A NOVEL 5.8 GHz ARRAY DIELECTRIC RESONATOR ANTENNA

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Abstract—In this paper, a novel nine elements array dielectric resonator antenna (DRA) is presented. The DRA was excited by a microstrip feeder with a rectangular aperture coupled slots. The slot positions were determined based on the characteristic of standing wave ratio over a short ended microstrip. The measured gain of the array DRA operating at 5.84 GHz was about 10 dBi having impedance bandwidth of 60 MHz. The proposed DRA exhibits an enhancement of the gain in comparison with a single pellet DRA. The size of the whole antenna structure is about 60 mm × 40 mm and potentially can be used in wireless systems.

1. INTRODUCTION

Since the dielectric resonator antenna (DRA) was introduced by Long et al. in 1983 [1], DRAs have been extensively studied. These antennas overture the benefits of light weight, small size, low cost, ease of excitation and deficiency of conduction losses in the resonator [2]. Moreover, various antenna features such as input impedance, bandwidth, and radiation patterns can be easily regulated by varying the antenna specifications and feed mechanisms. Recently, extensive research has been done to achieve wide DRA bandwidth using embedded DRAs, stacked DRAs, or other specific formations of the DRAs [3]. All these aspects make wideband DRAs favorable as antenna elements for array implementations.

Tremendous efforts have been made in investigating the production of linearly polarized (LP) wide band DRAs [4, 5], and several methods have been proposed. The first one is to use special shaped DRAs [6, 7], but these DRAs may not be easy to obtain commercially. Some feeding structures [5, 8] can also be used to obtain a wide-band DRA. The second approach is to use more than one dielectric resonator (DR) element [4–9], which is often called as a "stacked" DRA, with different sizes of different dielectric materials.

DRAs are commonly low gain antennas with a broad radiation pattern. As with other conventional low gain antennas, DRAs can be arrayed to acquire higher gain. Various types of feeding methods have been used to feed a linear array of DRAs to obtain this goal, such as microstrip lines [10], coplanar waveguide [11], slotted waveguide [12], and dielectric image line [13]. Among these excitement schemes, aperture coupling with a microstrip feed line is mainly used because of ease of assembly, suitability to integrate with circuits, and isolation among the antenna and feeding network.

In this paper, a design of nine element DRA array operating at 5.8 GHz is addressed. The design was based on the standing wave ratio microstrip short ended offers an enhancement of the gain [19, 20]. A slot coupling feeding technique was used, because it is most suitable for large DRA arrays where relatively simple circuit integration is required, as compared to other feeding mechanisms. Moreover, since a ground plane isolates the feeding structure from the radiator, the radiation characteristics are mainly from the dielectric resonator.

2. DESIGN CONCEPT OF ARRAY DRA

The DRA was excited with a $50\,\Omega$ microstrip feeder with a width of 1.7 mm, designed on a RO4003C microwave substrate with ε_s of 3.38 and a thickness of 0.813 mm. The CCTO (CaCu3Ti4O12) material with a dielectric constant $\varepsilon_r = 55$ was used as a resonator.

The length and width of the rectangular slot should be cautiously selected as in Equations (1) and (2) respectively. It should be large enough to construct an effective coupling existence between the DRA and the feed line, which generally directs to a relevant radiated back lobe [14, 15].

$$l_s = \frac{0.4\lambda_0}{\sqrt{\frac{\varepsilon_r + \varepsilon_s}{2}}} \tag{1}$$

where ε_r and ε_s are the dielectric of the DRA and the substrate, respectively.

The width (W_s) of the slot can be calculated as in Equation (2) and should be narrow to avoid large back lobe component

$$W_s = 0.2l_s \qquad (2)$$

Equations (1) and (2) give an accurate dimension of the rectangular slot in a single element DRA, but for an array, it gives an initial idea of the actual dimensions of the slot.

The dimension of the individual DRAs was determined to be approximately 5.8 GHz using Equations (3) and (4) in [16, 17].

$$F = \frac{f_{\mathrm{GHz}} \cdot w_{\mathrm{cm}} \cdot \pi \cdot \sqrt{\varepsilon_r}}{15} \qquad (3)$$

$$F = a_0 + a_1 \left(\frac{w}{b}\right) + a_2 \left(\frac{w}{b}\right)^2 \qquad (4)$$

where

$$a_0 = 2.57 - 0.8\left(\frac{d}{b}\right) + 0.42\left(\frac{d}{b}\right)^2 - 0.05\left(\frac{d}{b}\right)^3$$

$$a_1 = 2.71\left(\frac{d}{b}\right)^{-0.282}$$

$$a_2 = 0.16$$

F is the normalized frequency; w is the width; d is the length; and b is the height divided by 2.

3. THE STUB EXTENSION AND STANDING WAVE RATIO

Microstrip fed aperture coupled patch antennas were first used in 1985 [18]. This technique has seen extensive use for both microstrip patch and DRA applications, with the advantages of easy integration with MIC component and effective use at high frequencies, making this method very popular. A simple representation is shown in Figure 1. Typically, a radiating dielectric element is placed over the slot. A microstrip transmission line on top of the substrate is electromagnetically coupled, through an aperture in the common ground plane, to the dielectric resonator antenna.

A quarter-wavelength shorted stub is a special case of the stub concept, used only in particular applications in microwave circuits. The feed line is terminated by a quarter-wavelength short-ended stub to maximize the amount of power coupled to the antenna [19, 20]. The distance of the stub should be meticulously selected to match the input impedance of the antenna. When slot coupled patch antennas are used
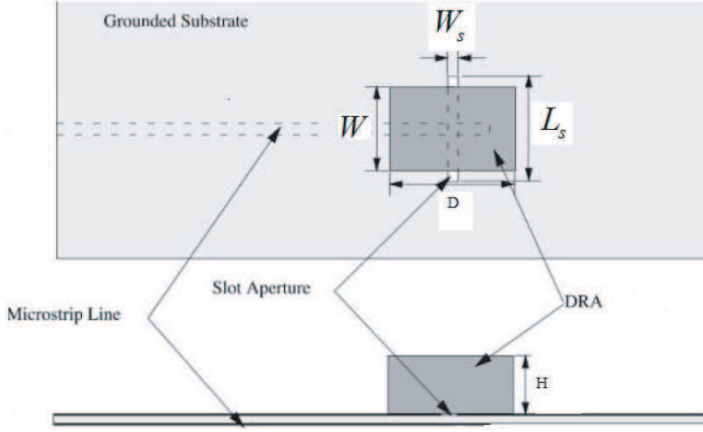
Figure 1. A rectangular slot coupled with dielectric element [24].

in a series' fed array configuration, the input impedance of one of the antenna acts as a load for the former array component. Thus the design of a series' fed array requires very fine tuning on the antenna. The stub lengthening S is mostly chosen to be:

$$S = \frac{\lambda_g}{4} \tag{5}$$

where λ_g is the guided wavelength.

Equations to find the guided wavelength in a microstrip were stated in [21].

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{\text{eff}}}} \tag{6}$$

$$\varepsilon_{\text{eff}} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + 10\frac{h}{w}\right)^{-0.555} \tag{7}$$

$$\frac{w}{h} = \frac{2}{\pi}\left[\left(\left(\frac{59.95\pi^2}{z_0\sqrt{\varepsilon_r}}\right) - 1\right) - \ln\left(2\left(\frac{59.95\pi^2}{z_0\sqrt{\varepsilon_r}}\right) - 1\right)\right.$$
$$\left. + \frac{(\varepsilon_r - 1)}{\pi\varepsilon_r}\left[\ln\left(\frac{59.95\pi^2}{z_0\sqrt{\varepsilon_r}} - 1\right)\right] + 0.293 - \frac{0.517}{\varepsilon_r}\right] \tag{8}$$

where λ_0 is the wavelength in free space.

Z_0 is the microstrip input impedance which equals 50 Ohm.

Figure 2 indicates the voltage allocation over the length of the line when the load end of the line is shorted. The same impedance and voltage condition is periodic every half-wavelength down further the
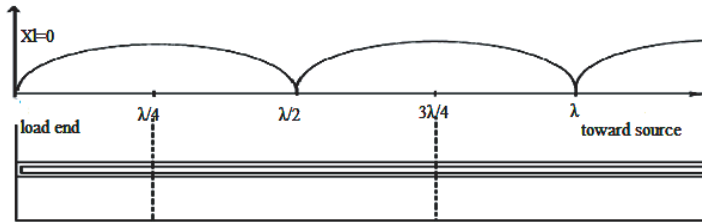
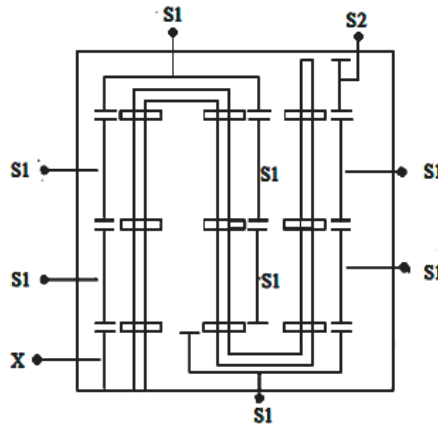**Figure 2.** Voltage allocation over a microstrip line.

Figure 3. The designed array antenna showing the spacing between the elements.

line from the load completion toward the generator. Voltage minima are called nodes, and voltage maxima are called antinodes [22].

Since the antinodes will repeat at every half wavelength along the transmission line, the array elements were positioned every half wavelength in order to get the maximum radiation of the antenna array. Figure 3 shows the spacing between the array elements depending on the calculation of the wavelength. S_1 is the distance to separate the elements which are equal to half wavelength, while S_2 equals a quarter wavelength, which represents the last element of the array. X is the distance from the source to the first element.

Since the array elements are placed on X and Y directions, Equation (7) is used to calculate the array factor

$$AF = \frac{1}{nm} \frac{\sin\left[m\left(k_0 s_x \sin\theta\cos\phi\right)/2\right]}{\sin\left[\left(k_0 s_x \sin\theta\cos\phi\right)/2\right]} \cdot \frac{\sin\left[n\left(k_0 s_y \sin\theta\sin\phi\right)/2\right]}{\sin\left[\left(k_0 s_y \sin\theta\sin\phi\right)/2\right]}$$

where m, n are the array elements

$$k_0 = \frac{2\pi}{\lambda_0}$$

S_x, S_y elements spacing in x and y directions.

4. RESULTS AND DISCUSSIONS

The dimensions of the slot were 6 mm in length and 2 mm in width. By solving Equation (3) at the frequency of 5.8 GHz, the quarter wavelength was equal to 7.9 mm, and half wavelength was equal to 15.8 mm, while X as in Figure 3 was set to 12 mm. A design of 9 array elements was carried out using the results shown in Figure 4. By solving Equations (3) and (4), the dimensions of the DRA array were found to be 4 mm (width), 4 mm (length), and 6 mm (height). The spacing between the dielectric pellets in term of wavelength in X and Y directions is $S_x = 0.056\lambda_0$ and $S_y = 0.111\lambda_0$ respectively.

Figure 5 shows the array factor of E-plane. The array factor AF of Configuration A is dependent on both $\phi = 0$ and $\phi = 90$, where n and m equal 3, and S_x and S_y are $0.056\lambda_0$ and $0.111\lambda_0$ respectively.

Figure 6 shows the simulated radiated power at antinodes over the microstrip line using CST microwave studio software. It was clearly shown that the antinodes took their places approximately at the positions calculated using Equation (3) at 5.8 GHz. As can be seen in Figure 4, the slots were placed to take their positions on the antinodes, while the DRA elements were placed over the coupling slots.
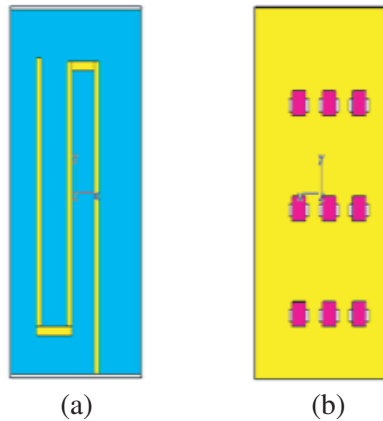

(a)   (b)

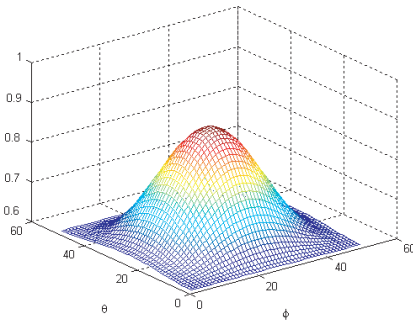**Figure 4.** The designed structure in CST (a) front view and (b) back view.

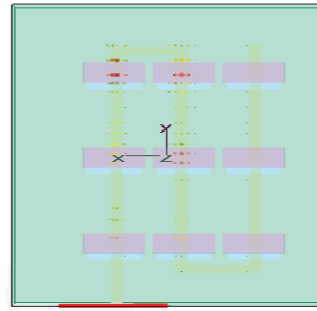**Figure 5.** 3D radiation pattern of E-plane array.

Figure 6. The maximum power radiated by antinodes along the microstrip at 5.8 GHz.

The simulation and measurement results for the input return loss are given in Figure 7. The simulated input return was -21.4 dB at 5.79 GHz with a bandwidth of 80 MHz and impedance of 52.23-j4.55 Ω. The measured input return loss at 5.85 GHz was -19.8 dB with a bandwidth of 60 MHz and impedance of $51.23 + j3\,\Omega$.
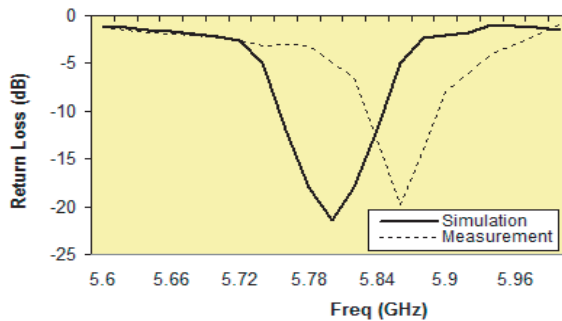

Figure 7. Measured and simulated return loss.

Figure 8 shows the simulated and measured gains of the antenna at a frequency range of 5.6 GHz to 6 GHz. The simulated gain obtained from CST was 11.4 dBi. The measured gain was 10.7 dBi using gain absolute methods compared to a standard monopole antenna. It indicates that the proposed DRA has high efficiency with minimum loss. This is because there is no conductor loss in the dielectric resonator. However, a small conductor loss exists in the microstrip line.

Figure 9 shows the simulated and measured radiation patterns in the xy-plane at 5.84 GHz. In simulation, the main loop magnitude was 11.4 dBi, and the main loop direction was $90°$, whereas in measurement,
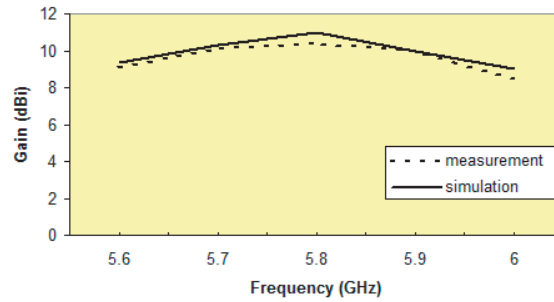
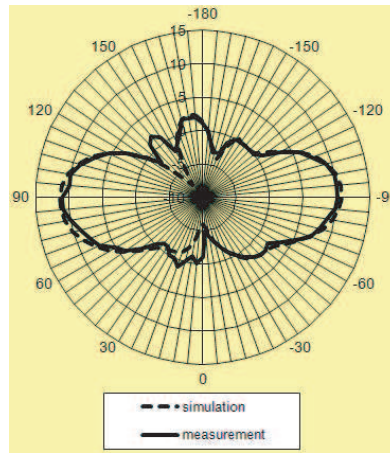**Figure 8.** The measured and simulated gain in dBi of proposed DRA.

Figure 9. Measured and simulated radiation pattern.

the main loop magnitude was 10.7 dBi, and main loop direction 88°. Simulation results also show good agreement with measured radiation patterns.

5. CONCLUSION

In this paper, a new feeding method for high gain DRA array at 5.8 GHz is presented. The proposed arrays are fed by a microstrip slot coupled structure employing the characteristic of short ended microstrip line. Reasonable agreement between simulation and measurement data was obtained.

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