Rectangular DRA Reflectarray with an Inclined Top-loading Micostrip Patch

Eng-Hock Lim, Hong Yik Wong, and Fook Loong Lo
Department of Electrical and Electronic Engineering
Universiti Tunku Abdul Rahman, Kuala Lumpur, Malaysia

Abstract— This paper presentsa dielectric resonator antenna (DRA) unit element that can be used for designing a compact reflectarray. Here, a rectangular DRA is incorporated with a top-loading metal strip where the strip inclination angle is used as the phase-shifting parameter. When modeled using the waveguide model, it is found that this DRA reflectarray unit element is able to give a reflection phase range of 162.29°. To understand further, the same unit element is also simulated using the Floquet model. It is found that the separation distance of the elements can affect the phase range and gradient of the S-curve significantly.

1. INTRODUCTION

The use of dielectric resonator antenna (DRA) in reflectarray was first proposed in 2000 [1], where the length of a rectangular DRA was varied to bring about phase shift to ascattered wave. The DRA reflectarray has many advantages such as low loss, broad bandwidth, low mutual coupling, good frequency response, and high radiation efficiency [2]. It has been found that the reflection phase range of the DRA reflectarray is usually comparable with that of the microstrip. A DRA reflectarray unit element can also be incorporated with various microstrip elements such as patches and strips for designing broadband reflectarrays. In [3, 4], a patch-loaded DRA reflectarray was proposed where a rectangular microstrip patch was stuck on the top surface of a DRA element. By varying the patch length while keeping the patch width unchanged, the reflection phase angle of the scattered wave can be easily varied.

A glass-made DRA loaded with a metallic patch on its top surface is proposed in this paper. In this case, the inclination angle of the top-loading strip is altered to provide phase shift to the scattered wave. When modelled using a waveguide, the proposed unit element is found to be able to give a reflection phase angle of greater than 160°. In this paper, the same element is also simulated using the Floquet model.It was found that the reflection phase range and gradient of the S-Curve are greatly affected by the separation distance of the elements.Simulation was done using the CST Microwave Studio software and measurements were conducted on a Vector Network Analyser (VNA). Good agreement is found between the simulated and measured results.

2. REFLECTARRAY UNIT ELEMENT

First, the waveguide model is deployed for characterizing the proposed reflectarray unit element.The simulation model places the element at one end of a rectangular waveguide (dimension: $a \times b \times l$) to receive incident wave, operating at TE_{10} mode, coming from the waveguide port located at the other, as shown in Fig. 1. With reference to the figure, it can be seen that the incident angle (α) can be calculated as $\alpha = 90° - \beta = 90° - \cos^{-1}\sqrt{1 - (\frac{f_c}{f})^2}$. To demonstrate, a C-band rectangular waveguide (5.85 GHz–8.20 GHz), with a dimension of $a = 34.85$ mm, $b = 15.8$ mm, $l = 154$ mm, is used. The frequency of interest is 6 GHz, which is equal to an incident angle of $\alpha = 44.21°$. The unit element here is a glass DRA ($\varepsilon_r = 7$, $\tan\delta = 0.01$, $L_d = 14$ mm, and $H_d = 6$ mm) which has a top-loading metallic patch ($L_s = 13$ mm and $W_s = 2$ mm). In this case, no substrate has been used and the DRA is directly placed at the centerof a ground plane. It is found that inclining the patch angle (θ) can cause the incident wave to scatter with different phases.Therefore, it can be used as the phase shifter for the reflectarray.In experiment,a waveguide section and a SMA-to-waveguide adaptor, shown in Fig. 2, are deployed for measuring the reflection characteristics. Standard OPEN-SHORT-LOAD calibration procedure is performed on the SMA port. Here, a piece of sticky copper tape is cut and stuck on the top surface of the DRA. The reflection coefficient is directly measureable through the SMA connector, and the reflection magnitude and phase are then extracted for plotting the reflection loss and S-Curves.

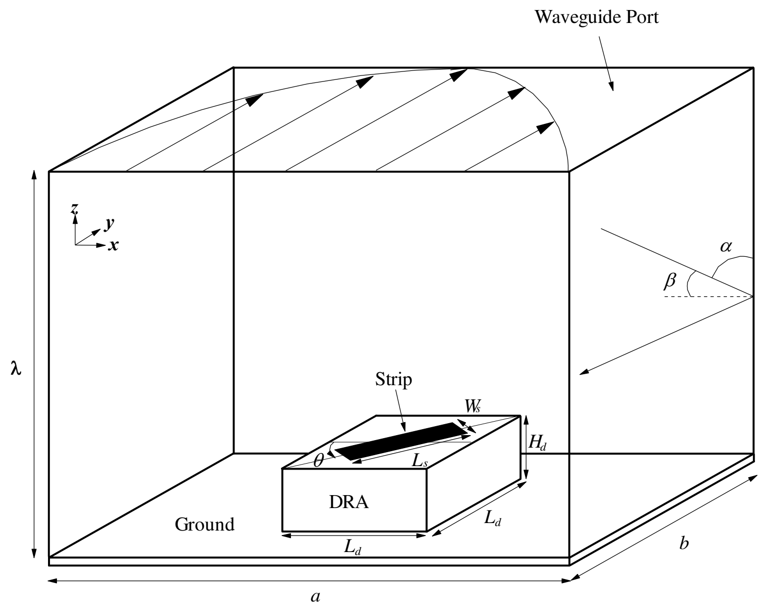

Figure 1: Waveguide model for the proposed DRAunit element with a top-loading inclined metallic patch (L_s = 13 mm, W_s = 2mm, $0° \leq \theta \leq 90°$, L_d = 14 mm, H_d = 6 mm, a = 34.85 mm, b = 15.8 mm, l = 154 mm).

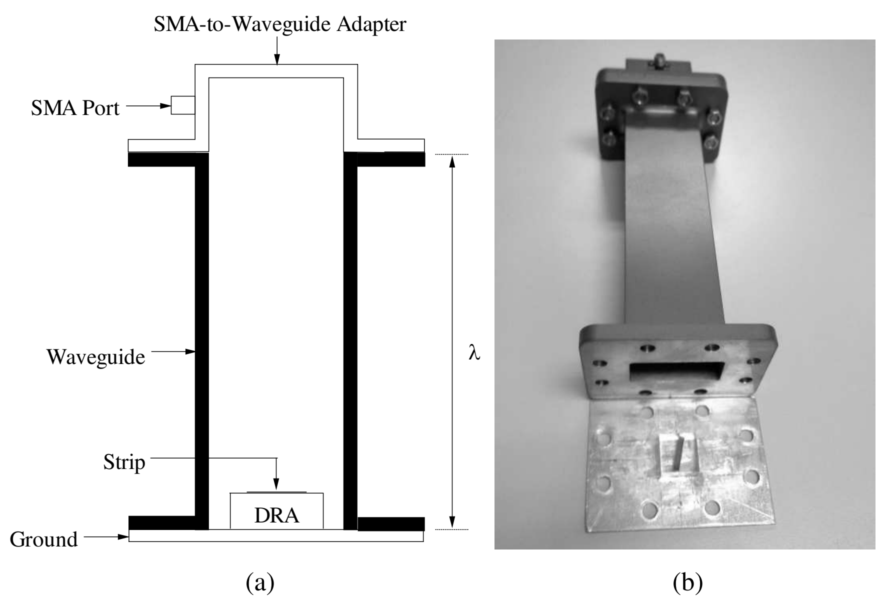

Figure 2: Experimental setup for the waveguide method. (a) Cross-sectional view. (b) Photograph.

3. RESULTS AND DISCUSSION

Figure 3(a) shows the simulated and measured reflection losses and reflection phases (S-Curve), demonstrating reasonable agreement between them. The loss peaks at −0.4 dB at the inclination angle of $\theta = 25°$. This is because the resonant frequency of the strip-loaded DRA is around 6 GHz at this particular inclination angle, causing much energy dissipation. Also depicted in Fig. 3(b) is the S-Curve. The reflection phase range introducible by the strip rotation is measured to be 162.29° (simulation 147.01°). For the waveguide method, simulating as quare cell is not possible as the cell size has to follow the waveguide cross profile ($a \times b$). This creates a limitation on the spacing between the reflectarray elements.

Next, the same DRA element is simulated using the Floquet method, shown in Fig. 4. This method provides a sort of periodic boundary condition in the way that the unit element is virtually extended into an infinite array by considering the mutual coupling effect between the elements.This makes the simulation model closer to the actual reflectarray. In this case, the angle of the incident wave does not depend on frequency. This gives much more freedom as the incident angle and operating frequency can now be chosen freely. For Floquet model, the spacing between the elements can be arbitrarily defined by simply changing the cell size ($L_1\times L_2$). To simplify our design process, a square cell ($L_1 = L_2$) is used here. The simulated S-Curves for different element spacings are given in Fig. 5. For ($L_1 = L_2$), it can be seen that the changeable range increases when the spacing becomes smaller. The distance between the Floquet port and the unit element is not important as the port can always be de-embedded flush to the element surface.

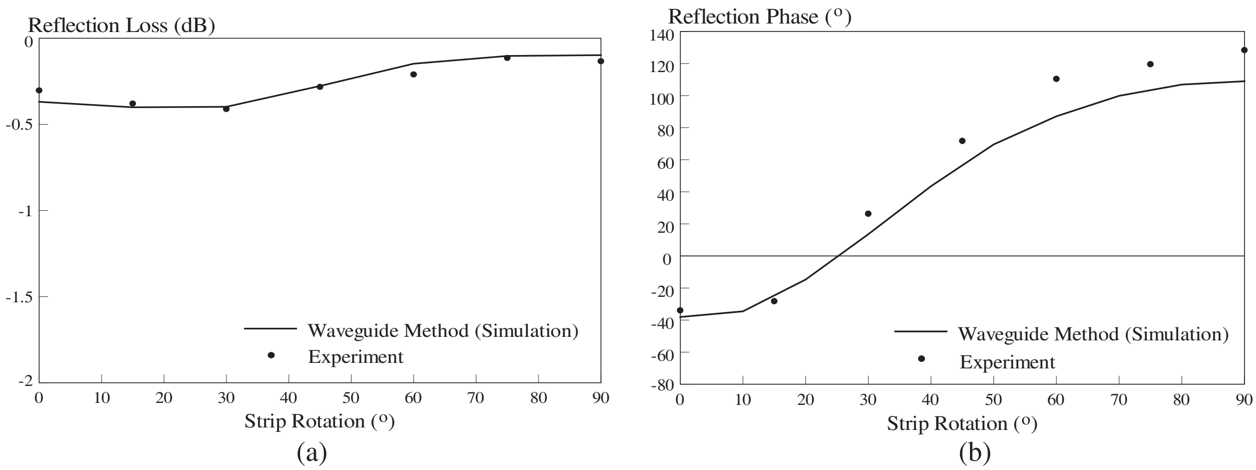

Figure 3: Simulated and measured (a) reflection loss, (b) reflection phase (S-Curve) of the proposed DRA reflectarray unit element using the waveguide method.

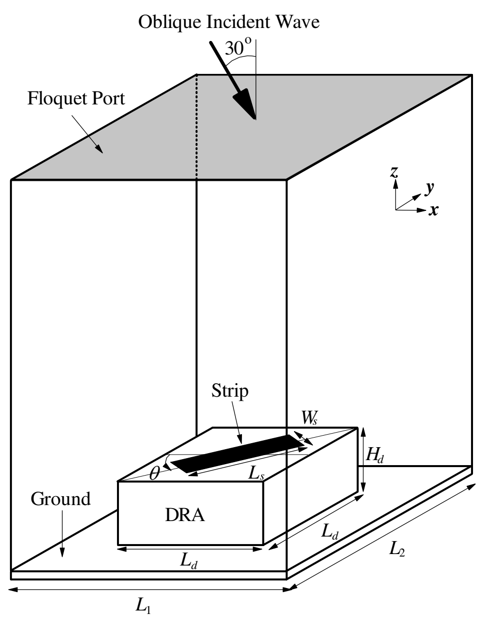

Figure 4: The Floquet model for the proposed DRA unit element.

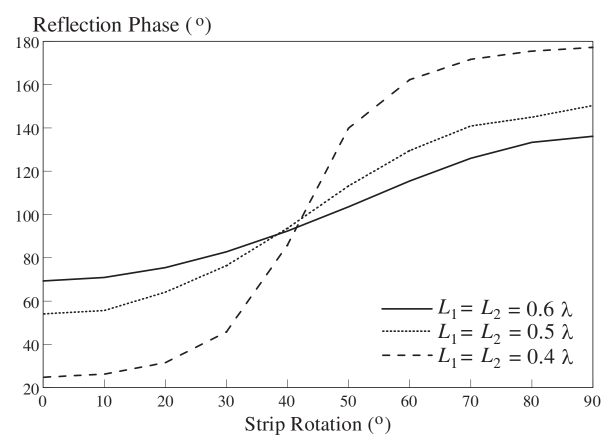

Figure 5: Simulated S-Curves for different element spacings ($L_1 = L_2$).

4. CONCLUSIONS

In this paper, the inclination angle of a top-loading patch that is stuck on top of a rectangular DRA is varied to provide reflection phase shift for designing a reflectarray. Waveguide and Floquet methods have been used to simulate this unit element. It has been found that the reflection phase range and the gradient of the S-curve are significantly affected by the spacing distance between the elements.

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