

“SCATTMAT: A Mode Matching and Generalized Scattering Matrix Code for Personal Computers in a Windows Environment”

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ABSTRACT

In this paper, a computer aided design tool is presented to simulate symmetrical radially deformed circular waveguide microwave components. This tool works with the well-known “Mode Matching and Scattering Matrix” techniques, and it has been developed in C++ language in a Windows environment, to obtain the most friendly interface between the user and the code.

The most important feature of the presented code is that it includes the possibility to display the internal mode power evolution along the component.

The code has been successfully validated with numerical and experimental results from different authors.

INTRODUCTION

Nowadays, there are a lot of microwave and millimeter waves applications like satellite communications, radar, remote sensing, plasma heating, etc., where circular waveguide components using radial deformations to achieve convenient features. Due to high fabrication cost it is very important to simulate these components before construction; in this way, then it is desirable to predict their experimental behaviors.

Mode converters, filters, tapers, horn antennas (smooth and corrugated), Bragg reflectors, resonators and many others can be analyzed readily.

The main features of the code are the following:

- It runs in a personal computers (486 or higher) under Windows environment.
- The program controls the memory resources to avoid the machine overflow. Besides it displays a message if the total machine resources are insufficient to calculate the component.
- Logically, TE and TM modes can be considered.
- A two-dimensional graphic design program to specify the component geometry is also given.
- Internal mode power evolution can be tracked down the component showing magnitude and phase at certain points given as input to the code.
- Any mode mixture is allowed at the input of the component, if needed.

The computation time, other than the processor speed, depends on the number of modes taken into account which fixes the size of the matrix. Also the number of internal component points to be

visualized determine the number of considered and stored matrices. These two parameters, number of modes and points to visualize determine the memory resources for the calculation.

NUMERICAL METHOD

The used numerical method is the well-known “Mode Matching and Scattering Matrix” method [1]. In order to visualize the internal power evolution along the whole component, it is compulsive to store all the partial scattering matrices. To get the power distribution in one particular point, it is also compulsive to know the whole scattering matrix from this point toward the input, and the whole scattering matrix from the same point toward the output or end of the component.

The calculation procedure has two different steps:

- *Calculation of the whole scattering matrix*, in this stage, all the submatrices are stored in a binary tree form. This means, two matrices of one level are combined to get a new matrix of a higher level. Working in this way, at the end of the process, on the top of the tree, we will obtain the global scattering matrix of the whole component. This is illustrated in Fig. 1 for the case of 4 elements or sampling points. Where \mathbf{z} is the longitudinal position and $\mathbf{a}_s(\mathbf{z})$ is the component radius function.

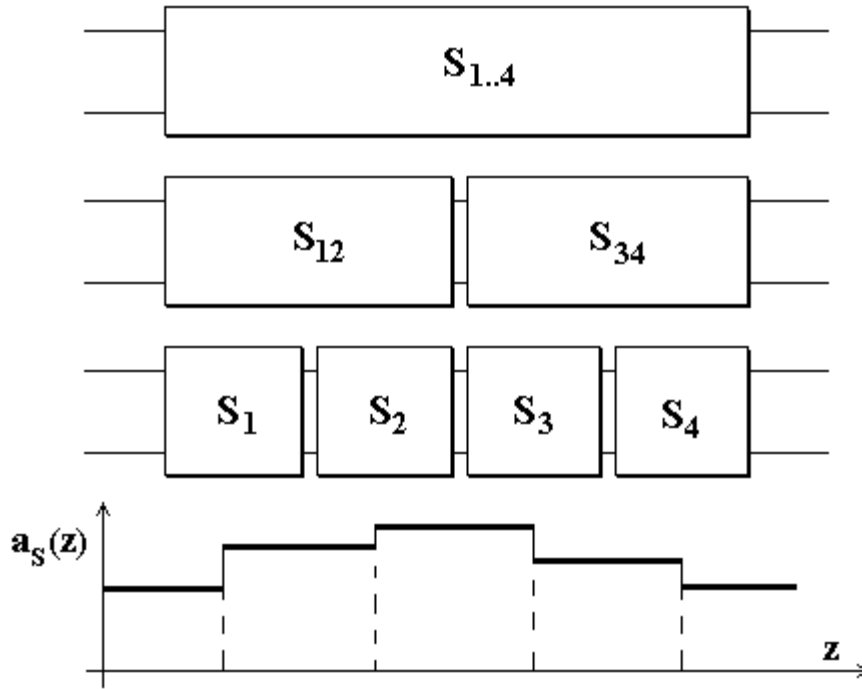


Figure 1.- Generated binary tree of scattering matrices of a simplified profile function $\mathbf{a}_s(\mathbf{z})$ for the case of 4 sampling points.

- *Calculation of the internal power evolution*, from the input power data, and the calculated ones at the output, by using the previously calculated global scattering matrix, and if we go down the submatrice tree then we obtain the internal power distributions between the matrices of each level. For instance, just at the level under the top, we will have two matrices representing each one the half of the

component. In this point, we have absolutely defined the scattering matrices from the middle point of the component toward the input and the output, we are able to determinate the power distribution at the middle point of the component. At this point, we can consider the tree splitted in two, and we can apply the same process again for these two trees independently. We can work in this way since arrive to the bottom of the tree where the single scattering matrices are placed.

EXAMPLE

As a validation of the code, and to show how to proceed in order to analyze one particular component, we will develop in detail the whole calculation process from the geometrical description of the component, until the final presentation of results.

In particular, the component used to test the code will be the mode converter proposed by Vernon [2] from the TE_{02} circular smooth waveguide mode to the TE_{01} mode. The profile is defined by the formula:

$$a(z) = a_0 \left\{ 1 + 0.42 \left[1 - 0.31 \cos(20.9z) \right] \left[1 - \cos(34.9z + B_1 \sin(34.9z) + 0.2 \sin(69.8z)) \right] \right. \\ \left. - 0.043 \left[1 + 0.6 \cos(44.72z) \right] \left[1 - \cos(34.9z) \right] + E_2 \left[1 - \cos(87.3z) \right] \right\} m \quad (1)$$

where $0 \leq z \leq 0.18m$,

$$B_1 = \begin{cases} 0.85 & \text{if } z \leq 0.09m \\ 1.07 & \text{if } z > 0.09m \end{cases} \quad \text{and} \quad E_2 = \begin{cases} -0.014 & \text{if } z \leq 0.09m \\ 0 & \text{if } z > 0.09m \end{cases} \quad (2)$$

and a_0 is the input radius value.

Such formidable expression can be introduced directly in a text file form to the SCATTMAT code to be sampled by te code or it can be introduced as sampled list of data containing the format of radius and positions. The graphical representation of mode converter profile is presented in Fig. 2.

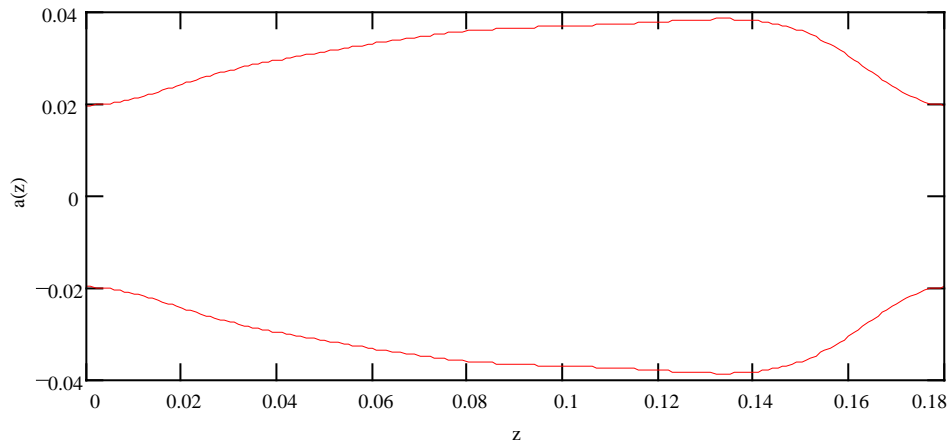


Figure 2.- Vernon's TE_{02} - TE_{01} mode converter profile. All the dimensions are given in meters.

The main idea is to step-wise approximate the component by several waveguide slices of constant radius and to apply the mode matching techniques in order to obtain the scattering matrix at each interface between two slices. Then, combining properly all the scattering matrices of all the interfaces, we obtain the global and some partial scattering matrices defining the response of the whole or a section of the component.

Because of the symmetrically radius deformations, if we introduce at the input the TE_{02} circular smooth waveguide mode, only TE_{0m} modes can couple some power along the component [3]. Then, the mode azimuthal index value must be defined previously to start the calculations, because it will be constant.

Also the number of modes to take in account in the calculation must be defined. It is important to consider some evanescent modes, modes in cut-off, because they are also necessary to represent the fields in every interface between slices.

Obviously, the frequency has to be also defined and also some additional parameters as the metallic conductivity of the conductor employed to produce the component, the input radius, the inner media characteristics, etc. (See Fig. 3).

The screenshot shows the 'Basic Data' input window for SCATTMAT. It is organized into several functional areas:

- Modals:** Contains '1st Index' (0), 'Max 2nd Index' (TE 15, TM 0), and checkboxes for 'TE' (checked) and 'TM'.
- Frequency:** A text box with '60.000000' and a unit label 'GHz'.
- Radius:** A text box with '1.000000' and a unit label 'mm.'.
- Resistivity:** A text box with '1.721853943E-08' and a unit label 'Ohm/m', with a checked 'Perfect Conductor' checkbox below it.
- Material Properties:** Includes 'Rel. Epsilon' (1.000000), 'Rel. Mu' (1.000000), and a checked 'Use Vacuum' checkbox.
- Advanced Settings:** Includes a checked 'Use Data Profiles' checkbox and a 'Tolerancy' field set to '1.00E-09'.
- Buttons:** 'OK', 'Cancel', and 'Help' buttons are located at the bottom right.

Figure 3.- Input data window of SCATTMAT

In order to define the number of points to be presented inside the component, we define a reduction factor. This factor corresponds with the number of single matrices composing one matrix of the lower level of the binary tree. This procedure allow us to save machine resources. It is important to remember that all the matrices of the binary tree have to be stored in logical or physical memory, consuming finally machine resources. Working with this factor, we can reduce the number of matrices to be stored in the calculation process, increasing probably the speed of the code (See Fig. 4).

Scattering Matrix Data

?

Number of Points:

Reduction Factor: to 1

i Info

Profile Analysis

◆ Start to End

◇ Other:

From mm.

to mm.

✓ OK

✗ Cancel

? Help

Figure 4.- Scattering Matrix data window input.

Results On Ports

Step

Mode

TE[0,1]	↓
TE[0,1]	↑
TE[0,2]	↓
TE[0,3]	↓
TE[0,4]	↓
TE[0,5]	↓

✓ OK

? Help

1st Port	Radius:	mm.	Position:	mm.
In	35.5285	%	Out	0.0001
	-80.0617	°		119.8194

2nd Port	Radius:	mm.	Position:	mm.
In	0.0001	%	Out	35.3134
	-137.0734	°		176.9756

Figure 5.- Numerical data presentation of each mode power between slices.

RESULTS

The program allows different ways to present the results:

- *numerical data presentation* for each slice of the binary tree (Fig. 5). For any considered mode, it is possible to determine his amplitude at the input and output of every interface between slices.
- *graphical representation* of the mode power evolution along the component. Each mode is represented using different colors. From the whole list of the considered modes, we have to choose six of them to be represented. We can represent the forward mode power (in the mode list, an additional “i” after the label of the mode has been added, i.e. TEi[0,1]), and the backward mode power (TEr[0,1]).

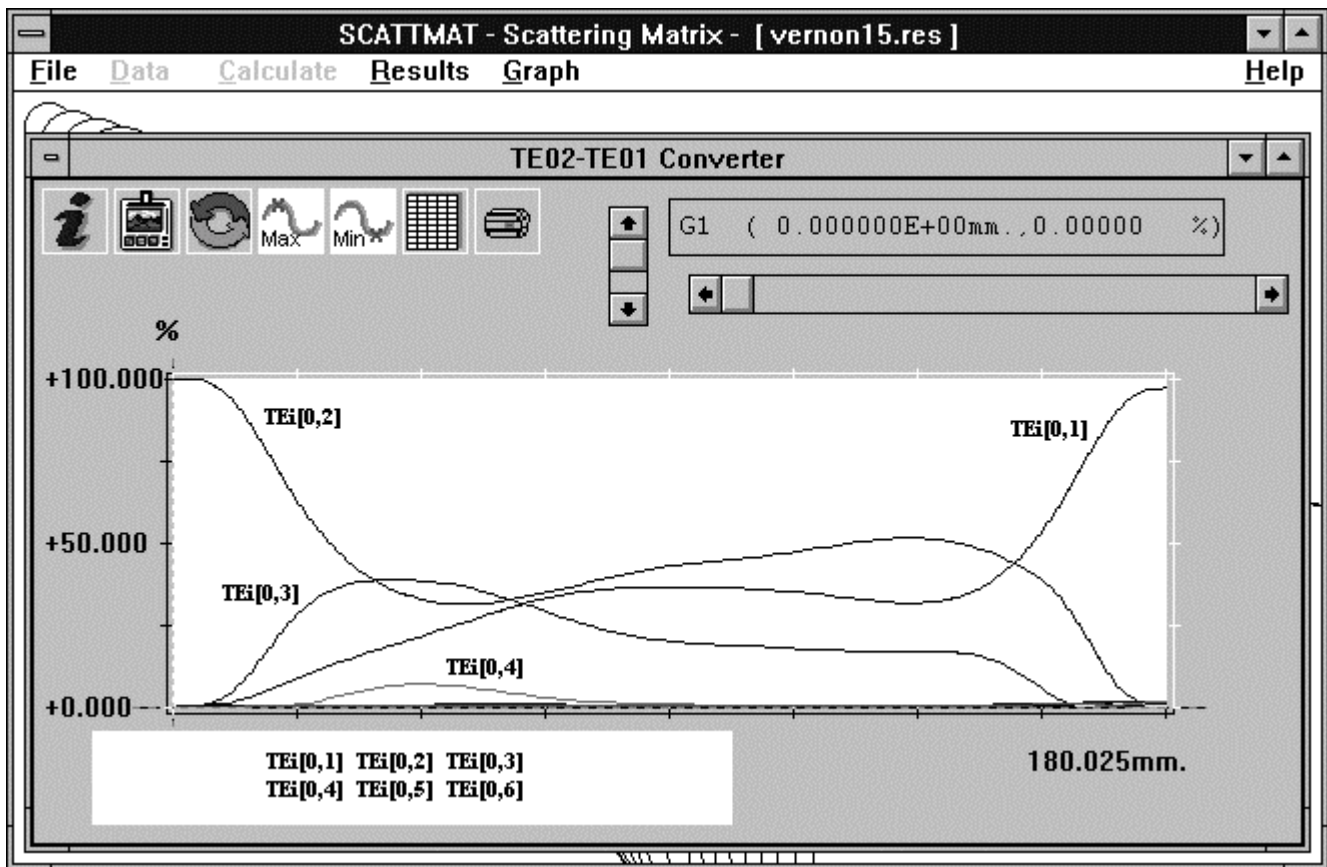


Figure 6.- Graphical representation of the internal evolution of mode power along the component.

One can see in figure 6 how the all the power at the beginning of the component (converter) is in the TE₀₂ mode, and the output is practically in the TE₀₁ mode. A cursor is provided in order to know the instantaneously power value of every represented mode.

The obtained conversion coefficient is 97%, the same one that Vernon gave in his reference [2]. More other cases and components have been used in order to test the code, and in all cases the results have been in very good agreement with the provided by the authors.

The calculation time process depends on the number of matrices to take in account and the size of these matrices (number of modes).

CONCLUSIONS

A new and very friendly mode matching and scattering matrix code for PC under windows environment is presented.

The code allows to analyze circular symmetric waveguide components having the capability to represent the internal mode power along the component.

The code has been proved very useful for several well known problems giving excellent processing times.

A far field radiation pattern evaluation routine is under development to employ the code for horn antenna design. A graphical design tool, real ohmic losses calculation and tolerance effects predictions will be implemented in the near future.

REFERENCES

- [1] Collin, R.E. "Field theory of guided waves". Mc Graw Hill, 1960.
- [2] Buckley, M.J., Stein, D.A. and Vernon, R.J. "A single-period TE_{02} - TE_{01} mode converter in a highly overmoded circular waveguide". IEEE Transactions on Microwave Theory and Techniques, Vol. 39, N° 8, pp. 1301-1306, August 1991.
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