

Effect of the Relative Feed Position on a Triple-Mode Dielectric Resonator Antenna

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Abstract

This paper discusses the effect of the position of a dielectric resonator (DR) on the resonances of a double-bowtie-slot fed dielectric resonator antenna (DRA). In this structure, a particularly wide impedance bandwidth is obtained due to the combination of the two slot modes with the DR mode. The fundamental $HEM_{11\delta}$ mode of the cylindrical DR radiates as a horizontal magnetic dipole and thus, stable radiation patterns and linear polarization are expected within the entire operational bandwidth of the DRA. However, the interference between the two bowtie slots might result in non-broadside radiation at higher frequencies. In this study an investigation is carried out, which demonstrates the effect of the position of the DR on top of the feeding structure upon the radiation characteristics of the DRA.

1. INTRODUCTION

The advent of mobile and personal communication systems has resulted in a rapid increase in the demand for wireless applications in the lower GHz range. Long et al. [1] introduced the dielectric resonator antennas (DRAs) in 1983, which are very attractive candidates for such applications due to their many advantageous features. These include their high radiation efficiency, their compact size, light weight, low fabrication cost and the versatility in their shape and feeding mechanism. Compared to microstrip antennas, DRAs have no inherent conductor or surface wave losses, and their impedance bandwidth is wider.

One of the most important properties of the DRAs is the dependence of their size as well as their radiation Q-factor and impedance bandwidth on their permittivity. A low permittivity results in a low radiation Q-factor and consequently also in a high bandwidth. However, for a certain frequency of operation the DRA dimensions scale down with the square root of permittivity and thus, a low permittivity contributes to a larger – and heavier – DRA. As a result, a compromise needs usually to be made between size and bandwidth. In the recent years however, efforts have been made towards increasing the impedance bandwidth by exciting multiple modes while keeping the size within reasonable proportions [2], [3].

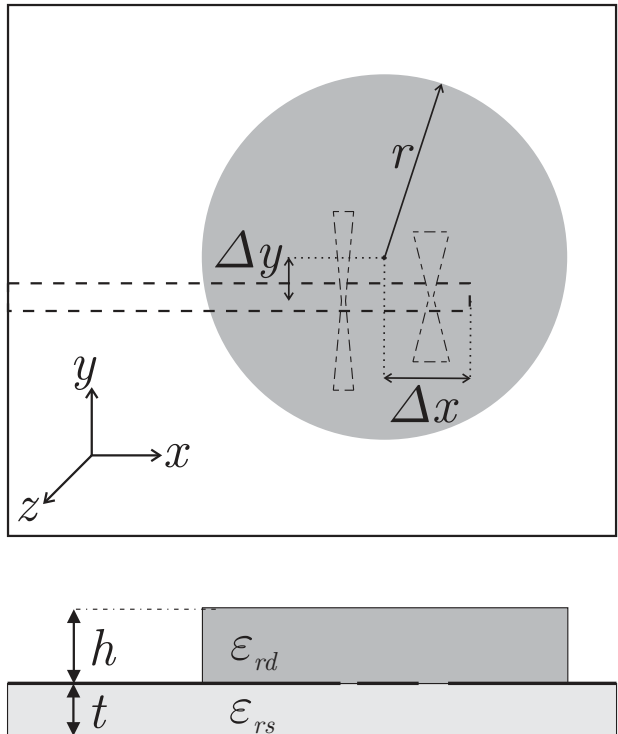


Fig. 1: Schematic of the double-bowtie-slot-coupled cylindrical DRA [4].

In [4] a novel wideband DRA is proposed, in which a dielectric cylinder is fed from a microstrip line through two parallel bowtie-slots (Figure 1). The concept of the partial independence of the slot modes from the dielectric resonator mode [5], [6] is used and consequently, the resonances of the slot modes and of the DRA are designed to occur at different frequencies. A very wide operational bandwidth of the DRA is finally obtained (33 per cent), while stability in the radiation patterns and low cross-polarization are maintained, due to the fact that both slot modes and the fundamental $HEM_{11\delta}$ mode of the cylindrical DR radiate as horizontal magnetic dipoles.

As can be expected, the two bowtie slots in parallel configuration have an effect on the radiation characteristics of the DRA because of their relative phase. Thus, the interference between the two slots results in radiation patterns, which exhibit peak gain at non-broadside direction at higher frequencies. This effect can be avoided by carefully positioning the DR on top of the double-bowtie-slot scheme. In this paper, numerical analysis will demonstrate that a change Δx in the position of the dielectric disc center (Δx is along the line connecting the centers of the two slots, measured from the end of the microstrip line in Figure 1) permits to achieve broadside radiation patterns. From the other side, a displacement of the DR center by Δy (distance along y-direction from the center line of the microstrip in Figure 1) may serve to improve the matching of the antenna, without however having any serious impact on its radiation characteristics.

2. ANTENNA CONFIGURATION

The DRA geometry, which was presented in [4] and shown in Figure 1 for easier reference, consisted of a cylindrical DR of permittivity $\epsilon_{rd} = 9.8$, radius $r = 12$ mm and height $h = 4.5$ mm situated on top of two parallel bowtie slots. The substrate was a Duroid material of permittivity $\epsilon_{rs} = 2.2$ and thickness $t = 0.7874$ mm. The center of the dielectric disc was at a distance $\Delta x = 3.1$ mm from the open end of the microstrip line, while its displacement along the y-direction was $\Delta y = 0$ mm. For this antenna configuration, a prototype was fabricated. The return loss was measured and compared to the simulation, as reproduced [4] in Figure 2.

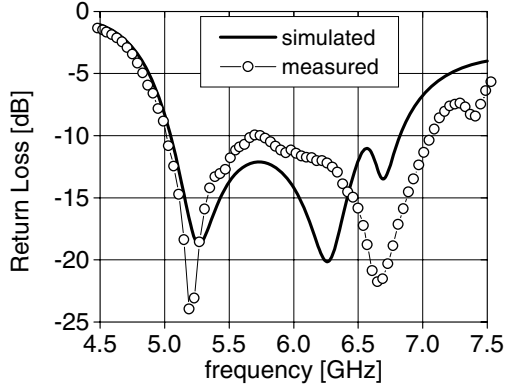


Fig. 2. Measured and simulated Return Loss of the cylindrical DRA as a function of frequency [4].

The return loss shows three resonances. The first two resonances (at 5.26 GHz and 6.24 GHz) define the resonant frequencies of the slot modes, while the third one (at 6.7 GHz) is the $HEM_{11\delta}$ mode of the cylindrical DR.

3. EFFECT OF THE DISPLACEMENT ALONG X

As stated before, the two bowtie slots in parallel configuration act as a 2-element antenna array. Consequently, a phase shift

in the excitation of the two elements is bound to affect the radiation patterns of the antenna by steering the peak gain at a non-broadside angle.

The placement of the cylindrical DR on top of the double-bowtie-slot scheme has two obvious advantages:

- It excites a mode, whose radiation characteristics are dependent on the permittivity and the dimensions of the radiator, as well as on the feeding mechanism. Therefore, the modes of the feeding scheme can be combined with the modes of the DR in order to achieve a large bandwidth of operation.
- It improves the front-to-back ratio, as it also partially serves as a dielectric loading.

In addition to those attractive features, the position at which the DR centre is placed on top of the feeding circuit also influences the antenna performance and thus, an optimized location can offer additional features to the design. Figures 3, 4, 5 illustrate the radiation patterns (E – and H- planes) of the DRA under discussion at various distances Δx of the disc centre from the open end of the microstrip line and at frequencies 5.26 GHz, 6.24 GHz and 6.70 GHz.

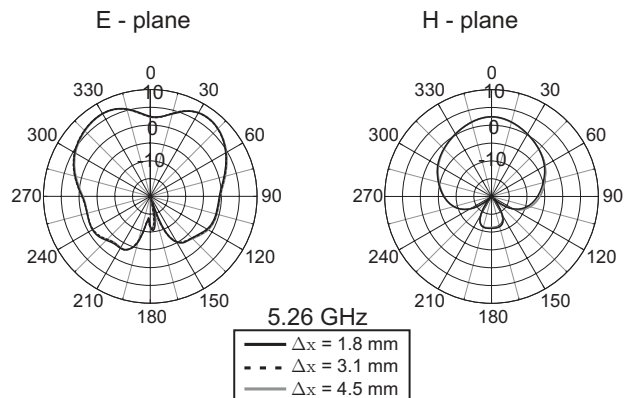


Fig. 3. Radiation Patterns of the cylindrical DRA at 5.26 GHz for $\Delta x = 1.8$ mm, 3.1 mm and 4.5 mm.

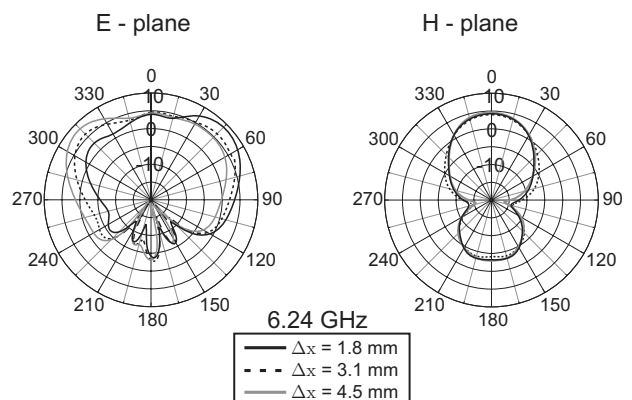


Fig. 4. Radiation Patterns of the cylindrical DRA at 6.24 GHz for $\Delta x = 1.8$ mm, 3.1 mm and 4.5 mm.

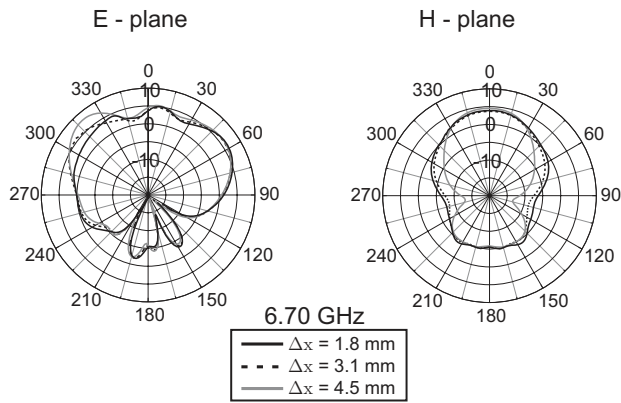


Fig. 5. Radiation Patterns of the cylindrical DRA at 6.70 GHz for $\Delta x = 1.8$ mm, 3.1 mm and 4.5 mm.

A careful observation of the radiation patterns at the three frequencies of resonance and for various values of the displacement Δx can produce the following conclusions:

- Only the radiation patterns in the E-plane are significantly affected by the change in the position Δx of the DR centre along the x-direction.
- At lower frequencies (e.g. Figure 3) there does not seem to be a strong dependence of the radiation patterns on Δx .
- At higher frequencies, a dependence on Δx is apparent. If the centre of the dielectric disc is on the right of the double bowtie-slot scheme (for instance $\Delta x = 1.8$ mm that is represented by position A in Figure 6), the peak gain is at approximately 45° . If the centre of the DR is on the left of the double bowtie-slot scheme ($\Delta x = 4.5$ or position C in Figure 6), the peak gain is at 315° . Finally, if the disc is centred at a suitable position between the two slots ($\Delta x = 3.1$ mm represented by the position B in Figure 6), the radiation patterns become symmetric and broadside.

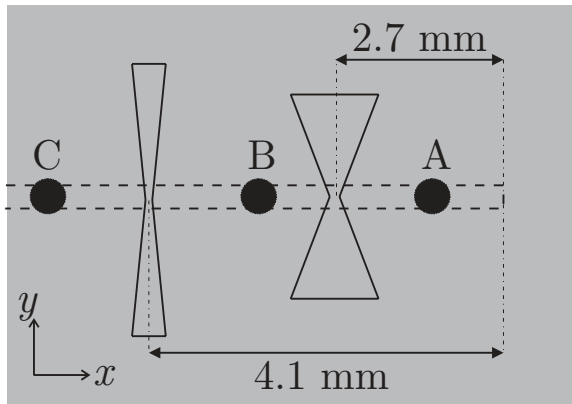


Fig. 6. Double-bowtie-slot feeding scheme. The dots represent possible displacements of the centre of the dielectric disc.

To further illustrate the above analysis, Figure 7 displays the asymmetry of the radiation patterns (defined as the difference between gain at 45° and at 315°) versus the displacement along the x-direction. For a small displacement from the open-end of the microstrip line, the asymmetry is very large and positive (peak gain at 45°). As the displacement increases, the asymmetry decreases and at $\Delta x = 3.1$ mm the radiation patterns become symmetric. Further increase of the distance Δx shifts the asymmetry towards 315° .

As a conclusion, a displacement of the DR centre along the x-direction may significantly enhance the performance of the DRA, by creating broadside radiation characteristics. A discussion about the reasons for this behaviour is made in Section 6.

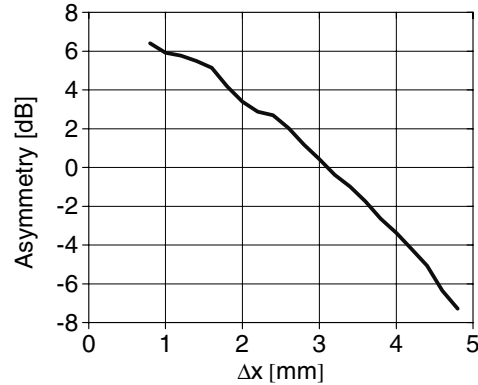


Fig. 7. Asymmetry of the radiation patterns as a function of displacement Δx at 6.24 GHz.

Additionally, it needs to be emphasized that the displacement along x-direction does not have a severe affect on the matching of the antenna. Figure 8 depicts the Return Loss of the double-bowtie-slot fed DRA, for displacements $\Delta x = 1.8$ mm, 3.1 mm and 4.5 mm. It can be observed that the displacement of the DR mostly influences the third mode (at 6.7 GHz), while the other two are not so seriously affected. This is another hint that the third resonance refers to the DR mode, whereas the other two are the slot modes.

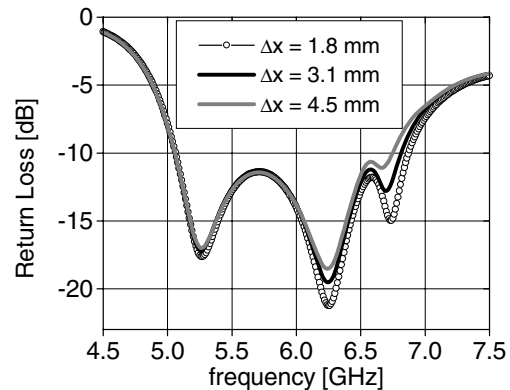


Fig. 8. Simulated Return Loss of the cylindrical DRA as a function of frequency for $\Delta x = 1.8$ mm, 3.1 mm and 4.5 mm.

4. EFFECT OF THE DISPLACEMENT ALONG Y

In the previous section, an optimum displacement $\Delta x = 3.1$ mm of the disc centre from the open end of the microstrip line was found, so that broadside radiation characteristics would be achieved. In this section, the performance of the DRA is investigated, while the disc centre is displaced by Δy from the microstrip centre line along the y-direction.

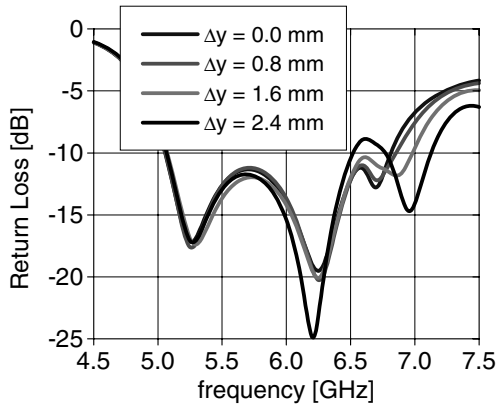


Fig. 9. Simulated Return Loss of the cylindrical DRA as a function of frequency for various values of Δy .

In Figure 9, the Return Loss of the DRA is illustrated for various values of the displacement Δy , while Figures 10, 11 and 12 depict the radiation patterns (E – and H – plane) of the resonant modes. It is observed that in this case, the patterns are no longer significantly affected by the disc position, whereas there is a small change in the matching of the modes (especially the modes at the higher frequencies). Consequently, the displacement (to a certain limit) of the DR centre along the y-axis can become an advantageous tool during the design of the DRA, due to the fact that it can be used as an additional degree of freedom for impedance matching.

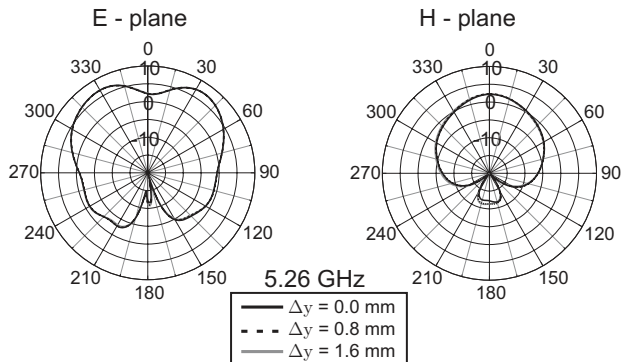


Fig. 10. Radiation Patterns of the cylindrical DRA at 5.26 GHz for $\Delta y = 0.0$ mm, 0.8 mm and 1.6 mm.

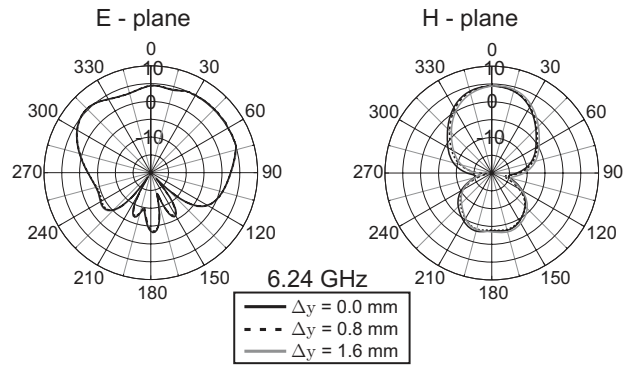


Fig. 11. Radiation Patterns of the cylindrical DRA at 6.24 GHz for $\Delta y = 0.0$ mm, 0.8 mm and 1.6 mm.

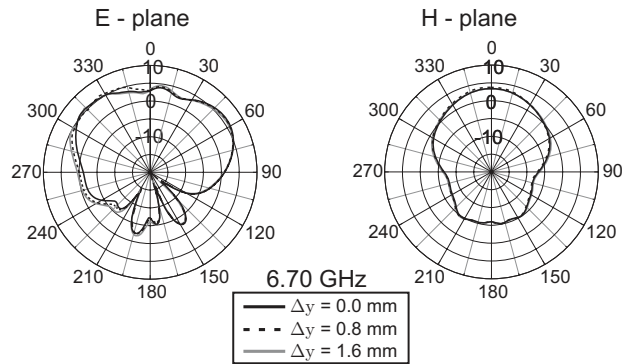


Fig. 12. Radiation Patterns of the cylindrical DRA at 6.70 GHz for $\Delta y = 0.0$ mm, 0.8 mm and 1.6 mm.

5. DISCUSSION

In a cylindrical DR, the $TE_{01\delta}$, the $TM_{01\delta}$ and the hybrid $HEM_{11\delta}$ modes are the lowest order modes that can be excited. From those, if a perfect electric ground plane (PEC) is inserted parallel to the circular facet of the cylinder (like in the case of the DRA design in Figure 1), only the $TM_{01\delta}$ (radiation patterns with a null at 0°) and the $HEM_{11\delta}$ (broadside radiation) modes can be supported. Figure 13 shows the electric and the magnetic field distribution for these two modes [7]. A careful observation of the near fields can give valuable information about the feeding method required, so that these modes will be excited.

The electric probe and the narrow slot are two of the simplest and most effective coupling schemes. In order to excite a certain mode, a probe should be placed along the electric field lines of the mode, while a slot should be situated along its magnetic field lines. So, a slot in the centre of a cylindrical DR would excite the $HEM_{11\delta}$ mode very efficiently, whereas its displacement close to the periphery of the disc would result in the excitation of the $TM_{01\delta}$ mode. For any other position (at a distance a from the disc centre, $0 < a < r$, r being the disc radius) of the slot relative to the disc centre, both modes are partially excited. In conclusion, the cylindrical DR

can support various modes with different radiation characteristics, depending on the relative position of its centre from the coupling circuit.

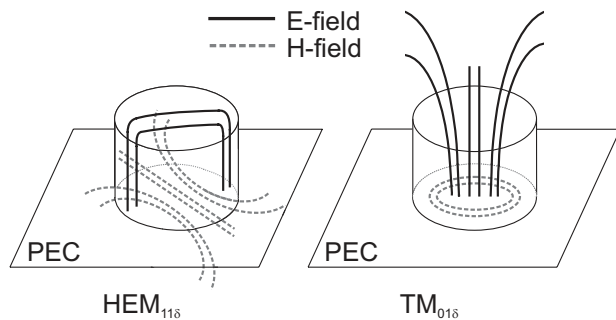


Fig. 13. Electric and magnetic field distribution of the HEM_{118} and the TM_{018} modes.

The aforementioned statement can give some insight to the dependence of the DRA's radiation characteristics on the position of the dielectric disc on top of the double-bowtie-slot scheme. As the DR centre is shifted along the x-direction (Figure 1), apart from the HEM_{118} mode, the TM_{018} mode is also excited together with other higher order modes. Therefore, varying radiation patterns are obtained. At a certain position, the excited modes cancel the non-broadside radiation characteristics of the parallel bowtie-slot and consequently peak gain at 0° is acquired.

Finally, the displacement of the DR centre along the y-direction (Figure 1) does not have an appreciable effect on the radiation patterns, because still only the HEM_{118} mode can be efficiently excited. This is the reason for using the y-displacement solely for matching purposes.

6. CONCLUSION

This paper addressed the effect of the position of a DR on the overall performance of the DRA. It was shown that the proper placement of the disc centre on top of a double-bowtie-slot circuit can influence the radiation characteristics of the DRA. Moreover, it can be used as a tool during the antenna design in order to achieve impedance matching. Finally, a discussion was made about the reasons for this behaviour. The displacement of the DR position results in the excitation of several DR modes, whose radiation characteristics are different from the fundamental HEM_{118} mode. Therefore, at an optimized location of the disc centre, broadside radiation patterns and good impedance matching can be obtained.

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