, **2** of Fig. 1*b*;
f_m=the mean frequency of the pass band;
ω_2=the angular frequency at the lower cutoff frequency;
ω_3=the angular frequency at the upper cutoff frequency;
R_1=nominal image impedance across terminals **1**, **1**;
R_2=nominal image impedance across terminals **2**, **2** of Fig. 1*a*;
R_2'=nominal image impedance across terminals **2**, **2** of Fig. 1*b*.

In Fig. 1*c* there is illustrated the form of the image-impedance characteristic at the terminals **2**, **2** of each of the filter half-sections of Figs. 1*a* and 1*b*. Each half-section includes one tuned

circuit and has at the terminals 1, 1 a constant-k mid-shunt impedance of mid-band value R_1 associated with the maximum tolerable shunt capacitance C_1, where

$$C_1=\frac{1}{R_1(\omega_2-\omega_1)} \quad (9)$$

From Fig. 1c it is seen that the image impedance across terminals 2, 2 has opposite extreme values at the cutoff frequencies of the pass band; that is, it is infinite at the lower cutoff frequency f_1 and zero at the upper cutoff frequency f_2, and this type of image impedance serves as a basis for joining the half-sections of further embodiments of the invention in filter networks comprising additional filter sections of different types.

In Fig. 2a there is illustrated a filter half-section in accordance with the present invention which includes a trap for frequencies below the pass band. This filter half-section includes a shunt-reactance arm across terminals 3, 3 comprising inductance L_5 and a series-reactance arm including inductance L_6 in series with parallel-connected trap-circuit inductance L_7 and capacitance C_7. The following equations are applicable to the circuit of Fig. 2a:

$$Z_3=R_3 \text{ at } f_m=\sqrt{f_2 f_3} \quad (10)$$

$$L_5=\frac{R_3}{\omega_3}\sqrt{\frac{\omega_3^2-\omega_1^2}{\omega_2^2-\omega_1^2}} \quad (11)$$

$$L_6=\frac{(\omega_2^2-\omega_1^2)L_5}{(\omega_3^2-\omega_2^2)} \quad (12)$$

$$L_7=\frac{(\omega_3^2-\omega_1^2)(\omega_2^2-\omega_1^2)L_5}{\omega_1^2(\omega_3^2-\omega_2^2)} \quad (13)$$

$$=\frac{(\omega_3^2-\omega_1^2)L_6}{\omega_1^2}$$

$$C_7=\frac{1}{\omega_1^2 L_7} \quad (14)$$

where,

Z_3=image impedance at terminals 3, 3;
f_1=resonant frequency of trap circuit L_7, C_7;
ω_1=angular frequency corresponding to f_3; and
R_3=mid-band image resistance at terminals 3, 3.

The image-impedance characteristic of the filter of Fig. 2a at the terminals 3, 3 has the same form as that illustrated in Fig. 1c of the drawings but has upper and lower cutoff frequencies f_1 and f_3, respectively.

It is seen that the band-pass filter half-section of Fig. 2a has input and output pairs of terminals 3, 3 and 4, 4, respectively, and effectively comprises series- and shunt-reactance arms, of which at least each of two includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies within the pass band. Specifically, the shunt-reactance arm includes a portion comprising inductance L_5 and the series-reactance arm includes a portion comprising inductance L_6, the portions both having inductive reactance at frequencies in the pass band and the same reactance at frequencies in the pass band and the same reactance-frequency characteristic. A trap circuit is included in the series-reactance arm which is adjacent to the pair of terminals 4, 4 and comprises the only other reactance of the half-section. The trap circuit is resonant at a frequency below the pass band and presents capacitive reactance, which is of the kind opposite to that of the said portions at frequencies in the pass band.

Another filter half-section in accordance with the present invention, including a trap circuit for frequencies below the pass band and having the same cutoff frequencies, is illustrated in Fig. 2b. This filter half-section comprises pairs of terminals 5, 5 and 6, 6 and includes a series-reactance arm comprising inductance L_8, a shunt-reactance arm comprising inductance L_9, and a series arm including parallel-connected inductance L_{10} and capacitance C_{10}. The circuit of Fig. 2b is readily derived from that of Fig. 2a by a simple impedance transformation.

The image impedance Z_5 at terminals 5, 5 is identical with that at terminals 3, 3 of Fig. 2a. That at terminals 6, 6 has the same form as that at terminals 4, 4 but a different magnitude.

In Fig. 3a of the drawings there is illustrated a band-pass filter half-section in accordance with the invention, including a trap circuit for frequencies above the pass band. This filter half-section includes a series-reactance arm comprising inductance L_{11} and a shunt-reactance arm including inductance L_{12} connected in parallel with series-connected inductance L_{13} and capacitance C_{13}, the pairs of terminals of the filter half-section being identified by numerals 7, 7 and 8, 8. The following equations are applicable to the circuit of Fg. 3a:

$$Z_7=R_7 \text{ at } f_m=\sqrt{f_2 f_3} \quad (15)$$

$$L_{11}=\frac{R_7}{\omega_3}\sqrt{\frac{\omega_4^2-\omega_2^2}{\omega_4^2-\omega_2^2}} \quad (16)$$

$$L_{12}=\frac{\omega_4^2(\omega_3^2-\omega_2^2)L_{11}}{\omega_2^2(\omega_4^2-\omega_3^2)} \quad (17)$$

$$L_{13}=\frac{\omega_4^2(\omega_3^2-\omega_2^2)L_{11}}{(\omega_4^2-\omega_2^2)(\omega_4^2-\omega_3^2)}$$

$$=\frac{\omega_2^2 L_{12}}{\omega_4^2-\omega_2^2} \quad (18)$$

$$C_{13}=\frac{1}{\omega_4^2 L_{13}} \quad (19)$$

where,

Z_7=image impedance at terminals 7, 7;
R_7=mid-band image resistance at terminals 7, 7; and
ω_3=angular frequency of trap circuit L_{13}, C_{13}.

The image impedance Z_7 at terminals 7, 7 is of the same form as that illustrated in Fig. 1c.

In Fig. 3b there is illustrated another modification of a band-pass filter half-section in accordance with the invention including a trap circuit for frequencies above the pass band. The half-section of Fig. 3b comprises pairs of terminals 9, 9 and 10, 10, a shunt-reactance arm across terminals 9, 9 including inductance L_{14}, a series-reactance arm including inductance L_{15}, and a shunt-reactance arm across terminals 10, 10 including series-connected inductance L_{16} and capacitance C_{16}. The circuit of Fig. 3b is readily derived from that of Fig. 3a by a simple impedance transformation. The image impedance Z_9 at terminals 9, 9 is of the same form as that illustrated in Fig. 1c.

In Fig. 4a there is illustrated a band-pass filter circuit in accordance with the invention comprising a trap circuit for frequencies above the pass band, which is utilized to couple a pair of vacuum tubes 15 and 16 in cascade. The band-pass filter circuit of Fig. 4a includes four filter half-sections; they are connected with image-impedance matching at their respective junctions

so the filter is said to be confluent. Each of the two end half-sections includes a shunt-reactance arm including capacitance C_{20}, a series-reactance arm including inductance L_{21}, and a shunt-reactance arm including inductance L_{22} and is of the type represented by Fig. 1*b*. Each of the two intermediate half-sections is identical with the half-section of Fig. 3*b* described above and similar circuit elements have identical reference numerals. It is seen that the last-mentioned half-sections are connected with image-impedance matching at their terminals corresponding to terminals **10**, **10** of Fig. 3*b*. The end half-sections to which the opposite terminals of each of the intermediate half-sections are connected provide a constant-k band-pass mid-shunt image impedance across the input and output terminals. The end half-sections and, therefore, the composite filter circuit is of a type which tolerates maximum shunt capacitance across the output circuit of tube **15** and across the input circuit of tube **16**. It will be understood that the capacitances C_{20}, C_{20} may be comprised in whole or in part of the interelectrode capacitances of the tubes to which they are coupled. It is also seen that the band-pass filter section, including the series-inductance arms L_{15}, L_{15} of Fig. 4*a* effectively comprises series- and shunt-reactance arms, of which each of at least three includes portions individually of the same impedance-frequency characteristic and of a given kind of reactance at frequencies within the pass band. Specifically, four of the arms individually include inductances L_{14}, L_{15}, L_{15}, and L_{14}, each of which portions has an inductive reactance at frequencies within the pass band. Furthermore, a trap circuit, including both trap circuits L_{16}, C_{16}, is included in the one of the reactance arms of the filter section which is between two of the three inductance arms and comprises the only other reactance of the filter section. This resultant trap circuit is resonant at a frequency above the pass band and presents reactance of the opposite kind, that is, capacitance, at frequencies within the pass band.

The circuit of Fig. 4*b* is the full electrical equivalent of that of Fig. 4*a* and differs only in that adjacent shunt-inductance arms L_{22} and L_{14} of Fig. 4*a* have been combined into the single inductance element L_{25} and the adjacent series-inductance arms L_{21} and L_{15} have been combined into the single inductance element L_{23} in the circuit of Fig. 4*b*.

A further modification of the circuit of Fig. 4*b* is illustrated in Fig. 4*c* which differs from that of Fig. 4*b* only in that the adjacent trap circuits L_{16}, C_{16} and the inductances L_{25}, L_{25} have been respectively combined in the circuit of Fig. 4*c* to provide a single trap circuit L_{26}, C_{26} and a single shunt-inductance element L_{28}.

The circuit of Fig. 4*d* is identical with that of Fig. 4*c* except that a transformer including inductively-coupled primary and secondary inductances L_{30}, L_{31} has been substituted for the adjacent inductance elements L_{23}, L_{28} of Fig. 4*c* in a manner which is well understood in the art.

The circuit of Fig. 4*e* is identical with that of Fig. 4*d* except that a further similar transformation has been made to provide an equivalent circuit including three inductors L_{31}, L_{32}, and L_{33} each of which is coupled to each of the others. They are respectively tuned by condensers C_{31}, C_{32}, and C_{33}.

In Fig. 5*a* there is illustrated another modification of the invention comprising trap circuits resonant at frequencies both below and above the pass band which may be utilized for effecting an impedance transformation between two pairs of terminals. The filter of Fig. 5*a* comprises all of the elements of the filter of Fig. 4*a* and includes in addition a filter section comprising two filter half-sections, each identical with the half-section of the filter of Fig. 2*a*. Circuit elements which are similar to those of Fig. 2*a* and Fig. 4*a* have identical reference numerals. The filter section comprising the two half-sections similar to that of Fig. 2*a* is included between one of the end filter half-sections including elements L_{21}, L_{22}, C_{20} and the adjacent half-section including a trap circuit which is resonant at a frequency above the pass band. The operation of the circuit of Fig. 5*a* will be understood from the description which has been given with reference to the individual filter half-sections which form component parts thereof, rendering a further description unnecessary herein. As stated above, the image impedance at the terminals **3**, **3** of Fig. 2*a* is of the same form as that at terminals **2**, **2** of Fig. 1*b* and the terminals **9**, **9** of Fig. 3*b*, so that these filter sections can be connected in cascade with image-impedance matching at their junctions.

It is, therefore, seen that the filter circuit of Fig. 5*a* is a confluent band-pass filter effectively comprising a series of filter half-sections with image-impedance matching at their junctions, each of two adjacent ones of the half-sections comprising both series- and shunt-reactance arms of which each of two of the four arms adjacent their junction includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies in the pass band; specifically, the said two half-sections include inductances L_{15}, L_{14} and L_5, and L_6, each having an inductive reactance at frequencies in the pass band. A trap circuit is included in each of the two adjacent half-sections under discussion which is removed from their junction by at least one of the above-mentioned adjacent arms and comprises the only other reactance of such half-section. One of the trap circuits comprises a shunt arm of series-connected capacitance C_{16} and inductance L_{16} resonant at a frequency on one side of the pass band and the other trap circuit comprises a series arm having parallel-connected capacitance C_7 and inductance L_7 resonant at a frequency on the other side of the pass band.

In Fig. 5*b* is shown a modification of the filter of Fig. 5*a* in which single trap circuits are substituted for the two adjacent trap circuits of each type in the filter of Fig. 5*a*, adjacent inductance elements of similar kind being combined in a single inductance element and impedance transformation being effected between like elements in adjacent arms of opposite type. The circuit of Fig. 5*b* thus comprises a single trap circuit L_{36}, C_{36} resonant at a frequency above the pass band, a single trap circuit L_{39}, C_{39} resonant at a frequency below the pass band, shunt-inductance elements L_{37} and L_{40}, and series-inductance elements L_{33} and L_{38}.

The circuit of Fig. 5*c* is identical to that of Fig. 5*b* except that an equivalent transformer L_{43}, L_{44} has been substituted in a manner well understood in the art for the adjacent inductance elements L_{37}, L_{38} of Fig. 5*b*.

The filter circuit of Fig. 5*d* is also the elec-

trical equivalent of the filter circuit of Fig. 5*a* and is derived from the circuit of Fig. 5*a* by combining adjacent inductance elements, combining each of the two pairs of trap circuits into a single pair of trap circuits, and effecting an impedance transformation. The filter of Fig. 5*d* thus comprises a single trap circuit L_{51}, C_{51} resonant at a frequency above the pass band, a single trap circuit L_{53}, C_{53} resonant at a frequency below the pass band, series-inductance elements L_{56} and L_{57}, and shunt-inductance elements L_{50} and L_{54}.

The filter circuit of Fig. 5*e* is similar to that of Fig. 5*d* except that an equivalent transformer L_{60}, L_{61} has been substituted for the adjacent inductance elements L_{50}, L_{56} of Fig. 5*d* and a second transformer L_{64}, L_{65} has been substituted for the adjacent inductance elements L_{54}, L_{57} of Fig. 5*d* in a manner well understood in the art.

It is apparent that the band-pass filter of Fig. 5*e* comprises two resonant circuits L_{60}, C_{20} and L_{65}, C_{20} having inductors L_{61} and L_{64} individually coupled therewith by mutual inductance. The filter comprises a series circuit including the inductors L_{61}, L_{64} and a trap circuit with parallel-connected capacitance C_{53} and inductance L_{53} resonant at a frequency below the pass band. The filter also comprises a second trap circuit connected in parallel with inductor L_{61} including series-connected capacitance C_{51} and inductance L_{51} resonant at a frequency above the pass band, whereby a single continuous band of frequencies is caused to be passed by the filter and maximum attenuation is secured at the resonant frequencies of the trap circuits above and below the pass band.

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 confluent band-pass filter effectively comprising, a series of filter half-sections with image-impedance matching at their junctions, each of two adjacent ones of said half-sections having both series- and shunt-reactance arms of which each of two of said arms adjacent their junction includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies within the pass band, a trap circuit included in each of said two adjacent half-sections and removed from said junction by at least one of said adjacent reactance arms and comprising the only other reactance of the half-section, one of said trap circuits comprising a shunt arm of series-connected capacitance and inductance resonant at a frequency on one side of the pass band, and the other of said trap circuits comprising a series arm having parallel-connected capacitance and inductance resonant at a frequency on the other side of the pass band, whereby the matched image impedance at said junction is caused to have opposite extreme values at the upper and lower cut-off frequencies of the pass band and unlike trap circuits are provided in the said two adjacent half-sections.

2. A confluent band-pass filter effectively comprising, a series of filter half-sections with image-impedance matching at their junctions, each of two adjacent ones of said half-sections having both series- and shunt-reactance arms of which each of two of said arms adjacent their junction includes a portion individually of the same reactance-frequency characteristic and of inductive reactance at frequencies in the pass band, a trap circuit included in each of said two adjacent half-sections and removed from said junction by at least one of said adjacent reactance arms and comprising the only other reactance of the half-section, one of said trap circuits comprising a shunt arm of series-connected capacitance and inductance resonant at a frequency above the pass band, and the other of said trap circuits comprising a series arm having parallel-connected capacitance and inductance resonant at a frequency below the pass band, whereby the matched image impedance at said junction is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cut-off frequency of the pass band and unlike trap circuits are provided in the said two adjacent half-sections.

3. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least two includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies within the pass band, and a trap circuit included in one of said reactance arms which is adjacent to one of said pairs of terminals and which comprises the only other reactance of said half-section, said trap circuit being resonant at a frequency outside of the pass band and having a reactance of the opposite kind at frequencies within the pass band, whereby the image impedance at the other of said pair of terminals is caused to have opposite extreme values at the upper and lower cutoff frequencies of the pass band.

4. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least two includes a portion individually having inductive reactance at frequencies in the pass band, and a trap circuit included in one of said reactance arms which is adjacent to one of said pairs of terminals and comprising the only other reactance of said half-section, said trap circuit being resonant at a frequency outside of the pass band and having capacitive reactance at frequencies within the pass band, whereby the image impedance at the other of said pairs of terminals is caused to have a maximum value at the lower cut-off frequency and a minimum value at the upper cutoff frequency of the pass band.

5. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least two includes a portion individually having an inductive reactance at frequencies within the pass band, and a trap circuit comprising a series-connected inductance and capacitance resonant at a frequency above the band and having capacitive reactance at frequencies within the pass band. said trap circuit being included in one of said shunt arms which is adjacent to one of said pairs of terminals and comprising the only other reactance of said half-section. whereby the image impedance at the other of said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

6. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-inductance arms of which one is adjacent to one of said pairs of terminals, and a shunt-reactance arm across the other of said pairs of terminals consisting of a trap circuit comprising a series-connected inductance and capacitance resonant at a frequency above the band, whereby the image impedance at said one of said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

7. A band-pass filter section having input and output pairs of terminals and effectively comprising, two shunt arms each comprising a single inductance connected across a different one of said pairs of terminals, two series arms each including a single inductance, and a shunt arm between said series arms consisting of a trap circuit comprising series-connected inductance and capacitance resonant at a frequency above the pass band, said trap circuit presenting capacitive reactance at frequencies within the pass band.

8. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least two includes a portion individually having an inductive reactance at frequencies in the pass band, and a trap circuit comprising parallel-connected inductance and capacitance resonant at a frequency below said pass band and having capacitive reactance at frequencies within the pass band, said trap circuit being included in one of said series-reactance arms which is adjacent to one of said pairs of terminals and comprising the only other reactance of said half-section, whereby the image impedance at the other of said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

9. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least two includes an inductance, and a trap circuit included in one of said reactance arms which is adjacent to one of said pairs of terminals and comprising the only other reactance of said half-section, said trap circuit being resonant at a frequency outside of the pass band and having capacitive reactance at frequencies in the pass band, whereby the image impedance at the other of said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

10. A band-pass filter section having input and output pairs of terminals and effectively comprising, two shunt-reactance arms each including a single inductance and connected across a different one of said pairs of terminals, a series-reactance arm between said shunt arms including in series an inductance and a trap circuit having parallel-connected inductance and capacitance which is resonant at a frequency below the pass band and which has capacitive reactance at frequencies within the pass band.

11. A band-pass filter half-section having input and output pairs of terminals and effectively comprising, a series arm including inductance, a shunt arm including inductance, and a trap circuit included in one of said arms and comprising the only other reactance of said half-section, said trap circuit being resonant at a frequency outside of the pass band and having capacitive reactance at frequencies within the pass band, whereby the image impedance at the pair of said terminals furthest removed from the arm including said trap circuit is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

12. A band-pass filter section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least three includes a portion individually of the same reactance-frequency characteristic and of a given kind of reactance at frequencies within the pass band, and a trap circuit included in one of said reactance arms which is between two of said three reactance arms and comprising the only other reactance of said filter section, said trap circuit being resonant at a frequency outside of the pass band and having reactance of the opposite kind at frequencies in the pass band, whereby the image impedance at both said pairs of terminals is caused to have opposite extreme values at the respective cutoff frequencies of the pass band.

13. A band-pass filter section having input and output pairs of terminals and comprising, series- and shunt-reactance arms of which each of at least three includes a portion individually having inductive reactance at frequencies within the pass band, and a trap circuit included in one of said reactance arms which is between two of said three reactance arms and comprising the only other reactance of said filter section, said trap circuit being resonant at a frequency outside of the pass band and having capacitive reactance at frequencies within the pass band, whereby the image impedance at both said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

14. A band-pass filter section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least three includes a portion individually having inductive reactance at frequencies within the pass band, and a trap circuit comprising a series-connected inductance and capacitance included in one of said shunt-reactance arms which is between two of said three reactance arms and comprising the only other reactance of said filter section, said trap circuit being resonant at a frequency above the pass band and having capacitive reactance at frequencies within the pass band, whereby the image impedance at both said pairs of terminals is caused to have a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

15. A band-pass filter section having input and output pairs of terminals and effectively comprising, series- and shunt-reactance arms of which each of at least three includes a portion individually having inductive reactance at frequencies within the pass band, and a trap circuit including a parallel-connected inductance and capacitance included in one of said series arms which is between two of said three reactance arms and comprising the only other reactance of said filter section, said trap circuit being resonant at a frequency below the pass band and having capacitive reactance at frequencies within the pass band, whereby the image impedance at both said pairs of terminals is caused to have

a maximum value at the lower cutoff frequency and a minimum value at the upper cutoff frequency of the pass band.

16. A band-pass filter comprising, two resonant circuits each having an inductor coupled therewith by mutual inductance, a series circuit including said inductors and a trap circuit with parallel-connected capacitance and inductance resonant at a frequency below the pass band, and a second trap circuit connected in parallel with one of said inductors including series-connected capacitance and inductance resonant at a frequency above the pass band, whereby a continuous band of frequencies is passed by said filter and maximum attenuation is secured at frequencies above and below the pass band.

17. A confluent band-pass filter comprising, two resonant circuits each having an inductor coupled therewith by mutual inductance, a series circuit including said inductors and a trap circuit with parallel-connected capacitance and inductance resonant at a frequency below the pass band, and a second trap circuit connected in parallel with one of said inductors including series-connected capacitance and inductance resonant at a frequency above the pass band, the reactive constants of the filter being proportioned to pass a single continuous band and to provide a band-pass constant-k form of image impedance at each of said two resonant circuits.

18. A confluent band-pass filter comprising, two parallel-resonant circuits each having an inductor coupled therewith by mutual inductance, a series circuit including said inductors and a trap circuit with parallel-connected capacitance and inductance resonant at a frequency below the pass band, and a second trap circuit connected in parallel with one of said inductors including series-connected capacitance and inductance resonant at a frequency above the pass band, the reactive constants of the filter being proportioned to pass a single continuous band and to provide a band-pass constant-k mid-shunt form of image impedance across each of said two resonant circuits.

19. A band-pass filter comprising, a plurality of series- and shunt-reactance arms, one said shunt arm including a trap circuit with series-connected inductance and capacitance resonant at a frequency on one side of the pass band, and an adjacent series arm including a trap circuit with parallel-connected inductance and capacitance resonant at a frequency on the other side of the pass band, whereby said trap circuits are caused to present reactance of opposite kind at frequencies within the pass band and to give maximum attenuation at frequencies above and below the pass band.

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