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ENHANCED RADIATION PATTERNS OF A WIDE-BAND STRIP-FED DIELECTRIC RESONATOR ANTENNA

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ABSTRACT

A simple wide-band rectangular dielectric resonator antenna (DRA) is designed for the X-band and Ku-band applications. The DRA is excited by a vertical strip placed on the middle of the DRA's wide side wall through a coaxial probe attached to a finite size ground plane. Good agreement between measured and simulated results is obtained. The measured 10 dB return loss bandwidth of the antenna is about 7.8 GHz (62%). The simulated gain of the antenna is 6.1 dBi at 12 GHz. The antenna excites undesired modes that perturb the radiation patterns and increase the cross-polarization level. The dielectric resonator is wrapped by a conducting strip to suppress some modes and improve the radiation characteristics of the antenna. Adding the strip reduces the cross-polarization level and improves the co-polarization radiation pattern.

KEYWORDS

Wide-band antenna, Dielectric resonator antenna, Strip-fed antenna, Low cross-polarization.

1. INTRODUCTION

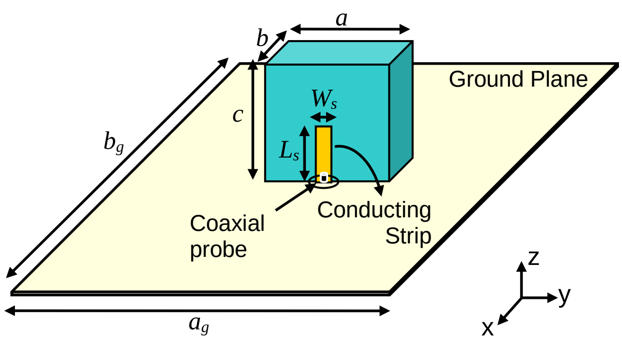
Dielectric resonator antennas (DRAs) have recently been investigated and found to be efficient radiators. The DRAs have the potential to provide significant advantages in terms of size reduction, improved bandwidth, higher power handling capability, and increased efficiency in comparison with the microstrip antennas [1]-[6]. Different DRA shapes, such as cylindrical, rectangular, hemispherical, elliptical, pyramidal and triangular, have been presented in the literature [7]-[12]. The rectangular-shaped DRAs offer practical advantages over cylindrical and hemispherical ones because they are easier to fabricate and have more design flexibility. In order to excite the DRA [13], different techniques have been used, such as probe feeding, in which the probe can be placed adjacent to the DRA [14]; an aperture-coupled dielectric resonator antenna using a strip-line feed [15]; an aperture-fed DRA using a dielectric image guide [16]; and direct coupling using a dielectric image guide [17]. These coupling mechanisms can have a significant impact on the resonant frequency and Q factor. Many methods have been proposed in recent years to achieve a wide-band DRA. One method was to use stacked antennas of different sizes and/or dielectric materials [18], but this increases the size and cost of the antenna. Another approach was to use specially shaped DRAs [7], but these are not easy to fabricate.

Recently, a strip-fed rectangular dielectric resonator antenna was studied [19]. The feeding mechanism—a conformal conducting strip mounted on the surface of the DRA—allows the entire electric current to flow on the DRA surface, and thus its energy coupling is more efficient than the probe-feed. The obtained 10 dB return loss bandwidth was 43%, and the center frequency was about 4 GHz. Here, we present a strip-fed dielectric resonator antenna design that operates at the X-band and Ku-band. In order to improve the co-polarization radiation patterns at high frequencies and to reduce the cross-polarization, a conducting strip is wrapped around the DRA [20]-[22]. The proposed antenna is fabricated, and the return loss and radiation patterns are measured and compared to the simulated results. In the simulation, the Ansoft HFSS commercial software is used [23]. The proposed antenna geometry is shown in Section 2, while the results and discussion are provided in Section 3. Cross-polarization reduction is studied in Section 4, which is followed by the conclusion.

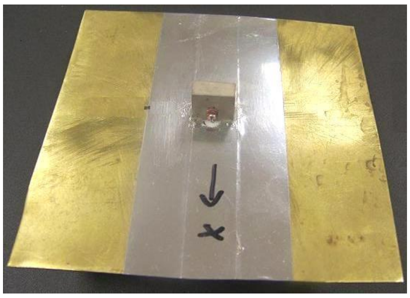
2. ANTENNA GEOMETRY

The rectangular-shaped DRAs offer more design flexibility than other shapes. For a given resonant frequency, two aspect ratios of the rectangular DRA (height/length and width/length) can be chosen independently. Since the bandwidth of the DRA also depends on the aspect ratio(s), a rectangular-shaped DRA provides more flexibility in terms of bandwidth control. Referring to the DRA and the coordinate system shown in Figure 1, the modes—based on magnetic conducting walls [24]-[26]—with the lowest order indices are TE^{x}_{111}, TE^{y}_{111}, and TE^{z}_{111}. If the dimensions of the DRA are such that $2c > a > b$, the modes (in order of increasing resonant frequency) are TE^{x}_{111}, TE^{y}_{111}, and TE^{z}_{111}. The feeding strip is placed in the middle of the DRA side wall in the y-z plane. With this feeding, the fundamental mode is the TE^{y}_{111}, and the bandwidth is wide because of the excitation of higher order modes.

The geometry of the proposed antenna and the coordinate system are shown in Figure 1 (a), and the fabricated antenna is shown in Figure 1 (b). The rectangular DRA dimensions are calculated using the theory in [17] so that the resonant frequency is approximately 8.4 GHz, following optimization using HFSS software, and the optimized parameters are a = 11.2 mm, b = 5 mm, and c = 9.5 mm, with a dielectric constant of 10.2. The feeding strip has dimensions L_s = 4 mm and W_s = 2 mm. The feeding strip is placed in the center of the DRA's wide side wall. These values are also obtained through a parametric study of the length and width using HFSS. The ground-plane dimensions are a_g = b_g = 90 mm (2.7 λ_0 × 2.7 λ_0 at 10 GHz).



(a)



(b)

Figure 1. (a) configuration of the proposed antenna, and (b) photo of the fabricated antenna.

3. Results and Discussion

The antenna is simulated and measured. The reflection coefficients of the antenna are shown in Figure 2. As shown in the figure, the measured and simulated -10 dB reflection coefficient level bandwidths are 7.75 GHz (62%) and 7.5 GHz (57%), respectively, but the simulated reflection coefficient is poor at around 15 GHz. The upper and lower frequencies in the band are 16.35 GHz and 8.6 GHz, respectively, for the measured reflection coefficient, while for the simulated reflection coefficient the upper and lower frequencies are 16.9 GHz and 9.4 GHz, respectively. The maximum error between the measured and simulated results is 8%. The difference between the measured and simulated results is due to the fabrication errors, the soldering, and the adhesive glue used; these factors affect the measured results. The co-polarization radiation patterns at different frequencies within the band are shown in Figure 3. There is good agreement between the simulated and measured results. Also, in the radiation pattern at 12 GHz, there is a null at about 55°. This may be due to the radiation of the feeding strip. The cross-polarization at different frequencies is shown in Figure 4. As shown in the figure, the maximum cross-polarization level is 10 dB below the co-polarization level, and there is good agreement between the measured and simulated cross-polarization radiation patterns. The measured gain of the antenna is compared to the simulated one at different frequencies, as shown in Figure 5, and there is acceptable agreement between them. The figure also shows the maximum gain of the antenna and its corresponding direction.

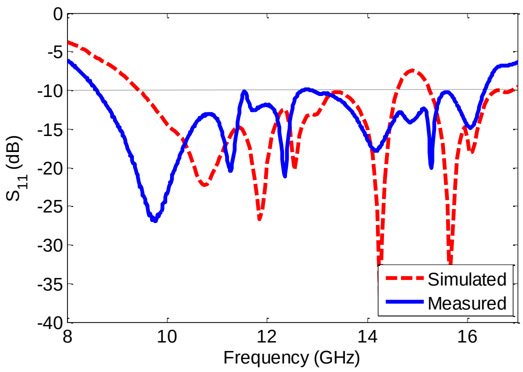


Figure 2. The reflection coefficient of the proposed antenna.

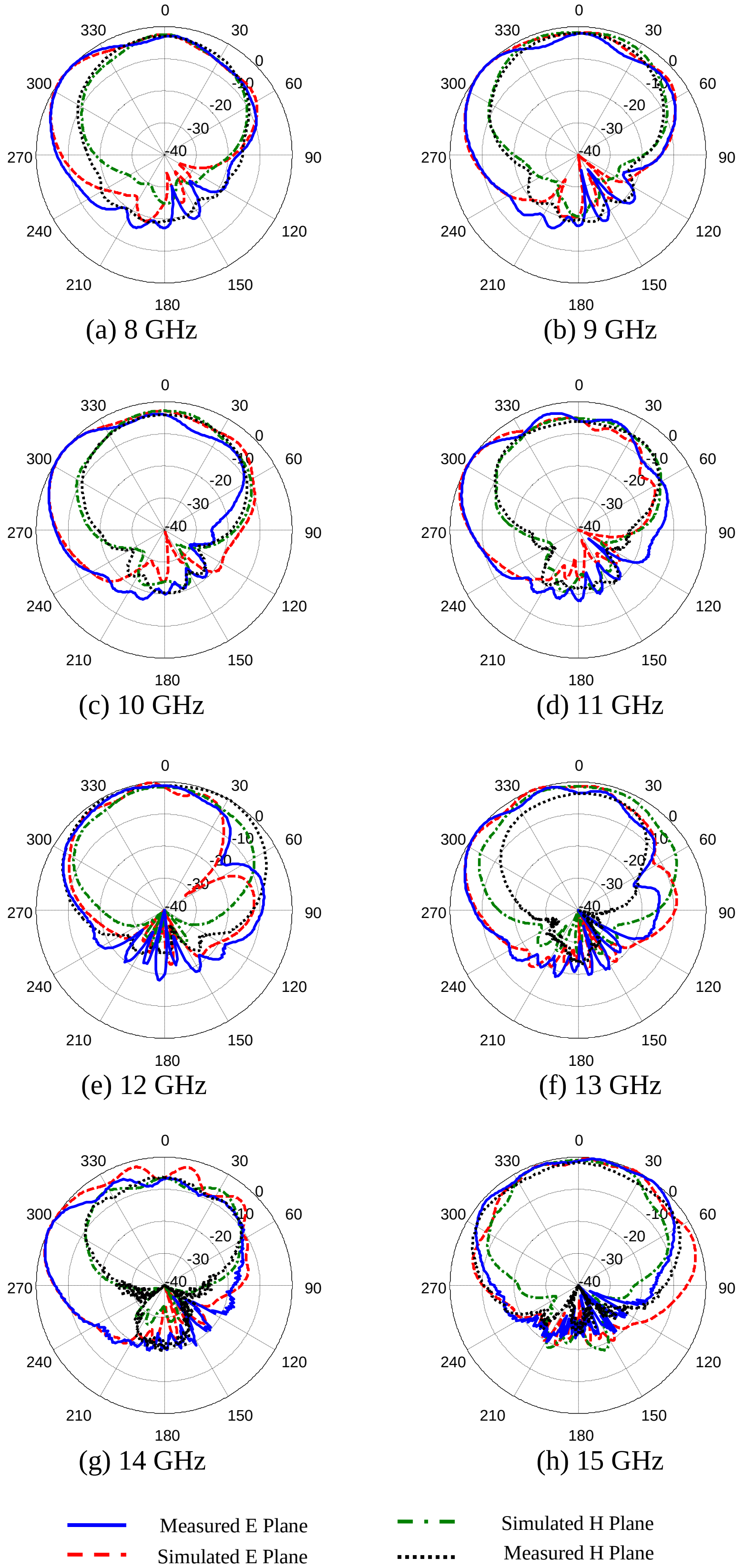


Figure 3. Co-polarization radiation patterns of the proposed antenna at different frequencies.

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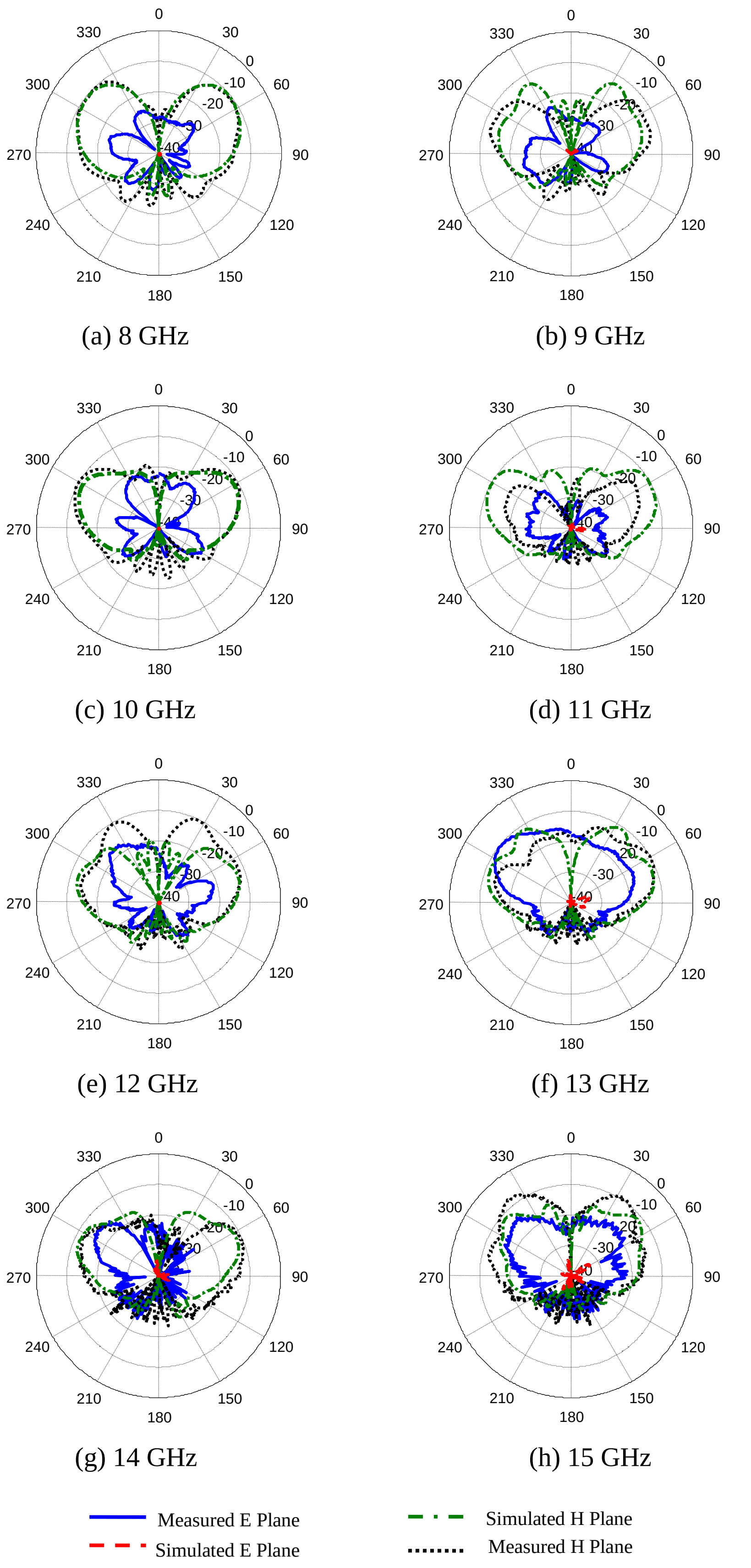


Figure 4. X-polarization radiation patterns of the antenna at different frequencies.

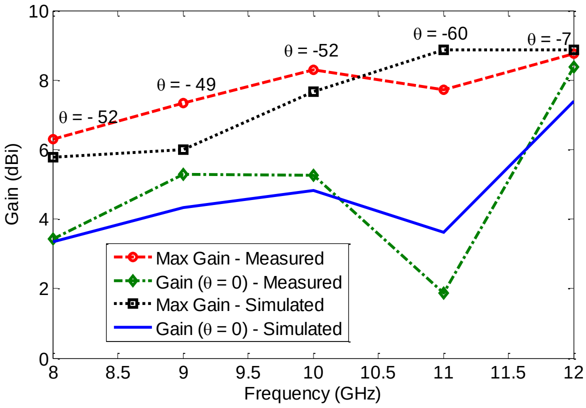


Figure 5. Simulated and measured gain of the antenna at different frequencies.

The simulated radiated power of the antenna is shown in Figure 6. High radiation efficiency is achieved over the entire band. There is a drop in efficiency at 15 GHz; which is due to the mismatch at this frequency, as seen in Figure 2.

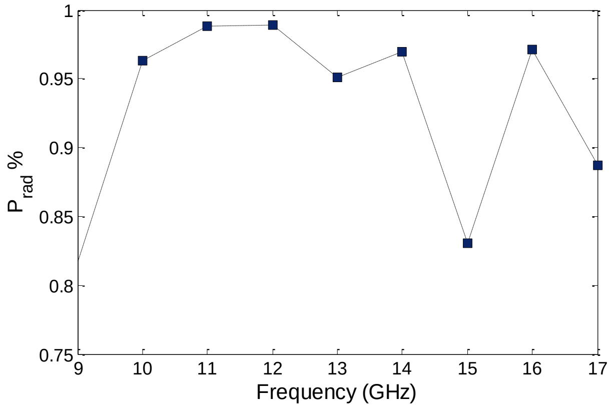
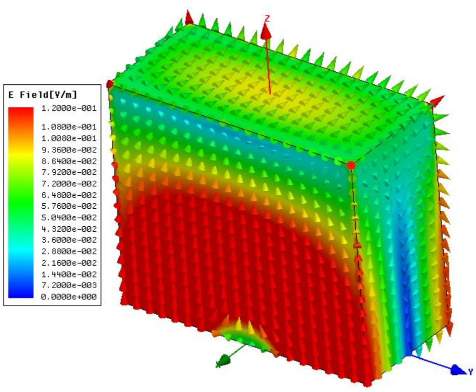
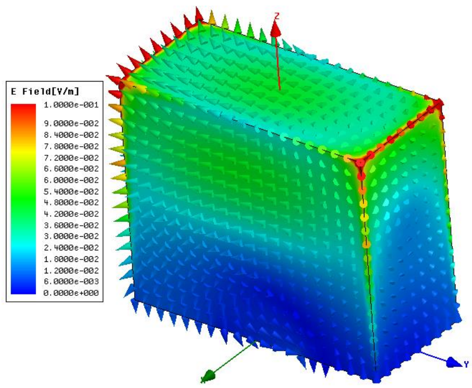


Figure 6. Simulated radiated power of the antenna.

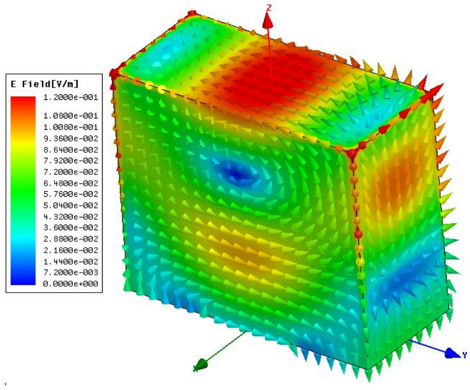
Figure 7 shows the electric field lines for some modes excited by the DRA within the band. These modes are obtained using the Eignmode solution in the HFSS software.



(a) Mode 1 (9.2 GHz)



(b) Mode 2 (9.35 GHz)



(c) Mode 3 (9.9 GHz)

Figure 7. Electric field lines on the DRA for different modes.

4. CROSS-POLARIZATION SUPPRESSION

In order to reduce the cross-polarization and improve the radiation patterns at high frequencies, a strip is wrapped around the DRA, as shown in Figure 8. This is like placing a shorting wall at the centre of the DRA in the y-z plane, as it has little effect on the co-polarization radiation patterns and it suppresses some of the high-order modes, and thus cross-polarization level is improved [17]. The strip will have no effect if the electric field is perpendicular to the strip (or the sheet), but it will disturb or eliminate the modes with electric field vectors parallel to the strip. The antenna was fabricated and tested. Comparison between the simulated and measured reflection coefficients is shown in Figure 9. The measured and simulated 10 dB return loss bandwidths are 7.83 GHz (62.4%) and 6.79 GHz (53.5%), respectively. The upper and lower frequencies in the band are 16.47 GHz and 8.64 GHz, respectively, for the measured reflection coefficient, while for the simulated reflection coefficient the upper and lower frequencies are 16.09 GHz and 9.3 GHz, respectively. The maximum error between the measured and simulated results is 7.1%. The co-polarization radiation patterns at different frequencies are shown in Figure 10. A good agreement is noted between the simulated and measured results, the axial symmetry in the radiation patterns is improved, and there is no null in the radiation pattern at 12 GHz. The cross-polarization radiation patterns are shown in Figure 11. The maximum cross-polarization level is around -20 dB at 10 GHz; thus, adding the strip reduces the cross-polarization level and improves the co-polarization radiation pattern.

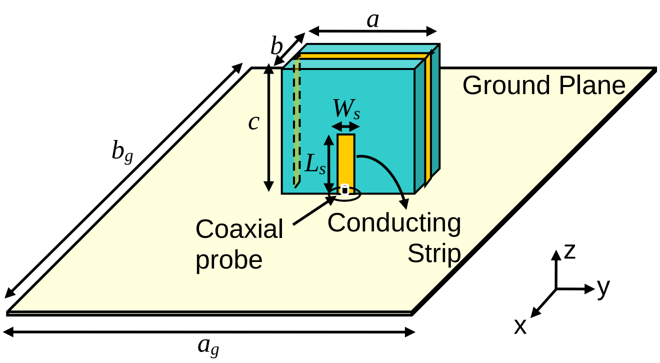


Figure 8. Configuration of the antenna with a strip wrapped around the DRA.

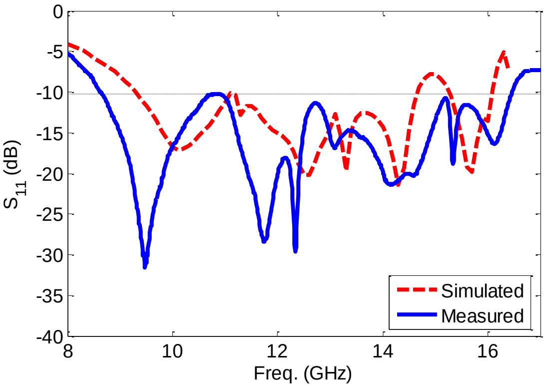
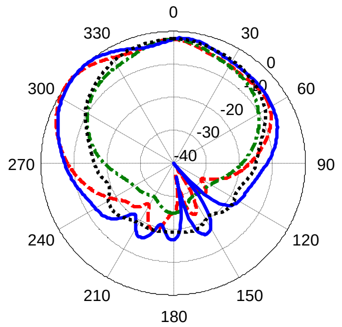
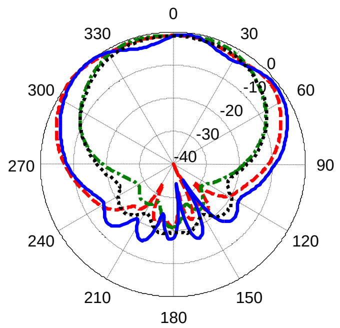


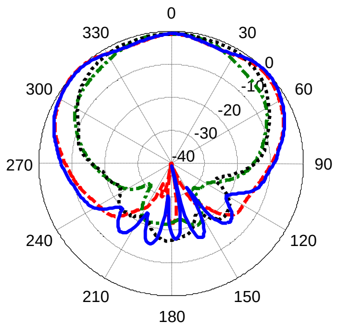
Figure 9. The return loss of the antenna with a strip around the DRA.



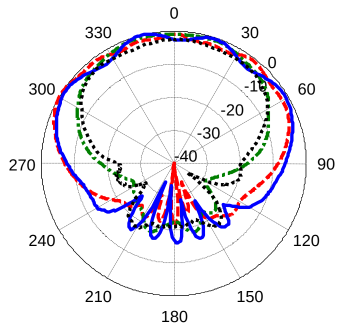
(a) 8 GHz



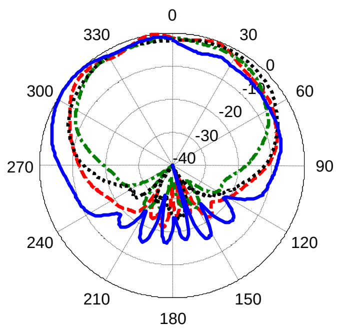
(b) 9 GHz



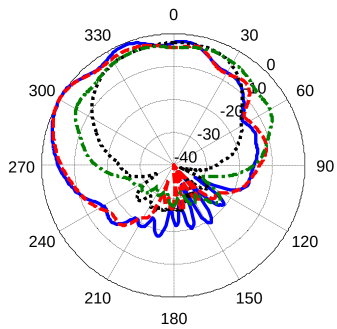
(c) 10 GHz



(d) 11 GHz



(e) 12 GHz



(f) 13 GHz

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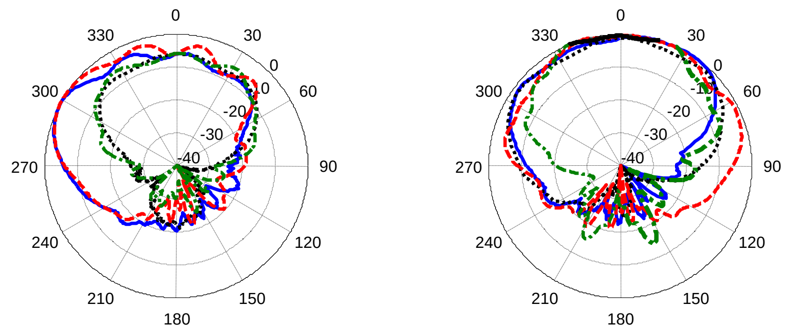


(g) 14 GHz

(h) 15 GHz

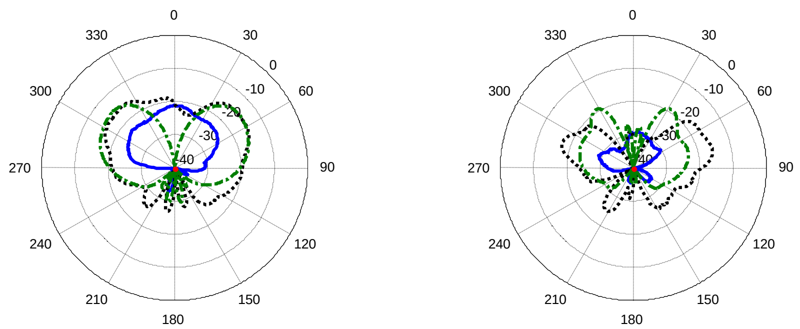
Measured E Plane

Simulated E Plane

Simulated H Plane

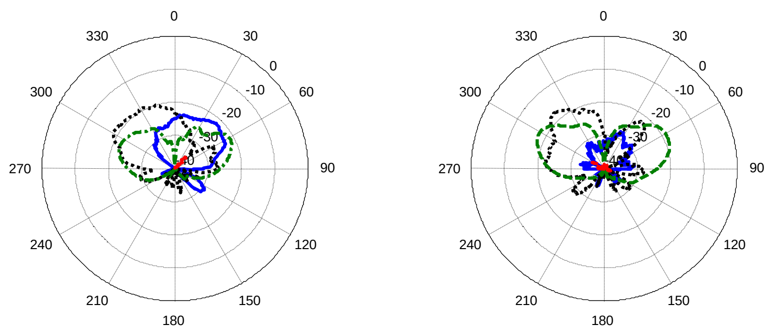
Measured H Plane

Figure 10. Co-polarization Radiation patterns of the antenna with a strip around the DRA at different frequencies.



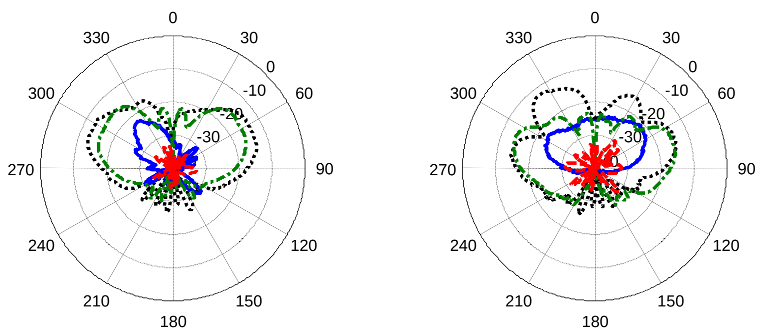
(a) 8 GHz

(b) 9 GHz



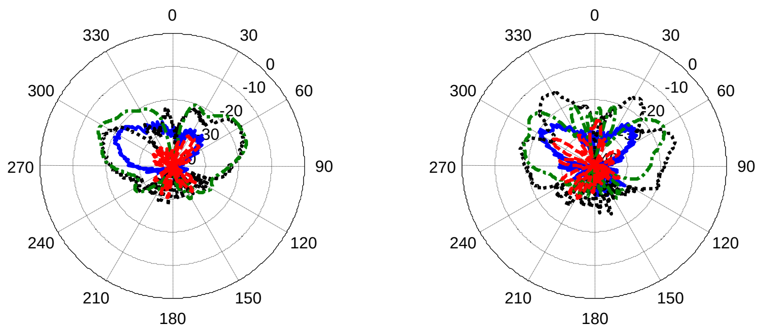
(c) 10 GHz

(d) 11 GHz



(e) 12 GHz

(f) 13 GHz



(g) 14 GHz (h) 15 GHz

Measured E Plane
Simulated E Plane
Simulated H Plane
Measured H Plane

Figure 11. X-polarization Radiation patterns of the antenna with strip around the DRA at different frequencies.

The measured gain of the antenna is compared to the simulated one at different frequencies as shown in Figure 10, showing a very good agreement between them. The figure shows also the maximum gain of the antenna and its direction. It is noticed that in this case the maximum gain and the gain at θ = 0 are close to each other, this is because adding the strip around the DRA makes the radiation pattern more uniform than the case when there is no strip. The electric field lines for the modes are shown in Figure 14.

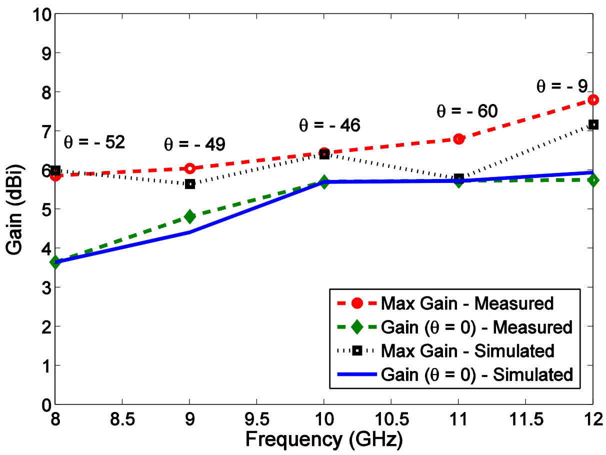


Figure 12. Simulated and measured gain of the antenna with a strip around the DRA at different frequencies.

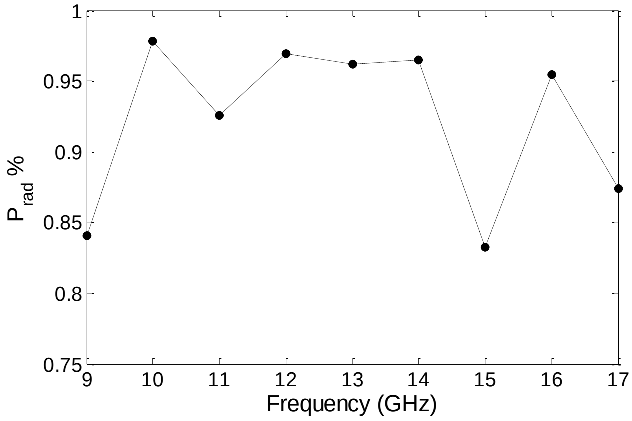
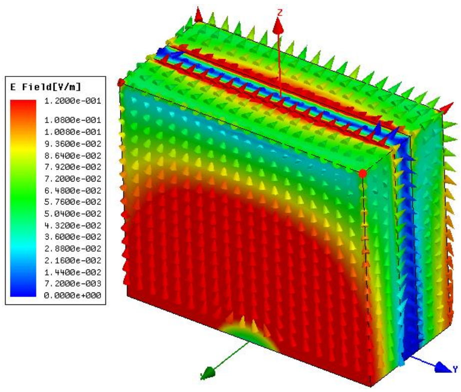
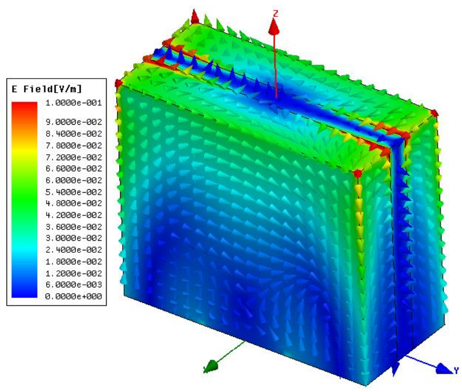


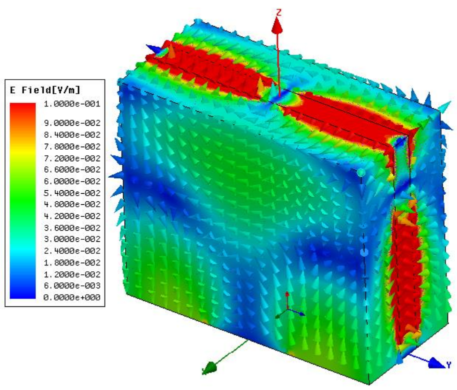
Figure 13. Simulated radiated power of the antenna with a strip around the DRA.



(a) Mode 1 (9.2 GHz)



(b) Mode 2 (9.35 GHz)



(c) Mode 3 (9.9 GHz)

Figure 14. Electric field lines on the DRA with the strip for different modes.

5. CONCLUSIONS

A strip fed rectangular dielectric resonator antenna on a finite size ground plane was designed and fabricated which operates in the X-band and Ku-band frequency ranges. A good agreement between the simulated and measured return loss and radiation patterns was achieved. In order to reduce the cross-polarization level and improve the co-polarization radiations patterns, a strip conductor was wrapped around the DRA, the measured and simulated results for this case were in good agreement. The measured 10 dB return loss bandwidth of the antenna is about 7.8 GHz (62%). The simulated gain of the antenna is 6.1 dBi at 12 GHz.

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ملخص البحث:

يعرض هذا البحث تصميماً لهوائي بسيط عريض النطاق ذي مرنان عازل، مستطيل الشكل، مصمم للعمل في تطبيقات النطاقين X وKu. تتم تغذية الهوائي عن طريق شريط رأسي موضوع في منتصف الجدار الجانبي العريض للهوائي، بحيث يتصل الشريط بالسلك الداخلي للكبل المحوري؛ في حين يتصل السلك الخارجي للكبل بالقاعدة الموصلة محدودة المساحة.

تم الحصول على توافق جيد بين نتائج القياس العملي ونتائج المحاكاة. و كان عرض النطاق الترددي المقاس للهوائي (7.8) غيغاهيرتز عند فقد ارتداد مقداره (10) ديسيبل؛ أي (62%). أما كسب الهوائي المحسوب عن طريق المحاكاة فبلغ (6.1) ديسيبل عند تردد مقداره (12) غيغاهيرتز. والجدير بالذكر أنّ الهوائي يبثّ أمواجاً غير مرغوب فيها تشوش أنماط الإشعاع وتزيد من مستوى الاستقطاب المتقاطع. لذا، تمّ لفّ شريط موصل حول الهوائي لكبت الأمواج غير المرغوب فيها و تحسين خصائص الإشعاع للهوائي. و قد أدت إضافة الشريط الموصل إلى خفض مستوى الاستقطاب المتقاطع و تحسين نمط إشعاع الاستقطاب المتماثل.