Radiation Pattern Characterization of Single Patch Spiral Resonator (SR) Structure Using Linear Array Approach

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***Abstract* – Spiral resonator (SR) structure is used in many microstrip antenna design due to its unique properties, such as negative permeability value as an artificial magnetic inclusion. This paper present the formulation of the radiation pattern of the microstrip antenna with single patch SR shaped structure using linear array model of *n* nonisotropic similar point sources. The linear array is assumed by modeling of each stripline of the spiral with length *l* and width *w* as a nonisotropic point source. The result of this approach is compared to the simulation result through CST software and it shows the similarity between both results for the same *N*. Moreover, with both *w* and *s* are constant; the radiation level tends to increase with the increasement of *N*.**

Keywords : Spiral Resonator; Radiation Pattern; Linear Array Approach

I. INTRODUCTION

Mobile communication needs portable device with characteristics such as compact, light and small size. To achieve this requirement, many research on size reduction of microstrip antanna has been conducted such as [1]–[2]. Commonly, the dimensional miniaturization of the microstrip antenna has been done by using the high permitivity substrate. However, if the high permitivity substrate is used to design microstrip antenna, this will increase the surface wave which will impact to the reduction of gain, efficiency, and bandwidth parameters. To solve these problems, the negative permeability or Miu Negative (MNG) material is used to design the microstrip antenna. MNG material has unique properties, such as no wave absorbsion or transmission in this material, so that it is suitable used to miniaturize the micostrip antenna dimension. Generally, the MNG microstructure is shaped as split ring resonator (SRR) or spiral resonator (SR), both are the artificial magnetic inclusion [3]–[4]. The SR structure is better than the SRR due to dimensional reduction. Bilotti [5]–[6] has presented the lumped element model to calculate the *R*, *L*, *C* calculation of SRR and SR structures and give the *L*, *C*, and resonance frequency values to the variation of the spiral turn number *N*. However, these model can not be used to calculate and predict the radiation pattern. Therefore, this paper discusses the formulation of the radiation pattern of the microstrip antenna with single patch SR shaped structure as linear array approach.

II. SR LOOP PLANAR STRUCTURE

To derive the radiation pattern formulation, consider the single patch SR structure with *N* loop as shown in Fig. 1(a). This structure is assumed as a planar loop that has a continuous path. The single patch SR structure is a square loop with the length of each stripline l_n, where *n* is the number of stripline as nonisotropic similar point sources, *N* is total amount of the spiral turn, *w* is the stripline width, and *s* is a gap between stripline. Therefore, using *N* variation and *w*, *s*, and inner radius parameters that defined constant, the different length of each stripline due to inward turning of spiral can be calculated. For the linearly array model, *s* is assumed to be equally distant. For further analysis, the planar loop as shown in Fig. 1(a) can be assumed geometrically as linear arrays of *n* nonisotropic similar point sources at the *X-Z* or *Y-Z* plane and the vector addition of *E* field as shown in Fig. 1(b) and Fig. 1(c), respectively. The length of stripline at the *X-Z* plane can be calculated as $l_1 = 5(w + s)$, $l_2 = 3(w + s)$, $l_3 = (w + s)$, $l_4 = l_3 + (w + s)$, $l_5 = l_4 + 2(w + s)$, $l_6 = l_5 + 2(w + s)$; while at the *Y-Z* plane one is $l_1 = 6(w + s)$, $l_2 = 4(w + s)$, $l_3 = 2(w + s)$, $l_4 = l_3 + (w + s)$, $l_5 = l_4 + 2(w + s)$, $l_6 = l_5 + (w + s)$.

Consider to substitute the slot line [7] with the stripline, the radiation pattern can be formulated as

$$E_\phi = I_0 \frac{\sin\left[\left(\frac{2\pi}{\lambda}\frac{l}{2}\right)\cos(\theta)\right]}{\left(\frac{2\pi}{\lambda}\frac{l_1}{2}\right)\cos(\theta)} \;;$$

$$E_\theta = I_0 \frac{\sin\left[\left(\frac{2\pi}{\lambda}\frac{w}{2}\right)\cos(\phi)\right]}{\left(\frac{2\pi}{\lambda}\frac{w_1}{2}\right)\cos(\phi)} \qquad (1)$$

If the (1) is applied to Fig. 1, then the n^{th} stripline *E* is :

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

$$E_{\theta 0n} = I_0 \frac{\sin\left[\left(\frac{2\pi}{\lambda}\frac{w_n}{2}\right)\cos(\phi)\right]}{\left(\frac{2\pi}{\lambda}\frac{w_n}{2}\right)\cos(\phi)} \qquad (2)$$

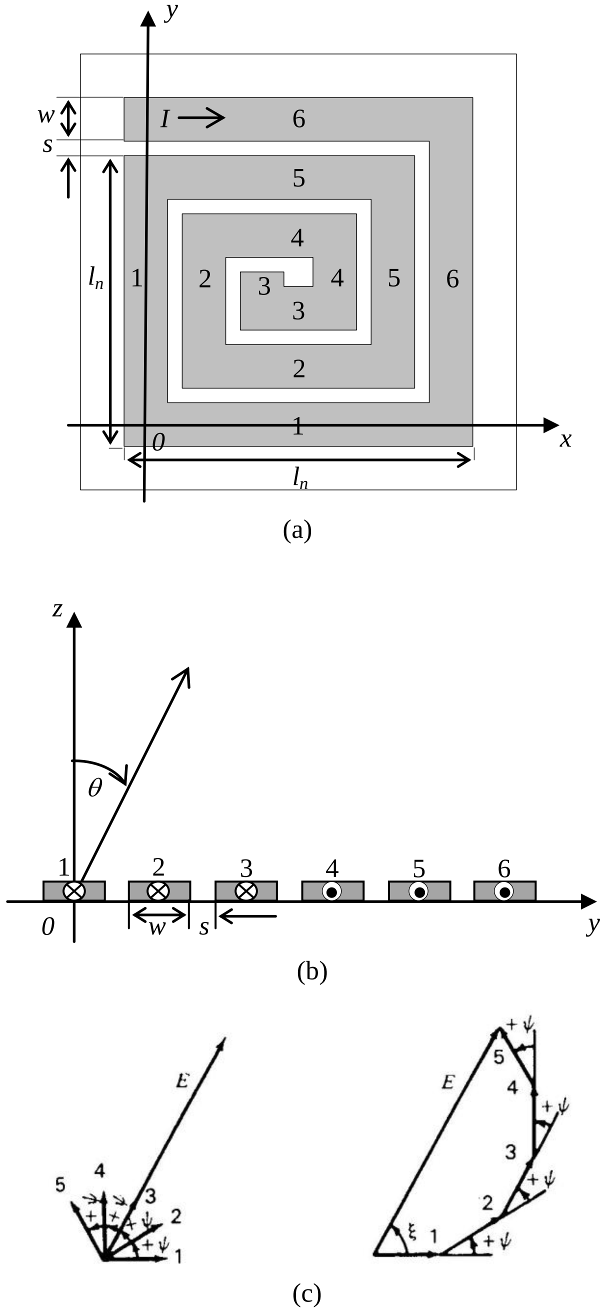


Fig. 1 (a) Single Patch SR Structure as a Continuous Loop (N=3, w=3 mm, s=1 mm, inner radius 1 mm); (b) Linear Array of Six Nonisotropic Similar Point Sources for X-Z or Y-Z Plane; (c) Vector Addition of E Field for n=5 [8]

According to the electric current direction at each stripline, the electric current at the 1^{st} up to 3^{rd} striplines are opposite with the electric current at the 4^{th} up to 6^{th} striplines. If the electric current at the 4^{th} up to 6^{th} striplines are positive, then the electric current at the 1^{st} up to 3^{rd} striplines are negative.

The radiation pattern of each nonisotropic point source can be formulated :

$$\begin{aligned} E_{\phi n} &= -E_{\phi 0n} e^{j(n-1)\psi} \; ; \; 1 \le n \le N \; ; \\ E_{\phi n} &= +E_{\phi 0n} e^{j(n-1)\psi} \; ; \; N < n \le 2N \\ E_{\theta n} &= -E_{\theta 0n} e^{j(n-1)\psi} \; ; \; 1 \le n \le N \; ; \\ E_{\theta n} &= +E_{\theta 0n} e^{j(n-1)\psi} \; ; \; N < n \le 2N \end{aligned} \qquad (3)$$

where :

$$\psi = \frac{2\pi d}{\lambda}\sin\theta \; ; d = s = 0.5mm \; ; N \ge 2 \qquad (4)$$

The radiation pattern of linear array of nonisotropic similar point sources is the product of the pattern of the individual source and the pattern of linear array of isotropic point sources, having the same locations, relative amplitudes and phases as the nonisotropic point sources. The individual nonisotropic source or antenna may be of finite size but can be considered as a point source situated at the point in the antenna to which phase is referred. Therefore, the total radiation pattern of the single patch SR structure can be formulated :

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

If the (2) to (4) are applied to the (5), and by splitting its real and imaginary parts, then the radiation pattern of $E_{\phi,SR}$ and $E_{\theta,SR}$ can be solved.

III. Results And Discussion

For the comparison of the radiation pattern between the simulation and the linear array approach, the microstrip antenna with single patch SR structure is designed at FR4 substrate with thickness 1.6 mm, ε_r = 4.3 and μ_r = 1. The microstrip antenna is designed without the ground plane for both the simulation and linear array approach. The single patch SR characteristic due to the variation of w and s parameters through CST simulation is shown in Table 1 and Fig. 2. The parameter variation of w and s shows similar radiation pattern, with a slight difference of amplitude level of the E field.

TABLE I. SINGLE PATCH SR CHARACTERISTICS USING CST SIMULATOR WITH *W* AND *S* VARIATIONS

Parameters	Single Patch SR, *N* = 3							
	w= 3	*s*= 1	*w*= 3	*s*= 2	*w*= 2	*s*= 3	*w*= 2.5	*s*= 2.5
Freq (GHz)	2.325		2.175		2.400		2.290	
S_{11} (dB)	–23		–25		–25		–25	
BW (MHz)	150		181		251		215	
E (V/m)	4.3		4.1		4.5		3.8	
Pattern	Similar							

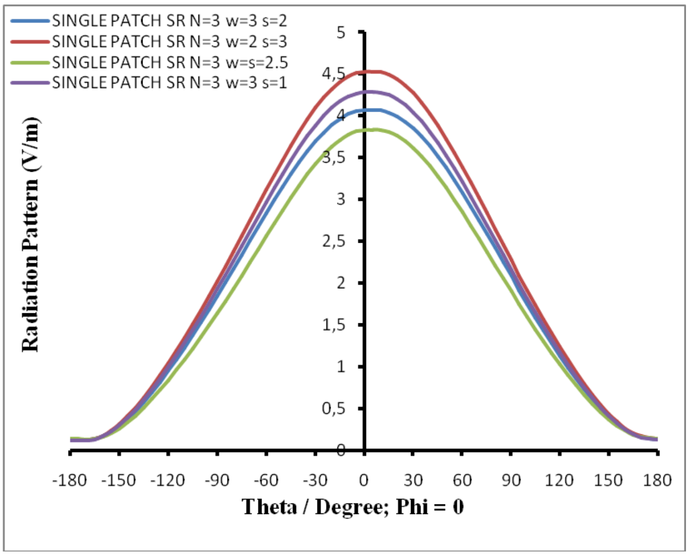
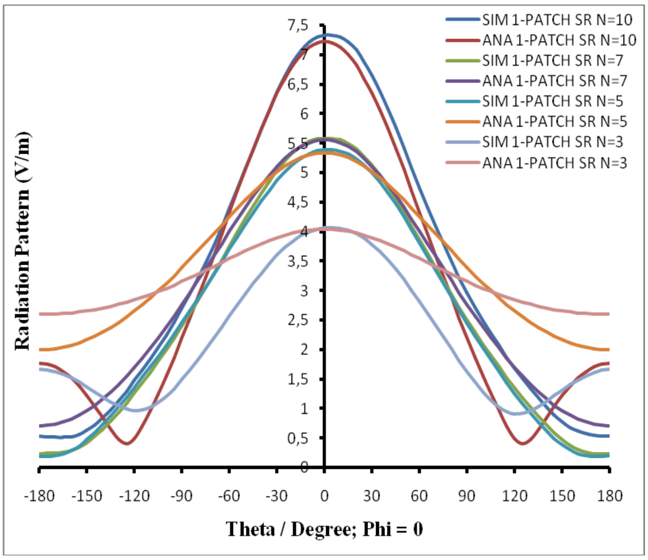
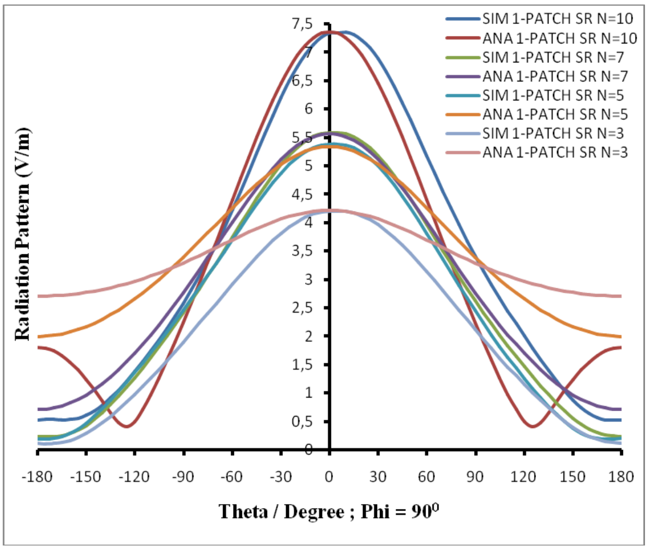


Fig. 2 Radiation Pattern of Single Pacth SR with *w* and *s* Variation Using CST Simulation

Figure 3 shows the radiation pattern for *w* = 3 mm and *s* = 1 mm. The radiation pattern is obtained by using CST simulation and linear array approch from (5). The simulation results using CST software are compared to the achieved result of the absolut values from linear array approach as shown in Fig. 3 (a) for *X-Z* plane and Fig. 3 (b) for *Y-Z* plane. The radiation pattern using linear array approach has the similarity with the radiation pattern using the CST simulation for the same *N* at boresight direction. The radiation level tends to increase with the increasement of *N* for both approaches. The difference at the sidelobes occur due to the different method between CST simulation and linear array approach. The radiation pattern simulated with CST Studio Suite uses the finite difference time domain (FDTD) with finite integration technique (FIT) algorithm and cartesian mesh but with much improved PBA (perfect boundary approximation), whereas the calculation of the radiation pattern proposed uses the linear array of point source method. Table 2 shows the difference value of the side lobe level between CST simulation and linear array approach from $\pm 90^0$ to $\pm 180^0$. From Table 2, the minimum average value difference occurs for *N* = 7. Therefore with the increasement of N, it does not show a more accurate sidelobe level of radiation pattern. Thus, the proposed linear array approach can be used as an alternative method to solve the radiation pattern problem of the microstrip antenna with single patch spiral resonator structure.



(a)



(b)

Fig. 3 Comparation of Radiation Pattern Between Linear Array Approach and Simulation Results: (a) *X-Z* Plane; (b) *Y-Z* Plane

TABLE II. LEVEL DIFFERENCE OF RADIATION PATTERN BETWEEN CST SIMULATION AND LINEAR ARRAY APPROACH

Theta/ Degree	Level Difference of Radiation Pattern				
	N = 3	*N* = 5	*N* = 7	*N* = 10	*N* = 12
±180	2.5967	1.8013	0.4705	1.2794	2,2277
±170	2.6058	1.8159	0.4976	1.2096	2,0837
±160	2.5779	1.7890	0.5380	1.0098	1,7645
±150	2.4850	1.6969	0.5392	0.6346	1,2631
±140	2.3473	1.5707	0.5079	0.0730	0,5804
±130	2.1811	1.4333	0.4666	0.5689	0,2538
±120	1.9969	1.2973	0.4281	0.8762	1,1614
±110	1.8018	1.1685	0.3973	0.7611	1,7055
±100	1.6007	1.0473	0.3738	0.5562	1,4581
±90	1.3964	0.9305	0.3539	0.3377	1,0985
Average Value Difference	2.1590	1.4551	0.4573	0.7306	1,4187

IV. CONCLUSIONS

The radiation pattern characteristics of single patch SR structure have been studied using linear array approach synthesis. The computation results have been verified by simulation using CST Microwave Studio which shows good agreement. Therefore, this approach can be used as the alternative method to provide field pattern.

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