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Parametric study on effect of solar-cell position on the performance of transparent DRA transmitarray

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ABSTRACT

Linearly polarized transparent dielectric resonator antenna (TDRA) transmitarray is designed and investigated for 12 GHz applications. A parametric study on the effect of solar-cell position on the radiation characteristics of the TDRA transmitarray. The unit cell consists of two TDRAs arranged back-to-back with one on either side of a perfect transparent conducting ground plane. The waveguide model is used to calculate the required compensation phase of each cell in the transmitarray. The radiation characteristics of a 9 × 9 linearly polarized transparent transmitarray antenna are investigated in different positions of solar-cell with respect to the DRA. The peak gain is 20.22 dB with a 1-dB gain bandwidth is more than 2 GHz (16.67%) for the TDRA transmitarray without solar-cell. The solar-cell is integrated with TDRA transmitarray with different positions for small satellite applications. The radiation characteristics of the transmitarray are simulated and calculated using the finite integral technique (FIT).

1. Introduction

The small satellites have a limited surface area. The satellite surface area is occupied by the solar-cells, test instruments, and antennas which affect the overall size and weight of the satellites. An important challenge for a small satellite is to make use of the limited surface area and save cost [1,2]. The design of small satellite antenna includes some limitations such as limited surface area, limited antenna mounting positions, and deployed mechanism [3]. The integration of antennas with solar-cell offers a wide range of advantages as small surface coverage, light weight, low costs and improving the economic viability of renewable energy [4–7].

Solar powered communication systems have advantages that operate without the necessity of an electrical grid connection. There are two types of photovoltaic-antenna integration techniques used in communication systems. The first technique used the solar-cells as an independent power source operating separately from the antennas [8]. The solar-cells are separated from the antennas by a certain distance to ensure that the cells do not effect on the RF characteristics of the antennas [9,10]. The second technique is the full integration of photovoltaics with microwave antennas in a compact communication system, which used the solar-cells as a part of RF operation [8]. Recently, transparent antennas can be integrated with solar-cells to save surface area of small satellites [3]. Transparent conductive films allow the transmission of electric currents and keep optical transparency of the film, which is more suitable for antennas integrated with solar-cells [7]. The conventional high-gain antennas are parabolic reflectors. The parabolic dish transforms a spherical wave into a planar one and vice versa. Some of the drawbacks of the parabolic reflector are weighted, fabrication complexity, and large overall size [11,12]. The phased arrays offer several advantages over the parabolic antennas, such as electronic steering capability, light-weight and ease of production [13,14], but losses arise from both the physical length of line and from radiation produced at the feed network junctions. The reflectarray is a good choice for the intended satellite-based application since it combines the light weight and low profile while emulating the electrical performance of a phased array or parabolic dish. The reflectarray still requires an offset feed to avoid blockage losses [15]. The offset geometry destroys the symmetry of an antenna aperture and increases the angle of the incident wave, thus reducing the reflector's gain, decreasing efficiency and complicating the design [16–21]. The transmitarray is similar to the reflectarray where, the feed signal is not reflected, but passes through the structure as it is collimated into a plane wave. Consequently, the feed horn cannot interfere with the transmitted and received waves, and there is no blockage loss [22–24]. The DRA is used for transmitarray to increase the bandwidth, compared to earlier transmitarrays which have been designed using patch elements [25], or using

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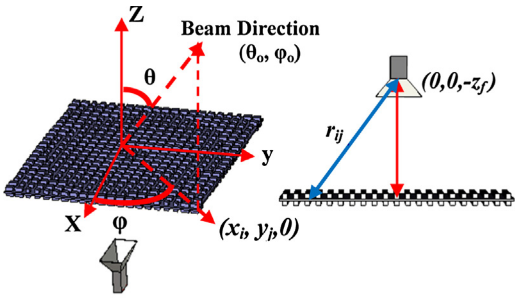
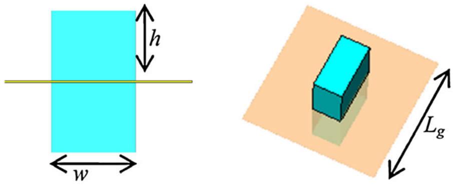


(b) 3-D view (b) Side view

Fig. 1. The structure of the transmitarray.



(a) (b)

Fig. 2. (a) The side view of the unit cell and (b) 3D-view of the unit cell.

cross-dipole elements as done by Chaharmir et al. [26]. DRAs offer many advantages, such as low-profile, low-cost, and high radiation efficiency and high power-handling capability [27–30].

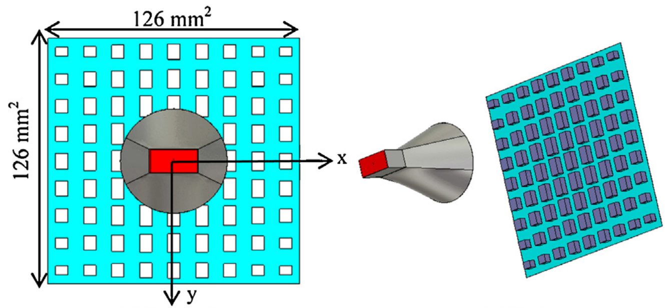
In this paper, 9 × 9 linearly polarized TDRA transmitarray integrated with solar-cell have been introduced. The effect of solar-cell position relative to the TDRA on the radiation characteristics of the transmitarray had been investigated. The TDRA transmitarray is designed and simulated using the finite integral technique (FIT) [31].

2. Theory

Considering the array on the x–y plane illuminated by a feed horn, the required phase distribution φ_{ij}, at each element of the array to collimate a beam in the (θ_o, φ_o) direction is determined from

$$\varphi_{ij} = kr_{ij} - k(x_i \sin\theta_o \cos\varphi_o + y_j \sin\theta_o \sin\varphi_o)$$

where k_o is the propagation constant in vacuum, r_{ij} is the distance from the feed horn (x_f, y_f, z_f) to the element ij of the array and (x_i, y_j) are the coordinates of the cell element ij as shown in Fig. 1.



(a) Front view (b) 3D view

Fig. 4. DRA transmitarray structure.

3. Numerical result

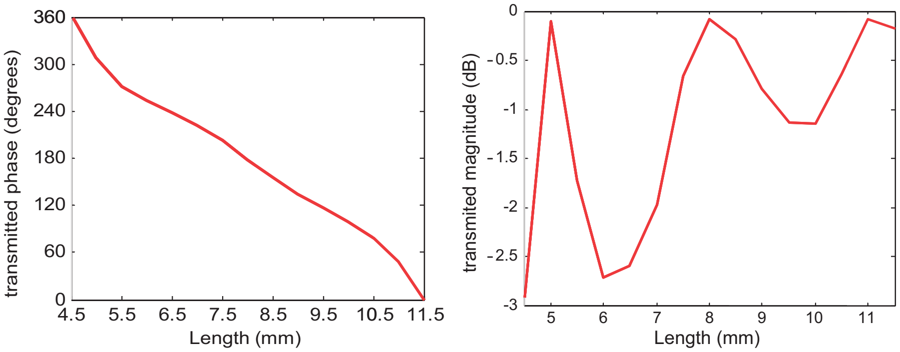
3.1. Design of the first unit-cell

The transmitarray cell element consists of two transparent rectangular dielectric resonators arranged back-to-back with one on either side of a perfect transparent conducting ground plane as shown in Fig. 2. The two RDRA are coupled by a rectangular slot (6 mm × 2 mm) in the ground plane. Each rectangular DRA cell element has a width W = 3 mm, a height h = 4 mm and a variable length L, the relative dielectric constant is $\varepsilon_r = 12$. The variation of the length of the transparent rectangular DRA changes the resonant frequency of the DRA which yields a change in transmission coefficient phase at the 12 GHz operating frequency.

The DRA is mounted on (14 mm × 14 mm) transparent conducting ground plane thickness $h_s = 0.1$ mm with $\sigma = 5 \times 10^5$ S/m. This RDRA cell element is designed to operate at 12 GHz. Fig. 3 shows the phase and the magnitude of the transmission coefficient of RDRA cell element as a function of RDRA length for normal incident plane wave. The results are obtained by applying the FIT technique. The minimum value of the transmission magnitude through the unit cell is lower than −3 dB, and the element achieves a phase tuning range of 360°.

3.2. The transparent DRA transmitarray

The configuration of the transmitarray and feed horn is shown in Fig. 4. The transmitarray is composed of 9 × 9 cell elements and is covering an area of 126 mm × 126 mm. The feed is a linearly polarized pyramidal horn. The dimensions of the horn are 60 mm × 30 mm × 50 mm. The F/D ratio is set to 1. The E-plane and H-plane patterns for the transmitarrays at 12 GHz are shown in Fig. 5. The radiation pattern in E-plane is different from that in



(a) (b)

Fig. 3. (a) Transmission coefficient phase variation versus DR length. (b) Transmission coefficient magnitude variation versus DR length.