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MICROWAVE FILTERS USING WAVEGUIDES FILLED BY MULTI-LAYER DIELECTRIC

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Abstract—In this paper, a new structure is proposed for microwave filters. This structure utilizes a waveguide filled by several dielectric layers. The relative electric permittivity and the length of the layers are optimally obtained using least mean square method. The usefulness of the proposed structure is verified using an example.

1. INTRODUCTION

Microwave filters are required in many communication circuits. Many structures have been introduced for microwave filters, which utilize microstrips or waveguides [1–3]. In this paper, a new structure is proposed for microwave filters. This structure utilizes a waveguide filled by several dielectric layers; the proposed structure is a multi-layer Longitudinally Inhomogeneous Waveguide (LIW) [4–6]. The relative electric permittivity and the length of the layers are optimally obtained using least mean square approach. The usefulness of the proposed structure is verified using an example.

2. ANALYSIS OF MULTI-LAYER LIWS

The analysis of continuous LIWs has been presented in [4–6]. In this section, the frequency domain analysis of the multi-layer LIWs is reviewed. Figure 1 shows a typical continuous and multi-layer LIW with dimensions of a and b. The multi-layer LIW has been filled by K dielectric layers whose relative electric permittivity and lengths are $\varepsilon_{r,k}$ and d_k, respectively, for $k = 1, 2, \ldots, K$. It is assumed that a TE_{10} mode propagates towards the positive z direction. With this assumption, we have the following transverse electric and magnetic

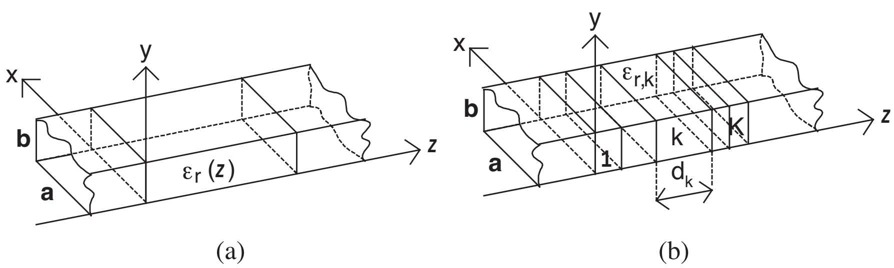

Figure 1. A typical LIW, (a) continuous type, (b) multi-layer type.

fields

$$E_y(x, z) = \sin(\pi x/a) E_y(z) \tag{1}$$
$$H_x(x, z) = \sin(\pi x/a) H_x(z) \tag{2}$$

The differential equations in the k-th layer and for the frequency of f are given by

$$\frac{dE_y(z)}{dz} = j\omega\mu_0 H_x(z) \tag{3}$$
$$\frac{dH_x(z)}{dz} = j\omega\varepsilon_0 \left(\varepsilon_{r,k} - (f_c/f)^2\right) E_y(z) \tag{4}$$

where

$$f_c = \frac{c}{2a} \tag{5}$$

in which c is the velocity of the light, is the cutoff frequency of the hollow waveguide, which must be less than f. The Equations (3) and (4) are similar to the differential equations of transmission lines with the following propagation coefficient and characteristic impedance.

$$\beta_{z,k}(f) = \frac{\omega}{c}\sqrt{\varepsilon_{r,k} - (f_c/f)^2} \tag{6}$$
$$\eta_{z,k}(f) = -\frac{\eta_0}{\sqrt{\varepsilon_{r,k} - (f_c/f)^2}} \tag{7}$$

in which $\eta_0 = \sqrt{\mu_0/\varepsilon_0}$ is the wave impedance in the free space.

From (3) and (4), the transverse electric and magnetic fields on two surfaces of the k-th layer can be related to each other by the $ABCD$ matrix, as follows

$$\begin{bmatrix} E_y(z) \\ H_x(z) \end{bmatrix} = \begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} \begin{bmatrix} E_y(z+d_k) \\ H_x(z+d_k) \end{bmatrix} \tag{8}$$

in which

$$A_k = D_k = \cos(\beta_{z,k} d_k) \tag{9}$$

$$B_k = \eta_{z,k}^2 C_k = j\eta_{z,k} \sin(\beta_{z,k} d_k) \tag{10}$$

The $ABCD$ parameters of the whole structure can be obtained from those of all dielectric layers as follows

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdots \begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} \cdots \begin{bmatrix} A_K & B_K \\ C_K & D_K \end{bmatrix} \tag{11}$$

Finally, the $ABCD$ parameters can be used to find the S parameters of the structure as follows

$$S_{11} = \frac{AZ_{TE} + B - CZ_{TE}^2 - DZ_{TE}}{AZ_{TE} + B + CZ_{TE}^2 + DZ_{TE}} \tag{12}$$

$$S_{21} = S_{12} = \frac{2Z_{TE}}{AZ_{TE} + B + CZ_{TE}^2 + DZ_{TE}} \tag{13}$$

$$S_{22} = \frac{-AZ_{TE} + B - CZ_{TE}^2 + DZ_{TE}}{AZ_{TE} + B + CZ_{TE}^2 + DZ_{TE}} \tag{14}$$

where Z_{TE} is the characteristic impedance of the input and output of the filter.

$$Z_{TE}(f) = -\frac{\eta_0}{\sqrt{1 - (f_c/f)^2}} \tag{15}$$

3. DESIGN OF FILTERS

In this section a general method is proposed to design optimally the LIW microwave filters. The method is based on the minimization of a suitable error function along with some constrained conditions to determine optimum values of the electric permittivity and the length of the dielectric layers. One may define the following error function for M frequencies $f_1, f_2, \ldots, f_M$ which are greater than f_c.

$$\text{Error} = \sqrt{\frac{1}{2M}\sum_{m=1}^{M}\left|\frac{|S_{21}(f_m)| - |H(f_m)|}{|H(f_m)|}\right|^2 + \frac{1}{2M}\sum_{m=1}^{M}\left|\frac{|S_{11}(f_m)| - \sqrt{1-|H(f_m)|^2}}{\sqrt{1-|H(f_m)|^2}}\right|^2} \tag{16}$$

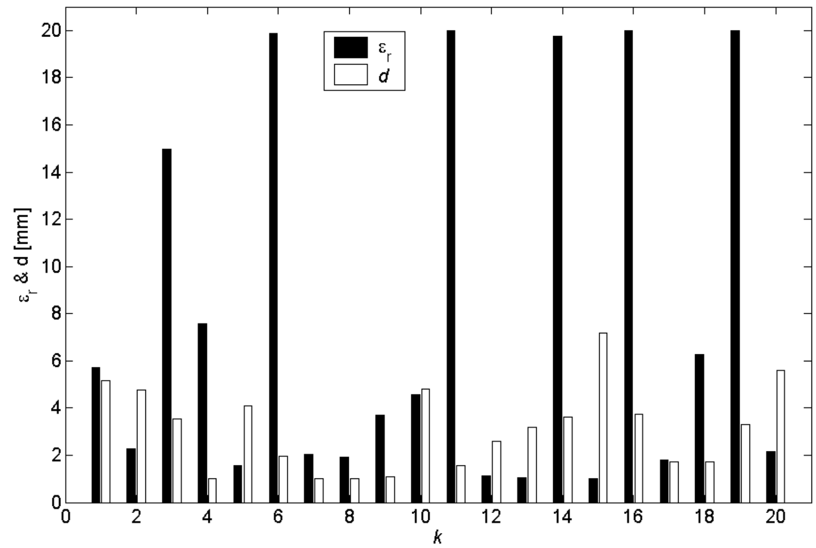

Figure 2. The relative electric permittivity and the length of dielectric layers.

where $H(f)$ is desired transfer function for designed filter. Moreover, defined error function has to be restricted by some constraints such as

$$\left|\frac{S_{21}(f)}{H(f)}\right| \leq \text{ or } \geq \text{ or } = 1 \text{ for some } f\text{s}, \tag{17}$$

to emphasize on some frequencies, or such as

$$d_k \geq d_{\min}; \qquad k = 1, 2, \ldots, K \tag{18}$$

$$1 \leq \varepsilon_{r,k} \leq \varepsilon_{r,\max}; \quad k = 1, 2, \ldots, K \tag{19}$$

to have easy fabrication.

To design optimally continuous microwave LIW microwave filters, one can consider the following truncated Fourier series expansion for the relative electric permittivity function.

$$\ln(\varepsilon_r(z) - 1) = C_0 + \sum_{n=1}^{N} (C_n \cos(2\pi nz/d) + S_n \sin(2\pi nz/d)) \tag{20}$$

The optimum values of the coefficients (C_n and S_n) of the above series are obtained through the proposed optimization approach and the mentioned analysis method.

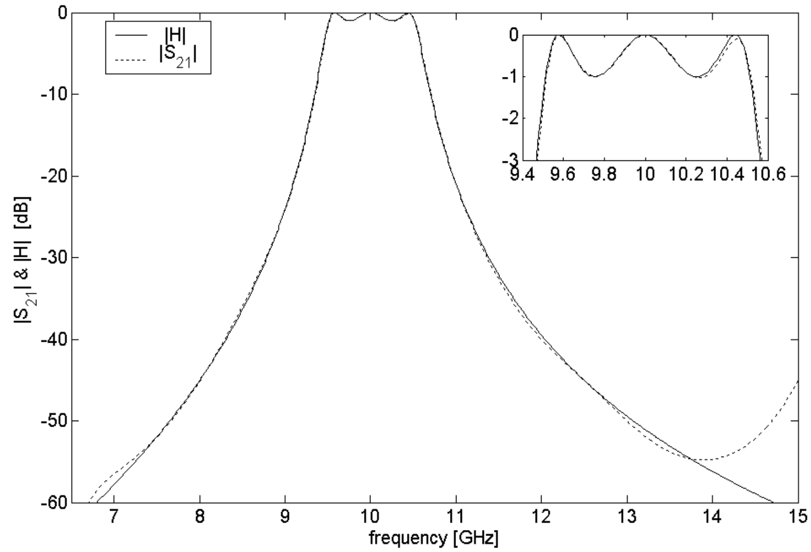

Figure 3. The magnitude of S_{21} parameter of designed filter the desired transfer function.

4. EXAMPLE AND RESULTS

In this section, a multi-layer LIW microwave filter is optimally designed. As an example, consider a WRG-90 waveguide ($a = 0.9$ in and $b = 0.4$ in). We would like to design a 3-order chebyshev bandpass filter with, the center frequency of 10 GHz, the relative bandwidth of 10% and equal ripples of 1.0 dB. Using the proposed optimization method, considering $K = 20$ layers, $d_{\min} = 1$ mm, $\varepsilon_{r,\max} = 20$, $f_1 = 7$ GHz and $f_M = 14$ GHz ($M = 350$), the optimum values of parameters were obtained. Figure 2 illustrates the relative electric permittivity and the length of dielectric layers. Total length of filter is 62.6 mm. It is seen that the designed filter is asymmetric. Figure 3 compares the magnitude of S_{21} parameter of designed filter with the desired transfer function versus frequency. One sees an excellent agreement between two curves in the range of optimization frequencies. It is evident that, as the number of dielectric layers K, increases the agreement is increased.

5. CONCLUSION

A new structure was proposed for microwave filters. This structure utilizes a waveguide filled by several dielectric layers. The relative electric permittivity and the length of the layers are optimally obtained using least mean square method. The usefulness of the proposed structure was confirmed by designing of an equal-ripple X-band filter.

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