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Interleaved Metallic Octagonal Structures for Low Frequency Applications

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Abstract: Interleave metallic structures that are used as the basic building blocks of active metamaterials with incorporated gain. The active split-ring resonator (aSRR) structures with gain elements can in theory have similar unusual electromagnetic responses such as negative effective permeability near their resonance of the artificial magnetic response just like their passive counterparts. At the same time a SRRs can have reversed imaginary part of the effective permeability and, therefore, mitigate the loss of passive SRRs. We explored in detail both passive and active SRRs through analytic theory, Broad research and development of microstrip antennas and arrays designed at exploiting their numerous advantages. Physical appearance of microstrip fabrication materials attract researchers because of the advantages like Light weight, low volume, low cost, conformal configuration and compatibility with integrated circuits. These antennas differ from conventional antennas as most of these antennas are constructed in which for a given substrate in the $x - y$ plane there is a freedom of allowing the printed conductor to take any shape with in the region that confine to the x & y coordinate system. Different impedance matching techniques, quality factor[1] and feeding techniques[2] were discussed by earlier researchers with a common limitation on the size and bandwidth of an antenna and improvement in one of the characteristic results in deterioration of the others. This paper defines the design, simulation and testing on the split ring octagonal patch to address the optimization on size and improving the band width so that it fits in to wireless applications. The proposed model is tested in the standard antenna test bench, and operates at a frequency of 1.314 GHz and offers good radiation characteristics. However, one fundamental drawback of the SRR based metamaterials is their intrinsic loss due to metals used for SRRs.

Keywords: Microstrip Patch Antenna, Wireless Applications, Impedance Matching, Vswr, Radiation.

1. INTRODUCTION

Broad research and development of microstrip antennas and arrays designed at exploiting their numerous advantages. Physical appearance of microstrip fabrication materials attract researchers because of the advantages like Light weight, low volume, low cost, conformal configuration and compatibility with integrated circuits. These antennas differ from conventional antennas as most of these antennas are constructed in which for a given substrate in the $x - y$ plane there is a freedom of allowing the printed conductor to take any shape with in the region that confine to the x & y coordinate system.

The patch conductor is normally of copper & gold and can take almost any shape but prediction and analysis of conventional shapes are a better choice. The patch can be of any geometric shape, but, the criteria of choosing a shape is independent to the frequency of operation.

In this paper, a patch with octagon structure is chosen to explore the structural advantage over other conventional shaped antennas. Apart from the structural representation the antenna parameters like radiation characteristics, effect of substrate thickness, size optimization, bandwidth and return loss are also studied.

2. SUBSTRATE CHOICE

A high performance FR4 substrate is chosen as it is capable of robust for standard processing, capable of lead free soldering, highly tensile. There are three categories of FR4[3] substrate materials that are available, and they are pure PTFE, Thermoset Hydrocarbon substrate, ceramic filled PTFE. The table below gives a comparison of all the three materials with respect to the dimensional stability, multi-layer fabrication and electrical performance.

Table 1
FR4 Material fabrication concern

	Dimensional stability	*Multilayer fabrication*	*Electrical performance*
Hi performance FR4	Very good	Robust	Poor
Pure FR4(nearly)	Poor	Difficult	Excellent
Ceramic filled PTFE	Good	Moderate	Very good
High frequency hydrocarbons	Very Good	Robust	Good

Though the electrical performance is slightly less, a hi performance FR4 or a ceramic filled PTFE material is generally chosen as their performance is well understood and comes at a relatively low cost. FR4 has a higher dissipation factor, which increases steadily with frequency the insertion loss also increases. Most high frequency laminate thickness tolerance is less than ±7%.

3. ANTENNA DESIGN CONCERNS

Out of the conventional models like rectangular, square, circle etc.. to operate at a resonant frequency (f_r) < 2 GHz. The proposed antenna is an octagonal geometry after theoretical calculation for identifying the length and width of a regular rectangle optimization techniques are used to match with the octagonal structure. The antenna is initially designed at 1.8 GHz with a dielectric constant (ξ_r) of 4.4 and a substrate thickness of 1.6 mm. The side length of the octagonal shape[4] is 1.9740cm, two such patches are placed 0.511 cm apart.

A split ring resonator [4] is capable in revelation of quasi-static resonant frequency at wave lengths larger than its own sizes. The split ring resonator has the possibility to reduce the size of the antenna. In a split ring resonator the small gap between the two rings has the ability to produce a high capacitance value which may possibly diminish the value of the resonance frequency. At the ring the magnetic flux that penetrates though will affect the current flow with in. if the distance between the rings is large, avoids current from flowing around in single ring and the circuit is completed across the insignificant capacitive gap between the rings.

Two ground planes of rectangular dimension 1.6867×2.1978 cms is taken on the same side of the patch thus representing the entire structure to be coplanar (CPW). The ground planes of significant dimensions are so chosen so as to reduce the ground plane effects. By placing the ground plane close to the radiating patch [5] the resonating frequency is shifted to below 2GHz.

The frequency shift is strongly dependent on the width of the feedline is 0.511 cm and the length of the feed line is 2.3096 cms. This feed line joins both the octagons together so that the power delivered through the feed will be equally distributed.

When iterating to a smaller scale from the initial sizes was carried out by obtaining various length and width calculations for the given resonant frequency. The final parameters that are obtained are in line to operate with the resonant frequency.

3.1. Setting up Waveport

An excitation source has been chosen to excite the structure. A wave port has been chosen as the principal mode of the microstrip line and hfss will use this field to stimulate entire structure. The wave port is to be defined properly so as to meet the design requirements because if the waveport[6] is too small the field will be truncated and when large a waveguide node will appear.

3.2. Radiation Box and Boundary Conditions

The model is to be placed in a radiation box filled will air as the medium inside the box, so that the radiation from the structure is absorbed and doesn't reflect back. The length of the radiation box is chosen to be longer than the quarter wavelength long of the desired operational frequency. The height of the radiation box is 50mm.

3.3. Quality Factor

The quality factor Q [2] is derived from antenna impedance

$$Q = \frac{\omega_0}{2R_0(\omega_0)} \left| Z_0'(\omega_0) \right| \tag{1}$$

where, R_0 is the real part of the impedance and Z_0' is the derivative part of the complex impedance. The associated maximum frequency bandwidth is given by

$$FBW = \frac{\sqrt[2]{\beta}}{Q} \text{ where } \sqrt{\beta} = \frac{S-1}{\sqrt[2]{S}} \leq 1 \tag{2}$$

The quality factor for a compact lossless radiating structure with a radius a is given by

$$Q_{min} = \frac{1}{k^3 a^3} + \frac{1}{ka} \tag{3}$$

It is observed that the antenna Q is much higher than the theoretical limit. The value of Q is inversely proportional to the size of the antenna. As the bandwidth is narrowing with the antenna miniaturization we can assume that the bandwidth is inversely proportional to the inverse of Q factor.

3.5. Influence of Antenna Volume on Bandwidth and Efficiency

Antennas having $a << a << \frac{\lambda_0}{2\pi}$ the fundamental frequency limits can be reduced to $\eta \times \frac{1}{Q} \approx ka^3$ where η being the fundamental frequency. This indicates that the quality factor, efficiency and antenna volume are linked.

Table 2
Length and Q comparison

Length	*Ka*	*η/Q(ka)³*	
		Simulated	*Measured*
0	0.77	0.042	0.040
50.5	0.6	0.024	0.022
79.5	0.37	0.032	0.034

Thus when then antenna size is reducing the calculated values seem to be more stable.

4. METHODS TO EVALUATE Q

There are two methods that are used to in evaluating Q of an antenna. In numerical method, the Q factor is measured using magnetic and electric fields in terms of stored energy and in analytical methods the radiated power can be expressed in terms of input impedance.

4.1. Analytical Approach

The expression that defines the radiated power [3] in terms of current and resistance is given by the following equation:

$$Q_{Exact} = \left| \frac{\omega_0}{2R_0\omega_0} X_0'(\theta_0) - \frac{2\omega_0}{|I_0|^2 R_0\omega_0} [W_L(\omega_0) + W_R(\omega_0)] \right| \tag{4}$$

From the above if the second term is deserted we obtain Q as

$$Q_{Exact} = \left| \frac{\omega_0}{2R_0\omega_0} X_0'(\omega_0) \right| \tag{5}$$

from this expression if there is slope of the reactance then there is a possibility that Q can become negative.

4.2. Numerical Approach

The numerical approach is based on FDTD method, in which all the energies that are stored even in the smallest circle or sphere are taken into account. The field components amplitude in each cell is taken into account.

A true value of Q is determined by the following

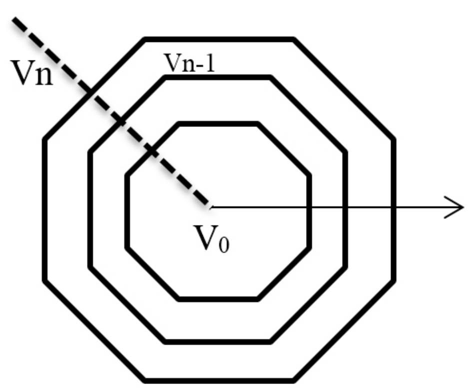

Figure 1: Method of computation

$$Q = \left| \frac{\omega W}{P_{Rad}} \right| \tag{6}$$

where, W is the average energy stored in an interval.

This method is suitable to design or calculate Q for complex antenna to a certain extent.

To compute the radiating Q we calculate the average total magnetic and electrical energies. The average energy stored is thus obtained by subtracting the total radiation energy away from the total energy which is given by

$$Q = \omega \frac{W_e^{tot} + W_m^{tot} - W_{Rad}^{tot}}{P_{rad}} \tag{7}$$

The quality factor can be easily calculated once the far field radiated power is acquired.

Computing the energy that is not propagated in V_0, V_1, …. V_{n-1}, V_n.

Since the energy is mostly stored in near field region of the antenna (d <= 12 mm) and gradually reduces when reaching above 18 mm or so, it is evident that the quality factor as calculated by earlier researcher will be surely low as the key stored energy is not being considered. So we optimised the patch dimension to be less than 1cm per side of the octagon.

In this model hence we considered 2 octagonal structures with sides (a) of 18mm, that are placed representing a split ring resonator separated by a distance of 0.5 cm(nearly). Both the octagons are excited by using a strip feed mechanism. The overall dimension of antenna resulted in occupying an area of 5cm × 5cm. two rectangles of size 16.86 mm × 21.98 mm are placed on either side of the strip line thus making the antenna structure to be using a CPW layout.

The antenna gain is measured as a minimum at lowest and nearly middle at the declared frequency band. The method of partial gains may be used to determine the circularly polarised. Any two perpendicular orientations can be used, and can be shown as the total power in any elliptically polarised wave will contain the sum of two orthogonal polarizations.

The simulation results are plotted for a resonating frequency of 1.3 GHz. The testing procedure for a circular polarization is based on the initial adjustments are made at the centre frequency. The azimuth and elevation of the transmit antenna and test antenna should be aligned for maximum signal.

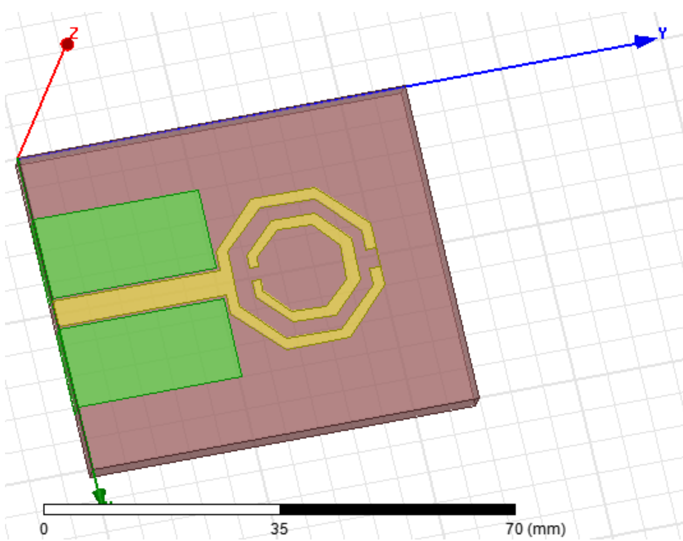

Figure 2: Patch modellin in HFSS

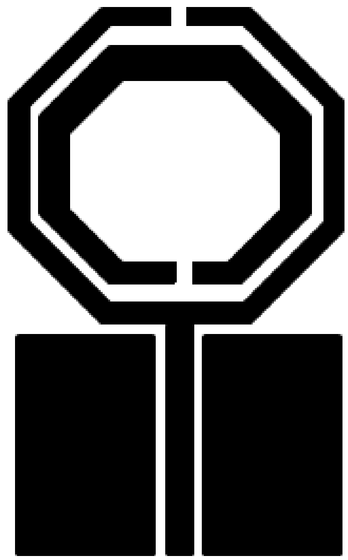

Figure 3: Antenna model on PCB layout

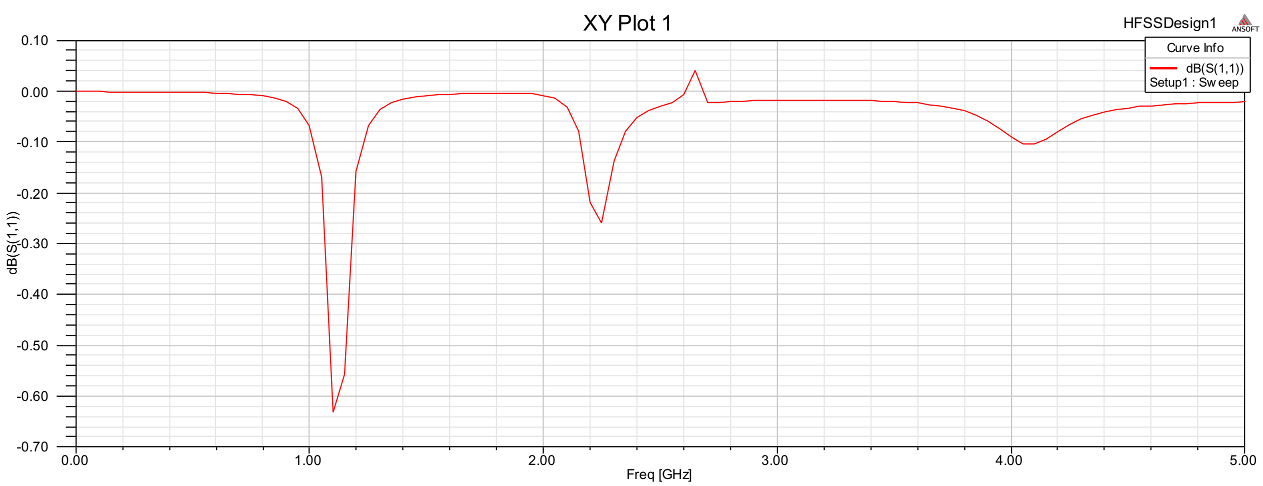

Figure 4: Rectangula Plot of Gain

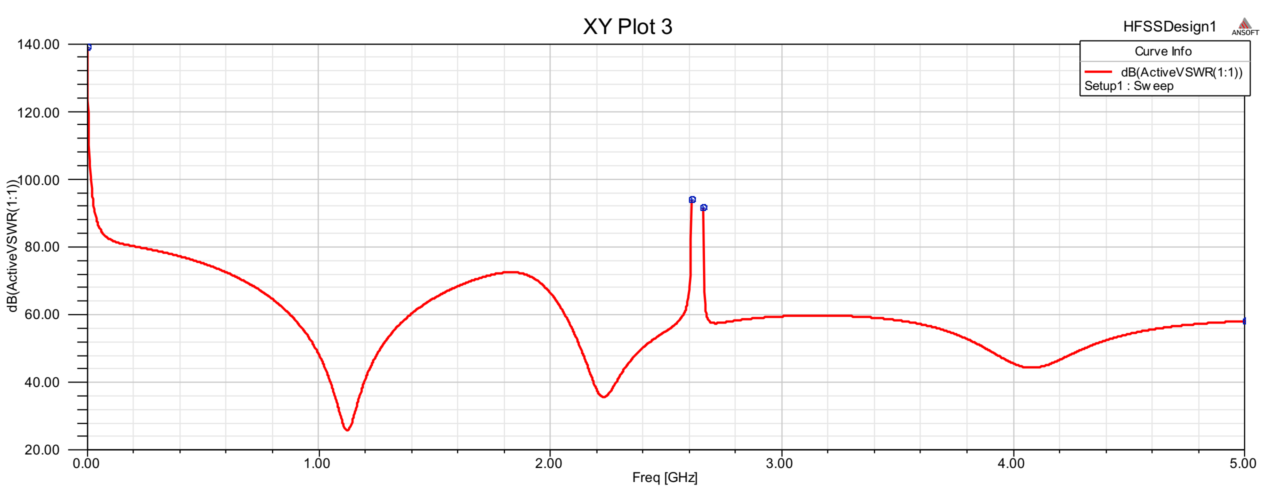

Figure 5: Frequecy Vs Active VSWR

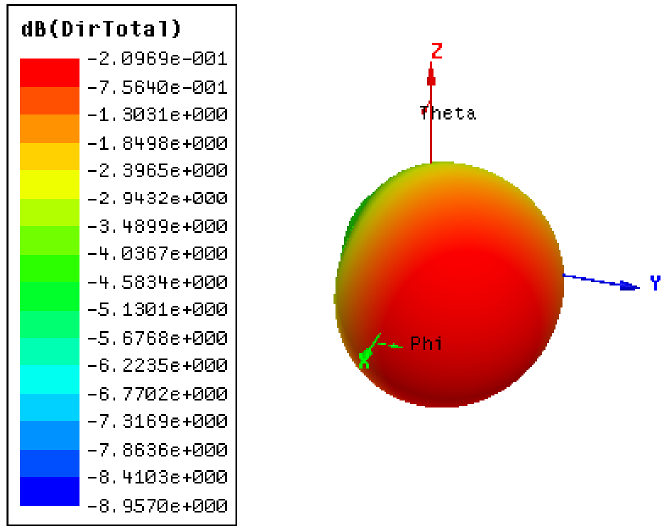

Figure 6: Directivity

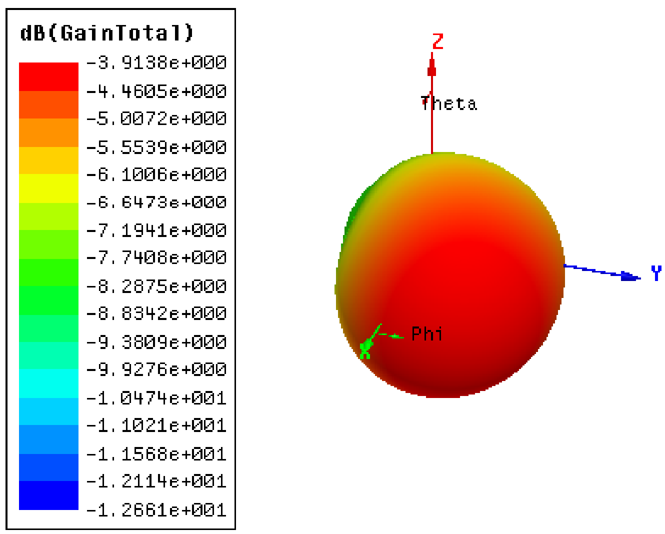

Figure 7: Gain Total

The main advantage of using the split ring resonator is that the multipoint split ring resonator is simple and by changing the number of rings we can retain the same physical size. The transmission coefficient of the split ring resonator is minimum at magnetic resonance frequency, the design of split ring resonator should match the microstrip substrate components, the orientation and alignment of structures as the inductance and capacitance change basing on the shape. We have proposed an octagonal structure on FR4 material basing on the Q characteristics of the FR4 material.

5. ANALYSIS/SWEEP SETUP FOR SOLUTION FREQUENCY

A fast sweep from 1 GHz to 5 GHz is chosen, the solution frequency should lie within the frequency sweep range. As the antenna is designed for operating at lower frequency[8] ie.. around 1.1 GHz to 2GHz. The field data is saved for each frequency in order to do post processing.

The resonant frequency of octagonal split ring resonator is obtained at 1.3 GHz, and the return loss is –12.3dB.

Comparison for different SRR Structures: A comparison between square, hexagonal and octagonal SRR are as shown in the table below:

Table 3
Structure Shape and Resonant Frequency

S.No	*Shape of the structure*	*Side length (mm)*	*ReturnLoss (dB)*	*Resonant Frequency (GHz)*
1	SRR- Square	20	12.2	1.9
2	SRR- Hexagonal	20	15.4	1.9
3	SRR- Octagonal	20	23.1	1.3

Far field patterns of antenna has been created for E & H Planes, and dimensional patterns for 2D and 3D. For 2D the values have to be chosen such that phi should start at 0 Deg and stop at 90 deg, with 90 deg step size. The resonant frequency of octagonal structure is different because of the gap capacitance, resonator inductance and distributed capacitance.

5.1. Antenna Export Parameters

Table 4
Antenna Export Parameters

Quantity	*Value*
Max U	2.79401e-010(W/sr)
Peak Directivity	3.33654e-005
Peak Gain	0.00779063
Peak Realized Gain	3.51114e-009
Radiated Power	0.000105233(W)
Accepted Power	4.50688e-007(W)
Incident Power	1(W)

6. CONCLUSION

From the study it shows that the Q factor[9] of a substrate material also impacts the gain and resonant frequency of the patch antenna. In order to maintain quality factor, the antenna shape can be varied so as to align with the distributed capacitance or inductance of the resonator as there will be no limitation on the size[10] of the antenna. A split ring resonator has a good potential to advance the performance of the antenna. Further, multiband effects are to be addressed using meta-materials whose negative dielectric constant can be exploited instead of using thick substrate materials.

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