June 8, 1943. H. SALINGER 2,321,521

FREQUENCY BAND FILTER

Filed Jan. 10, 1941 2 Sheets-Sheet 1

FIG. 1

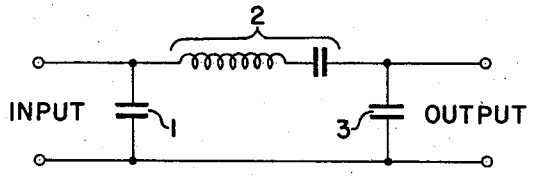


FIG. 2

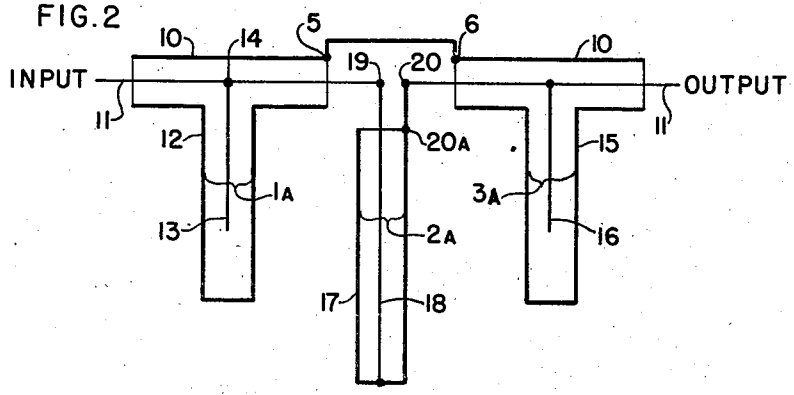


FIG. 3

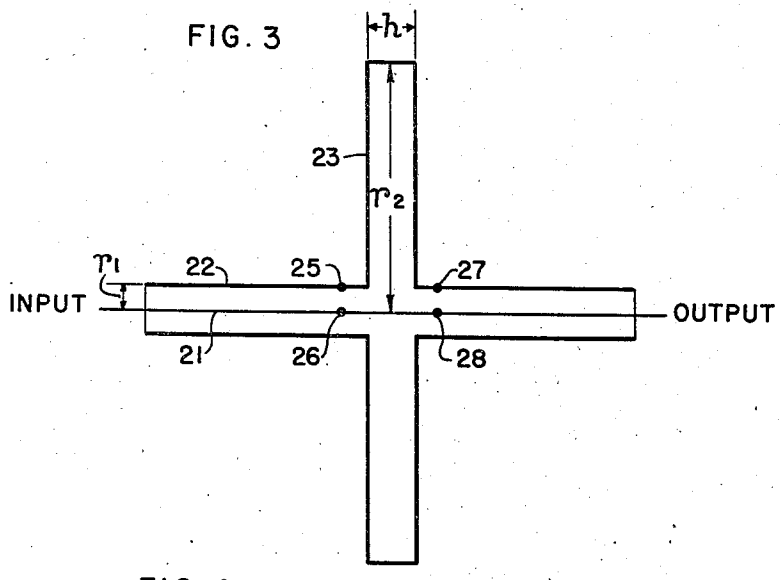
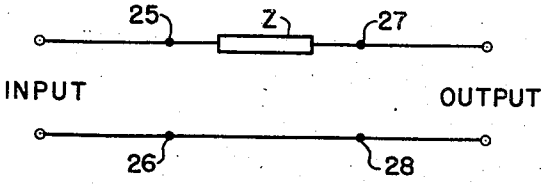


FIG. 4



INVENTOR

HANS SALINGER

BY Edwin S. Hartin

ATTORNEY

June 8, 1943. H. SALINGER 2,321,521

FREQUENCY BAND FILTER

Filed Jan. 10, 1941 2 Sheets-Sheet 2

FIG. 5

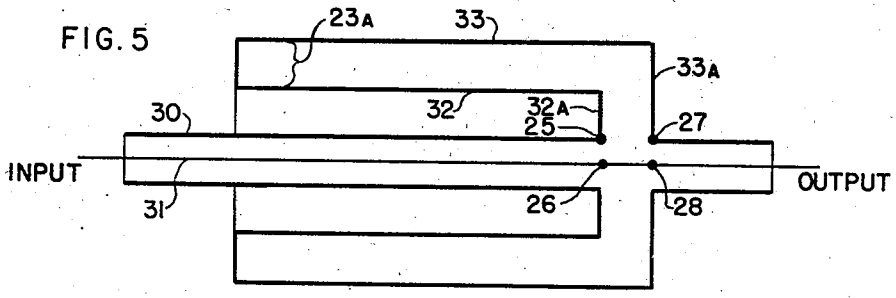


FIG. 6

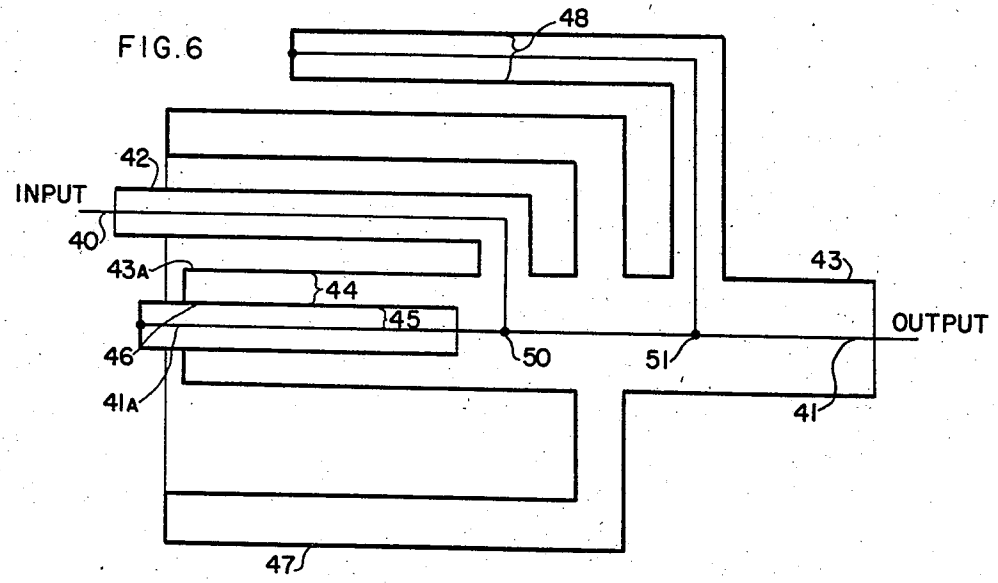
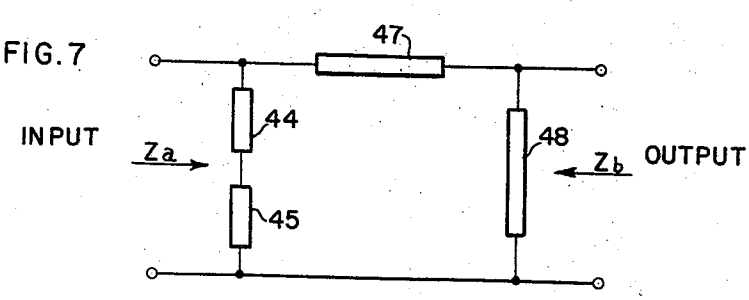


FIG. 7



INVENTOR
HANS SALINGER
BY Edwin S. Martin
ATTORNEY

Patented June 8, 1943

2,321,521

UNITED STATES PATENT OFFICE

2,321,521

FREQUENCY BAND FILTER

Hans Salinger, Fort Wayne, Ind., assignor to Farnsworth Television and Radio Corporation, a corporation of Delaware

Application January 10, 1941, Serial No. 373,870

2 Claims. (Cl. 178—44)

This invention relates to four-terminal networks composed of transmission-line elements and particularly relates to such networks having filter or transformer characteristics.

Filtering and transforming networks of various types generally comprise shunt reactances and series reactances. For relatively low frequencies these reactances may be represented by lumped elements such as conventional inductance elements and condensers. At higher frequencies, in the order of 30 megacycles and above, however, such practice is no longer practical and it is preferable to employ transmission-line elements.

Consequently, it is necessary to provide transmission-line elements representing shunt and series reactances. Various satisfactory methods of obtaining shunt reactances have been proposed but heretofore no satisfactory transmission-line element and incorporation thereof in a main transmission line to represent a series reactance has been provided.

The main disadvantage hitherto encountered in providing a series-reactance element in a main transmission line was that such an element could not be connected into the main transmission line without causing serious defects such as radiation losses, changes in transmission characteristics and the like.

The object of the present invention, therefore, is to provide a new and improved four-terminal network composed of transmission-line elements including a series-reactance element in which no radiation losses and no changes in transmission characteristics are incurred.

In accordance with the present invention there is provided a four-terminal transmission-line network comprising a coaxial main line having an inner conductor and a shield conductor joining the input and output ends of the network. There are also provided means connected to the main line and providing a surface constituting an extension of the surface of one of said main-line conductors whereby current waves travel a substantially longer distance along the surface of one of said conductors than along the other between the input and output ends of the network, thereby effectively providing a series reactance in the network.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 shows a conventional type of four-terminal network while Fig. 2 shows the same network composed of transmission-line elements in the conventional manner; Fig. 3 shows an embodiment of the invention while Fig. 4 shows its equivalent network; Fig. 5 shows preferred modifications of the embodiment of Fig. 3 while Fig. 6 shows a four-terminal network embodying the present invention and Fig. 7 shows its equivalent circuit.

Referring now more particularly to Fig. 1 of the drawings, there is shown a single mesh of a conventional filter having input and output terminals as labelled, an input shunt capacitance element 1, a series reactance 2 comprising inductance and capacitance elements as shown and an output shunt capacitance element 3.

Fig. 2 shows the equivalent four-terminal network composed of transmission-line elements constructed in the conventional manner in which reactance elements corresponding to the elements 1, 2 and 3 of the circuit of Fig. 1 are indicated by the numerals 1A, 2A and 3A respectively. The network of Fig. 2 comprises a main coaxial-transmission line including an outer shield conductor 10 and concentrically arranged therein an inner conductor 11. The main line is interrupted between points 5 and 6. Joined to the portion of the shield conductor 10 shown to the left of point 5 there is provided a shield conductor 12 and an inner conductor 13 which latter is connected to the inner conductor 11 of the main line at a point 14. The transmission line 1A comprising the conductors 12 and 13 is designed to constitute a shunt capacitance element. Similarly, the portion of the main line to the right of point 6 is likewise provided with a transmission-line element having an outer conductor 15 and an inner conductor 16 constituting the transmission-line element 3A which, as said before, represents a shunt capacitance element.

For the purpose of providing a series-reactance element, it is conventional to provide a transmission-line element 2A comprising an outer shield conductor 17 and an inner conductor 18 connected thereto at one end. At the other end of the transmission line, the inner conductor 18 is connected to the left portion of the inner conductor 11 of the main line at a point 19, while the shield conductor 17 is connected to the right portion of the inner conductor 11 of the main line at a point 20. It may be seen that current flows from the inner conductor 11 to the inner conductor 18 of the transmission-line element

2A then through the inner surface of the shield conductor 17 of line 2A to the junction point 20 on the inner conductor 11 of the main line. It may also be noted that at the point 20A at which a lead wire to the point 20 is connected, current also flows on the outer surface of the shield conductor 17. This current flows through distributed stray capacity to adjacent filter elements or to ground, hence constituting a radiation loss and thereby also changing the transmission characteristics of the four-terminal network which is highly undesirable.

Fig. 3 shows an embodiment of the present invention comprising a main transmission line having an inner conductor 21 and an outer shield conductor 22. For the purpose of providing a series-reactance element in the transmission line there is provided a hollow annular member 23, joined to the shield conductor 22 and constituting an extension of the inner surface thereof. The member 23 shall, for sake of convenience, be referred to as a radial channel.

In operation, current flows along the outer surface of the inner conductor 21 and the inner surface of the shield conductor 22 from the input to the output end of the transmission line. For the purpose of determining the electrical effect of the member 23, voltage measurements may be made between points 25 and 26, and 27 and 28, respectively. It is then found that the voltage between points 27 and 28 is equal to the sum of the voltages between points 25 and 26 and the voltages between points 25 and 27. Due to the fact that the current traveling along the inner surface of the element 23 between points 25 and 27 travels a substantially longer distance than the current along the inner conductor between points 26 and 28, the current through the outer conductor will be delayed in phase with respect to the current through the inner conductor and hence the voltage between points 27 and 28 will differ in phase from that between points 25 and 26 as if a lumped series-reactance element had been connected in one of the current paths.

Fig. 4 shows the equivalent circuit, like points being indicated by the same numerals as in Fig. 3 and Z representing the effective reactance of the member 23. The impedance of the structure shown in Fig. 3 can be calculated to be

$$Z=\frac{60hj}{r_1}\times\frac{J_0(\rho_1)Y_0(\rho_2)}{J_1(\rho_1)Y_0(\rho_1)}-\frac{J_0(\rho_2)Y_1(\rho_1)}{Y_1(\rho_1)J_0(\rho_2)}$$

whereby h indicates the distance between the radial portions of the member 23, r_1 the inner radius of the shield conductor 22, r_2 the radius of the annular member 23,

$$\rho_1=\frac{\omega}{c}r_1,\ \rho_2=\frac{\omega}{c}r_2$$

ω the frequency in radians per second, c the velocity of propagation, j the square root of minus 1, J_0, J_1, Y_0, Y_1 Bessel functions of order 0 and 1, first and second kind, respectively.

In practice, the radius r_2 of the member 23 becomes rather large and therefore renders a rather cumbersome structure, particularly so if this element is to be incorporated in a network together with other transmission-line elements.

Therefore, the embodiment shown in Fig. 5 is preferred. This embodiment includes a main transmission line having a shield conductor 30 and an inner conductor 31. The member generally indicated at 23A and corresponding to member 23 of Fig. 3 is bent over so as to form a pair of members 32 and 33, substantially concentric with the main line and extending throughout a substantial portion of the length thereof. The same fundamental considerations apply to this embodiment as to that of Fig. 3 and similar voltage relations between points 25 and 26, and 27 and 28, respectively.

It may be seen from the drawings of Fig. 5 that the short radial channel comprising portions 32A and 33A of the members 32 and 33, respectively, is also a part of the concentric transmission line formed by the members 32 and 33. The radial channel should be so designed that it has the same characteristic impedance Z_0 as the transmission line comprising the cylindrical portions of members 32 and 33. The radial channel also has an electrical length L which will add to that of the concentric portion of the transmission line. If r_1 and r_2 are the inner and outer radius of the short radial channel respectively, h the distance between members 32A and 33A, then Z_0 and L may be found approximately from the following formulas:

$$Z_0=60h\sqrt{\frac{2\log_e r_2/r_1}{r_2^2-r_1^2}}$$

$$\sin\frac{\omega}{c}L=\frac{\omega}{c}\sqrt{\frac{r_2^2-r_1^2}{2}\log_e\frac{r_2}{r_1}}$$

An example of how this invention may be used in a four-terminal network is shown in Fig. 6. A composite transmission line comprising inner conductors 40 and 41 with their respective shield conductors 42 and 43 is considered as the main line connecting the input with the output ends. For the purpose of providing an input shunt impedance there is provided a pair of concentric transmission lines 44 and 45. The line 44 comprises the inner surface of a shield conductor 43A which is an extension of the shield conductor 43 and the outer surface of a concentric shield conductor 46. The transmission line 45 is composed of the inner surface of the shield conductor 46 and an inner conductor 41A, the latter being an extension of the inner conductor 41. The structure comprising transmission lines 44 and 45 represents a shunt reactance across the input end of the main line comprising the inner conductor 41 and the shield conductor 42, since an input current flowing along the inner surface of the shield conductor 42 proceeds along the inner surface of the shield conductor 43A, the outer surface of shield conductor 46, the inner surface of shield conductor 46, finally to the inner conductor 41A. Hence it may be seen that the shunt reactance across the input end of the main line comprises the series combination of transmission lines 44 and 45.

For the purpose of providing a series reactance, there is provided a concentric cylindrical structure 47 which is substantially identical with the structure 23A of Fig. 5 comprising members 32 and 33 with their respective radial portions 32A and 33A. For the purpose of providing an output shunt impedance, there is provided a transmission line element 48 in the conventional manner.

Fig. 7 shows the equivalent circuit of the transmission-line structure of Fig. 6, the equivalent lump impedances being designated by the same reference numerals as the transmission line in Fig. 6. In the design of such a filter, it is necessary first to compute the impedance values which the transmission-line elements 44, 45 and 48 respectively, represent. If, for ex-

ample, the transmission line 44 is short-circuited at its end, this impedance will be

$$jZ_1 tg \frac{\omega}{c} L_1$$

wherein Z_1 is the characteristic impedance of this line and L_1 its length. Z_1 is, as well known, given by the formula

$$Z_1 = 60 \log_e \frac{r_2}{r_1}$$

wherein r_2 is the radius of the inner surface of the shield conductor 43A while r_1 is the outer radius of the shield conductor 46. The method of filter design will be evident to those skilled in the art.

Usually two characteristic image impedances, Z_a and Z_b, are ascribed to a filter mesh as shown in Fig. 7. The main line of the wave filter should have at its output end, a characteristic impedance Z_b and at its input end a characteristic impedance Z_a. In order to minimize undesired reflections Z_a may be made equal to Z_b in the desired transmission range of the frequency band. If this is not done, the filter will, at the same time, act as a transformer, stepping up or down the input voltage according to whether Z_b is greater or smaller than Z_a respectively. While this effect may be undesirable in some cases, it can be made use of in the construction of ultra-high frequency transformers composed of transmission-line elements to which the filter action is only incidental.

If a single network mesh, as shown by Figs. 6 and 7, does not provide sufficient filtering or transforming action, further meshes may be added thereto. The characteristic input impedance Z_{a2} of the second mesh should then be made equal to the characteristic output impedance Z_{b1} of the first mesh connected thereto. The main transmission line may have any length between the filter sections, provided the whole structure is properly matched by the final load. However, the distance within a filter section, that is, the distance between points 50 and 51 of Fig. 6, should be as small as possible as compared with the electrical wavelengths of the frequency band to be transmitted.

While the transmission-line elements 44, 45, 47 and 48 constituting shunt and series reactances have been shown as short-circuited at their far ends for the purpose of preventing radiation losses, it may be understood, however, that these transmission-line ends may also be open-circuited or terminated by condensers or the like without departing from the scope of this invention. In some cases it is possible to leave these transmission-line ends open-circuited without incurring losses as in the case of transmission-line elements 1A and 3A of Fig. 2 where the center conductors 13 and 14 are not connected to their shields 12 and 15 respectively, and are much shorter than the latter, so that the shields can be mechanically closed without electrically short-circuiting the lines at their ends.

It may also be understood that the transmission-line elements representing shunt and series reactance may also be made tunable by providing movable plugs at the short-circuited end thereof. In the case of the series reactance element, as shown in Fig. 5, it is also possible to make either or both of the radial portions 32A or 33A respectively movable in axial direction so as to provide a tuning means. Other possibilities will be evident to those skilled in the art.

In the above there has been described a new and improved series-reactance transmission-line element and its connection in a main transmission line without incurring radiation losses or changes. There has also been shown how this transmission-line element can be used in combination with others in a composite four-terminal transmission-line network comprising shunt and series-reactance elements to provide a network having filter or transformer characteristics, or both.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A four-terminal transmission-line network comprising a coaxial main line having an inner conductor and a shield conductor connected to the input and output ends of the network, and means connected to said main line providing a surface constituting a physical extension of the surface of one of said main line conductors and having a configuration such that it presents a pair of spaced cylindrical elements concentric with said main line conductors throughout a substantial portion of the length thereof, whereby current waves travel a substantially longer distance along the surface of said one of said conductors than along in the other between said input and output ends of said network effectively to provide a series reactance in said network.

2. A four-terminal transmission-line network comprising a coaxial main line having an inner conductor and a shield conductor connected to the input and output ends of the network, and means connected to said main line providing a surface constituting a physical extension of the surface of one of said main line conductors and having a configuration such that it presents a pair of spaced cylindrical elements surrounding said main line conductors throughout a substantial portion of the length thereof, whereby current waves travel a substantially longer distance along the surface of said one of said conductors than along the other between said input and output ends of said network effectively to provide a series reactance in said network.

HANS SALINGER.

CERTIFICATE OF CORRECTION.

Patent No. 2,321,521. June 8, 1943.

HANS SALINGER.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 3, second column, line 46, claim 1, after the word "along" strike out --in--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 24th day of August, A. D. 1943.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.