# Very High Q-Factor Based On G-Shaped Resonator Type Metamaterial Absorber

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## Abstract

High Q-factor based on absorption can be achieved by tuning (the reflection and the transition percentage). In this work, the simple design and simulated in S-band have been investigated. The simulation results of G-shape resonator are shown triple band of absorption peaks 60%, 91.5%, and 70.3%) at resonance frequency 2.7 GHz, 3.26 GHz, and 4.05 GHz respectively. The results exhibited very high of the Q-factor (271) at resonance frequency (3.26 GHz). The high Q-factor can be used to enhance the sensor sensing, narrowband band filter and image sensing.

**Keywords**: Metamaterial, Q-factor, S-band; absorber and triple band absorber.

# 1. Introduction

In ten years ago, there has been a new technique used to produce perfect absorption based on Left Handed Material (LHM) or metamaterial [1] because it has interest properties not found in nature such as negative refractive index, backward waves [2&3], sub of operating wavelength, in homogeneities medium, and small unit cells thickness [11]. The specials properties of metamaterial open the way for many range of applications such as: perfect metamaterials absorber [1, 2 &4], negative refraction index [5], sensing applications [6], and modulator [6&7]. Meanwhile, Metamaterials become hot topic because of frequency scalability property [1, 2 & 3-7] from microwave [6] to THz [4&7]. In the past, one important disadvantage point of electromagnetic devise based on metamaterials structure is absorption loss. This loss lead to a weakening the sensitivity of devise and power dissipated, thus due to limiting the practical application which depend on metamaterial [12]. Until the moment, when Landy, N. I. et.al. mention to use metamaterial as a perfect absorber in 2008 [1]. They showed perfect absorption for the incidence electromagnetic wave by carefully engineered metamaterial structure. Generally, many metamaterials structures consisting from three layers as a sandwich structures. One substrate layer with high permittivity and very low loss tangent. It is Bounded by two metallic layers. The front is resonator. The back layer is ground plane. However, metamaterial absorber was able to overcome the disadvantage of traditional absorbing materials problems, such as: complex structure and low absorption ratio. Therefore, perfect metamaterial plays important role in great applications, for example reduce radar cross [13], sensing [6], thermal image [1&4], and stealth material [13]. Unfortunately, we can note this advantage the metamaterial absorbers suffer from some weak points narrow band of absorption because of the strong EM resonances [12]. Meanwhile, the narrow bandwidth later become key point in sensing applications [14] .

In order to describe the mechanism of metamaterials, the researchers used equivalent medium theory. The complex permittivity ε(ω) and complex permeability μ(ω) are explained as the eq. (1 & 2).

$$\varepsilon(\omega) = \varepsilon'(\omega) + i\varepsilon''(\omega) \tag{1}$$

$$\mu(\omega) = \mu'(\omega) + i\mu''(\omega) \tag{2}$$

Where the real parts $(\mu'(\omega), \varepsilon'(\omega))$ describe the degree of polarization and magnetization of electromagnetic wave. In the other hands the losses of electromagnetic wave can be explained by $(\mu''(\omega)$ and $\varepsilon''(\omega))$. In the investigation of metamaterial absorber, many scientists pay attention to study the effect of real parts, and decrease the tangent loss as much as possible by reducing the imaginary parts [12 & 15]. However, for the perfect absorber based on metamaterials, the tangent loss of substrate is very beneficial. According to electromagnetic transmission theory, many principle of the absorber structure can be investigating. The good explanation for physical reason of absorption depends on input impedance of the structure. When the structure impedance Z match the surrounding impedance, the perfect absorption by carefully tuning the parameters of structure can be get.

In this study, the very simple design, that is consist of three layers has been used to generate very high Q-factor in S-band frequency. The results show three absorption peaks

60%, 91.5%, and 70.3% at frequencies 2.7 GHz, 3.26GHz, and 4.05GHz respectively. The high Q-factor is achieved 271 at resonance frequency 3.26 GHz .

By compared with previous studies, this structure promise in many advantages of very high Q-factor comparing with study in reference [8], ability to scaling to THz regime and sensing applications that due to the very sharp of Q-factor.

## 2. Design

The G-shaped structure consists of two conductive layers separated from each other by 1.5 mm FR-4 substrate as a dielectric spacer. The top layer is a two symmetric G-shaped resonators; the back side layer is continuous metallic (as a mirror) to reflect all transmitted wave. The FR-4 chosen as the dielectric spacer with their permittivity constant 3.4 and tangent losses 0.025. The all conductive layers are choosing as copper with conductivity $5.8\times10^{7}$ S/m. The design dimensions and unit cell dimension are listed in table I. In order to examine the simulation results the commercial software CST microwave studio was chosen, which is based on the finite integration technique [16]. The simulation is applied under periodic boundary condition of planner unit cell in fig. 1. to calculate the two scattering parameters. The electromagnetic wave is normally incident the E electric field polarization, H magnetic field polarization and propagation vector are set along y, x and –z respectively.

The Q-factor was calculated from resonance frequency of absorption peak divided by HPBW. Meanwhile, the absorption [1,17] was found from eq. (3).

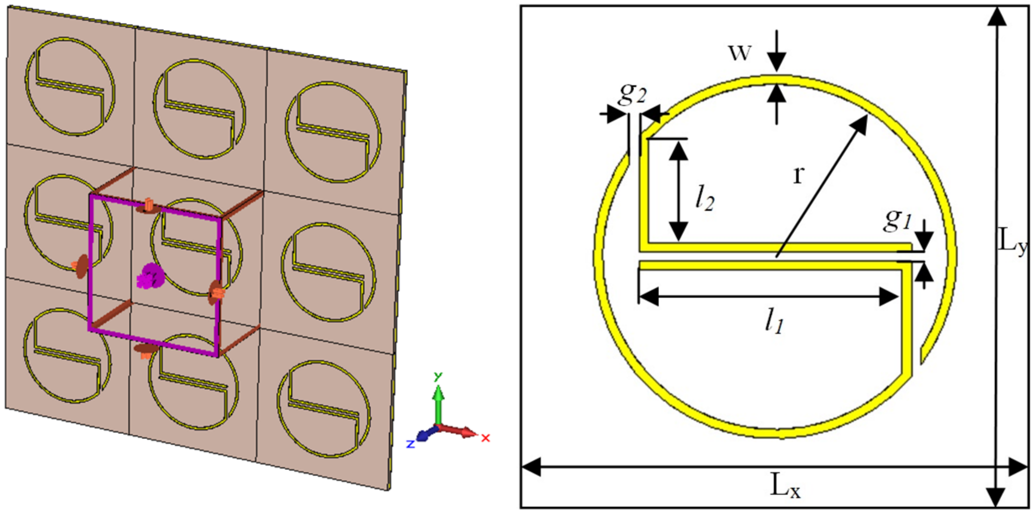
$$A = 1 - R - T \tag{3}$$

Where A, R, and T is absorption, reflection= |S11|2 and transmission = |S21|2 respectively. The absorption is depending on the reflection only, because the back side was fully covered by copper. Therefore, the input of proposed structure can be calculated from scattering parameters according to eq. (4).

$$Z = \sqrt{\frac{(1+S_{11})^2 - {S_{21}}^2}{(1-S_{11})^2 - {S_{21}}^2}} \tag{4}$$

**Table (1): Design dimensions**.

| Parameter | Value (mm) |
|---|---|
| Lx | 34.036 |
| Ly | 34.036 |
| R | 12 |
| l1 | 17.4 |
| l2 | 6.8 |
| g1 | 0.6 |
| g2 | 0.6 |
| w | 0.6 |



(a) (b)

**Figuer (1): G-shaped metamaterial absorber, (a) CST simulation setup based on periodic boundaries and(b) schematic view.**

## 3. Results

In order to investigate the performance of the G-shaped as a high Q-factor resonator, (S) parameters of a G-shaped is simulated. Additionally, the influences of the geometry parameters such as the r radius of structure, the width of metal (w) and finally length of l2 are compared with absorption level and resonance frequency.

However, fig. 2 shows the absorption response of G-shaped when the parameters as in table 1. The high Q factor (271) excited at high absorption peak (91.5%) at resonance frequency (3.26) GHz. The structure at this orientation does not depend on symmetry broken as in [9&10]. Fig. 3 shows the simulated surface currents at resonance frequency (3.26) GHz, which it approves the resonance type of the electric dipole.

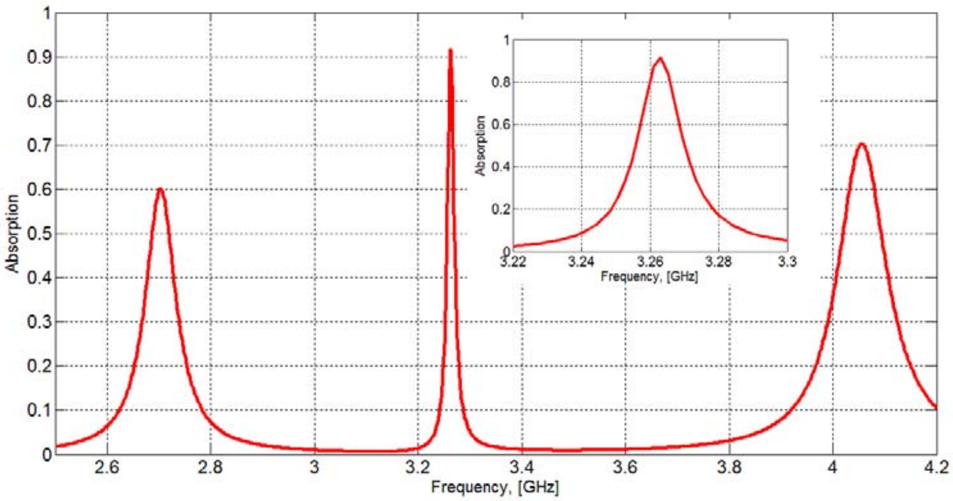


**Figure (2): Absorption response of G-shaped**

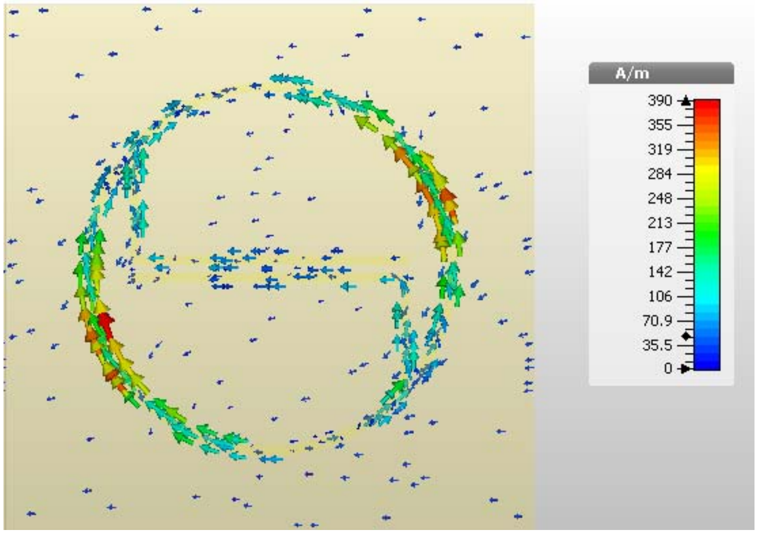


**Figure (3): Surface current simulated at resonance frequency 3.26 GHz**

The influences of different parameters in Q-factor and resonance frequency are investigated. Firstly fig. 4 shows the absorption as a function of frequency for different radiuses (r). Evidently, when the radiuses of G-shaped structure increase, the resonance frequency is decrease (red-shift). Additionally, the Q-factor increases when (r) increase nonlinearly and the highest Q-factor (204) at (r = 12.5 mm). The next parameter investigated is width of metallic resonator (w). The result shown increasing in (w), which it leads to distinctly decrease in HPBW, with increase in Q-factor and resonance frequency. The relation between (w) and resonance frequency, as shown in Figure 5.

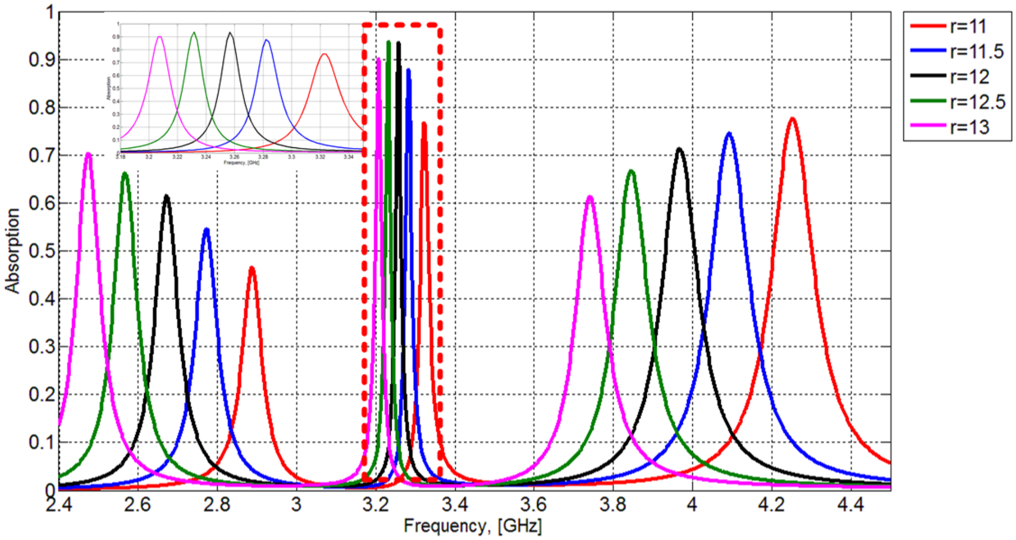


**Figure (4): Absorption of the G-shaped resonator for the change of the radius r from 11 mm to 13 mm, step 0.5 mm.**

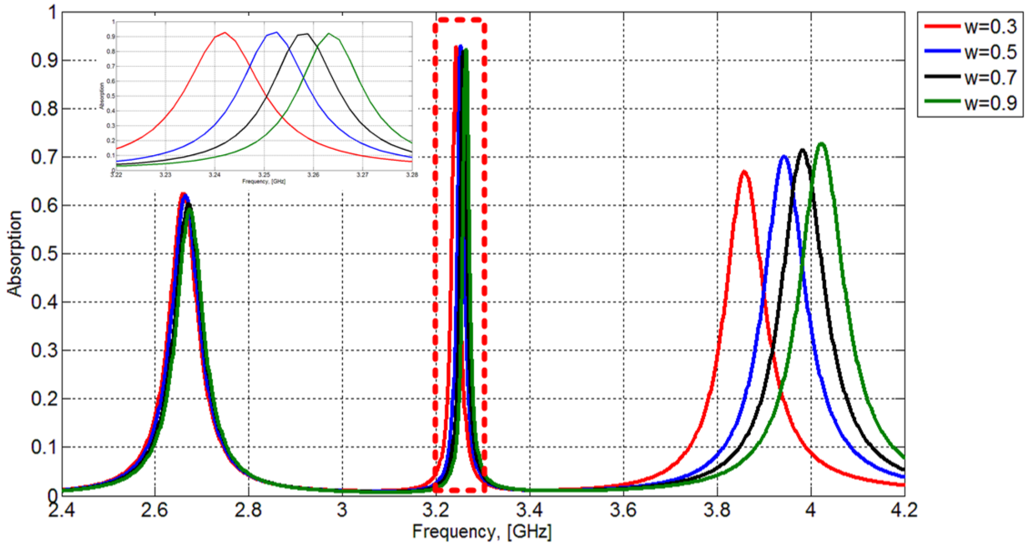


**Figure (5): Absorption of the G-shaped resonator for the change of the w from 0.3 mm to 0.9 mm, step 0.2 mm.**

Finally, Figure 6 shows the absorption as a function of frequency for different $l_2$. The increasing length of l2 lead to decrease in g1 and vies versa. When the $l_2$ decrease, the resonance frequency and HPBW are increase (i.e. Q-factor decrease).

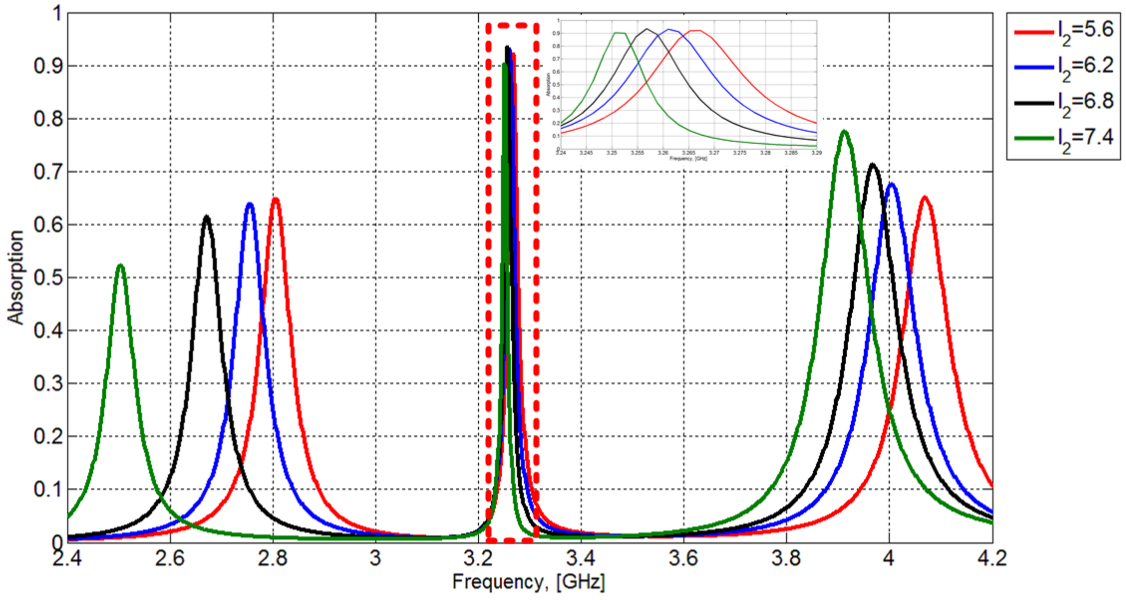


**Figure (6): Absorption of the G-shaped resonator for the change of the $l_2$ from 5.6 mm to 7.4 mm.**

## 4. Conclusions

In this paper, the very high Q-factor (271) metamaterial structure is presented. Three absorption bands at 2.7 GHz, 3.26 GHz and 4.05 GHz are formed with the absorption peaks levels 60%, 91.5%, and 70.3% respectively. The proposed G-shaped resonator has significant potential in practical applications, especially when it scaling to THz such as detection, imaging and sensing

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