Jan. 14, 1947. W. P. MASON 2,414,115

WAVE FILTER

Filed Aug. 19, 1943

FIG. 1

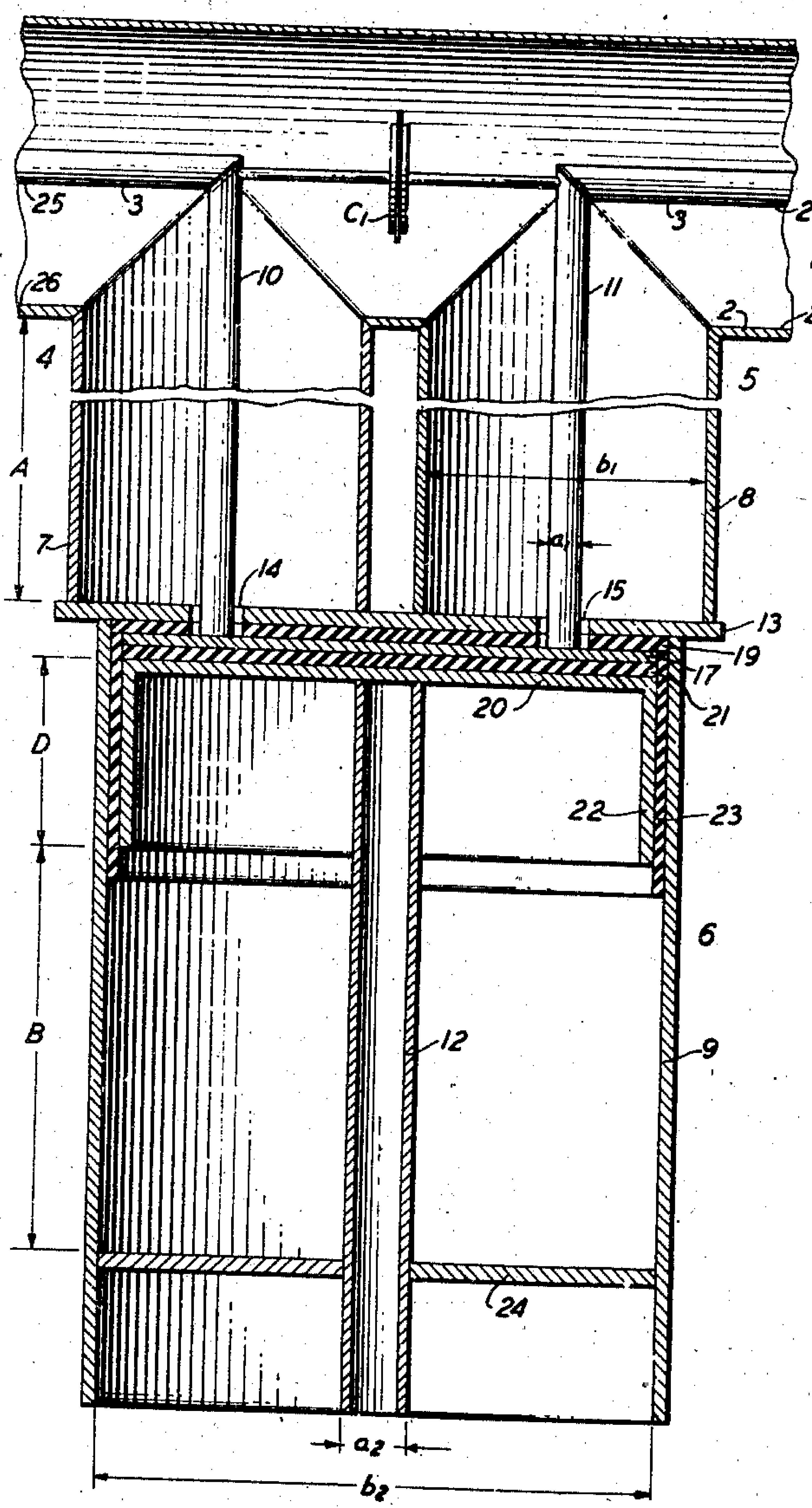


FIG. 2

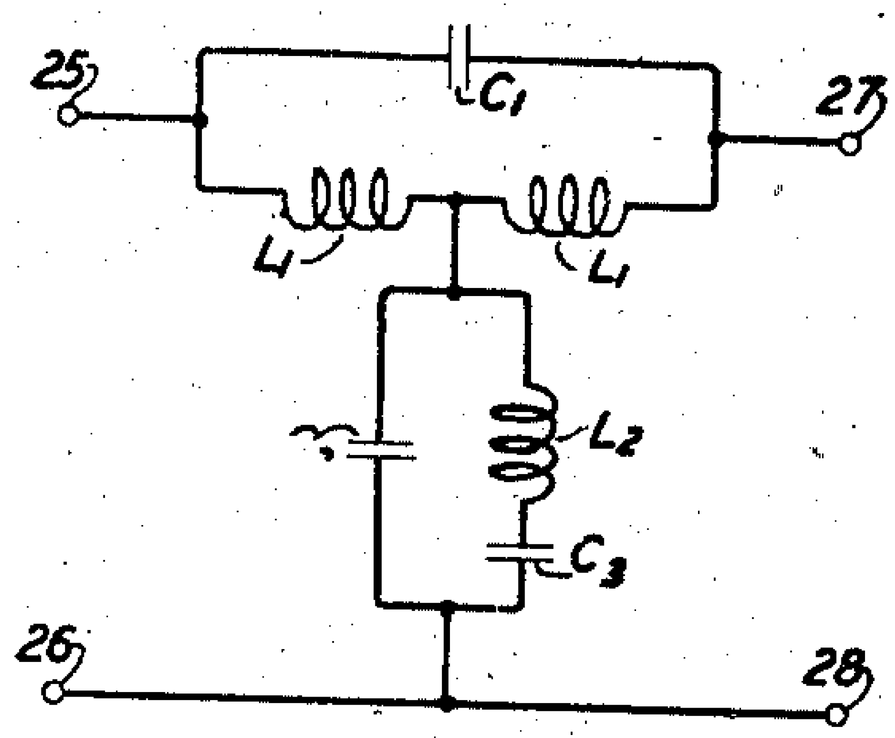


FIG. 4

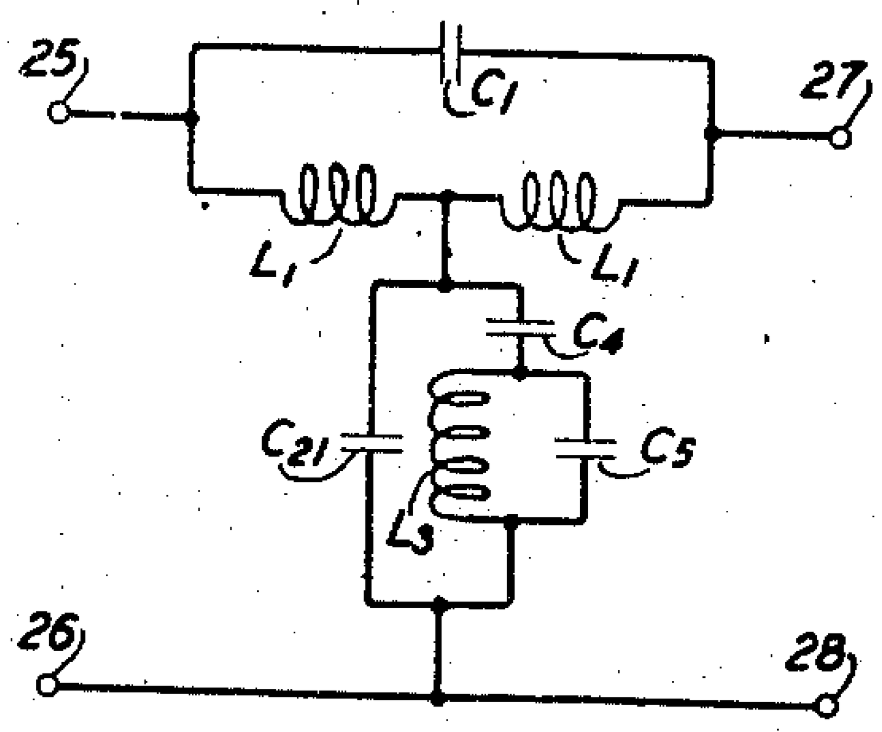


FIG. 3

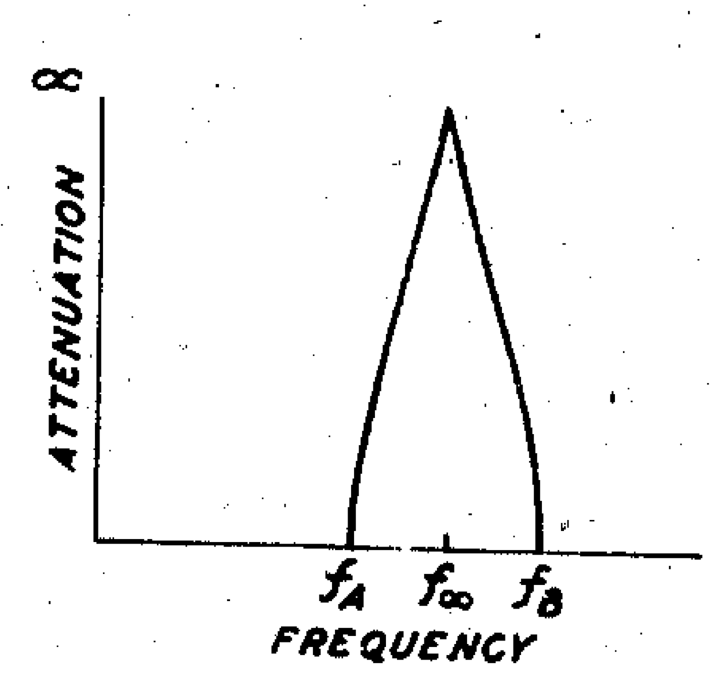
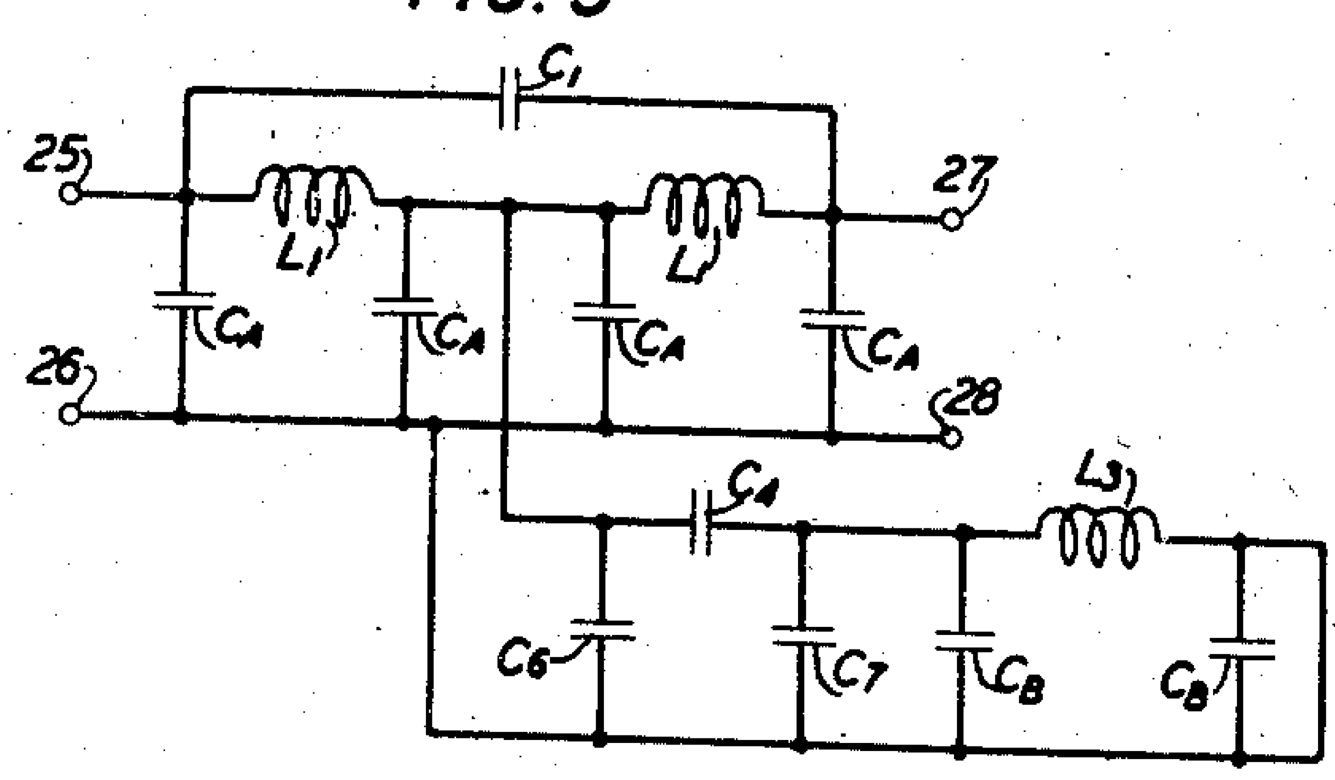


FIG. 5



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WAVE FILTER

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10 Claims. (Cl. 178—44)

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This invention relates to wave filters and more particularly to those employing sections of transmission line as component impedance elements.

The principal object of the invention is to suppress one or more bands of high frequencies while freely transmitting other frequencies. Other objects are to decrease the attenuation distortion, sharpen the cut-offs, increase the height of the attenuation peaks and increase the power carrying capacity of wave filters intended for use at high frequencies.

The filter in accordance with the invention comprises sections of transmission line and capacitors arranged in the form of a bridged-T structure having two equal series arms, an interposed shunt branch and a bridging branch. The series arms are constituted by two sections of transmission line connected in tandem. The shunt branch may also include one or more sections of line and one or more capacitors. If a band-suppression characteristic is desired, the bridging branch includes a capacitor. The line sections are preferably of the coaxial type. The sections used in the series arms are preferably arranged physically in parallel, with their ends close together, so that only short connections will be required for the bridging branch. Certain of the capacitors may be built within the line sections to ensure adequate shielding and short connections. By proper design of the line sections the dissipation therein may be kept low, resulting in a filter having small distortion within the transmission band, sharp cut-offs and high attenuation peaks. If sufficient separation is provided between inner and outer conductors, a large amount of power may be transmitted without voltage breakdown.

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

Fig. 1 is a longitudinal cross-section of a band-suppression wave filter in accordance with the invention;

Fig. 2 is a simplified equivalent electrical circuit used in designing the filter;

Fig. 3 gives a typical attenuation-frequency characteristic obtainable with the filter;

Fig. 4 is another equivalent circuit used in one step of the design; and

Fig. 5 is a more exact equivalent electrical circuit for the filter of Fig. 1.

Taking up the figures in more detail, Fig. 1 is a longitudinal cross-sectional view of a band-suppression filter in accordance with the invention connected to a coaxial transmission line 1 having a cylindrical outer conductor 2 and an inner conductor 3. The filter comprises two similar tandem-connected sections of transmission line 4 and 5, branching off from the line 1, and a third section of line 6 connected at the junction of the sections 4 and 5. In order to save drawing space, portions of the sections 4 and 5 have been cut out. As shown, each line section is of the coaxial type, comprising a hollow cylindrical outer conductor and, concentric therewith, a cylindrical inner conductor. The sections 4, 5 and 6 have outer conductors 7, 8 and 9, respectively, and inner conductors 10, 11 and 12, respectively. The cylinder 9 is closed at its upper end by a circular metallic end plate 13. The cylinders 7 and 8 are arranged side by side, physically in parallel, and extend upward from the plate 13 to their points of connection with the line 1. The inner conductors 10 and 11 extend through the apertures 14 and 15, respectively, in the plate 13 and terminate in the circular metallic condenser plate 17. The plate 13 is separated from the plate 17 by a disk 19 of dielectric material which also has holes to permit passage therethrough of the conductors 10 and 11.

The inner conductor 12 terminates at its upper end in a circular metallic condenser plate 20 which is separated from the plate 17 by a disk 21 of dielectric material. Extending downward from the plate 20 is a cylindrical condenser plate 22 separated from the outer conductor 9 by a cylinder 23 of dielectric material. The line section 6 is short-circuited at its lower end by means of the annular metallic member 24 which may be slid in or out to adjust the electrical length of the section. The portion of the inner conductor 3 between the points of connection of the conductors 10 and 11 is removed and a capacitor of capacitance C_1, located within the line 1, is connected between the upper ends of the conductors 10 and 11. Input energy may be applied at one end of the line 1 at the points 25 and 26 and the output taken off at the points 27 and 28.

Fig. 2 shows a simplified equivalent electrical circuit for the structure of Fig. 1. The network is of the bridged-T type, comprising two equal series arms, an interposed shunt branch and a bridging branch. Each of the series arms is an inductance L_1, the bridging branch is the capacitance C_1 and the shunt branch is constituted by a capacitance C_2 connected in parallel with an arm comprising an inductance L_2 in series with a capacitance C_3. The filter is of the band-suppression type, having a lower cut-off at the frequency f_A, an upper cut-off at f_B and a peak of attenuation at an intermediate frequency f_∞. For maximum attenuation f_∞ should be the geometric mean of f_A and f_B. A typical attenuation-frequency characteristic, assuming negligible dissipation in the component elements, is shown in Fig. 3.

The design formulas for a filter of the type shown in Fig. 2 are given on page 284 of applicant's book entitled "Electromechanical Transducers and Wave Filters," published by D. Van Nostrand Company, Incorporated. Using the notation of Fig. 2, the component elements have the following values:

$$C_1=\frac{f_A}{4\pi Z_0 b f_B f_\infty}\text{ farads} \tag{1}$$

$$C_2=\frac{b f_A f_\infty}{\pi Z_0 f_B(f_A^2+b^2f_\infty^2-f_B^2)}\text{ farads} \tag{2}$$

$$C_3=\frac{Z_0 f_B(f_A^2+b^2f_\infty^2-f_B^2)^2}{\pi Z_0 b f_A f_\infty(f_B^2-f_A^2)(b^2f_\infty^2-f_B^2)}\text{ farads} \tag{3}$$

$$L_1=\frac{Z_0 f_B}{2\pi b f_\infty f_A}\text{ henries} \tag{4}$$

$$L_2=\frac{Z_0 f_B(f_A^2+b^2f_\infty^2-f_B^2)^2}{4\pi b f_A f_\infty(f_B^2-f_A^2)(b^2f_\infty^2-f_B^2)}\text{ henries} \tag{5}$$

in which

$$b=\frac{1}{\sqrt{2}}\sqrt{\frac{f_B^2+f_\infty^2-2f_A^2}{f_\infty^2-f_A^2}+\sqrt{\frac{f_B^2+f_\infty^2-2f_A^2}{f_\infty^2-f_A^2}-4}} \tag{6}$$

and Z_0 is the image impedance of the filter at zero frequency.

In some cases the inductance L_2 will be too large to be furnished conveniently by a section of line. This difficulty may be overcome, however, by adding a redundant capacitance to the shunt branch. First, the capacitance C_2 is split into two capacitances C_{21} and C_{22}, the sum of which is equal to C_2. Then the portion of the shunt branch comprising L_2, C_3 and C_{22} is transformed into the equivalent form of a capacitance C_4 connected in series with an anti-resonant loop made up of a capacitance C_5 and an inductance L_3. The formulas to be used for this transformation are the following:

$$C_4=C_3+C_{22} \tag{7}$$

$$C_5=\frac{C_{22}}{C_3}(C_3+C_{22}) \tag{8}$$

$$L_3=\frac{L_2}{\left(1+\frac{C_{22}}{C_3}\right)^2} \tag{9}$$

The resulting network is shown in Fig. 4.

It remains now only to explain how the mechanical structure of Fig. 1 may be designed to be electrically equivalent to the circuit shown in Fig. 4. An equivalent electrical circuit for the filter of Fig. 1 is shown in Fig. 5. Since each of the line sections **4**, **5** and **6** will ordinarily have a length which is only a small fraction of a wavelength at the frequency f_∞, it may be represented by an inductance having at each end a shunt capacitance. Each of the sections **4** and **5** is represented by an inductance L_1 and the two equal shunt capacitances C_A, C_A and the portion of the section **6** of length B by the inductance L_3 and the equal shunt capacitances C_B, C_B. The

approximate values of these elements are given by the following formulas:

$$C_A \doteq \frac{A}{3.6\times10^{-12}\log_\epsilon\frac{b_1}{a_1}}\text{ farads} \tag{10}$$

$$C_B \doteq \frac{B}{3.6\times10^{-12}\log_\epsilon\frac{b_2}{a_2}}\text{ farads} \tag{11}$$

$$L_1 \doteq 2A10^{-9}\log_\epsilon\frac{b_1}{a_1}\text{ henries} \tag{12}$$

$$L_3 \doteq 2B10^{-9}\log_\epsilon\frac{b_2}{a_2}\text{ henries} \tag{13}$$

in which A is the length in centimeters of each of the line sections **4** and **5**, a_1 and b_1 are, respectively, the inner diameter of the outer conductor **7** or **8** and the outer diameter of the inner conductor **10** or **11**, B is the length in centimeters of the line sections **6** from the lower end of the cylinder **22** to the short-circuiting member **24** and a_2 and b_2 are, respectively, the inner diameter of the outer conductor **9** and the outer diameter of the inner conductor **12**. The capacitance C_1 is the one connected between the upper ends of the inner conductors **10** and **11** in Fig. 1, C_4 is the capacitance between the plates **17** and **20**, C_6 is the capacitance between the plates **13** and **17** and C_7 is the capacitance between the cylinder **22** and the outer conductor **9**.

It will be noted that the capacitance C_B at the right end of L_3 is shorted out by the member **24**. The shunt capacitances C_A at the ends of the filter are usually small enough to be neglected. When this is done, the circuit of Fig. 5 is seen to have the same configuration as that shown in Fig. 4. The two circuits will be equivalent when

$$2C_A+C_6=C_{21} \tag{14}$$

and

$$C_B+C_7=C_5 \tag{15}$$

A suggested procedure for designing the filter of Fig. 1 is as follows: First, the cut-off frequencies f_A and f_B and the frequency of peak attenuation f_∞ are chosen. Then the values of the capacitances C_1, C_2 and C_3 and the inductances L_1 and L_2 are computed from Equations 1 to 5. Next, the capacitance C_2 is split into C_{21} and C_{22} and the values of the elements C_4, C_5 and L_3 found from Equations 7, 8 and 9. Now, the required length A of each of the line sections **4** and **5** is found from Equation 12, using any convenient ratio of b_1/a_1. However, to provide a minimum longitudinal cross-sectional area for the sections **1** and **2** this ratio should be 9.2. The diameter b_1 of the outer conductor will, in any event, be made large enough so that the dissipation is kept within allowable limits and the separation between the conductors such as **7** and **10** is sufficient to withstand, without breakdown, the voltage to be applied to the filter. Next, the value of each of the capacitances C_A is found from Equation 10. The value of the capacitance C_6 may now be found from Equation 14. The area of the plate **17**, the spacing between the plates **13** and **17** and the dielectric constant of the separator **19** are proportioned to give the required capacitance C_6. The spacing between the plates **17** and **20** and the dielectric constant of the separator **21** are proportioned to provide the required capacitance C_4. The capacitance C_1 is furnished by any suitable type of capacitor.

Next, the required partial length B of the line section 6 is found from Equation 13. The ratio of b_2/a_2 may be taken as 9.2, for the reason given above, or as any other appropriate value. The diameter b_2 of the outer conductor 9 may conveniently be chosen as approximately $2b_1$. The value of the capacitance C_B is found from Equation 11 and the value of C_7 from Equation 15. The length D of the cylinder 22, the spacing between the cylinder 22 and the outer conductor 9 and the dielectric constant of the separator 23 are proportioned to provide the required capacitance C_7. There will be a small amount of inductance associated with the cylinder 22 but if its length D is kept short enough this inductance may be neglected.

Although the embodiment disclosed herein is a band-suppression filter, it will be apparent to those skilled in the art that other types such, for example, as low-pass, band-pass or high-pass, falling within the scope of the invention, may be provided by suitably modifying the component impedance branches in accordance with well-known filter theory.

What is claimed is:

1. A wave filter comprising three sections of coaxial transmission line, an end plate and a condenser plate, one of said line sections extending in one direction from said end plate, the other two of said line sections extending in the opposite direction from said end plate and said condenser plate being located within said one line section near said end plate and electrically connected to the inner conductors of said other line sections.

2. A filter in accordance with claim 1 which includes a second condenser plate located within said one line section near said first-mentioned condenser plate and electrically connected to the inner conductor of said one line section.

3. A filter in accordance with claim 1 which includes a second condenser plate located within said one line section near said first-mentioned condenser plate and electrically connected to the inner conductor of said one line section and a cylindrical condenser plate located within said one line section and electrically connected to said second condenser plate.

4. A filter in accordance with claim 1 which includes a capacitor connected between the ends of said other two line sections remote from said end plate.

5. A filter in accordance with claim 1 in which said other two line sections form the series arms of a T network.

6. A filter in accordance with claim 1 in which said other two line sections form the series arms of a bridged-T network.

7. A wave filter comprising three sections of coaxial transmission line, an end plate common to all three of said sections, and a condenser plate located within one of said sections near said end plate and electrically connected to the inner conductors of the other two of said sections.

8. A filter in accordance with claim 7 which includes a second condenser plate located within said one line section near said first-mentioned condenser plate and electrically connected to the inner conductor of said one line section.

9. A filter in accordance with claim 7 which includes a second condenser plate located within said one line section near said first-mentioned condenser plate and electrically connected to the inner conductor of said one line section and a cylindrical condenser plate located within said one line section and electrically connected to said second condenser plate.

10. A filter in accordance with claim 7 which includes a capacitor connected between the ends of said other two line sections remote from said end plate.

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