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IMPEDANCE MODELLING OF METAMATERIAL STRUCTURE BASED ON DOUBLE QUAD-SQUARE SPLIT RING RESONATOR (DQS-SRR) AT 2.4 GHZ AND 7.4 GHZ

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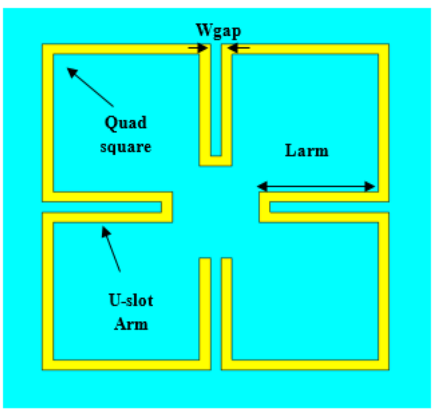
Graphical abstract



Abstract

This paper represents the impedance modelling of metamaterial structure based on Double Quad-Square Split ring Resonator (DQS-SRR). The impedance was modelled for DQS-SRR design structures. This structure simulation works had been done in CST Microwave Studio simulation software while the impedance was modelled by using polynomial type in Matlab for resistance, *R*, and reactance, *X*, of the impedance. The modelling of the impedance was based on the length of U-slot arm (*Larm*) and the width of U-slot arm gap (*Wgap*) of the DQS-SRR design structure .The impedances were divided into the certain ranges of length and width for dimensions of DQS-SRR so that an accurate impedance modelling was produced. The impedance was modelled for the resonant frequency of 2.4 GHz and 7.4 GHz. This DQS-SRR structure has potential application to improve of pyramidal microwave absorber to for certain frequency range.

Keywords: Impedance modelling, resistance, reactance, split ring resonator.

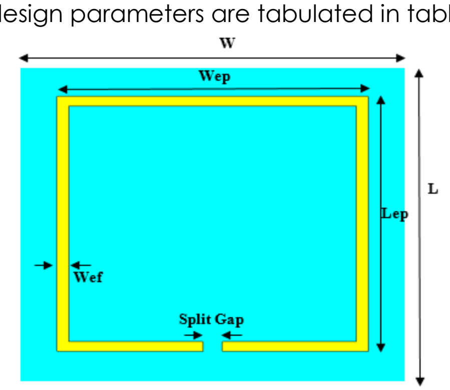
1.0 INTRODUCTION

Metamaterials are artificially created or engineered materials that typically have periodically arranged features of dimensions smaller than that of the wavelength of light. They demonstrate electromagnetic properties quite different from those of naturally occurring materials. Metamaterials derive their properties from a combination of composition and structure, rather than from their composition alone. Metamaterial or left handed material is an artificial material that does not exist in the real nature [1-2]. Metamaterial has categorized structure or design that has simultaneously negative permeability and permittivity [3]. The metamaterial structure can significantly miniaturize the design size [4]. It also achieves better reflection coefficient performances than a normal design without metamaterial structure [5]. The metamaterial artificial left-handed materials (LHMs) were initially discovered by Veselago [6]. Only after 3 decades, researchers in the field manage to apply the materials in practical applications. The first artificial metamaterial was fabricated by Smith et al. in 2000 [7]. Their design is based on Pendry split ring resonator-base artificial negative magnetic permeability media [8]. Split ring resonators (SRRs) design is used to produce the negative magnetic permeability. In 1999, it was proposed by [9] that by creating artificial structures of dimensions smaller than the wavelength of light in a periodic manner can give rise to negative refractive index. These materials were subsequently named as "metamaterials" or "Left handed materials (LHM)". Pendry proposed that an array of homogeneously spaced sub-wavelength Split Ring Resonators (SRRs) as metal hoops, which as a whole behave like a composite material. These SRRs can act as an impedance of LC oscillating circuit containing a magnetic coil of inductance L and capacitor of capacitance C. In their fundamental resonance, they behave as an LC oscillatory circuit that contains a single turn magnetic coil of inductance - in series with a capacitance produced by the gap between the arms of the SRR.

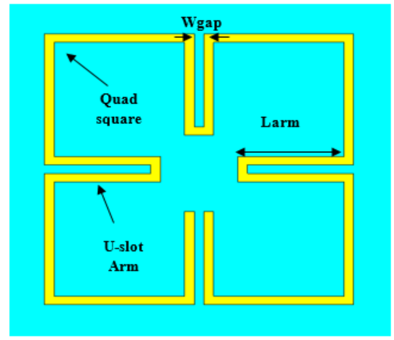
The impedance modelling of the SRR had been investigated by many researchers using Equivalent circuit, which is a fine tune technique [10-15]. On the other hand, no study has been carried out on the accurate modelling of the impedance SRR, such as mathematical modelling. So, this paper present the impedance modelling of Double Quad-Square Split ring resonator using polynomial type in Matlab for resistance, *R*, and reactance, *X*, of the impedance. The impedance was modelled for the resonant frequency of 2.4 GHz and 7.4 GHz. The length of U-slot arm (*Larm*) and the width of U-slot arm gap (*Wgap*) of the DQS-SRR were investigated to model the impedance. This DQS-SRR structure has potential application to improve the performance of pyramidal microwave absorber for certain frequency.

2.0 DQS-SRR DESIGN

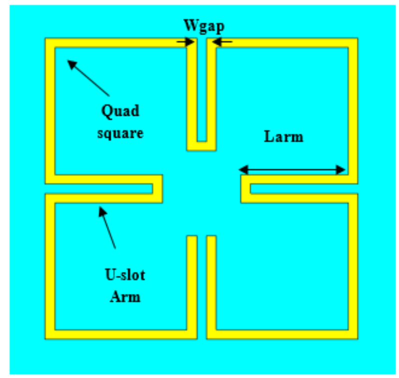
The proposed design of DQS-SRR has three step. The first step is the square edge structure with the split gap 0.25 mm at the bottom of SRR structure. The width and Length of square edge is 10mm with 0.25 width of square edge frame. By adding U-slot arm at the each square dimension, the quad square has formed in each corner on the square edge. The last step is slanted square split ring structure inside the edge slot structure. These designs are propose to achieve the targeted resonant frequency of EC-SRR at 2.4 GHz and 7.4 GHz .Figure 1 shows the design structure of DQS-SRR. The value of each design parameters are tabulated in table 1.



(a)



(b)



(c)

Figure1 Design structure of DQS-SRR (a) Edge structure (b) slot arm on four side of edge structure (c) Squere split ring structure inside the egdge slot structure.

Table 1 Antenna parameters

Parameter	Names	Diameters (mm)
W	Width of patch	10
L	Length of patch	10
Wep	Width of square edge patch	8
Lep	Length of square edge patch	8
Wef	Width of square edge frame	0.25
Split Gap	Split Gap of square edge patch	0.25
Wgap	Width of U-slot arm	0.25
Larm	Length of U-slot arm	3
Ws	Width of slanted square SRR	2.5
Ls	Length of slanted square SRR	2.5
h	High of Substrate	1.6
t	Thickness of Patch	0.035

The proposed SRR was design on FR4 board withthickness of substrate, h = 1.6mm.The dielectric constant of the FR4 substrate, ε_r = 4.4 and tangent loss, *tan* δ = 0.019. The thickness of copper, *t* is 0.035 mm. This DQS-SRR structure is placed inside a waveguide environment in figure 2 to simulate the reflection coefficient properties. The perfect electric conductor (PEC) boundary condition is applied to the two opposite side of the walls waveguide in ***y***- direction whereas perfect magnetic conductor (PMC) boundary condition is applied at the rest side of walls waveguide in **x**-direction. This simulation is done considering a normal wave incident angle (0^0) or straight line signal.

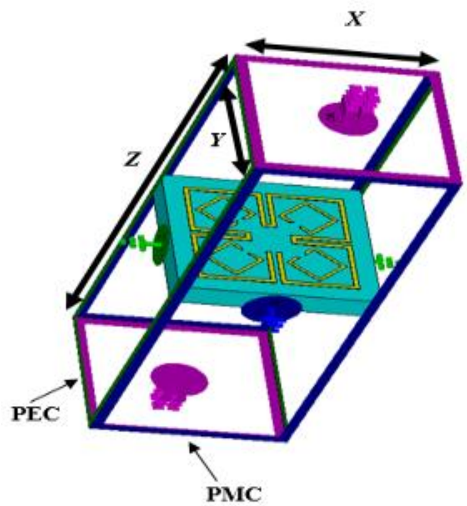


Figure 2 Waveguide simulation setup for DQS-SRR

3.0 DQS-SRR RESULT

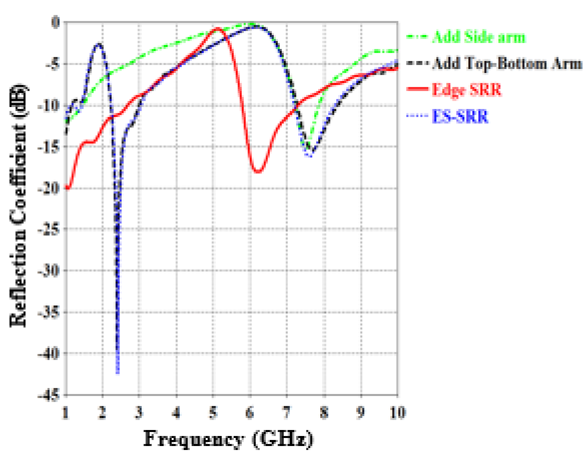


Figure 3 Reflection coefficient DQS-SRR

From figure 3, the width of split gap are affect the resonant frequency of DQS-SRR. By adding the U-slot arm at the side of EC-SRR, the resonant frequency of 7.4 GHz are achived. The U-slot arm at top and bottom of EC-SRR are to obtaion the second resonant frequency at 2.4 GHZ. When the length of U-slot arm (*Larm*) and witdh of U-slot arm (*Wgap*) was increase, the resonant frequency will be decrease and shifted to approched the targeated resonant frequency. However, by adding the slanted Square SRR into the Edge structure, the reflection coefficient was increaced.

4.0 DQS-SRR IMPEDANCE MODELLING

This section represents the impedance modelling of DQS-SRR. The impedance was modelled for DQS-SRR design structures. The modelling of the impedance was based on the length of U-slot arm (*Larm*) and the width of U-slot arm gap (*Wgap*)of the SRR design structure. The impedance was modelled by using polynomial type in Matlab for resistance, *R,* and reactance, *X,* of the impedance base on equation (1) and (2). Reflection coefficient can be represented as Γ. Meanwhile, the impedance at the load, Z_L, can be calculated by using equation (1) where $Z_0$is the impedance of free space (377 Ω). The waveguide ports in the design represent the Z_0.

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (1)$$

Then, the complex impedance, Z, can be written as equation (2) where the real part of the impedance (Re) is resistance, *R,* and the imaginary part of the impedance (Im) is reactance, *X*.

$$Z = R + jX \qquad (2)$$

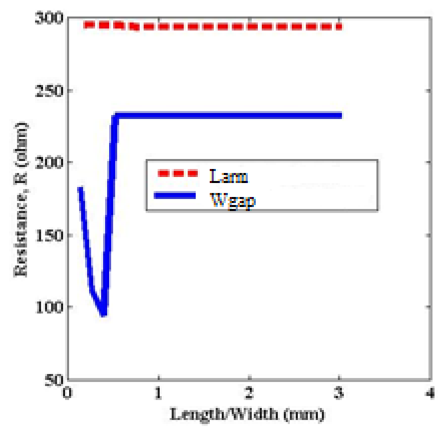


Figure 4 Resistance versus parameters Larmand Wgap

There were smaller changes of the resistance when the length (Larm) and the width (Wgap) of the DQS-SRR were varied, as shown in figure 4. The resistance of the DQS-SRR decreased for Wgap between 0.2 to 0.5 mm, while the resistance increased from 95 Ω to 240 Ω for width between 0.5 to 0.8 mm. After that, the resistance remained at 240 Ω when the parameter Wgap was more than 0.6 mm. However, the changes of parameter Larm did not affect the resistance of DQS-SRR where the resistance remained at 295 Ω. The highest degree of resistance of the DQS-SRR was 4th degree polynomial. The resistance modelling of the dielectric substrate is presented in Table 2.

Table 2 Impedance modelling of the resistance

Parameter	Impedance Modelling	
	Resistance, ohm(Ω)	Length/Width (mm)
Length of arm (Larm)	$X = 59.59\ Larm^3 + 51.13\ Larm^2 + 13.5\ Larm + 39.24$	Larm > 0.25
Width of arm gap (Wgap)	$X = -6.64e^{-15}\ Larm + 41.32$	0.5< Wgap < 3
	$X = -3.659e^4\ Wgap^4 + 5.629\ e^4\ Wgap - 2.944\ e^4\ Wgap + 6179\ Wgap - 32.2$	Wgap < 0.5

Figure 5 showed that the reactance remained at 40 Ω for all values of parameter *Larm*, while the reactance remained at 164 Ω for parameter *Wgap* more than 0.5 mm. When parameter *Wgap* increased from 0 to 0.2 mm, the reactance increased from 95 Ω to 109 Ω. Then, the reactance decreased from 109 Ω to 98 Ω when parameter *Wgap* was set between 0.2 and 0.5 mm. The highest degree of the reactance for parameter *Larm* was cubic, while for parameter *Wgap* was the 4th degree polynomial, as portrayed in Table 3.

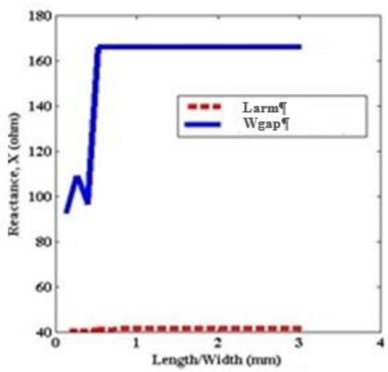


Figure 5 Reactance versus parameters *Larm*and*Wgap*

Table 3 Impedance modelling of the reactance

Parameter	Impedance Modelling	
	Resistance, ohm(Ω)	Length/Width (mm)
Length of arm (Larm)	$X = 59.59\ Larm^3 + 51.13\ Larm^2 + 13.5\ Larm + 39.24$	Larm > 0.25
Width of arm gap (Wgap)	$X = -6.64e^{-15}\ Larm + 41.32$	0.5< Wgap < 3
	$X = -3.659e^4\ Wgap^4 + 5.629\ e^4\ Wgap - 2.944\ e^4\ Wgap + 6179\ Wgap - 32.2$	Wgap < 0.5

5.0 CONCLUSION

The impedance of the DQS-SRR had been modelled based on the length of arm and width of arm gap for both resistance and reactance of impedance. The designed parameters of DQS-SRR affected the resistance and the reactance of the impedance. As the parameters were varied, the resistance and the reactance were also varied. The reactances for all parameters were mirror with the resistance. The types of polynomial that had been used cubic polynomial and 4th degree polynomial.

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1.

References

[1] Rahim, M. K. A., H. A. Majid, and T. Masri. 2009. Microstrip antenna incorporated with left-handed metamaterial at 2.7 GHz. *IEEE International Workshop on Antenna Technology (iWAT 2009)*.1–4.

[2] Wu B., Wang W., Pacheco J., Chen X., Grzegorczyk T., Kong J. A., and P. Art. 2005. A Study of Using Metamaterials as Antenna Substate to Enhance Gain. 295–328.

[3] Radoni V., Jokanovi B., and Crnojevi V. 2007. Different Approaches to the Design of Metamaterials. 2–7.

[4] Raghavan S. and Jayaram A. 2013. Metamaterial Loaded Wideband Patch Antenna. (0):760–763.

[5] Feresidis, A. and J. C. Vardaxoglou. 2001. Flat Plate Millimetre Wave Antenna Based On Partially Reflective FSS. *International Conference on Antennas and Propagation*. 1: 33–36.

[6] Veselago, V. G. 1968. The Electrodynamics of substances with simultaneously negative values of permittivity and permeability. *Soviet Physics USPEKI*. 10(4): 509–514.

[7] Smith, D. R., Padilla W.J., Vier D.C., Nemat-Nasser S.C., and Schultz S. 2000. Composite Medium With Simultaneously Negative Permeability And Permittivity. *Physical Review Letters*. 84: 4184–4187.

[8] Pendry, J. B., Holden A.J., Robbins D.J., and Stewart W.J. 1999. Magnetism From Conductors And Enhanced Nonlinear Phenomena. *IEEE Trans. Microwave Theory Tech*. 47: 2075–2084.

[9] Pendry J. B, Holden A. J., Robbins D. J. and Stewart W. J. 1999. Magnetism from conductors and enhanced Non-Linear Phenomena. *IEEE Trans. Microwave Theory Tech*. 47: 2075-2084.

[10] Baena, J. D., Bonache J., Martin F., et al. 2005. Equivalent-Circuit Models For Split-Ring Resonators And Complementary Split-Ring Resonators Coupled To Planar Transmission Lines. *IEEE Trans. Microw. Theory Tech*. 53(4): 1451–1461.

[11] Shamonin M., Shamonina E., Kalinin V., and Solymar L. 2005. Resonant Frequencies of A Split-Ring Resonator: Analytical Solutions and Numerical Simulations. *Microwave and Optical Technology Letters*. 44(2): 133-136.

[12] Garcia-Garcia, J., F. Aznar, M. Gil, J. Bonache, and F. Martin. 2007. Size reduction of SRRs for metamaterial and left handes media design.*PIERS Online*.3(3):266-269.

[13] Nornikman, H., F. Malek, P. J. Soh, and A. A. H. Azremi. 2010. Design A Rice Husk Pyramidal Microwave Absorber With Split Ring Resonator. *The Asia-Pacific Symposium on Applied Electromagnetics and Mechanics 2010 (APSAEM 2010)*.

[14] Ezanuddin, A. A. M., F. Malek, and P. J. Soh. 2010. Investigation of complementary split ring ringresonator with dielectric ring. *Loughborough Antennas and Propagation Conference (LAPC*). 297-300.

[15] Yuandan, D. and T. Itoh. 2011. Miniaturized patch antennas loaded with complementary split ring resonators and reactive impedance surface.*5th European Conference on Antennas and Propagation (EUCAP)*. 2415-2418.