THE STEPPED CAVITY COUPLED ELLIPTIC FILTER

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Abstract

A design procedure is presented whereby compact, narrow-band (<30%) T.E.M. line, band-pass, elliptic function filters may be realized. The proposed realization is in the form of a stepped impedance, digital n-wire line which is one half of a wavelength long at midband and short circuited to ground at both ends, where the digital line is stepped in impedance along any arbitrary prescribed plane in the filter. Due to its physical form and the mode of electrical operation, the filter has been called "The Stepped Cavity Coupled Elliptic Filter".

Recently, "The Stepped Digital Elliptic Filter" has been proposed as a realization of the narrow-band, band-pass elliptic filter and consisted of a stepped impedance digital n-wire line, one quarter of a wavelength long at mid-band where the line was shorted to ground at one end and open-circuited at the opposite end. In this filter, the fringing capacitances at the open-circuited ends of the line necessitate the use of a compensation procedure based upon an estimation of these parasitic lumped capacitances. Consequently, in the very narrow-band cases, where these end effect capacitances have a considerable effect upon the performance of the filter, it is very difficult to construct a filter with the required electrical performance.

In the new design procedure, this problem is eliminated since the digital line is short circuited to ground at both ends and this also provides the filter with greater physical rigidity.

Introduction. "The Stepped Cavity Coupled Elliptic Filter" is constructed from a stepped impedance n-wire digital line, one half of a wavelength long at mid-band. The entire line is short-circuited to ground at both ends with the input and output ports coupling into the first and last transmission nodes of the filter through transformer action as shown in

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Fig. 1 for a 7th degree filter. The design procedure for this filter is initially similar to that of the recently described "Stepped Digital Elliptic Filter[1]", being based upon the odd-ordered low-pass, elliptic function filter. This prototype filter, whose element values may be obtained readily from tables[2], is shown in Fig. 2 in the form of a cascade of pi-sections.

In order 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. The first results in an exact realization by short and open circuited commensurate transmission lines and the additional transformation, in general, results in an approximate realization by the stepped cavity coupled filter. However, in the particular case where the stepped impedance plane is located at one third of the distance between the short circuited ends of the digital line, this latter transformation is also exact at all frequencies.

Finally, the computed response of a 7 element, 1% bandwidth filter is presented and the corresponding experimental results will be available shortly.

The Distributed Band-Pass Transformation. The general form of the insertion loss function for a low-pass, odd-ordered, elliptic function filter is

$$L = 1 + \varepsilon^2 F^2(\omega) \qquad \text{. . . . (1)}$$

where F (ω) is an odd function in ω. The general distributed, band-pass transformation for commensurate T.E.M. mode networks is

$$\omega \rightarrow a\left[\frac{\tan\Theta}{\tan\Theta_o} - \frac{\tan\Theta_o}{\tan\Theta}\right] \qquad \text{. . . . (2)}$$

where

$$\Theta = \frac{\omega\,\ell}{v}$$

ℓ = length of commensurate distributed elements

v = velocity of propagation

and a is a bandwidth scaling factor dependent upon the band edge frequencies and $\tan\theta_o$. Upon defining the band edge frequencies, we are still in a position to arbitrarily prescribe θ_o, and this property will be used when conversion is made to the cavity coupled form.

Consider a basic pi-section of the low-pass prototype with shunt capacitances C_{r-1} and C_{r+1} with a transmission zero at $\Omega_r = \frac{1}{\sqrt{L_r C_r}}$. Upon the application of the frequency transformation (2), the resonated distributed section shown in Fig. 3 may be generated. The corresponding element values are:-

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

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

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

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

where

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

We are now in a position to apply the second transformation in order to obtain a stepped cavity coupled realization.

<u>The Transformation to Stepped Cavity Coupled Sections.</u> The basic section in the resonated distributed prototype shown in Fig. 3 consists of a ladder formation of basic admittances whose susceptance may be written in the form

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

From equation (3) it may be noted that all of the shunt elements possess the property $Y_1 = Y_2$.

The basic sub-section will now be equated to a single, stepped impedance, half-wavelength cavity at $\Theta = \Theta_O$. This half-wave cavity consists of two short circuited transmission lines of characteristic admittance Y_1' and Y_2', connected in parallel. The combined length of these stubs is Π electrical radians long at $\Theta = \Theta_O$ with the step in impedance occurring at Θ_O electrical radians from one end as shown in Fig. 4. The resulting susceptance of this cavity is

$$-\frac{Y_2'}{\tan\Theta} - \frac{Y_1'}{\tan(\Theta(\frac{\Pi}{\Theta_O} - 1))} \quad . \; . \; . \; . \; (6)$$

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

$$Y_1' = \frac{2\Theta_O}{\Pi}|\tan\Theta_O|Y_1$$

and

$$Y_2' = |\tan\Theta_O| \left[Y_2 + \left(\frac{2\Theta_O}{\Pi} - 1\right)Y_1\right] \quad . \; . \; . \; . \; (7)$$

It may be noted that for $\Theta_O = \frac{\Pi}{3}$ or $\frac{2\Pi}{3}$, equations (6) imply that the expressions (5) and (6) will be identical, within the arbitrary positive or negative sign. For $Y_1 = Y_2, Y_1' = Y_2'$ since the cavity is one half wavelength long at $\Theta = \Theta_O$.

Having applied these transformations to all of the basic sections in the filter it is then possible to obtain the pair of characteristic admittance matrices which define the n-wire, digital stepped impedance line. In order to obtain normalized impedance values of the order of unity, transformer elements may be introduced at the input and output ports resulting in the final configuration as depicted in Fig. 1.

From the two frequency transformations, the insertion loss of the stepped cavity coupled elliptic filter will be given approximately by (exactly for $\Theta_O = \frac{\Pi}{3}$ or $\frac{2\Pi}{3}$),

$$L = 1 + \varepsilon^2 F^2 \left[\frac{2a\Theta_O\tan\Theta_O}{\Pi} \left[\frac{1}{\tan\Theta} + \frac{1}{\tan(\Theta(\frac{\Pi}{\Theta_O} - 1))}\right]\right] \quad . \; . \; . \; (8)$$

The exact computed response of a 7 element, 1% bandwidth filter, with $\theta_o = \frac{\pi}{4}$ is shown in Fig. 5 and experimental results of this filter operating in the 3.7 → 4.2 GHz frequency band will be available shortly.

Conclusions.

The main advantages of this cavity coupled filter as compared to "The Stepped Digital Elliptic Filter" are:-

1). There is no necessity to calculate end effect capacitances since the digital line is short circuited to ground at both ends.

2). The filter is physically more rigid since all of the lines are supported at both ends.

3). There is a small deviation in impedance values throughout the filter.

A possible disadvantage associated with, "The Stepped Cavity Coupled Elliptic Filter" in certain applications is that it inherently possesses a first harmonic passband.

References

1. J. D. Rhodes, "The Stepped Digital Elliptic Filter", to be published in I.E.E.E. Trans. on Microwave Theory and Techniques.

2. R. Saal, "Der Entwurf von Filtern mit Milfe des Kataloges Normierter Tiefpasse", Backnay/Wurtemberg, W. Germany. Telefunken, G.M.B.M., 1964.

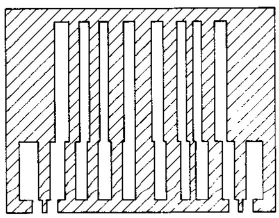


Figure 1. "The Stepped Cavity Coupled Elliptic Filter."

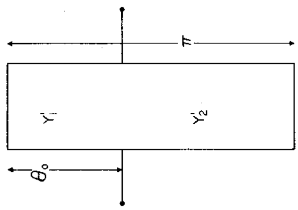
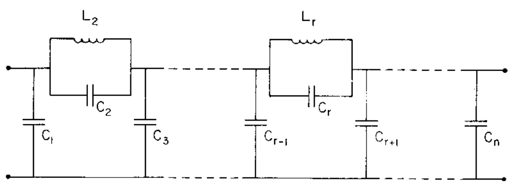
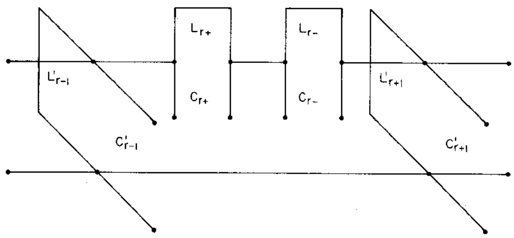


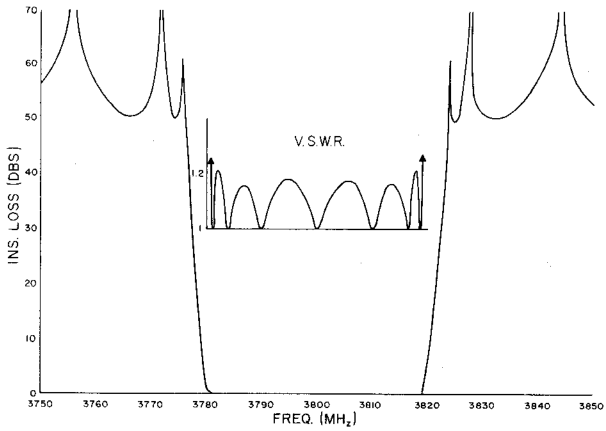
Figure 4. "Stepped Impedance, half-wave, cavity."



2. "Low-pass, prototype, elliptic function filter".



3. "Typical resonated distributed section".



5. "Computed response of a 1% bandwidth 7-element filter with $\Theta_0 = \frac{\Pi}{4}$.