Effective segmentation in Multiport Network Model method for analysis of planar antennas with thin slots

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1. Abstract

In this paper a novel approach to Multiport Network Model (MNM) method for electromagnetic analysis of planar structures with thin slots is presented. Real slots with certain width are incorporated in the model as a slot with null width by leaving their ports disconnected during process of segmentation. These ports are connected to the Edge Admittance Networks (EANs). The advantage of this approach is the compact and more efficient computational algorithm.

2. Introduction

The computing techniques used for successful computer-aided design (CAD) approach in electromagnetic fields are based on finding a formal solution to the governing wave equation and associated boundary conditions. The Green’s function approach, which is the basis of the MNM method, is an analytical approach that offers an accurate and compact analytical solution. Its usage is restricted to planar circuit components with regular shapes. These limitations do not become a question in many planar antennas’ applications.

2.1 Multiport Network Model Method

The MNM method is an analytical method for electromagnetic analysis of planar structures composed of regular shapes. It may be considered as an extension of the cavity model. The electromagnetic fields underneath the patch and outside the patch are modelled separately. The patch is analyzed as a two-dimensional planar network with a multiple number of ports located all around the edges. For patches of regular (canonical) shapes the Green’s functions are available in [1], [2]. The fields outside the patch are incorporated by adding equivalent edge admittance networks (EANs) [3]. These networks can be radiating (R-EANs) or non-radiating (NR-EANs). NR-EAN is the multiport network consisting of capacitances C (representing the energy stored in the fringing field), R-EAN consists of parallel combination of capacitances C and the conductances G (representing the power carried away by radiation and surface waves).

The MN modelling of non-regular shaped components requires the use of segmentation and desegmentation methods [4]. The segmentation allows to connect simple elements via ports into the complex shape, on the contrary by the desegmentation we "cut out" elements from the fulfilled area.

2.2 Collinear Microstrip Patch Antenna

The analyzed structure is collinear microstrip patch antenna (CoMPA). This antenna structure and its principle have been presented before in [5]. The idea of CoMPA is based on application of geometrical perturbations (slots) on a patch operating with suitable higher mode (TM₀₅ in this case). These perturbations eliminate radiation from second out-phase half current
wavelength. The principle of the antenna is well comprehensible from the surface current distribution (figure 3a).

The MN modelling of Collinear Microstrip Patch Antenna (CoMPA) has been presented before in [6] and [7]. In this paper we present a novel method of implementation of thin inner slots in segmentation procedure. This approach leads to a simpler and efficient algorithm for computing impedance matrix of the whole structure preserving the original accuracy and can be used for thin slots in general.

3. Effective MN modelling of CoMPA

The shape of the CoMPA₀₅ is composed of the rectangular patch and two rectangular slots. It is obvious that the easiest way to create an MN model is the desegmentation of slots from the rectangular area. During the process of desegmentation it is necessary to place some ports inside the “desegmented area” - inside the slots. Unfortunately, the slots are too narrow and the distances between the ports are too small. Because of the inversion of the matrix with too small values, calculation causes error.

One drawing of the segmentation, which has been presented before in [7], is shown in figure 1a). In that case three different elements have to be calculated: the central matrix with coaxial feeding, four corner matrices, central top and bottom segments. The widths of the ports have to be suited to the length and width of the slots. The distribution of the EANs is shown in figure 1b).

The idea of effective usage of segmentation method for MNM is shown in figure 1c). The slot is considered infinitely thin therefore only two unequal matrices have to be computed: the central matrix with coaxial feeding and the top-bottom matrices. In this case, the width of the slot is neglected and after the process of segmentation the ports along the opposite edges of the slots are located at the same position. The width used at MNM calculation was considered null (instead of $W_s=0.5$ mm), which had an insignificant effect on the results.

![Figure 1: Segmentation of canonical elements forming CoMPA₀₅ and the connection of the EANs to the MN model. a-b) slots with realistic width, c-d) infinitely thin slots.](image)

3.1 Edge Admittance Networks

As we have mentioned above, the edge fields are modelled by introducing EANs. We can determine which edges are radiating and which are not from the knowledge of the structure and its surface current distribution (figure 3a).

The distribution of the EANs for CoMPA₀₅ is shown in figure 1b) and 1d). The ports along the slot edges are connected to the modified radiating EANs (MR-EANs). The experimental results
confirmed that the MR-EANs should not contain the capacitances representing fringing fields at the edges. This field is minor because of the opposite edge of the slot. Its influence is partly included in the model by the shift of the ports along the slot to the axis of the slot. The elements of the Y-matrix characterizing the EANs are computed from the equivalent circuits shown in figure 2. The capacitance C is represented by the edge susceptance B [8] and the edge conductance G, [9].

Figure 2: The elements of the Y-matrices characterizing the non-radiating edge admittance network (NR-EAN), radiating edge admittance network (R-EAN) and modified radiating EAN (MR-EAN).

3.2 Advantages of the Presented Solution

The main advantage of the presented solution is its compactness and simplicity. Compared to the previous segmentation, the presented solution requires much less steps during segmentation – we need just two different matrices instead of three matrices. However, the speed of the algorithm depends on total number of computational cycles. In the first segmentation (Fig. 1a), there are three unique matrices with 26, 30 and 39 ports. The number of computational cycles for each Z-matrix is 351, 465 and 780 which is 1596 cycles in total. On the other hand, the effective segmentation (Fig. 1b) contains two unique matrices with 38 and 39 ports. The number of computational cycles is 741 and 780 which adds up to 1521 cycles. The saved computing time is about 5%. This result will be different for different port distribution (different number of the ports along the edges). The saved computing time is not significant, but the segmentation is less complicated.

Figure 3: a) The vector surface current distribution on the antenna surface obtained by IE3D from Zeland software, b) Distribution of the voltage on the longitudinal ports, c) MS11 obtained by effective MN modelling and measurement.

4. Comparison of the Simulation with Measurement

The CoMPA05 antenna has been designed for frequency f = 2.44 GHz. The dimensions of the structure according to figure 1c) was: L1=74 mm; L2=91 mm; Ls=58 mm; W=96 mm. The slots width was Ws=0.5 mm. The distance between the feeding port (coaxial probe) and the bottom slot was 13.1 mm. The height of the substrate was d=5 mm with $\varepsilon_r=1$ (air).

MS11 obtained by effective MN modelling and measurement is presented in figure 3c. The parameter N represents the number of cycles (modes) during summation of the eigenfunctions in calculation of the Z-matrices. For the sufficient accuracy N should be at least 30. With higher N the accuracy is better but the time needed for the calculation increases rapidly. Difference between
simulated and measured resonant frequencies for N=50 was 1.2 %. The agreement with the real antenna can be seen from comparison of the current distribution on the antenna surface (Fig. 3.a) and the voltage distribution along the longitudinal ports of the MN model (Fig. 3b). The arrows display the directions of the currents along the non-radiating edges.

5. Conclusion

The effective segmentation in MNM method has been presented. This improvement is based on neglecting the slot width. The main advantages of the novel type of segmentation are compactness and simplicity of the algorithm in comparison with the original implementation. Used algorithm is about 5% faster than the solution presented before and in case of larger structure this difference will be bigger.

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