United States Patent

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[54] **LADDER LINE ELLIPTIC FUNCTION FILTER**
3 Claims, 6 Drawing Figs.

[52] **U.S. Cl.** **333/73,** 333/70
[51] **Int. Cl.** **H03h 7/08**
[50] **Field of Search** ..... 333/70 S, 73, 73 S, 73 W

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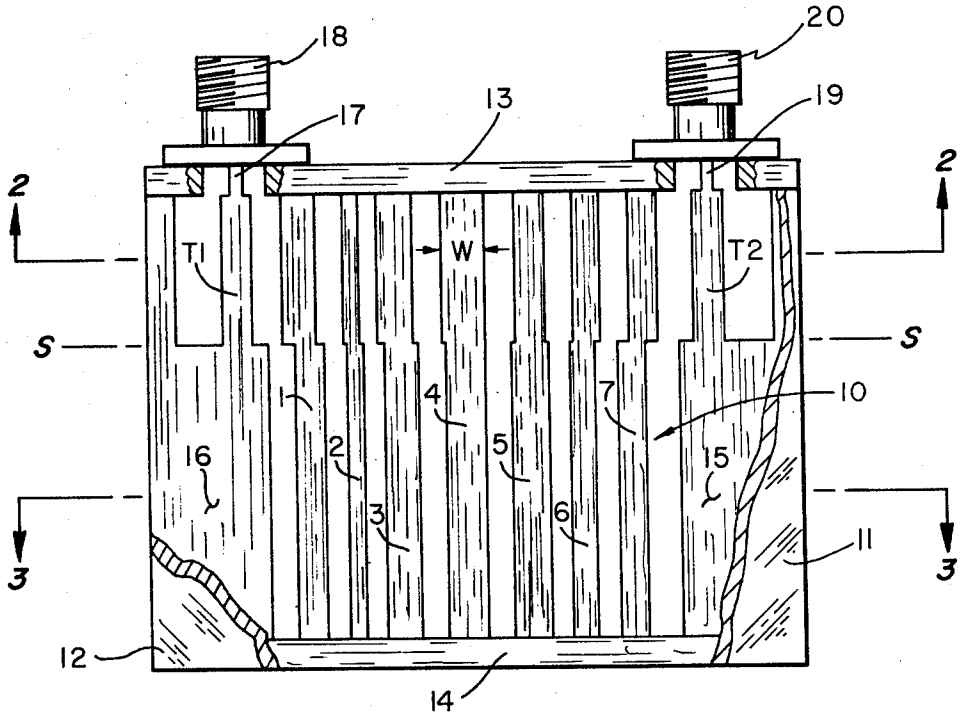
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ABSTRACT: A band pass, elliptic function, microwave filter employs a network of parallel digits forming a ladder line that is disposed between and spaced from a pair of ground plane plates. Each digit is a half wavelength long at the filter's mid-band frequency. Each digit is short circuited at both its ends to the ground planes and is stepped in impedance. Input and output coupling to the ladder line are accomplished by transformer digits located at the ends of the ladder line.



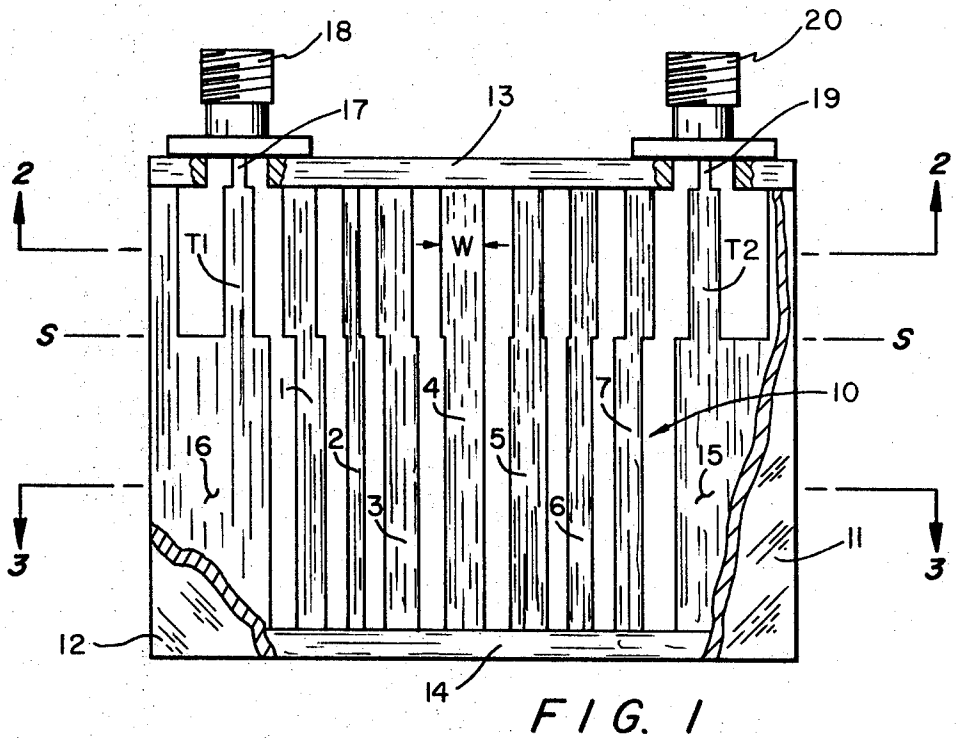


FIG. 1

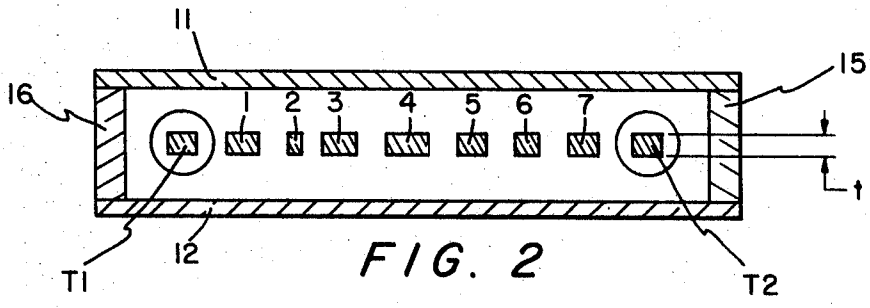


FIG. 2

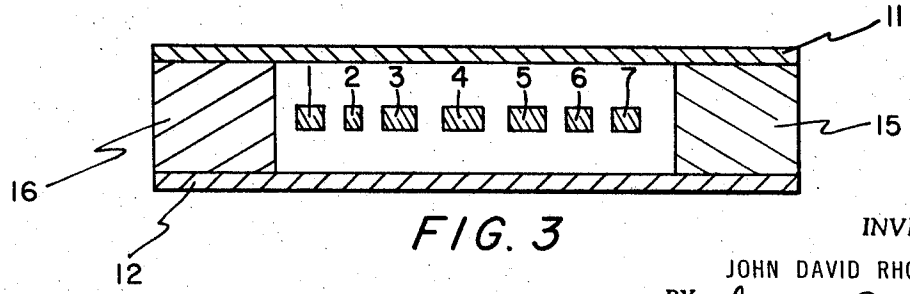


FIG. 3

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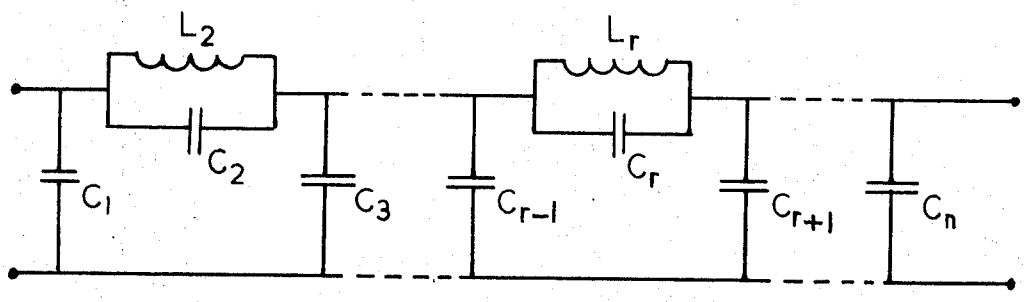


FIG. 4

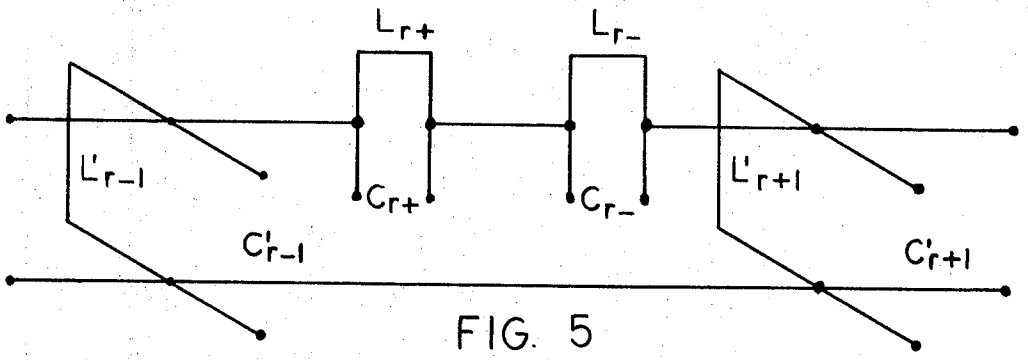


FIG. 5

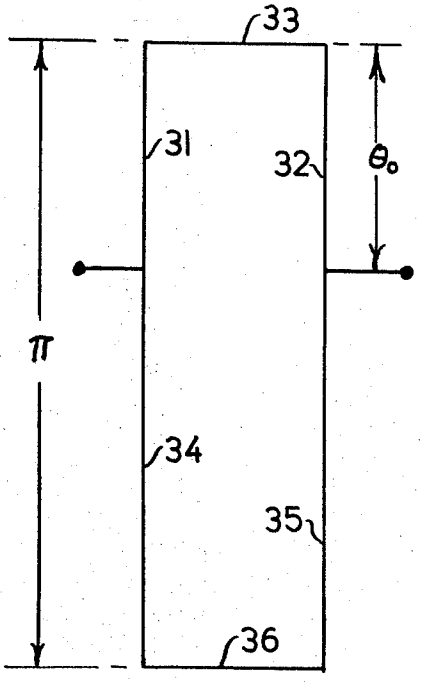


FIG. 6

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LADDER LINE ELLIPTIC FUNCTION FILTER

SUMMARY OF THE INVENTION

This invention relates in general to passive apparatus for filtering signals which are in the microwave portion of the electromagnetic frequency spectrum. More particularly, the invention pertains to an elliptic function, microwave filter utilizing a digital line having stepped impedance levels.

DISCUSSION OF RELATED INVENTION

This invention is related to the stepped digital filter described in my copending U.S. Pat. application Ser. No. 748,318 which was filed in the U.S. Pat. Office on July 29, 1968 and which has issued as U.S. Pat. 3,525,954. In that patent, a realization is presented of a narrow-band, band-pass, elliptic function, microwave filter which utilizes a pair of digital networks connected in parallel. Each network is formed of a series of parallel digits disposed between ground planes. All the digits in each network are of equal length and each is one-eighth wavelength long at the midband frequency of the filter. Corresponding digits of the two networks are in substantial alignment and have their ends joined to form one quarter wavelength long digits. The eighth wavelength digits of one network terminate in short circuits whereas the eighth wavelength digits in the other network terminate in open circuits so that the structure roughly resembles a comb line. The impedances of the digits in one network are different from the impedances of the digits in the parallel network causing a step in impedance to occur at the nodes where aligned digits are joined. The resulting digital structure is analogous to a comb having uneven and crooked teeth. The fringing capacitances at the open circuited ends of the digits, in the very narrow-band filters, have an appreciable effect upon filter performance. Even with the use of a compensation procedure based upon an estimate of the fringing capacitances, it is difficult to construct a very narrow-band filter having the desired electrical performance. Further, in environments where shock or vibration are encountered, the digits, being cantilevered members, can, unless special provisions are made to secure their free ends, be set into mechanical oscillation to the extent that the performance of the filter is affected.

OBJECTIVES OF THE INVENTION

The principal objective of the invention is to provide a narrow-band, band-pass elliptic function, microwave filter having equivalent or better performance than the filter described in my aforesaid patent while eliminating the difficulties caused by the open circuited ends of the stepped digits. The invention resides in employing a stepped digital line in which each digit is short circuited to ground at both ends. That is, a line in which the impedance stepped digits are secured at both ends in the manner of the rungs in a ladder. The digits in the ladder line form cavities that are one half wavelength long at the filter's mid band frequency so that the signal attenuation of the filter is inherently lower than the attenuation of the filter is inherently lower than the attenuation caused by the quarter wave digits in the comb line of my related invention. Further, my ladder line permits greater separation between the ground planes than is feasible in the related invention, thus further reducing the loss in the ladder line filter over that of the comparable comb line filter.

THE DRAWINGS

The invention, both as to its construction and mode of operation can be better understood from the following exposition when considered together with the accompanying drawing in which:

FIG. **1** depicts an embodiment of the invention with parts broken away to show the stepped digital ladder line;

FIG. **2** is a sectional view taken along the plane **2–2** of FIG. **1**;

FIG. **3** is a sectional view taken along the plane **3–3** of FIG. **1**;

FIG. **4** shows, in diagrammatic form, the scheme of a low-pass prototype, lumped constant, elliptic function filter;

FIG. **5** shows the scheme of the filter having short circuited and open circuited commensurate transmission lines that is obtained by performing a frequency transformation upon the FIG. **4** prototype; and

FIG. **6** represents a stepped impedance half wave, cavity formed by two parallel transmission lines.

THE EXPOSITION

FIG. **1** depicts an embodiment of the invention having a digital line **10** disposed between a pair of ground plane plates **11** and **12**. The digital line has seven digits **1**, **2**, **3**, **4**, **5**, **6**, **7**, each of which is a half wavelength long at the center frequency of the filter. Each digit is secured at one end to a side rail **13** and has its other end fastened to a side rail **14**. The digits and the side rails roughly correspond to a ladder and that structure is here termed a "digital ladder." The digits of the ladder are located, as indicated in FIGS. **2** and **3**, between the ground planes **11** and **12** whose uniform separation is maintained by spacers **15**, **16** and the side rails **13**, **14**. In the assembled filter, the digits are completely enclosed by a structure that is at a common (i.e., ground) potential except for the input and output connections. The enclosure is formed by the ground plane plates, the side rails and the spacers. Because the digits are secured to the rails **13**, **14**, each digit is effectively short circuited at both its ends. The digits are stepped in impedance at the plane denominated s–s in FIG. **1**. Because the digits are electrically conductive bars of uniform thickness t and of rectangular cross section, the impedance step occurs as a change in the width W of the digit. From the sectional views of FIGS. **2** and **3**, it can be seen that the widths of the digits indicated in FIG. **2** are different from the widths of the digits in FIG. **3**. Input and output coupling to the digital ladder is accomplished by transformer action through digits T1 and T2 located at the ends of the ladder line. Transformer digit T1 couples to the first digit of the line and transformer digit T2 couples to the last digit of the line. One end of transformer digit T1 is short circuited upon the spacer **16** and its other end is connected to the center conductor **17** of a coaxial connector **18**. Similarly, the transformer digit T2 has one end short circuited upon spacer **15** and has its other end connected to the center conductor **19** of a coaxial connector **20**. The rail **13** is provided with apertures which permit the center conductors to be brought to the transformer digits. The digits are stepped in impedance at the plane denominated s–s in FIG. **1**. Because the digits are electrically conductive bars of uniform thickness t and of rectangular cross section, the impedance step occurs as a change in the width W of the digit. From the sectional views of FIGS. **2** and **3**, it can be seen that the widths of the digits indicated in FIG. **2** are different from the widths of the digits in FIG. **3**.

Referring now to FIG. **4** of the drawings, that figure schematically depicts a basic form of a low pass prototype, lumped, constant, elliptic function filter. This basic form is a cascade of π sections. In each section the legs of the π are shunt capacitances and the cap is a parallel resonant circuit. The "comb" filter described in my aforesaid patent is based upon this prototype and the design procedure for my "ladder" filter is initially similar to the procedure set out in my copending application for the comb filter. The entire disclosure of that patent is here incorporated by reference. An understanding of the design procedure described in that patent is requisite to the apprehension of the design procedure hereinafter set forth. The element values of the FIG. **4** prototype filter may be obtained from "Der Entwurf Von Filtern mit Hilfe des Kalatoges Normierter Trefpasse" by R. Saal, Backnay/Wurtemberg, W. Germany, Telefunken G.M.B.H. 1964. Reliance on R. Saal's tables avoids the task of constructing bounded, real, reflection coefficients from the prescribed insertion-loss function.

To obtain the characteristic admittance matrices which define the stepped digital line, it is necessary to perform two

distinct frequency transformations upon the low pass prototype filter of FIG. 4. The first transformation results in an exact realization by short and open circuited commensurate transmissions lines as schematically represented in FIG. 5 and the second transformation, in general, results in an approximate realization by the ladder filter. In the particular case where the stepped impedance plane s–s is located at one third of the distance between the short circuited ends of the digits, the second transformation is exact at all frequencies.

The general form of the insertion loss function for the low-pass, odd ordered, elliptic function filter of FIG. 4 is

$$L=1+\epsilon^2F^2(\omega) \qquad (1)$$

where $F(\omega)$ is an odd function in ω.

The general distributed band-pass transformation for commensurate transverse electromagnetic mode (T.E.M.) networks is

$$\omega \rightarrow a\left[\frac{\tan\theta}{\tan\theta_0}-\frac{\tan\theta_0}{\tan\theta}\right] \qquad (2)$$

Where

$\theta=\frac{\omega l}{v}$

l = length of commensurate distributed elements

v = velocity of propagation

and a is a bandwidth scaling factor dependent upon the filters band edge frequencies and tan θ_0. Even where the band edge frequencies are defined, we are still in a position to arbitrarily prescribe θ_0, and this property is used when conversion is made to the "ladder" form.

Consider now the basic π section of the low-pass prototype shown in FIG. 4 with shunt capacitances C_{r1}, C_{r+} and a transmission zero at

$$\Omega_r=\frac{1}{L_rC_r}.$$

Upon the application of the frequency transformation given in equation (2), the resonated distributed section shown in FIG. 5 is generated. The corresponding element values for that generated section are

$$C'_{r-1}=\frac{aC_{r-1}}{\tan\theta} \qquad C'_{r+1}=\frac{aC_{r+1}}{\tan\theta_0}$$

$$L'_{r-1}=\frac{1}{aC_{r-1}\tan\theta_0} \qquad L'_{r+1}=\frac{1}{aC_{r+1}\tan\theta_0}$$

$$C_{r+}=\frac{1}{L_{r-}\tan^2\theta_0}=\frac{aC_r(1+\lambda_{r-}{}^2)}{\tan\theta_0} \qquad (3)$$

$$C_{r-}=\frac{1}{L_{r+}\tan\theta_0}=\frac{aC_r(1+\lambda_{r+}{}^2)}{\tan\theta_0}$$

where

$$\lambda_{r\pm}=\sqrt{\left(\frac{\Omega_r}{2a}\right)^2+1}\pm\frac{\Omega_r}{2a} \qquad (4)$$

Having effected the first transformation, the second transformation may now be made to obtain a realization in the form of a digital ladder network. The basic section in the resonated distributed prototype of FIG. 5 consists of a ladder formation of basic admittances whose susceptance may be written in the form

$$Y_1\frac{\tan\theta}{\tan\theta_o}-Y_2\frac{\tan\theta_o}{\tan\theta} \qquad (5)$$

From equation (3) it may be noted that all of the shunt elements possess the property $Y_1=Y$.

The basic section of FIG. 5 is equated to a single, stepped impedance, cavity which is a half wavelength at $\theta=\theta_0$. The half wavelength cavity consists, as shown in FIG. 6, of two transmission lines of characteristic admittance Y_1 and Y_2, connected in parallel. The first transmission line is formed by the stubs 31 and 32 which are short circuited at 33. The second transmission line is formed by stubs 34 and 35 which are short circuited at 36. The combined length of the parallel connected stubs is π electrical radians at $\theta=\theta_0$ with the step in impedance occurring at θ_0 electrical radians from one short circuited end as indicated in FIG. 6. The resulting susceptance of this cavity is

$$\frac{Y'_2}{\tan\theta}-\frac{Y'_1}{\tan\left[\theta\left(\frac{\pi}{\theta_o}-1\right)\right]} \qquad (6)$$

Upon equating expressions (5) and (6) and their derivatives at $\theta=\theta_0$, within a positive or a negative sign, we have

$$Y'_1=\frac{2\theta_0}{\pi}\left|\tan\theta_o\right|Y_1$$

and

$$Y'_2=\left|\tan\theta_o\right|\left[Y_2+\left(\frac{2\theta_o}{\pi}-1\right)Y_1\right] \qquad (7)$$

It may be noted that for

$$\theta_o=\frac{\pi}{3}\text{ or }\frac{2\pi}{3},$$

expressions (5)and (6) will be identical, within the arbitrary positive or negative sign. For $Y_1=Y_2$, Y'_1 is equal to Y'_2 because the cavity is one-half wavelength long at $\theta=\theta_0$.

After applying these transformations to all of the basic sections in the filter, the pair of characteristic admittance matrices can be obtained which define the n-digit, stepped impedance, ladder line in a manner analogous to that set forth in my cited copending application. To obtain normalized impedance values of the order of unity, transformer elements T1 and T2 may be introduced at the ends of the line, resulting in the configuration depicted in FIG. 1. Because coupling to the digital network is made by transformer action, the resonant sections in the filter are relatively invariant to bandwidth scaling. By employing the unit elements, the number of digits in one of the two parallel networks forming the stepped impedance ladder line is increased to $n+2$ and an augmented characteristic admittance matrix results, as explained in my aforesaid patent. From the two frequency transformations, the insertion loss of the digital ladder filter is given approximately by

$$L=1+\epsilon^2F^2\left\{\frac{2a\theta_o\tan\theta_o}{\pi}\left[\frac{1}{\tan\theta}+\frac{1}{\tan\left[\theta\left(\frac{\pi}{\theta_o}-1\right)\right]}\right]\right\} \qquad (8)$$

The insertion loss is given exactly by equation (8) for

$$\theta=\frac{\pi}{3}\text{ or }\frac{2\pi}{3}$$

The stepped impedance digital ladder network here described can be viewed as formed by a pair of parallel networks, as explained in my aforesaid patent. Because the digits in the ladder line form cavities that are one-half wavelength long at the filter's midband frequency, the loss of the ladder line filter is inherently lower (by a factor of about two) over a comparable comb line filter. In addition, the ladder line permits greater separation between the ground planes than is feasible in the comb line filter, thus making it possible to further reduce the loss in the ladder line filter over that of comparable comb line filter. In the ladder line filter, the plane s–s of the impedance steps can be shifted along the digits to obtain the desired filter characteristics. In the comb line, shifting the plane of the impedance steps is not a useful procedure.

The invention can be embodied in varied structures and it is not intended that the invention be limited to the form here illustrated and described. Rather, it is intended that the invention be delimited by the appended claims and include those structures that do not fairly depart from the essence of the invention.

I claim:

1. A band-pass microwave filter comprising

a pair of spaced ground plane plates,

a network of spaced digits disposed between the ground planes, the digits being one-half wavelength long at a frequency in the filter's pass band, each digit being terminated at both its ends in short circuits to the ground planes, each digit being stepped in impedance intermediate its ends, and

input and output means coupled to the digital network.

2. A band-pass, microwave filter comprising,

a pair of spaced ground plane plates, and

a pair of digital network disposed between the spaced ground plane plates, each network comprising a plurality of spaced parallel digits, the spacing between digits being approximately the same in both networks, all the digits in each network being equal in length, corresponding digits

of the two networks being substantially in alignment and having their ends joined to form one-half wavelength long digits, each of the half wavelength long digits being short circuited at both its ends to the ground plane plates, and the impedances of the digits in one network being different from the impedances of the digits in the other network, whereby the half wavelength digits are stepped in impedance at the junctions between the two networks.

3. A microwave filter according to claim 2, further including impedance transformers providing input and output coupling to the digital networks, the impedance transformers being additional digits disposed at each end of one of the parallel networks.