Jurnal Teknologi

Full Paper

Impedance Modelling of Metamaterial Structure based on Double Quad-Square Slot Split ring Resonator (DQSS-SRR) at 4.6 GHz

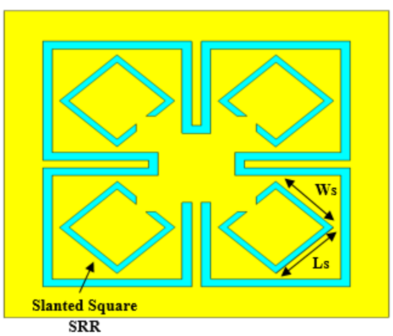
Article history
Received
17 June 2015
Received in revised form
16 September 2015
Accepted
15 December 2015

Adibah Azman[a], Azahari Salleh[a], Mohamad Zoinol Abidin[b*] Abd Aziz[a], Mohd Kadim Suaidi[a], Hamzah Asyrani Sulaiman[b]

[a]Centre for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia
[b]Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding author
mohamadzoinol@utem.edu.my

Graphical abstract



Abstract

This paper represents the impedance modelling of metamaterial structure based on Double Quad-Square Slot Split ring Resonator (DQSS-SRR). The impedance was modelled for DQSS-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 DQSS-SRR design structure .The impedances were divided into the certain ranges of length and width for dimensions of DQSS-SRR so that an accurate impedance modelling was produced. The impedance was modelled for the resonant frequency of 4.6 GHz. This DQSS-SRR structure has potential application to improve of pyramidal microwave absorber for certain frequency range.

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

1.0 INTRODUCTION

The development of wireless communication devices by empowering materials with unique characteristics has extensively investigated during last 2 decades. One of among material types frequently applied is split ring resonators (SRR). Some devices which utilize the SRR in various forms as a part of their structures include hybrid coupler, coplanar waveguide, coupled transmission lines, bandpass filter and antenna [1-5]. Basically, the SRR which is composed of a non-magnetic metal conductor was introduced at first time in 1999 [6]. It is constructed of a pair concentric enclosed-loop rings with some splits at opposite ends which is possibly printed on a dielectric substrate. Since the SRR has unique features, for instance, having strong coupling connection while working as lumped LC series components and capability to produce large values of capacitance, it is oftentimes implemented to improve the performance of some devices.

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.

By using Equivalent Circuit method, SRR can be modeled as an energy-storing inductive or capacitive component which is determined by the shape of its elements. At any specific frequency, impedance may be represented by either a series or a parallel combination of an ideal resistive element and an ideal reactive element which is either capacitive or inductive. Such a representation is called an equivalent circuit. The values of these elements or parameters depend on which representation is used, series or parallel, except when the impedance is purely resistive or purely reactive. Impedance is a comprehensive expression of any and all forms of opposition to electron flow, including both resistance and reactance.

The impedance modelling of the SRR had been investigated by many researchers using Equivalent circuit, which is a fine tune technique [7-11]. 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 Slot 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 4.6 GHz. The length of U-slot arm (Larm) and the width of U-slot arm gap (Wgap) of the DQSS-SRR were investigated to model the impedance. This DQSS-SRR structure has potential application to improve the performance of pyramidal microwave absorber for certain frequency.

2.0 DQSS-SRR DESIGN

The first step of proposed design of DQSS-SRR 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 slot is 10mm with 0.25 width of square edge slot frame. Through adding U-slot arm at the each square dimension, the quad square slot has formed in each corner on the square edge slot. The final step is slanted square slot split ring structure inside the edge slot structure. These designs are propose to achieve the targeted resonant frequency of DQSS-SRR at 4.6 GHz. Figure 1 shows the design structure of DQSS-SRR. The value of each design parameters are tabulated in Table 1.

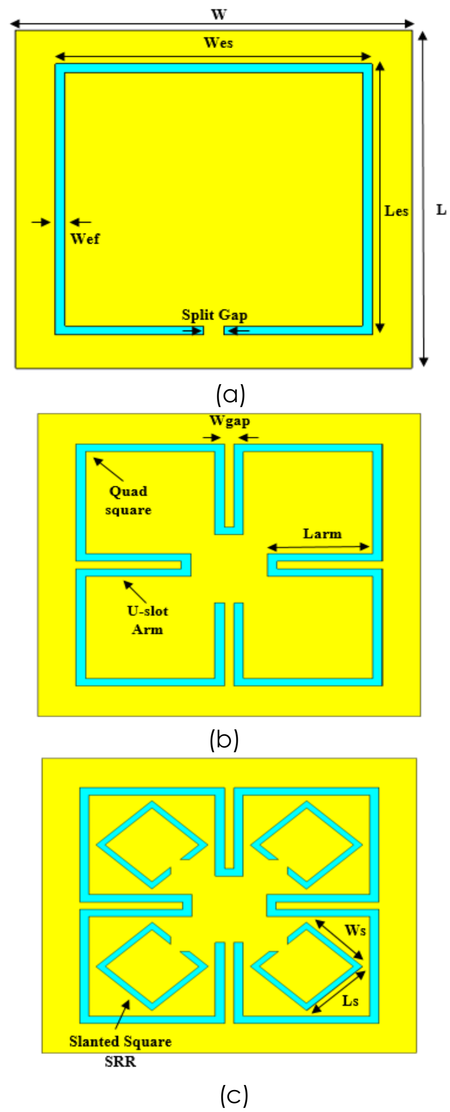


Figure 1 Design structure of DQSS-SRR (a) Edge structure (b) slot arm on four side of edge structure (c) Squere split ring structure inside the egdge slot structure

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 DQSS-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.

Table 1 Antenna Parameters

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

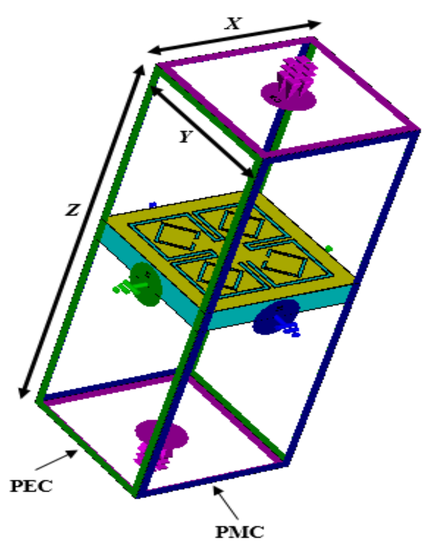


Figure 2 Waveguide simulation setup for DQSS-SRR

3.0 DQSS-SRR RESULT

From Figure 3, the width of split gap are affect the resonant frequency of DQSS-SRR. The U-slot arm at top and bottom of DQSS-SRR are to obtaion the resonant frequency at 4.6 GHZ. When the length of U-slot arm (*Larm*) and witdh of U-slot arm (*Wgap*) was enlarge, 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.

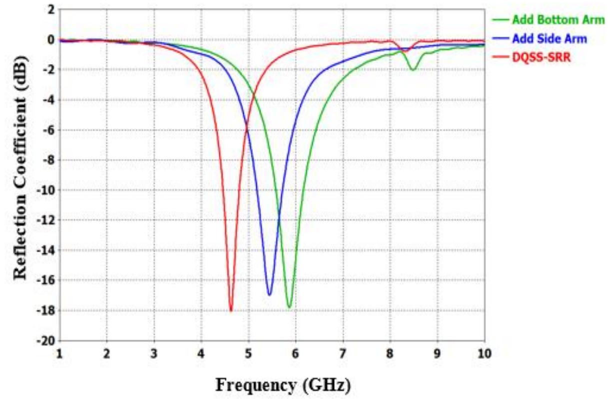


Figure 3 Reflection coefficient DQSS-SRR

4.0 DQSS-SRR IMPEDANCE MODELLING

This section represents the impedance modelling of DQSS-SRR. The impedance was modelled for DQSS-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, , can be calculated by using equation (1) where is the impedance of free space (377 Ω). The waveguide ports in the design represent the .

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

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*.

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

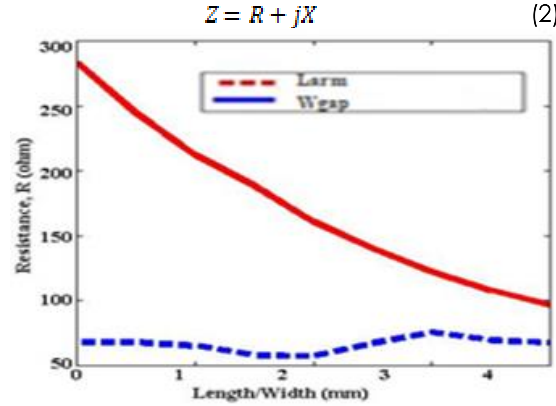


Figure 4 Resistance versus parameters *Larm* and *Wgap*

There were smaller changes of the resistance when the length (*Larm*) and the width (*Wgap*) of the DQSS-SRR were varied, as shown in Figure 4. The results show that the highest resistance was 290 Ω when *Larm* = 0.25 mm and the lowest resistance was 59 Ω when *Wgap* = 2.0 mm. The resistance of parameter *Larm* was inversely proportional with the length of *Larm*, while the resistance for parameter *Wgap* fluctuated as the length was varied. Parameter *Larm* also provided the highest degree of impedance, which was 6^{th} degree by using 6^{th} degree polynomial type, as presented in Table 2.

Table 2 Impedance modelling of the resistance

Parameter	Impedance Modelling	
	Resistance, ohm(Ω)	**Length/Width (mm)**
Length of arm (Larm)	$R=3.206Larm^6+0.001502Larm^5+0.3652Larm^4+42.05Larm^3+1809Larm^2-3.59Larm^4$ $Larm+2.756Larm^5$	Larm > 0.25
Width of arm gap (Wgap)	$R = -1.322e^{-14}$ Wgap + 233.2	0.5< Wgap < 3

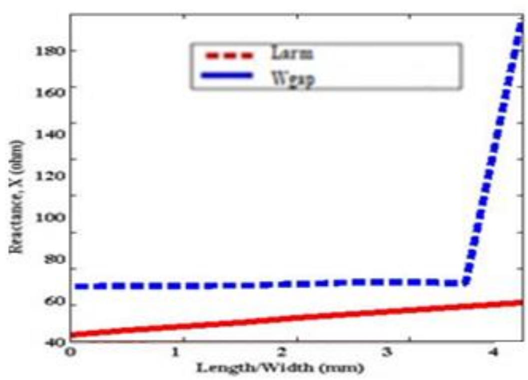


Figure 5 Reactance versus parameters *Larm* and*Wgap*

From Figure 5, the graph indicates that from length 0.25 mm to 4.0 mm, the reactance of parameter *Larm* increase, while the reactance of parameter *Wgap also* increased. When the length increased from 3.0 mm to 4.0 mm, the reactance of parameters *Larm* and *Wgap* increased as well, but at length 4.0 mm, the reactance for parameter *Larm* increased well, while for parameter *Wgap*,the resistance kept increasing. The degrees of impedances that had been used for parameters *Larm* and *Wgap* had been 1^{st} degree, 2^{nd} degree, and 3^{rd} degree. Parameter *e* achieved the highest degree of impedance, as concluded in Table 3.

Table 3 Impedance modelling of the reactance

Parameter	Impedance Modelling	
	Resistance, ohm(Ω)	**Length/Width (mm)**
Length of arm (Larm)	$X = 79.59\ Larm^3 + 51.13\ Larm^2 + 13.5\ Larm + 39.24$	Larm > 0.25
Width of arm gap(Wgap)	$X = -6.64e^{-15}$ Larm + 41.32	0.25< Wgap < 3

5.0 CONCLUSION

The impedance of the DQSS-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 DQSS-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 6th degree polynomial.

Acknowledgement

The authors would like to thanks UniversitiTeknikal Malaysia Melaka (UTeM) for supporting in obtain the information and material in the development for our work. Authors also want to thanks anonymous referees whose comments led to an improved presentation of our work. Lastly, authors also thank The Ministry of Science, Technology and Innovation Malaysia (MOSTI) for 06-01-14-SF0096 L00022 research grant.

References

[1] Siso, G., Bonache, J. and Martin, F. 2009. Dual-Band Rat Race Hybrid Coupler Implemented Through Artificial Lines Based on Complementary Split Ring Resonators. *Proceeding of IEEE MTT-S International Microwave Symposium (IMS)*. Boston, USA. 625-628.

[2] Braaten, B. D., Aziz, M. A., Schroeder, M. J. and Li, H. 2010. Meander Open Complementary Split Ring Resonator (MOCSRR) Particles Implemented Using Coplanar Waveguides. *Proceeding of IEEE International Conference on Wireless Information Technology and Systems* (ICWITS). Honolulu, USA. 1-4.

[3] Munir, A. and Soeka, L. R. G. 2014. Performance Enhancement of Coupled Microstrip Lines Using Split Ring Resonators. *Proceeding of International Conference on Electrical Engineering and Computer Science* (ICEECS). Denpasar, Indonesia. 385-388.

[4] Horestani, A. K., Withayachumnankul, W., Chahadih, A., Ghaddar, Zehar, A. M., Abbott, D., Akalin, T. and Fumeaux, C. 2014. Bandpass Filters Based on Coupled Split Ring Resonators for Surface Waves on Planar Goubau Lines. *Proceeding of International Workshop on IWAT*. Sydney, Australia. 57-60.

[5] Harfianto, M. A. Suprayogi and Munir, A. 2015. Incorporation of Square Patch and SRR Metamaterials for Dual-Band Printed Antenna. *Proceeding of IEEE International Symp.* APS-URSI. Vancouver, Canada.

[6] Pendry, J. B., Holden, A. J. Robbins, D. J. and Stewart, W. J. 1999. Magnetism from Conductors and Enhanced Nonlinear Phenomena. *IEEE Trans. Microw. Theory Techn*. 47(11): 2075-2081.

[7] 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.

[8] 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.

[9] Garcia-Garcia, J., Aznar, F., Gil, M., Bonache, J. and Martin, F. 2007. Size Reduction of Srrs for Metamaterial and Left Handes Media Design. *PIERS Online*. 3(3): 266-269.

[10] Nornikman, H., Malek, F., Soh, P. J. and Azremi, A. A. H. Design a Rice Husk Pyramidal Microwave Absorber with Split Ring Resonator. *The Asia-Paci¯c Symposium on AppliedElectromagnetics and Mechanics 2010 (APSAEM 2010)*.

[11] Ezanuddin, A. A. M., Malek, F. and Soh, P. J. 2010. Investigation of Complementary Split Ring Ring Resonator with Dielectric Ring. *Loughborough Antennas and Propagation Conference (LAPC)*. 297-300.