Designing a Microstrip Patch Antenna with Performance Efficiency

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ABSTRACT: *In this work we have designed a micro strip patch antenna with two arc shaped slots. We have used in the in-house solver based TLM method. We have tested it to know the performance efficiency. The designed antenna reflects the dual-frequency operation. We also found that the arc-shaped slot dimensions are easily controlled.*

Keywords: TLM Method, Cylindrical Mesh, Circular Patch Antenna, Dual Frequency Operation

Received: 27 October 2020. Revised 28 January 2021. Accepted 10 February 2021

DOI: 10.6025/jic/2021/12/2/54-60

1. Introduction

Microstrip and printed circuit antennas have gained prominence over the past decades as viable and desirable antenna elements and arrays. The interest in these antennas stems directly from advantages such as low profile, low cost, light weight, conformity to surface, mass production, dualfrequency operation possibilities and direct integrability with microwave circuitry. There are some limitations, however, principally in characteristics such as low gain and narrow bandwidth [1,2].

Dual-band antennas have received much attention for application in mobile communications systems and radar applications. Dual-frequency operation can be obtained by using several techniques: multilayer structures, parasitic elements coupled to the main patch, aperture coupled parallel resonators, log-periodic or quasi-log-periodic structures [3,4]. All of these structures might face problems with design and manufacture stages while the overall size is considerably larger than that of the patch. Similarly, stagger-tuned resonators, reactively loaded patches with short pins, varactor diodes or optically controlled pin diodes can also be used to either increase the bandwidth or perform dual frequency operation. However, it might be difficult to accommodate the diodes or pins underneath the patch which has to be small for high frequencies. Likewise, the resonant frequency of a microstrip patch antenna is possible to be tuned by an adjustable air gap between the substrate and the ground plane. Complications that might emerge are: mechanical change of the air-gap height and it is difficult to design an array consisting of a large number of elements, [5].

In addition to all these attempts made to improve the frequency agility of patch antennas, the main demands for applications in mobile communications systems is to obtain a dual-frequency patch antenna without increasing either its size or height. One of the approaches to achieve dual band operation is to embed a pair of arc-shaped slots close to the radiating edge of a microstrip antenna [6]. Such configuration does not increase the size of the antenna and at the same time provides flexibility in changing the frequency of operation by proper choice of the slots parameters.

Generally, patch antennas can be analyzed either by approximate techniques (the cavity model, the transmissionline model etc.) [1,7] or by numerical full-wave methods. Besides simplification of the problem by using certain assumptions, the approximate techniques cannot be applied to the structures of complex geometry, such as for instance the circular patch containing sectoral or arced slots. Hence, the full-wave methods are inevitable to be used. Among them, the Transmission-Line Matrix (TLM) method is one of the most accurate and versatile [8]. However, commercial software ackages that use the TLM method for electromagnetic (EM) field analysis are generally developed in the rectangular coordinate system. In accordance with this, complications emerge: staircase approximation of the circular/cylindrical boundaries and associated numerical errors, limitations of the coaxial feed radius, difficulties with creating the model containing sectoral and arced slots etc. To achieve better conformity of the mesh, which is highly associated with the accuracy of the results, and to overcome limitations of the rectangular TLM approach, the authors of this paper propose usage of the TLM method developed in the orthogonal polar mesh for modelling and analysis of structures of circular/cylindrical geometry [9].

In this paper, in-house solver based on the TLM method adjusted to the cylindrical grid and enhanced with the compact wire model is used as a tool for design and analysis of the single-feed circular patch antenna with two arc-shaped slots. In addition to better accommodation of the cylindrical mesh to the analyzed structure, the efficiency of the cylindrical solver will be compared with the rectangular one, in terms of the number of cells required for simulation and limitations .

2. Cylindrical TLM Solver

The TLM method is a time-domain numerical technique used for solving various problems in electromagnetic engineering. It uses the network of interconnected link-lines to model EM field in a propagation space through scattering and connection of voltage pulses [1].

To overcome limitations associated with the TLM algorithm developed in the rectangular coordinate system, which is generally exploit by commercial available software packages, an in-house TLM solver has been realized in a

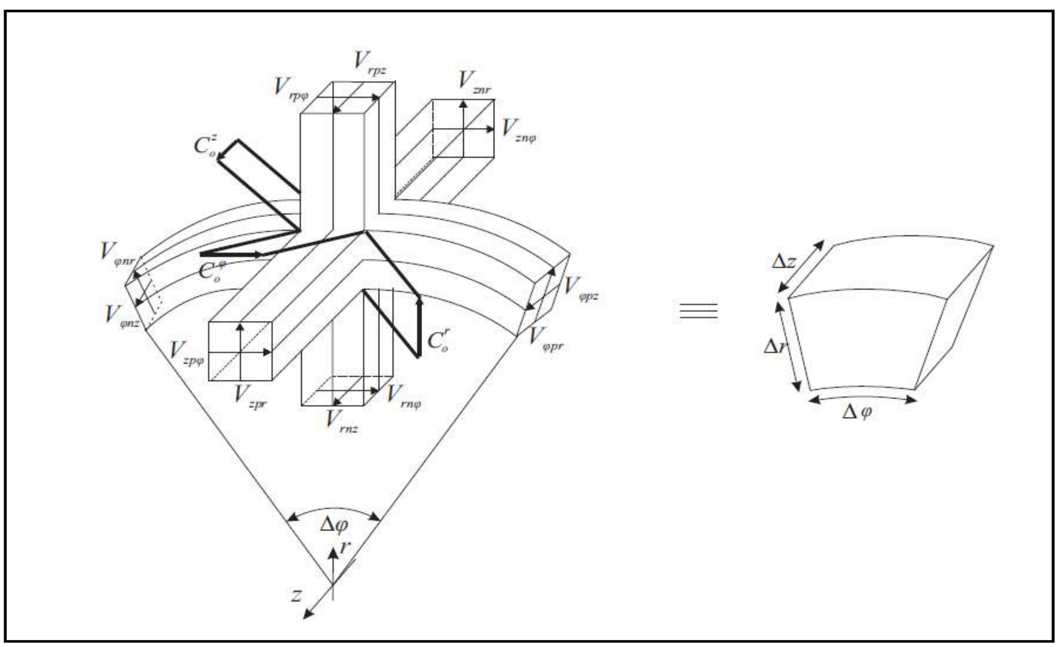

Figure 1. HSCN cylindrical node

cylindrical coordinate system [9]. The solver generates an orthogonal polar mesh consisting of TLM cells known as hybrid symmetrical condensed nodes (HSCN), given in Fig.1 [10]. The compact wire model [11] has been adjusted to the cylindrical grid and embedded into the solver allowing for modelling of wire elements within the considered structure. It is actually a wire network interposed over the existing network which consists of additional link and stub lines to account for increased capacitance and inductance caused by the wire presence.

The solver enables adequate description of an inhomogeneous media, which in case of patch antennas allows for modelling of a substrate. Likewise, modelling of three types of boundaries has been also enabled: electric wall, magnetic wall and absorbing wall. Since the patch antenna represents an open problem, it is necessary to extend the area to be modelled to take into account fringing field associated with the patch edges. The external boundary is then described as absorbing, while the ground plane and the radiated patch are defined as perfectly conducted boundaries. A coaxial feedattached between the ground plane and the circular patch is used as an excitation, where a voltage source is connected to the coaxial feed through the so-called wire port. Because of the pulses propagation through different material properties, the mesh is requested to be relevantly chosen to maintain a time synchronism.

After determination of the link and stub lines impedances as well as wire nodes impedances, the 3DTLMcyl_cw algorithm goes through the next stages: problem definition and imposing initial conditions, equivalent voltages and currents calculation for each node (EM field components can be calculated as well), scattering procedure for regular and wire nodes, connection procedure for regular and wire nodes, modification of the connection procedure at boundaries, calculation of the current induced in the probe wire (output result) in the time domain, transforming data into the frequency domain, calculation of S parameters or input impedance.

3. Results and Discussion

To explore an effect of adding the arc-shaped slots to the radiated patch, a coax-fed circular patch antenna has been first analyzed by *3DTLMcyl_cw* solvers in cylindrical and rectangular grid (Figure 2). Figure 3. illustrates the magnitude of the S_{11} parameter of the single-feed classic circular patch antenna realized on the FR4 substrate. A radius of the radiated patch equals to 20 mm, and that of a ground plane is 30 mm. A probe feed for excitation is optimized to provide an impedance matching betwwen the antenna and the feed and it equals 7.5 mm. As can be seen, a resonant frequency of the excited TM_{11} mode is equal to 2.075 GHz, while TM_{12} mode is excited at 4.24 GHz. A good agreement between results obtained in cylindrical and rectangular solvers is achieved.

When the above CP antenna is modified by inserting two arc-shaped slots, a dual-frequency antenna is obtained. The layout of the dual-band circular patch antenna which includes two arc-shaped slots discussed above is shown in Figure 4. The circular patch has a diameter of a = 20 mm, and is printed on a FR4 substrate of thickness h = 1.5mm, and relative permittivity ε_r = 4.2. The two arc-shaped slots, having a narrow width w = 1 mm and subtended by an angle θ, are placed close to the boundary of the circular patch with a distance of s = 1 mm. Also, the two arc-shaped slots are centered with respect to the r-axis. A single probe feed for dual-frequency operation is placed along the r-axis with a distance ρ = 7.5 mm away from the patch center. In order to find an optimum location for matching the impedance of the feeding line the parametric analysis using in-house *3DTLMcyl_cw* software has been carried out.

Since the circular radiated patch surface is modified by embedding a pair of slots close to the boundary, where the excited patch surface current for the TM_{11} mode has a minimum value, the resonant frequency f_1 will be slightly changed. On the other hand, another resonant mode that is excited in the considered design is the TM_{12} mode for which the excited patch surface current has a maximum value close to the patch boundary. As a result, the resonant frequency f_2 of TM_{12} mode might be significanly decreased by the introduction of the narrow slots close to the patch edges. This effect is investigated for various angle θ and illustrated in Figure 5. As can be seen, the first resonant frequency remains almost the same, whereas the second resonant frequency decreases with rising angle θ. The corresponding resonant frequency values and bandwidths, determined from 10dB return loss, for all considered cases are compared in Table 1.

To compare efficiency of the *3DTLMcyl_cw* solver to the corresponding solver in the rectangular grid, the considered antenna configuration has been also simulated by the rectangular TLM solver. Obtained simulated reflection coefficients for different mesh resolution (1mm, 0.5mm, and 0.66mm) are plotted in Figure 6. Aparently, the mesh of higher resolution, and consequently greater number of cells, has to be used to reach satisfactory accuracy. Additionally, a wire radius has to be decreased with reducing the cell sizes.

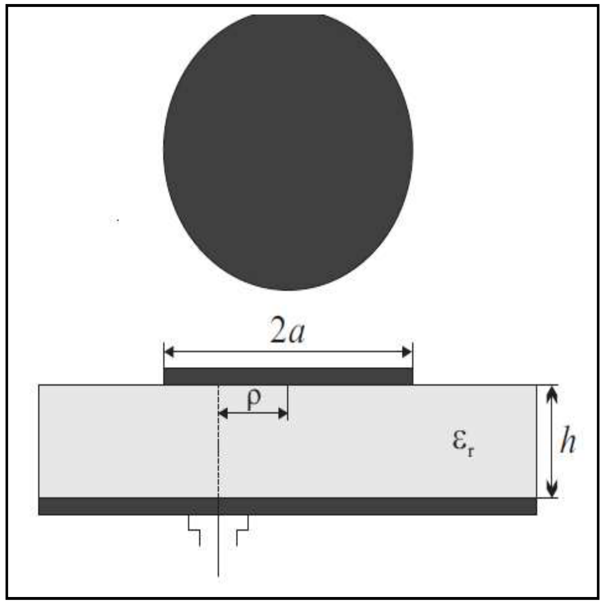

Figure 2. Layout of the single-feed circular patch antenna

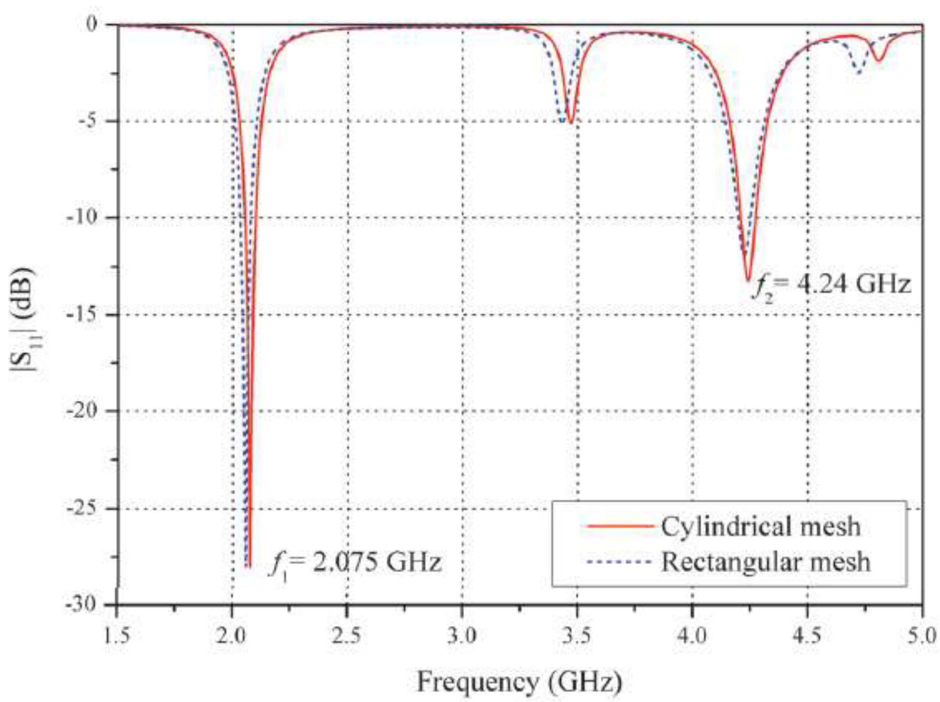

Figure 3. Simulated S11 pararmeter of the classic single-feed circular patch antenna using the cylindrical and rectangular mesh

Number of cells used for each rectangular mesh resolution and corresponding wire radius are given in Table 2. On the other hand, the cylindrical mesh of 1mm cell size has required 37×60×83 cells with the wire radius 0.25mm to obtain the good result.

Θ (deg)	f_1 (GHz)	f_2 (GHz)	f_2/f_1
60	2.027	3.478	1.72
70	1.996	3.134	1.57
80	1.952	2.878	1.47

Θ (deg)	BW_1 (%)	BW_2 (%)
60	2.03	0.91
70	1.82	1.04
80	1.51	1.24

Table 1. Dual-frequency Characteristics of the Circular Patch Antenna with ARC-shaped Slots

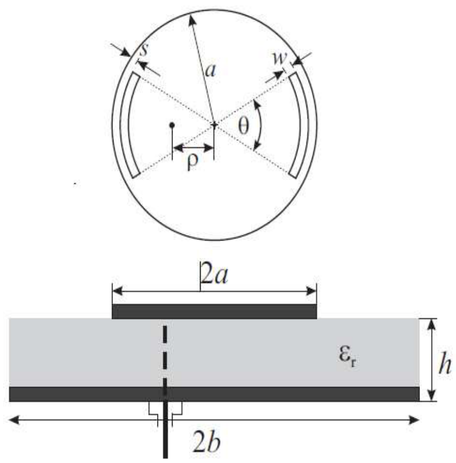

Figure 4. Layout of the single-feed circular patch antenna with two arcshaped slots

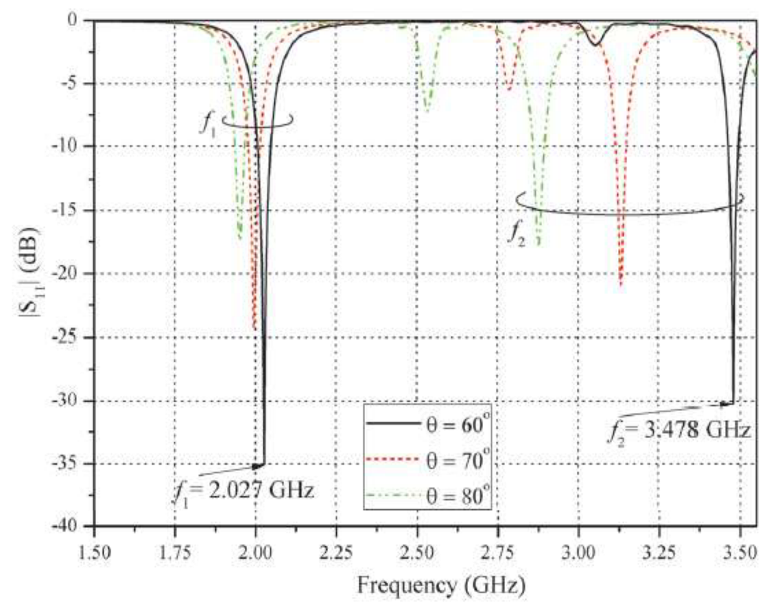

Figure 5. Simulated magnitude of S_{11} parameter for various arc-shaped slots subtended by an angle θ= 60°, 70°, and 80°

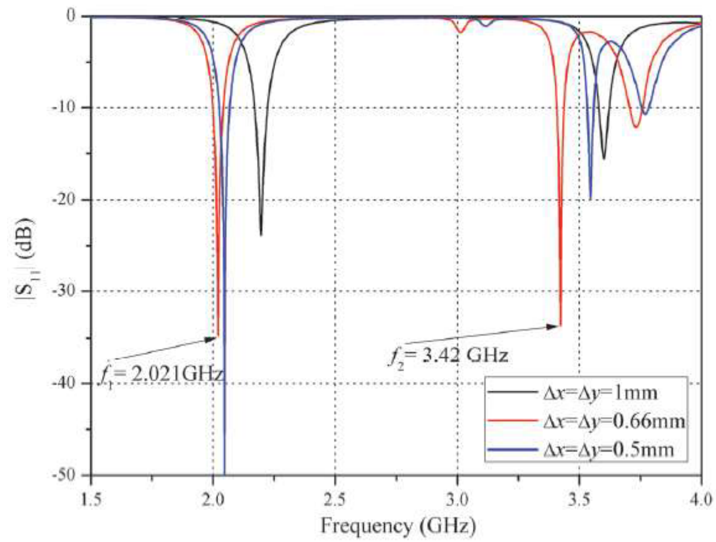

Figure 6. Simulated magnitude of S_{11} parameter for various rectangular mesh resolutions

Cell size along x, y (mm)	Number of cells	
	3DTLMrec_cw	*Wire radius (mm)*
0.5	179×179×63	0.15
0.66	149×150×63	0.20
1.0	119×119×63	0.25

Table 2. Comparison of Number of Cells used in Different Meshes

4. Conclusion

In this paper, the in house solver based on the TLM method adjusted to the orthogonal polar mesh has been used to design and analyze the circular patch antenna with two arc-shaped slots embedded. Advantages of the used solver compared to the rectangular TLM are found in much easier antenna model building, better conformity of the mesh to the narrow arced slots, less complicated optimization of the coaxial feed position and, particularly, better efficiency due to much smaller number of cells requested for the modelling procedure.

Acknowledgement

This paper is funded by means of the Ministry of Education and Science of Republic of Serbia within the project numbered III 44009 and III43012.

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