TITLE: Data Preprocessing for Generalized Mode-Matching Method

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: 2002 International Conference on Mathematical Methods in Electromagnetic Theory [MMET 02]. Volume 2

DATA PREPROCESSING FOR GENERALIZED MODE-MATCHING METHOD

Anatoly Kirilenko, Dmitry Kulik

Institute of Radio Physics and Electronics National Academy of Sciences of Ukraine
12 Akad. Proskury St., Kharkov, 61085, Ukraine; E-Mail: kirilenko@ire.kharkov.ua

ABSTRACT

The paper goal is to describe a geometrical data preprocessor, which is used at realization of the generalized mode-matching technique (GMMT). Its destination consists in processing of the geometry specification of the cross-section a complicated waveguide line by the manner that allows the unificate the process of the matrix operators required to find the mode basis.

In spite of widespread using of finite difference and other lattice methods the MMT [0,0] is still the most attractive procedure of the waveguide problem solution regarding to common efficiency-universality estimation. Nevertheless the drawback of this method is an individual approach to each of problem under consideration. This makes MMT algorithms relatively time-consuming ones both at analytical and numerical consideration of the solutions and at testing and tuning as well. Really this reason increases the time of waiting of the final results and hampers somewhat the practical usage of MMT.

The goal of our work was to generalize the MMT, making it possible to unificate the process of the numerical algorithm development for initially unpredetermined geometries of a wide class. Saving the well-known efficiency and accuracy of MMT algorithms this brings such GMMT solutions to lattice methods [0] regarding to both the easiness of usage and the universality of approach as well.

We consider such a generalization of MMT as a procedure that creates the MMT-algorithms without any preliminary analytical consideration. Here we describe the part of this algorithm that responsible for processing of a geometrical data. We named it "preprocessor" by analogy with corresponding parts of the software based on the lattice methods. Its function here consists in the data preparing for implementation of MMT matrix equation at calculation of the full mode bases for a waveguide line with arbitrary cross-section having the coordinate piecewise-linear boundary.

A waveguide line that may be considered as a rough approximation of the coaxial line is presented in Fig. 1. The line cross-section has to be divided into a set of nonoverlapping rectangular subregions. This fragmentation may be performed in Y or in X directions meaning that all such the subregions have metallized sidewalls parallel to Y or X axis (Fig. 1 demonstrates typical Y-fragmentation). The sidewalls of these subregions are metallized and the upper and low walls may be open or closed by electrical (PEW) or magnetic (PMW) walls. They may appear at consideration of the lines with symmetrical cross-section. In other words the cross-section will be presented as a set of peaces of plane-parallel waveguides that make it possible using the transverse resonance method to obtain the mode basis.

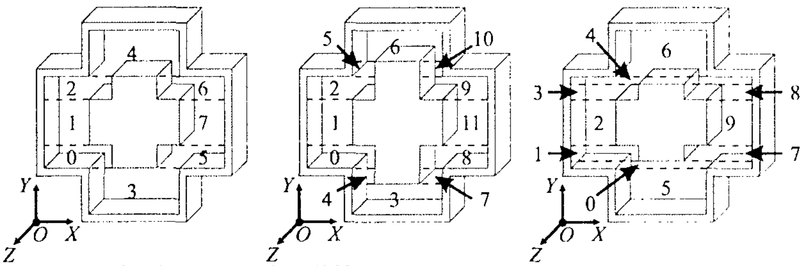

Fig. 1 The possible sets of subregions for different configurations of the coaxial line formed by a cross internal conductor within the crossed waveguide.

The number and coordinates of the rectangular subregions forming the line cross-sections provides really the full information required to calculate the mode basis. Naturally the situations exist when a weak geometry varying may require not only corresponding changing the geometrical parameters but also rearranging the set of subregions and even their total number as well. Such a situation is illustrated by the left and right pictures of Fig. 1. This is a reason of the necessity of the preprocessor operations not only at the initial stage of calculation but at any variations of the geometrical parameters as well.

The main purpose of the preprocessor consists in fragmentation the cross-section specified by a simple and easy in use manner into the set of subregions. Initial specification may consists, for example, of several contours specified by arranged sets of vertex points. Fig. 2 illustrates successive steps of preprocessing procedure.

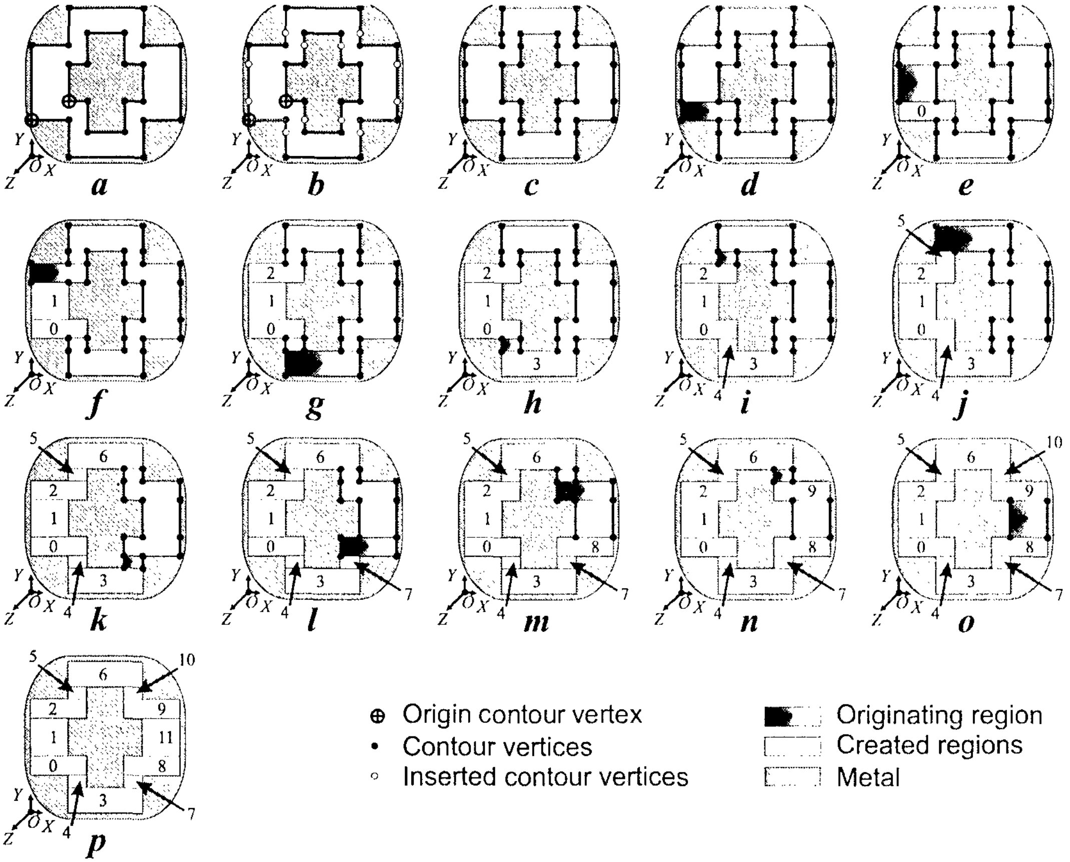

Fig. 2 The stages of the subregions set forming according to specified piece-wise coordinate contours which describe the cross-section.

Fig. 2a shows two initial contours forming the cross-section. The dark circles mark the vertices. At the first step the ensamble U of the y-coordinates, which characterize the points of the uniformity breakdown in vertical direction have to be found. After that the corresponding to U additional vertices are inserted in all contours. The light circles in Fig. 2b mark them.

Using the all set of vertices the set of vertical line pieces are formed. They represent the sidewalls of the future subregions (Fig. 2c).

The next steps of subregion ensamble forming presented in Fig. 2*d*-Fig. 2*o*. They are the following:

– The found pieces set is successfully looked through to find the "pairs". The pair is two pieces with the same height and placed at the same coordinates.

– The pair of the nearest on horizontal pieces forms the subregion. The pieces generative it are moved away of the set of pieces.

– The process is continued until the pieces set is not empty. In principle this step finished the stage of cross-sections segmentation.

The following steps are aimed to prepare the data for MMT matrix operators:

– The matrix of the subregion couplings is formed. Each geometrical coupling matrix element is a data structure that determine : a) if the subregion I is coupled by an open aperture with subregion j; b) if "*Yes*", the what are the coordinates and the placement peculiarities of a common aperture. The determination of the geometrical subregion coupling matrix is performed by successive looking through all set of subregions and analyzing the type of subregions' contact.

– After that it is possible to extract the subsets of noncontacting subregions that describe possible separate waveguides (for example a hollow waveguide within the hollow waveguide). This accelerates the computational process in times.

At the calculation of a TEM mode field distribution it is required to know the potentials of the subregions sidewalls. The equipotental contour to which a sidewall belongs is determined according to the number of contour to which the wall belonged initially.

To facilitate the mode basis search for the lines with symmetrical cross section the dividing the problems into two or four ones is foreseen. These subproblems are the boundary value problems relative the halves or the quarters of initial cross-section with PEW or PMW in the planes of symmetry. Sometimes these subproblems have to be divided in its turn etc. Except of rarefying the roots of dispersion equation this enables to avoid the root omission for twinned cutoffs of the TM-modes, when the field is totally concentrated in the left part or in the right one of a cross-section.

Above discussed steps of preprocessing provides all required data to create the matrix operators of generalized mode-matching technique. One way to create dispersion equation is to use the matching operations immediately for the subregions fields at their common boundaries defined by the coupling matrix. The role of unknowns here play the amplitudes of the field space harmonics within subregions. Though it is the simplest approach, however it is immediately applicable to the situations when all subregion couplings may be described as a contact a "big" subregion with a "small" one. In the opposite case the intermediate zero-length virtual subregion has to be implemented.

Another way is to use the matching procedure basing on the unknown field distributions on the subregion coupling apertures. Except of a possibility to reduce somewhat the number of unknown amplitude vectors there is essential advantage to use special bases for the field distribution expansion. They may take into account all types of the fields behavior near coupling aperture ends: rectangular or sharp edge, electrical wall or magnetic wall. Such algorithms have shown very good convergence on a range of partial configurations [0,0]. Last time they came to attention again [0].

The above-described preprocessor and the electromagnetic solver corresponding to first of MMT approaches was realized in the frames of AutoCAD based electromagnetic software for analysis and synthesis of waveguide devices *MWD01*. Detailed description of the solver background, realization and numerical peculiarities are the subject of a separate message. See, for example [0].

Here we present a set of the field distribution of the main and high modes of the waveguides with complicated cross-sections.

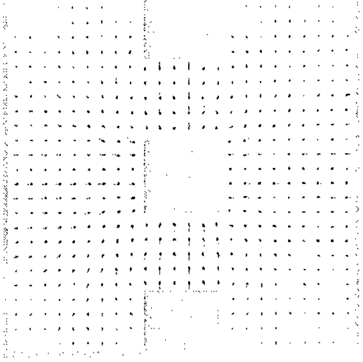

Fig. 3

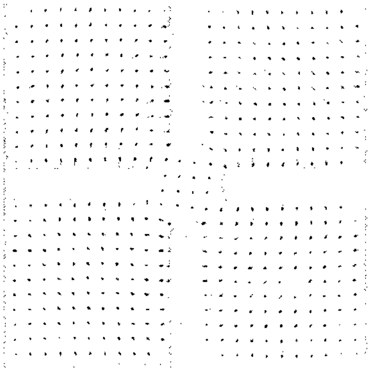

Fig. 4

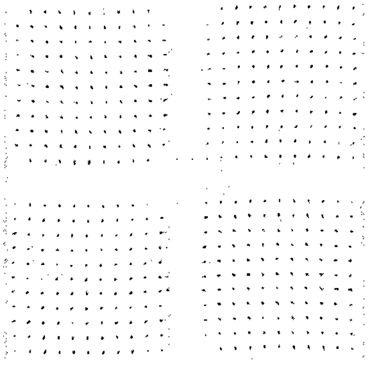

Fig. 5

The Fig. 3 presents the field of the dominant TEM-mode of a ridged rectangular bar line that used in special types of the bandpass filters. The Fig. 4 demonstrates a like to TE01-mode of circular waveguide distribution of a higher TE4 mode of the rectangular quadruple ridged waveguide. The origin of this mode may be treated as a difference of the TE20 and the TE02 modes of the square waveguide. By the same manner the origin of the higher TE5 mode of the rectangular quadruple ridged waveguide (Fig. 5) may be explained as the sum of the TE20 and the TE02 modes.

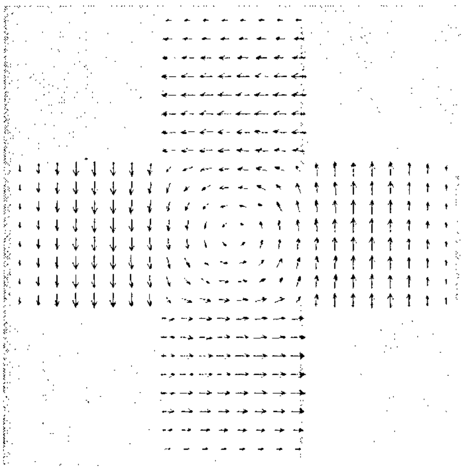

Fig. 6

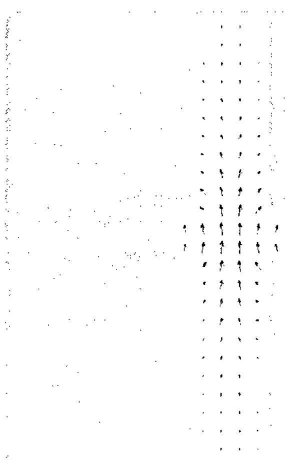

Fig. 7

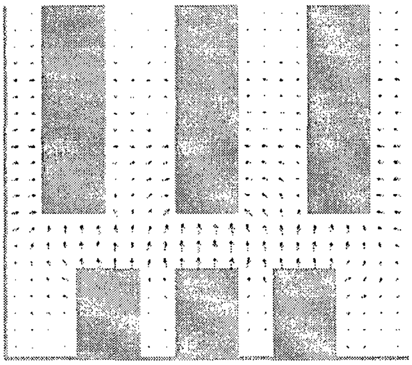

Fig.. 8

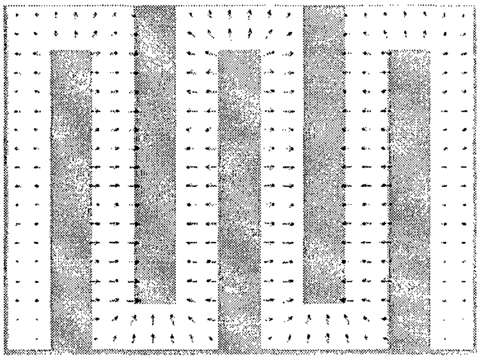

Fig. 8

Fig. 6 demonstrates the TE4 mode of the crossed rectangular waveguide with the axially symmetrical distribution of the transversal electrical field as well. Fig. 7presents the field of the main mode of the grooved waveguide. It confirms the possibility to calculate the groove mode a mode of crossed waveguide (TE3). The cross-sections similar to shown in Fig.8 are used at design of the waffle-iron low-pass filters. Finally the Fig.9 presents the dominant mode field of the waveguide with a serpentine cross-section. Due to such type of the cross-section it has a very low cutoff.

REFERENCES

[1] G.V. Kisunko, *Electrodynamics of the Hollow Systems*, VKAS Publ., Leningrad, 1949 (in Russian).

[2] A. Wexler, "Solution of Waveguide Discontinuities by Modal Analysis", IEEE Trans. on MTT, vol. 15, #9, 1967, pp. 508-517.

[3] T. Itoh (ed), *Numerical Techniques for Microwave and Millimeter-Wave Passive Structures*, New York: J. Wiley, 1989.

[4] G.I. Veselov, N.I. Platonov, E.S. Slesarev, "Taking into account the field singularities near edges and mode-matching", Radiotechnika, vol. 35, #5, 1980, pp. 27-34, (in Russian).

[5] G.F. Zargano, V.P. Lyapin and others, *The Waveguides of Complicated Cross-sections,* Radio i Svyaz', Moskow, 1986, (in Russian).

[6] S. Amari, J. Borneman, R. Vahldieck, Application of Coupled –Integral-Equation Technique to Ridged Waveguides, IEEE Trans. on MTT, vol. 44, #12, 1996, pp.2256-2264.

[7] A. Kirilenko, D. Kulik, Yu. Parkhomenko, L. Rud, V. Tkachenko, "Automatic electromagnetic solvers based on mode-matching, transverse resonance, and S-matrix techniques", MICON-2002 Conf. Proc. Gdansk, Poland, May 20-22, 2002, vol. 3 pp.815-824.