Mutual Coupling Reduction in Dielectric Resonator Antenna Arrays Embedded in a Circular Cylindrical Ground Plane

S. H. Zainud-Deen, H. A. Malhat, and K. H. Awadalla

Department of Electronics and Electrical Communications Engineering
Faculty of Electronic Engineering, Menoufia University, Egypt
anssaber@yahoo.com, er_honida@yahoo.com

Abstract **─** In this paper, the radiation characteristics and the mutual coupling between two identical cylindrical dielectric resonator antennas embedded in a cylindrical structure in different configurations are calculated. To reduce the mutual coupling between the two antennas, the surface of the cylinder ground plane is defected by cutting slots, or inserting quarter wavelength grooves between the two antennas. The finite element method and the method based on the finite integration technique are used to calculate the radiation characteristics of the antenna.

Index Terms **─** Antenna arrays, dielectric resonator antenna, finite element method, mutual coupling.

I. INTRODUCTION

Dielectric resonator antennas (DRAs) have been widely discussed since they were introduced by Long et al. [1] in 1983. DRAs have many attractive features in terms of high radiation efficiency, light weight, small size, and low profile [2-7]. A comparison between the DRA and the microstrip antenna was presented in [8]. The development of antennas on curved surfaces is of great interest in aerospace and modern communication applications. Analysis of mutual coupling between elements mounted on cylinders using high-frequency or more analytical techniques are introduced in [9,10]. The mutual coupling or isolation between closely packed antenna elements is important in a number of applications [11]. Researchers have found that mushroom-like electromagnetic band gap structures (EBG) and the defected ground structure (DGS) are able to reduce the mutual coupling between elements [12, 13]. The objective of this paper is to analyze the radiation characteristics as well as the mutual coupling reduction between DRAs embedded in a cylindrical structure. The finite element is used to calculate the radiation characteristics of the antenna and the method based on finite integration technique is used to validate the results.

II. METHOD OF SOLUTION

A. Finite element method (FEM)

FEM is a numerical method that is used to solve boundary-value problems characterized by partial differential equations and a set of boundary conditions [14]. The geometrical domain of a boundary-value problem is discretized using sub-domain elements, called the finite elements (often triangles or quadrilaterals in 2D and tetrahedral, bricks, or prisms in 3D), and the differential equation is applied to a single element after it is brought to a "weak" integro-differential form. A set of shape functions is used to represent the primary unknown variable in the element domain. A set of linear equations is obtained for each element in the discretized domain. A global matrix system is formed after the assembly of all elements. FEM is one of the most successful frequency domain computational methods for electromagnetic simulations. It combines geometrical adaptability and material generality for modeling arbitrary geometries and materials of any composition. More details about FEM can be found in [15].

B. Finite integration technique (FIT)

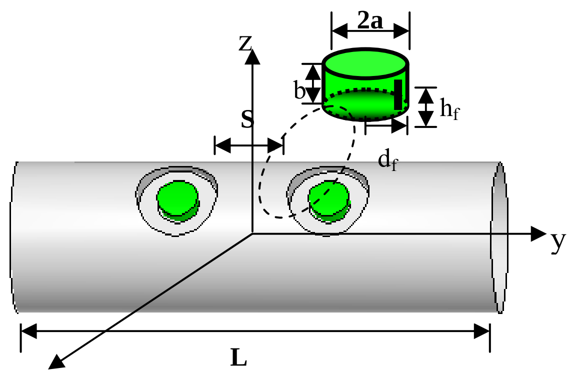
The finite integration technique (FIT) with the perfect boundary approximation (PBA) is a generalization of the finite-difference time-domain (FDTD). In this method, the integral form of Maxwell's equations in time domain is discretized instead of the differential ones. The PBA mesh has excellent convergence properties. The simulation doesn't require a huge memory to be carried out. Accordingly, using the PBA mesh is suitable to simulate the large structures as the simulated results can be obtained in a very short time [16, 17]. Comparing the PBA with the staircase mesh and the tetrahedral mesh, it is considered the best one in terms of the low memory requirements. The tetrahedral mesh, also, has excellent convergence properties but it requires large memory and a long computing time if large structures are to be simulated. As for the staircase mesh, it is suitable for simple structures without curved structures as it will not converge in a reasonable computing time.

The FEM is used for the parametric study as it uses the tetrahedral mesh which is accurate because the simulation is repeated at each frequency. In FIT (i.e. time domain method), a wideband pulse is used to excite the antenna, and the solution is transformed to the frequency domain to determine the input impedance over a wide band of frequencies [18].

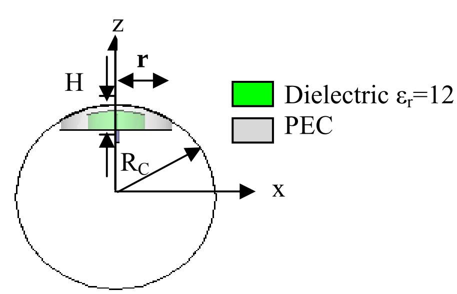
III. NUMERICAL RESULTS

Figure 1 shows the two identical CDRA embedded in a hollow circular cylindrical ground plane. A single-element cylindrical dielectric resonator antenna (CDRA) embedded in a hollow circular cylindrical ground plane with a shallow cavity is shown in Fig.1*a* and Fig.1b. A CDRA with dielectric constant (ε_r) 12 is used. It has radius, "a" of 4.2 mm and a height, "b" of 3 mm. A coaxial probe with radius of 0.2 mm excites the antenna and is located off the center by distance d_f = 3.5 mm and height, "h_f" of 2.4 mm. The coaxial cable is located inside the hollow circular cylindrical ground plane. This CDRA is designed to operate around 10.36 GHz. The CDRA is centrally housed in a shallow cavity with radius r =8.4 mm and depth H = 4 mm. The length of the circular cylindrical ground plane, "L" is 100 mm, with radius R_C of 15mm. The thickness of the cylindrical conductor sheet is 0.6 mm.

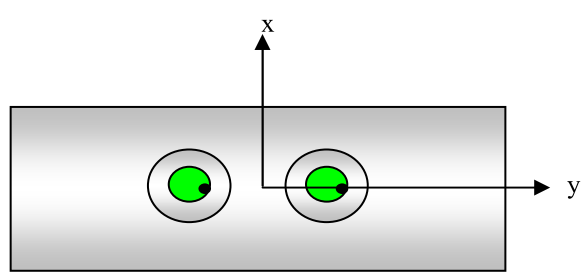
Figure 2 shows the magnitude of S_{21} plotted as a function of separation, in wavelength, for both E – plane coupling and H – plane coupling at f=10.32 GHz. The coupling decreases faster for the H – plane configuration than for the E – plane with increasing separation between them "S". Figure 3 shows the magnitude S_{21} versus frequency with R_C=15mm and S=14.53 mm. The radiation patterns for the coupled antennas, CDRAs, in different orientations using the same input voltage excitations at f= 10.32 GHz are plotted in Fig. 4.



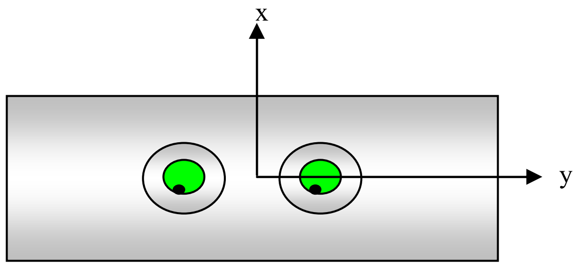
a. 3-D view.



b. Side view.



c. E-plane coupling, 2D.



d. H-plane coupling, 2D.

Fig. 1. The construction of two identical CDRAs embedded in a hollow circular cylindrical ground plane in E-plane and H-plane.

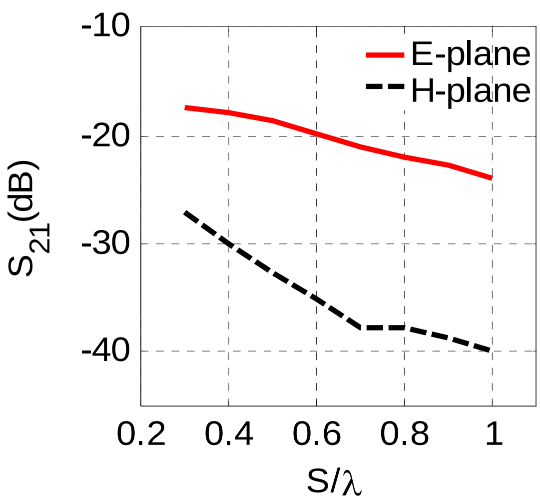


Fig. 2. Mutual coupling coefficient (S_{21}) versus separation in wavelengths for the E-plane coupling and H-plane coupling of two identical embedded CDRAs at f=10.32 GHz.

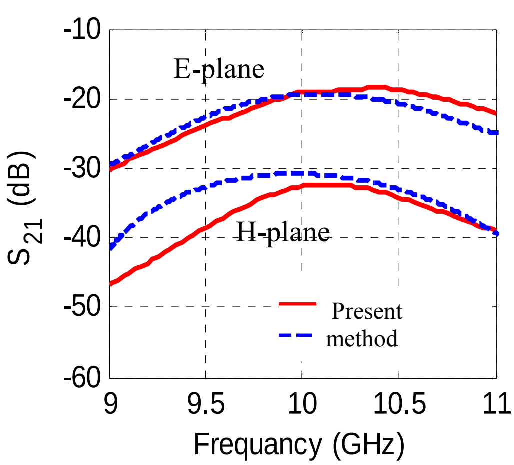
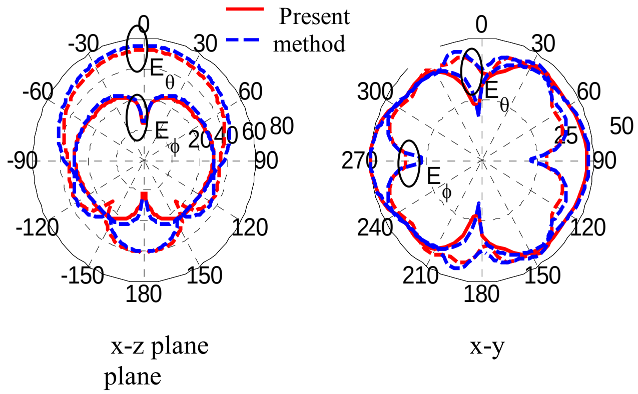
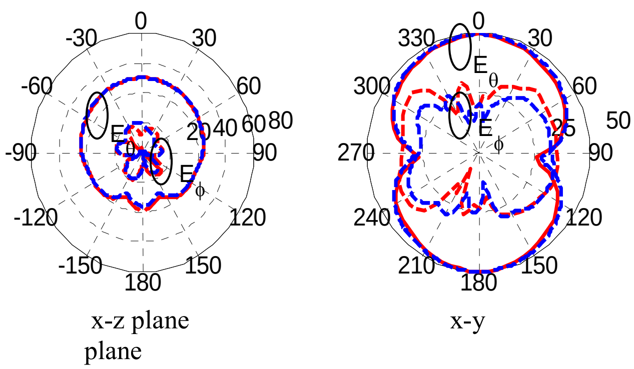


Fig. 3. Mutual coupling coefficient (S_{21}) versus frequency for the E-plane coupling and H-plane coupling two identical embedded CDRAs at S=14.53mm.



a. E- plane coupling.

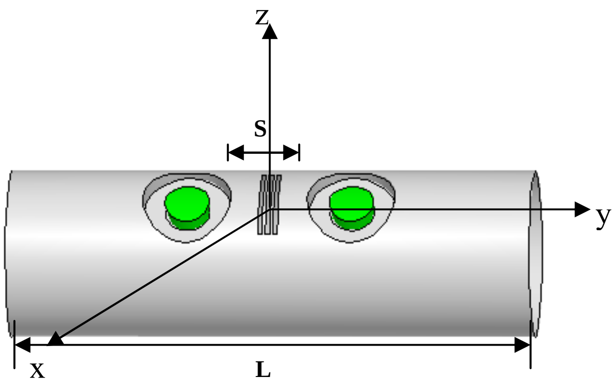


b. H- plane coupling.

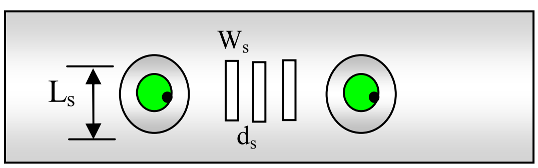
Fig. 4. The radiation pattern for two identical embedded CDRAs with tilted defected ground plane structure at 10.32 GHz.

Figure 5 shows two identical CDRA embedded in a hollow circular cylindrical shape with defected ground plane structure (DGS). The DGS is composed of cutting slots in surface of the cylinders (case 1). The axis of the slot is perpendicular to the cylinder axis. The slot radial length L_s, width W_s, depth H_s, and the slots separation d_s. These dimensions are designed for their stop-band around 10.32 GHz. The mutual coupling coefficient S_{21} between two identical CDRAs (with dimensions as in Fig.1) versus frequency for one slot, two slots, and three slots is shown in Fig. 6. The optimized dimensions are L_s=0.5λ, W_s=0.01λ, d_s=0.05 λ, S=0.5 λ, and R_C=15 mm at the operating frequency 10.32 GHz. The results are compared with that calculated with a solid conventional cylindrical ground plane (without defect ground plane). It is observed that, the isolation of the defected ground plane provides a significant improvement of isolation of 5.46 dB for one slot, 6.66 dB for two slots, and 5.53 dB for three slots in the cylindrical ground plane at 10.32

GHz. The mutual coupling is increased in the case of using three slots due to the redistribution of the surface current on the cylinder between the two DRAs. Figure 7 shows the radiation patterns in different planes for one slot, two slots, and three slots at 10.32 GHz. Little effect on the radiation patterns for different numbers of the slots is observed.

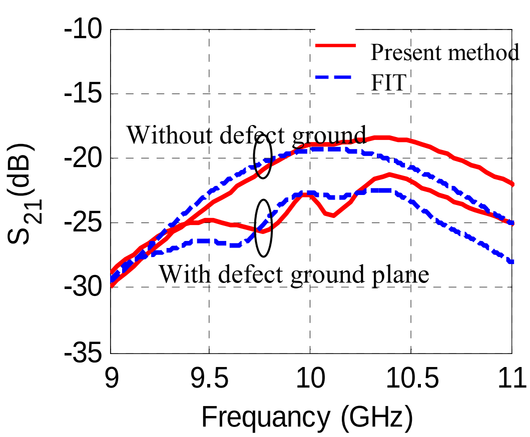


a. 3-D view.

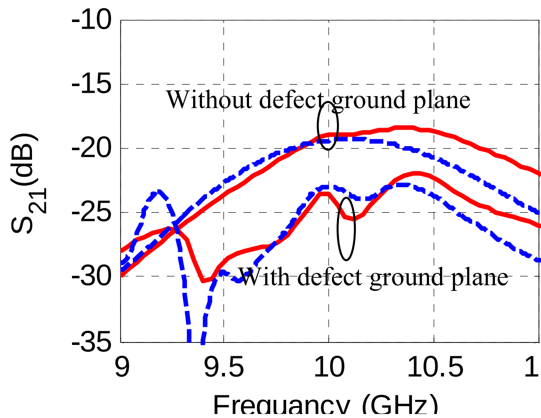


b. E-plane.

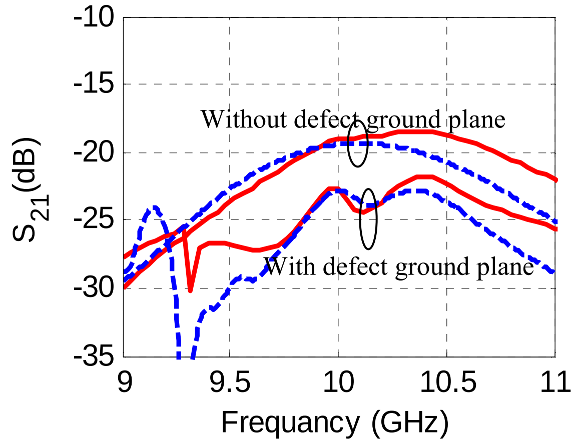
Fig. 5. The construction of two identical CDRA embedded in a hollow circular cylindrical shape with defected ground plane structure.



a. One slot.

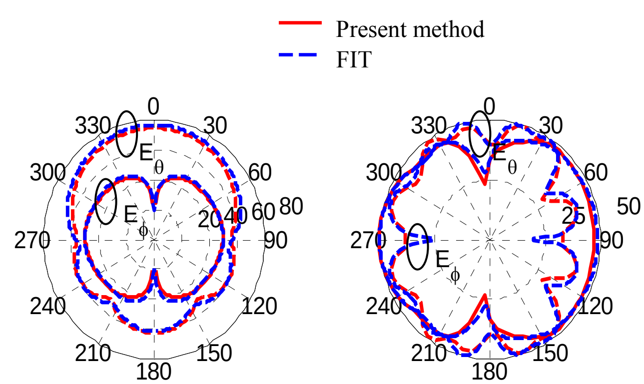


b. Two slots.



c. Three slots.

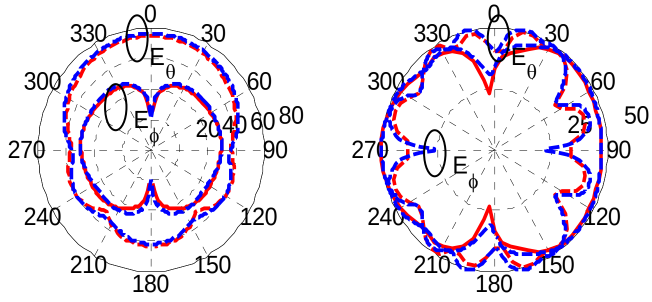
Fig. 6. The mutual coupling coefficient S_{21} between two identical embedded CDRAs versus frequency.



x-z plane

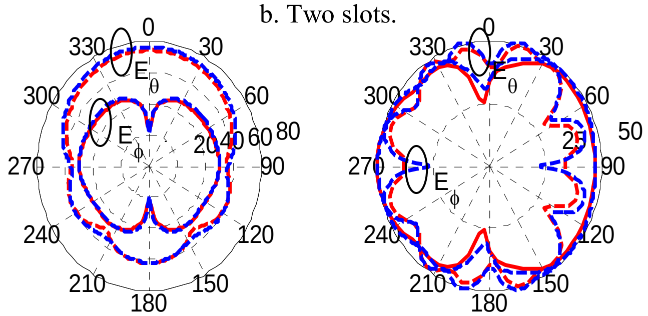
x-y plane

a. One slot.



x-z plane x-y plane

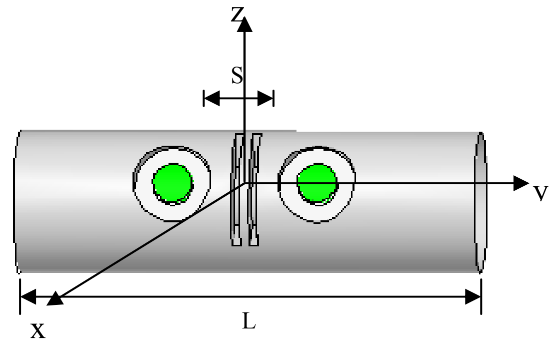
b. Two slots.



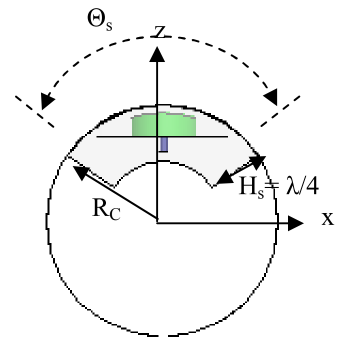
x-z plane x-y plane

c. Three slots.

Fig. 7. The radiation pattern for two identical embedded CDRAs with tilted defected ground plane structure at 10.32 GHz.



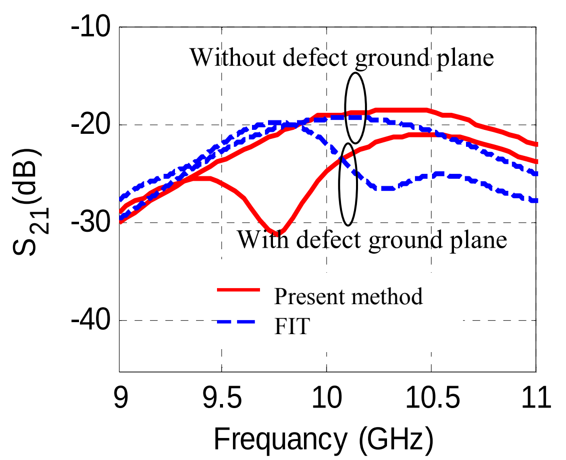
a. 3-D view.



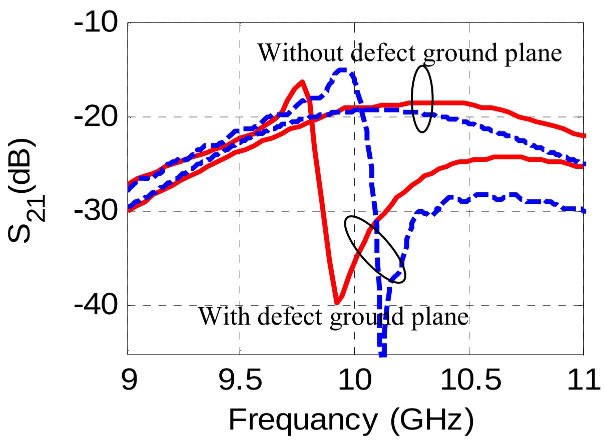
b. 2-D view.

Fig. 8. The construction of two identical CDRAs embedded in a hollow cylindrical shape with tilted defect cylindrical ground plane.

Another shape for the cutting slots (with metallic grooves) are shown in Fig.8. The cutting slot (quarter wavelength groove) is tilted and its bottom is made cylindrical with the same axis of the ground cylinder (case 2). The depth H_s= $\lambda/4$(the metallic grooves depth) and θ_s=60.3° with W_s=0.02λ, and d_s=0.1λ at the center frequency 10.32 GHz. Figure 9 shows S_{21} versus frequency for one slot and two slots. The separation distance S=14.53 mm, cylinder radius R_C=15 mm. An isolation of 4.07 dB for one slot and 12.14 dB for two slots over the solid conventional ground plane is obtained. The radiation patterns at 10.32 GHz and R_C=15 mm for one slot in different planes are plotted in Fig. 10.

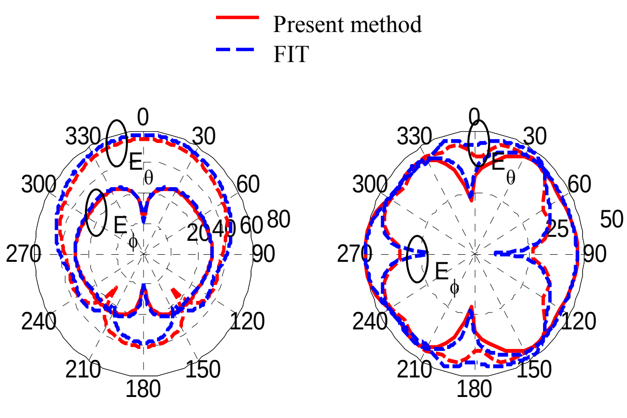


a. One slot.



b. Two slots.

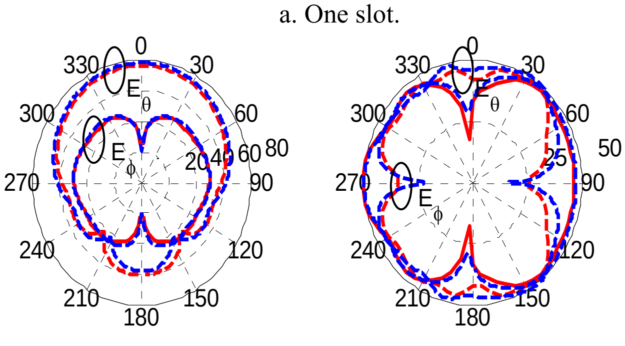
Fig. 9. The mutual coupling coefficient, S_{21}, between two identical embedded CDRAs versus frequency. With tilted defected ground plane.



x-z plane
plane

x-y

a. One slot.



x-z plane
plane

x-y

b. Two slots.

Fig. 10. The radiation pattern for two identical embedded CDRAs with tilted defected ground plane structure at 10.32 GHz.

IV. CONCLUSION

This paper presented the simulated results for the mutual coupling between two identical CDRAs embedded in a metallic hollow circular cylindrical structure in E-plane coupling and H- plane coupling. Two methods of solutions are used, the FEM and FIT. The coupling decreases faster for the H- plane coupling than for the E- plane coupling. In case 1, the surface of the cylinder is defected by using slots to decrease the mutual coupling between the two CDRAs. The S_{21} is decreased by 5.46 dB for one slot and 5.53 dB for three slots at the center frequency f=10.32 GHz. While in case 2, the cutting slot (quarter wavelength groove) is tilted and its bottom is made cylindrical with the same axis of the ground cylinder. The S_{21} is decreased by 4.07 dB for one slot and 12.14 dB for two slots at the center frequency f=10.32 GHz.

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S. H. Zauind-Deen: (S'81-M'88) was born in Menouf, Egypt, on November 15, 1955. He received the B.Sc. and M.Sc. degrees from Menoufia University in 1973 and 1982, respectively, and the Ph.D. degree in Antenna Engineering from Menoufia University, Egypt in 1988.

He is currently a professor in the Department Of Electrical and Electronic Engineering in the Faculty of Electronic Engineering, Menoufia University, Egypt. His research interests at present include microtrip and leaky wave antennas, DRA, RFID, optimization techniques, FDFD and FDTD, scattering problems, and breast cancer detection

Hend A. Mahat: was born in Menouf, Egypt, on October 12, 1982. She received the B.Sc. and M.Sc. degrees from Menoufia University in 2004 and 2007, respectively. She is currently working for her Ph.D. in Antenna Engineering from Menoufia University, Egypt.

She is currently an assistance lecture in the Department Of Electrical and Electronic Engineering in the Faculty of Electronic Engineering, Menoufia University, Egypt. Her research interests at present include DRA, RFID, reflectarray, and wavelets technique.

K. H. Awadalla: was born in El-Santa – Gharbiya - Egypt, on February 1, 1943. He received the B.Sc. and M.Sc. from the Faculty of Engineering, Cairo University, Egypt, in 1694 and 1972, respectively and the Ph.D. degree from the University of Birmingham, UK, in 1978.

He is currently a Professor emeritus in the Dept. of Electrical and Electronic Engineering in the Faculty of Electronic Engineering, Menoufia University, Egypt. His research interests at present include microtrip and leaky wave antennas, DRA, RFID, and optimization techniques.