Planar Array Approach as Alternative Method to Characterize Radiation Pattern of 2 × 2 Spiral Resonator (SR) Structure

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Abstract— This paper presents the planar array approach as an alternative method to characterize radiation pattern of spiral resonator (SR) structure. The method involves the development of linear array approach of SR structure with a single patch discussed herein. The planar array is constructed of 2 × 2 SR structure in which each single patch of SR structure is assumed as a similar non-isotropic point source. To verify the proposed planar array approach, the 2 × 2 SR structure implemented as an antenna radiator is characterized using 3D simulation software and experimentally measured to obtain its radiation pattern. The maximum electric field intensities of radiation pattern at the boresight direction obtained from the proposed approach, simulation, and measurement are 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. It shows that the electric field intensities at the boresight direction have good agreement each other.

1. INTRODUCTION

Microstrip antennas are widely used in mobile communications due to their advantages such as having planar structure, compact size, and light weight [1, 2]. Numerous researchers have involved in exploiting the features of microstrip antennas which have stripline or planar form including the exploration of methods to reconfigure the beam pattern and characterize the radiation characteristic [3–9]. Some methods for reconfiguring the beam were investigated based on experimentation [3–6], while for characterizing the radiation pattern the methods were obtained through simulations and analytical approaches [7–9]. Unfortunately, the method of planar array has not yet been included in the discussion as potential analytical approach.

Therefore, in this paper, the planar array approach is applied as an alternative method to characterize radiation pattern of 2 × 2 SR structure. The approach involves the development of linear array of a single patch of SR structure which has been previously discussed [7]. It has been reported that the simulation and the linear array approach for a single patch of SR structure have shown similar results in terms of radiation pattern. Furthermore, the planar array used for the approach is obtained based on the arrangement of single patch of SR structure in 2 × 2 patch array in which each single patch is regarded as a similar non-isotropic point source. Hence, a two-dimensional arrangement of $a \times b$ planar array will be configured as a two-mutually-perpendicular linear arrangement [10].

2. RADIATION PATTERN OF 2×2 PLANAR ARRAY OF SR STRUCTURE

The planar array approach to characterize radiation pattern of a 2 × 2 SR structure is established from a two-dimensional $a \times b$ planar array. In general, the electric field intensity of radiation pattern for the $a \times b$ planar array can be formulated in (1) [10].

$$E(x, y, z) = AF(\theta, \phi)\frac{e^{-jkr}}{r} \tag{1}$$

where k, r, and $AF(\theta, \phi)$ are the propagation constant, the distance from the planar array, and the array factor which is given by (2) [10].

$$AF(\theta, \phi) = \left[\sum_{a=-A}^{A} I_a \exp(jakd_x \sin\theta\cos\phi)\right] \times \left[\sum_{b=-B}^{B} I_b \exp(jakd_y \sin\theta\sin\phi)\right] \tag{2}$$

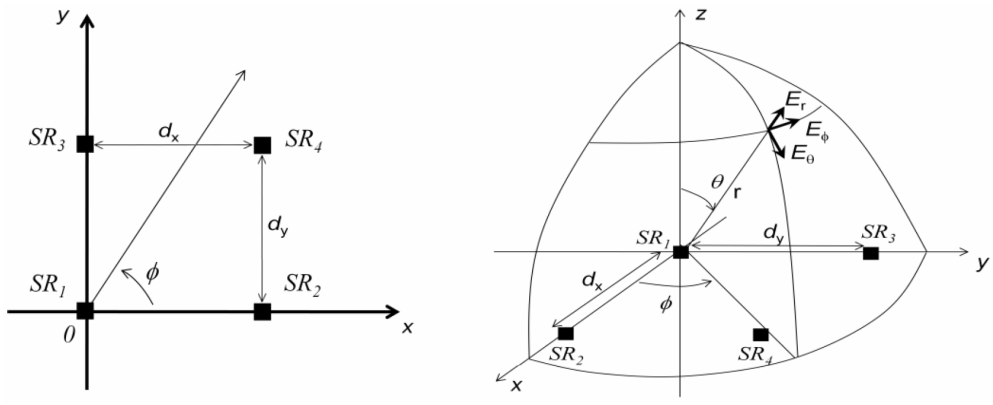

Figure 1. Geometrical configuration of planar array of 2 × 2 SR structure as four non-isotropic radiation sources; left is planar configuration; right is spherical configuration.

By using the configuration of $a \times b$ planar array, the 2×2 SR structure is constructed and assumed as an arrangement of four similar non-isotropic radiation sources ($SR_1, \ldots, SR_4$) as illustrated in Figure 1. This arrangement forms the configuration of two-dimensional formation in xy-plane with the distance of $d_x = d_y$ which is regardable as a single patch of SR structure. Based on the geometrical configuration, therefore (2) can be reformulated as given in (3).

$$\begin{aligned} AF(\theta,\phi) = &\left[E_{\phi,SR_1}\exp\left(j\frac{2\pi}{\lambda}ad_x\sin\theta\cos\phi\right) + E_{\phi,SR_2}\exp\left(j\frac{2\pi}{\lambda}ad_x\sin\theta\cos\phi\right)\right]\times \\ &\left[E_{\phi,SR_3}\exp\left(j\frac{2\pi}{\lambda}bd_y\sin\theta\sin\phi\right) + E_{\phi,SR_4}\exp\left(j\frac{2\pi}{\lambda}bd_y\sin\theta\sin\phi\right)\right] \end{aligned} \tag{3}$$

In this case, the element number of planar array, i.e., a and b, is a single patch of SR structure constructed as 2×2 non-isotropic point sources. By setting the distance between elements or patches is equal, $d_x = d_y$, and each single patch is identical, the array factor in (3) can be expressed in (4).

$$AF(\theta,\phi) = 4 \times \left[E^2_{\phi,SR}\right] \times \left[\exp\left(j\frac{2\pi}{\lambda}ad_x\sin\theta\cos\phi\right)\right] \times \left[\exp\left(j\frac{2\pi}{\lambda}bd_y\sin\theta\cos\phi\right)\right] \tag{4}$$

Furthermore, the array factor in (4) can be simply expressed as (5).

$$AF(\theta,\phi) = 4 \times (P + jQ)^2 \times (U + jV) \times (X + jY) \tag{5}$$

The expansion of array factor expression in (5) is given in (6) and (7).

$$\begin{aligned} AF(\theta,\phi) = 4 \times &\Big[(P^2UX + Q^2UX - P^2VY - Q^2VY - 2PQUY - 2PQVX) + \\ &j(P^2UY + Q^2UY + P^2VX + Q^2VX + 2PQUX + 2PQVY)\Big] \end{aligned} \tag{6}$$

$$\begin{aligned} &\mathrm{Re}\{AF(\theta,\phi)\} = 4 \times \left[(P^2UX + Q^2UX - P^2VY - Q^2VY - 2PQUY - 2PQVX)\right] \\ &\mathrm{Im}\{AF(\theta,\phi)\} = 4 \times \left[(P^2UY + Q^2UY + P^2VX + Q^2VX + 2PQUX + 2PQVY)\right] \\ &AF(x,y) = A(\theta,\phi)_{\theta=90^\circ} \\ &AF(x,z) = A(\theta,\phi)_{\phi=0^\circ} \\ &AF(y,z) = A(\theta,\phi)_{\phi=90^\circ} \end{aligned} \tag{7}$$

By using (6) and (7), the radiation pattern of planar array of 2×2 SR structure can be calculated.

3. DESIGN, CHARACTERIZATION, AND RESULT COMPARISON

As shown in Figure 2, the planar array of 2×2 SR structure is designed by using 4 identical patches fed using proximity feeding line. Each single patch which has been deeply discussed in [7] has the dimension of 22.6 mm $\times$ 22.6 mm which is made in a spiral shape with turn number of 3, strip width of 3.1 mm, gap width of 0.5 mm, and inner radius of 1 mm. The distance between patches is set equal each other to be 7.4 mm. Therefore, the total dimension of 2×2 SR structure is 52.6 mm $\times$ 52.6 mm. By using (6) and (7), the radiation pattern of planar array of 2×2 SR structure is theoretically calculated.

Furthermore, to simulate the 2×2 SR structure, the design is deployed on an FR4 epoxy dielectric substrate with the total thickness of 1.6 mm. By using 3D simulation software, the design is then simulated to obtain the radiation pattern. While to verify the result of proposed approach as well as the simulation result, a prototype of 2×2 SR structure is fabricated for experimental measurement. The prototype is realized using 2 layers of 1.6 mm thick FR4 epoxy dielectric substrate which are stacked together tightly in such a way to avoid any gap between them.

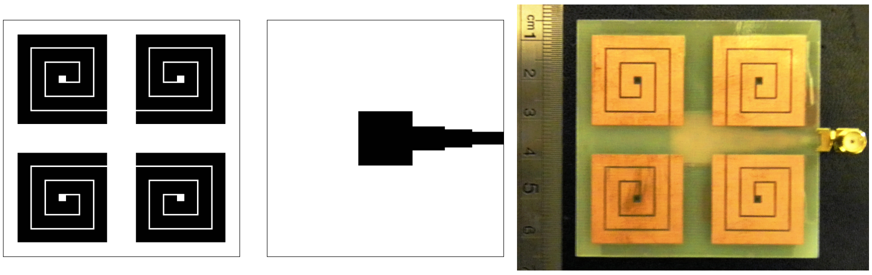

Figure 2. Planar array of 2×2 SR structure with proximity feeding line; left is 4 patches; center is feeding line; right is realized planar array.

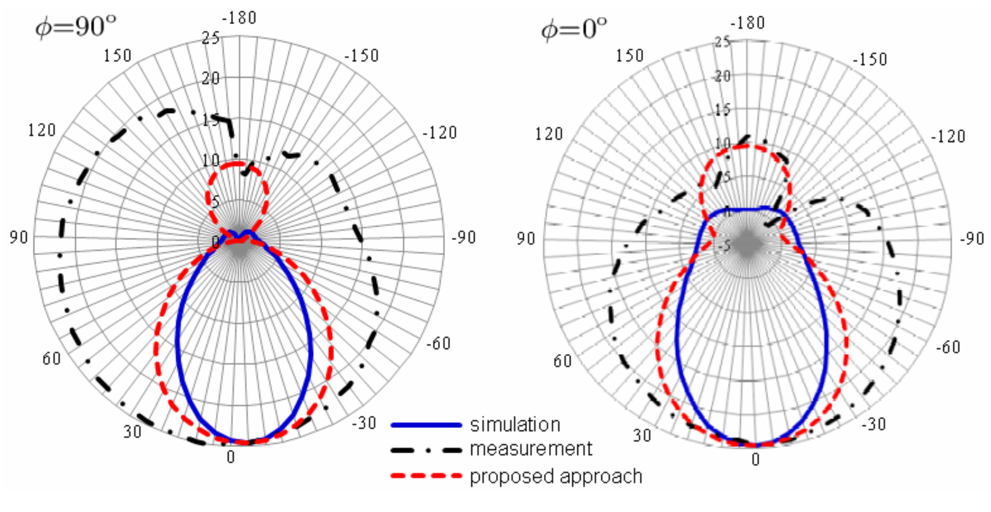

Figure 3. Comparison of radiation pattern between analytical approach, simulation, and measurement for 2×2 SR structure; left is xz-plane; right is yz-plane.

The results of calculation using the proposed method, simulation, and measurement for 2×2 SR structure are plotted in Figure 3. The radiation pattern obtained from the planar array approach is similar in the boresight and backlobe directions compared to the simulation and measurement results. However, the proposed approach and the simulation results slightly differ to the measurement result at the sidelobe direction. It shows that the radiation pattern obtained from the proposed approach, simulation, and measurement at the boresight direction are coincided each other with the maximum electric-field intensities of 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. Meanwhile, the electric-field intensities of radiation pattern at the backlobe direction are 9.46 V/m, 0.27 V/m, and 9.76 V/m for the proposed approach, simulation, and measurement, respectively.

4. CONCLUSION

The planar array approach applied as an alternative method to characterize the radiation pattern of of 2×2 SR structure has been demonstrated. A planar array of 2×2 SR structure has also been characterized using 3D simulation software and realized for experimental measurement to be compared with the proposed approach. It has been shown that the result of proposed approach has had similar trend with the simulation and measurement results at the boresight and backlobe directions. However, both results of proposed approach and simulation were slightly different to the measurement result at the sidelobe direction. The maximum electric fled intensities of radiation pattern obtained from the planar array approach, simulation, and measurement at the boresight direction are 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. Meanwhile, at the backlobe direction the electric fled intensity is 9.46 V/m for the planar array approach, 0.27 V/m for the simulation, and 9.76 V/m for the measurement.

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