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MODE-MATCHING APPROACH FOR THE CALCULATION OF A WAVEGUIDE TEE DISTORTED BY SEMI-PLATES IN THE BRANCHING REGION

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One of configurations of OMT is a tee with metal plates in one of the straight arms. These plates form a system of cutoff waveguides and reflect the mode of one of the polarizations. The simplest example is a waveguide tee with one plate within the direct port and no overlapping of the plate and the branching region (Fig. 1a). This configuration, as shown in [1], provides a good matching of side arm in a narrow frequency band only and has increased dimensions. These facts limit OMT application. The authors have pointed that MMT can be used *only* if there is no overlapping of plate and branching region ([1], p. 388).

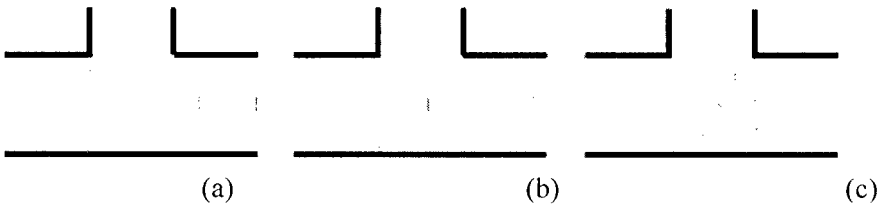


Fig. 1. OMTs based on the tee with metal plates

As it turned out later, one can solve the of mode diffraction on a tee with coordinate discontinuities in branching region by using MMT (se [2] for configuration in Fig. 1b). However the calculations have shown that a low return loss can be obtained in direct arm for the single-plate case only in the beginning of operating frequency range. This is caused by too deep penetration of the electromagnetic field into the cutoff regions. Due to this fact the plate and below-cutoff waveguides cannot “imitate” the mitered bend. It is obvious that increasing the number of plates can facilitate the problem solution.

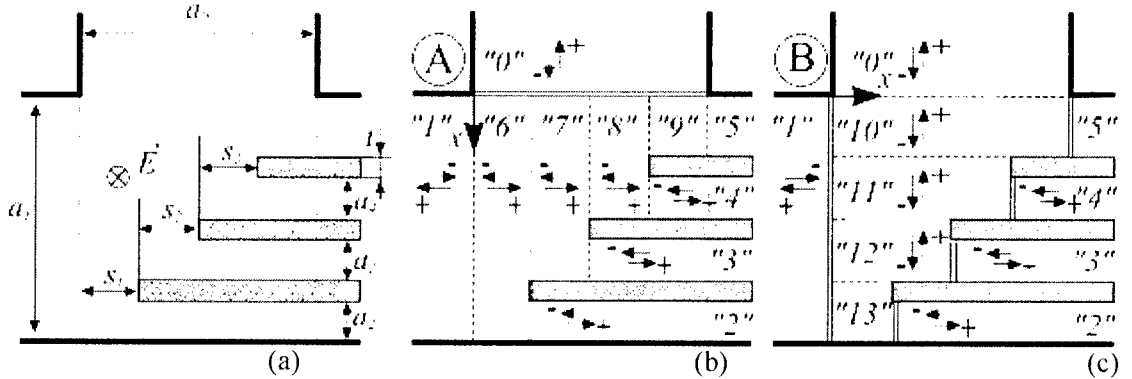


Fig. 2. Tee with three plates and its division to subregions

In this paper we use the modification of MTT published in [2]. The field in branching region (Fig. 2a) is represented as a superposition of two fields: a) horizontal configuration with PEW on the top and b) vertical configuration with PEWs on right and left side waveguides. We consider the case of E-field parallel to semi-plate edges. The field matching for the inner regions of the subproblem geometries can be performed independently for both subproblems A and B.

Fig. 3 shows some elementary cell formed by subregions "6", "7" and "2" belonging to subproblem A (Fig. 3a) and subregions "13", "2" of subproblem B (Fig. 3b).

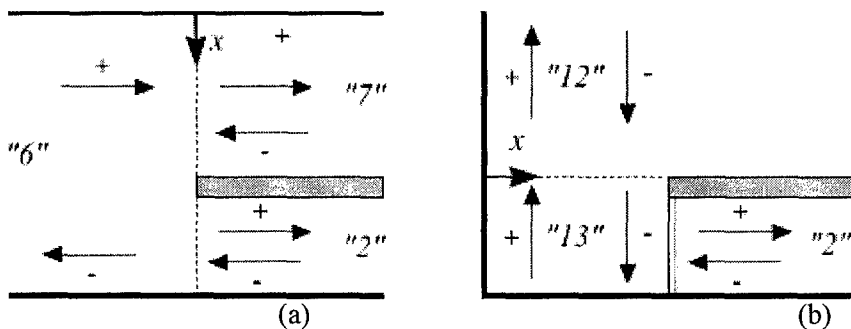


Fig. 3. Field matching in the elementary cell

Transverse field in subregions can be expressed as a superposition of eigen waves of parallel-plate waveguide:

$$E_y^{(p)} = \sum_{n=1}^{\infty} \left[p_n^+ \cdot e^{i\gamma_n^{(p)} z^{(p)}} + p_n^- \cdot e^{-i\gamma_n^{(p)} (z^{(p)} - h^{(p)})} \right] \cdot \sin(\beta_n^{(p)} x^{(p)}),$$

$$H_x^{(p)} = \sum_{n=1}^{\infty} i\gamma_n^{(p)} \cdot \left[p_n^+ \cdot e^{i\gamma_n^{(p)} z^{(p)}} - p_n^- \cdot e^{-i\gamma_n^{(p)} (z^{(p)} - h^{(p)})} \right] \cdot \sin(\beta_n^{(p)} x^{(p)}),$$

where p is the subregion number, p_n^+ and p_n^- are the mode amplitudes, $\beta_n^{(p)} = n\pi/a^{(p)}$ and $\gamma_n^{(p)} = \sqrt{k^2 - (\beta_n^{(p)})^2}$ are transverse and longitudinal wave numbers. The field must satisfy the following boundary conditions:

$$\begin{cases} E_y^{(6)} = E_y^{(7)} & \text{on aperture "6"-"7"} \\ E_y^{(6)} = 0 & \text{on metall} \\ E_y^{(6)} = E_y^{(2)} & \text{on aperture "6"-"2"} \end{cases} \quad \begin{cases} H_x^{(6)} = H_x^{(7)} & \text{on aperture "6"-"7"} \\ H_x^{(6)} + H_z^{(13)} = H_x^{(2)} & \text{on aperture "6"-"2"} \end{cases}$$

Now we can perform field matching and project it on the basis functions of corresponding subregions. Resulting equations are presented in matrix form as follows:

$$\begin{aligned} N^{(6)} E^{(6)} \vec{\mathbf{6}}^+ + N^{(6)} \vec{\mathbf{6}}^- &= M^{(67)} \vec{\mathbf{7}}^+ + M^{(67)} E^{(7)} \vec{\mathbf{7}}^+ + M^{(62)} \vec{\mathbf{2}}^+ + M^{(62)} \vec{\mathbf{2}}^-, \\ M^{(76)} \gamma^{(6)} E^{(6)} \vec{\mathbf{6}}^+ - M^{(76)} \gamma^{(6)} \vec{\mathbf{6}}^- &= N^{(7)} \gamma^{(7)} \vec{\mathbf{7}}^+ - N^{(7)} \gamma^{(7)} E^{(7)} \vec{\mathbf{7}}^-, \\ iM^{(26)} \gamma^{(6)} E^{(6)} \vec{\mathbf{6}}^+ - iM^{(26)} \gamma^{(6)} \vec{\mathbf{6}}^- &+ Me_-^{(2-13)} \beta^{(13)} J^{(13)} \vec{\mathbf{13}}^+ + \\ &+ Me_+^{(2-13)} \beta^{(13)} J^{(13)} \vec{\mathbf{13}}^- = iN^{(2)} \gamma^{(2)} \vec{\mathbf{2}}^+ - iN^{(2)} \gamma^{(2)} \vec{\mathbf{2}}^-, \end{aligned}$$

where $\vec{\mathbf{p}}^{\pm} = \{p_n^{\pm}\}$, $N^{(p)} = \text{diag} \left\{ \frac{a^{(p)}}{2} \right\}$, $E^{(p)} = \text{diag} \left\{ e^{i\gamma_n^{(p)} h^{(p)}} \right\}$,

$\gamma^{(p)} = \text{diag} \left\{ \gamma_n^{(p)} \right\}$, $\beta^{(p)} = \text{diag} \left\{ \beta_n^{(p)} \right\}$, $J^{(p)} = \text{diag} \left\{ (-1)^n \right\}$, $n = 1, 2, 3, \dots$

Here $M^{(pq)}$ are the matrices of conventional coupling integrals and the elements of matrices $Me_{\pm}^{(pq)}$ are the following integrals:

$\{Me_+^{(pq)}\}_{m,n} = \int_S \sin(\beta_m^{(p)} x) \cdot \exp(i\gamma_n^{(q)} x) \cdot dx$. Note, that the electric field has been

matched on the wide cross-section (subregion "6"), and the magnetic field has been matched on the two narrow ones (subregions "7" and "2").

The field matching on each of apertures results in 21 equations with 21 unknown vectors of field expansion amplitudes. This allows us to form the matrix equation of the 2nd kind with a block type operator. By solving it we obtain the S -matrix of full circuit and also the internal field. A study of the obtained solution numerical convergence shows that it has non-monotonous character. Nevertheless, taking into account 40 modes in port "0" (number of modes in the each of other regions is proportional to its width according to Mittra's rule [3]) is quite enough for rather good accuracy. Power disbalance between incoming and outgoing modes is less than 10^{-4} . Under these conditions the calculation of S -matrix per frequency point takes about 2 sec on 1100 MHz PC. In examination of the algorithm certain instabilities were revealed. The are accompanied with a sudden change of the matrix operator condition number

$cond(A) = \frac{\|A\| \cdot \|A^{-1}\|}{|\det(A)|}$ (by several orders). Simultaneously the power conservation law fails. This phenomenon causes sharp spikes on frequency response curves. The spike width decreases with increasing the matrix dimension. It is determined that the positions of spikes coincides with the eigen frequencies of the branching region (the resonator formed by assuming PEWs of subproblems A and B simultaneously).

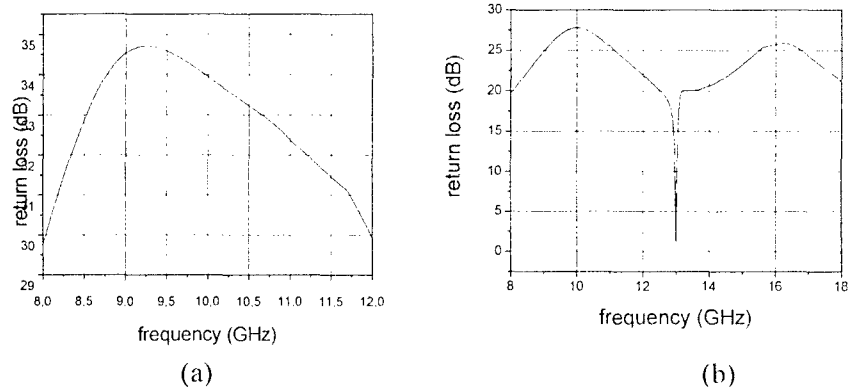


Fig. 4. Frequency response of optimized construction

In order to obtain a good matching of the device under consideration, optimization procedure was applied in two frequency bands. Corresponding results are shown in Fig 4. In the optimization within operating range of the waveguide (8-12 GHz) it is possible to ensure the return loss less than 28 dB (Fig. 4a). For a wider band (8-18 GHz) the return loss is about 22 dB except of the resonance area near 13 GHz (Fig. 4b). This resonance is caused by the appearance of the second mode and has the same nature as discussed in [4].

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