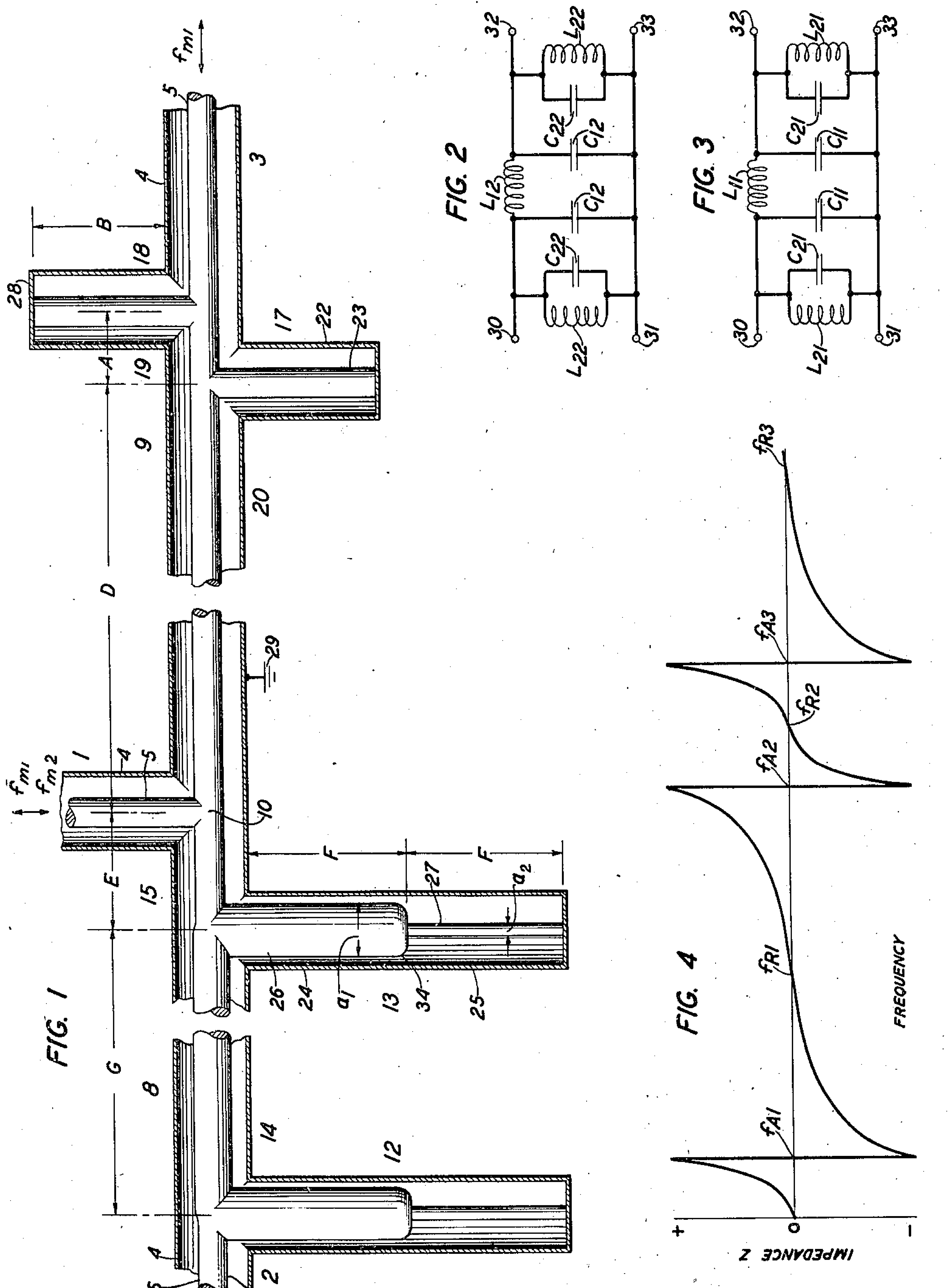
May 27, 1947. W. P. MASON 2,421,033

WAVE TRANSMISSION NETWORK

Filed May 15, 1943



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Patented May 27, 1947

2,421,033

UNITED STATES PATENT OFFICE

2,421,033

WAVE TRANSMISSION NETWORK

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Application May 15, 1943, Serial No. 487,081

16 Claims. (Cl. 178—44)

1

This invention relates to wave transmission networks and more particularly to branching circuits comprising two parallel-connected wave filters made up of sections of transmission line for combining or separating two different bands of frequencies.

The principal object of the invention is to place upon a common transmission line simultaneously two bands of frequencies from different sources or to separate into individual channels two bands simultaneously transmitted by one line.

Other objects are to broaden the transmission bands, sharpen the cut-offs and increase the transmission efficiency of the individual channels and increase the discrimination between channels.

When a transmission line is to be supplied with two bands of frequencies from different sources or when signals on a line are to be separated into individual channels on a frequency basis a branching circuit is required. Often it is desired that the channels be capable of transmitting efficiently comparatively wide bands, with sharp cut-offs. High discrimination between channels is also often desirable. Always there is the requirement that the presence of one channel does not decrease unduly the transmission efficiency of the other channel. Simplicity in mechanical structure is also of importance in cost reduction.

The present invention provides a branching circuit which fulfills the above requirements in a compact, fully shielded structure especially adapted for use in the higher frequency ranges of the order of hundreds of megacycles. The circuit comprises two wave filters connected to the common transmission line in parallel. The filters are of the ladder type, are shunt terminated and each comprises one or more sections. The filters may be designed to transmit substantially any desired width of band. The discrimination between channels may be increased to any required amount by adding sections. The image impedances of the filters are chosen to match the impedance of the terminal loads with which they are associated. The component impedance elements used in the filters are sections of transmission line. Such elements have low dissipation and therefore provide high transmission efficiency within the band and sharp cut-offs. If coaxial line is used for the sections the outer conductors may be grounded, thereby providing almost perfect shielding for the structure.

In order that the two filters may operate in parallel without adversely affecting the transmission efficiency, it is necessary that, at the paralleled end, each filter have a high input impedance over the band of the other. Special arrangements are provided to accomplish this. The terminating shunt branch at the paralleled end of the higher frequency filter is a section of transmission line short-circuited at its distant end. The filter also has at this end a building-out section of line the length and characteristic impedance of which are chosen to provide at the junction of the filters a high shunting impedance over the band of the other filter. One way of accomplishing this is to make the building-out section and the shunt branch of the same characteristic impedance and with a combined length approximately equal to an odd multiple of a quarter wavelength at the mid-band frequency of the other filter. The terminating shunt branch at the paralleled end of the lower frequency filter is made up of two tandem-connected sections of line having different characteristic impedances proportioned to provide an antiresonance at the mid-band frequency of that filter and a resonance at the mid-band frequency of the other filter. For ease of computation the two sections may be made of the same length and the second section may be short-circuited at its distant end. An impedance-inverting section of line, having a length approximately equal to an odd multiple of a quarter wavelength at the mid-band frequency of the higher frequency filter, is added at the paralleled end of the lower frequency filter to provide at the junction of the filters a high shunting impedance over the band of the higher frequency filter.

If either the band widths or the mid-band frequencies of the two channels may be chosen at will the outer conductors of all of the component coaxial elements used in the filters may be made of the same diameter, thus considerably simplifying the mechanical structure and reducing the cost.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a longitudinal cross-sectional view, with parts of two sections removed, of a two-channel branching circuit in accordance with the invention;

Figs. 2 and 3 show equivalent electrical circuits for the filters used in the arrangement of Fig. 1; and

Fig. 4 gives the impedance-frequency characteristic of the shunt branches of the lower frequency filter.

In Fig. 1 a common transmission line 1 branches into two channels 2 and 3. All of these lines may, for example, be of the coaxial type, comprising a hollow cylindrical outer conductor 4 and concentric therewith an inner conductor 5 which may be either solid or hollow. The channels 2 and 3 may be supplied from separate sources with bands of signals having mid-band frequencies of f_{m1} and f_{m2}, respectively, which are combined in the common line 1, or the line 1 may carry the two bands which are to be separated into the individual channels 2 and 3, as indicated by the double-pointed arrows. The combining or separating is accomplished by means of the two band-pass wave filters 8 and 9 which are connected in parallel to the line 1 at the junction point 10.

The filters 8 and 9 are of the ladder type, comprising shunt impedance branches and interposed series impedance branches, and are shunt-terminated at each end. The filter 8, shown as a single-section structure, comprises two identical shunt branches 12 and 13, an interposed series branch 14 and an impedance-inverting section of line 15 connected between the shunt branch 13 and the junction point 10. The filter 9, also shown as a single-section structure, comprises two identical shunt branches 17 and 18, an interposed series branch 19 and a building-out section of line 20 connected between the branch 17 and the junction 10. The discrimination between the channels 2 and 3 may, of course, be increased to any required extent simply by adding more sections to the filters 8 and 9. All of the component impedance branches of the filters are formed by sections of transmission line. As shown, these are of the coaxial type. The branch 17, for example, has a cylindrical outer conductor 22 and concentric therewith an inner conductor 23. Each of the shunt branches 12 and 13 of the filter 8 is constituted by two sections of line 24 and 25, having inner conductors 26 and 27, connected in tandem. Each of the shunt branches 12, 13, 17 and 18 is short-circuited at its distant end as, for example, by the conductive end plate 28 on the branch 18. The use of coaxial line sections has the advantage that the outer conductors may all be grounded, or otherwise fixed in potential, as shown at 29, thus providing substantially perfect shielding for the entire structure. Other types of line sections may, however, be used in some circumstances. In Fig. 1 portions of the line sections 14 and 20 have been removed in order to save space.

The electrical design of the filters will now be considered. It will be assumed that the filter 8 is required to transmit a band of frequencies extending from f_{11} to f_{21} with a mid-band frequency of f_{m1}, which is the geometric mean of the two, and the filter 9 a higher band between f_{12} and f_{22} with a mid-band frequency f_{m2}. The design may be worked out most conveniently by referring to the equivalent electrical circuit which, for the filter 9, is shown in Fig. 2. The circuit is an unbalanced, single-section, three-element, ladder-type structure, with input terminals 30, 31 and output terminals 32, 33. The shunt branches at the ends of the filter, each comprising a capacitance C_{22} and an inductance L_{22} connected in parallel, are furnished by the line sections 17 and 18, which are identical. The series inductance L_{12} and the two shunt capacitances C_{12} at the ends thereof represent the line section 19.

The approximate values of these elements in terms of the lengths and characteristic impedances of the line sections are given by the following formulas:

$$C_{12}=\frac{A}{2VZ_{01}}\text{ farads} \tag{1}$$

$$C_{22}=\frac{B}{2VZ_{02}}\text{ farads} \tag{2}$$

$$L_{12}=\frac{AZ_{01}}{V}\text{ henries} \tag{3}$$

$$L_{22}=\frac{8}{\pi^2}\frac{BZ_{02}}{V}\text{ henries} \tag{4}$$

in which A and B are the lengths in centimeters of the line sections 19 and 18, respectively, Z_{01} and Z_{02} are, respectively, the characteristic impedances and V is the velocity of propagation in the sections, which may be taken as 3×10^{10} centimeters per second. It is assumed that the distributed resistance and conductance of the line sections are small enough to be neglected. In Equation 4 the factor $8/\pi^2$ is used because the section 18 is in the neighborhood of a quarter wavelength long and is short-circuited at the end. In this connection reference is made to Equation 2.139 and the accompanying discussion on page 65 of applicant's book "Electromechanical Transducers and Wave Filters" published by D. Van Nostrand, Inc.

The circuit of Fig. 2 will be recognized as the filter designated Type III_3 on page 316 of "Transmission Networks and Wave Filters" by Shea, also published by D. Van Nostrand, Inc. The following design formulas may be used:

$$L_{12}=\frac{Z_K}{\pi(f_{12}+f_{22})} \tag{5}$$

$$L_{22}=\frac{(f_{22}-f_{12})Z_K}{2\pi f_{12}^2} \tag{6}$$

$$C_{12}+C_{22}=\frac{1}{2\pi(f_{22}-f_{12})Z_K} \tag{7}$$

where Z_K is the image impedance of the filter at the mid-band frequency f_{m2}. In comparing Equations 6 and 7 with the corresponding ones given by Shea it should be remembered that applicant's filter has a mid-shunt termination.

A suggested design procedure for the filter 9 will now be outlined. It will be assumed that the common line 1 and the channels 2 and 3 all have the same characteristic impedance Z_{0K}. The image impedance Z_K of the filter is, therefore, chosen equal to Z_{0K} to provide an impedance match at the junctions of the filter and the lines. The cut-off frequencies f_{12} and f_{22} are chosen and the required values of the elements L_{12}, L_{22} and the sum of C_{12} and C_{22} are computed from Equations 5, 6 and 7. The value of L_{22} found from Equation 6 is now substituted in Equation 4 and the required length B of each of the shunt sections 17 and 18 is found assuming, for a reason to be explained below, that the characteristic impedance Z_{02} is equal to Z_{0K}. Next, the value of C_{22} is found from Equation 2. Since the sum of C_{12} and C_{22} is known from Equation 7 the value of C_{12} may now be found. This value of C_{12} is substituted in Equation 1, the value of L_{12} found from Equation 5 is substituted in Equation 3 and the two equations solved simultaneously for the required length A and characteristic impedance Z_{01} of the series branch 19.

At the junction point 10 the filter 9 must have a high input impedance at the mid-band frequency f_{m1} of the lower frequency filter 8. At this frequency the input impedance will be approximately the impedance of the shunt branch 17, which is a section of line short-circuited at its distant end. In order to build this up to a high value a building-out section of transmission line 20 of characteristic impedance Z_{0K} is connected between the junction point 10 and the shunt branch 17. Since the branch 17 also has a characteristic impedance of Z_{0K}, it is only necessary to make the length D of the section 20 plus the length B of the branch 17 approximately equal to an odd multiple of a quarter wavelength at the frequency f_{m1}. That is,

$$B+D=\frac{2n-1}{4}\frac{V}{f_{m1}} \tag{8}$$

where n is any integer but is usually taken as unity. The characteristic impedance Z_{02} of the shunt branch 17 might have been chosen as something different from Z_{0K} but in that case the simple relationship given by Equation 8 for the length D of the building-out section 20 would not hold.

It is seen that the line sections 17, 18 and 20 all have the same characteristic impedance, namely, Z_{0K}. It is possible, by proper choice of the cut-off frequencies f_{12} and f_{22}, to make the characteristic impedance Z_{01} of the series section 19 also equal to Z_{0K}. If this is done, then the entire filter 9 may be constructed out of a single size of coaxial line, thus simplifying the assembly and reducing the cost.

The design of the lower frequency filter 8 will now be considered in more detail. To prevent the filter 8 from adversely affecting the operation of the filter 9, it is necessary that the input impedance of the former at the point of junction 10 be high over the transmission band of the latter. The length E of the impedance-inverting section 15 is, therefore, made approximately equal to an odd multiple of a quarter wavelength at the mid-band frequency f_{m2} of the filter 9, that is,

$$E=\frac{2n-1}{4}\frac{V}{f_{m2}} \tag{9}$$

where n is any integer but is usually taken as unity. The input impedance Z of the shunt branch 13 must be low over the band of the filter 9. This may be accomplished by making the branch 13 resonant at f_{m2}. It is also required that Z be high over the transmission band of the filter 8. This is done by making the branch 13 antiresonant at f_{m1}. In order to get a wide spacing between the resonance and antiresonance used, the shunt branch 13 is preferably made up of two sections of transmission line 24, 25 having different characteristic impedances Z_{0A} and Z_{0B}, respectively, with the second section 25 short-circuited at its distant end. If the distributed resistance and conductance are neglected and the sections 24 and 25 have the same length F, the impedance Z is given by the expression

$$Z=\frac{\frac{Z_{0A}+Z_{0B}}{2}\sin\frac{2\omega F}{V}}{\cos^2\frac{\omega F}{V}-\frac{Z_{0B}}{Z_{0A}}\sin^2\frac{\omega F}{V}} \tag{10}$$

where ω is equal to 2π times the frequency f. If the impedance Z_{0A} is smaller than the impedance Z_{0B} the impedance Z plotted against frequency will be of the form shown in Fig. 4. The resonances occur when the numerator in Equation 10 is zero, that is, when the total length 2F of the section 13 is a multiple of a half wavelength. In equation form

$$\frac{2\omega F}{V}=n\pi \tag{11}$$

where n is any integer. The first three resonances f_{R1}, f_{R2} and f_{R3} are shown in Fig. 4. The antiresonances occur where the denominator in Equation 10 is zero, that is, when

$$\frac{\sin^2\frac{\omega F}{V}}{\cos^2\frac{\omega F}{V}}=\tan^2\frac{\omega F}{V}=\frac{Z_{0A}}{Z_{0B}} \tag{12}$$

The first three antiresonances f_{A1}, f_{A2} and f_{A3} are shown. If Z_{0A} and Z_{0B} were equal the antiresonance would occur at equal frequency intervals. However, by making Z_{0A} smaller than Z_{0B} the odd antiresonances f_{A1} and f_{A3} are lowered in frequency and the even antiresonances, such as f_{A2}, are raised. The result is that in the neighborhood of the odd resonances f_{R1} and f_{R3} there is a considerable frequency space between resonance and antiresonance.

The length 2F of the shunt branch 13 is therefore so chosen that one of the odd resonances f_{R1}, f_{R3} or a higher one occurs at the mid-band frequency f_{m2} of the higher frequency filter 9. If the frequency spacing between the two mid-band frequencies f_{m1} and f_{m2} is not too great, the first resonance f_{R1} may be used. However, when this spacing is considerable it is preferable to use f_{R3} or a higher resonance. If f_{R3} is used the length 2F will be 3/2 wavelengths at f_{m2} and the length F may be found from Equation 11 by taking n as three and ω as $2\pi f_{m2}$, that is,

$$F=\frac{3V}{4f_{m2}} \tag{13}$$

The first antiresonance f_{A1} will now be placed at the mid-band frequency of the lower frequency filter 8. As explained above, the antiresonances depend upon the ratio of the characteristic impedances Z_{0A} and Z_{0B} of the two lengths of line 24 and 25. The required ratio may be found from Equation 12 by taking F as the length found from Equation 13 and setting ω equal to $2\pi f_{m1}$, that is,

$$\frac{Z_{0A}}{Z_{0B}}=\tan^2\frac{2\pi f_{m1}F}{V} \tag{14}$$

The next step is to determine the characteristic impedances Z_{0A} and Z_{0B} of the sections 24 and 25 and the diameters of the conductors. Here certain mechanical and electrical considerations must be kept in mind. The outer conductors may conveniently have the same inner diameter b as that used in the sections of the filter 9. The diameter a of the inner conductor of a coaxial line is related to the diameter b and the characteristic impedance Z_0 by the formula

$$Z_0 \doteq 60\log_e\frac{b}{a} \tag{15}$$

It is seen from this equation that, for a given diameter b of outer conductor, the diameter a of the inner conductor decreases as the impedance Z_0 is increased, and increases as Z_0 is decreased. But when the impedance of one of the sections 24 or 25 is chosen, the impedance of the other one is fixed in accordance with equation 14. The impedance Z_{0B} of the higher impedance section 25 will, therefore, be chosen low enough so that its inner conductor 27 will be large enough for mechanical stability but high enough so that the inner conductor 26 and outer conductor of the lower impedance section 24 will have sufficient separation to prevent a voltage breakdown. After the impedance Z_{0B} has been chosen, the impedance Z_{0A} is found from Equation 14 and the diameters a_1 and a_2 of the inner conductors 26 and 27 from Equation 15. In order to avoid the formation of a corona discharge in the branch 13, the end of the inner conductor 26, where it joins the inner conductor 27, should be rounded off as shown at 34. Each length F will then be measured from the point where the diameter of the inner conductor is the average of a_1 and a_2. The shunt branch 12 will be identical with the branch 13.

There remains now only to determine the series branch 14 of the filter 8. The equivalent electrical circuit of the filter, which is similar to that of the filter 9, is shown in Fig. 3. The series inductance L_{11} and the two shunt capacitances C_{11} at the ends thereof, representing the line section 14, have the values

$$C_{11}=\frac{G}{2VZ_{02}} \qquad (16)$$

$$L_{11}=\frac{GZ_{02}}{V} \qquad (17)$$

where G is the length of the section 14 and Z_{02} is its characteristic impedance. The shunt branches at the ends of the filter, each comprising a capacitance C_{21} and an inductance L_{21} connected in parallel, represent the shunt branches 12 and 13 in the neighborhood of the mid-band frequency f_{m1} which coincides with the first antiresonance at f_{A1}. By analogy with the procedure followed on pages 63 to 65 of applicant's above-mentioned book, C_{21} and L_{21} may be evaluated as

$$C_{21}=\frac{F}{VZ_{0A}}\text{ farads} \qquad (18)$$

$$L_{21}=\frac{1}{(2\pi f_{m1})^2C_{21}}\text{ henries} \qquad (19)$$

The filter design formulas, which are similar to Equations 5, 6 and 7 above, are

$$L_{11}=\frac{Z_K}{\pi(f_{11}+f_{21})} \qquad (20)$$

$$L_{21}=\frac{(f_{21}-f_{11})Z_K}{2\pi f_{11}^2} \qquad (21)$$

$$C_{11}+C_{21}=\frac{1}{2\pi(f_{21}-f_{11})Z_K} \qquad (22)$$

Since the length F and the impedance Z_{0A} have been determined, the value of C_{21} may now be found from Equation 18. Since the mid-band frequency f_{m1} has also been selected, the value of L_{21} may be found from Equation 19. This value of L_{21} is now substituted in Equation 21 and the cut-off frequencies f_{11} and f_{21} so chosen that Equation 21 is satisfied, keeping in mind that

$$f_{m1}=\sqrt{f_{11}f_{21}} \qquad (23)$$

These values of f_{11} and f_{21} are substituted in Equation 20 to find L_{11} and in Equation 22 to find the sum of C_{11} and C_{21}. Since the value of C_{21} has already been determined, the value of C_{11} may be found. These values of C_{11} and L_{11} are now substituted in Equations 16 and 17, respectively, and the equations solved simultaneously for the length G of the section 14 and its characteristic impedance Z_{02}. There remains now only to find the diameters of the conductors for the section 14. The outer conductor may conveniently be made of the same diameter as the outer conductors used in the other component line sections of the filters. The diameter of the inner conductor may be found from Equation 15.

The above formulas for the lengths of the coaxial sections are based on the assumption that the concentric outer conductor will extend for the full length of the section. As is apparent in Fig. 1, however, when a side branch is connected at the end of a series branch at least a portion of the outer wall will be missing at the connected ends of the sections. To correct for this condition the lengths of the line sections must be increased somewhat. This factor is of more importance in the higher frequency filters. In the case of the shunt branches it has been found that a more nearly correct result will be obtained if the length is measured from the outer conductor of the series branch as shown, for example, by the dimension B for the branch 18.

What is claimed is:

1. In combination, two wave filters connected at one end, one of said filters comprising a series impedance branch and a shunt impedance branch, said series branch being connected between said shunt branch and the junction of said filters and being constituted by a section of transmission line having a length approximately equal to an integral number of quarter wavelengths at the mid-band frequency of the other of said filters and said shunt branch comprising two tandem-connected sections of transmission line having different characteristic impedances and having their lengths and characteristic impedances chosen to make said branch antiresonant near the mid-band frequency of said one filter and resonant near said mid-band frequency of said other filter.

2. The combination in accordance with claim 1 in which said mid-band frequencies are widely spaced in frequency and said shunt branch has at least two intermediate resonances occurring in the frequency range between said mid-band frequencies.

3. The combination in accordance with claim 1 in which said mid-band frequency of said one filter is located near the first antiresonance of said shunt branch and said mid-band frequency of said other filter is located near the third resonance of said shunt branch.

4. The combination in accordance with claim 1 in which said shunt branch is short-circuited at its distant end.

5. The combination in accordance with claim 1 in which said sections of line in said shunt branch have approximately the same length.

6. The combination in accordance with claim 1 in which said sections of line in said shunt branch are of the coaxial type having outer conductors of the same inner diameter.

7. The combination in accordance with claim 1 in which said sections of line in said shunt branch are of the coaxial type having outer conductors of the same inner diameter and inner conductors which differ from each other in diameter, said inner conductor of larger diameter being associated with said tandem-connected section of line nearer to said series branch.

8. In combination, two wave filters and an impedance-inverting section of transmission line, said filters being connected in parallel at one end, one of said filters comprising a shunt branch, said

impedance-inverting section being connected between said shunt branch and the junction of said filters and having a length approximately equal to an odd multiple of a quarter wavelength at the mid-band frequency of the other of said filters and said shunt branch comprising two tandem-connected sections of transmission line having different characteristic impedances and having their lengths and characteristic impedances chosen to make said branch antiresonant near the mid-band frequency of said one filter and resonant near the mid-band frequency of said other filter.

9. The combination in accordance with claim 8 in which all of said sections of line are of the coaxial type having outer conductors of the same inner diameter.

10. The combination in accordance with claim 8 in which said one filter includes a series impedance branch constituted by a section of transmission line the length and characteristic impedance of which are so chosen that both of said filters have the same image impedance at the mid-band frequency.

11. The combination in accordance with claim 8 in which said one filter has a lower mid-band frequency than said other filter.

12. The combination in accordance with claim 8 which includes a building-out section of transmission line, said other filter comprising a shunt branch constituted by a section of transmission line short-circuited at its distant end, said building-out section being connected between said shunt branch of said other filter and said junction of said filters and the combined lengths of said building-out section and said section of line in said shunt branch of said other filter being approximately equal to an odd number of quarter wavelengths at the mid-band frequency of said one filter.

13. In combination, two wave filters and a building-out section of transmission line, said filters being connected in parallel at one end, one of said filters comprising a shunt branch constituted by a section of transmission line short-circuited at its distant end, said building-out section being connected between said shunt branch and the junction of said filters and the combined lengths of said building-out section and said section of line in said shunt branch being approximately equal to an odd number of quarter wavelengths at the mid-band frequency of the other of said filters.

14. The combination in accordance with claim 13 in which said one filter has a higher mid-band frequency than said other filter.

15. The combination in accordance with claim 13 in which both of said sections of line have the same characteristic impedance.

16. The combination in accordance with claim 13 in which said sections of line are of the coaxial type having outer conductors of the same inner diameter and inner conductors of the same diameter.

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