Design of a Groundless Metamaterial Absorber Based Sensor Integrated into X-Band Waveguide

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ABSTRACT

This work presents two different novel groundless absorber based sensor design to be integrated in a single mode waveguide. This metamaterial absorber is used in high resolution measurements of variations in the permittivity of the dielectric material where variations in the dielectric constant can be detected by considering the shift in the resonant frequency. The sensor is analyzed in terms of transmission, reflection and absorbance parameters. The first design configuration proposed gives transmission and reflection below -15 dB at the design frequency 11.5 GHz which concludes an absorption of 97%. As for the second proposed groundless configuration, it gives transmission and reflection below -30 dB 9.75 GHz which concludes an absorption of 99.7%. The reflection spectra for different values of superstrate permittivity for both configurations is reported and a comparison was conducted between both configurations and previously reported designs to summarize the efficiency of the proposed design structures.

KEYWORDS

Metamaterial; absorber; permittivity; sensor; waveguide; superstrate

1 INTRODUCTION

Metamaterials represent one of the most recent developments in the field of unconventional materials [1]. They are non-traditional materials that exhibit different parameters for any incident electromagnetic wave upon its surface [2]. For the past decade, MTMs have been extensively used for various applications including absorbers, resonators, antennas and sensors with reduced electrical size and improved functionality [3]. Absorbers are devices that disable some of the properties of electromagnetic waves including reflectivity, transmittance, and scattering [4]. The metamaterial absorber structures are arranged in such a way that the composite material, which is used as an absorber could absorb both magnetic and electric energies of the incident field perfectly [5]. The fundamental challenge is to maintain sufficiently high absorption levels under arbitrary excitation conditions regarding the incidence direction and polarization [6]. Within a single-mode waveguide, on the other hand, the directions of E-field vector and the propagation vector are already known. Therefore, there is no need for complicated absorber topologies when the structure is embedded into a waveguide [7].

In this study, a novel metamaterial absorber is proposed. The absorber based sensor embeds a pair of the absorber unit cells into a single mode waveguide. The topology used is to cover the absorber unit cells by a superstrate of thickness (tsen) and permittivity (εr) so as to measure the permittivity using the variation relation of the resonance frequency with respect to the layer permittivity. The first absorber configuration proposed used in this sensor design is the groundless version of the absorber proposed in [7]. Illustrated in Figure (1), the design structure for the first absorber configuration is composed of a cross-wire resonator and an 8 gap circular ring resonator on both sides of the substrate layer. Figure (2) illustrates the design structure of the second absorber configuration is composed of squared enhanced groundless version of first configuration in terms of absorption percentage and bandwidth. The design structure and parameters are presented in section 2 along with the absorption equations are explained. Followed by the simulation results for power absorption, reflection and transmission parameters. In section 3, a comparison between previous reported metamaterial absorber and the proposed configurations is presented. Finally, in section 4 a conclusion is reported to summarize the design configuration, simulated results and the comparison formulated.

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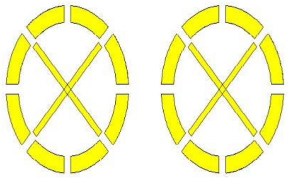

Figure 1: The first proposed sensor configuration.

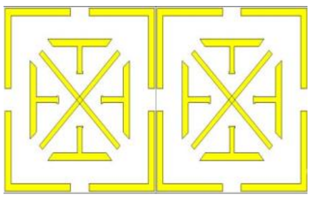

Figure 2: The second proposed sensor configuration.

2 DESIGN ANALYSIS

The suggested absorber configurations is a three layer design made up of copper metallic structure (top and bottom layers) and a dielectric substrate (middle layer). Copper metallization on both sides of the substrate has a conductivity of 5.8x107 S/m and thickness of 0.035 mm, whereas the thickness, loss tangent and relative permittivity of the FR4 substrate are 1.6, 0.025 and 4.3 respectively. The substrate perfectly fits within the X-band waveguide of dimensions 10.16 and 22.86 mm in the y and x directions, respectively. The design parameters for both configurations are shown in Figures (3 and 4) and defined in the tables I and II.

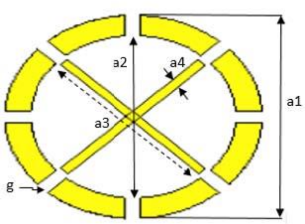

Figure 3: First configuration design structure.

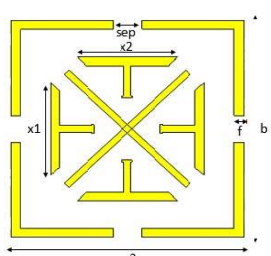

Figure 4: First configuration design structure.

Table 1: The design parameters for configuration 1.

Parameter	Length in mm
a1	9
a2	7.2
a3	6.8
a4	0.35
g	0.5

Table 2: The design parameters for configuration 2.

Parameter	Length in mm
x1	4.2
x2	4.2
f	0.4
sep	1.2

In order to achieve a near unity absorbance, the principle operation of the absorber is based on matching the designed absorber mettalic layer impedance to the free space impedance for perfect matching and minimized reflection. For grounded designs, the transmission of the incident wave is absorbed by a metal ground plane; hence a zero transmission is obtained [8]. However, in this study, groundless designs is proposed and the transmission coefficient should be included in calculations. The performance of the proposed absorber is evaluated by the absorption level and it can be calculated using the below presented equations [9].

$$A(\omega) = 1 - R(\omega) - T(\omega) \quad (1)$$
$$R(\omega) = |S_{11}|^2 \quad (2)$$
$$T(\omega) = |S_{21}|^2 \quad (3)$$

2.1 Simulation Results

Following the simulation setup in [7], the scattering parameters (S11, S21) and the absorption parameter of the MTM sensor are simulated using the CST Microwave Studio, within a computational volume defined by the X-band waveguide dimensions. As indicated in Figure (5), perfect electric conductor boundary conditions are imposed at the boundary surfaces coinciding with the metal walls of the waveguide, whereas input and output ports are defined at those surfaces which are perpendicular to the propagation direction.

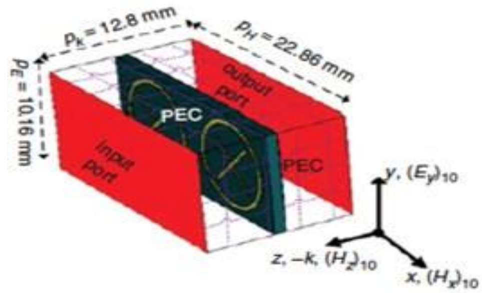

Figure 5: CST simulation setup [7].

As for the first proposed groundless configuration, Figures (6 and 7) shows transmission and reflection below -15 dB at the design frequency 11.5 GHz which concludes an absorption of 97% according to the above mentioned equations. This design configuration is fabricated as shown in Figure (8) in order to compare the measurement results to the simulation results and verify the proposed design structure efficiency. The measurements were conducted using the network analyzer as shown in Figure (9) to obtain the S-parameters and calculate the absorption percentage. Experimental results for absorption, transmission and reflection are plotted in Figure 10 - it shows an agreement with the simulated results as absorption value is 91% at frequency 11.9 GHz.

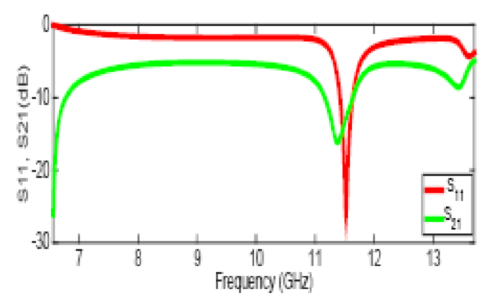

Figure 6: Simulated transmittance and reflectance for design 1.

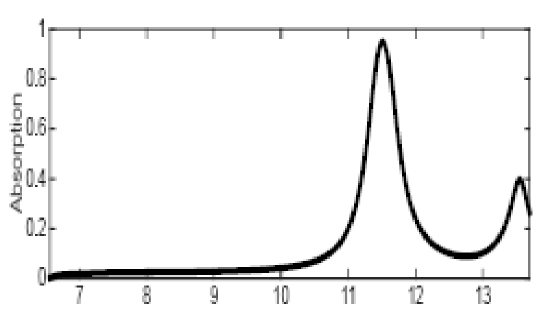

Figure 7: Simulated absorption for design 1.

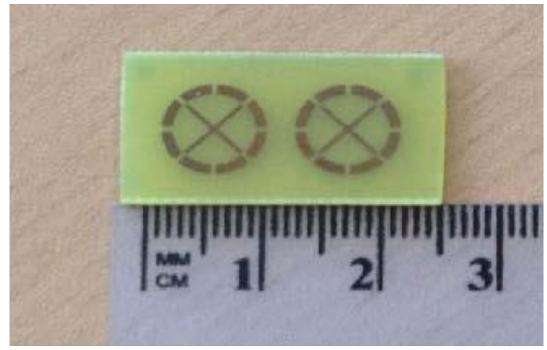

Figure 8: The fabricated structure of configuration 1.

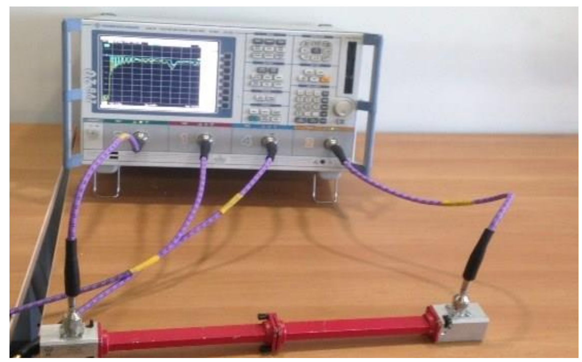

Figure 9: The S-parameter measurement setup.

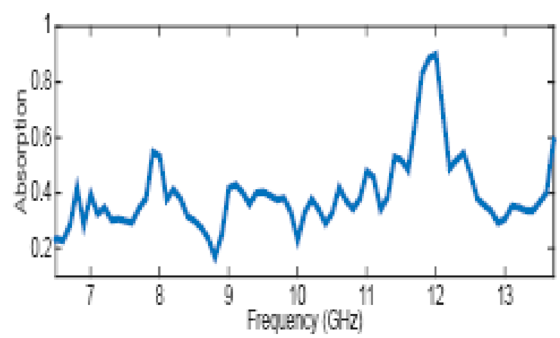

Figure 10: Experimental absorption.

As for the second proposed groundless configuration, Figures (12 and 13) shows transmission and reflection below -30 dB 9.75 GHz which concludes an absorption of 99.7% according to the above mentioned equations. This design structure is currently under the fabrication process for measurements and testing.

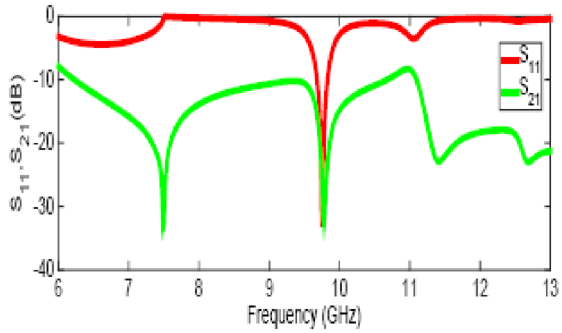

Figure 11: Simulated transmittance and reflectance for design 2.

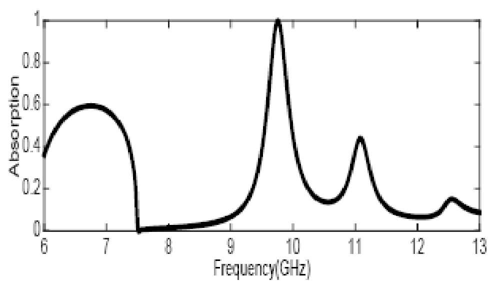

Figure 12: Simulated absorption for design 2.

2.2 Sensor Resolution

For the purpose of sensor resolution assessment for both design configurations, a superstrate layer is added on top of the structure. The thickness (tsen) of the sensing superstrate was kept constant at 0.1 mm. The |S11| spectra were simulated for different values of superstrate permittivity and the results are plotted in Figures (14 and 15). As presented, the resonance frequency is shifted with respect to different values of the permittivity of the superstrate with constant thickness.

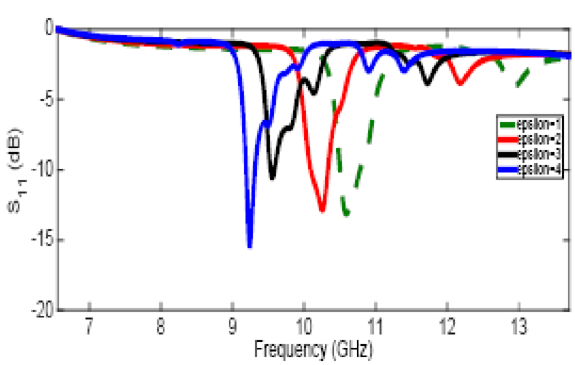

Figure 13: The reflection parameter with respect to different values of ε_r for the first configuration.

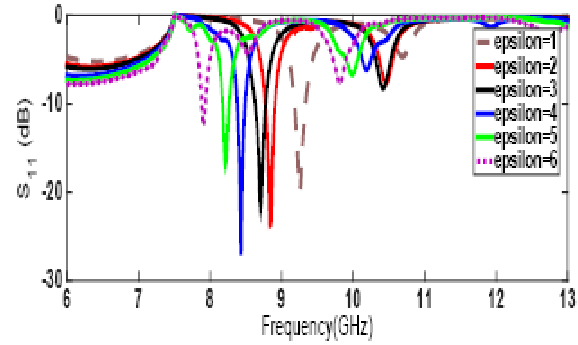

Figure 14: The reflection parameter with respect to different values of ε_r for the second configuration.

3 COMPARISON RESULTS

In this section of the study, a previously reported grounded design [7] will be used as a comparison to the current proposed groundless design configurations. The comparison is shown in the table below and conducted in terms of absorption efficiency, sensor resolution and the frequency of operation.

Table 3: The design parameters for configuration 2

	Design 1	Design 2	[7]
Absorption efficiency	97%	99%	99%
Sensor resolution	ε_r = 1 to 4	ε_r = 1 to 6	ε_r = 1 to 6
Frequency of operation	11.5 GHz	9.75 GHz	11.9 GHz
Metal structure	Groundless	Groundless	Grounded

4 CONCLUSIONS

This work presents two groundless absorbers designed in the X-band to be used in sensor applications. A pair of the absorber unit cells is patched on the front and backside of the substrate to give the groundless symmetric design. It is required to minimize both reflection and transmission in order to reach maximum absorption. As for the first design structure, the absorption reaches 97% at frequency 11.5 GHz for simulation and 91% at frequency 11.9 GHz according to the measurements. As for the second design structure, the absorption reaches 99.7% at 9.75 GHz. Fabrication prototypes of the second absorber structure is currently under the process of measurement and testing. Variation of the resonance frequency with respect to sensing layer permittivity with a constant superstrate thickness is plotted for both designs and a table of comparison is presented to verify the proposed designs efficiency.

REFERENCES

[1] R. Marqu´es, F. Mart´ın, and M. Sorolla, "Metamaterials with Negative Parameters: Theory, Design, and Microwave Applications," *John Wiley & Sons*, New York, 2008.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[2] J. B. Pendry , A. J. Holden , D. J. Robbins , W. J. Stewart, *IEEE Trans. Microwave Theory Tech. 1999* , Vol. 47 , 2015.

[3] E. Ekmekci, and E. Turhan-Sayan. : 'Multi-functional metamaterial sensor based on a broad-side coupled SRR topology with a multilayer substrate', *Appl. Phys. A, Mater*, 2013, 110, pp. 189–197.

[4] C.M. Watts, X.L. Liu & W.J. Padilla. "Metamaterial Electromagnetic Wave Absorbers". *Journal of Advanced Material*, Vol. 24, 98-120, 2012.

[5] N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, and W. J. Padilla, "Perfect metamaterial absorber," *Phys. Rev. Lett.*, Vol. 100, 207402-1-4, May 2008.

[6] F. Bilotti, L. Nucci, and L. Vegni. : 'An SRR-based microwave absorber', *Microw. Opt. Technol. Lett.*, 2006, 48, pp. 2171–2175.

[7] C. Sabah, O. Turkmen-Kucuksari and G. Turhan-Sayan, "Metamaterial absorber-based sensor embedded into X-band waveguide," in *Electronics Letters*, vol. 50, no. 15, pp. 1074-1076, July 17 2014. doi: 10.1049/el.2014.1753.

[8] F. Dincer, M. Karaaslan, E. Unal, K. Delihacioglu, and C. Sabah. : 'Design of polarization and incident angle insensitive dual-band metamaterial absorber based on isotropic resonators', *Prog. Electromagn. Res.*, 2014, 144, pp. 123–132.

[9] T. S. Almoneef, and O. M. Ramahi, "Metamaterial electromagnetic energy harvester with near unity efficiency," *Appl. Phys. Lett.*, Vol. 106, 153902, 2015.