Investigation on Split Ring Resonators Based on Different Substrates and Dimensions Operating at Terahertz Frequency

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Abstract—The purpose of this paper is to investigate the response of split-ring resonators (SRRs) with the operating or resonant frequency approximately at 1THz. Different substrates and dimensions of the rings are investigated to observe the response of the SRR at the operating frequency. The main parameters concern for this project is the voltage standing wave ratio (VSWR), return loss (S_{11}) and the resonant frequency. The SRRs is simulated using CST Microwave Studio to obtain the response used for the investigation.

Keywords: Terahertz, metamaterial, CST Microwave Studio, split-ring resonators, resonant frequency, voltage standing wave ratio, return loss.

1.0 INTRODUCTION

1.1 Background

Radiation in the THz regime, 0.3 to 30 THz, presents a bit of difficulties to workers in the engineering and physics field; because the band is positioned between microwave and optical frequencies [1].
Applications include THz radiography for high-contrast images similar to x-ray, but without harmful ionizing effects. THz imaging has been indicated as a replacement for x-ray in soft tissue imaging and security screening. Spectroscopy is another valuable application due to the strong interaction of THz with organic compounds which create chemical signatures for detection and identification [2, 3]. Because this frequency range offers significant benefits for numerous applications, much effort has been spent on development of smaller cheaper THz technologies [4].

1.2 Split-ring Resonators

Split ring resonators have been investigated for a long time by different researchers. These form typical LC circuits with effective inductance and capacitance. First proposed for metamaterials by Pendry [5], the SRR is one of the basic structures that provide negative permeability. The behaviour of the SRRs as a THz metamaterial has been characterized by numerous researchers [6, 7, 8, 9, 10]. Moreover, many other configurations have been examined in the following years [11]. Use of the SRRs in the THz has progressed to the point where design guidelines have been defined [8].
In this project, the CST software is utilized to modeled and simulate the SRRs under frequency range of 0.6 to 1.4 THz. This program is especially suited to the fast, efficient analysis and design components like antenna (including arrays), filters, transmission lines, couplers, connectors (single and multiple pin), printed circuit boards, resonators and many more [12]. By using a 3D approach, CST can solve virtually any high frequency field problem. The software is based on a method that requires the discretization of the entire calculation volume.

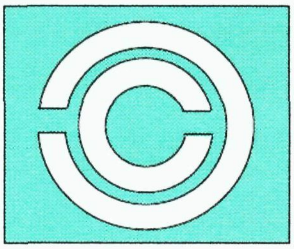


Figure 1 Split-ring resonators

2.0 THEORY

Figure 2 shows the basic topology of the SRR, as well as its equivalent-circuit model proposed in [10].

In this figure, C_o stands for the total capacitance between the rings, while C_{pul} is the per unit length capacitance between the rings.

$$C_o = 2\pi r_o C_{pul} \quad (1)$$

The series capacitance of the upper and lower halves of the SRRs is given by

$$C_s = C_o / 4 \quad (2)$$

The resonance frequency of the SRR is given by

$$f_o = (L_s C_s)^{-1/2} / 2\pi \quad (3)$$

where, C_s is the series capacitance of the upper and lower halves of the SRR.

The inductance L_s can be approximated by that of a single ring with averaged radius r_o and width c [13].

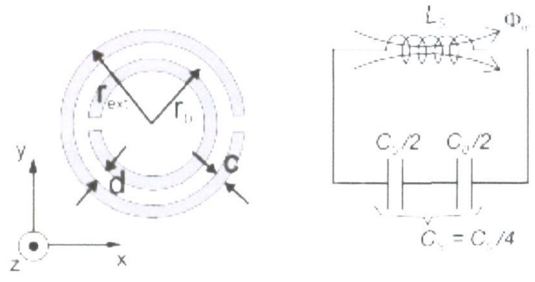


Figure 2 Topology of SRR and its equivalent-circuit model

3.0 MODELING

3.1 Modeling with CST MWS

The modeling was done based on the dimensions taken from the previous research [1]. The SRR dimensions used is shown in figure 3. To achieve 1 THz operation, the SRR was dimensioned with parameters summarized in Table 1.1.

Table 1.1 Simulation parameters for geometry in figure 3, with inner radius (*IR*), outer radius (*OR*), and metal thickness (*z*)

	IR (µm)	OR (µm)	Z (µm)
Inner ring	60	90	20
Outer ring	110	140	20
C	30	30	
d	20	20	

In this design, the structure is modeled on a two-metal substrate, with metal 1 supplying input and ground connections, and metal 2 providing ring material, as shown in figure 3 [1]. Choices of substrates include semiconductor substrate such as Gallium Arsenide, Glass (Pyrex), Polyimide, Quartz and Teflon (PTFE). The objective is to achieve the desired operating frequency at 1 THz.

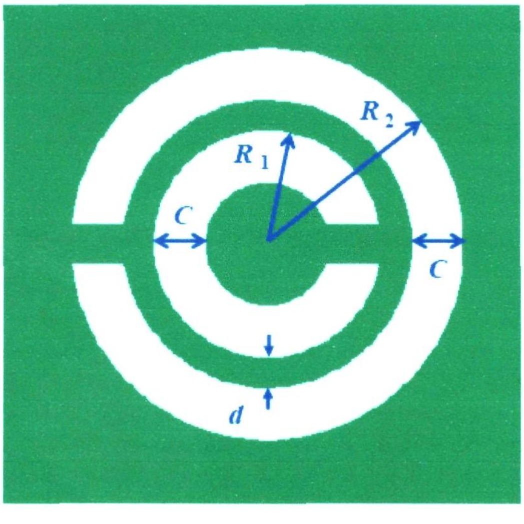
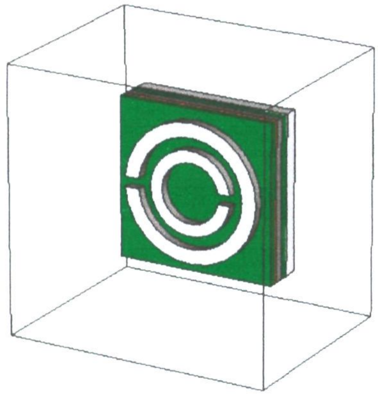
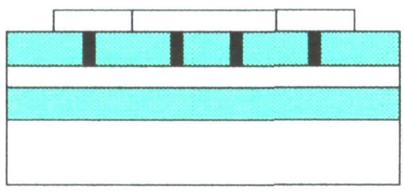


Figure 3 Split ring resonator geometry and dimensional parameters [1]



(a)



(b)

Figure 4 (a) Perspective view of SRRs, (b) side view of the SRRs

4.0 RESULTS

4.1 Results using different substrates

Table 4.1.1 Response obtained by simulation for different substrates using original dimensions [1]

Substrate	S_{11} (dB)	VSWR	Resonant Frequency (THz)
Gallium Arsenide (ϵ=12.9)	-8.068	2.306	0.9624
Glass (Pyrex) (ϵ=4.82)	-8.629	2.176	0.9624
Quartz (ϵ=3.78)	-8.769	2.136	0.9624
Polyimide (ϵ=3.5)	-8.821	2.136	0.9624
Teflon (PTFE) (ϵ=2.08)	-9.193	2.063	0.9618

Table 4.1.1 show the comparison between the simulation results based on the original dimension from paper [1] using different substrates. By comparing the results, it can be observed that substrate with lower permittivity, ϵ, has lower values of S_{11} and lower VSWR than the substrate with higher permittivity.

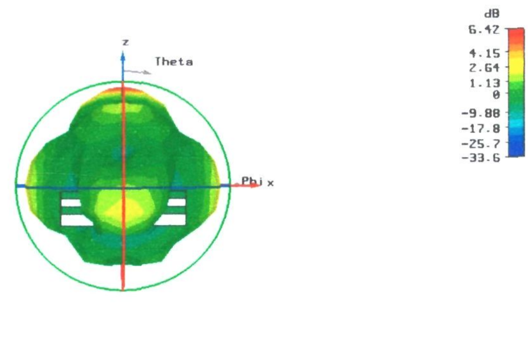


Figure 5 Far-field at f=1THz using Gallium Arsenide with actual dimensions from paper [1]

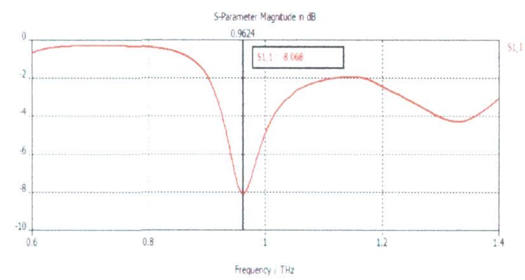


Figure 6 S_{11} at f=0.9624 THz for Gallium Arsenide

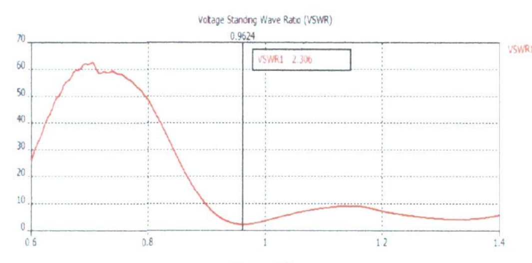


Figure 7 VSWR at f=0.9624 THz for Gallium Arsenide

The best operating frequency is at 0.9624 THz for four substrates which are Gallium Arsenide, Glass (Pyrex), Quartz and Polyimide but each of the substrate has different value of S_{11} and VSWR. The value of S_{11} for the substrates is -8.068 dB for Gallium Arsenide, -8.629 dB for Glass, -8.769 dB and -8.821 dB for Polyimide. While the value for VSWR for the substrates is 2.306 for Gallium Arsenide, 2.176 for Glass, 2.136 and 2.136 for Polyimide.

4.2 Results using different dimensions of the outer ring

Table 4.2.1 Response obtained by simulation for different radius of the outer ring

Substrate	Outer Ring (µm)		S_{11} (dB)	VSWR	Resonant Frequency (THz)
	IR	OR			
Gallium Arsenide (ε=12.9)	110	135	-7.758	2.386	0.6184
	110	140	-8.068	2.306	0.9624
	110	145	-12.860	1.589	1.1344
Glass (Pyrex) (ε=4.82)	110	135	-8.291	2.252	0.6192
	110	140	-8.629	2.176	0.9624
	110	145	-12.680	1.605	1.1392
Quartz (ε=3.78)	110	135	-8.440	2.218	0.6192
	110	140	-8.769	2.136	0.9624
	110	145	-12.660	1.607	1.1392
Polyimide (ε=3.5)	110	135	-8.470	2.211	0.6192
	110	140	-8.821	2.136	0.9624
	110	145	-12.650	1.607	1.1392
Teflon (PTFE) (ε=2.08)	110	135	-8.681	2.165	0.6200
	110	140	-9.193	2.063	0.9618
	110	145	-2.448	7.144	1.1264

From the table 4.2.1, we obtained that the value of S_{11} decrease when the width of the outer ring increased for all the substrates excluding Teflon. The value of the resonant frequency increase when the width of the outer ring increased for all the substrates. It can be observed that the value of VSWR decrease when the radius of the outer ring increased except for Teflon (PTFE).

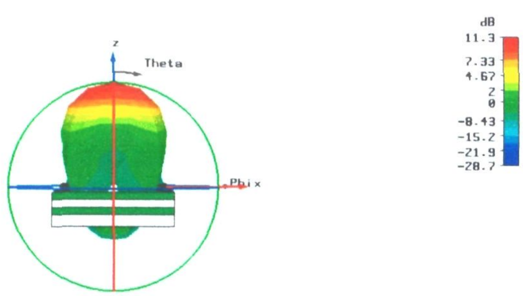


Figure 7 Far-field at f=1THz for Gallium Arsenide

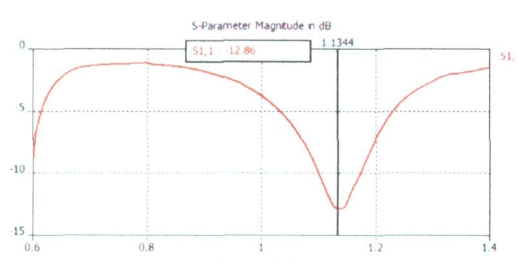


Figure 8 S_{11} at f=1.1344 THz for Gallium Arsenide

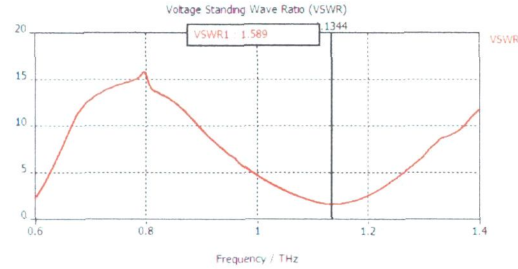


Figure VSWR at f=1.1344 THz for Gallium Arsenide

The best operating frequency is at 1.1344 THz for Gallium Arsenide which has the highest value of S_{11} and lowest value of VSWR when increasing the width of the outer ring of the SRRs from 30µm to 35µm.The value of S_{11} is -12.860 dB and the value of the VSWR is 1.589.

4.3 Results using different radius of the inner ring

Table 4.3.1 Response obtained by simulation for different radius of the inner ring

Substrate	Inner Ring (µm)		S_{11} (dB)	VSWR	Resonant Frequency (THz)
	IR	OR			
Gallium Arsenide (ε=12.9)	60	85	-28.020	1.083	0.6128
	60	90	-8.068	2.306	0.9624
	60	95	-11.540	1.721	1.1022
Glass (Pyrex) (ε=4.82)	60	85	-22.470	1.163	0.6144
	60	90	-8.629	2.176	0.9624
	60	95	-11.360	1.741	1.0985
Quartz (ε=3.78)	60	85	-21.260	1.185	0.6144
	60	90	-8.769	2.136	0.9624
	60	95	-11.370	1.740	1.1003
Polyimide (ε=3.5)	60	85	-21.260	1.189	0.6144
	60	90	-8.821	2.136	0.9624
	60	95	-11.370	1.739	1.0994
Teflon (PTFE) (ε=2.08)	60	85	-19.810	1.228	0.6144
	60	90	-9.193	2.063	0.9618
	60	95	-11.370	1.741	1.0985

From the table 4.3.1, it can be analyzed that the value of the resonant frequency becomes higher as the width of the inner ring increased. It can be observed that the value of VSWR decrease higher when the width of the inner ring decreased from 30µm to 25µm.

The best operating frequency is at 0.6128 THz for Gallium Arsenide which has the lowest value of S_{11} and lowest value of VSWR when decreasing the width of the outer ring of the SRRs from 30µm to 25µm.The value of S_{11} is -28.020 dB and the value of the VSWR is 1.083.

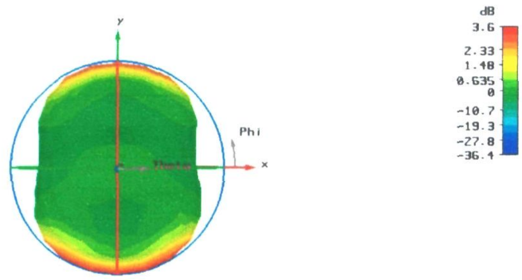


Figure 9 Far-field at f=0.6 THz for Gallium Arsenide

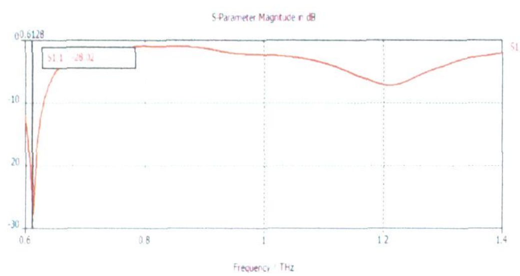


Figure 10 S_{11} at f=0.6128 THz for Gallium Arsenide

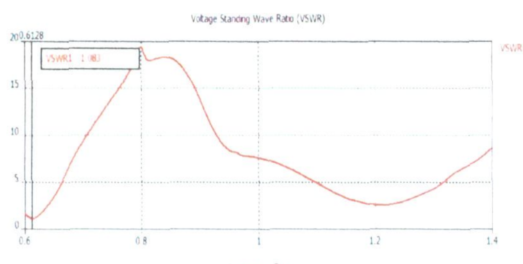


Figure 11 VSWR at f=0.6128 THz for Gallium Arsenide

5.0 DISCUSSIONS

The split-ring resonator has been presented by using CST software to obtain the resonant frequency, S_{11} and VSWR. The value from CST Microwave Studio is compared based on different substrates and width of inner and outer ring of the SRRs.

For a given dimension of SRRs without stating the substrate used is set to have a fundamental resonant frequency at 1THz [1]. Hence, different substrates are used in the simulation to obtain the resonant frequency at 1THz. Five different substrates are used for this simulation. By comparing all the results, it can be observed that substrate with lower permittivity, ϵ, has lower values of S_{11} and lower VSWR than the substrate with higher permittivity, ϵ.

The value of S_{11} decreases when the width of the outer ring increased for all the substrates excluding Teflon. It can be observed that the resonant frequency increase when the width of the outer ring increased for all the substrates and the value of VSWR decrease when the width of the outer ring increased except for Teflon (PTFE).

The value of the resonant frequency becomes higher as the width of the inner ring increased. It can be observed that the value of VSWR decrease higher when the width of the inner ring decreased from 30μm to 25μm than when the width of the inner ring increased from 30μm to 35μm.

The results from initial simulation in CST using original dimension differ from the results obtained in the previous research [1]. It is because the previous researchers use Remcon XFDTD software to simulate the SRRs, which is another CAD package used in microwave technology that give different simulation results than CST MWS. The simulation using CST MWS and Remcon XFDTD is different, which lead to different simulation results. In order to achieve resonant frequency at about 1THz, we have to vary the dimension of the SRRs taken from paper [1] including the substrate used.

6.0 CONCLUSIONS

From all the investigations done, the best substrate used for the SRRs is Gallium Arsenide. The SRRs operates at 1.1344 THz when increasing the width of the the outer ring of the SRRs from 30μm to 35μm. It also has the lowest value of S_{11} and lowest value of VSWR. The value of S_{11} is -12.860 dB and the value of the VSWR is 1.589.

The substrates also give best response when investigating on decreasing the width of the the inner ring of the SRRs from 30μm to 25μm, which operates at 0.6128 THz. It has the lowest value of S_{11} and the lowest value of VSWR, which is -28.020 dB for the S_{11} and 1.083 for the VSWR.

6.0 FUTURE DEVELOPMENT

CST Microwave Studio is 3D software which deals with high field simulation. Thus modeling and simulation using CST Microwave Studio give better understanding for electromagnetic waves. By using high-end computer, the SRRs modeling using CST MWS can give accurate results for determining response of the SRRs or other sample. It also can give accurate radiation pattern for the SRRs. For given dimensions used in this project from previous research [1], the response is obtained below 1 THz.

Further works could be done to design the SRRs to operate at higher frequency rather than 1 THz. The terahertz frequency offers significant benefits for numerous applications, especially in medical applications such as imaging and security screening in soft tissues. The terahertz radiation promises some advantages such as highly reduced risk of irradiation, increased image contrast to differentiate between various soft materials, and the possibility of chemical identification.

To observe the behaviour of the SRRs more, it is possible to fabricate the SRRs using circuit board or semiconductor substrates such as investigated in this project. The fabricated SRRs then measured to compare the results obtain from the measurement and CST MWS simulations.

7.0 ACKNOWLEDGEMENT

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