EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF POLARIZATION ON THE MEASURED RADIATION EFFICIENCY OF A DIELECTRIC RESONATOR ANTENNA

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Abstract: The radiation efficiencies of two rectangular dielectric resonant antennas (DRAs) were investigated using the directivity/ gain (D/G) method and the Wheeler cap method. Both antennas are linearly polarized but have different linear polarization purities. Through comparison of their radiation efficiencies, it's shown that the polarization purity strongly affects the D/G measurement of the DRAs' radiation efficiency.

Introduction

It's well known that dielectric resonator antennas (DRAs) are effective radiators. Extensive research on various types of the DRA such as rectangular [1], cylindrical [2], and hemispherical [3] has demonstrated this characteristic over the passed years. For the measurement of the DRA radiation efficiency, the two most commonly applied techniques are the directivity / gain (D/G) method [4] and the Wheeler cap method [5]. The D/G method directly exploits the relation between the directivity and gain (per definition) to find the radiation efficiency, and therefore its theory is quite straightforward and easy to understand. However, carrying out the D/G measurement is time consuming since a well-resolved three dimensional sampling of the radiation pattern is required. Furthermore, the results are highly dependent on inaccuracies from the uncertainties of the experimental data. In contrast to the D/G method, the Wheeler cap method is based on the assumed antenna's equivalent circuit model and is not derived directly from the definition of the antenna radiation efficiency. The most important advantage of the Wheeler cap method is its convenient implementation and the repeatable results.

A noticeable discrepancy between the efficiencies measured using the D/G method and the Wheeler method has been reported for three microstrip antennas and one microstrip array in [4], which sheds some doubts as to whether which method to use. In the present paper, the radiation efficiencies of two linearly polarized rectangular dielectric resonant antennas (DRAs) are analyzed to investigate the cause of such discrepancy. Both antennas are made of the same dielectric material and fed by coaxial probes. Both dielectric resonators resonate at around 7.4 GHz in the TE_{111} mode but exhibit different geometric dimensions so as to present different linear polarization purities. Through analysis, it is demonstrated that because the effect of the cross-polarization is taken intrinsically into account in the Wheeler cap method, the radiation efficiency obtained with this method is higher than that gained in the D/G method, where the (undesired) cross-polarization contribution is usually neglected. This explains to a large extent the discrepancy between measurements results obtained through the two methods. The findings are furthermore confirmed by the fact that the radiation efficiency measured using the D/G method increases as the polarization purity rises in the case of the linearly polarized DRAs.

Configuration of the DRAs and Description of the Measurement Methods

The configuration of the two considered DRAs and all geometric parameters are shown in Fig. 1. The values of the parameters are listed in Table I. Both antennas are designed to operate in the mode of TE^{y}_{111} at around 7.4 GHz and are made of the same dielectric material, whose dielectric permittivity is 9.8±0.1 and loss tangent is 0.002 at 10 GHz. In order to obtain different linear polarization purities, the first antenna (labeled #1) has been designed narrower along the y axis and higher along the z axis while the second antenna (labeled #2) is wider along the y axis and lower along the z axis, as given in Table I. As a result of these dimensions, the antenna #1 possesses purer linear polarization.

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In the directivity/gain method, the antenna (linearly polarized) gain G can be directly measured by using a standard gain horn. The directivity D can be calculated by numerically integrating the radiation intensity sampled on the three dimensional radiation pattern according to eq. (2-43) in [6]. Finally the radiation efficiency can be calculated through

$$\eta = G / D \ . \tag{1}$$

In the Wheeler cap method, the input reflection coefficient of the antenna radiating in free space is firstly measured at one frequency of interest labeled as S_{11fs}. Then the input reflection coefficients of the antenna enclosed in the metallic cap are measured at N frequency points $(N \geq 3)$ and recorded as $S_{11,wci}, i = 1, 2, \cdots, N$. Subsequently, both S_{11fs} and $S_{11,wci}, i = 1, 2, \cdots, N$ are plotted on the same Smith chart and a circle is fitted to $S_{11,wci}, i = 1, 2, \cdots, N$. Finally, the maximum and minimum distances between point S_{11fs} and the fitted circle are measured and recorded as $\Delta_{S,\max}$ and $\Delta_{S,\min}$. The radiation efficiency is calculated through

$$\eta = \frac{2}{(\Delta_{S,\max})^{-1} + (\Delta_{S,\min})^{-1}} \bullet \frac{1}{1 - \left|S_{11fs}\right|^2} \ . \tag{2}$$

For calculation of the radiation efficiency versus frequency, it is only necessary to repeat the above procedure by measuring S_{11fs} at each frequency of interest.

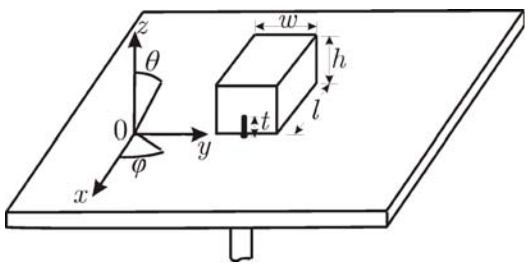

Fig. 1: Configuration of the rectangular DRA.

Table I Geometric parameters

Parameter	Value [mm]	
	#1	#2
w	5.4	6
l	9	9
h	11	7.6
t	4.7	4.3

Simulation and Measurement Results

The simulated return loss of both DRAs is presented in Fig. 2, in which the curve #1 corresponds to the DRA of the higher linear polarization purity and the curve #2 to that of the lower linear polarization purity. Both antennas resonate at around 7.4 GHz, and for this frequency the radiation patterns in the E plane and the H plane are shown in Fig. 3 and Fig. 4. From the figures, it is apparent that the co-polarization radiation patterns of both antennas are almost identical in both E and H planes, while the radiation intensity of the cross-polarization patterns in the E and H planes are around 5 dB lower in antenna #1 than in antenna #2.

The radiation efficiencies of both antennas measured with the D/G method and the Wheeler cap method are shown in Fig. 5. It is found that, on one hand, when only the co-polarization is taken into account in the D/G method, the obtained efficiency is lower that that gained with the Wheeler cap method. However, when the cross-polarization is also considered in the D/G method, then both methods can provide identical results. On the other hand, because the linear polarization purity of the antenna #1 is higher than that of the antenna #2 as shown in the cross-polarization patterns, the radiation efficiency of the former is higher than that of the latter when only the co-polarization is measured in the D/G method. For a clearer impression of the effects of the polarization purity on the efficiency, the differences between the efficiency considering only co-polarization ("cp") and the efficiency that considers both co- and cross- polarization ("cp+xp") are shown in Fig. 6 for both considered antennas. The curves confirm that the polarization purity has a relevant effect on the measured efficiency when cross-polarization is neglected. The reason is that the cross-polarization has little effect on the gain but decreases the directivity. This is confirmed by considering, for antenna #2, the values of the simulated gain and directivity. It is found that the gain and the directivity obtained by considering both the cross-polarization and co-polarization are G = 6.29 dB and D = 6.32 dB, ,while those considering only the co-polarization are G = 6.28 dB and D = 6.45dB.

To validate the above numerical analysis through experiment, the antenna #2 was fabricated, and its return loss, radiation patterns and radiation efficiency were measured. The measured and simulated return losses are shown in Fig. 7. Due to the fabrication tolerance and the effect of a vaseline layer used to stick the DRA on the metallic ground plane, the measured resonance frequency is slightly shifted to 7.3 GHz. The co-polarization and cross-polarization patterns measured at 7.3 GHz in both E and H planes are shown in Fig.8, demonstrating a very good agreement to simulated results. The measured maximum gain is 6.18 dB at 7.3 GHz.

The radiation efficiencies measured by the D/G method and the Wheeler cap method are demonstrated in Fig. 9. It is obvious that the radiation efficiency measured in the D/G method is lower than that in the Wheeler cap method because of the absence of the contribution from the cross-polarization when sampling the 3-D radiation pattern in the D/G method. This explains the discrepancy between the results from both methods.

Conclusion

The effects of polarization on the measurement of the radiation efficiency for dielectric resonant antennas have been investigated in this paper. Radiation efficiencies of two DRAs with different linear polarization purities have been obtained using the D/G method and the Wheeler cap method. It is found that for similar devices, the radiation efficiency measured with the D/G method decreases with the decline of the polarization purity. The cross-polarization explains the discrepancy between the D/G method and the Wheeler cap method, because only the co-polarization is normally measured when sampling the 3-D radiation pattern in the D/G method while both the co-polarization and the cross-polarization are intrinsically taken into account in the Wheeler cap method.

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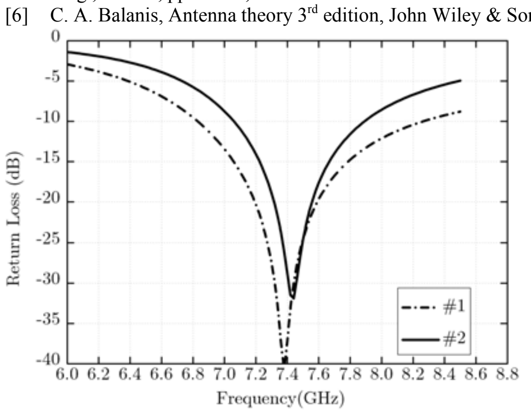


Fig. 2: Simulated return loss of the DRAs.

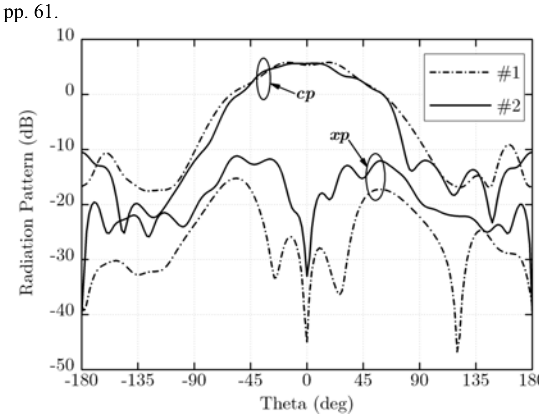


Fig. 4: Simulated radiation pattern of the DRAs in the H plane.

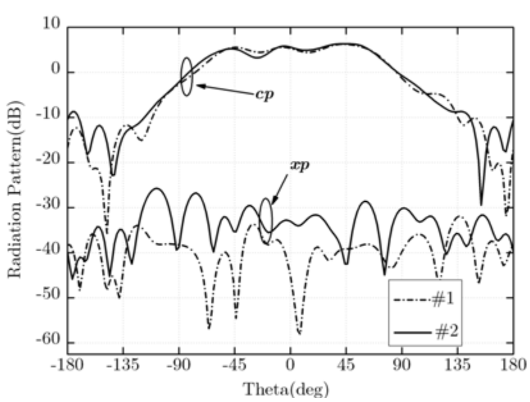


Fig. 3: Simulated radiation pattern of the DRAs in the E plane.

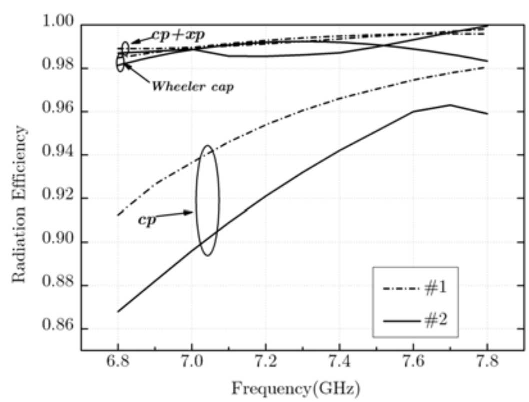


Fig. 5: Simulated radiation efficiencies of the DRAs with the D/G method and the Wheeler cap method.

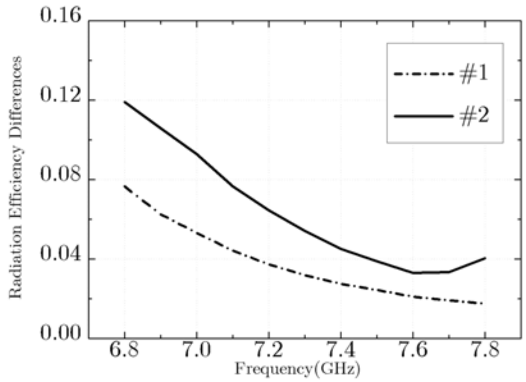


Fig. 6: Differences between the simulated "cp" radiation efficiencies versus the "cp+xp" efficiencies of the DRAs.

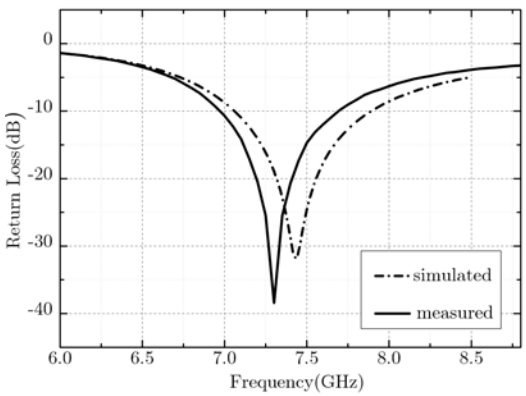


Fig. 7: Simulated and measured return loss of the DRA #2.

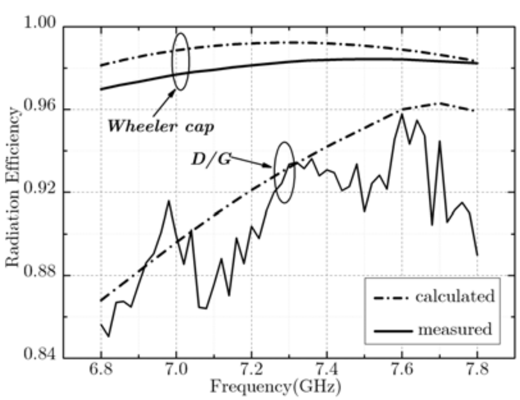
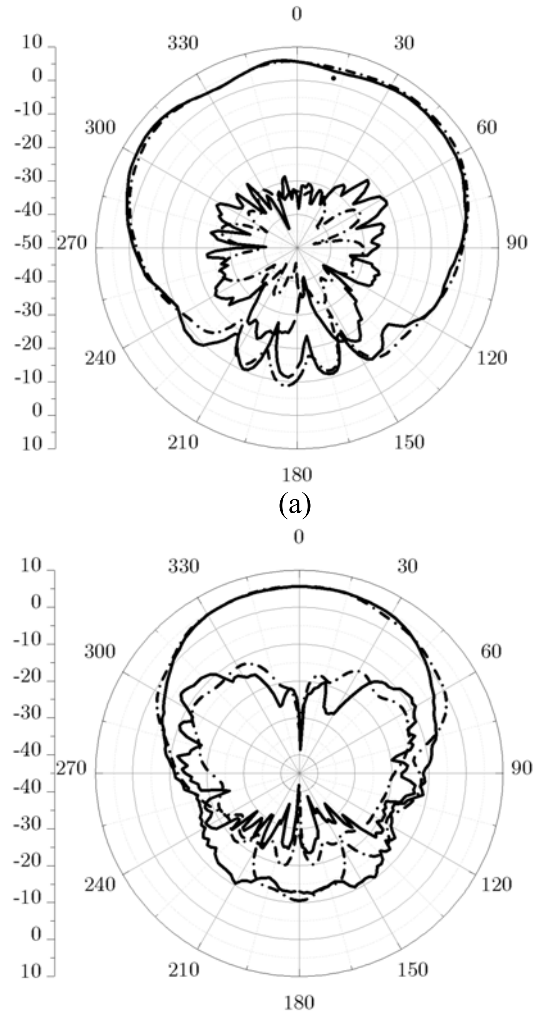


Fig. 9: Simulated and measured radiation efficiency of the DRA #2.



(b)

Fig. 8: Simulated and measured radiation patterns of the DRA #2 at 7.3 GHz (a) E plane and (b) H plane Solid line is the measured results and dashed line is the simulated results.