ANALYSIS AND DESIGN OF ASYMMETRIC AND MULTIPLE COUPLED FINLINE COUPLERS AND FILTERS

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ABSTRACT:

The procedure to compute the scattering parameters of a general asymmetric and multiple coupled finline multiport is formulated in terms of the normal mode parameters of the structure. The normal mode parameters of the structures are computed by applying the spectral domain technique to general shielded multilayered structure.In addition, closed form expressions for the immittance parameters and characteris-tically terminated scattering parameters of the asymmetric coupled line and three line structure are presented.The multiport parameters of the finline structure are used to design filters, couplers and power dividers.

INTRODUCTION:

Symmetrical coupled finline structures have been studied for various applications as directional couplers and other circuit elements [1-3]. Spectral domain and related techniques have been used to compute the propagation constants associated with asymmetric and multiple coupled finline structures [1-3]. In this paper, in addition to the computation of the normal mode papameters associated with a general multiple coupled finline structure, the procedure to compute the scattering parameters of a general finline multiport is formulated in terms of these parameters.The analysis and design procedure for coupled line filters and couplers are presented in terms of these multiport parameter matrices. Such structures offer additional degree of freedom in the design of multiport circuits at millimeter wave frequencies as compared to a pair of identical coupled fin lines.

NORMAL MODE PARAMETERS:

The numerical technique formulated to solve for the normal mode parameters of the general finline structure here is the spectral domain technique and represents a direct extension of the procedure used in [3] for single and symmetrical coupled finlines. Here in Fig.1, the electric and magnetic fields are expanded in terms of modal fields and the application of the boundary conditions at each interface leads to the dyadic Green's function interrelating the aperture fields and the surface currents. The slot fields are then expressed in terms of series of known basis functions with unknown coefficients. For example for the single sided structure of Fig 1a,the currents and fields are related by the boundary Green's function as given by:

$$G_{11}=\frac{\frac{j\omega\epsilon_0\alpha_n^2}{\Gamma_{n1}}\cdot F_{11}+\frac{j\beta^2}{\omega\mu_0}\cdot F_{22}}{(\alpha^2+\beta^2)\sin(\Gamma_{n1}h_1)} \quad ..(1a)$$

$$G_{12}=\frac{-\frac{\omega\epsilon_0\alpha_n\beta}{\Gamma_{n1}}\cdot F_{11}+\frac{\alpha_n\beta}{\omega\mu_0}\cdot F_{22}}{(\alpha^2+\beta^2)\sin(\Gamma_{n1}h_1)} \quad ..(1b)$$

$$G_{21}=-G_{12} \quad ..(1c)$$

$$G_{22}=\frac{\frac{j\omega\epsilon_0\beta^2}{\Gamma_{n1}}\cdot F_{11}+\frac{j\alpha_n^2}{\omega\mu_0}\cdot F_{22}}{(\alpha^2+\beta^2)\sin(\Gamma_{n1}h_1)} \quad ..(1d)$$

$$F_{11}=\cos(\Gamma_{n1}h_1)-\epsilon_r F_1\frac{\Gamma_{n1}}{\Gamma_{n2}}\sin(\Gamma_{n1}h_1) \quad ..(1e)$$

$$F_{22}=\Gamma_{n1}\cos(\Gamma_{n1}h_1)+F_2\Gamma_{n2}\sin(\Gamma_{n1}h_1) \quad ..(1f)$$

$$F_1=\frac{\epsilon_r\Gamma_{n1}\sin(\Gamma_{n2}d)\sin(\Gamma_{n1}h_2)-\Gamma_{n2}\cos(\Gamma_{n2}d)\cos(\Gamma_{n1}h_2)}{\epsilon_r\Gamma_{n1}\cos(\Gamma_{n2}d)\sin(\Gamma_{n1}h_2)+\Gamma_{n2}\sin(\Gamma_{n2}d)\cos(\Gamma_{n1}h_2)} \quad ..(1g)$$

$$F_2=\frac{\Gamma_{n1}\cos(\Gamma_{n2}d)\cos(\Gamma_{n1}h_2)-\Gamma_{n2}\sin(\Gamma_{n2}d)\sin(\Gamma_{n1}h_2)}{\Gamma_{n1}\sin(\Gamma_{n2}d)\cos(\Gamma_{n1}h_2)+\Gamma_{n2}\cos(\Gamma_{n2}d)\sin(\Gamma_{n1}h_2)} \quad ..(1h)$$

where,

$$\alpha_n=\frac{n\pi}{b}$$

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$$\Gamma_{n1} = \sqrt{\omega^2\mu_0\epsilon_0 - \alpha_n^2 - \beta^2}$$

$$\Gamma_{n2} = \sqrt{\omega^2\mu_0\epsilon_0\epsilon_r - \alpha_n^2 - \beta^2}$$

The Galerkin procedure, that is taking the inner product of both sides by the same basis function and utilizing the Parseval's theorem lead to the determinantal equation whose roots give the phase constants for the all the dominant normal modes of the coupled fin structure. We have used the Chebychev polynomials with edge terms for the basis and the test functions.

The total power associated with each eigenvalue is then computed.Computation of the power associated with each slot for each mode and the normalized voltage across each slot for each mode also leads to the line mode impedance (or admittance) matrix characterizing the general fin line structure. The slot mode characteristic impedance is defined by using the power voltage definition as,

$$Z_{sm} = V_{sm}^2/P_{sm} \qquad ..(2)$$

where V_{sm} is the the integral of the electric field along the slots for mode m and P_{sm} is the power associated with that mode.

This results in a NxN characteristic admittance matrix where N is the number of slots in the system. The normalized voltage across the slot for each mode defines a voltage eigenvector matrix $[M_V]$.

MULTIPORT PARAMETYERS:

Impedance (or admittance) matrix of the finite length multiport can then be derived by solving the equivalent coupled line equations for the finite length structure in the same manner as for the case of asymmetric and multiple coupled microstrips [4-7]. For example the short circuit admittance matrix of the coupled system is given by,

$$[Y_{sh}] = \begin{bmatrix} [Y_a] & [Y_b] \\ [Y_b] & [Y_a] \end{bmatrix} \qquad ..(3)$$

$$[Y_a] = -j[Y_{sm}]*[M_v][\cot(\tilde{A}_i l)\mathrm{diag}[M_v]^{-1} \qquad ..(4)$$

$$[Y_b] = -j[Y_{sm}]*[M_v][\csc(\tilde{A}_i l)\mathrm{diag}[M_v]^{-1} \qquad ..(5)$$

The admittance matrix is used to compute the elements of the 2N port scattering parameters required for the multiport analysis and design.

For asymmetric two and three line structures the admittance impedance and the general circuit parameters as well as the scattering parameters for characteristically terminated lines can be obtained in a closed form as for the case of coupled microstrips [4,5,8,9]. These can then be used to formulate the design procedure for the directional couplers, power dividers and filters.

EXAMPLES:

The admittance papameters of a two port filter consisting of asymmetric coupled finline structure are given by (inset Fig.4):

$$Y_{11} = -j[Y_{c1}R_\pi\cot(\beta_c l) - Y_{\pi 1}R_c\cot(\beta_\pi l)]/R_d \qquad ..(6a)$$

$$Y_{13} = j[Y_{c1}\csc(\beta_c l) - Y_{\pi 1}\mathrm{cse}(\beta_\pi l)]/R_d \qquad ..(6b)$$

$$Y_{33} = -j[Y_{c2}R_c\cot(\beta_c l) - Y_{\pi 2}R_\pi\cot(\beta_\pi l)]/R_d \qquad ..(6c)$$

$$R_d = R_c - R_\pi$$

The frequency respose of a typical coupled fin structure is shown in Fig.4. The coupled asymmetric finline and multiple coupled finline structures in general lead to both co- and contradirectional coupling as for the case of coupled dielectric waveguides. The contradirectional coupling which results in coupling to the side or thenear end port can, however, be decreased by reducing the difference between the line mode impedences. The techniques used in the past for the analysis and design of codirectional couplers have been the coupled mode analysis and normal mode analysis with loose coupling approximation [10-12]. The analysis and design procedure presented here is based on the scattering matrix derived from the normal mode parameters without any assumptions regarding loose coupling or the terminations .

The scattering parameters of two line and symmetrical three line structures terminated in non mode converting impedances are readily derived [8-9]. Ideal couplers can then be realized in terms of these expressions. As an example, ideal two line codirectional coupler requires equal mode impedances for both lines,i.e, $Z_{c1}=Z_{\pi 1}$ and then $Z_{c2}=Z_{\pi 2}$. Such structure terminated in $Z_1=Z_{c1}$ and $Z_2=Z_{c2}$ lead to

$$S_{ii} = 0 , \quad i=1,2,3,4 \qquad ..(7a)$$

$$S_{12}=S_{34}=0 \qquad ..(7b)$$

$$S_{41} = \frac{e^{-j\theta_c}[R_\pi - R_c e^{-j(\theta_\pi-\theta_c)}]}{(R_\pi - R_c)} = S_{14} \qquad ..(7c)$$

$$S_{31} = \frac{\sqrt{-R_\pi R_c}\; e^{-j\theta_c}[1 - e^{-j(\theta_\pi-\theta_c)}]}{(R_\pi - R_c)} = S_{13}=S_{24}=S_{42} \qquad ..(7d)$$

The above equations can be used to realize any arbitrary coupling by properly chosing the asymmetry in terms of $Z_2/Z_1= -R_cR_\pi$.For the three line structure with input at port 2(inset Fig.5), it is seen that for arbitrary but non mode converting terminations,

$$S_{21}=S_{12}= (\Gamma_b-\Gamma_c)\sqrt{\frac{-R_bR_c}{2}} \cdot \frac{1}{R_b-R_c} \qquad ..(8a)$$

$$S_{51}= (T_b-T_c)\sqrt{\frac{-R_bR_c}{2}} \cdot \frac{1}{R_b-R_c} \qquad .(8b)$$

$$S_{22}=S_{33}=\frac{R_b\Gamma_b-R_c\Gamma_c}{R_b-R_c} \qquad ..(8c)$$

$$S_{52}=S_{25}=\frac{R_bT_b-R_cT_c}{R_b-R_c} \qquad ..(8d)$$

Again equal mode impedance case leads to an ideal coupler. Expressions like the ones given above form the basis for an initial design based on this ideal case results. The final anlysis and design is the based on the exact computation of the scattering parameters of the multiport.

RESULTS:

In order to show the variation in the normal mode parameters, the results for a two coupled finline structure are shown in Fig.2. Note that the slot mode impedances of line 2 are related to that of line 1 in terms of the mode voltage ratio R_{cv} and $R_{\pi v}$ which are the elements of the eigenvector matrix as shown in ref.[4]. Figure 3 shows the normal mode parameters of a symmetrical coupled three line structure. Here R_b and R_c are the components of the eigen vector corresponding to the even-even and even-odd modes[5].

Figure 5 shows the scattering parameter of a symmetrical three line structure which is proposed for application as a three way power divider ($|S_{24}|^2=|S_{26}|^2=$ C and $|S_{25}|^2=$ 1-2C) e.g. C=.33 for a 3 way divider and .5 for a 3 db hybrid.

In conclusion a general unified procedure to compute the normal mode parameters of asymmetric and multiple coupled fin line structures has been presented. These parameters are then used to analyse an formulate design procedure for coupled fin line circuits such as filters couplers and power divider at millimeter wave frequencies.

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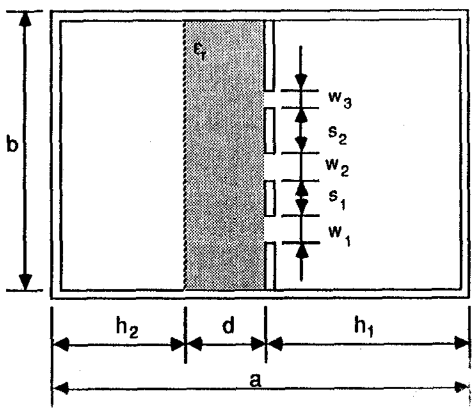

Fig.1 Cross-sectional view of multiple coupled finline

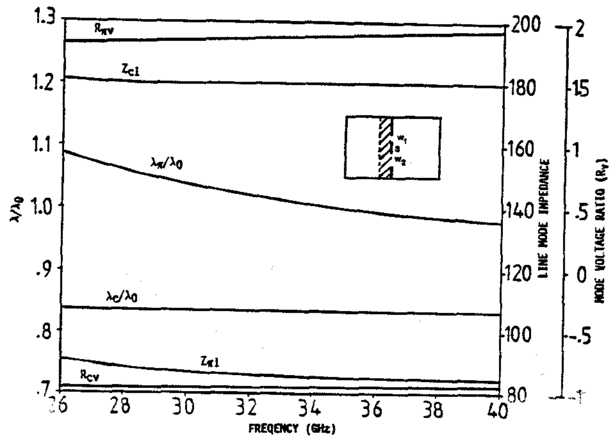

Fig.2 Normal mode parameters of an asymmetric coupled finline as a function of the frequency. a=7.112mm, b=3.556mm, d=.127mm, ϵ_r=2.22, w_1=.1mm, w_2=.3mm, s=.2mm, h_1=3.556mm.

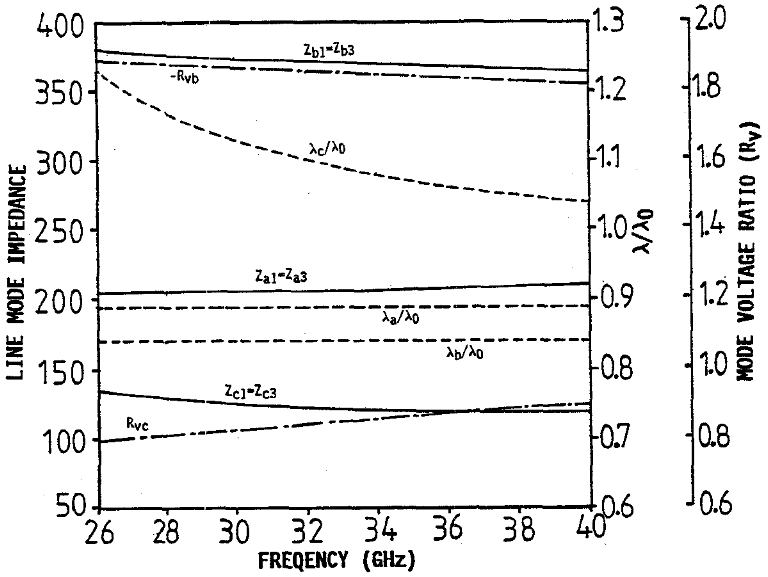

Fig.3 Normal mode parameters of multiple coupled finline as a function of the frequency. a=7.112mm, b=3.556mm, d=.127mm, ϵ_r=2.22, w_1=w_3=.3mm, w_2=.45mm, s_1=s_2=.2mm, h_1=3.556mm.

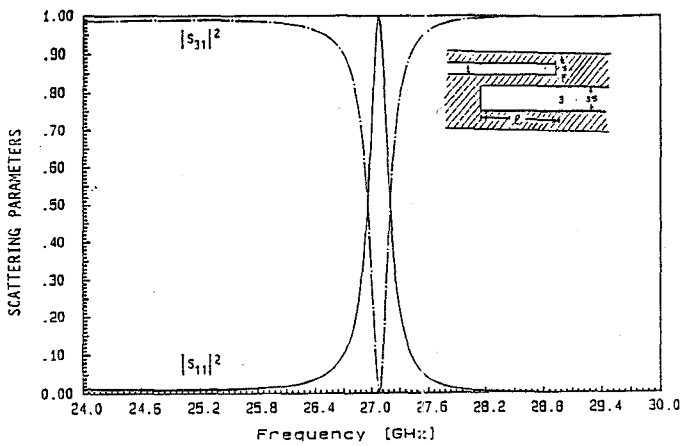

Fig.4 The frequency response of an asymmetric coupled finline two port section(shown in inset). a=7.112mm, b=3.556mm, d=.127mm, ϵ_r=2.22, w_1=.1mm, w_2=.3mm, s=.2mm, h_1=3.556mm.

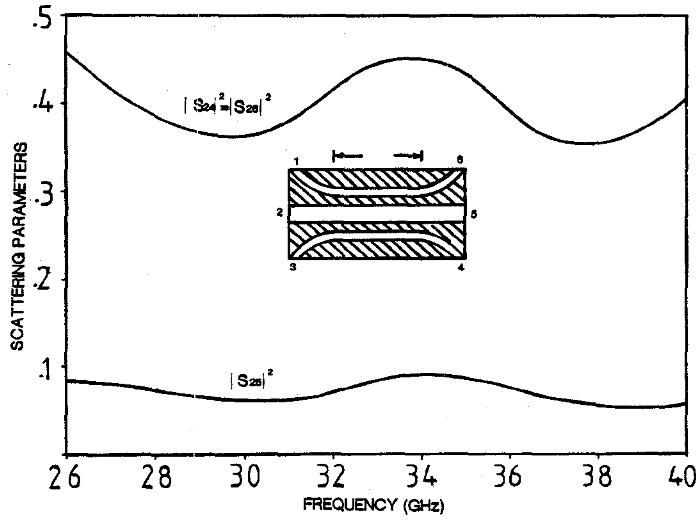

Fig.5 Variation of scattering parameters of three slot coupled finline with frequency(shown in inset). a=7.112mm, b=3.556mm, d=.127mm, ϵ_r=2.22, w_1=w_3=.3mm, w_2=.45mm, s_1=s_2=.2mm, h_1=3.556mm.