Design of Broadband Microwave Absorber with 20 dB Absorption Bandwidth

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Abstract

A simple design configuration has been presented for broadband microwave absorber. The proposed designed structure is made using thin resistive film of indium tin oxide (ITO) to exhibits 20 dB absorption bandwidth in the frequency range of 7.36 GHz to 14.05 GHz with absorptivity nearly 99% at the normal incidence. It is first time when bandwidth is represented with respect to 20 dB of return loss instead of conventional 10 dB of return loss. This makes the design specification really stringent and needs extra attention while designing microwave absorber. Here the proposed structure is polarization insensitive and gives good oblique incidence behavior for both TE and TM. An equivalent circuit model is also derived to study the absorption mechanism of the structure.

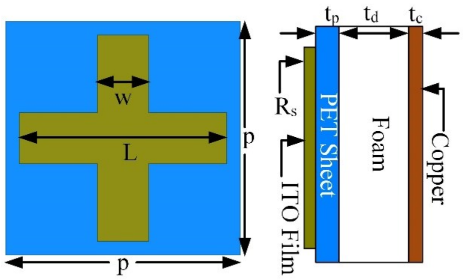
1. Introduction

Microwave absorbers have several applications in different domain such as stealth technology, reduction of radar cross section, thermal emitter, imaging devices, wireless communication and so forth [1]-[3].]. The conventional microwave absorber such as Salisbury screen is one of the oldest radar absorber, is formed by placing a resistive sheet at $\lambda/4$ distance in front of the conducting ground plane [4] but they exhibits narrow band absorption. By increasing number of resistive sheets with separation of $\lambda/4$ from each other broad bandwidth is achieved, (Jaumann absorber) but that was at the cost of increasing overall absorber thickness [5]. Pyramidal absorber are most widely used absorbing material for broadband applications [6]. They consist of typically thick materials with pyramidal or cone structure extending perpendicular to the surface and arranged in a regularly spaced pattern. They exhibit low reflection coefficient (40 dB of return loss), but pyramidal absorbers are bulky and fragile. Here we try to propose FSS based absorber whose reflection coefficient is below 20 dB. This is different from what we usually observe. Literature survey reflects that 10 dB return loss is the mostly reported. Here we focus on 20 dB return loss because this gives us an almost 99% absorption.

In this paper, a frequency selective surface (FSS) based broadband absorber with 20 dB absorption bandwidth is proposed for X-band application. The design is made of a layer of ITO resistive film coated on polymer substrate kept above the foam which acts as an additional intermediate dielectric spacer from the ground plane. The structure has the novelty of exhibiting 20 dB absorption bandwidth in a wide frequency range which gives nearly 99% absorptivity in the same range. It is found absorptive and polarization insensitive over a wide range of incident angles.

2. Structure Design

To achieve 20 dB absorption bandwidth the unit cell design of proposed broadband absorber is shown in Figure 1. The proposed absorber consists a layer of resistive film consisting of indium tin oxide (ITO) uniformly deposited on polyethylene terephthalate (PET) sheets (ε_r = 3.2 and $\tan\delta$ = 0.003) of thickness (t_p) 0.127 mm. A flexible, low-loss, polyethylene foam Eccostock PP2 [13], with relative permittivity (ε_r) of 1.03 has been used in between the resistive film and the ground plane. The overall structure has been terminated by a metal ground. The bottom ground plane is made of copper having conductivity $\sigma = 5.8 \times 10^7$ S/m and thickness of the ground plate (t_c) is 0.035 mm. A periodic pattern of patch type cross-dipole is designed at the top surface of resistive film. The top resistive film has a surface resistance (R_s) of 60 Ω/sq. The optimized geometric dimensions are: p = 13.8 mm, L = 12.2 mm, t_d = 6 mm, w = 3 mm.



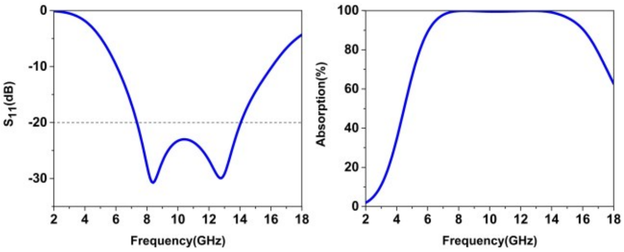
(a) (b)

Figure 1. Unit cell design of the proposed absorber structure: (a) top view and (b) side profile.

3. Simulated Responses

The proposed structure is simulated in finite element method based EM solver ANSYS HFSS using periodic boundary conditions. Figure 2(a) shows the reflection coefficient under normal incidence where reflectivity is less than -20 dB over the frequency range from 7.36 GHz to 14.05 GHz (bandwidth of 6.69 GHz), covering the entire X band and giving 99% absorptivity as shown in Figure 2(b). Transmission is zero due to copper laminated ground plane. The fractional bandwidth is obtained as 62.49% with respect to center frequency. Two resonance dips are also observed at 8.4 GHz and 12.8 GHz with reflection coefficients of -30.74 dB and -29.91 dB respectively. When an EM wave is incident on a structure the relation between absorptivity (A) and reflectivity (S_{11}) is given by:

$$A = 1 - |S_{11}|^2$$

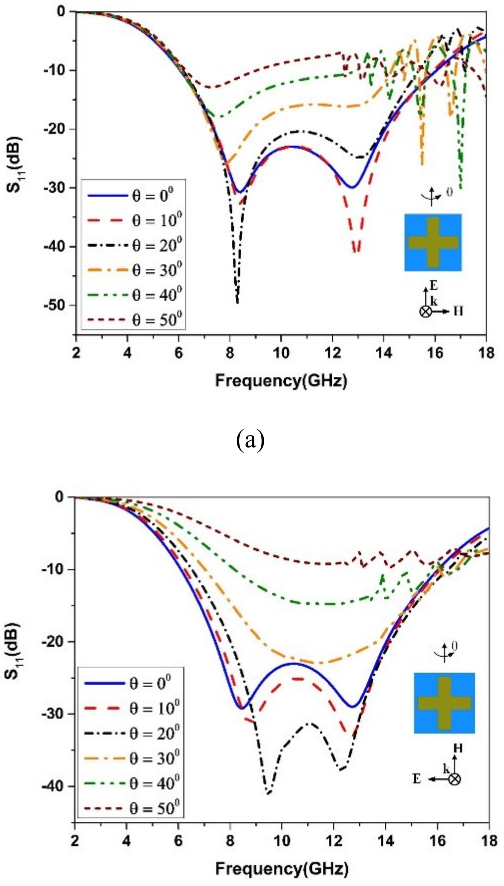


(a) (b)

Figure 2. Simulated responses under normal incidence (a) Reflection coefficient and (b) Absorptivity.

The absorbers are designed such that they absorb the maximum input radiation but at the same time the absorptivity should be less dependent of the incident angle. Therefore, we also examine the performance of the proposed absorber at different incident angles. The simulated reflection coefficient at different angles of incidence for TE and TM waves are depicted in Figure 3(a) and 3(b) respectively, to attain the 20 dB broadband absorption. In case of TE polarization as we increase the angle of incidence, the response still maintains the 20 dB broadband absorption up to 30° and bandwidth becomes narrow beyond 40°. Similarly in case of TM polarization, with the increase of angle of incidence, the reflection coefficient responses shift gradually to higher frequency bands but maintains the broadband nature of absorption bandwidth.

The proposed 20 dB broadband absorber is also studied for various polarization angles of the incident wave, under normal incidence as shown in Figure 4. Undoubtedly, the reflection coefficient is almost unchanged with the changes in polarization angles due to the four-fold symmetric nature of the design, thus making the structure polarization-insensitive.



(a)

(b)

Figure 3. Reflection coefficients under oblique incidence for (a) TE polarization and (b) TM polarization.

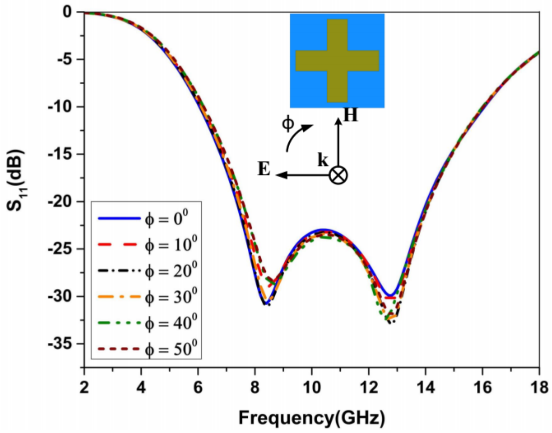
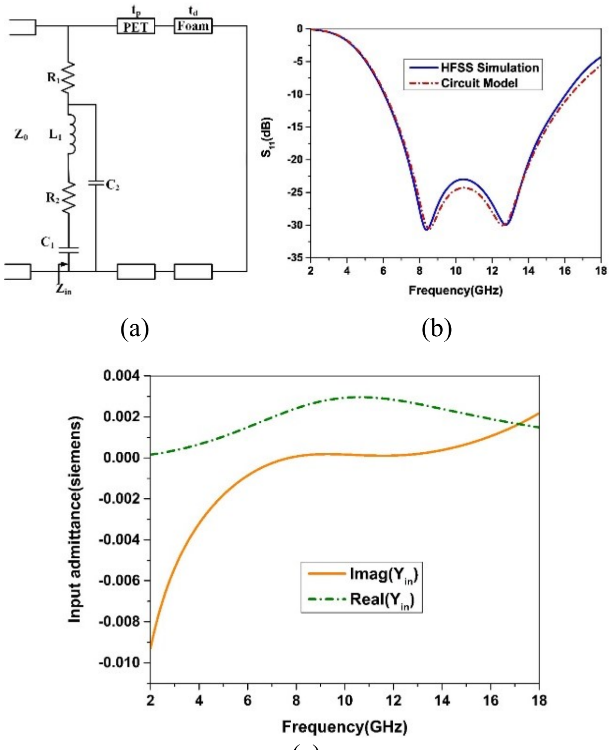


Figure 4. Reflection coefficient response under normal incidence for different angles of polarization.

An equivalent circuit model of the proposed structure is depicted in Figure 5(a) which consists of series resistor inductor & capacitor (*RLC*) circuits in parallel connection with the capacitance terminated by the metal ground. R_1 and L_1 represent the equivalent resistance and inductance, respectively, due to the narrow ITO strips present on the top surface, whereas R_2 is the equivalent resistance due to the wide ITO strips in the middle part of the top surface. C_1 is due to inter unit cell capacitance between two adjacent resistive strips and C_2 is the equivalent capacitance due to removal of ITO from the upper and lower halves of the top surface. To verify the equivalent circuit model of proposed absorber, the value of lumped resistance, inductance and capacitance of the circuit model are determined as: $R_1 = 80\ \Omega$, $L_1 = 4.15$ nH, $R_2 = 260\ \Omega$, $C_1 = 51.75$ fF, $C_2 = 10.8$ fF using curve fitting technique. The simulated reflection coefficient plot obtained from the equivalent circuit model is compared with the full wave analysis under normal incidence as displayed in Figure 5(b). The two resonance at 8.4 GHz and 12.8 GHz are presented where imaginary part of input admittance is vanished and real part of input admittance is close to free space input admittance value as shown in Figure 5(c), thus resulting is very good matching.



(a) (b)

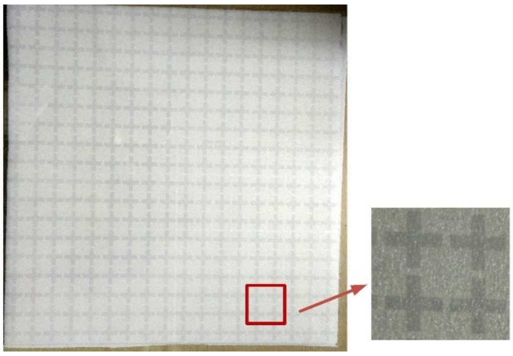
(c)

Figure 5. (a) Equivalent circuit model, (b) simulated reflection coefficient obtained by full wave analysis and equivalent circuit model, and (c) input admittance of the proposed absorber.

4. Experimental Results

In order to experimentally verify the proposed broadband structure, the top surface of the structure has been fabricated using ITO film coated on PET sheet of 0.127 mm thickness [12], then the pattern of top surface has been ablated from the required places using micromachining by excimer laser. Thus, a 24.84 cm x 24.84 cm sample consisting of 18 x 18 unit cell has been fabricated which is shown in Figure 6.

To measure the reflection coefficient of proposed structure, a pair of broadband horn antennas connected with an Agilent N5230A network analyzer is used. The measurement is performed using free space technique in anechoic chamber. As illustrate in Figure 7 the measured reflection coefficient exhibits -15 dB reflectivity which is not in good agreement with simulated results. Possible reasons for such deviation would be imperfections in fabrication. Thus another prototype will be fabricated & measured. Those experimental results will be included in final manuscript.



(a) (b)

Figure 6. (a) Photograph of fabricated Structure and (b) Zoom View of proposed absorber.

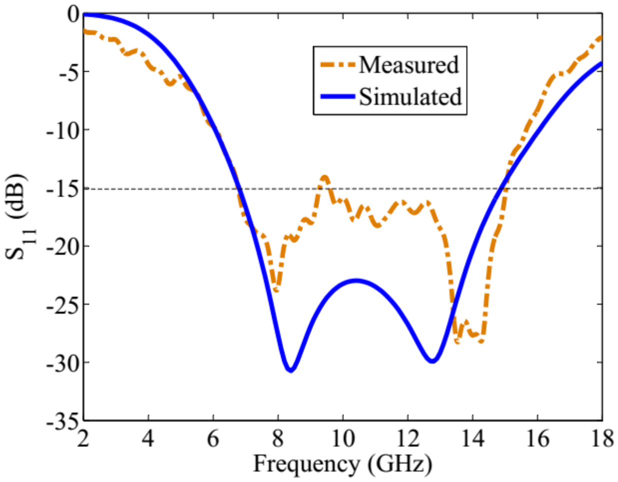


Figure 7. Measured and simulated reflection coefficient under normal incidence.

5. Conclusion

A design of FSS based broadband absorber has been presented, which is composed of structured ITO resistive film separated by foam spacer from the copper ground plane. The simulated results indicates that the structure exhibits 20 dB absorption bandwidth of 62.49%, thus obtained 6.69 GHz wide absorption from 7.36 GHz to 14.05 GHz and also achieved a higher absorptivity of almost 99% at normal incidence. Comparison of other broadband absorber with proposed structure is listed in Table 1, where λ_0 is free space wavelength at center frequency. It is polarization insensitive due to four-fold symmetry. The designed structure has good absorption effect under TE and TM incidence in a wide band as analyzed through simulated S-parameters. For proposed absorber an equivalent circuit model is presented to explain the absorption mechanism of the absorber. The proposed structure in this paper has great potential in stealth technology.

Table 1. Comparison of other broadband absorbers

Absorber Structure	Frequency Range (GHz)	Fractional bandwidth (%)	Absorption (%)	Thickness (mm)
[7]	3.96 – 8.16	69.31	90	6 (0.122 λ_0)
[8]	7.56 – 14.58	63.41	90	3 (0.110 λ_0)
[9]	6.06 – 14.66	83.01	90	5 (0.173 λ_0)
[10]	3.65 – 13.93	116.96	90	8 (0.235 λ_0)
[11]	5.00 – 12.00	82.00	90	4 (0.117 λ_0)
Proposed Absorber	7.36 – 14.05	60.78	99	6 (0.213 λ_0)

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