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A Review: The Development of Metamaterial Absorber

Siti Adlina Md Ali[1]*, Maisarah Abu[1], Siti Normi Zabri[1]

[1]Centre for Telecommunication Research and Innovation (CeTRI),
Faculty of Electronic and Computer Engineering (FKEKK),
Universiti Teknikal Malaysia Melaka (UTeM), 76100, MALAYSIA

*Corresponding Author

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Abstract: A metamaterial is an artificial resonant structure that is designed to obtain specific characteristics which are not naturally occurring in nature. One of the applications is metamaterial absorber, which offers benefits over conventional absorbers. Metamaterials absorber is a structure that attenuates the energy in electromagnetic waves, soak up the incident energy, convert into heat and reduce the energy reflected back to the source. Various designs on metamaterial absorber have been investigated exhibiting different characteristics; single-band, multi-band, as well as broadband. Starting from thick and rigid substrates, followed by a thin and also flexible substrate materials are being considered. Perfect absorbency is achieved when the surface impedance of the structure equal to the free space impedance. Different methods in introducing the loss in an absorber; lumped resistor, resistive pattern and lossy dielectric. These unique characteristics of metamaterial absorber enable wide applications in various technologies.

Keywords: Metamaterial, AMC, FSS, EBG and absorber

1. Introduction

The ancient Greek prefix, "meta" which means beyond has been used to describe the composite materials with unique features that do not exist in the nature [1]. Nowadays, the use of metamaterial in technology is rapidly growing. Metamaterial structure which can either be Artificial Magnetic Conductor (AMC), Frequency Selective Surface (FSS) or Electromagnetic Band Gap (EBG), provides more advantages in communication electronic technologies such as antenna [2-10], Radio Frequency Identification (RFID) [11-15], and absorber [16-20].

AMC is a type of metamaterial which introduces an in-phase reflection phase within the bands gap of the desired frequency. It contains three main sections; ground plane, substrate and a patch. The in-phase reflection phase is the property of a Perfect Magnetic Conductor (PMC). It is extensively used in recent years to improve the radiation efficiency and enhance the antenna gain [21-25]. The directive antenna is developed as the radiation is improved and is used in wearable applications [26-32], which is one of the critical consideration as the radiation that penetrates the human cells is a major health concern and the human body causes performance degradation [33-35].

The antenna with AMC (AAMC) is being introduced in previous research [34]. The AAMC is successfully enhanced the bandwidth of the antenna by 52%, the gain by 2 dBi and boost the efficiency up to 30%. Meanwhile, in [34], the textile diamond dipole with AMC was desired. The performance of the structure is analyed under bending, wetness and specific absorption rate measurements. The directive antenna with high gain is obtained which the radiation towards the human body is minimized.

On the other hand, FSS works as a filter, which is constructed using substrate and patch. The radiation characteristics; gain and the directivity of the antenna, are enhanced by using an appropriate designed FSS reflector to provide an in-

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*Corresponding author: p021810003@student.utem.edu.my phase reflection with a very low transmission coefficient over the entire bandwidth [36]. Designing a reflector in narrow band system is a challenging task where the reflectors should be at a distance of λ/4 [37-40]. A super wideband printed antenna with an enhanced gain using FSS [41]. FSS is placed below the antenna at a distance “d” so that the wave radiated towards the FSS is reflected back.

EBG is also a metamaterial, which suppresses unwanted surface waves within a band gap frequency region. Structure of the mushroom-like EBG was primary introduced in [42]. It consists of ground plane, substrate, patches and using vias. Flexible dual band dipole antenna incorporated with EBG as proposed in [43]. The antenna resonated at 2.45 GHz and 5.8 GHz while the EBG is designed at 5.8 GHz. EBG works as a ground plane for the antenna and helps improve the realized gain and radiation pattern. Besides, an EBG also act as a filter as the resonant frequency of the antenna close to the EBG band gap. The 2.45 GHz resonant is eliminated while the antenna performance at 5.8 GHz is improved. Thus the realized gain is increased up to 6.86 dB and the back lobes are clearly reduced.

In this paper, the previous development of the microwave absorber were classified and explained briefly with the different methods. Losses in microwave absorber were introduced by using differ mechanism: lumped resistor [53-56], resistive patterns [57-62] and lossy dielectrics [62-65]. The resistive element mechanism used the low loss of dielectric while the dielectric loss mechanism consider the lossy substrates. Meanwhile the lump element mechanism introduced the losses of the microwave absorber based on the lump resistor. Various designs on metamaterials absorber have been investigated exhibiting different characteristics; single-band, multi-band, as well as broadband [48-52]. Starting from rigid substrates, followed by a thin, an ultra-thin and also flexible substrate materials are being considered.

2. Metamaterial Absorbers

Metamaterial absorbers is one of such applications that the characterization do not naturally exist. Same goes to AMC, the structure contains of four main sections; ground plane, substrate and patches. AMC is a high impedance structure with magnitude and phase of +1 and 0^0 at resonant frequency. While for developing a perfect metamaterial absorber, the surface impedance Z(ω) should be similar to free space impedance, η_o = 377 Ω.

Theoretically, a perfectly match layer is the basis of the principal of the metamaterial absorber to maximize the absorbency. Approximately to free space impedance contribute to nearly close to zero of reflection which is totally no reflection and maximum absorbance, A as given in Eq. 1.

$$A = 1 - |S_{11}|^2 - |S_{21}|^2 \qquad (1)$$

Where $|S_{11}|$ is reflected power and $|S_{21}|$ is transmitted power.

The transmitted power of the absorber is approximately to zero due to the full metal layers at the bottom of the structure, hence $S_{21} \approx 0$. Therefore, the absorbance, A is simplified as in Eq. 2.

$$A = 1 - |S_{11}|^2 \qquad (2)$$

Metamaterial absorber is widely applied in radar technology. In sealth application, the absorber is able of detect the presence of the target. In radar cross section (CRS), the radar absorber described the target as an effective area or energy that reflect back towards source which is also known as backscattering [44-47]. For conventional/passenger aircraft, the backscatter from the airframe is important to be as large as possible. Thus continuously be tracked by radar antenna. Differ to stealth aircraft, absorber should reduce the backscatter in order to decrease the visibility of an aircraft as seen by the radar.

3. Development of Metamaterial Absorbers

Different types of structures had been introduced as metamaterial absorber in single band and multiband applications [48-52]. AMC and FSS structures were applied in designing the absorber. It is important for the structure to have the surface impedance was approximately similar to free space impedance. Three methods used to identify surface impedance of the metamaterial absorber; lumped resistor [53-56], resistive patterns [57-62] and lossy dielectrics [62-65]. In resistive patterns, FSS structure with ground plane at a distance λ/4 is applied. The resistive loss represents FSS loss and should be match to free space impedance in order to maximize the absorbency. Inkjet printing methods used to fabricate the resistive loss [57] to represent the surface impedance of the absorber. Past research on designing metamaterial absorber are shown in Table 1.

Table 1 - Past research on designing metamaterial absorber

(Author) Year	Research's title	Substrate	Methods of design
(P. Munaga) 2015 [66]	An Ultra-Thin Dual-Band Polarization Independent Metamaterial Absorber for EMI/EMC Applications	FR-4 1 mm Rigid	AMC
(S. Gosh) 2015 [67]	Triple-Band Polarization Independent M-material Absorber using Destructive Interference	FR-4 1 mm Rigid	AMC
(D. Chaurasiya) 2015 [68]	An Ultra-Thin Triple Band Polarization-Insensitive Metamaterial Absorber for C-Band	FR-4 1 mm Rigid	AMC
(H.B. Baskey) 2014 [69]	A Dual Band Multiple Narrow Slits based Metamaterial Absorber over a Flexible Polyurethane Substrate	PU 0.8 mm Flexible	AMC
(H.B. Baskey) 2015 [70]	A Flexible,Ultra-thin, FrequencySelective-Surface Based Absorber Film for the Radar Cross Section Reduction of a Cubical Object	Polymide 0.135 mm Flexible	AMC
(O. Ayop) 2014 [71]	Dual band polarization insensitive and wide angle circular ring metamaterial absorber	FR-4 0.8 mm Rigid	AMC
(S.N. Zabri) 2014 [72]	Ultra-Thin Resistively Loaded FSS Absorber for Polarisation Independent Operation at Large Incident Angle	Taconic TLP-5 0.13 mm Flexible	FSS with gap
(H.M. Lee) 2012 [73]	A Method for Extending the Bandwidth of Metamaterial Absorber	FR-4 0.8 mm Rigid	AMC (double negative)
(D.W. Yu) 2017 [74]	A sextuple-band ultra-thin metamaterial absorber with perfect absorption	FR-4 1 mm Rigid	AMC
(F.Y. Nong) 2013 [75]	An ultrathin wide-band planar metamaterial absorber based on fractal frequency selective surface and resistive film	FR-4 0.4 mm Rigid	AMC (resistive film)
(L.G. Zhen) 2016 [76]	An ultra-thin and broadband absorber using slotted metal loop with multi layers	FR-4 0.4 mm Rigid	FSS multilayer
(Y.P. Lee) 2014 [77]	Flexible and Elastic Metamaterial Absorber for Low Frequency, based on Small Size Unit Cell	Teflon 1.27 mm Flexible	AMC
(Y.P. Lee) 2017 [78]	Miniaturization for Ultrathin Metamaterial Perfect Absorber in the VHF Band	FR-4 3.6 mm Rigid	AMC

Recently, researcher designed a thin and rigid absorber which used the FR-4 substrate with the thicker board which was $0.024\lambda_{(9\ \mathrm{GHz})}$ [71]. Then, others take a challenged in designing an ultra-thin and flexible absorber by considering $0.00635\lambda_{(1.5\ \mathrm{GHz})}$ (Teflon [77]) and $0.0045\lambda_{(10.37\ \mathrm{GHz})}$ (TaconicTLP-5 [72]), $0.00504\lambda_{(11.20\ \mathrm{GHz})}$ (Polymide [70]). All of the structures were resonated at X-band frequency accept for the Teflon based absorber which was resonated at L-band frequency. Absorbency with more than 95% was achieved while considering a thin substrate for both high and low frequencies. Meanwhile, S. N. Zabri et al. were investigated the effect of thickness and resistance value on the reflectivity bandwidth and angular sensitivity [72].

Gosh et al. designed the metamaterial absorber based on AMC structure. One of the designs considered the resistive FSS with gap to introduce loss in the absorber. Lossy substrate, FR-4 with different thickness and permittivity was used to create loss in absorber. They claimed 1 mm thickness of substrate as an ultra-thin absorber [67]. Different shapes in Fig. 1 were designed to have a multi-resonant frequency including C-band to Ku-band frequencies [66-68]. FR-4 substrate with 1 mm thickness was used and achieved almost perfect absorption which was more than 95% for each resonating frequency. The absorptivity at different incident angle also was validated at 0^o, 15^o, 30^o and 45^o for both simulation and measurement.

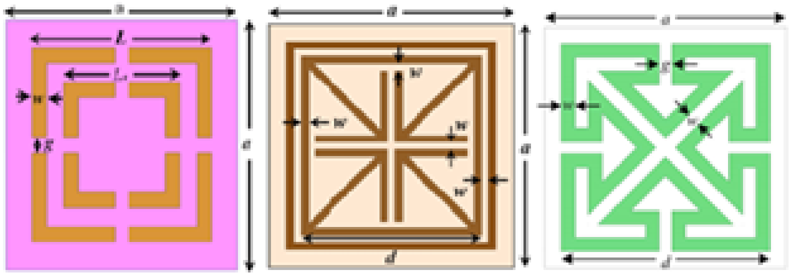


Fig. 1 - Different shapes of metematerial absorber [44-46]

Meanwhile, a single band, dual band and triple band absorber using circular ring were presented as in Fig. 2 [81-83]. All the designs resonated at Ku-band frequencies and considered the rigid substrate; FR-4 with 0.8 mm thickness. The authors investigated the relationship between the various sizes of specific part of the structure with the resonance frequency and the absorbance value of the absorber. Then, the operating frequency of the structure can be predicted by varying a specific part of the patch [84]. They also studied the circular ring metamaterial absorber with the existing of copper lines and found that circular ring structure with vertical and horizontal copper lines is not only polarization insensitive, but it can works at wide operating angle of incident waves [85].

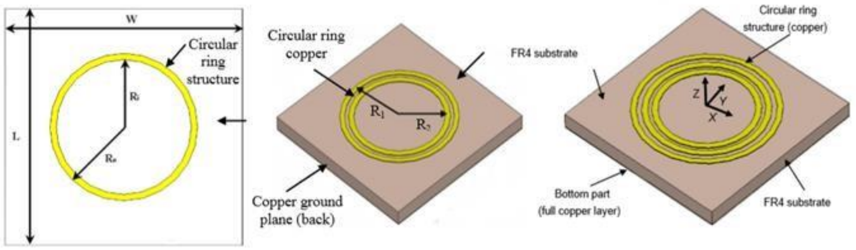
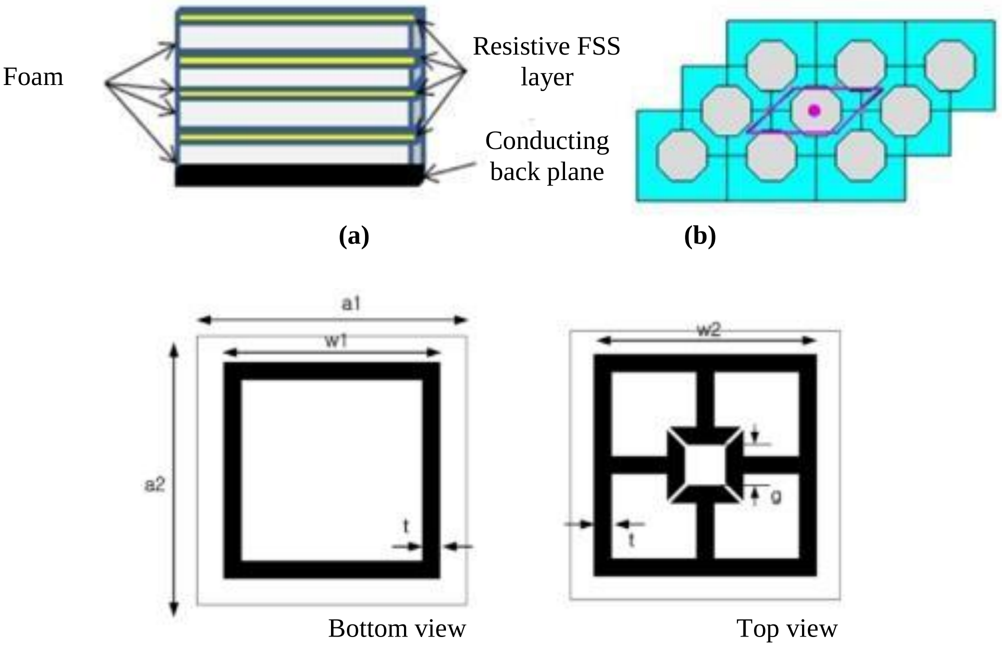


Fig. 2 - Different simple and symmetrical patches of metematerial absorber [81-83]

FSS based absorber were introduced in [72] where the FSS was printed on the substrate separated with foam spacer from the metal ground plane. A substrate with the thickness of $0.0045\lambda_{(10.37\ \text{GHz})}$ is used and an inkjet printing technique is applied to present the resistively loaded FSS elements. Similarly to [57], an inkjet printing method is imprinted on the $0.0074\lambda_{(2.45\ \text{GHz})}$ of flexible organic paper. However, this technology is used to develop low-cost flexible wearable metamaterial. This fabrication technique is cost-efficient, environmental friendly, and enables rapid fabrication due to its additive nature.

Eventually, Chandrika Sudhendra et al. explored on methods to widen the absorber bandwidth which is multi-layer FSS arrangements [85]. A frequency range from 1.7 GHz to 25 GHz is achieved which is around 23.3 GHz of bandwidth and is defined as an ultra-wideband absorber. Meanwhile, skewed lattice arrangements was studied by H. Hassan et al. where the bandwidth of absorber was relatively small 135 MHz is then being increased to 171 MHz [86]. Hong Ming Lee et al. introduces an alternative method to improve the bandwidth of the absorber by using double negative metamaterial [87]. The bandwidth of the absorber is expended from 470 MHz to 770 MHz by combining five unit cell structures with different geometric dimensions into a co-planar unit cell. Figure 3 shows the configurations on the methods used to enhance the bandwidth of the absorber which are multi-layer FSS arrangements, skewed lattice arrangements and double negative material.



(a) **(b)**

(c)

Fig. 3 - Methods to wideband the absorber (a) multi-layer FSS arrangements [85]; (b) skewed lattice arrangements [86]; (c) double negative material [87]

4. Conclusion

A review has been made of the development of metamaterial absorber. Some concluding observations from the review are given below.

- Such a symmetrical structures were designed to obtain insensitive polarization of absorber.
- Various techniques that been used to increase the bandwidth; skewed grid, multi-layer FSS arrangements and the design of double negative metamaterial absorber.
- Consideration of thin, ultra-thin and flexible metamaterial absorber was extensively studied.

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