PLANAR ARRAY APPROACH AS ALTERNATIVE METHOD TO CHARACTERIZE RADIATION PATTERN OF *2x2* SPIRAL RESONATOR (SR) STRUCTURE

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Abstract

This paper presents the planar array approach of the 2x2 SR structure as an alternative method to characterize the radiation pattern. This method involves the development of the linear array approach of the SR structure with a single patch, which is discussed herein. The planar array is obtained by the arrangement of the *2x2* SR structure, and each of the single patches of the SR structure are regarded as similar nonisotropic point sources. To verify the proposed planar array approach, the 2x2 SR structure that implemented as an antenna radiator is also characterized using 3D simulation software and measurement to obtain radiation pattern. The maximum radiation-pattern that obtained from the planar array approach, simulation, and mesurement at boresight direction are 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. Meanwhile, the radiation pattern at backlobe direction is 9.46 V/m from planar array approach, 0.27 V/m from simulation, and 9.76 V/m from measurement. It shows that the radiation pattern obtained from planar array approach, simulation, and measurement have good agreement each other at boresight direction.

Keywords *: Radiation Pattern Characteristics; 2x2 SR Structure; Planar Array Approach.*

1. Introduction

Microstrip antennas are widely used in mobile communications because of their planar, compact and lightweight form. Various methods are used to characterize the radiation pattern of microstrip antennas that have stripline or planar forms [1]–[4]. The characteristics of the radiation pattern can be obtained through simulations and analytical approaches. The planar array method has not yet been discussed as a potential analytical approach. Therefore, in this paper, the planar array approach is used to characterize the radiation pattern of a *2x2* planar array of an SR structure. The planar array approach involves the development of a linear array of a single patch of the SR structure, which has been previously discussed [5]. The simulation and linear array approach of a single patch of the SR structure show similar results in terms of the radiation pattern. The planar array can be obtained based on the arrangement of the single patch of the SR structure in *2x2* patches, and each of the single patches are regarded as similar nonisotropic point sources. Therefore, the two–dimensional planar arrangement of the *a x b* will be configured as two mutually perpendicular linear arrangements [6].

2. Design and Geometry of *2 x 2* Planar Array SR Shaped

The broadside radiation pattern of the $a \times b$ planar array can generally be formulated as follows [6]:

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

in which:

$$AF(\theta,\phi) = \text{array factor}$$

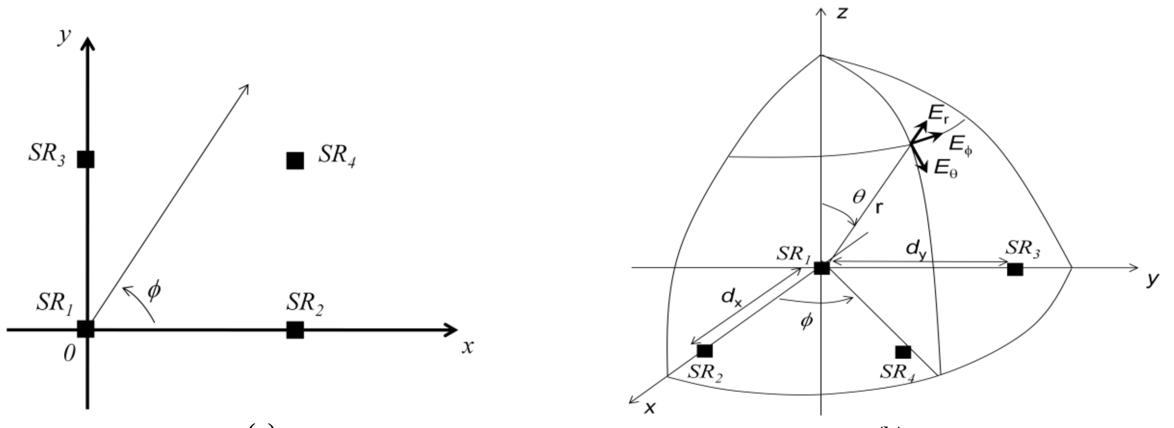
$$\begin{aligned} AF(\theta,\phi) &= \sum_{a=-A}^{A}\sum_{b=-B}^{B} I_{a,b}\exp\left[jk\sin\theta\left(ad_x\cos\phi + bd_y\sin\phi\right)\right] \\ AF(\theta,\phi) &= \left[\sum_{-A}^{A} I_a \exp\left(jakd_x\sin\theta\cos\phi\right)\right]\times \\ &\quad \left[\sum_{-B}^{B} I_b \exp\left(jbkd_y\sin\theta\sin\phi\right)\right] \end{aligned} \tag{2}$$

$$
\begin{gathered}
x' = ad_x \,;\, y' = bd_y \,;\, z' = 0 \\
x = r\sin\theta\cos\phi;\; y = r\sin\theta\sin\phi \\
k = \frac{2\pi}{\lambda}
\end{gathered}
\tag{3}
$$

Equation (1) shows that the radiation pattern is determined by the planar array factor AF (θ, ϕ). The array factor in Eq. (2) is the product of two linear array factors.

2.1 Geometry of the *2x2* Planar Array of the SR Structure Used to Characterize the Radiation Pattern

The *2x2* planar array of the SR structure is assumed as an arrangement of four similar nonisotropic radiation sources. This arrangement forms the configuration of the two–dimensional formation in the *xy* plane at the same distance apart as shown in Figure 1(a).



(a) (b)

Figure 1 Geometrical configuration of the *2x2* planar array of the SR structure as *2x2* nonisotropies radiation sources: (a) planar plane; (b) spherical plane

All of the four nonisotropic radiation sources form a single patch of the SR structure, respectively, such as, SR_1, SR_2, SR_3, and SR_4. In a spherical coordinate system, Figure 1(a) can be replaced by the following Figure 1(b). Planar array of four nonisotropic radiation sources, namely SR_1, SR_2, SR_3, and SR_4 separated by a distance of $dx = dy$

Based on Figure 1, Eq. (2) can be reformulated into the array factors (*AF*) as follows:

$$
\begin{aligned}
AF(\theta,\phi) = {} & \left[E_{\phi,SR1}\exp\left(j\frac{2\pi}{\lambda}ad_x \sin\theta\cos\phi \right) + E_{\phi,SR2}\exp\left(j\frac{2\pi}{\lambda}ad_x \sin\theta\cos\phi \right) \right] \\
& \times \left[E_{\phi,SR1}\exp\left(j\frac{2\pi}{\lambda}bd_y \sin\theta\sin\phi \right) + E_{\phi,SR3}\exp\left(j\frac{2\pi}{\lambda}bd_y \sin\theta\sin\phi \right) \right]
\end{aligned}
\tag{3}
$$

In which, *a* and *b* is the elemen number of the planar array. In this case, the elemen number of the planar array is the single patch of the SR structure as *2 x 2* similar nonisotropic point sources. the distance between point source is $d_x = d_y = 7.4$ mm. Therefore, Eq.(3) can be rewritten as,

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

$$
\begin{aligned}
AF(\theta,\phi) = {} & \left(4E_{\phi,SR}^2\right)\left[\cos\left\{ \left(\frac{4\pi\times 7{,}4}{\lambda} \right)\sin\theta\cos\phi \right\} + j\sin\left\{ \left(\frac{4\pi\times 7{,}4}{\lambda} \right)\sin\theta\cos\phi \right\} \right] \\
& \times\left[\cos\left\{ \left(\frac{4\pi\times 7{,}4}{\lambda} \right)\sin\theta\sin\phi \right\} + j\sin\left\{ \left(\frac{4\pi\times 7{,}4}{\lambda} \right)\sin\theta\sin\phi \right\} \right]
\end{aligned}
\tag{4}
$$

From [11], the radiation pattern of the single patch of the SR structure as a unit cell of the radiator is expressed as,

$$\begin{aligned} E_{\phi,SR} &= -\sum_{n=1}^{N} E_{\phi n} + \sum_{n>N}^{2N} E_{\phi n} \ ; \\ E_{\theta,SR} &= -\sum_{n=1}^{N} E_{\theta n} + \sum_{n>N}^{2N} E_{\theta n} \end{aligned} \tag{5a}$$

$$\begin{aligned} E_{\phi n} &= -E_{\phi 0n} e^{j(n-1)\psi} \ ; \ 1 \le n \le N \ \text{ and} \\ E_{\phi n} &= +E_{\phi 0n} e^{j(n-1)\psi} ; \ N < n \le 2N \\ E_{\theta n} &= -E_{\theta 0n} e^{j(n-1)\psi} \ ; \ 1 \le n \le N \ \text{ and} \\ E_{\theta n} &= +E_{\theta 0n} e^{j(n-1)\psi} \ ; \ N < n \le 2N \end{aligned} \tag{5b}$$

$$\psi = \frac{2\pi d}{\lambda} \sin\theta \ ; d = s = 0.5mm \ ; N \ge 2 \tag{5c}$$

in which:

N = spiral turn number of the single patch SR structure;
n = number of similar nonisotropic point sources of the single patch SR structure.

$$E_{\phi 0n} = I_0 \frac{\sin\left[\left(\frac{2\pi}{\lambda}\frac{l_n}{2}\right)\cos(\theta)\right]}{\left(\frac{2\pi}{\lambda}\frac{l_n}{2}\right)\cos(\theta)} \quad ; \quad E_{\theta 0n} = I_0 \frac{\sin\left[\left(\frac{2\pi}{\lambda}\frac{w_n}{2}\right)\cos(\phi)\right]}{\left(\frac{2\pi}{\lambda}\frac{w_n}{2}\right)\cos(\phi)} \tag{5d}$$

If Eq. (5a) is expanded and the real and imaginary parts are separated, Eq. (5e) is obtained as

$$\begin{aligned} P = \operatorname{Re}\{E_{\phi,SR}\} = {} & \frac{\sin\left[\left(\frac{\pi l_6}{\lambda}\right)\cos(\theta)\right]}{l_6 \cos(\theta)} \cos\left[\frac{10\pi d}{\lambda}\sin(\theta)\right] + \frac{\sin\left[\left(\frac{\pi l_5}{\lambda}\right)\cos(\theta)\right]}{l_5 \cos(\theta)} \cos\left[\frac{8\pi d}{\lambda}\sin(\theta)\right] + \\ & \frac{\sin\left[\left(\frac{\pi l_4}{\lambda}\right)\cos(\theta)\right]}{l_4 \cos(\theta)} \cos\left[\frac{6\pi d}{\lambda}\sin(\theta)\right] - \frac{\sin\left[\left(\frac{\pi l_3}{\lambda}\right)\cos(\theta)\right]}{l_3 \cos(\theta)} \cos\left[\frac{4\pi d}{\lambda}\sin(\theta)\right] - \\ & \frac{\sin\left[\left(\frac{\pi l_2}{\lambda}\right)\cos(\theta)\right]}{l_2 \cos(\theta)} \cos\left[\frac{2\pi d}{\lambda}\sin(\theta)\right] - \frac{\sin\left[\left(\frac{\pi l_1}{\lambda}\right)\cos(\theta)\right]}{l_1 \cos(\theta)} \end{aligned} \tag{5e}$$

$$\begin{aligned} Q = \operatorname{Im}\{E_{\phi,SR}\} = {} & \frac{\sin\left[\left(\frac{\pi l_6}{\lambda}\right)\cos(\theta)\right]}{l_6 \cos(\theta)} \sin\left[\frac{10\pi d}{\lambda}\sin(\theta)\right] + \frac{\sin\left[\left(\frac{\pi l_5}{\lambda}\right)\cos(\theta)\right]}{l_5 \cos(\theta)} \sin\left[\frac{8\pi d}{\lambda}\sin(\theta)\right] + \\ & \frac{\sin\left[\left(\frac{\pi l_4}{\lambda}\right)\cos(\theta)\right]}{l_4 \cos(\theta)} \sin\left[\frac{6\pi d}{\lambda}\sin(\theta)\right] - \frac{\sin\left[\left(\frac{\pi l_3}{\lambda}\right)\cos(\theta)\right]}{l_3 \cos(\theta)} \sin\left[\frac{4\pi d}{\lambda}\sin(\theta)\right] - \\ & \frac{\sin\left[\left(\frac{\pi l_2}{\lambda}\right)\cos(\theta)\right]}{l_2 \cos(\theta)} \sin\left[\frac{2\pi d}{\lambda}\sin(\theta)\right] - \frac{\sin\left[\left(\frac{\pi l_1}{\lambda}\right)\cos(\theta)\right]}{l_1 \cos(\theta)} \end{aligned} \tag*{5f)}$$

Each term of Eq. (4) is substituted by *U, V, X, and Y*, respectively, so that Eq. (5f) is obtained as,

$$\begin{aligned} U &= \cos\left[\left(\frac{2\pi}{\lambda}\times ad_x\right)\sin\theta\cos\phi\right] \\ V &= \sin\left[\left(\frac{2\pi}{\lambda}\times ad_x\right)\sin\theta\cos\phi\right] \\ X &= \cos\left[\left(\frac{2\pi}{\lambda}\times bd_y\right)\sin\theta\sin\phi\right] \\ Y &= \sin\left[\left(\frac{2\pi}{\lambda}\times bd_y\right)\sin\theta\sin\phi\right] \end{aligned} \tag{5g}$$

Furthermore, Eq. (3) and Eq. (4) can be expressed as,

$$AF(\theta,\phi) = 4\times(P+jQ)^2\times(U+jV)\times(X+jY) \tag{6}$$

The expansion of Eq. (6) gives Eq. (7) :

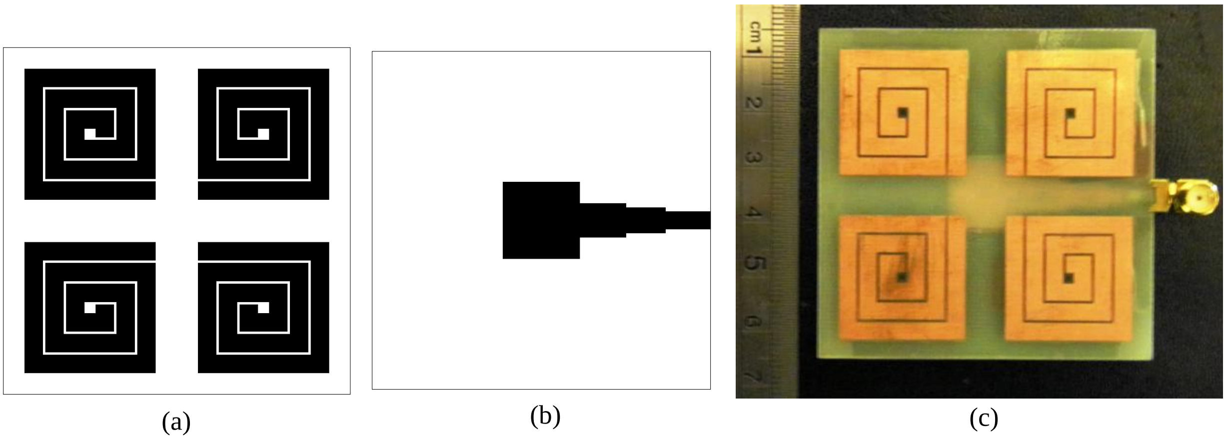
$$AF(\theta,\phi) = 4\times\left[\begin{pmatrix} P^2UX + Q^2UX - P^2VY - \\ Q^2VY - 2PQUY - 2PQVX \end{pmatrix} + j\begin{pmatrix} P^2UY + Q^2UY + P^2VX + \\ Q^2VX + 2PQUX + 2PQVY \end{pmatrix}\right] \tag{7a}$$

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

From Eq. (7a) and Eq. (7b), the radiation pattern of the *2x2* planar array of the SR structure can be calculated.

2.2 Desain and Implementation

As discussed in [11], the dimensions of the single patch of the SR structure are 22.6 x 22.6 mm, which is formed by the spiral turn number of $N = 3$, with a strip width $w = 3.1$ mm, gap width $s = 0.5$ mm, and inner radius of 1 mm. By using the dimensions of the single patch of the SR structure, the SR structure is arrayed into a *2x2* planar array with the distance of each patch = 7.4 mm. Therefore, the dimension of the antenna array becomes 52.6 x 52.6 mm, and by using Eq. (3) in Eq. (7), the radiation–pattern characteristic of the *2x2* planar array of the SR structure is calculated. To simulate the *2x2* planar array of the SR structure, an electro-magnetically coupled (EMC) feed system is used for the FR4 substrate, with a thickness of 1.6 mm, $\varepsilon_r = 4$ and $\mu_r = 1$ as shown in Figure 3. Desain of *2 x 2* planar array SR shaped structure is also fabricated on the same material with simulation, which used FR4 substrate, with a thickness of 1.6 mm, $\varepsilon_r = 4$ and $\mu_r = 1$ as shown in Figure 3(c).



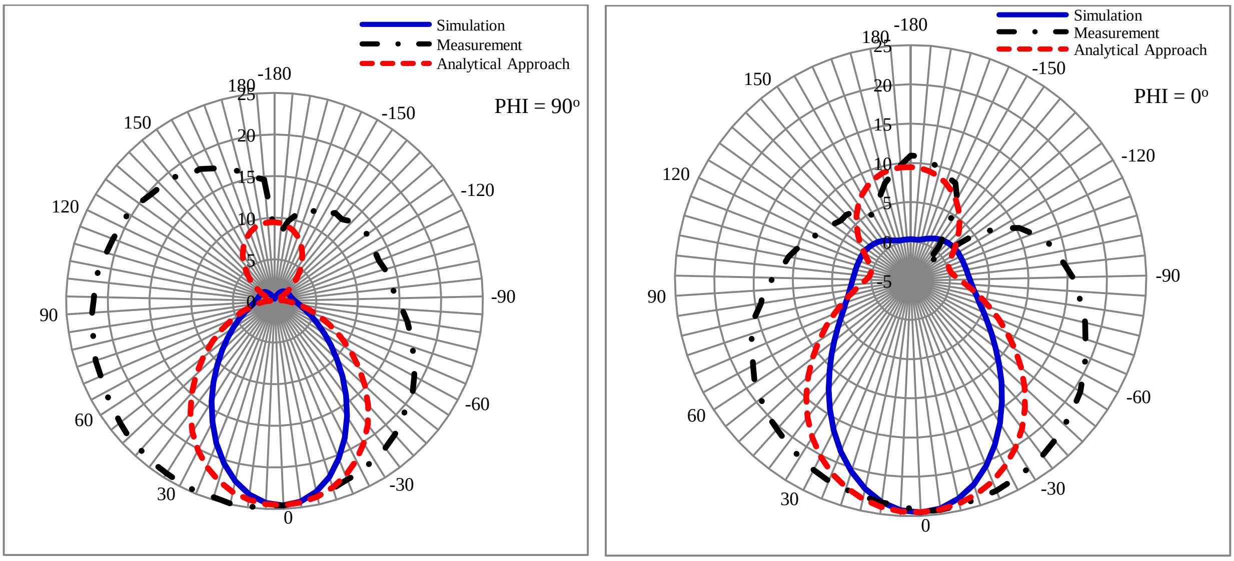
(a) (b) (c)

Figure 3: *2x2* planar array of the SR structure with EMC Feeding : (a) radiator, (b) feeder; (c) realized antenna

Based on the design above, *2 x 2* planar array SR shaped antennas are characterized by using software simulation to obtain the radiation pattern. While to verify the simulation results, designed 2 x 2 planar array SR shaped antennas are fabricated on 2 layers of 1.6 mm thick FR4 epoxy dielectric substrate. Both layers are then stacked each other and tight in such a way to avoid any gap between them.

3. Result and Discussion

The calculation, simulation, and measurement results are shown in Figure 5. The radiation pattern obtained using the planar array approach is similar in the boresight and backlobe directions compared to the simulation and measurement results. However, both analytical approach and simulation results slightly differ to the measurement result at the sidelobe direction. The maximum radiation-pattern that obtained from the planar array approach, simulation, and mesurement at boresight direction are 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. Meanwhile, the radiation pattern at backlobe direction is 9.46 V/m from planar array approach, 0.27 V/m from simulation, and 9.76 V/m from measurement.



(b)

(a)

Figure 5: Comparison of the radiation pattern between analytical approach, simulation and measurement of *2x2* planar array SR shaped : (a) *xz* plane; (b) *yz* plane

4. Conclusion

The analytical approach of *2 x 2* planar array SR shaped that implemented as an Antenna has been presented. *2 x 2* planar array SR shaped structure have also been characterized using 3D simulation software and fabricated and measured to compare with the analytical approach. The analytical approach of *2 x 2* planar array SR shaped structure has had similar graph with the simulation and measurement at the boresight and backlobe directions. However, both analytical approach and simulation results slightly differ to the measurement result at the sidelobe direction. The maximum radiation-pattern that obtained from the planar array approach, simulation, and mesurement at boresight direction are 24.54 V/m, 24.56 V/m, and 24.49 V/m, respectively. Meanwhile, the radiation pattern at backlobe direction is 9.46 V/m from planar array approach, 0.27 V/m from simulation, and 9.76 V/m from measurement.

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