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ELECTRICAL TRANSMISSION SYSTEMS AND FILTERS THEREFOR

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Fig. 1.

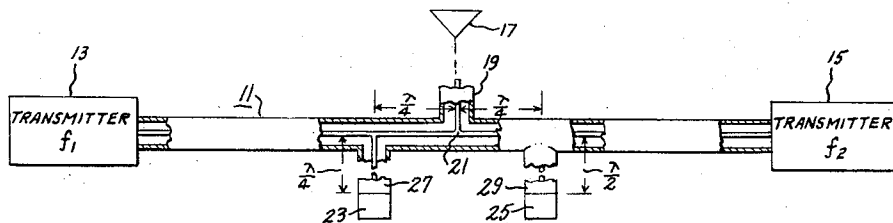


Fig. 2

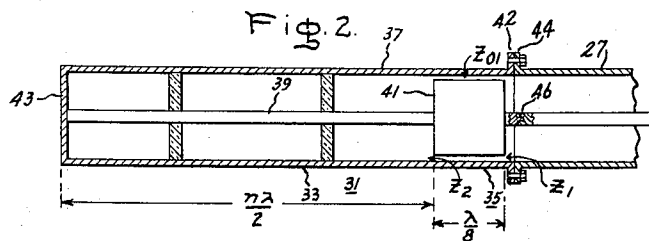


Fig. 4.

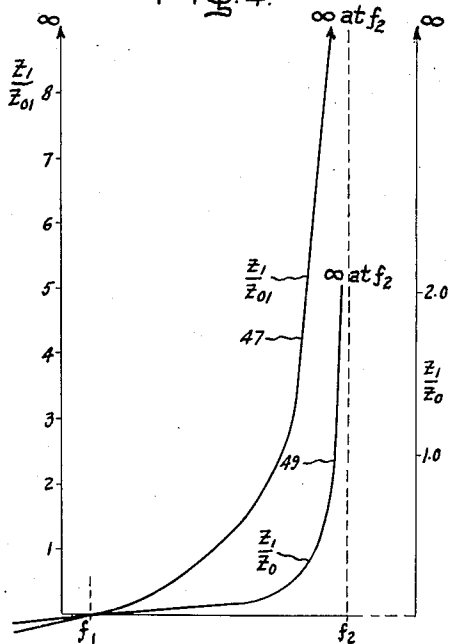
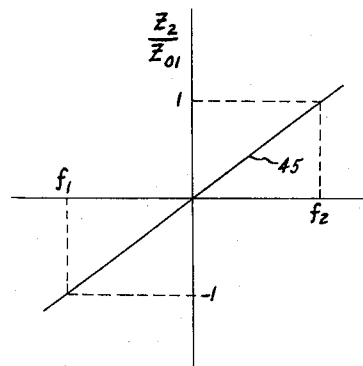


Fig. 3.



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ELECTRICAL TRANSMISSION SYSTEMS AND FILTERS THEREFOR

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10 Claims. (Cl. 333—9)

This invention relates to high frequency electrical transmission systems, and more particularly, to systems for feeding energy from two transmitters operating at different frequencies to a common load, and to filters for such systems. Such systems are commonly employed in television transmitter apparatus where energies from a visual transmitter and an aural transmitter are simultaneously fed to a single antenna. Systems of this type are commonly referred to as diplexers.

The diplexer embodying this invention operates simultaneously to feed energy from two transmitters to a common load through an intermediate circuit comprising filter elements that are constructed and arranged relative to the individual transmitters and the common load so that both transmitters may feed into the load and yet remain adequately decoupled. The principles of diplexer operation are well known and will not be described in detail. My invention resides in certain improved constructional features of the diplexer assembly and in novel filter elements employed therein, whereby improved functioning of the assembly is obtained.

One of the objects of this invention is to provide a new and improved system for transmitting energy generated by a pair of transmitters to a single antenna in such a manner that there is no reaction between the transmitters.

A further object of this invention is to provide a novel diplexer embodying filter apparatus that is characterized in that substantially zero attenuation is effected at a first frequency value and substantially infinite attenuation is effected at a second frequency value.

Still another object is to provide a compact coaxial-line filter element that is sharply resonant at a first frequency value and also sharply antiresonant at a second frequency value, said frequency values being spaced a small predetermined amount in the spectrum of high frequencies.

Another object is to provide a filter apparatus of the type hereinbefore described that is simple and economical to produce.

In carrying out the invention in one form, there is provided a system incorporating novel filter elements in the form of coaxial transmission line sections each comprising a tandem arrangement of a first section having a relatively low characteristic impedance and a second section having a relatively high characteristic impedance, the electrical length of the low-characteristic impedance section being of the order of $\lambda/8$, and the electrical length of the high-characteristic impedance section being of the order of

$$\frac{n\lambda}{4}$$

where λ is the wavelength at the mean frequency of the design range of the diplexer and n is an integer.

Other objects will become apparent and the invention better understood from a consideration of the following description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a block diagram of an electrical transmission system in accordance with one embodiment of the invention;

Fig. 2 is a longitudinal cross sectional view of a filter

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element constructed according to the principles of one aspect of the invention; and

Figs. 3 and 4 are graphs explanatory of the operation of the invention.

Referring to Fig. 1, there is shown, in block-diagram form, an electrical transmission system embodying the novel feature of the invention. The system comprises a transmission line 11, which may be of the well-known coaxial, waveguide or parallel-wire type, extending between a visual television transmitter 13 operable at a frequency f_1 and an aural television transmitter 15 operable at a frequency f_2 . The operating frequencies f_1 and f_2 of the visual transmitter 13 and aural transmitter 15, respectively, can be of any suitable value, and according to current practice, the visual frequency is lower than and spaced from the frequency at which the aural transmitter operates by approximately 4.5 megacycles per second. Modulation components of f_1 , the frequency of the visual transmitter 13, usually extends to 4 megacycles or .5 megacycles below f_2 , which is about $\frac{1}{2}\%$ at the frequency values currently employed by commercial telecasting. It will, of course, be understood that the values here indicated are by way of example only and are not intended as limitations or restrictions.

The signals from the visual transmitter 13 and aural transmitter 15 are applied to a common antenna 17, which is coupled to the transmission line 11 by means of a line section 19 forming a junction 21 with the line 11.

For minimizing reaction between the visual transmitter 13 and the aural transmitter 15, (preventing the signal from one transmitter from reaching the other transmitter) and at the same time providing a low-impedance path for the signals from each transmitter to the antenna 17, a pair of filter elements 23 and 25 is provided, (indicated by rectangles), one of which, say filter element 23, provides a termination for a quarter-wave section 27 of coaxial transmission line connected to the transmission line 11 at a point in the visual arm thereof one quarter wavelength from the junction 21. The other filter element 25 provides a termination for a half-wave section 29 of coaxial transmission line connected to the transmission line 11 at a point in the aural arm thereof one quarter wavelength from the junction 21. The distances expressed herein, in terms of fractions of a wavelength, may for practical purposes refer to the wavelength at the mean frequency of the design range of the system. Further, these distances may vary about these mean values for purposes of compensation.

Each of the filter elements 23 and 25, as will be more fully explained hereinbelow, is adapted to be series resonant at the frequency f_1 of the visual transmitter 13 and parallel resonant at the frequency f_2 of the aural transmitter 15. Thus, since the filter element 23 terminates the quarter-wave section 27, which as is known, operates as an impedance-inverting element, the combined filter element 23 and quarter-wave section 27 present very high shunt impedance to signals of the visual frequency (f_1) and very low, substantially zero, shunt impedance to signals of the aural frequency (f_2). The opposite is true with respect to the filter element 25 that terminates the half-wave section 29, since a half-wave section of coaxial transmission line, as is well known, presents at its input the same impedance as seen at its termination. Thus, the combined filter element 25 and half-wave section 29 present very low, substantially zero, shunt impedance to signals of the visual frequency (f_1) and very high shunt impedance to signals of the aural frequency (f_2).

The ability of the stub-connected filters to effect substantially complete separation between the signals from one transmitter and the other transmitter is dependent on the sharpness of the cut-off characteristic of the filter element itself.

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Fig. 2 illustrates a filter element 31 constructed in accordance with the principles of one aspect of this invention and having a desirably sharp cut-off characteristic. The filter element 31 comprises a high impedance section 33 of coaxial transmission line in series with a relatively low impedance section 35 of coaxial transmission line. A suitable construction of the series-connected sections consists, as shown, of a conductive cylinder 37 that serves as a common outer conductor for the high impedance section 33 and the low impedance section 35, and a coaxially mounted conductive rod or tube which over a first portion 39 of its length is of a relatively small cross-sectional diameter and over a second portion 41 is of a relatively large cross-sectional diameter.

The end of the high-impedance section 33 remote from the low-impedance section 35 is closed as by a conductive plate 43 short circuiting the conductive cylinder 37 to the first portion 39 of the coaxially mounted conductive rod (the inner and outer conductors of the high-impedance section 33). The low-impedance section 35 is open circuited at both ends. To facilitate connection of the filter element 31 to the quarter-wave section 27, the open end of filter element 31 can be flanged, as at 42, for fastening to a similarly flanged end 44 of the quarter-wave section 27. Also, the second portion 41 of the coaxially mounted conductive rod can be formed with a projecting tip 46 that fits into a mating slot in the inner conductor of the quarter-wave section 27 thus to provide smooth electrical continuity at the junction of the filter element 31 and the quarter-wave section 27. The connection of a similar filter element 31 to the half-wave section 29 may be likewise effected. By dimensioning the high-impedance section 33 and the low-impedance section 35 so that the latter is substantially an eighth wavelength at the mean frequency of the design range, and the former is an effective integral number of half wavelengths at said mean frequency, the series-connected sections provide, in effect, a capacitance-inductance L section in series circuit with a series-resonant inductance-capacitance circuit. At the visual frequency (f_1), the total series resonant circuit offers zero impedance. At the aural frequency (f_2), the series circuit and the L section go into parallel resonance and present substantially infinite input impedance.

To explain in greater detail the operation of the filter element 31 whereby the desired extremely sharp cut-off characteristic is derived, reference is made to Figs. 3 and 4, which are graphs illustrating certain impedance relationships existent at various points of the element. In these figures, the following symbols are used having the definitions indicated:

Z_0 is the characteristic impedance of the transmission lines 11, the quarter-wave section 27 and the half-wave section 29 to which the filter elements 31 are connected.

Z_1 is the impedance seen looking into the low-impedance section 35.

Z_{01} is the characteristic impedance of the low-impedance section 35.

Z_2 is the impedance seen looking into the high-impedance section 33 at the junction of the sections 33 and 35.

In Fig. 3, the line 45 is a graph depicting the slope of the reactance provided by the high-impedance section 33, the ordinates of the graph being the ratio Z_2/Z_{01} and the abscissas being frequency. As shown, the reactance slope is selected so that the ratio Z_2/Z_{01} is -1 at the frequency f_1 of the visual transmitter 13 and $+1$ at the frequency f_2 of the aural transmitter 15. It will be understood that, although this slope of reactance is obtained, in the illustrated embodiment, by a short-circuited section of transmission line of effective length equal to an integral number of half wavelengths at the mean frequency of the design range of the diplexer, such a slope

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may also be obtained by open-circuited sections of length $m\lambda/4$ where m is an odd integer and λ is the same mean frequency, or by proper coupling into a resonant cavity.

The significance of the reactance slope will be clear from a consideration of the following analysis. From well-known transmission line theory, in a lossless line, and since low-impedance section 35 is of electrical length equal to 45° , we have

$$Z_1/Z_{01} = j \frac{Z_{01} \tan 45^\circ + Z_2}{Z_{01} - Z_2 \tan 45^\circ} \quad (1)$$

Since $\tan 45^\circ = 1$

$$Z_1/Z_{01} = j \frac{Z_{01} + Z_2}{Z_{01} - Z_2} = j \frac{1 + \frac{Z_2}{Z_{01}}}{1 - \frac{Z_2}{Z_{01}}} \quad (2)$$

Now, if

$$\frac{Z_2}{Z_{01}} = -1$$

$$Z_1/Z_{01} = 0$$

which is the condition of resonance. Also, if

$$\frac{Z_2}{Z_{01}} = 1$$

$$Z_1/Z_{01} = \infty$$

which is the condition of antiresonance. From the graph of Fig. 3, it will be seen that

$$\frac{Z_2}{Z_{01}} = -1$$

at the frequency f_1 and

$$\frac{Z_2}{Z_{01}} = 1$$

at the frequency f_2 and the requirements for the location of the resonant and antiresonant frequencies are thus established.

Fig. 4 illustrates the slope of the reactance in the region of aural frequency f_2 , curves 47 and 49 thereof being the plots of the ratio Z_1/Z_{01} against frequency and Z_1/Z_0 against frequency, respectively. Curve 49 illustrates the reactance slope after transformation through the eighth-wavelength low-impedance section 35. It will be noted that resonance occurs at the visual frequency f_1 and antiresonance occurs at the aural frequency f_2 , since the curve passes through zero at the former frequency and to infinity at the latter.

For the investigation of the conditions in the region of aural frequency f_2 it is convenient to consider the susceptance instead of the reactance because the susceptance passes through zero at aural frequency f_2 and in this manner the analytical difficulty of an infinite reactance slope at aural frequency f_2 is avoided, when losses are neglected.

The relative susceptance is obtained by inverting the relation for the relative reactance given in Equation 2. Thus,

$$\frac{Z_{01}}{Z_1} = -j \frac{Z_{01} - Z_2}{Z_{01} + Z_2} \quad (3)$$

Normalizing Equation 3 with respect to Z_0 , the impedance across which the element is connected, by multiplying through by Z_0/Z_{01} , we have

$$Z_0/Z_1 = -j \frac{Z_0 \cdot Z_{01} - Z_2}{Z_{01} \cdot Z_{01} + Z_2} \quad (4)$$

Differentiating with respect to frequency, we have

$$\frac{d(Z_0/Z_1)}{df} = j \frac{Z_0}{Z_{01}} \frac{dZ_2}{df} \left[\frac{Z_{01} - Z_2}{(Z_{01} + Z_2)^2} + \frac{1}{Z_{01} + Z_2} \right] \quad (5)$$

Now, at aural frequency f_2 , the antiresonance frequency $Z_2 = Z_{01}$. Then, at f_2 ,

$$\frac{d(Z_0/Z_1)}{df} \Big|_{f=f_2} = j \frac{Z_0}{Z_{01}} \frac{dZ_2}{df} \frac{1}{2Z_{01}} \quad (6)$$

Now, dZ_2/df is determined by the location of visual frequency f_1 and aural frequency f_2 , the resonant and antiresonant frequencies. Since, at visual frequency f_1 , $Z_2 = -Z_{01}$ and at aural frequency f_2 , $Z_2 = Z_{01}$, we have

$$\frac{dZ_2}{df} = \frac{2Z_{01}}{f_2 - f_1} \quad (7)$$

Substituting the value of dZ_2/df from Equation 7 into Equation 6 we have

$$\frac{d(Z_0/Z_1)}{df} = j \frac{Z_0}{Z_{01}} \left(\frac{1}{f_2 - f_1} \right) \quad (8)$$

which demonstrates that for a given fixed frequency separation, $f_2 - f_1$, the normalized susceptance slope at f_2 is directly proportional to the ratio

$$\frac{Z_0}{Z_{01}}$$

e. g., the larger the value of the ratio, the steeper the slope. Or, by suitably selecting Z_{01} , any desired slope may be obtained. This is graphically shown by the curve 49, plotting as abscissas the reactance Z_1/Z_0 instead of the susceptance Z_0/Z_1 for ease of comparison with curve 47.

It will thus be seen that the region around f_2 may be termed a slot region, the width of which can be controlled by selecting a suitable value of Z_{01} , the characteristic impedance of the low-impedance section 35.

In an operative embodiment, an impedance characteristic as illustrated by the curve 49, obtained for the case where $Z_{01}/Z_0 = 0.065$ effectively short-circuited the transmission line 11 (Fig. 1) except in the region of the slot at aural frequency f_2 . It was found that a normalized reactance of 0.5 at 4 megacycles per second above visual frequency f_1 , the frequency width of the visual transmitter 13, is sufficiently small to permit a flat pass characteristic for all the visual frequencies, by employing compensation techniques.

The employment of filter elements of the kind described above in the system of Fig. 1 thus provides the desired steep slot for ensuring substantially complete separation between the signals from one transmitter and the other transmitter.

A further advantage following from the use of the filter element of the invention resides in the fact that while at aural frequency f_2 a condition of antiresonance is obtained for the filter elements 23 and 25, resonance is at the same time obtained at the visual frequency f_1 . This results in a very high rejection for frequency values at and around visual frequency f_1 , and since visual frequency f_1 is generally the visual carrier of a television signal, most of the energy is concentrated thereabout. In a practical system it has been observed that this feature results in an additional rejection of about 30 decibels with respect to the rejection heretofore obtained using prior-known circuits only sharply antiresonant at the mean frequency of the aural carrier.

While a particular embodiment of this invention has been shown and described, it will, of course, be understood that various modifications may be made without departing from the invention. Therefore, by the appended claims, it is intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A high-frequency wave filter for attenuating waves of a first frequency value and transmitting waves of a second frequency value, said two frequency values being spaced apart a small predetermined amount, comprising a first section of coaxial transmission line having an electrical length substantially equal to an integral number of

half wavelengths at the mean value of said first and second frequency values and short circuited at one end thereof, and a second section of coaxial transmission line having one end coupled to the other end of said first section and having an electrical length substantially equal to an odd number of eighth wavelengths at said mean frequency value, the characteristic impedance of said second section having a value such that the reactance characteristic of said first section as seen from the other end of said second section is transformed into a resultant characteristic defining a resonance at said first frequency value and an antiresonance at said second frequency value.

2. A high-frequency wave filter having resonance at one frequency and antiresonance at another frequency closely spaced from said one frequency comprising a section of transmission line substantially one-eighth of a wave length long at the mean of said frequencies, a reactive impedance element connected across one end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said one frequency and an inductive reactance at said other frequency, said capacitive reactance at said one frequency and said inductive reactance at said other frequency each being equal to the characteristic impedance of said section of transmission line whereby at the other end of said section appears a low impedance at said one frequency and a high impedance at said other frequency.

3. A high-frequency wave filter element for presenting a low impedance to waves of a first frequency and a high impedance to waves of a second frequency closely spaced from said first frequency, comprising a first section of transmission line having a length equal to an integral number of half wave lengths at the mean of said frequencies and being shortcircuited at one end, a second section of transmission line having a length equal substantially to an odd number of substantially one-eighth wave lengths at said mean value and having a characteristic impedance relatively low with respect to the characteristic impedance of said first section of transmission line, one end of said second section being connected to the other end of said first section, the characteristic impedance and length of said first section being so chosen such that said first section of said transmission line presents a capacitive reactance to said one end of the one-eighth section at said first frequency and an inductive reactance at said second frequency, said capacitive reactance at said first frequency and said inductive reactance at said second frequency each being equal to the characteristic impedance of said section of transmission line.

4. A high-frequency wave filter system for transmitting with one degree of effectiveness waves having frequencies lying in the vicinity of a first frequency and for transmitting with another degree of effectiveness waves having frequencies lying in the vicinity of a second frequency closely spaced from said first frequency, comprising a main transmission line for carrying waves of said frequencies, a section of transmission line substantially one-eighth of a wave length long at the mean of said first and second frequencies, said section of transmission line having one end coupled to said main transmission line, a reactive impedance element connected across the other end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, the capacitive reactance at said first frequency being equal to the inductive reactance at said second frequency and each of said reactances being equal to the characteristic impedance of said section of transmission line.

5. A high-frequency wave filter system for transmitting with one degree of effectiveness waves having frequencies lying in the vicinity of a first frequency and for transmitting with another degree effectiveness waves having frequencies lying in the vicinity of a second frequency closely spaced from said first frequency, comprising a

main transmission line for carrying waves of said frequencies, a section of transmission line substantially one-eighth of a wave length long at the mean of said first and second frequencies, said section of transmission line having one end coupled to said main transmission line, a reactive impedance element connected across the other end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, the magnitude of said capacitive reactance at said first frequency being equal to the magnitude of said inductive reactance at said second frequency and the magnitude of each of said reactances being equal to the magnitude of the characteristic impedance of said section of transmission line, said section of transmission line having a characteristic impedance substantially less than the characteristic impedance of said main transmission line.

6. A high-frequency wave filter system for passing waves over a broad band of frequencies in the vicinity of a first frequency and attenuating waves having frequencies extending over a narrow band of frequencies in the vicinity of a second frequency from said first frequency comprising a main transmission line for carrying waves having frequencies lying in said bands of frequencies, a section of transmission line substantially one-eighth of a wave length long at the mean of said first and second frequencies, a reactive impedance element connected across one end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, the magnitude of said capacitive reactance at said first frequency and magnitude of said inductive reactance at said second frequency each being equal to the magnitude of the characteristic impedance of said section of transmission line, said section of transmission line having a characteristic impedance substantially less than the characteristic impedance of the main transmission line, and an impedance transformer for coupling the other end of said one-eighth section in shunt with said main transmission line.

7. A high-frequency wave filter system for rejecting waves over a broad band of frequencies in the vicinity of a first frequency and transmitting waves having frequencies extending over a narrow band of frequencies in the vicinity of a second predetermined frequency closely spaced from said first frequency, comprising a main transmission line for carrying waves having frequencies lying in said bands of frequencies, a section of transmission line substantially one-eighth of a wave length long at the mean of said first and second frequencies, a reactive impedance element connected across one end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, the magnitude of said capacitive reactance at said first frequency and the magnitude of said inductive reactance at said second frequency each being equal to the magnitude of the characteristic impedance of said section of transmission line, said section of transmission line having a characteristic impedance substantially less than the characteristic impedance of said main transmission line, a section of transmission line one-half of a wave length long at said mean frequency having one end connected in shunt with said main transmission line and the other end connected to the other end of said one-eighth wave length section.

8. A high-frequency wave filter system for rejecting waves over a broad band of frequencies in the vicinity of a first frequency and transmitting waves having frequencies extending over a narrow band of frequencies in the vicinity of a second predetermined frequency closely spaced from said first frequency, comprising a main trans-

mission line for carrying waves having frequencies lying in said bands of frequencies, a section of transmission line substantially one-eighth of a wave length long at the mean of said first and second frequencies, a reactive impedance element connected across one end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, the magnitude of said capacitive reactance at said first frequency and the magnitude of said inductive reactance at said second frequency each being equal to the magnitude of the characteristic impedance of said section of transmission line, said section of transmission line having a characteristic impedance substantially less than the characteristic impedance of said main transmission line, a section of transmission line one-quarter wave length long at said mean frequency having one end connected in shunt with said main transmission line and the other end connected to the other end of said one-eighth wave length section.

9. A high-frequency wave filter element for presenting a low impedance to waves of a first frequency and a high impedance to waves of a second frequency closely spaced from said first frequency, comprising a first section of transmission line having a length equal to an integral odd number of quarter wave lengths at the mean of said frequencies and being open circuited at one end, a second section of transmission line having a length equal substantially to an odd number of substantially one-eighth wave lengths at said mean value and having a characteristic impedance relatively low with respect to the characteristic impedance of said first section of transmission line, one end of said second section being connected to the other end of said first section, the characteristic impedance and length of said first section being so chosen such that said first section of said transmission line presents a capacitive reactance to said one end of the one-eighth section at said first frequency and an inductive reactance at said second frequency, said capacitive reactance at said first frequency and said inductive reactance at said second frequency each being equal to the characteristic impedance of said section of transmission line.

10. A high-frequency wave transmission system comprising a source of high-frequency waves, a utilization means for high-frequency waves responsive to said source of high-frequency waves, and a high-frequency wave filter having resonance at a first frequency and anti-resonance at a second frequency closely spaced from said first frequency, interposed between said source of high-frequency waves and said utilization means, said high-frequency wave filter comprising a section of transmission line substantially one-eighth of a wavelength long at the mean of said first and second frequencies, a reactive impedance element connected across one end of said section, said reactive impedance element having zero reactance at said mean frequency, a capacitive reactance at said first frequency and an inductive reactance at said second frequency, said capacitive reactance at said first frequency and said inductive reactance at said second frequency each being equal to the characteristic impedance of said section of transmission line whereby at the other end of said section of transmission line appears a low impedance at one of said frequencies and high impedance at the other of said frequencies.

References Cited in the file of this patent

UNITED STATES PATENTS

2,270,416	Cork	June 20, 1942
2,421,033	Mason	May 27, 1947
2,484,798	Bradley	Oct. 11, 1949
2,507,692	Collard	May 16, 1950
2,626,990	Pierce	Jan. 27, 1953
2,701,339	Everett	Feb. 1, 1955
2,751,557	Sosin	June 19, 1956