A NOVEL APPROACH TO MULTIPLEXER SIMULATION AND SENSITIVITY ANALYSIS

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Abstract

A novel approach to the simulation of multiplexer responses, which also results in the simple and direct evaluation of first-order sensitivities w.r.t. all variables of interest including frequency, is presented. Fundamental concepts that correspond to a general cascaded structure are utilized in the analysis.

A general contiguous-band multiplexer consisting of synchronously and asynchronously tuned coupled-cavity filters distributed along a waveguide manifold has the basic geometry as illustrated in Fig. 1. For this geometry, namely a branched cascaded structure, we develop an efficient and elegant approach to the simulation of such responses as common-port return loss, insertion loss and group delay between source and branch output ports and their first-order sensitivities w.r.t. network parameters as well as frequency[1]. The idea originates from the work by Bandler et al. on cascaded networks[2]. The constructing units for the whole structure are cascaded two-port equivalents and three-port junctions. A three-port junction described by its hybrid matrix **H** is reduced to an appropriate two-port representation, depending on the desired direction of analysis. Denoting the vector containing voltage and current at reference plane x by $\mathbf{y}^x$, we have

$$\mathbf{y}^1 = \mathbf{A}\,\mathbf{y}^2 \tag{1}$$

or

$$\mathbf{y}^1 = \mathbf{B}\,\mathbf{y}^3 \tag{2}$$

where 1, 2 and 3 are the port reference planes for the junction. Evaluation of $\mathbf{A}$ ($\mathbf{B}$) requires the use of elements of $\mathbf{H}$ and an equivalent termination for port 3(2). We also have

$$\boldsymbol{\alpha}^T \mathbf{y}^2 = \boldsymbol{\beta}^T \mathbf{y}^3 \tag{3}$$

where $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are obtained from $\mathbf{H}$.

Now consider a cascade of two-ports described by their transmission matrices. We have

$$\mathbf{y}^i = \mathbf{Q}_{ij}\,\mathbf{y}^j \tag{4}$$

where $\mathbf{Q}_{ij}$ is the product of all transmission matrices between reference planes i and j. Also,

$$\mathbf{Q}_{ij}' = \sum_{\ell \in I_\phi} (\mathbf{Q}_{ij}^{\ell})' \tag{5}$$

where $'$ is used to denote $\partial/\partial\phi$, I_ϕ is an index set whose elements identify the chain matrices between reference planes i and j containing the variable parameter ϕ and $(\mathbf{Q}_{ij}^{\ell})'$ is the product of all chain matrices between reference planes i and j with the ℓth chain matrix replaced by its derivative w.r.t. ϕ.

Terminations for the structure are treated in a unified manner. If τ denotes a terminating reference plane, we have

$$(\boldsymbol{\mu}^\tau)^T \mathbf{y}^\tau = c^\tau . \tag{6}$$

For example, for a short-circuit termination, a terminating load of impedance Z and a terminating voltage source E, we have $\boldsymbol{\mu} = [1 \;\; 0]^T$, $c=0$, $\boldsymbol{\mu} = [1 \;\; -Z]^T$, $c=0$ and $\boldsymbol{\mu} = [1 \;\; 0]^T$, $c = E$, respectively. A termination can be transferred from one reference plane to another, if the chain matrix between the two planes is evaluated. For instance, from $\mathbf{y}^\sigma = \mathbf{Q}_{\sigma\tau}\,\mathbf{y}^\tau$, it is easily shown that $\boldsymbol{\mu}^\sigma$ and c^σ in $(\boldsymbol{\mu}^\sigma)^T \mathbf{y}^\sigma = c^\sigma$ are evaluated from

$$(\boldsymbol{\mu}^\sigma)^T \mathbf{Q}_{\sigma\tau} = (\boldsymbol{\mu}^\tau)^T, \;\; c^\sigma = c^\tau. \tag{7}$$

Assuming that the common port and any of the channel output ports, say reference plane τ are of interest, the whole structure is simplified as shown in Fig. 2. In Fig. 2 $\mathbf{Q}_{x1}$ and

$\mathbf{Q}_{sy}$ have been obtained by calculation of equivalent terminations looking into the channel from manifold and then reduction of three-port junctions to two-ports. By invoking eqn. (3) at the junction in Fig. 2, we get

$$\boldsymbol{\alpha}^T \mathbf{Q}_{x1} \mathbf{y}^1 = \boldsymbol{\beta}^T \mathbf{Q}_{\sigma\tau} \mathbf{y}^\tau . \tag{8}$$

Also, we have

$$\mathbf{y}^s = \mathbf{Q}_{s1} \mathbf{y}^1 \tag{9}$$

where $\mathbf{Q}_{s1}$ represents the equivalent chain matrix of the whole structure between manifold source and load terminations. $\mathbf{y}^1$, $\mathbf{y}^\tau$ and $\mathbf{y}^s$ are calculated from (8), (9) and three terminating conditions at reference planes 1, τ and s.

As an example, consider a multiplexer structure with a short-circuit main cascade termination and open-circuit termination at reference plane τ, excited by a voltage source E. We have $\mathbf{y}^1 = [0 \;\; I^1]^T$, $\mathbf{y}^\tau = [V^\tau \;\; 0]^T$ and $\mathbf{y}^s = [E \;\; I^s]$. Substituting the terminating conditions in (8), we get

$$\boldsymbol{\alpha}^T \mathbf{Q}_{x1} \mathbf{e}_2 I^1 = \boldsymbol{\beta}^T \mathbf{Q}_{\sigma\tau} \mathbf{e}_1 V^\tau \tag{10}$$

where $\mathbf{e}_1$ and $\mathbf{e}_2$ are the voltage and current selector vectors $[1 \;\; 0]^T$ and $[0 \;\; 1]^T$, respectively. Combining (9) with the terminating condition at s gives

$$E = \mathbf{e}_1{}^T \mathbf{Q}_{s1} \mathbf{e}_2 I^1 . \tag{11}$$

Finally, eliminating I^1 between (10) and (11) results in the channel output voltage formula

$$V^\tau = \frac{\boldsymbol{\alpha}^T \mathbf{Q}_{x1} \mathbf{e}_2 E}{\boldsymbol{\beta}^T \mathbf{Q}_{\sigma\tau} \mathbf{e}_1 \mathbf{e}_1^T \mathbf{Q}_{s1} \mathbf{e}_2} . \tag{12}$$

Insertion losses between the common and channel output ports are calculated using the channel output voltages directly. Having calculated $\mathbf{Q}_{s1}$, reflection coefficient and return loss at the common port are also readily evaluated. First-order sensitivities w.r.t. all parameters including frequency are obtained by utilizing $\mathbf{Q}'$ matrices as described by (5). The sensitivity of channel output voltage w.r.t. frequency is used in the calculation of exact group delay. The efficiency of our approach lies in the fact that once $\mathbf{Q}$ matrices between all reference planes have been evaluated for the simulation of responses, first-order sensitivity calculations are performed with minimum extra effort. Each $(\mathbf{Q}^{\ell})'$ term requires two additional 2x2 matrix multiplications; the partial derivative of the chain matrix for the ℓth two-port is multiplied by a previously evaluated $\mathbf{Q}$ (from the starting reference plane up to and excluding the ℓth two-port) and the product is multiplied by another known $\mathbf{Q}$ (from the ℓth two-port up to the final reference plane).

One interesting property of the sensitivities for the structure under consideration is that for a variable parameter at any part of the network, the sensitivities of all channel insertion losses corresponding to the channels between the variable element and the manifold load termination are identical. Applying the property

$$x = \frac{a}{bc} \Rightarrow \frac{x'}{x} = \frac{-c'}{c} \quad \text{if a and b are independent of } \phi$$

and using (12), for a variable ϕ contained in $\mathbf{Q}_{sy}$, we have

$$\frac{(V^{\iota})'}{V^{\iota}} = -\frac{\mathbf{e}_1^T \mathbf{Q}_{s1}' \mathbf{e}_2}{\mathbf{e}_1^T \mathbf{Q}_{s1} \mathbf{e}_2} . \tag{13}$$

It is clear that Q_{s1} and Q_{s1}' are independent of ι. The sensitivities of insertion loss for port ι are directly proportional to the LHS of (13).

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References

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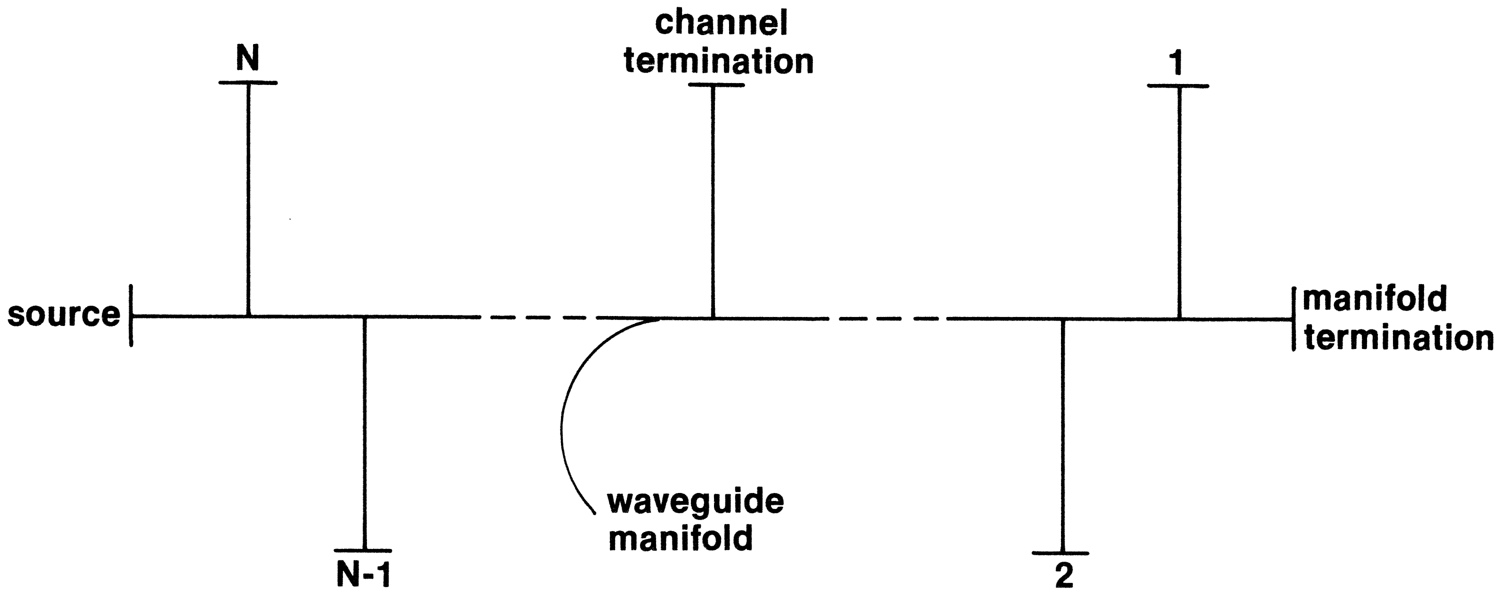

Fig. 1 The basic structure of an N-channel multiplexer

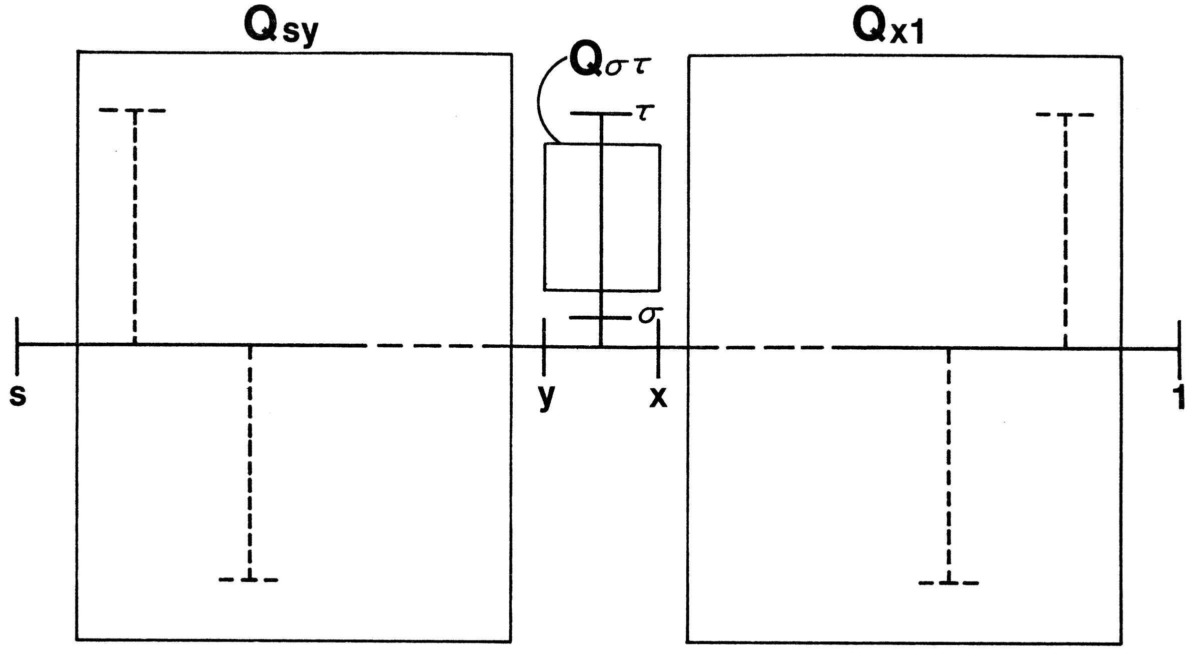

Fig. 2 The simplified structure of the multiplexer when channel output port τ is of interest.