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3 선 3 포트 대역통과/대역소거 필터의 해석과 설계

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An Analysis and Design of Three-Line Three Port Bandpass / Bandstop Filter.

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요 약

본 논문에서는 3 선 마이크로스트리으로 구성된 3 선 3포트 대역통과/대역소거 필터를 해석하는 방법과 설계 예를 제시하였다. 실제로 제작한 대역통과/대역소거 필터의 측정 결과는 이론적인 특성과 잘 일치함을 보였다.

Abstract

Analysis and design procedure for three-line three port bandpass /bandstop fliter consisting of three line microstrip structures is reported. The measured results for experimental three port structure is shown to be in good agreement with theoretical poedictions.

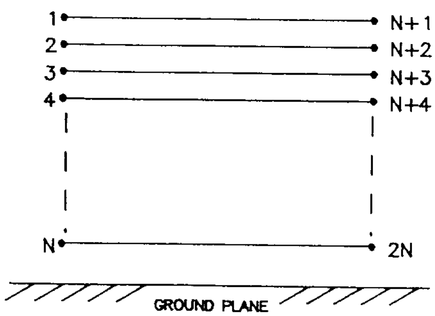
I. INTRODUCTION

Multiple coupled line structures, including the three-line structures, have been studied for various applications as directional couplers and other circuit elements[1,2,3]. The interdigitate directional coupler has been the most effective means for achieving tight coupling in microstrip circuits. The main advantages are its small size and the relatively large gaps between conductors as compared to a conventional two-line coupler case.

Directional bandpass / bandstop fillters have been realized in strip line and dielectric waveguide configurations by utilizing these lines coupled via single and multiple open ended and ring resonators. Among the many applications proposed for such filters include the basic multiplexer multiport which can be realized by cascading sections of such directional filters. Specific cases of a three-line microstrip filter considered in this paper is shown in figure 2. Utilization of more than two lines results in an increased effective coefficient of coupling and hence a broader bandwidth is as the case with Lange couplers and multiple microstrip DC blocks[4].

II. THEORY

The properties of this three port circuit can be obtained in terms of the quasi-TEM as the frequency dependent normal mode parameters of the multiple coupled line structures[5–7]. For the general case of an N line structure, this normal mode paramenters include N propagation constants, the elements of the N × N voltage and current eigenvector matrices, and the N × N characteristic impedance matrix. Three types of characteristic impedance matrices have been defined for multiconductor structures. These are the line mode impedances, the decoupled modal impedances, and the impedance matrix which terminates all the lines are arbitrary excitation. The 2N-port admittance matrix expressed in terms of the normal mode paramenters.



〔Fig. 1〕 Schematic of the coupled line 2N-port.

The transmission line equations for the N line system shown in figure 1 are given by:

$$\frac{d[V]}{dx} = -[Z]\,[I] \qquad (1)$$

$$\frac{d[I]}{dx} = -[Y]\,[V] \qquad (2)$$

where [V] and [I] are the N dimensional column vectors representing the voltages and currents on the lines respectively, and [Z] and [Y] are N × N impedance and admittance matrices as given by

$$[Z] = \begin{bmatrix} Z_{11}\ Z_{12} \cdots Z_{1N} \\ Z_{21}\ Z_{22} \cdots Z_{2N} \\ \vdots \qquad \vdots \\ Z_{N1}\ Z_{N2} \cdots Z_{NN} \end{bmatrix}$$

and

$$[Z] = \begin{bmatrix} Y_{11}\ Y_{12} \cdots Z_{1N} \\ Y_{21}\ Y_{22} \cdots Z_{2N} \\ \vdots \qquad \vdots \\ Y_{N1}\ Y_{N2} \cdots Y_{NN} \end{bmatrix}$$

where Z_{ii} and Y_{ii} (i=1,2,...,N) are the equivalent self impedance and admittance per unit length of the ith line, and Z_{ij} and Y_{ij} (i≠j) are the mutual impedence and admittance per unit length between the ith line and the jth line.

The voltages and currents for the case of uniformly coupled lines considered here are then the solutions of the following characteristic equations:

$$\frac{d^2[V]}{dx^2} + [Z]\,[Y]\,[V] = 0 \qquad (3)$$

$$\frac{d^2[I]}{dx^2} + [Y]\,[Z]\,[I] = 0 \qquad (4)$$

where, for the N line 2N-port case

$$[Y]\,[Z] = \{\,|\,[Z]\,[Y]\,|\,\}^T$$

The general solutions for the port voltages on N line 2N-port structures are given by

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \\ V_{N+1} \\ \vdots \\ V_{2N} \end{bmatrix} = \begin{bmatrix} [M_V] & [M_V] \\ [M_V][e^{-j\theta_i}]_{diag} & [M_V][e^{j\theta}]_{diag} \end{bmatrix} \begin{bmatrix} A_1 \\ A_3 \\ \vdots \\ A_{2N-1} \\ A_2 \\ \vdots \\ A_{2N} \end{bmatrix} \quad (5)$$

where $[\ ]_{diag}$ indicates a diagonal matrix.

The corresponding currents for N line 2N-port are determined by substituting the expressions for voltages(5) into (1). These currents are given by

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \\ I_{N+1} \\ \vdots \\ I_{2N} \end{bmatrix} = \begin{bmatrix} [M_V] & [M_V] \\ [M_I][e^{-j\theta_i}]_{diag} & [M_I][e^{j\theta}]_{diag} \end{bmatrix} \begin{bmatrix} A_1 \\ A_3 \\ \vdots \\ A_{2N-1} \\ A_2 \\ \vdots \\ A_{2N} \end{bmatrix} \quad (6)$$

where, i=1,2,...N.

In the above equation, the eigenvalues, β_i's, representing the solutions of $\det\{[Z][Y]+\beta^2[U]\}=0$, are the propagation constants for the normal modes of the system. A_j (j=1,2,...2N) is an arbitrary amplitude coefficient and $\theta_i=\beta_i \ell$ is the electric length of lines for the N normal modes.

$[M_V]$ is the voltage eigenvector matrix (N×N) corresponding to eigenvalues:

$$[M_V] = \begin{bmatrix} 1 & 1 \cdots & 1 \\ \alpha_2 & \beta_2 \cdots & \zeta_2 \\ \vdots & & \vdots \\ \alpha_N & \beta_{N2} \cdots & \zeta_N \end{bmatrix}$$

$[M_I]$ is the current eigenvector matrix (N×N) defined as $[M_I] = [Y]_C^T * [M_V]$ with the element $M_{Iij}=Y_{ji} \cdot M_{Vij}$:

$$[M_I] = \begin{bmatrix} Y_{11} & Y_{21} & \cdots & Y_{N1} \\ \alpha_2 Y_{12} & \beta_2 Y_{22} & \cdots & \zeta_2 Y_{N2} \\ \vdots & & & \vdots \\ \alpha_N Y_{1N} & \beta_N Y_{2N} & \cdots & \zeta_N Y_{NN} \end{bmatrix}$$

where, Y_{jk} is the characteristic admittance of line k for mode j.

Eliminating $A_1, A_2, \ldots, A_{2N}$ leads to 2N equations for the 2N-port currents where coefficients represent the immittance parameters. These admittance parameters of the 2N-port are found to be:

$$[Y]=\begin{bmatrix} [M_I] & -[M_I] \\ -[M_I][e^{-j\theta_i}]_{diag} & [M_I][e^{j\theta_i}]_{diag} \end{bmatrix} \begin{bmatrix} [M_V] & [M_V] \\ -[M_V][e^{-j\theta_i}]_{diag} & [M_V][e^{j\theta_i}]_{diag} \end{bmatrix} \quad (7)$$

The second matrix can be inverted as follows:

$$\begin{bmatrix} [U]+[\frac{e^{-j\theta_i}}{2j\sin\theta_i}]_{diag} & -[\frac{1}{2j\sin\theta_i}]_{diag} \\ -[\frac{e^{-j\theta_i}}{2j\sin\theta_i}]_{diag} & [\frac{1}{2j\sin\theta_i}]_{diag} \end{bmatrix} \begin{bmatrix} [M_V]^{-1} & [0] \\ [0] & [M_V]^{-1} \end{bmatrix} \quad (8)$$

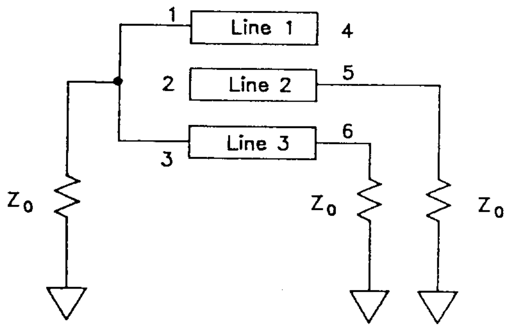
Hence

$$[Y]=\begin{bmatrix} [M_I] & [0] & -j[\cot\theta_i]_{diag} & j[\csc\theta_i]_{diag} & [M_V]^{-1} & [0] \\ [0] & [M_I] & j[\csc\theta_i]_{diag} & -j[\cot\theta_i]_{diag} & [0] & [M_V]^{-1} \end{bmatrix} \quad (9)$$

The normal mode parameters of the above admittance matrix are found in terms of the quasi-static [R], [L], [G] and [C] matrices per unit length as shown in [8] or directly from the full wave simulation as shown in [7].

Ⅲ. Analysis and Design

The adimittance matrix [Y] derived by equation (9) is reduced to a three port matrix of the bandpass/bandstop filter by adding the rows corresponding to the connected ports and reducing the resulting matrix by suppressing the nodes corresponding to the open ports as shown in figure 2.



[Fig. 2] Schematic of three-line three port structure.

For this case, using the boundary conditions given by $I_2 = I_4 = 0$ and $V_1 = V_3$ with $I_a = I_1 + I_3 = 2I_1$, the reduced matrix of the bandpass/bandstop filter is described by the following immittance matrix:

$$[Z] = \begin{bmatrix} \frac{Z_{11}+Z_{13}}{2} & Z_{15} & Z_{16} \\ Z_{15} & Z_{55} & Z_{12} \\ \frac{Z_{11}+Z_{13}}{2} & Z_{13} & Z_{11} \end{bmatrix} \quad (10a)$$

or

$$[Y] = [Z]^{-1} \quad (10b)$$

where the elements of [Z] are expressed by [5].

The scattering paramenters are calculated by using the above reduced [Y] matrix. Here the discontinuity effects associated with the open end, steps, and bends are not includes. These can of course be included in the final design of the multiport. The scattering matrix is then calculated from the normalized reduced [Y] matrix for the given set of terminations from [8]:

$$[S] = \{[U] + [Y]\}^{-1}\{[U] - [Y]\} \quad (11)$$

Approximate procedures to reduce the multiconductor section to eqivalent sections with lesser number of lines or superposition of coupling terms as in ref. [9] may also be used to help facilitated the design.

The dimensions for the desired bandwidth of bandpass/bandstop filter were found by trial and error method as follow: the quasi-TEM mode parameters for given relative dielectric constant and arbitrarily chosen physical dimensions of the structure were first determind by using numerical analysis. These parameters were substituted into the equivalent admittance paramenters. The above procedure has been repeated until one can find the desired bandwidth. The length of the filter section is quater of the center frequency wavelength. This would lead to an approximate design which can be a good starting point for the computer aided optimazation procedure. It should be noted that the three-line three port bandpass/bandstop filter design is somewhat similar to the coupler design and the impedance renormalization procedure[10] helps enhance the matching of the three port structure.

Ⅳ. RESULT AND CONCLUSION

The structure geometeries for the fabracated filters are shown in figure 3. Figure 4 shows the frequency response of a three line structure designed for a 50 ohm system which is founded by CAD program LIBRA. The experimental results for the three-line three port structure fabricated with the dimensions shown in figure 3 are shown in figure 5 and 6.

The design procedure for three-line three port bandpass/bandstop filter has been presented. The experimental results for a three-line three port structure fabricated on 1.588mm Teflon substrate with $\varepsilon_r = 2.5$ validate the original procedure and demonstrate the filtering properties of this multiport. The example given here is based on the computation of the S parameters of the multiport from the quasi-TEM parameters to help demonstrate the feasibility of this bandpass/bandstop filters.

The quasi-TEM normal mode parameters can be computed the moment method[11]. In this structure, each parameters are given by:

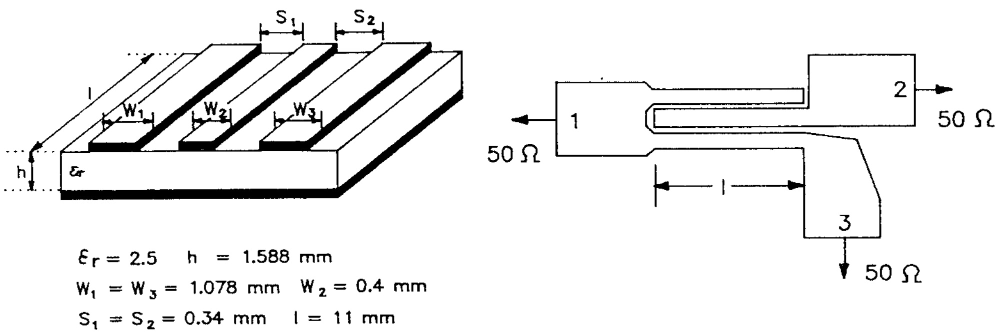
$$[C]=\begin{bmatrix} 50.71724 & -14.743572 & -3.808687 \\ -14.73572 & 41.19752 & -14.73572 \\ -3.808687 & -14.73572 & 50.71724 \end{bmatrix} (\mathrm{pF/m})$$

$$[L]=\begin{bmatrix} 0.4924950 & 0.2348620 & 0.1266783 \\ 0.2348620 & 0.6550249 & 0.2348621 \\ 0.1266783 & 0.2348621 & 0.4924950 \end{bmatrix} (\mu\mathrm{H/m})$$

$$[M_v]=\begin{bmatrix} 1.00000 & 1.03728 & 1.00000 \\ 1.00000 & -0.00001 & -1.00000 \\ 1.00000 & -4.76924 & 1.00004 \end{bmatrix}$$

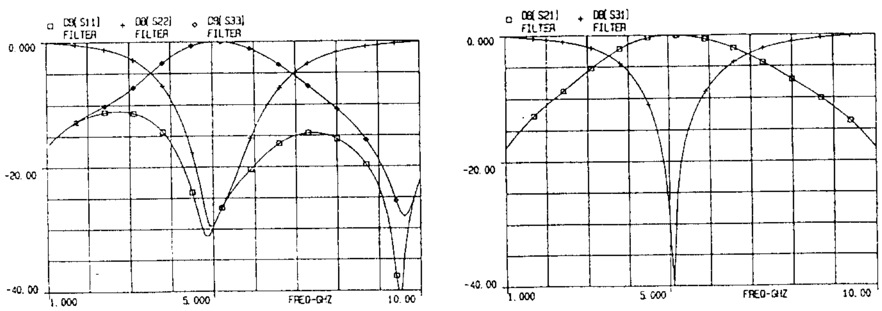
$$[M_i]=\begin{bmatrix} 1.00000 & 0.41936 & 1.00000 \\ 1.00000 & -0.00001 & -0.99999 \\ 1.00000 & -1.92815 & 1.00002 \end{bmatrix}$$

Effects of various discontinuities, dispersion, and losses are readily included in the analysis and account for the minor differences between the theoretical and the experimental curves for the three line example presented in this paper.



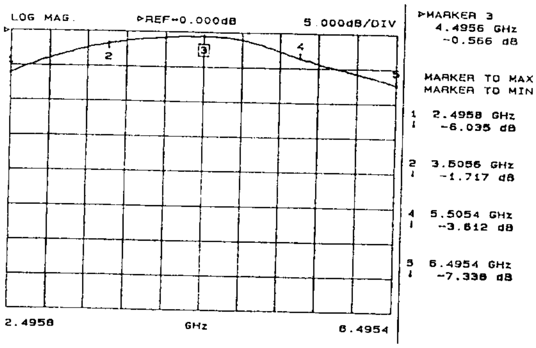
(a) (b)

〔Fig. 3〕 Schemetic of (a) Coupled three microstripline, (b) Layout for three-line three port bandpass / bandstrop filter.

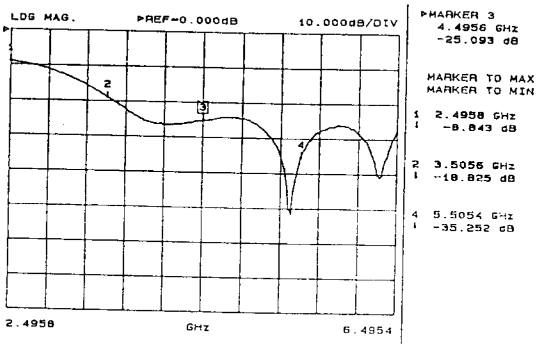


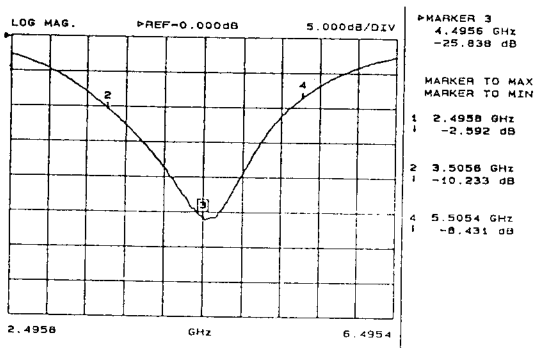
(a) Return loss vs. frequency, (b) Insertion loss vs. frequency.

〔Fig. 4〕 Calculated results for the bandpass/ bandstop filter.



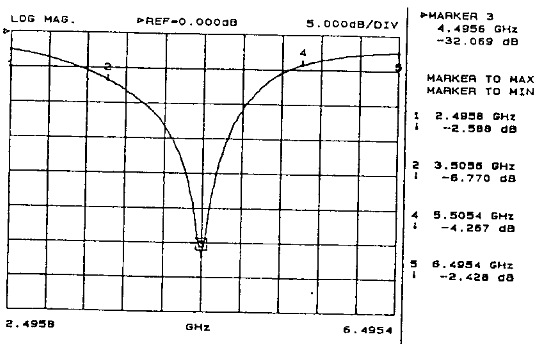
(a) Insertion loss,



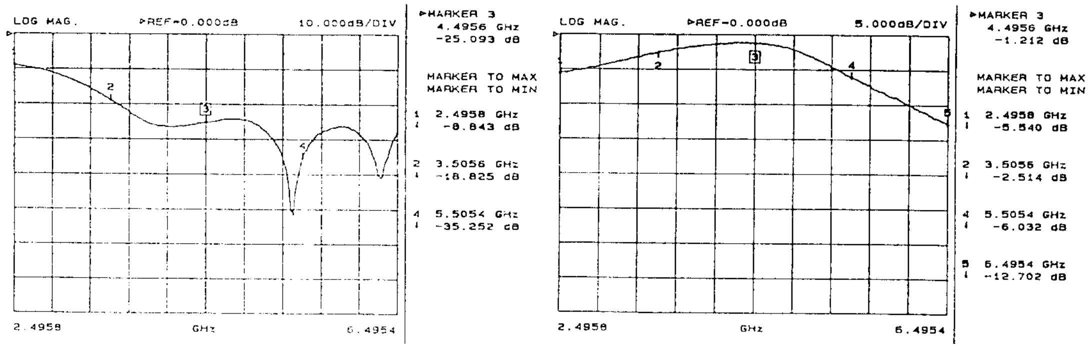


(b) Return loss(S_{11}), (c) Return loss(S_{22})

〔Fig. 5〕 Measured data for the bandpass filter.



(a) Insertion loss(S_{31}),



(b) Return loss(S_{11}), (c) Return loss(S_{33})

[Fig. 6] Measured data for the bandstop filter.

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