SRR Inspired Microstrip Patch Antenna Array

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Abstract—This paper presents a novel approach for bandwidth enhancement and gain improvement of a microstrip patch antenna array for IEEE 802.16a 5.8 GHz Wi-MAX applications. A split ring resonator (SRR) has been designed to load the microstrip patch antenna array. The unloaded antenna array resonates at 5.8 GHz with gain of 4.3 dBi and bandwidth of 425 MHz, whereas when loaded with split ring resonator the gain approaches to 5.7 dBi and bandwidth increases to 610 MHz which corresponds to bandwidth enhancement of 3%. The electrical dimension of the patch is $0.23\lambda \times 0.3\lambda$.

1. INTRODUCTION

Recently, there has been a great demand of compact antennas in RF communication systems and handheld devices to transfer voice, data and multimedia information at very high data rates. Additionally, these antennas should also have high gain, wide bandwidth. Microstrip patch antennas are best suited for such applications, as they possess all the above mentioned properties, along with low fabrication cost. However, there exists some electromagnetic mutual coupling between the patches of the array due to the presence of surface waves, which results in severe degradation in antenna parameters such as radiation characteristics, bandwidth, gain, errors in beam forming, scanning, etc. [1, 2]. To achieve low mutual coupling between closely spaced antenna elements is quite difficult. However, various strategies have been applied to reduce the same. Some of the most common methods are moving the antennas with different orientations around the printed circuit board [3, 4], use of defected ground structures [5, 6], insertion of slots [7], electromagnetic band-gap structures [8–10], parasitic elements between the antennas [11], tilting the patch elements along the elevation [12], etc. As discussed in [3, 4], best isolation is achieved when the antennas are spaced by the largest available distance on the PCB, but it results in increased size. In [5], Ismaiel et al. used meander shaped defective ground structure to reduce the mutual coupling. This method efficiently reduces the mutual coupling, but also distorts the radiation pattern to some extent. Mukherjee et al. in [6] proposed split ring shaped defective ground plane. The reduction in mutual coupling was significant but optimization technique required for locating the two ports is quite cumbersome. Ou Yang et al. inserted a slot in the ground plane. This technique reduced the mutual coupling but also changed the radiation pattern at rear side [7]. Ebadi, in [8], placed 4×28 array of mushroom-like EBG structures over the radiating face of a 2×4 waveguide-slot-array antenna. The technique successfully reduced the mutual coupling but these structures are complex in nature, and their optimum designs are difficult to achieve and fabricate. A simple structure composed of two parasitic elements is presented in [11]. The difficulty with that scheme is that it needs an additional layer, along with metalized holes for grounding. In [12], Ibraheam et al. tilted the patch elements along the elevation to reduce the mutual coupling between elements. Though this method provided good results, but the structure is quite difficult to implement as precise tilting is required. In [13], Dossche et al. used 180° hybrid couplers to isolate highly coupled monopole antenna elements. This mechanism unnecessarily increases the hardware cost.

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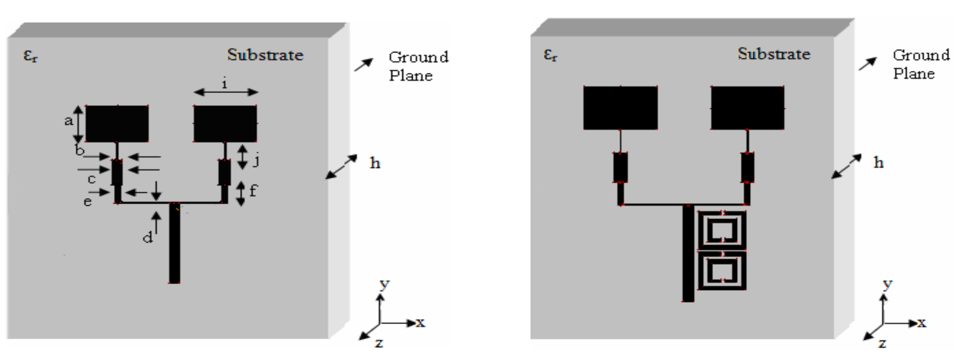
Hence it is observed that even today, to establish a proficient mutual coupling reduction technique while conserving the radiation properties is a highly challenging task. Since the introduction of the novel man-made structure called metamaterial, the electromagnetic researcher community has made use of them in antenna design, as their use is found to be an advantageous approach to overcome these limitations. Metamaterial inclusions, such as square SRR, circular SRR, MSRR, labyrinth etc., are directly used as loading elements for size reduction, mutual coupling reduction, enhancement in bandwidth and gain etc.. Metamaterials are the composite structures of periodically arranged split ring resonators (SRRs) and thin wires elements to generate negative permeability and permittivity. Therefore these materials possess negative refractive index and hence, they are also known as double negative materials (DNG) or negative index materials (NIM). Metamaterials can suppress electromagnetic wave propagation in certain frequency band [14]. Therefore, this type of material can reduce the mutual coupling between the elements in the array antenna due to suppressing the surface wave propagation.

The objective of this work is to load the conventional microstrip antenna array with a metamaterial inclusion and to compare the performance of these two arrays. For this purpose, a split ring resonator has been designed to decrease the mutual coupling between the elements of the microstrip antenna arrays. The proposed SRR is used to load the antenna array. This technique did not add any extra hardware and hence cost to the conventional array, which is the one of the novel feature of this work. Presented simulation results are obtained with the method of moment based full wave IE3D electromagnetic simulator. The performance comparison of the proposed loaded antenna array and conventional unloaded antenna array show that metamaterial has a good potential to improve the mutual coupling between the elements of the array.

2. ANTENNA ARRAY DESIGN

Figure 1(a) shows the geometrical structure of a two-element conventional antenna array whereas, and Figure 1(b) depicts the antenna array loaded with split ring resonator. The proposed antenna array, resonating at frequency (f_0) of 5.8 GHz, is designed on an FR-4 substrate of thickness (h) = 1.48 mm, dielectric constant (ε_r) = 4.3 and loss tangent = 0.01. 50 Ω SMA coaxial connector is used to feed the array. The width (W) and length (L) of patch, as calculated using the transmission line model equations [14], are 15.88 mm and 11.95 mm, respectively. Thus the aspect ratio (L/W) of the patch is 0.75. Table 1 shows the various dimensions of the proposed antenna array. The resonant input resistance of the rectangular patch antenna, as calculated from [14], is 238.5 Ω. The corporate feed network is used to edge feed the elements of the array. The spacing between the two patches of the antenna array is 0.96 ($\lambda_g/2$), where λ_g is the guided wavelength. This type of feeding network provides power split using quarter wave impedance transformer [15]. A quarter wave transformer of 109.2 Ω is used for matching the rectangular patch with 50 Ω line. The width (w) of this quarter wave transformer and 50 Ω transmission line, as calculated from [15], is 0.5237 mm and 2.8758 mm, respectively. The length of quarter wave transformer is calculated as 7.55 mm. The dimensions of the substrate are



(a) (b)

Figure 1. Geometrical sketch of (a) 2-element antenna array, (b) proposed antenna array loaded with SRRs.

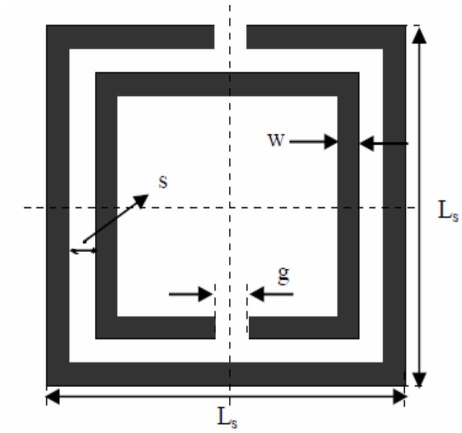
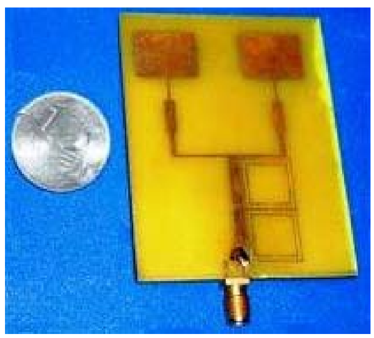


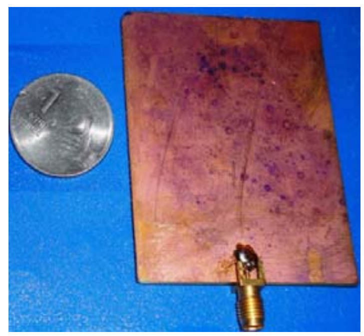
Figure 2. Geometrical structure of square SRR.

Parameters	Dimensions (mm)
a	11.95
b	0.5237
c	2.8758
d	0.5237
e	1.38
f	7.55
i	15.88
j	7.55
h	1.48

Table 1. Dimensions of proposed antenna array.



(a)



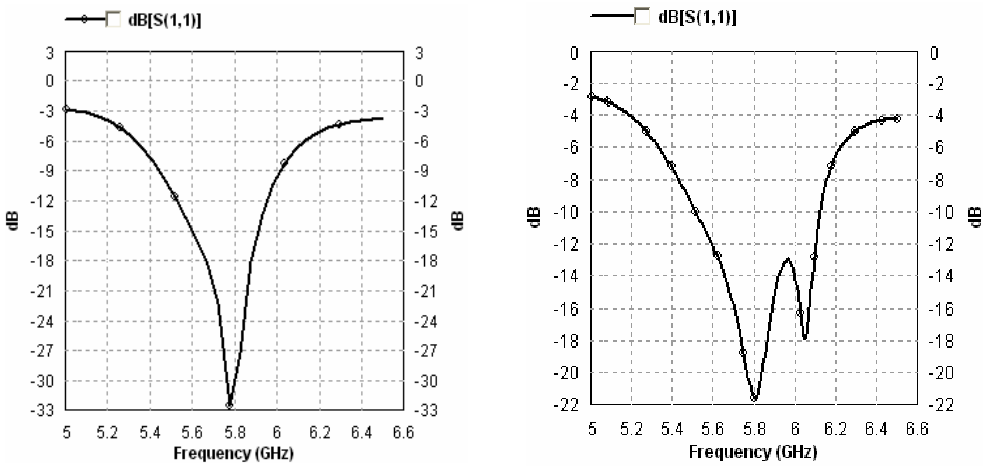
(b)

Figure 3. Photographs of fabricated SRR loaded microstrip patch antenna array. (a) Radiating patch. (b) Ground plane.

52.5 mm × 67.1 mm. The length of the feeding strip is 26 mm and the driven parts are 26.98 mm apart from each other. Figure 2 presents the structure of SRR, the pair of which is integrated into the array in such a way that it do not increase the overall size of the proposed antenna array, that is, the dimensions of loaded as well as unloaded antenna are same. The geometrical dimensions of the SRR unit cell are; length of outer split ring $L_s = 12.50$ mm, width of rings $(w) = 0.2$ mm, gap at split of rings $(g) = 0.2$ mm and separation between inner and outer split rings (s) is set to as 1 mm. The distance between feeding network and SRR unit cell is 0.5 mm in both vertical as well as horizontal direction. The spacing between two SRRs is fixed at 0.1 mm. Figure 3 shows the fabricated antenna array loaded with the pair of SSRs. Method of moment based IE3D electromagnetic simulator is used to simulate this antenna array, and equivalent circuit based theory is developed. The antenna measurements are done to validate the theoretical and simulated results.

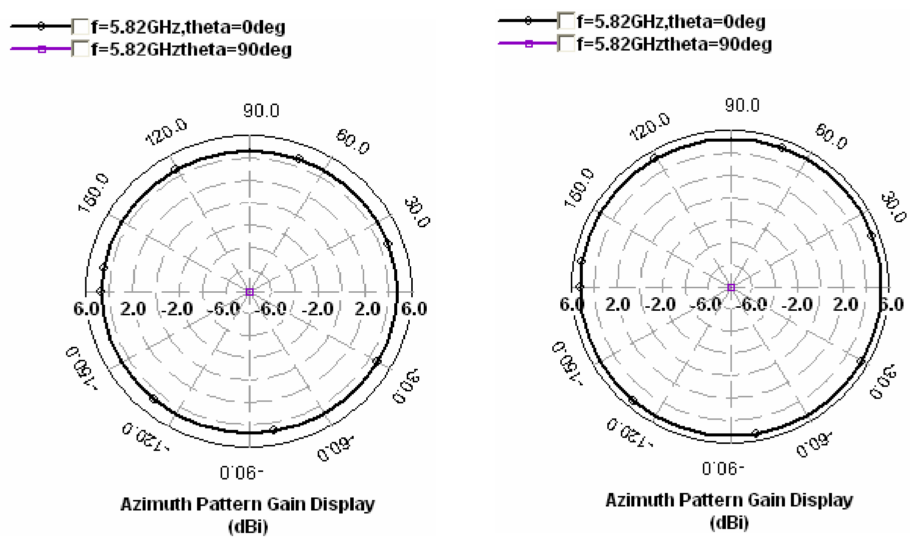
3. RESULTS AND DISCUSSION

In this section, the simulated and measured results of the proposed antenna array in loaded as well as in unloaded conditions are presented. Figure 4 depicts the simulated return loss characteristics of the proposed array under both loaded and unloaded conditions. It is observed that the unloaded antenna array resonates at 5.8 GHz with bandwidth of 425 MHz, whereas, when the proposed array is loaded with two square SRRs, the bandwidth increases to 610 MHz at the same resonant frequency, thus corresponding to the bandwidth improvement of 3%. The dimensions of the array under both the conditions are same. Thus the bandwidth has improved at no extra hardware cost. Figures 5 and 6 represent azimuth plane and elevation plane radiation pattern characteristics of loaded and unloaded



(a) (b)

Figure 4. S_{11} characteristics of (a) unloaded antenna array (b) SRR loaded proposed antenna array.



(a) (b)

Figure 5. Azimuth plane radiation pattern characteristics of (a) unloaded antenna array (b) proposed loaded antenna array.

antenna array. As observed from Figure 5, the antenna array resonates with gain of 4.3 dBi under unloaded conditions and when the same array is loaded with split ring resonators, gain increases to 5.7 dBi. Moreover, significant improvement is also observed in elevation plane radiation pattern of the SRR loaded array. However, a dip in the elevation plane radiation pattern is observed due to the excitation of the some spurious modes on patch conductor. Figure 7 presents an inset photograph of experimental set up to measure the return loss of the fabricated SRR loaded antenna array. Bird site analyzer® Model No. SA-6000 EX, frequency range 25 MHz to 6 GHz is used to test this antenna. Figure 8 depicts the measured return loss characteristics of the loaded antenna array, obtained by zooming Figure 7. It is observed antenna array is resonating at 5.8 GHz with bandwidth of about 600 MHz. Figure 9 shows the comparison between the simulated and measured return loss characteristics of the SRR loaded antenna array. Thus it is observed that both the results are in good agreement with each other. However, some change in shape of two curves is due to the inaccuracy in fabrication and use of FR-4 substrate, which is lossy in nature but quite cheap, and hence suitable for making the prototype.

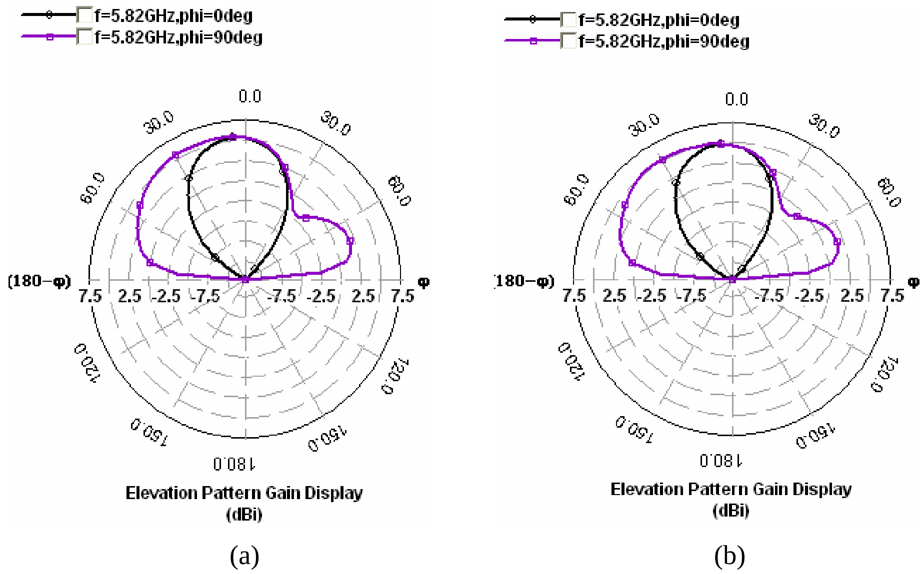


Figure 6. Elevation plane radiation pattern characteristics of (a) unloaded antenna array (b) proposed SRR loaded antenna array.

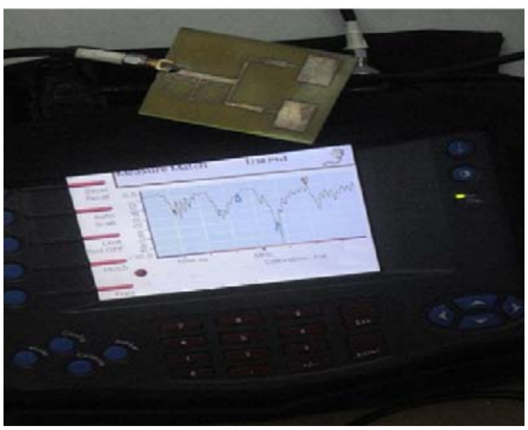


Figure 7. Photograph of the experimental set up to measure the return loss of the proposed SRR loaded antenna array.

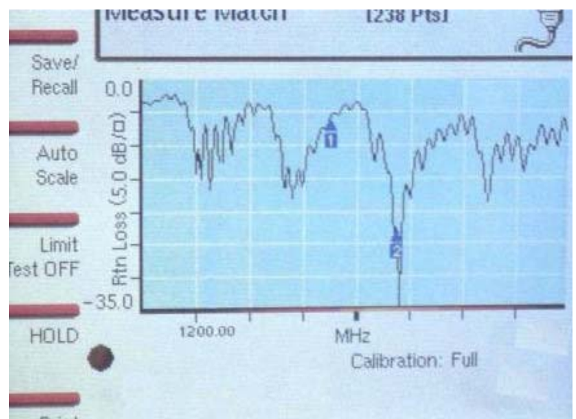


Figure 8. Measured S_{11} of the loaded array obtained by zooming Figure 7.

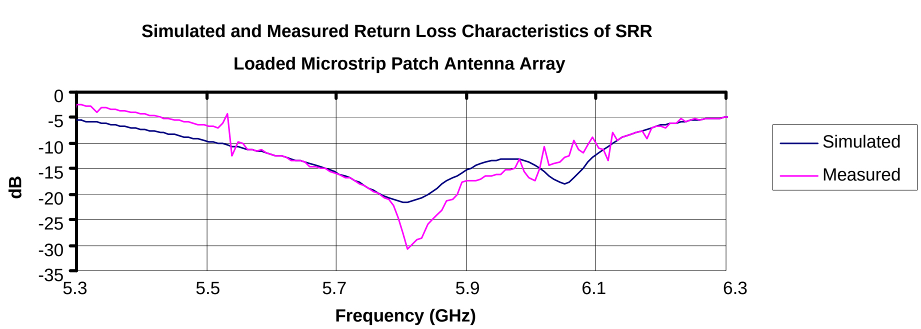


Figure 9. Comparison between simulated and measured return loss characteristics of SRR loaded microstrip patch antenna array.

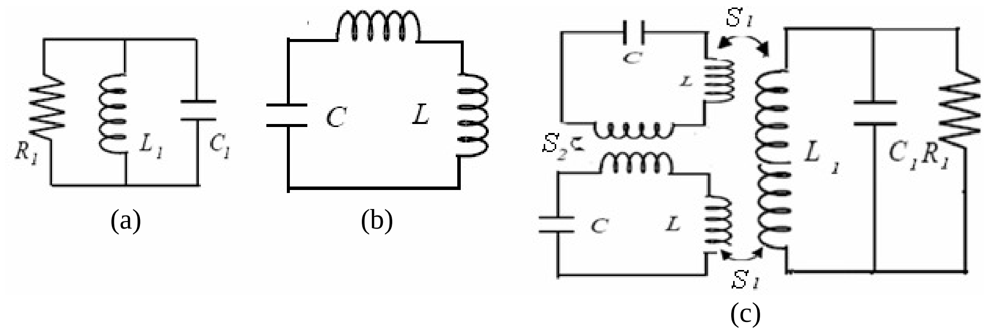


Figure 10. Equivalent circuit of (a) microstrip patch antenna, (b) SRR, (c) proposed antenna array.

4. EQUIVALENT CIRCUIT ANALYSIS AND THEORETICAL DISCUSSION

Figure 10 depicts the equivalent circuit of (a) microstrip patch antenna (b) SRR (c) proposed antenna array. According to the principles of equivalent theory, the SRR can be modeled as a LC resonant circuit. The values of L and C (which are equivalent inductance and capacitance of SRR, respectively) are calculated using Equations (1) and (2) [16].

$$L = \frac{\mu_0}{2}\frac{L_{savg}}{4}4.86\left[\ln\frac{0.98}{\rho} + 1.84\rho\right] \tag{1}$$

where, μ_0 is the permeability of free space, ρ the filling ratio, L_{savg} the average length of the square SRR, which is given as $L_{savg} = 4[L_s - (N-1)(w+s)]$, and N the number of split rings. S_1 represents the mutual inductance between microstrip patch antenna and SRR. The equivalent capacitance (C) of SRR is given as [16]

$$C = \varepsilon_0\varepsilon_r^{sub}\frac{N-1}{2}\left[2L_s - (2N-1)(w+s)\right]\frac{K\sqrt{1-k_1^2}}{K(k_1)} \tag{2}$$

where, ε_0 is the permittivity of free space, ε_r^{sub} the effective relative permittivity related to the dielectric filling the substrate, K the complete elliptic integral of first kind, and k_1 the argument of integral expressed as $(s/2)/(w+s/2)$. By using these mathematical equations the calculated values of equivalent circuit elements are inductance (L) = 83.38 nH and capacitance (C) = 0.095 nF. The values of L_1, C_1 and R_1 (which are equivalent inductance, capacitance and resistance of the patch antenna respectively) can also be calculated using various mathematical relations [17].

When SRR is placed in a varying magnetic field, a circular electric current is induced in the ring which causes charge accumulation across the gaps. The electric field produced by the charge at the gap counteracts the circular current leading to energy stored close to the gaps and magnetic field energy concentrated in the region enclosed by the ring. The SRR, thus, couples the perpendicular magnetic field and is characterized by the effective capacitance of the gaps and effective inductance of ring. When the conventional microstrip patch antenna array is loaded with SRRs, the time varying magnetic flux generated by the antenna induces current on SRRs. Hence SRRs get mutually coupled with each other and also with the patch antenna array. It results in large electric field across the gap capacitance at the splits and mutual capacitance between the split rings. This capacitance of SRR is sufficiently large to match with the inductance of the patch antenna array, which leads to the reduction in mutual coupling between the elements of the array. The mutual inductance between SRRs is calculated as $S_2 = 1.17$ nH using Equation (3) [18, 19].

$$M = \frac{\mu_0 L_s}{2\pi}\left[0.467 + \frac{0.059(w)^2}{L_s^2}\right] \tag{3}$$

Feed lines provide the coupling paths between array elements and the SRRs. These feed lines also act as the additional conducting strips to reduce the existing mutual coupling. This reduction in mutual coupling between the array elements results in gain and bandwidth enhancement of the proposed loaded array.

5. CONCLUSION

In this paper, a microstrip patch antenna array loaded with SRRs has been presented. The proposed antenna array can be used for IEEE 802.16a 5.8 GHz Wi-MAX applications. When the conventional microstrip patch antenna array is loaded with a pair of SRRs, gain improves by 1.4 dBi, and bandwidth enhances by 3%. Loading of SRR reduces the surface waves and mutual coupling between the elements of array. The advantage of this proposed antenna is that its performance gets improved at no extra size and cost. The performance comparison of the proposed loaded antenna array and conventional unloaded antenna array shows that metamaterial has a good potential to reduce the mutual coupling between the elements of the array.

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