Oct. 3, 1967 G. C. DI PIAZZA 3,345,589

TRANSMISSION LINE TYPE MICROWAVE FILTER

Filed Dec. 14, 1962

2 Sheets-Sheet 1

FIG. 1

PRIOR ART

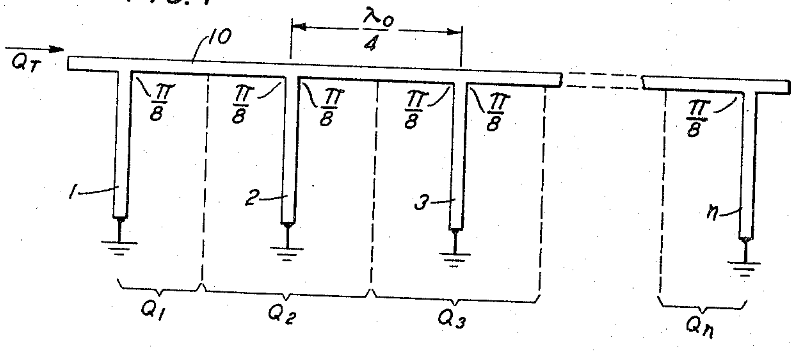

FIG. 2

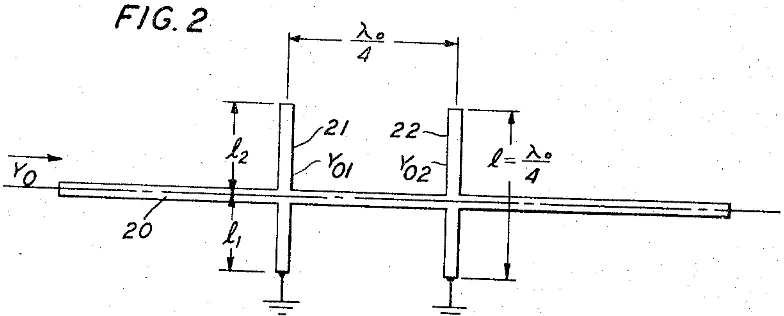

FIG. 3

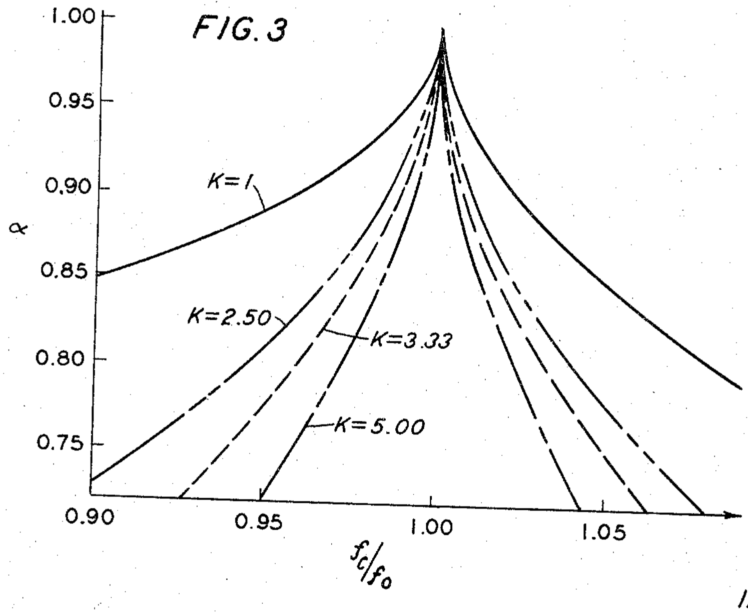

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FIG. 4

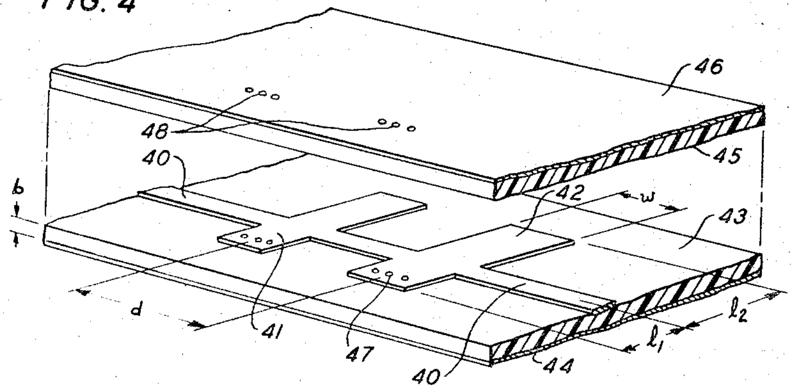


FIG. 5

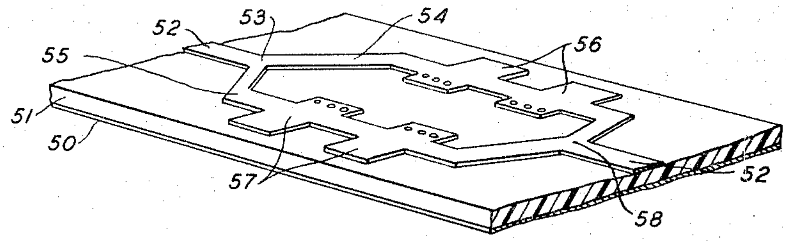


FIG. 6

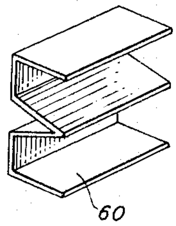


FIG. 8

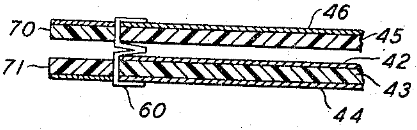
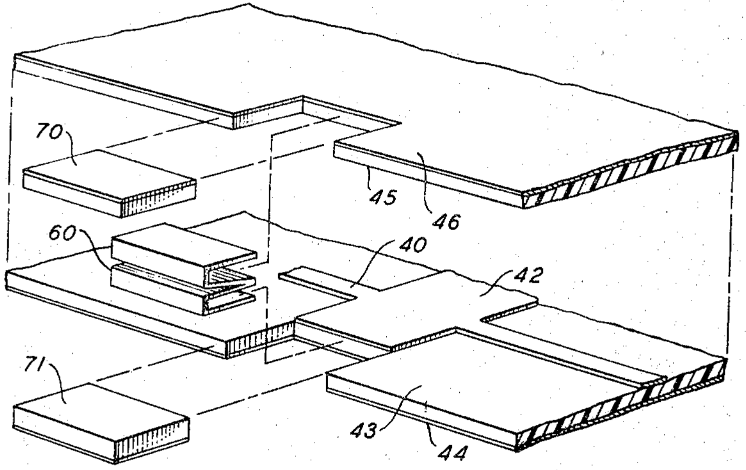


FIG. 7



United States Patent Office

3,345,589

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3,345,589

TRANSMISSION LINE TYPE MICROWAVE FILTER

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7 Claims. (Cl. 333—73)

The present invention relates to frequency selective networks, and more specifically to narrow-band microwave filters.

In many microwave applications, it is desirable to transmit a narrow band of frequencies while simultaneously suppressing all other frequencies. Prior art filters for accomplishing this end have taken many and varied forms including the well known capacity-coupled half-wave resonator structures. Examples of such devices are disclosed in United States Patents Nos. 2,859,417 and 2,867,782, both granted to M. Arditi on Nov. 4, 1958, and Jan. 6, 1959, respectively.

Most of the prior art filters, due largely to the inherent limitations of the resonator structures employed, suffer one or more practical disadvantages. These disadvantages often include high inband insertion loss, relatively low selective capability and relative difficulty of design or construction. It is therefore an object of the present invention to reduce the inband insertion losses in narrow-band microwave bandpass filters.

It is a further object of the present invention to increase the selective capabilities of microwave bandpass filters.

It is another object of the present invention to simplify the design and construction of high selectivity microwave bandpass filters.

The foregoing objects are accomplished in accordance with the principles of the present invention by utilizing a transmission line having a uniform characteristic admittance across which there are shunt-connected transmission line elements having characteristic admittances greater than that of the uniform line. As used herein, the term "transmission line" is understood to mean any structure capable of supporting propagating high frequency electromagnetic wave energy. Such structures can include coaxial lines, strip transmission lines, parallel wire transmission lines and conductively bounded waveguiding structures. The shunt transmission line elements are open-circuited at one end and short-circuited at the other end. The connection between the uniform line and each shunt line is at a point intermediate these two ends. A shunt transmission line element connected in this fashion is known as a "tapped stub." The ratio of the length of the open stub section to the total stub length is known as the "tapping ratio."

By utilizing the so-called "loaded Q" approach, it has been found that, as the ratio of stub-to-line characteristic admittance is increased, the selectivity of the filter is likewise increased. The selectivity of the filter of the present invention can be further increased by increasing the tapping ratio mentioned above.

In another embodiment of the invention, even greater selectivity is obtained by the utilization of a branched transmission line configuration. In this embodiment, a first uniform transmission line branches into a plurality of secondary uniform transmission lines. In general, the characteristic admittance of each branching line is substantially equal to that of the first uniform line divided by the number of branching lines. Frequency selective stubs or circuits are shunt-connected across each of the secondary lines. The secondary transmission lines again converge to form a uniform transmission line having a characteristic admittance substantially equal to that of the first uniform line.

A distributed shorting element for conductively shorting a section of a strip transmission line or stub to a pair of extended conductive ground planes is also described. This element consists of a thin piece of conductive material bent into the form of an E and held in physical and electrical contact with the ground planes and center conductive strip by external clamping means.

The above mentioned and other features and objects of the present invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic illustration of a transmission line filter of the type well known in the prior art;

FIG. 2 is a schematic illustration of a two-element bandpass filter in keeping with the principles of the present invention;

FIG. 3 is a graphical representation of the tapping ratio of the shunt stubs of the embodiment of FIG. 2 plotted as a function of normalized frequency for various ratios of stub-to-line characteristic admittances;

FIG. 4 is a pictorial view of the embodiment of FIG. 2 adapted for a strip transmission line configuration;

FIG. 5 is a pictorial illustration of a second embodiment of the present invention adapted for strip transmission line configuration;

FIG. 6 is a pictorial view of an improved distributed-type shorting element capable of being employed in stirp transmission line devices;

FIG. 7 is an exploded pictorial view of a portion of the embodiment of FIG. 4 showing the manner in which the distributed shorting element of FIG. 6 is utilized; and

FIG. 8 is a cross-sectional view of the embodiment of FIG. 4 showing the distributed shorting element of FIG. 6 in place.

Referring more specifically to the drawings, FIG. 1 is a schematic illustration of a transmission line filter of the type well known in the art. In this structure, a plurality of transmission line stubs designated **1**, **2**, **3** . . . *n* are connected at one-quarter wavelength intervals to a uniform transmission line **10**.

The total Q of the filter Q_T represents a combination of the Q's of the constituent sections. These Q's are designated Q_1, Q_2, Q_3 . . . Q_n and comprise the Q of each stub plus the compensation for the selectivity introduced by the sections of line **10** immediately adjacent to each stub. It is well known that the Q attributable to a one-quarter wavelength section of uniform line in such a filter can be approximated, in a narrow-band filter, by the addition of the factor $\pi/8$ to the Q of each stub. (See U.S. Patent No. 2,540,488 granted to W. W. Mumford on Feb. 6, 1951.)

The Q's of each section can therefore be specified as

$$
\begin{aligned}
Q_1 &= Q_{s1}+\frac{\pi}{8} \\
Q_2 &= Q_{s2}+\frac{2\pi}{8} \\
Q_3 &= Q_{s3}+\frac{2\pi}{8} \\
&\cdot \quad \cdot \quad \cdot \\
&\cdot \quad \cdot \quad \cdot \\
&\cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\
&\cdot \quad \cdot \quad \cdot \\
Q_n &= Q_{sn}+\frac{\pi}{8} \qquad (1)
\end{aligned}
$$

where Q_{s1}, Q_{s2}, Q_{s3}, . . . Q_{sn} represents the Q of each stub **1**, **2**, **3**, . . . *n*, respectively.

In the above cited patent of W. W. Mumford, it is stated that for a maximally-flat bandpass filter, the Q of any section is given by

$$Q_r = Q_T \sin\left(\frac{2r-1}{2n}\right)\pi \tag{2}$$

where r denotes the order of the stub. (See also U.S. Patent No. 1,849,656 granted to W. R. Bennett on Mar. 15, 1932.)

In terms of the characteristic admittance, it can be shown that

$$Q_{sr} = \frac{\frac{\pi}{4}}{\tan^{-1}\left(\frac{2Y_0}{Y_{0r}}\right)} \tag{3}$$

where Y_0 is the characteristic admittance of line **10** and Y_{0r} is the characteristic admittance of the rth stub.

Since it is a useful parameter in the design of filters in accordance with the present invention, the ratio Y_{0r}/Y_0 will be designated hereinafter as k_r.

From Equation 3 it is obvious that the Q of a stub increases as its characteristic admittance Y_{0r} increases. In general, therefore, high Q is characterized by high stub admittance.

It has been found that the use of a tapped stub configuration in transmission line filters yields higher Q's than the shorted stub configuration of FIG. 1. A schematic diagram of a two element tapped stub bandpass filter is shown in FIG. 2. In general, any number of stubs can be utilized in practicing the present invention; however, for the purposes of illustration, a filter utilizing two stubs is described.

The bandpass filter of FIG. 2 consists of a length of uniform transmission line **20** having a characteristic admittance Y_0 across which are connected tapped transmission line stubs **21** and **22**. Stubs **21** and **22**, which have characterstic admittances Y_{01} and Y_{02}, respectively, are connected in shunt with line **20** and spaced apart one-quarter wavelength at the midfrequency of the band of frequencies to be passed. The overall length of each stub **21** and **22** is also one-quarter wavelength at said midband frequency, although as will be discussed in greater detail hereinbelow, the length and spacing of these stubs can be any odd multiple of one-quarter wavelength. The connections between line **20** and stubs **21** and **22** are made at points intermediate their respective ends. Each stub is open circuited at one end and short circuited at the other end. The electrical distance from the tapped connection to the shorted end of each stub is designated l_1 and the distance between this connection and the open end is designated l_2. From Equation 2 the Q's of stubs **21** and **22** are

$$Q_1 = Q_T \sin\left(\frac{2-1}{4}\right)\pi = 0.707 Q_T$$
$$Q_2 = Q_T \sin\left(\frac{4-1}{4}\right)\pi = 0.707 Q_T \tag{4}$$

or

$$Q_1 = Q_2 \tag{5}$$

and since Y_0 is constant, it is seen from Equation 3 that $Y_{02} = Y_{01}$.

The value of susceptance due to stub **21** or **22** at the junction of line **20** and the stub is described by

$$jB = jY_{01} \tan \beta l_2 - jY_{01} \cot \beta l_1 \tag{6}$$

where β is the phase constant of the stub and is equal to $2\pi/\lambda$, where λ is the wavelength measured along the stub. The normalized susceptance B_N can be found by dividing Equation 6 by the characteristic admittance Y_0 of line **20**.

$$jB_N = \frac{jY_{01}}{Y_0} \tan \beta l_2 - \frac{jY_{01}}{Y_0} \cot \beta l_1 \tag{7}$$

and since

$$\frac{Y_{01}}{Y_0} = k_1 = \frac{Y_{02}}{Y_0} = k_2 = k$$

then

$$jB_N = jk \tan \beta l_2 - jk \cot \beta l_1 \tag{8}$$

Since the tapping ratio $\alpha = l_2/l$, then $l_1 = (1-\alpha)l$, and

$$B_N = k[\tan \alpha\beta l - \cot (1-\alpha)\beta l]$$
$$= k\left[\tan \alpha\beta l - \frac{1+\tan \beta l \tan \alpha\beta l}{\tan \beta l - \tan \alpha\beta l}\right]$$
$$B_N = k\left[\frac{\tan^2 \alpha\beta l + 1}{\tan \alpha\beta l - \tan \beta l}\right] \tag{9}$$

Solving for $\tan \alpha\beta l$,

$$\tan \alpha\beta l = \frac{B_N}{2k} \pm \sqrt{\left(\frac{B_N}{2k}\right)^2 - \left(\frac{B_N}{k} \tan \beta l + 1\right)} \tag{10}$$

It can further be shown that at the half power points the normalized susceptance B_N of the stub is equal to two. Substituting this value of B_N in Equation 10 gives

$$\tan \alpha\beta_c l = \frac{1}{k} \pm \frac{1}{k}\sqrt{1 - k^2 - 2k \tan \beta_c l} \tag{11}$$

where β_c is the phase constant of the stub at the cutoff or half power points. Since $l = \lambda_0/4$,

$$\beta_c l = \left(\frac{2\pi}{\lambda_c}\right)\left(\frac{\lambda_0}{4}\right) = \frac{\pi f_c}{2f_0} \tag{12}$$

where f_0 and f_c are the frequencies corresponding to midband and cutoff respectively.

Substituting and solving for α

$$\alpha\Big|_{f>f_0} = \frac{\tan^{-1}\left[\frac{1\left[1-k^2-2k \tan \frac{\pi f_c}{2f_0}\right]^{1/2}}{k}\right]}{\frac{\pi f_c}{2f_0}} \tag{13}$$

$$\alpha\Big|_{f<f_0} = \frac{\tan^{-1}\left[\frac{-1+\left[1-k^2-2k \tan \frac{\pi f_c}{2f_0}\right]^{1/2}}{k}\right]}{\frac{\pi f_c}{2f_c}} \tag{14}$$

As shown hereinabove, the loaded Q or each stub section can be increased by increasing the ratio *k* while keeping the other variables constant. The selectivity of a bandpass filter in accordance with the present invention, therefore, can be improved by making the ratio *k* larger than unity. However, since the relationship between *k* and the loaded Q is a smooth function this improvement is gradual. As will be discussed in greater detail hereinbelow, it is generally desirable to make *k* as large as possible within limits imposed by the physical dimensions of the filter structure; although in a practical filter, a significant improvement is obtained when the ratio *k* is larger than two.

FIG. 3 is a graphical representation of the tapping ratio α plotted as a function of f_c/f_0, for values of *k* equal to 1.0, 2,5, 3.33, and 5.0. The curves were obtained by inserting the appropriates values of *k* and f_c/f_0, into Equations 13 and 14 and solving for α. From a physical standpoint, the graph of FIG. 3 indicates that, for a given bandwith, a filter can be realized by choosing either a relatively high tapping ratio, α, and low *k*, or a relatively low α and high *k*.

As an illustration of the design procedure, the following example is given. It is the objective of the design to obtain a two-section maximally-flat narrow-band bandpass filter having a center frequency of 2220 megacycles per second and an attenuation of at least 10 decibels at a frequency of 2100 megacycles per second. The filter is to have an insertion loss as small as possible at the center frequency.

The loss function of a maximally-flat filter is given by

$$\frac{P_0}{P_L}=1+\left[Q_T\left(\frac{f}{f_0}-\frac{f_0}{f}\right)\right]^{2n} \tag{15}$$

where again n is the number of stubs. By inserting the design values into Equation 15, the total Q, Q_T, of the filter can be obtained, Thus,

$$\log\frac{P_0}{P_L}=1=\log\left\{1+\left[Q_T\left(\frac{2100}{2220}-\frac{2220}{2100}\right)\right]^4\right\} \tag{16}$$

or

$$Q_T \approx 16$$

In other words, a two-section filter having a total Q of 16 will satisfy the specified design requirements. In order to provide a certain design margin, a convenient bandwith of 100 megacycles per second shall be chosen for the filter. At a center frequency of 2220 megacycles per second, this bandwith corresponds to a Q_T of 22.2.

The schematic diagram of the illustrative filter corresponds to that shown in FIG. 2 and the nomenclature and numbers of the various elements are therefore carried over to this example.

Substituting into Equation 2, the Q of each section is,

$$Q_1=22.2 \sin \pi/4=157 \tag{17}$$

$$Q_2=22.2 \sin 3\pi/4=15.7 \tag{18}$$

These values are then substituted into Equation 1 to determine the Q's of the stubs.

$$Q_{s1}=15.7-\pi/8=15.3 \tag{19}$$

$$Q_{s2}=15.7-\pi/8=15.3 \tag{20}$$

These values correspond to a stub bandwith of 145 megacycles per second in the illustrative filter structure. If this bandwidth is normalized by dividing it by the center frequency $f/_0$, the graph of FIG. 3 can be utilized to determine the tapping ratio α of the stubs.

$$\text{B.W.}=\frac{145}{2220}=0.065=\text{normalized bandwidth} \tag{21}$$

In this example, it is assumed that k_1 and k_2 equal 2.5. Therefore, from FIG. 3 the tapping ratio α is approximately 0.83. If a more exact ratio of a tapping ratio is desired, it can be obtained from Equations 13 and 14.

At this point, it should be noted that the curves of FIG. 3 are not quite symmetrical about the center frequency f_0. For this reason, a particular value of α will not yield a value of f_0 which corresponds exactly with the arithmetic mean of the upper and lower cutoff frequency. It is seen, however, that for stubs of high Q this difference between the desired and the actual values of f_0 is negligible.

Once the values of k and α have been determined, it is a relatively simple matter to realize the desired filter. The type of transmission line structure (for example, coaxial line, waveguide, strip transmission line, etc.) should be chosen to meet the application for which the filter is intended. The characteristic admittance of uniform line is generally dictated by the characteristic admittance of the connecting lines of the utilization circuit.

Because of the many advantages enjoyed by strip transmission line structures, further illustrative embodiments of the present invention will be shown with reference to such structure.

A strip transmission line filter, constructed in accordance with the teachings of the present invention, is illustrated in the pictorial view of FIG. 4. In FIG. 4 a uniform strip transmission line **40** having tapped stubs **41** and **42** is bonded, deposited or etched on a dielectric sheet **43**. The dielectric sheet **43** can comprise any suitable low loss material. For example, the materials known commercially as "Teflon" or "Tellite" have been successfully employed in these structures. A conductive ground plane **44** is bonded to the bottom side of sheet **43**. A second sheet of dielectric material **45**, having conductive ground plane bonded to its upper surface, is positioned above sheet **43**. For the purpose of clarity in FIG. 4, the two dielectric sheets are shown separated. In practice, however, it is understood that the two sheets would be clamped together by cover plates or other securing means well known in the art.

Shorting eyelets or rivets **47** are utilized to short circuit the bottom portion of stubs **41** and **42** to ground plane **44**. A similar set of eyelets **48** extend from the upper ground plane **46** through dielectric sheet **45** to contact eyelets **47** and thereby short stubs **41** and **42** to the upper ground plane.

The entire filter structure of FIG. 4 therefore resembles a sandwich wherein the center conductor and the stubs are sandwiched between two conductive ground planes separated by insulating sheets. In such a structure, the characteristic admittances of the center conductor and stubs are functions of their widths and thicknesses as well as the dielectric constant of the insulating sheets and the spacing between the ground planes. The relation between these variables is given in "Reference Data for Radio Engineers," 4th edition, International Telephone & Telegraph Corporation, New York, 1956, pages 598–600.

In the embodiment of FIG. 4, the thickness of the dielectric sheets **43** and **45** is 1/16 inch. The dielectric constant of the material of sheets **43** and **45** is 2.25 over the frequencies of operation. Although, for the sake of clarity, the thicknesses of the ground planes and conductive strips are shown in exaggerated proportion in the drawings, their actual thicknesses are negligible compared to the thicknesses of the dielectric insulating sheets. These dimensions are primarily determined by the commercial availability of the conductively clad dielectric insulating sheets. With the dielectric constant specified, the length of stubs **41** and **42** was determined as 0.88 inch. This corresponds to one-quarter wavelength at the center frequency of 2220 megacycles per second. Since

$$l_2=\alpha l \text{ and } l_1=(1-\alpha)l$$

then

$$l_2=0.732 \text{ inch} \tag{22}$$

and

$$l_1=0.148 \text{ inch} \tag{23}$$

The spacing d between stubs **41** and **42** likewise corresponds to one-quarter wavelength at frequency f_0. Due to the fringing effects associated with the finite width of the stubs, however, it was determined experimentally that the spacing should be increased a few percent for optimum results. The spacing finally employed was 0.905 inch. The characteristic admittance of the uniform line **40** was chosen as 1/50 mho which corresponds to a line width of 0.10 inch. Since the characteristic admittance of stubs **41** and **42** equals k times that of the line, or 1/20 mho, their width are 0.33 inch.

As shown above, high Q is associated with a high ratio k of stub-to-line characteristic admittance. With a filter having the physical structure of the embodiment of FIG. 4, however, the Q can only be increased to a certain point. This is so because as Q increases, k must increase, and with a transmission line of a given characteristic admittance, a greater k corresponds to a greater stub width. When the width of the stubs becomes significant compared to the one-quarter wavelength spacing between them, undesirable fringing effects and interaction between the two stubs occur.

One solution of this problem would be to increase the spacing between the stubs to a higher odd multiple of one-quarter wavelength (for example, three-quarter wavelength). This, however, has the obvious disadvantage of making the overall length of the filter much longer. In addition, such a structure has higher losses and a spurious resonance point corresponding to that frequency at which the spacing equals one-quarter wavelength.

Another solution is to construct the filter in accordance with the embodiment illustrated in the pictorial view of FIG. 5. The principal features of the filter of FIG. 5 are its lower insertion loss and its greater selective capabilities. In the embodiment of FIG. 5 there is shown a conductive ground plane **50** bonded to the lower surface of a dielectric insulating sheet **51**. A uniform transmission line **52** having a given characteristic admittance is bonded, deposited or etched on the upper surface of insulating sheet **51**. At junction **53** along its length, line **52** branches into two separate but substantially identical lines **54** and **55** which again merge into line **52** at junction **58**. The dimensions of lines **54** and **55** are proportioned so that their characteristic admittances are substantially equal to one-half the characteristic admittance of line **52**.

A pair of quarter-wave tapped stubs **56** are shunted across line **54** and spaced apart one-quarter wavelength at the center frequency. A substantially identical pair of stubs **57** are similarly connected across line **55**. The characteristic admittances and tapping ratios α of stubs **56** and **57** are determined in accordance with the design procedure given above except that the uniform line used as a reference is line **52** rather than branching lines **54** and **55**.

Although in the embodiment of FIG. 5, the upper ground plane and insulating sheet are not shown, it is understood that in order to prevent radiation and accompanying losses, it is generally advantageous to utilize these elements in a manner similar to that shown in connection with the filter structure of FIG. 4.

Although only one embodiment is illustrated in FIG. 5, it is understood that it is susceptible to many modifications. For example, more than two branching transmission lines may connect the two sections of uniform line **52**. In such cases, the characteristic admittance of each of the branching lines is substantially equal to that of the uniform line divided by the number of branching lines. Likewise the frequency selective portions of each branching line may take a form other than that of the tapped stubs shown in FIG. 5. Thus, tapped stubs **56** and **57** can be replaced by untapped stubs or other frequency selective microwave circuits known in the art.

Furthermore, if the electrical length of each of the branching lines is made equal to an integral multiple of one-half wavelength at the midband of the band of frequencies to be passed, their characteristic admittances can assume a value other than the described fraction of the characteristic admittance of the uniform line.

In the embodiment of FIGS. 4 and 5, the shorted ends of the tapped stubs are shown connected to the respective ground planes by means of small rivets or eyelets. FIG. 6 shows in pictorial view an alternative device for use in conductively shorting a portion of a strip transmission line to the upper and lower ground planes. Element **60** consists of a thin rectangular piece of conductive material, such as copper, bent into the form of an E. The width of this element is preferably equal to the width of the stub to be shorted.

FIG. 7 is an exploded pictorial view of a portion of the strip transmission line filter of FIG. 4 wherein shorting element **60** has replaced eyelets **47** and **48**. Like numbers have been carried over from FIG. 4 to FIG. 7 to correspond with like structural elements. Blocks **70** and **71** have been cut from the upper and lower dielectric sheets respectively to facilitate insertion of element **60**.

FIG. 8 is a cross-sectional view of the resulting structure with element **60** and blocks **70** and **71** in place. As mentioned hereinabove, cover plates or other securing means, not shown, are placed over ground planes **44** and **46** in order to clamp the two sections together. In FIGS. 6, 7, and 8, the relative thicknesses of the shorting element **60** and the ground planes **44** and **46** have been greatly exaggerated. In practice, these thicknesses are on the order of a few thousands of an inch. As a consequence, there is little if any gap between the strip transmission line and the lower surface of dielectric sheet **45**.

Although certain specific embodiments of the invention have been shown in the drawings and described in the foregoing specification, it is understood that the invention is not limited to those specific embodiments, but is capable of modification and rearrangement by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A filter capable of passing microwave energy over a given band of frequencies comprising, in combination, a uniform transmission line having a given characteristic admittance, a plurality of tapped transmission line stubs shunted across said line at intervals substantially equal to an odd multiple of one-quarter wavelength at the midfrequency of said given band of frequencies, each of said stubs having a length substantially equal to an odd multiple of one-quarter wavelength at said midfrequency, each of said stubs having one open-circuited and one short-circuited end, the connection between said uniform line and each of said stubs being intermediate said ends, and wherein the characteristic admittance of each of said stubs is substantially greater than that of said uniform line.

2. A microwave filter comprising, in combination, a first and second uniform transmission line section having a given characteristic admittance, a plurality of branching transmission lines connected between one end of said first transmission line section and one end of said second transmission line section, the characteristic admittance of each of said branching lines being substantially equal to said given characteristic admittance divided by the number of said branching lines, and at least one separate frequency selective means associated with each of said branching lines.

3. The filter according to claim **2** wherein the length of each of said branching lines is substantially an integral multiple of one-half wavelength at said midfrequency.

4. A balanced strip transmission line filter capable of passing microwave energy extending over a given band of frequencies comprising, in combination, a pair of extended conductive surfaces in spaced parallel relationship, a thin strip of conductive material having a substantially uniform width disposed between said surfaces in parallel relation thereto and conductively insulated therefrom, a plurality of conductive strip stubs conductively connected to said strip at intervals substantially equal to an odd multiple of one-quarter wavelength at the midfrequency of said band of frequencies, said stubs having lengths substantially equal to an odd multiple of one-quarter wavelength at said midfrequency and widths substantially greater than that of said strip, said stubs being connected to said strip at a region along their lengths intermediate their ends, and means for conductively shorting one end of each of said stubs to said conductive surfaces.

5. A balanced strip transmission line filter for electromagnetic wave energy comprising, in combination, a pair of extended conducting surfaces in spaced parallel relationship, first and second longitudinally spaced thin strips of conducting material disposed between said surfaces in parallel relation thereto and conductively insulated therefrom, said first and second strips being dimensionally proportioned to offer a given characteristic admittance to said energy, a plurality of branching strips conductively connecting adjacent ends of said first and second strips, each of said branching strips being dimensionally proportioned to offer a characteristic admittance to said energy which is substantially equal to said given characteristic admittance divided by the number of said branching strips, and separate frequency

selective means associated with each of said branching strips.

6. The filter according to claim 5 wherein two branching strips are utilized and wherein said frequency selective means comprises at least one tapped stub element.

7. A filter capable of passing microwave energy over a given band of frequencies comprising, in combination, a uniform transmission line having a given characteristic admittance, a plurality of tapped transmission line stubs shunted across said line at intervals substantially equal to an odd multiple of one-quarter wavelength at the midfrequency of said given band of frequencies, each of said stubs having a length substantially equal to an odd multiple of one-quarter wavelength at said midfrequency, each of said stubs having one open-circuited and one short-circuited end, the connection between said uniform line and each of said stubs being intermediate said ends, and wherein the characteristic admittance of each of said stubs is at least twice the characteristic admittance of said uniform line.

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Disclaimer

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Hereby enters this disclaimer to claims 1, 4 and 7 of said patent.

[*Official Gazette January 2, 1973.*]