A COMBINED MODE-MATCHING AND COUPLED-INTEGRAL-EQUATIONS TECHNIQUE FOR THE DESIGN OF NARROW-BAND H-PLANE WAVEGUIDE DIPLEXERS

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I. INTRODUCTION

H-plane waveguide diplexer and multiplexer configurations are well-known components in satellite and earth-to-earth communication systems [1]. They combine the advantages of ease of fabrication and simplicity in numerical analysis. Commonly, TE_{m0}-mode-based mode-matching procedures are used for the computer-aided design [1] - [4]. While the channel filters are presynthesized for the individual Tx and Rx specifications, the entire component must be optimized in order to achieve a satisfactory input return loss. This is a fairly straightforward and well-known procedure and has been successfully applied to many individual designs with several percent of channel bandwidths.

In narrow-band systems, however, the number of required modes for a reliable analysis increases dramatically. Especially for bandwidths below one percent, up to 50 odd modes might be necessary as has recently been demonstrated for individual H-plane filter components [5]. Since field symmetries cannot be utilized in a diplexer arrangement of filters, the entire component must then be analyzed and optimized with close to 100 modes. It has turned out that under such circumstances, the diplexer design can no longer be accomplished within typical industry-driven design cycles.

Therefore, this paper focuses on a new concept in diplexer design, namely a combination of the standard mode-matching technique (MMT) with the coupled-integral-equations technique (CIET), the latter being used only for the synthesis and analysis of the individual channel filters. Several major advantages are associated with this approach: First, for a full-cycle analysis of a diplexer configuration, the combined method reduces the CPU time significantly compared to ordinary MMT. Secondly, the numbers of basis functions in the CIET can be reduced during optimization without a shift in frequency as matrix sizes do not depend on the number of modes. In standard MMT algorithms, a reduced number of modes is usually associated with a (sometimes remarkable) shift towards lower frequencies. Thirdly, the CIET - at almost no additional computational cost - allows the extraction of the generalized scattering matrix so that the results are easily interfaced with mode-matching calculations of other components.

The procedure is demonstrated at the examples of two narrow-band H-plane diplexers with single-sided inductive-iris filters and individual channel bandwidths of approximately 0.4 percent. While the input transformer sections, bifurcation and T-junctions are computed in standard MMT (this part is known to be fairly insensi-

0-7803-5639-X/99/$10.00 (c)1999 IEEE

tive to a high number of modes), the channel filters employ the CIET for reliable performance predictions.

II. THEORY

The general principles of computing the generalized scattering matrix from MMT and the combinations of several of such matrices in multiport arrangements are well known, e.g. [1], [2]. Therefore, we focus our attention on extracting the generalized S-matrix from the CIET. As described in [5], the CIET leads to a block-diagonal matrix which, e.g. for six discontinuities, can be written as

$$\begin{bmatrix} \underline{A}^{11} & \underline{A}^{12} & \underline{0} & \underline{0} & \underline{0} & \underline{0} \\ \underline{A}^{21} & \underline{A}^{22} & \underline{A}^{23} & \underline{0} & \underline{0} & \underline{0} \\ \underline{0} & \underline{A}^{32} & \underline{A}^{33} & \underline{A}^{34} & \underline{0} & \underline{0} \\ \underline{0} & \underline{0} & \underline{A}^{43} & \underline{A}^{44} & \underline{A}^{45} & \underline{0} \\ \underline{0} & \underline{0} & \underline{0} & \underline{A}^{54} & \underline{A}^{55} & \underline{A}^{56} \\ \underline{0} & \underline{0} & \underline{0} & \underline{0} & \underline{A}^{65} & \underline{A}^{66} \end{bmatrix} \begin{bmatrix} \underline{c}^1 \\ \underline{c}^2 \\ \underline{c}^3 \\ \underline{c}^4 \\ \underline{c}^5 \\ \underline{c}^6 \end{bmatrix} = \begin{bmatrix} \underline{U} \\ \underline{0} \\ \underline{0} \\ \underline{0} \\ \underline{0} \\ \underline{0} \end{bmatrix}, \quad \begin{bmatrix} \underline{0} \\ \underline{0} \\ \underline{0} \\ \underline{0} \\ \underline{0} \\ \underline{V} \end{bmatrix} \tag{1}$$

where matrices containing $\underline{U}$ and $\underline{V}$ represent excitations at the input and output, respectively. For details on the matrix $[\underline{A}]$, the reader is referred to [5]. After performing a LU decomposition on $[\underline{A}]$ taking into account its block-diagonal structure, (1) is successively solved for vectors $\underline{c}$ due to excitation by the column vectors of

$$\underline{U} = 2[\underline{W}^{I,1}]^T \mathrm{Diag}\{Y^0\}, \quad \underline{V} = 2[\underline{W}^{II,N}]^T \mathrm{Diag}\{Y^N\}. \tag{2}$$

Y^0 and Y^N are the modal admittances at the input and output, respectively, and $[\underline{W}^{I,1}]$ and $[\underline{W}^{II,N}]$ are the coupling matrices, which contain the appropriate edge conditions, at the input and output discontinuities. T means transposed.

Let $\underline{c}_M^1$, $\underline{c}_M^N$, $\underline{c}_L^1$, $\underline{c}_L^N$ be the coefficient vectors at the first and last discontinuity due to excitation by the Mth mode at the input and the Lth mode at the output. Then a column vector of the unnormalized generalized scattering matrix is obtained through

$$(\bar{\underline{S}}_{11})_M = [\underline{W}^{I,1}]\underline{c}_M^1 - \delta_{kM} \tag{3}$$

$$(\bar{\underline{S}}_{21})_M = [\underline{W}^{II,N}]\underline{c}_M^N \tag{4}$$

$$(\bar{\underline{S}}_{22})_L = [\underline{W}^{II,N}]\underline{c}_L^N - \delta_{kL} \tag{5}$$

$$(\bar{\underline{S}}_{12})_L = [\underline{W}^{I,1}]\underline{c}_L^1 \tag{6}$$

where δ_{mn} is the Kronecker delta. Once all column vectors have been computed to form the matrix $[\bar{\underline{S}}]$, the final S-matrix requires a power normalization by the square roots of the frequency-dependent admittances

$$[\underline{S}_{11}]_{kM} = [\bar{\underline{S}}_{11}]_{kM}\sqrt{Y_k^0/Y_M^0} \tag{7}$$

$$[\underline{S}_{21}]_{kM} = [\bar{\underline{S}}_{21}]_{kM}\sqrt{Y_k^N/Y_M^0} \tag{8}$$

$$[\underline{S}_{22}]_{kL} = [\bar{\underline{S}}_{22}]_{kL}\sqrt{Y_k^N/Y_L^N} \tag{9}$$

$$[\underline{S}_{12}]_{kL} = [\bar{\underline{S}}_{12}]_{kL}\sqrt{Y_k^0/Y_L^N} \tag{10}$$

assuming that the cross-sectional dimensions have been incorporated in the computation of $[\underline{A}]$ through a suitable power normalization.

III. RESULTS

Fig. 1 shows an H-plane bifurcation diplexer with single-sided inductive-iris filters. The channel filters are predesigned for individual channel bandwidths of approximately 0.4 percent using the CIET. The input transformer section and bifurcation are computed in standard MMT and are interfaced through the generalized S-matrix of the channel filters obtained through the process described above. An optimization procedure, e.g. [6], varies transformer and filter dimensions to obtain a 25dB return loss and 50dB isolation (solid line). An all MMT analysis reveals results within the plotting accuracy (dashed lines), thus verifying the scattering-matrix extraction process. Note that both techniques employ a loss analysis based on the TE_{10}-mode resonances, the loaded Q value of the cavities and the bandwidths of the channel filters

The second example is a H-plane manifold diplexer for identical specifications (Fig. 2). T-junctions and the shorting stub are calculated using standard MMT and are interfaced at the respective ports with the generalized S-matrix of the channel filters obtained from the CIET. Note that the apertures of the filter sections face each other which permits an increase in resonator widths while maintaining a short distance between the two T-junctions. Again the agreement between the combined MMT-CIET (solid lines) and all-MMT approach (dashed lines) is within the plotting accuracy.

The major advantage of using the combined MMT-CIET design is the saving in CPU time. Depending on the number of modes and basis functions used, the combined method was five to 40 times faster than the all-MMT approach.

IV. CONCLUSIONS

A combined MMT-CIET approach for the design of narrow-band H-plane diplexers is presented. By extracting the generalized scattering matrix from the CIET formulation, an interface between the MMT and the CIET is created which takes full advantage of the salient features of the CIET and, therefore, permits the timely design of waveguide diplexers. Comparisons with all-MMT calculations verify the designs.

REFERENCES

1. J. Uher, J. Bornemann and U. Rosenberg, Waveguide Components for Antenna Feed Systems. Theory and CAD, Artech House, Norwood 1993.
2. J. Dittloff and F. Arndt, "Computer-aided design of slit-coupled H-plane T-junction diplexers with E-plane metal-insert filters", IEEE Trans. Microwave Theory Tech., Vol. 36, pp. 1833-1840, Dec. 1988.
3. M. Guglielmi, "Simple CAD procedure for microwave filters and multiplexers", IEEE Trans. Microwave Theory Tech., Vol. 42, pp. 1347-1352, July 1994.
4. W. Menzel, F. Alessandri, A. Plattner and J. Bornemann, "Planar integrated waveguide diplexer for low-loss millimeter-wave applications", in Proc. 27th EuMC, pp. 676-680, Sep. 1997.
5. S. Amari, J. Bornemann and R. Vahldieck, "Fast and accurate analysis of waveguide filters by the coupled-integral-equations technique", IEEE Trans. Microwave Theory Tech., Vol. 45, pp. 1611-1618, Sep. 1997.
6. K. Madsen, H. Schaer-Jacobsen and J. Voldby, “Automated minimax design of networks,” IEEE Trans. Circuits Systems, Vol. CAS-22, pp. 791-796, Oct. 1975.

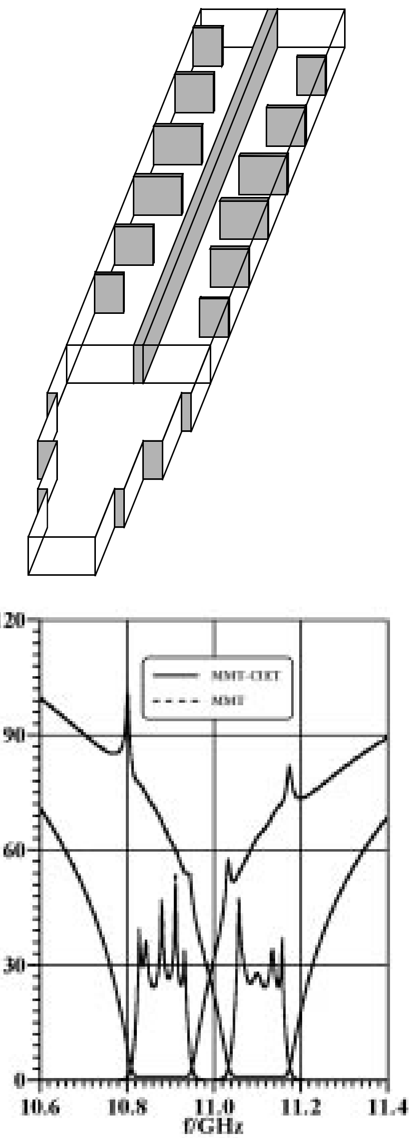

Fig. 1 Design example of a narrowband H-plane bifurcation diplexer with single-sided inductive-iris filters; combined MMT-CIET (solid lines), all-MMT (dashed lines).

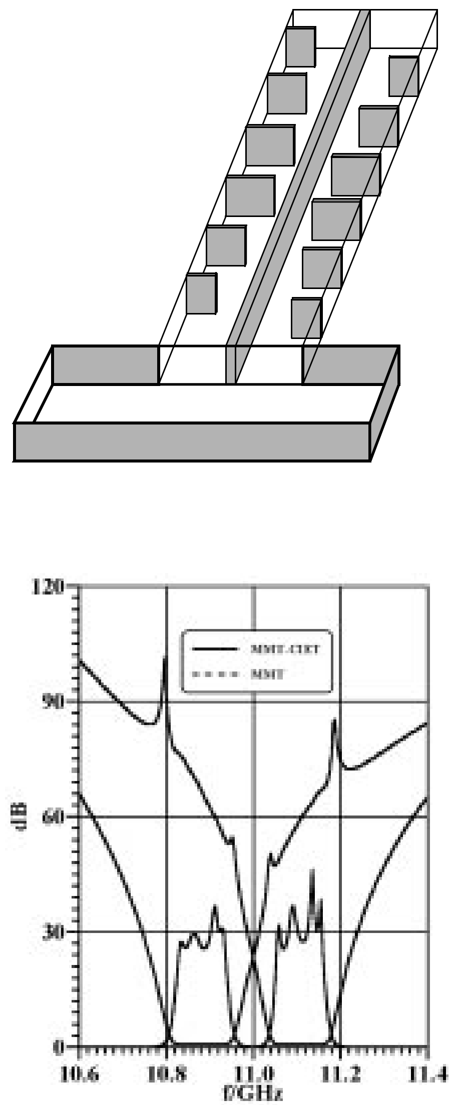

Fig. 2 Design example of a narrowband H-plane manifold diplexer with single-sided inductive-iris filters; combined MMT-CIET (solid lines), all-MMT (dashed lines).