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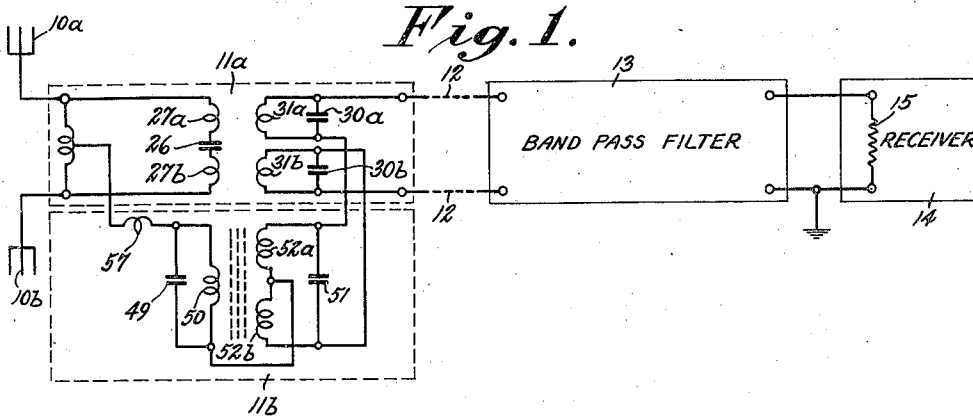
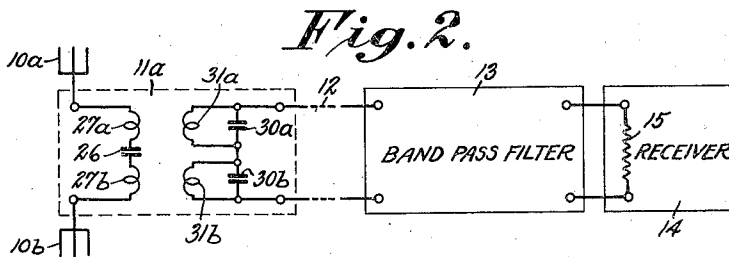
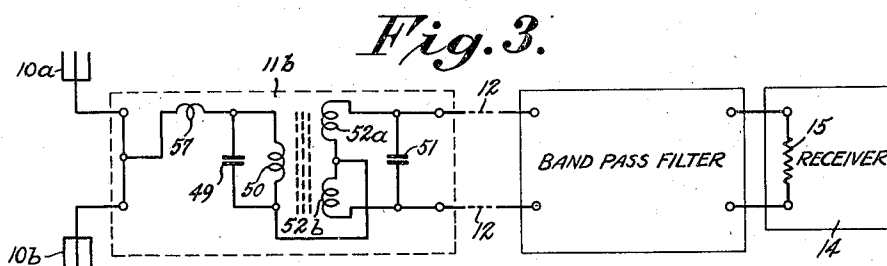
H. A. WHEELER

2,064,775

BAND PASS FILTER

Filed June 10, 1935

3 Sheets-Sheet 1



INVENTOR.

HAROLD A. WHEELER

BY

Lawrence B. Dodds

ATTORNEY.

Dec. 15, 1936.

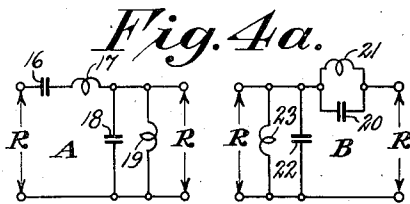
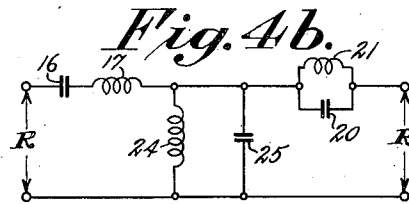
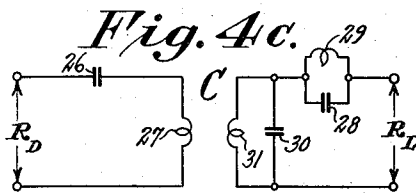
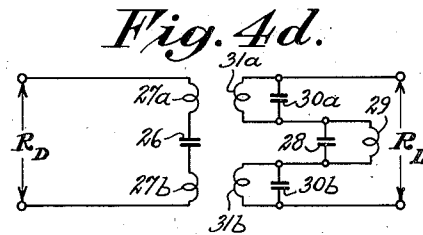
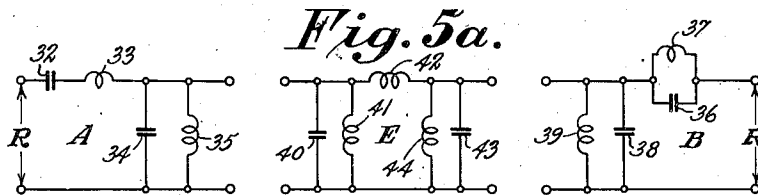
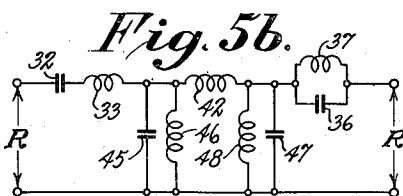
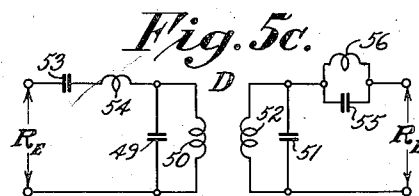
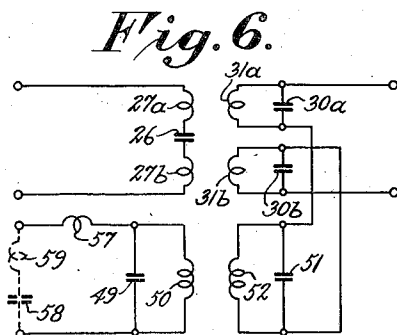
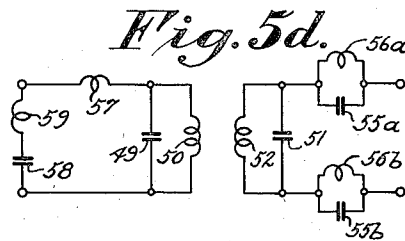
H. A. WHEELER

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BAND PASS FILTER

Filed June 10, 1935

3 Sheets-Sheet 2



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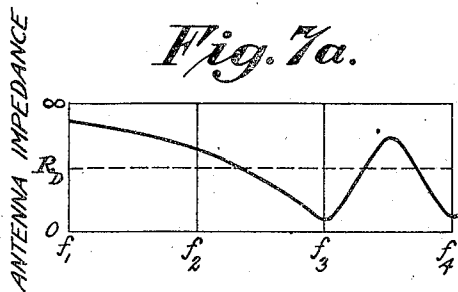
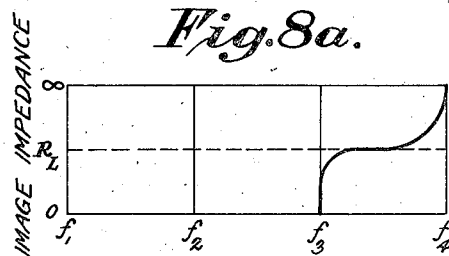
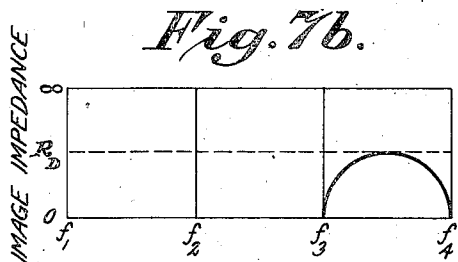
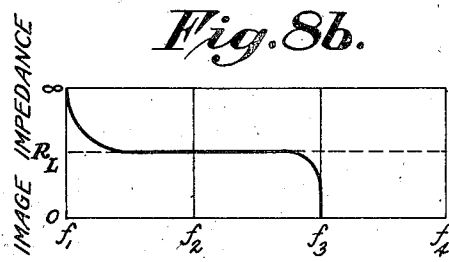
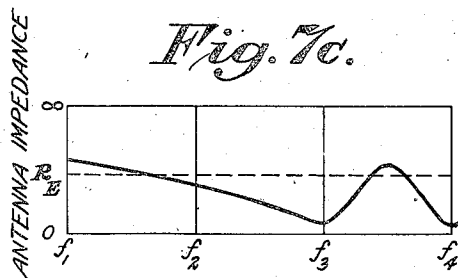
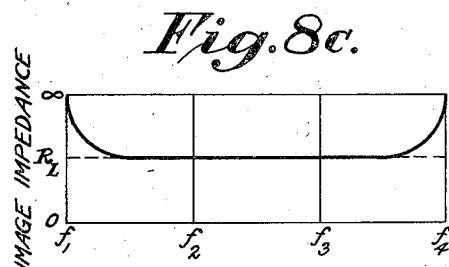
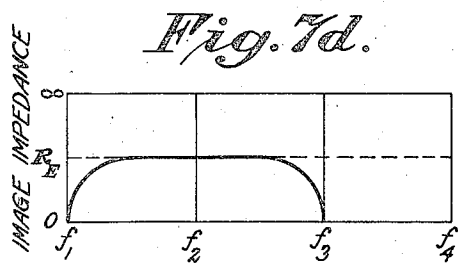
H. A. WHEELER

2,064,775

BAND PASS FILTER

Filed June 10, 1935

3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,064,775

BAND-PASS FILTER

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

Application June 10, 1935, Serial No. 25,736

7 Claims. (Cl. 178-44)

My invention relates to band-pass filters and more particularly to composite filters including a plurality of separate band-pass filters co-operating to pass a more extended band than any of the filters individually.

While my invention is of general application, it is especially suitable for coupling an antenna, adapted to receive or transmit a wide band or a plurality of bands of the radio-frequency spectrum, to a signal-translating circuit.

In many installations, particularly in radio-frequency receiving and transmitting circuits, it is desired to pass a wide band of frequencies, or selectively to pass any of a plurality of frequency bands aggregating a wide portion of the radio-frequency spectrum. However, certain difficulties are presented in the design of a band-pass filter operating between extreme frequency limits, both as to the complexity or number of filter elements required and the actual circuit design and as to the procurement of reasonably uniform responsiveness over the band.

It is an object of my invention, therefore, to provide a composite band-pass filter capable of passing a wide band of frequencies, which will overcome the above-mentioned difficulties of the arrangements of the prior art, and which will require a minimum of circuit elements.

More specifically, it is an object of my invention to provide a composite band-pass filter capable of covering a wide band of frequencies and including a plurality of co-operating band-pass filters designed to pass contiguous or adjacent frequency bands and having an over-all characteristic exhibiting a substantially uniform responsiveness over the entire frequency band.

In accordance with my invention, there are provided two or more band-pass filters, each comprising at least two half-sections of band-pass filters of any of several suitable types. The terminal sections of at least one end of the filters are of such a type and are so proportioned that they may be directly interconnected, as by a series connection, without substantially affecting the operation of either filter over its respective band. The terminal sections of the other end of the filters are of a type and so proportioned that they may be connected in different manners to an input circuit, and these latter sections include impedance elements effective substantially to isolate each input section from the other over its respective band.

For a better understanding of my 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.

In the drawings, Fig. 1 is a schematic diagram of a complete antenna system including a composite band-pass filter employing my invention; Figs. 2 and 3 are approximately equivalent simplified circuit diagrams of the system of Fig. 1 when operating in the short wave and long wave bands, respectively; Figs. 4a-4d are circuit diagrams illustrating the circuit transformations in developing the high-frequency filter component; Figs. 5a-5d are corresponding diagrams for the low-frequency component of the filter of Fig. 1; Fig. 6 is a composite equivalent circuit diagram of the networks of Figs. 4 and 5; Figs. 7a-7d are graphs representing certain operating characteristics of the primary side of the composite band-pass filter of Fig. 1; while Figs. 8a-8c are graphs of certain operating characteristics of the secondary side of the filter of Fig. 1.

Referring now more particularly to Fig. 1, there is shown schematically a wave-signal-collecting system, to which my invention is particularly applicable and in which the invention is embodied as a composite filter for coupling an antenna, for operation over an extended frequency band or a plurality of individual frequency bands, to a signal-translating or load device, such as a radio receiver, either directly, or indirectly by means of a transmission line. The general system of Fig. 1 is disclosed and claimed in my co-pending application Serial No. 25,735, filed June 10, 1935, so that a detailed description thereof is considered unnecessary.

In general, the system includes an antenna 10a-10b, preferably designed as a doublet for operation in the high-frequency portion of the band to be covered but including connections for converting it into a flat-top antenna for operation over the low-frequency band. The antenna 10a-10b is coupled to a transmission line 12 by a high-band filter 11a for balanced operation of both the doublet antenna and the line over a high-frequency band which may, for example, extend from 6 to 18 megacycles. Similarly, the low-band filter 11b couples the antenna, for unbalanced operation as a flat-top antenna, with the balanced line, for operation over a low-frequency band, for example, of 0.55 to 6 megacycles. The two filters are uncoupled on the antenna side because of the balanced and unbalanced operation of the antenna over the high- and low-frequency bands, respectively. They are joined together on the line side and

their operation is interdependent at frequencies in the neighborhood of the dividing frequency, for example, 6 megacycles. The two filters 11a, 11b are designed independently and then combined, as will be explained more fully hereinafter.

The other end of the line 12 is coupled by a band-pass filter 13, which may be of any of several types well-known in the art, to a signal-translating or load device 14 having an input circuit the impedance of which is represented at 15. One type of composite extended-band-pass filter particularly suitable for this purpose is disclosed and claimed in my copending application, Serial No. 25,737, filed June 10, 1935.

It is desired that the composite filter shall match the impedance of the doublet antenna to the constant image impedance of the line over the high-frequency range of operation, and that it shall connect the antenna as a flat-top antenna and match its impedance to that of the line over the low-frequency portion of the operating band. It is also desirable that the composite filter circuit shall include a transformer section which avoids direct connections between the primary and secondary circuits of the filter and permits impedance transformation. The impedance of the antenna 10a—10b, operating as a doublet, is shown in Fig. 7a, in which a value of impedance somewhat greater than the geometric mean of the antenna impedance over the high-frequency band is indicated by the value R_0 .

For the purpose of explanation, the characteristic of Fig. 7a is divided into portions separated by the frequencies f_1, f_2, f_3, f_4 , which arbitrarily divide the entire frequency band to be covered into three component bands. For example, f_1, f_2, f_3 and f_4 may have approximately the values 0.55, 1.8, 6 and 18 megacycles, respectively. With respect to the antenna filter circuits 11a, 11b, the lower frequency band is from f_1 — f_3 , while the upper frequency band is from f_3 — f_4 .

The antenna impedance, as shown in Fig. 7a, over the band f_3 — f_4 is approximated by the image impedance of a constant- k half-section with mid-series termination facing the doublet antenna. (For a more complete description of the several types of band-pass filter sections utilized in the preferred embodiment of this invention and discussed herein, reference is made to a textbook of T. E. Shea—Transmission Networks and Wave Filters, D. Van Nostrand Co., 1929.)

It has become common practice in the design of band-pass filters to make certain of the computations on the basis of a constant- k filter half-section of a standard type, which is adopted as a conventional reference standard and in terms of which the formulas for some of the other types are derived and expressed, even though, in certain instances, sections of this standard type are not actually included in the resultant filter. It is also customary to base the preliminary computations on an arbitrary value for the image impedance at each junction of the sections or half-sections. For the type generally used as a standard, the input and output image impedances have the same value at the frequency for which the slope of their characteristic curves is zero. This value is indicated by the symbol R , which may be taken as 100 ohms, for example, for the purposes of computation. Such a filter section will be referred to hereinafter as type A. (This type is referred to at page 315 of the Shea reference as type IV_K.)

In Fig. 4a is illustrated a constant- k filter half-

section of type A, just described, indicated at A. This filter half-section comprises a mid-series condenser 16 and inductance 17 and mid-shunt condenser 18 and inductance 19. Such a half-section permits the insertion of a transformer since it includes both series and parallel inductances, which may be realized by a transformer in an equivalent network. In computing the circuit constants of the section A, it will be assumed that it is to be designed for equal values of R of 100 ohms at both input and output terminals. The values of the circuit reactances may then be computed, in terms of R and the boundary frequencies of the band which the filter is to pass, from the formulas given by Shea for the IV_K type on page 316. These formulas are for the so-called "full-series" and "full-shunt" arms and must be modified in the well-known manner for computation of the "mid-series" or "mid-shunt" arms employed at the input and output terminals of a filter. Alternatively, the circuit constants may be computed by such formulas as modified for a half-section (the mid-series termination reactance one-half the full-series reactance; the mid-shunt termination reactance twice the full-shunt reactance), and for the particular boundary frequencies, as given in the appended table of formulas for the type A filter section of Fig. 4a.

In order to connect adjacent band filters together at one end to form a composite filter, it is desirable to include at that end of each component filter a half-section terminated in a mid-series reactance arm for which may be substituted reactance elements of the other adjacent band filter. There is represented at B, Fig. 4a, a type of half-section filter by which these characteristics can be procured. The filter half-section B includes the parallel-connected mid-series condenser 20 and inductance 21 and mid-shunt condenser 22 and inductance 23. In this type of filter, for the purposes herein described, the values of the mid-series elements 20, 21 are not critical and these elements can be replaced by reactance elements forming a part of, and critically proportioned for, a band filter designed for an adjacent band, without substantially affecting the operation of this type of filter. The filter half-section B has at its left-hand terminals a constant- k mid-shunt image impedance similar in form to that at the right-hand end of the filter section A, so that if these two image impedances are made equal, the two sections may be directly interconnected. The circuit constants of the filter section B may be computed by assuming for R the same value as for the section A, for example, 100 ohms, and by using the formulas given by Shea for filter sections of the same type or by such formulas modified for a half-section and for the particular boundary frequencies of this case, as given in the appended table for type B of Fig. 4a.

It will be noted that the formulas for the circuit constants of the type B filter section are in terms of the parameters m_1 and m_2 . Theoretically, the larger of the parameters m_1 and m_2 is a function of the cut-off frequencies of the filter and the frequency of infinite attenuation. For the purposes of this application, however, the larger of the values m_1 and m_2 is chosen rather to secure the desired shape of the mid-series image impedance characteristic and to determine the approximation of the major portion of this characteristic to a level value. These parameters have no effect on the cut-off frequencies

of the filter. In the designing of a type B filter for the higher of two adjacent bands (of the type IV₄ in Shea), the parameter m_2 is the greater, while in the case of a type B filter for the lower of two adjacent bands (type IV₃ in Shea), m_1 is the greater. In either case the value of the greater parameter m lies within the limits of about 0.25 to 0.75, generally ranging from about 0.3 for filters designed to pass a relatively narrow band, to about 0.6 for filters designed to pass a relatively wide band. For filters of this type and for the ranges described in this application, a value of m on the order of 0.4 to 0.5 has been found to be the optimum.

By the use of well-known equivalent circuit transformations, the half-sections A and B of Fig. 4a can be combined into the high-band filter 11a of Fig. 1. For example, the adjacent terminals of the sections A and B may be interconnected, and the condensers 18 and 22 combined into a single condenser 25 and the inductances 19 and 23, into a single inductance 24, since these elements are all connected in parallel. This transformation is shown in Fig. 4b. Similarly, it is well-known that the inverted-L connection of inductances 17 and 24 of Fig. 4b is the equivalent of a transformer in which the inductances 17 and 24 provide the self-inductance of the primary circuit, and the inductance 24 provides the mutual inductance and the self-inductance of the secondary circuit, in this case the two latter inductances being of equal value. The result of this transformation is the circuit of Fig. 4c, in which the inductances 27 and 31 are proportioned as just described.

In the computation of the values of the circuit reactances of the circuit of Fig. 4c, however, it is necessary to multiply all of the reactances of the primary circuit by the ratio of the nominal antenna impedance R_0 to the assumed image impedance R . The maximum image impedance of the filter at the antenna end will then have the value R_0 , as indicated in Fig. 7b, which, as stated above, is somewhat greater than the mean value of the antenna impedance over the band, so that the image impedance of the line reasonably approximates the antenna impedance over the band. Similarly, in order to match the secondary circuit to the line 12, it is necessary to multiply the circuit reactances of the secondary circuit by the ratio of the image impedance of the line 12, R_L , to the assumed image impedance R . The formulas for the circuit constants of the circuit of Fig. 4c, referred to hereinafter as a type C filter section, including the circuit transformations and the factors for the matching of the primary and secondary impedances, are given in the formula for type C of Fig. 4c, in the appended table. The formulas for type C filters may be derived from the formulas for types A and B by well-known algebraic transformations.

The circuit of Fig. 4c may be rearranged as shown in Fig. 4d, for balanced operation, by giving to the inductances 27a and 27b a combined value equal to that of the inductance 27 and, similarly, by dividing the condenser 30 and inductance 31 into two portions represented by the elements 30a, 31a and 30b, 31b. In general, the inductances 27a, 27b will not each have a value half that of the inductance 27, nor the inductances 31a, 31b, half that of the inductance 31, because of the mutual inductance between corresponding portions.

Similarly, the component band-pass filter 11b, for operation over the low-frequency band, for

example, 0.55-6 megacycles, may be designed to couple the antenna 10a-10b, operating as a simple, unbalanced, flat-top antenna, to the balanced transmission line 12 and to match the impedances of the antenna and line over the low-frequency band. The antenna characteristic impedance over this band is shown in Fig. 7c.

The design of the component low-band filter 11b is approached from the same standpoint as that of the high-band filter described above. Referring to Fig. 5a, the starting point is again a standard filter half-section of type A having a constant- k image impedance of nominal value R , for example, 100 ohms. The half-section A of Fig. 5a comprises a mid-series condenser 32 and inductance 33, and a mid-shunt condenser 34 and inductance 35. The formulas for the circuit constants of the half-section A of Fig. 5a are given in the appended table, Fig. 5a, type A. It is seen that these formulas are identical with those for computing the type A half-section of Fig. 4a, with the exception of the boundary frequencies.

The considerations which govern the selection of the right-hand type B half-section of Fig. 4a are similarly applicable to the selection of the right-hand type B half-section of the low-band filter 11b. As shown in Fig. 5a, the type B section is similar to the type B section of Fig. 4a, and comprises the parallel-connected mid-series condenser 36 and inductance 37, and the mid-shunt condenser 38 and inductance 39. The only difference between the type B half-section of Fig. 5a and that of Fig. 4a is that in the type B the parameter m_1 is greater than m_2 , while in the latter m_2 is greater than m_1 (parameter m_1 is greater or less than m_2 , depending on whether the natural frequency of the mid-shunt elements is greater or less than that of the mid-series elements). The formulas for the type B half-section of Fig. 5a are given in the appended table under this heading.

While the sections A and B of Fig. 5a could be merged directly into an equivalent network including a transformer section, as was done in the case of the high-band filter, for the particular operating frequencies and circuit characteristics disclosed herein, this transformer would require a coefficient of coupling very close to unity in order to cover the entire low-frequency band f_1-f_2 . This requirement may be made less severe by the addition of a transformer filter section such as the section E of Fig. 5a. The half-sections A and B both have constant- k mid-shunt image impedances and can, therefore, be properly joined by the symmetrical section E. This section comprises a mid-shunt condenser 40 and inductance 41, a series inductance 42 and a mid-shunt condenser 43, and inductance 44. The formulas for computing the circuit constants of the type E section of Fig. 5a are given in the appended table.

The components A, B and E of Fig. 5a can be merged into their electrical equivalents, as indicated in Figs. 5b, 5c and 5d. In Fig. 5b the mid-shunt condensers 34 and 40 are combined into the single condenser 45, the mid-shunt inductances 35 and 41 into the inductance 46, the mid-shunt condensers 38 and 43 into the condenser 47, and the mid-shunt inductances 39 and 44 into the inductance 48. It is seen that the inductances 46, 42 and 48 comprise a pi-section which may be replaced by an equivalent transformer. Such a transformation is shown in Fig. 5c, in which these inductances are converted into a transformer comprising inductances 50 and 52. The trans-

former 50—52 is effective to match the impedances of the antenna and the line over the low-frequency band f_1 — f_3 . The circuit of Fig. 5c is also modified in that the values of the reactance elements of its primary circuit are multiplied by such a factor that the condenser 53 has a capacitance equal to that of the flat-top antenna, effective at the lowest frequency f_1 . The nominal value of the antenna impedance and the image impedance of the antenna end of the filter of Fig. 5c is then determined by multiplying the assumed nominal image impedance R by the ratio of the capacitance of the condenser 53 to that of condenser 32. The image impedance characteristic of the antenna end of the filter of Fig. 5c is shown in Fig. 7d, in which the nominal value R_R is seen to be slightly greater than the mean antenna impedance over the band f_1 — f_3 , as shown in Fig. 7c.

The circuit of Fig. 5c is modified to that of Fig. 5d in order that the secondary circuit may operate into a balanced line. To this end the mid-series condenser 55 and inductance 56 are each divided into equal parts represented by the condensers 55a and 55b and the inductances 56a and 56b of Fig. 5d. In Fig. 5d is shown also a modification of the primary circuit of Fig. 5c, in which the capacitance 58, representing the value of antenna capacitance effective at the lowest frequency f_1 , is substituted for the mid-series condenser 53, and in which the inductance 59, representing the inductance required to tune with capacitance 58 to the fundamental frequency f_3 of the antenna, is substituted for a portion of the mid-series inductance 54 of Fig. 5c. The inductance 57, thus, represents the difference between the inductance 54 and the inductance 59.

The formulas for computing the equivalent filter circuit of Fig. 5c, which is referred to hereinafter as type D, are given in the appended table. These formulas are derived from the formulas for sections A, B and E of Fig. 5a, taking into consideration the circuit transformations and multiplying the primary circuit reactances by the ratio of the nominal antenna impedance R_R to the assumed nominal image impedance R and by multiplying the secondary circuit reactances by the ratio of the image impedance of the line R_L to the assumed nominal image impedance R of the section B of Fig. 5a.

It is seen that the arrangement of Fig. 5d is the equivalent of a filter section with constant- k mid-series termination on short circuit. As indicated in Fig. 7d, the image impedance of this arrangement is zero at the cut-off frequencies, so that the cut-off frequencies of the circuit are not affected by the short-circuit and the filter properties of the circuit are not destroyed.

In Fig. 6 is shown the combination of the high-band filter of Fig. 4d and the low-band filter of Fig. 5d. The primary circuits are unchanged, but the secondary circuits are combined in a particular manner. The mid-series elements 28 and 29 of Fig. 4d are replaced by elements 51 and 52, respectively, of the low-band filter, as shown in Fig. 6, while the mid-series elements 55a, 56a, 55b, 56b of the low-band filter are replaced by the elements 30a, 31a, 30b, 36b, respectively, of the high-band filter. In other words, each filter circuit proper operates as a mid-series reactance arm for the other filter. While the circuit constants of each of the filters may not be ideal for terminating the other, the values of these terminating reactances are not critical, so that these

constants may be selected primarily to satisfy the design of their respective filter sections, and the response of the filters over their respective bands will be satisfactory, while the cut-off frequencies will be unaltered.

The image impedance characteristic of the type B filter section of Fig. 4a is shown in Fig. 8a. The right-hand portion of this characteristic, near the upper cut-off frequency f_4 , has the gradual curvature characteristic of a constant- k mid-shunt image impedance. The curvature at the lower cut-off frequency f_3 , however, is considerably more abrupt than that of a constant- k section and is characteristic of the mid-series termination of the type B filter. Similarly, the image impedance characteristic of the type B section of Fig. 5a is shown in Fig. 8b. It is seen that these two filter characteristics are substantially complementary for the entire band f_1 — f_4 . The effect of connecting together the high- and low-band filters at the terminals of the line 12, as shown in Fig. 6, is to merge the image impedance curves of the two filters into a single curve substantially continuous over the band f_1 — f_4 , as shown in Fig. 8c. The characteristic of Fig. 8c is similar to that of a continuous band filter with constant- k mid-shunt termination, but the composite filter just described secures this characteristic by the merging of two separate adjacent band filters at one end.

The type B filter is fundamentally characterized by having only one frequency of infinite attenuation in an adjacent band and none outside of the composite band. This frequency of infinite attenuation is the natural frequency of the mid-series reactance arm comprising the parallel resonant circuit. For the purposes described herein, the values of the mid-series reactance elements are not critical, so that an adjacent band filter may be substituted therefor, as described above. This characteristic of a frequency of infinite attenuation in only one adjacent band is fundamentally associated with the above-described properties of the mid-series image impedance of this type of filter, as shown in Figs. 8a and 8b. These properties enable two band-pass filters designed for adjacent frequency bands to be combined into a composite filter having a resultant image impedance characteristic as shown in Fig. 8c.

It will be seen that the derived circuit of Fig. 6 is equivalent to that comprising the high-band and low-band filters 11a—11b of Fig. 1, the input terminals of the high-band filter being connected to the terminals of the doublet antenna, which are interconnected through an inductance 64. The input terminals of the low-band filter are connected, respectively, to the mid-point of the inductance 64 and to the junction of coils 52a and 52b, into which the coil 52 of Fig. 6 is divided to provide a ground connection through the line for the antenna 10a—10b when operating as a simple flat-top antenna in the low-frequency band. As an alternative this latter connection may be independently grounded, preferably in the immediate neighborhood of the antenna, as directly underneath. The transformer comprising the windings 50, 52a and 52b of the low-band filter preferably is provided with a core of finely divided iron.

It is believed that the general principles of operation of the above-described system will be clear from the foregoing detailed description of the circuit arrangements and the principles involved in its design. However, the operation in 75

the two frequency bands may be summarized by reference to Figs. 2 and 3, which include only the circuit elements primarily active in the high-frequency and low-frequency bands, respectively.

It will be clear that, at the higher frequencies of the high band, the inductance 64 and certain of the inductances of the low-band filter 11b have such a high impedance that their admittance may be neglected, while the condensers of this filter have such a low reactance that they may be considered as short circuits. Similarly, at the lower frequencies of the low band, the reactance elements of the high-band filter may be neglected. Thus, the primary circuits of the two filters effectively have separate input circuits of different impedances, even though they are connected in a conjugate manner to the same antenna structure.

Referring specifically to Fig. 2, the antenna 10a—10b operates as a balanced doublet and the high-band filter 11a is effective to couple the balanced antenna currents to the balanced line 12 as balanced circulating currents therein, at the same time approximately matching the impedance of the doublet antenna with that of the line over the high-frequency band f_3 — f_4 . The circulating currents in the line 12 are coupled by the filter 13 to induce unbalanced currents in the input circuit 15 of the receiver 14.

When operating in the low-frequency band, as illustrated in Fig. 3, the low-band filter 11b serves to couple the unbalanced currents of the antenna 10a—10b, operating as a simple flat-top antenna, as balanced circulating currents in the line 12. The filter 13 similarly couples the balanced circulating currents of the line 12 into the unbalanced input circuit 15 of the device 14. In this band the line 12 may serve also as a ground lead for the simple antenna, the connection being made at the junction between coils 52a and 52b so that the unbalanced ground currents flow in parallel through the conductors 12.

While the filter sections of my invention have been described with reference to primary or input circuits and secondary or output circuits, it will be clear that these designations are by way of illustration only, and that power may be transferred through the filters in either direction, so that either end may be considered as the "input" or "output" circuit.

While the composite band filter above-described may be designed for operation over a wide range of conditions, there are given herewith, by way of example only, the circuit constants of a particular composite filter embodying my invention in the form described above. The following circuit values were realized as closely as possible and include such effects as inherent capacitance or inductance of other related circuit elements:

System

$f_1=0.55$ megacycle
 $f_2=1.3$ megacycles
 $f_3=6$ megacycles
 $f_4=13$ megacycles

Composite filter

$R_D=500$ ohms

$R_L=1080$ ohms

Element 64=45 microhenries

27a+27b=9.8 microhenries

31a+31b=5.6 microhenries

57=32 microhenries

59=225 microhenries

52a+52b=124 microhenries

58=3 microhenries

26=44.2 micro-microfarads

30a, 30b=63 micro-microfarads each

49=59 micro-microfarads

51=98 micro-microfarads

58=240 micro-microfarads

Transformer 27a, 27b, 31a, 31b

Coefficient of coupling=67.3%

Transformer 58, 29a, 29b

Coefficient of coupling=89.3%

While I have described what I at present consider the preferred embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from my invention, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

TABLE OF DESIGN FORMULAS

FIGURE 4a

Type A	Type B
$C_{10} = \frac{f_4 - f_3}{2\pi f_3 f_4 R}$	$C_{20} = \frac{1 - m_1^2}{m_1} C_{10}$
$L_{17} = \frac{R}{2\pi(f_4 - f_3)}$	$L_{21} = \frac{m_2}{1 - m_2^2} L_{10}$
$C_{18} = \frac{1}{2\pi(f_4 - f_3)R}$	$C_{22} = m_1 C_{18}$
$L_{19} = \frac{(f_4 - f_3)R}{2\pi f_3 f_4}$	$L_{23} = \frac{L_{19}}{m_2}$
	$m_1 = \frac{f_3}{f_4} m_2$
	$m_2 < 1$

FIGURE 4b

Type C	
$C_{26} = C_{10} \frac{R}{R_D}$	$k_{27-31} = \frac{1}{\sqrt{1 + (1 + m_2) \frac{L_{17}}{L_{10}}}}$
$L_{27} = \left(L_{17} + \frac{L_{19}}{1 + m_2} \right) \frac{R_D}{R}$	$m_1 = \frac{f_3}{f_4} m_2$
$C_{30} = (1 + m_1) C_{18} \frac{R}{R_L}$	$m_2 < 1$
$L_{31} = \frac{L_{19}}{1 + m_2} \frac{R_L}{R}$	

FIGURE 5a

Type A	Type E	Type B
$C_{33} = \frac{f_2 - f_1}{2\pi f_1 f_2 R}$	$L_{42} = \frac{2m}{1 - m^2} L_{35}$	$C_{45} = \frac{1 - m_1^2}{m_1} C_{44}$
$L_{43} = \frac{R}{2\pi(f_2 - f_1)}$	$C_{40} = C_{43} = C_{34}$	$L_{47} = \frac{m_2}{1 - m_2^2} L_{45}$
$C_{44} = \frac{1}{2\pi(f_2 - f_1)R}$	$L_{41} = L_{44} = \frac{L_{35}}{m}$	$C_{38} = m_1 C_{44}$
$L_{45} = \frac{(f_2 - f_1)R}{2\pi f_1 f_2}$	$m = \frac{f_1}{f_2}$	$L_{40} = \frac{L_{35}}{m_2}$
		$m_1 < 1$
		$m_2 = \frac{f_1}{f_2} m_1$

FIGURE 5o

Type D

$$\begin{aligned}
 R_F &= R \frac{C_{32}}{C_{31}} \\
 L_{34} &= L_{31} \frac{R_F}{R} \\
 C_{45} &= 2C_{34} \frac{R}{R_F} \\
 L_{56} &= \frac{1+m^2+2mm_2}{(1+m)^2(1+m_2)} L_{35} \frac{R_F}{R} \\
 L_{52} &= \frac{L_{45}}{1+m_2} \frac{R_L}{R} \\
 C_{51} &= (1+m_1) C_{44} \frac{R}{R_L} \\
 k_{50-52} &= \frac{1-m}{\sqrt{1+m^2+2mm_2}} \\
 m_1 &< 1 \\
 m_2 &= \frac{f_1}{f_3} m_1 \\
 m &= \frac{f_1}{f_3}
 \end{aligned}$$

What I claim is:

1. A composite band-pass filter comprising a plurality of individual band-pass filters passing respectively a series of contiguous frequency bands and connected at one end to a common terminal circuit, each of said filters being terminated at said end in a half-section of a type characterized by a constant- k image impedance at its non-terminal end and by one frequency of infinite attenuation in only each adjacent one of said bands, each of said half-sections normally including a reactance arm at its terminal end resonant at each of its respective frequencies of infinite attenuation, each said reactance arm being replaced by reactance elements of the filter passing the band including its resonant frequency, and said filters being relatively proportioned to present across said terminal circuit a resultant image impedance approximating that of a constant- k continuous-band filter passing the band comprising said contiguous bands.

2. A composite band-pass filter comprising a plurality of individual band-pass filters passing respectively a series of contiguous frequency bands and connected at one end to a common terminal circuit, each of said filters being terminated at said end in a half-section of a type characterized by a constant- k image impedance at its non-terminal end and by one frequency of infinite attenuation in only each adjacent one of said bands, each of said half-sections normally including a reactance arm at its terminal end resonant at each of its respective frequencies of infinite attenuation, each said reactance arm being replaced by reactance elements of the filter passing the band including its resonant frequency, each of the terminal half-sections of the filters passing the two extreme frequency bands being of type B and proportioned substantially in accordance with the type B formulas, the two corresponding frequencies of infinite attenuation being each predetermined to give a value within the range 0.25-0.75 for the greater of m_1 and m_2 in the said formulas, and said filters being relatively proportioned to present across said terminal circuit a resultant image impedance approximating that of a constant- k continuous-band filter passing the band comprising said contiguous bands.

3. A composite band-pass filter comprising a plurality of individual band-pass filters passing respectively a series of contiguous frequency bands and connected at one end to a common terminal circuit, each of said filters being terminated at said end in a half-section of a type characterized by a constant- k image impedance at its non-terminal end and by one frequency of infinite attenuation in only each adjacent one of said bands, each of said half-sections normally

including a reactance arm at its terminal end resonant at each of its respective said frequencies of infinite attenuation, each said reactance arm being replaced by reactance elements of the filter passing the band including its resonant frequency, each of the terminal half-sections of the filters passing the two extreme frequency bands being of type B and proportioned substantially in accordance with the type B formulas, the two corresponding frequencies of infinite attenuation being each predetermined to give a value on the order of 0.4 to 0.5 for the greater of m_1 and m_2 in the said formulas, and said filters being relatively proportioned to present across said terminal circuit a resultant image impedance approximating that of a constant- k continuous-band filter passing the band comprising said contiguous bands.

4. A composite band-pass filter comprising a plurality of input circuits of different impedances and a common output circuit, a plurality of individual band-pass filters passing respectively a series of contiguous frequency bands and connected to said common output circuit, each of said filters being terminated at said common end in a half-section of a type characterized by one frequency of infinite attenuation in only each adjacent one of said bands and normally including a reactance arm at its terminal end resonant at each of its respective frequencies of infinite attenuation, each said reactance arm being replaced by reactance elements of the filter passing the adjacent band including its resonant frequency, each of said filters including also one or more impedance matching filter half-sections interconnecting its respective input circuit and said first-named half-section, adjacent half-sections of each filter having at their connecting terminals substantially equal constant- k image impedances, and said filters being relatively proportioned to present across said output circuit a resultant image impedance approximating that of a constant- k continuous-band filter passing the band comprising said contiguous bands.

5. A composite band-pass filter comprising a plurality of input circuits of different impedances and a common output circuit, a plurality of individual band-pass filters passing respectively a series of contiguous frequency bands and connected to said common output circuit, each of said filters being terminated at said common end in a half-section of type B and proportioned according to formulas of type B, each of said filters including also one or more impedance matching filter half-sections interconnecting its respective input circuit and its first-named half-section, adjacent half-sections of each filter having at their connecting terminals substantially equal constant- k image impedances, and said filter half-sections adjacent said input circuits being of the type A and being proportioned according to formulas of type A, whereby said filters present across said output circuit a resultant image impedance approximating that of a constant- k continuous-band filter passing the band comprising said contiguous bands.

6. A composite band-pass filter comprising a pair of input circuits of different impedances and a common output circuit, a pair of individual band-pass filters passing respectively high and low contiguous frequency bands and connected to said common output circuit, each of said filters being terminated at said common end in an equivalent half-section, each of said filters normally including a reactance arm at its terminal end resonant at a frequency of infinite attenua-

tion, each said reactance arm being replaced by reactance elements of the other filter, each of said filters including also one or more impedance matching equivalent half-sections interconnecting its respective input circuit and its first-named half-section, the equivalent half-sections of each filter being combined to form composite filter sections for the high and low bands of the types C and D, respectively, and proportioned according to the formulas of types C and D, respectively.

7. A composite band-pass filter comprising a pair of individual band-pass filters passing respectively two contiguous frequency bands and connected at one end to a common terminal circuit, each of said filters including a transformer provided with primary and secondary windings,

a transformer winding of the higher band filter being divided into sections with the corresponding winding of the lower band filter being interposed therebetween, condensers connected individually across each of said higher band winding sections and across said lower band winding, whereby said higher band filter constitutes terminal reactance arms for said lower band filter, and the lower band filter constitutes the equivalent of a terminal reactance arm for said higher band filter, said transformer windings and associated condensers being proportioned to approximate a constant- k mid-shunt image impedance of a continuous-band filter over said contiguous bands.

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