An Optically Transparent Microwave Broadband Absorber using Resistive Sheet

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***Abstract*— In this paper, an optically transparent broadband microwave absorber is presented, which is polarization-insensitive as well as angularly stable. The proposed structure is made of indium tin oxide (ITO) based resistive sheets, which exhibits absorption bandwidth (above 90%) from 3.6 to 15 GHz, thereby covering C, X, and partial Ku bands. The absorption mechanism of the structure has been studied by analyzing several parametric variations. The proposed design has also been fabricated and experimentally verified under normal incidence.**

***Keywords*— Circuit analog absorber; broadband absorber; High Impedence Surface; Transparent absorber.**

I. Introduction

Since past few decades, microwave absorbers are widely used in various commercial as well as military applications like radar cross section reduction, electromagnetic interference, electromagnetic compatibility, imaging device, wireless communication, and so forth [1], [2]. One of the earliest microwave absorbers reported was Salisbury screen, which had very narrow bandwidth [3]. Later, Jaumann absorber was developed to increase the bandwidth, but it suffers from large thickness. Other conventional microwave absorbers are usually bulky, and fragile, which restrict their uses from several applications [4], [5].

With the advent of circuit analog (CA) absorbers, reduced thickness could be achieved along with broadband response [6]. The general design of these structures comprises of periodic conductive patterns printed on the top surface of a dielectric followed by a ground plane as the bottom surface. These can be realized using lumped resistors, resistive paints, or resistive sheets. Lumped resistor based absorbers require large number of resistors, which need to be soldered in the periodic structures [7], [8]. This increases the overall cost of the design, and also introduces significant error while mounting the resistors. On the other hand, it is found to be tricky to maintain the required paint thickness uniformly in resistive paint based absorbers [9], [10]. Therefore, a better alternative for practical applications is the resistive sheet based CA absorbers, which are more reliable and less prone to fabrication error [11], [12].

In this paper, a polarization-insensitive broadband absorber is presented based on resistive sheets. The proposed design consists of different layers of ITO films separated by an air spacer, with the top layer being structured. The ITO films being optically transparent, the absorber can be used in several applications where optical transparency is required, such as touch panel controls, RFID systems, aircraft canopies etc. The novelty of the proposed structure lies in its improved bandwidth, and reduced thickness as compared to the existing transparent broadband absorbers. Furthermore, the design has been fabricated using laser micromachining, which shows good agreement between the measured result and the simulated response under normal incidence.

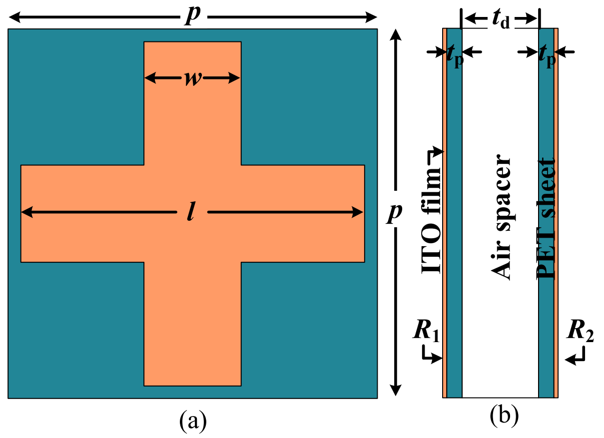

Fig. 1. Unit cell geometry of the proposed broadband absorber. (a) Top view, and (b) side view. The optimized dimensions are: p = 13.2 mm, l = 12.9 mm, w = 3.7 mm, t_d = 7 mm, t_p = 0.175 mm, R_1 = 60 Ω/□, and R_2 = 10 Ω/□.

II. Structure Design and Analysis

Figs. 1(a) and 1(b) depict the top and side views, respectively, of the unit cell geometry of the proposed broadband absorber. The proposed design consists of two resistive sheets separated by a dielectric substrate. The resistive layers are made of ITO films uniformly coated on Polyethylene Terephthalate (PET) (ε_r = 3.2 and $tan\ \delta$ = 0.003), whereas air spacer is used as the intermediate dielectric. The top surface ITO film is patterned as a periodic array of cross dipoles having surface resistance (R_1) of 60 Ω/□, whereas the bottom ITO film is a continuous sheet with surface resistance (R_2) of 10 Ω/□.

The proposed structure is simulated in Ansys HFSS using periodic boundary conditions, where the thin resistive films

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are modeled as 2-D sheets with specific surface resistance values. Since the bottom surface of the structure is formed by low surface resistance ITO films (instead of metal ground), both the reflectivity and transmissivity have to be considered while calculating the absorptivity of the structure (A = 1- $|S_{11}|^2$ - $|S_{21}|^2$). Fig. 2 shows the simulated response of the structure, which exhibits absorptivity above 90% over the frequency range of 3.6 GHz to 15 GHz, thus having fractional bandwidth of 122.58%. The design covers the entire C, and X bands, and partial Ku band in the microwave frequency range.

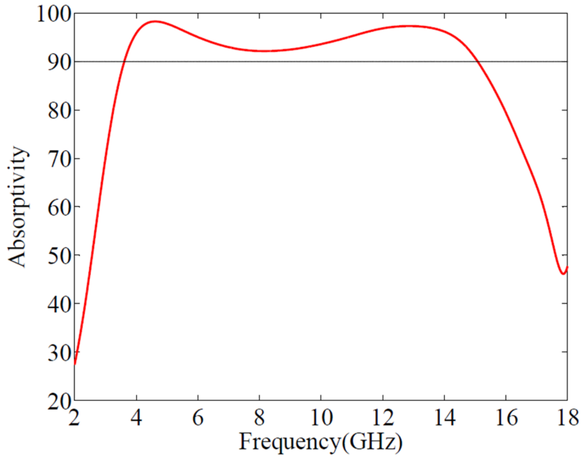

Fig. 2. Simulated absorptivity of the proposed broadband absorber.

The absorptivity plot shows two resonance frequencies, viz. 4.6 GHz (f_1) and 12.9 GHz (f_2), which can be explained using CA absorption mechanism. Fig. 3 depicts the equivalent circuit model of the proposed structure, where Y_d corresponds to the combined admittance of the three serially connected transmission lines, representing the cascaded PET-air-PET layers terminated by the resistive sheet at the bottom. Y_{in} is the input admittance of the structure, whereas Y_{fss} is the admittance of the top surface periodic pattern.

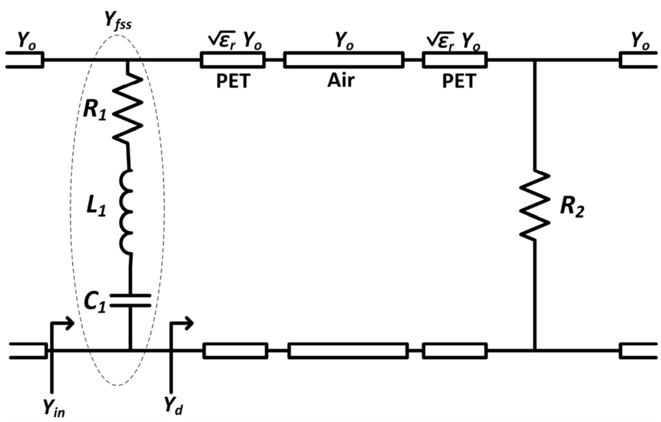

Fig. 3. Equivalent circuit model of the proposed broadband absorber.

As observed from Fig. 4, when the susceptance of the top surface gets cancelled with the susceptance of the grounded dielectric substrate (their values become equal in magnitude but opposite in sign), then the input admittance becomes purely real [13]. The susceptance values of top surface and the dielectric combinations are illustrated in Fig. 4, where the two quantities tend to nullify each other around two frequencies: one below the Salisbury screen zone (f_1) and the other above the Salisbury zone (f_2). The broadband response of the structure is thus obtained by bringing these two resonances together while optimizing the geometric dimensions of the design. It may be mentioned that the imaginary part of input admittance Im{Y_{in}} also vanishes at the Salisbury screen zone (9.50 GHz). However, the real part of input admittance Re{Y_{in}} is not matched with the free space admittance Y_0, and thus absorption reduces slightly around Salisbury screen zone.

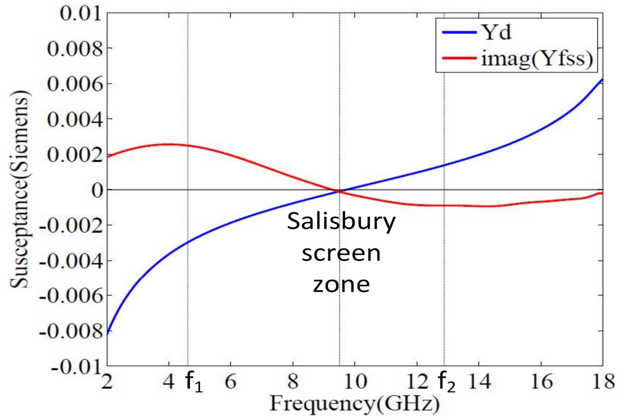

Fig. 4. Susceptance curves for the top surface ITO pattern and the cascaded dielectric substrates terminated by continuous ITO film.

Since the proposed design is four-fold symmetric, the structure exhibits identical absorption characteristics for different polarization angles as shown in Fig. 5. Therefore, the absorber can be considered as a polarization-insensitive structure, and hence is suitable for practical applications.

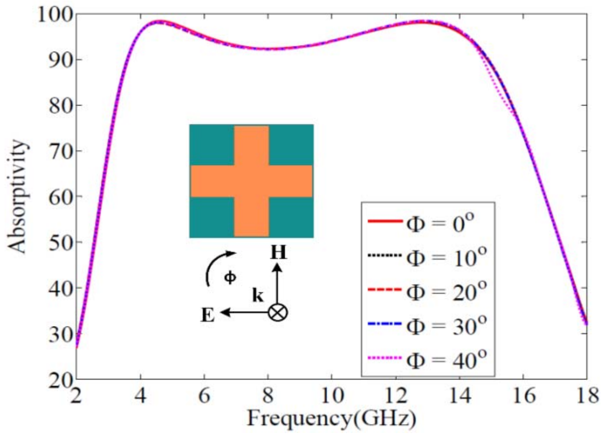

Fig. 5. Simulated absorptivity of the proposed structure for different polarization angles under normal incidence.

The structure has also been analyzed for different angles of incidence under TE and TM polarizations. While increasing the angle of incidence, the absorptivity decreases for TE polarized wave as observed from Fig. 6(a). On the contrary, the absorption bandwidth increases during TM polarization along with a shift in the response towards higher frequencies as depicted in Fig. 6(b). However, grating lobes appear in both the cases, as the operating wavelength becomes closer to the unit cell dimension with higher incident angles.

In order to further elucidate the absorption mechanism, the structure has been studied for different values of surface resistances of the ITO films used in the top and bottom layers. The responses for various values of R_1 and R_2 are plotted in Figs. 7(a) and 7(b), respectively. It is observed from Fig. 7(a) that while increasing the top layer resistance (R_1), the resonance frequencies are moved toward each other. This increases the overall absorption level, but also reduces the absorption bandwidth. Therefore, 60 Ω/□ has been selected as the optimum surface resistance, which gives rise to the widest 10 dB absorption bandwidth.

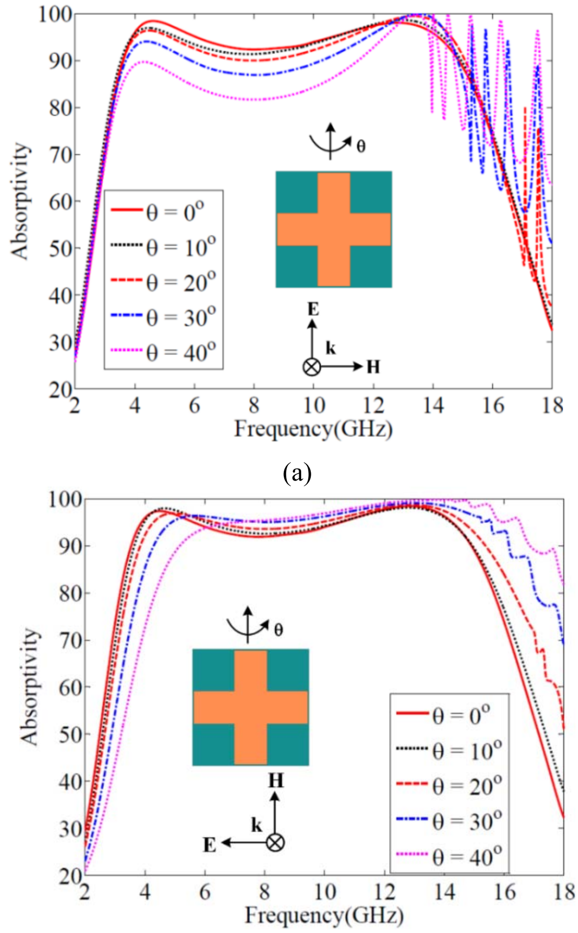

Fig. 6. Simulated absorptivity of the proposed structure for different angles of incidence under (a) TE polarization, and (b) TM polarization.

On the contrary, increase of the bottom layer surface resistance (R_2) decreases the absorptivity as depicted in Fig. 7(b). Since the higher values of the surface resistance deviates the bottom layer further away from the properties of an ideal ground plane, hence the absorption level starts reducing.

III. Fabrication and Measurement

In order to experimentally demonstrate the proposed absorber, the structure has been fabricated using commercially available ITO films (thickness ~1000 Å) uniformly deposited on PET sheets of 0.175mm thickness [14]. The pattern on the top surface has been achieved by ablating the ITO coating (R_1 = 60 Ω/□) from the required places using micromachining by excimer laser (Coherent Variolas Copres Pro 205F) [15]. Thus, a 10.5 cm × 10.5 cm sample consisting of 8 × 8 unit cells has been fabricated. Detailed fabrication procedure has been illustrated in Ref. [16].

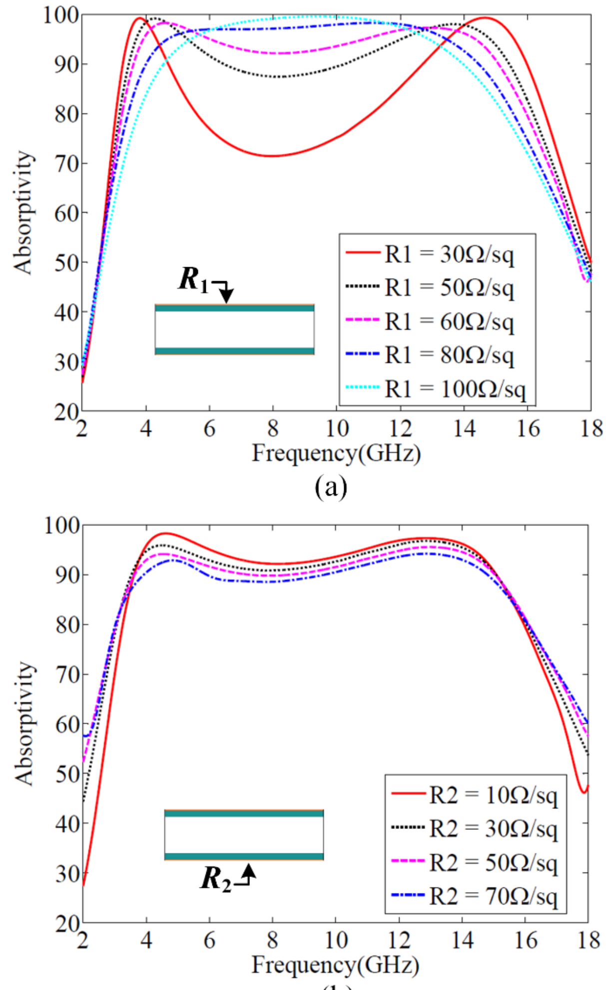

Fig. 7. Simulated absorptivity of the proposed structure for different values of surface resistance of (a) the top layer (R_1), and (b) the bottom layer (R_2).

Another ITO coated PET sheet having surface resistance of 10 Ω/□ has been used for the bottom surface. Then, a transparent square frame made from 7 mm thick acrylic glass is used to provide the air spacer. Both the top and bottom layer ITO sheets are stretched and taped with optically transparent adhesive on either side of the frame to realize the prototype. Fig. 8 shows the photograph of the fabricated structure, where the optical transparency of the ITO sheet is unperturbed by the FSS pattern as well as the micromachining process.

The fabricated structure has been measured in an anechoic chamber capable of emulating free space condition [17], [18]. Two broadband Horn antennas (LB-10180-SF), having frequency range from 1 to 18 GHz along with a vector network analyzer (Agilent N5230A) are used to measure the scattering parameters of the sample. Fig. 9 shows the measured absorptivity response of the proposed structure under normal incidence, which shows good agreement with the simulated result. The slight deviation between the responses can be attributed to finite size of the structure and the error tolerance of the commercially available ITO sheets.

Fig. 8. Photograph of the fabricated prototype.

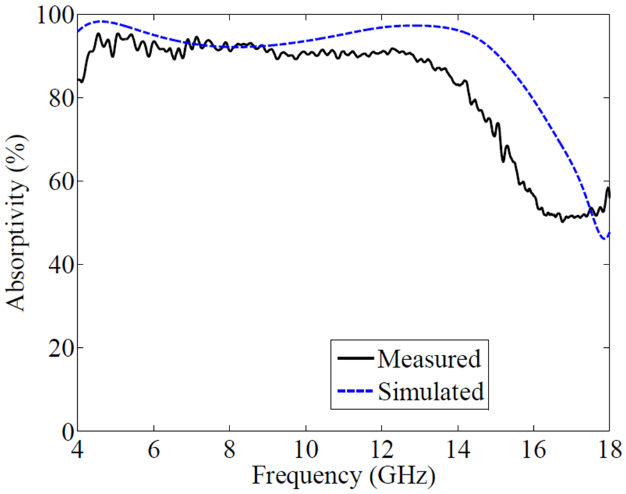

Fig. 9. Comparison of the measured and the simulated absorptivity responses of the proposed structure under normal incidence.

TABLE I. Comparison with other transparent absorbers (λ_g is the guided wavelength corresponding to the dielectric constant ε_r).

Absorber structure	Centre frequency (GHz)	-10dB bandwidth (GHz)	Dielectric constant (ε_r)	Thickness (λ_g)
[11]	9	2 (22.22%)	5	3.73 (0.25λ_g)
[12]	12.85	9.1 (70.8%)	2.25	3.85 (0.247λ_g)
[19]	11.5	7 (60.87%)	2.65	2.55 (0.157λ_g)
[20]	16.5	14 (84.84%)	3	5.5 (0.524λ_g)
Proposed	**9.3**	**11.4 (122.58%)**	**1**	**7.35(0.217λ_g)**

IV. Conclusion

In this paper, an optically transparent broadband absorber has been presented for microwave absorption. The structure exhibits 10-dB absorption bandwidth of 122.58%, which is significantly improved as compared to the earlier reported broadband absorbers. In addition, the design is polarization-independent, angularly stable, as well as experimentally validated under normal incidence. Therefore, the proposed absorber can be used for many practical applications, in particular where broad absorption is desired with good optical transparency.

References

[1] E. F. Knott, J. F. Shaeffer, and M. T. Tuley, *Radar Cross Section*, Raleigh, NC, USA: SciTech, 2004.

[2] G. Dayal, and S. A. Ramakrishna, "Design of multi-band Metamaterial Perfect Absorbers with stacked metal-dielectric disks," *J. Opt.*, vol. 15, p. 055106, 2013.

[3] W. W. Salisbury, "Absorbent body of electromagnetic waves," U. S. patent 2,599,944, Jun. 10, 1952.

[4] M. Park, J. Choi, and S. Kim, "Wide bandwidth pyramidal absorbers of granular ferrite and carbonyl iron powders," *IEEE Trans. Magn.*, vol. 36, no. 5, pp. 3272–3274, 2000.

[5] Y. Naito, and K. Suetake, "Application of ferrite to electromagnetic wave absorber and its characteristics," *IEEE Trans. Microw. Theory Tech.*, vol. 19, no. 1, pp. 65–72, 1971.

[6] B. A. Munk, *Frequency selective surfaces-theory and design*, New York, NY, USA: Wiley, 2000.

[7] M. Yoo, and S. Lim, "Polarization-independent and ultrawideband metamaterial absorber using a hexagonal artificial impedance surface and a resistor-capacitor layer," *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2652-2658, 2014.

[8] S. Ghosh, S. Bhattacharyya, and K. V. Srivastava, "Design, characterisation, and fabrication of a broadband polarization-insensitive multilayer circuit analogue absorber," *IET Microw. Antennas Propag.*, vol. 10, no. 8, pp. 850-855, 2016.

[9] F. Costa, A. Monorchio, and G. Manara, "Analysis and design of ultrathin electromagnetic absorbers comprising resistively loaded high impedance surfaces," *IEEE Trans. Antennas Propag.*, vol. 58, no. 5, pp. 1551–1558, 2010.

[10] S. N. Zabri, R. Cahill, and A. Schuchinsky, "Compact FSS absorber design using resistively loaded quadruple hexagonal loops for bandwidth enhancement," *Electron. Lett.*, vol. 51, no. 2, pp. 162-164, 2015.

[11] M. Grande, A. DOrazio, M. A. Vincenti, D. de Ceglia, G. V. Bianco, G. Bruno, and M. Scalora, *15th Mediterranean Microw. Symp. (MMS)*, Lecce, Italy, 30 november-2 December 2015, pp. 1-3.

[12] C. Zhang, Q. Cheng, J. Yang, J. Zhao, and T. J. Cui, "Broadband metamaterial for optical transparency and microwave absorption," *Appl. Phys. Lett.*, vol. 110, p. 143511, 2017.

[13] S. Ghosh, S. Bhattacharyya, and K. V. Srivastava, "Design and analysis of a broadband single layer circuit analog absorber," in *46th Proc. European Microw. Conf. (EuMC)*, pp. 584-587, London, UK, 2016.

[14] https://www.techinstro.com/ito-coated-on-pet/.

[15] S. N. Akhtar, S. Sharma, and J. Ramkumar, "Lasers based manufacturing," *5th International and 26th All India Manufacturing Technology, Design and Research Conference*, pp. 201-220, 2014.

[16] H. Sheokand, S. Ghosh, G. Singh, M, Saikia, K. V. Srivastava, J. Ramkumar, and S. A. Ramakrishna "Transparent broadband metamaterial absorber based on resistive films," *J. Appl. Phys.*, vol. 122, p. 105105, 2017.

[17] D. S. Wang, P. Zhao, and C. H. Chan, "Design and analysis of a high-selectivity frequency-selective surface at 60 GHz," *IEEE Trans. Microw. Theory Techn.*, vol. 64, no. 6, pp. 1694–1703, Jun. 2016.

[18] S. Ghosh, and K. V. Srivastava, "An angularly stable dual-band FSS with closely spaced resonances using miniaturized unit cell," *Microw. Wireless Compon. Lett.*, vol. 27, no. 3, pp. 218-220, Mar. 2017.

[19] K. Chen, L. Cui, Y. J. Feng, J. M. Zhao, T. Jiang, and B. Zhu, "Coding metasurface for broadband microwave scattering reduction with optical transparency," *Opt. Exp.*, vol. 25, no. 5, pp. 5571-5579, 2017.

[20] D. Hu, J. Cao, C. Zhang, T. Wu, Q. Li, Z. Chen, Y. Wang, and J. Guan, "Optically transparent broadband microwave absorption metamaterial by standing-up closed-ring resonators," *Adv. Opt. Mat.*, art. no. 1700109, 2017.