Frequency Selective Surface Microwave Absorber for WLAN Applications

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***Abstract*—Many researchers are studying electromagnetic wave absorbers. This is mainly due to the large number of existing wireless systems. The absorbers find numerous applications, from commercial to military systems. Allied to this, also the interest in Frequency Selective Surfaces (FSS), which are, basically, spatial filters, grows. Thus, this work proposes the use of FSS to design electromagnetic absorbers. In this study, Altair FEKO software was used. A parametric analysis is presented, demonstrating the understanding of the physical dimensions' effects. A prototype is built to validate the analysis performed. A good agreement between the numerical and experimental results is observed. Furthermore, measured results show that the absorber panel suppresses reflection (below – 10 dB) from 1.97 GHz to 3.15 GHz, covering the entire ISM band.**

***Index Terms*—Frequency selective surfaces, microwave absorber, WLAN**

I. Introduction

The increase in the number of electronic systems results in a corresponding growth in electromagnetic interference. These problems include false images, increased radar disorder, and reduced performance due to coupling between systems [1].

Microwave absorbers can be effectively used to minimize these types of problems. In some applications, such as in the military area, there is always a need to reduce the radar cross-section factor (RCS). As an example, one can cite the use of microwave absorber devices that play a key role in Stealth airplane technology [2].

For wireless security in buildings, traditional microwave absorbers, as Salisbury screen, can be placed in walls to provide isolation and reduce interference in nearby [3]. However, the ground plane of Salisbury screen may give rise to heavy reflections from its surfaces resulting in additional multipath, delay spread, and signal degradation [4].

Recently, we have observed an increase in the interest in using Frequency Selective Surfaces (FSS) in construction of microwave absorbers, since this type of structure allows an intelligent shielding, which absorbs only the frequency range of interest, becoming transparent to the other frequencies [5]-[9]. Therefore, with this structure we do not have additional multipath, delay spread, and signal degradation for the mobile communication frequencies, for example.

In this paper we propose a dual-layer FSS that is similar to a Salisbury screen with an important difference: the ground plane is substituted by a traditional FSS, which reflects only frequency range of interest. The advantage of the proposed structure is the use of a resistive layer, which does not spread, but absorbs signals in the frequency of interest, avoiding the increase of multipath, for example. A similar study was proposed by Rafique et al in [10], where unit cell circular patches were used to absorb WLAN signals in the 5 GHz band. In contrast to the study proposed in [10], our work presents experimental evidence and makes use of an extensive parametric study to define the optimal dimensions of the structure.

II. State of Art

Over the last few years, electromagnetic absorbers have attracted a massive attention from industry and academy for many applications, such as EMI/EMC issues, stealth techniques, among others [11]- [16]. Although the absorbers are well-defined engineering structures, many advances related to these structures are constantly published, with significant performance improvements presented. The main studies aim mainly to reduce volume and weight and maintain broadband absorption. In [15] the authors designed an ultra-wideband electromagnetic absorber based on the concept of metasurface Salisbury screen. The proposed absorber presented absorptivity above 88% from 3.74 to 18.5 GHz, which represents a fractional bandwidth of approximately 133%. In addition, the structure exhibits angular stability and polarization insensitivity. To obtain performance improvement, the metal ground was replaced by a metasurface and genetic algorithm was used to optimize the elements of the metasurfaces.

An absorber based on the metamaterial concept for sensing applications of grain with a non-destructive approach in the microwave range was presented by [16]. To demonstrate the viability of the method, the authors performed simulations and measurements and showed that the structure can perform quality control of grain by measuring variations in the resonance frequency.

In [17] the authors used a hybrid electromagnetic absorber for the in-band radar cross section reduction of a Vivaldi antenna. Results showed reduction of monostatic RCS values up to 27 dB for both polarizations without significant change in the antenna radiation characteristics.

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The design of a metamaterial absorber, which can be used to improve the performance and reliability of UHF RFID systems, was proposed by [18]. The structure exhibits absorption over 90% across the band, with relative bandwidth of approximately 14%, covering the entire band of the UHF RFID system. In addition, the structure is miniaturized and exhibits stability for TE e TM polarizations at low angles of incidence.

In [19], it was proposed the use of an absorber to improve electromagnetic environment pollution in a novel wireless inter/intra-chip communication channel system. The authors have shown that in addition to eliminating environmental pollution from the electromagnetic wave, the absorber layer can improve the propagation of the signal.

Another class of structures used to block electromagnetic signals is band-stop filters based on frequency selective surfaces. Studies have shown the shielding efficiency of these structures when applied in constructions, providing a radio secure environment. These structures allow the signal propagation in other bands, but may cause additional multipath or signal degradation due to reflection [20]- [22].

III. Microwave Absorber Design

The structure of the electromagnetic absorber is illustrated in Fig. 1. The layers are printed on FR4 dielectric substrates with 180x180mm^2 of area and relative electrical permittivity of 4.4. Bandstop filter characteristics are achieved by using a FSS of conducting square loops on a FR4 substrate with a thickness of 1.6 mm. Physical dimensions of the square loops and the periodic spacing, are depicted in Fig. 1. The function of this conventional FSS layer is to act as a reflector for WLAN signals, at 2.45 GHz, while passing another service signals. Then, the absorption characteristics are achieved by placing a second FSS layer consisting of resistive square loops, approximately 27 mm in front of the conducting FSS layer. A Nelco-4000 substrate, with a thickness of 0.254 mm, dielectric constant of 3.6 and loss tangent of 0.009, supported by a FR4 substrate was used and the surface resistance of resistive square loops is R_S = 50 Ω/□.

The FSS microwave absorber is designed to absorb signals in the 2 to 3 GHz frequency range. The resistive FSS absorbs the incident signals as well as the reflected signals from the conductive FSS. Other frequencies pass through the structure with a minimal or none interference. The resonance characteristic of the FSS depends mainly on the geometry. The square loop design was selected because it provides an angular stability and independence of polarization. In addition, the dielectric superstrate reinforces the angular stability characteristic for both, vertical and horizontal polarization without compromising absorption performance [23], [24]. A broad parametric study was carried out to evaluate how the design variables influence the frequency response of the microwave absorber, both from the point of view of reflection and transmission. The values of the parameters presented in this work were obtained based on this parametric study, performed in the software FEKO - Altair HyperWorks.

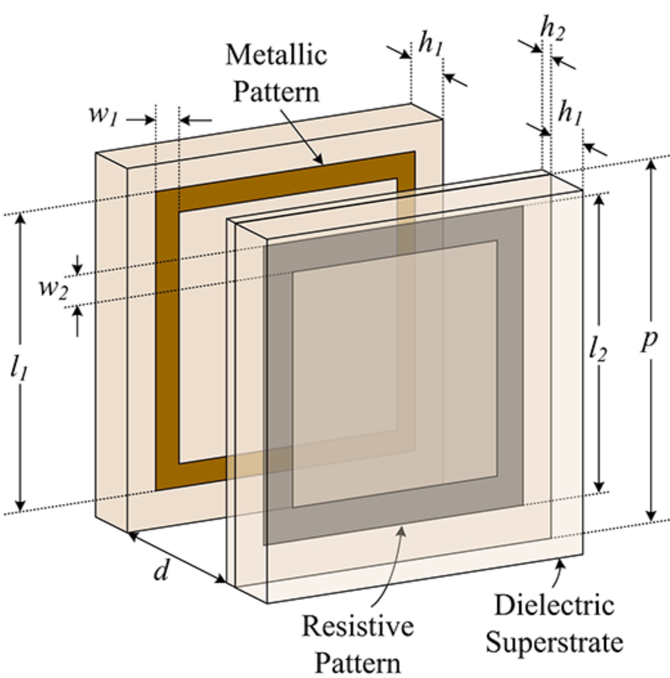

Fig. 1. Microwave absorber configuration composite by metal and resistive layers.

IV. Parametric Analysis

The resonance characteristic of the FSS depends mainly on the geometry. The square loop design was selected because it provides an angular stability and independence of polarization. In addition, the dielectric substrate reinforces the angular stability characteristic for both, vertical and horizontal polarization without compromising absorption performance [23], [24].

A parametric analysis was carried out to understand how the physical dimensions influence the frequency response of the transmission and reflection coefficients of the structure.

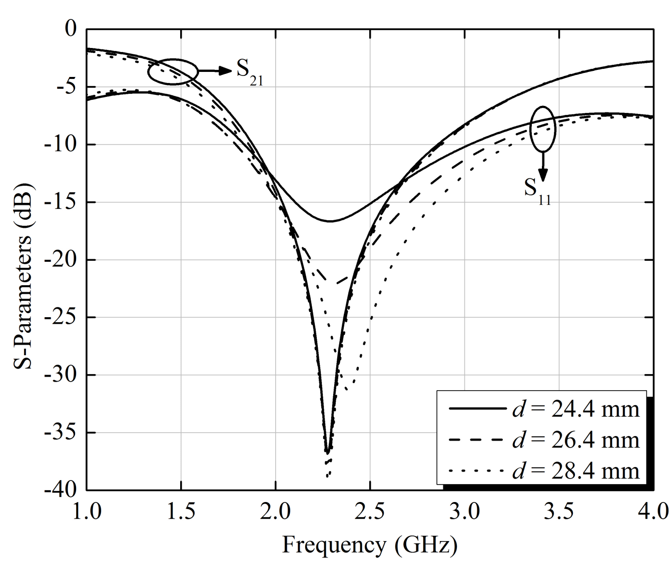

Fig. 2. S-parameters for different values of d.

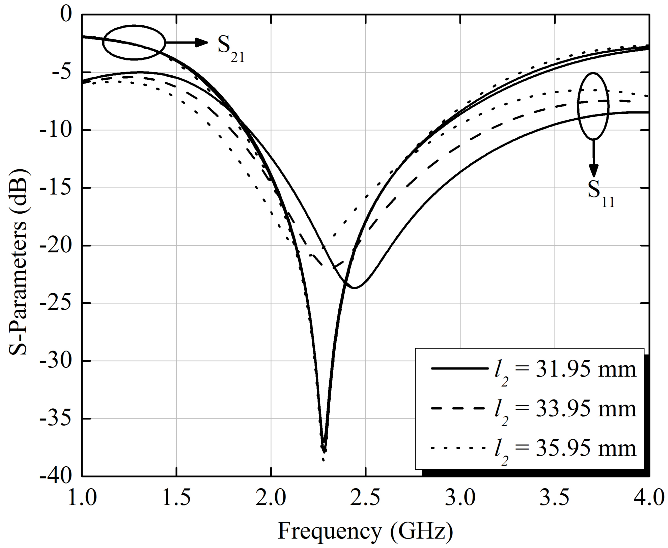

Fig. 3. S-parameters for different values of l_2.

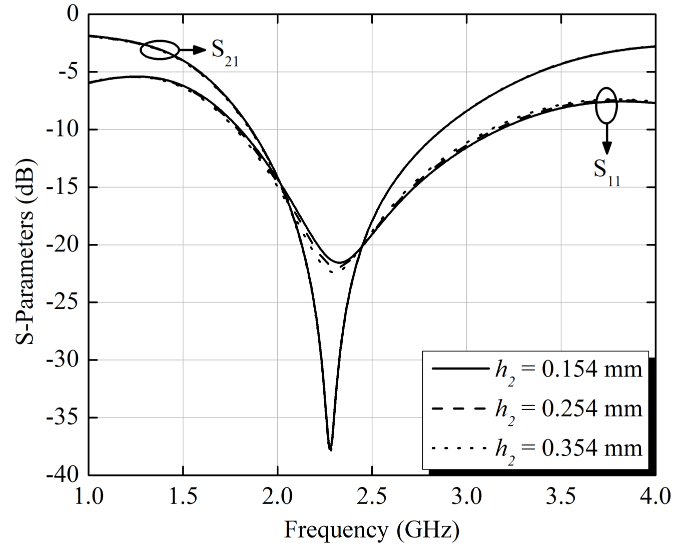

Fig. 5. S-parameters for different values of l_2.

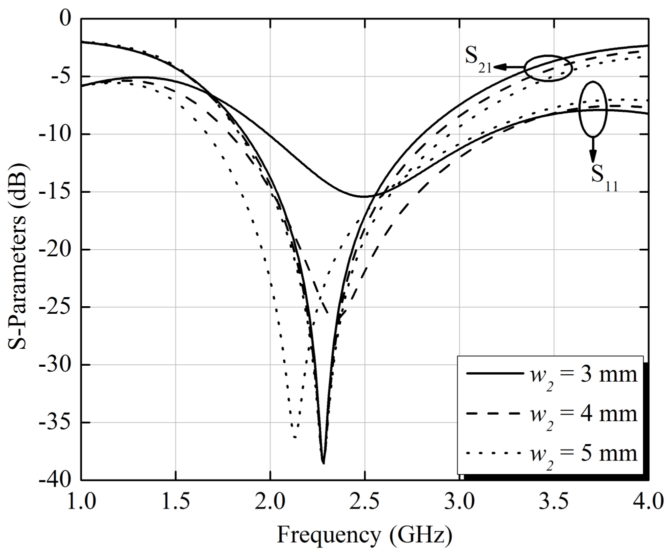

Fig. 4. S-parameters for different values of w_2.

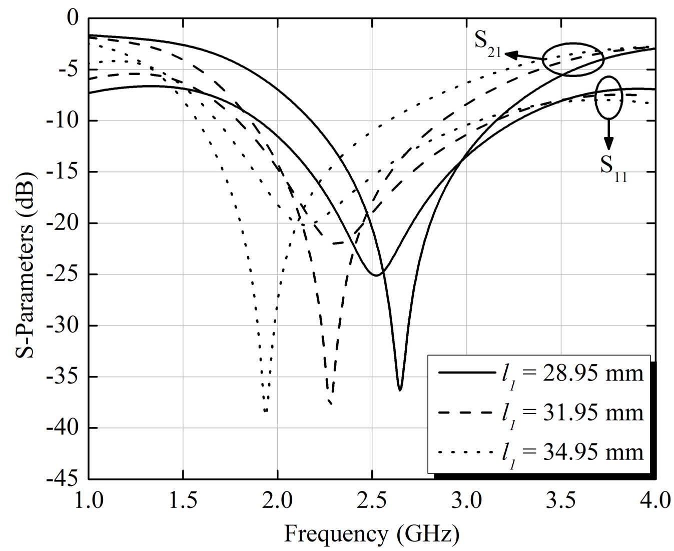

Fig. 6. S-parameters for different values of l_1.

An important parameter in design of this type of absorber is the distance of separation, d. Based on wavelength we chose three values for d: 24.4 mm, 26.4 mm, and 28.4 mm. For all parametric analysis, the periodicity was p = 42.5 mm for both FSS and for all parametric analysis of resistive FSS, conducting layer has dimensions: l_1 = 31.95 mm, w_1 = 2 mm, and h_1 = 1.6 mm. Resistive layer has dimensions: l_2 = 33.95 mm, w_2 = 4 mm, and h_2 = 0.254 mm. A FR4 superstrate of 1.6 mm thickness was used for layer 2. We can observe that d has a great influence on bandwidth and resonance frequency, for the case of reflection coefficient. When d increases, the bandwidth and resonance frequency increase, while the transmission coefficient remains, as illustrated in Fig. 2.

Another investigation is on the effect of square loop length, l_2, of the resistive layer. We chose three values for l_2: 31.95 mm, 33.95 mm, and 35.95 mm. Dimensions of conducting layer remain. Dimensions of resistive layer are: w_2 = 4 mm, and h_2 = 0.254 mm. The gap between two layers was d = 26.4 mm. We can observe that l_2 has a medium influence on resonance frequency, while bandwidth almost did not change, for the case of reflection coefficient, while transmission coefficient remains, as illustrated in Fig. 3.

The third effect parameter analyzed was the width of the resistive square loop strip, w_2. We chose three values for w_2: 3 mm, 4 mm, and 5 mm. Other dimensions of the resistive layer are: l_2 = 33.95 mm, and h_2 = 0.254 mm. The gap between two layers was the same of the past case. We can observe that w_2 has no influence about the transmission coefficient, while for reflection coefficient this parameter has a great influence on resonance frequency and bandwidth, when w_2 increases, resonance frequency and bandwidth decrease, as illustrated in Fig. 4.

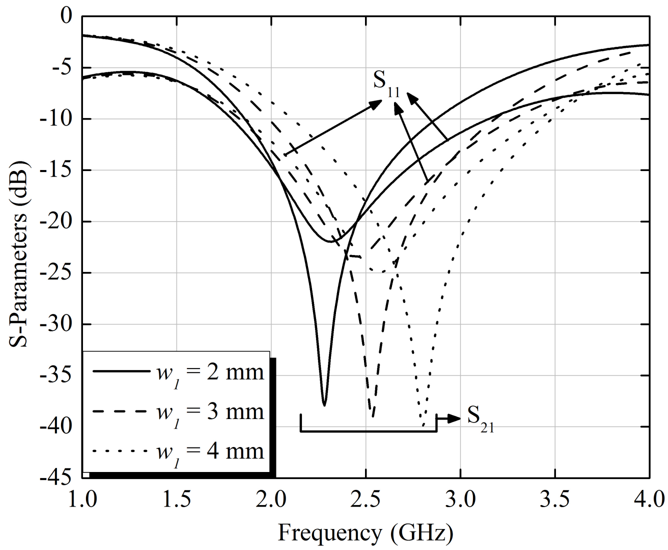

Fig. 7. S-parameters for different values of w_1.

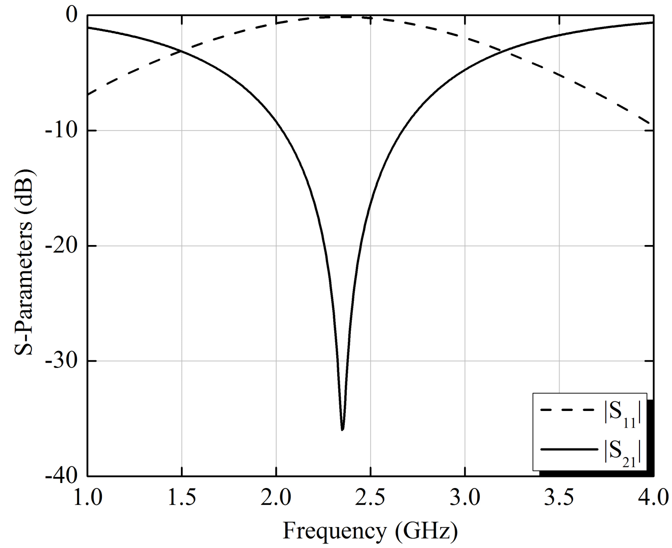

Fig. 9. S-parameters simulation of conducting FSS.

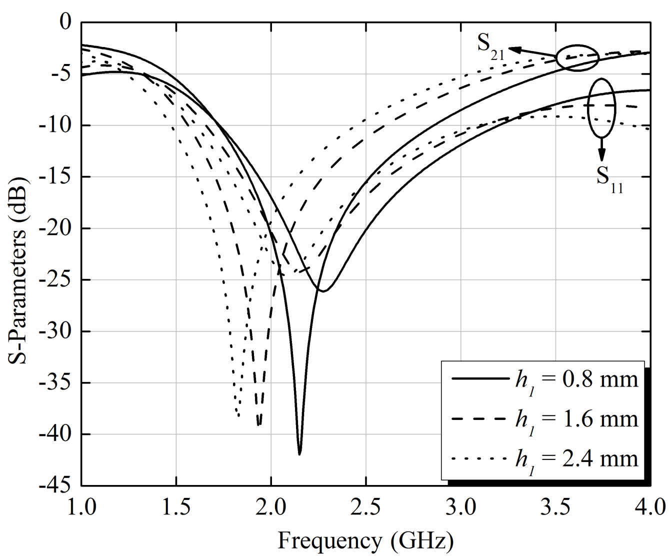

Fig. 8. S-parameters for different values of h_1.

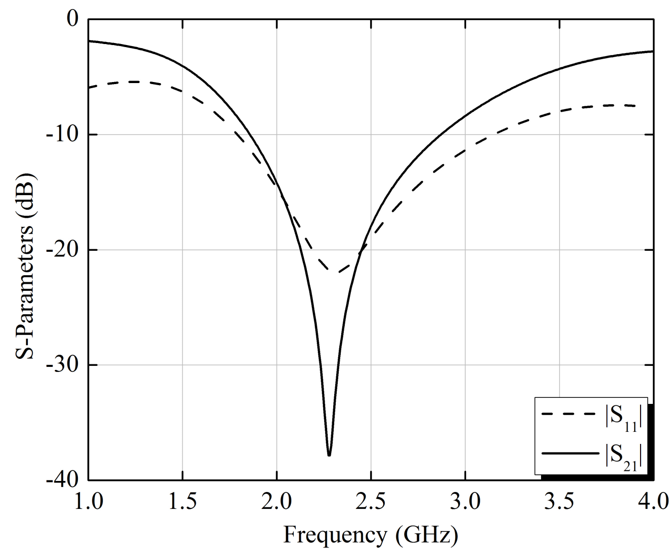

Fig. 10. S-parameters simulation of absorb/transmit structure.

The fourth effect parameter analyzed was the thickness of the dielectric resistive layer, h_2. We chose three values for h_2: 0.154 mm, 0.254 mm, and 0.354 mm. For this parametric analysis, the resistive layer has dimensions: p = 42.5 mm, w_2 = 4 mm e l_2 = 33.95 mm. The gap between layers was 26.4 mm. The effect of h_2 on reflection and transmission coefficients is negligible, as illustrated in Fig. 5.

Now, we will do a parametric analysis of the conducting FSS. The effect of the conductive square loop length, l_1 is considered. We chose three values for this parameter: 28.95 mm, 31.95 mm, and 34.95 mm. For next analysis the resistive layer has dimensions: p = 42.5 mm, l_2 = 33.95 mm, w_2 = 4 mm and h_2 = 0.254 mm. Conducting layer has dimensions: w_1 = 2 mm, and h_1 = 1.6 mm. The gap between two layers was 26.4 mm. As we can see, in Fig. 6, bandwidth and resonant frequency are strongly affected by l_1, for both reflection and transmission coefficients.

In Fig. 7 we can see the effect of conductive square loop strip width, w_1. We chose three values for w_1: 2 mm, 3 mm, and 4 mm. For this parametric analysis, conducting layer has dimensions: l_1 = 31.95 mm, and h_1 = 1.6 mm. The gap between two layers was 26.4 mm. As we can see, bandwidth and resonance frequency are proportional to w_1, and a great variation in reflection and transmission coefficients is observed.

We also investigated the influence of the dielectric thickness of the conducting layer, h_1, on frequency characteristics. Three values were chosen for h_1: 0.8 mm, 1.6 mm and 2.4 mm. Other dimensions of conducting layer were: l_1 = 31.95 mm and w_1 = 2 mm. Resistive layer has dimensions: p = 42.5 mm, l_2 = 33.95 mm w_2 = 4 mm, and h_2 = 0.254 mm. The gap between two layers was 26.4 mm. As we can see, in Fig. 8, the parameter h_1 has little influence on reflection coefficient and it has a moderate influence on transmission coefficient, reducing the resonance frequency and producing a negligible variation in bandwidth.

V. Absorber Simulations and Measurements

The structure dimensions were chosen to provide a more appropriate frequency response. Periodicity for both FSS, p, was 42.5mm. The dielectric used in the FSS conducting layer was the FR4, with dielectric constant ε_r = 4.4 and thickness h_1 = 1.6 mm. For the resistive layer, a Nelco-4000 substrate with thickness h_2 = 0.254mm was used. The FSS layers are composed of square loop arrays. The conducting layer has dimensions: l_1 = 31.95 mm and w_1 = 2 mm, while resistive layer is parameterized as: l_2 = 33.95 mm and w_2 = 4 mm. In addition, between the two layers there is a separation d = 26.4 mm, which is in according to specification of a quarter-wave distance for the frequency of operation used. The surface resistance of resistive layer is R_S = 50 Ω/□. Finally, the resistive FSS has a FR4 dielectric superstrate of with thickness of 1.6 mm for support purposes.

To investigate the frequency characteristics of the conducting FSS structure, electromagnetic simulations were made, and they are show in Fig. 9. The results show the characteristic behaviour of a stop-band structure, with an attenuation pole as expected. As it can be seen, the FSS transmission coefficient magnitude is almost – 36 dB in a frequency close to 2.45 GHz, while the reflection coefficient magnitude remains around – 0.2 dB which is a good insertion loss.

The result of the absorber FSS structure is shown in Fig. 10. It is clear from the results that the structure does not spread incoming signals, but attenuates waves through absorption. Simulated results show that the absorber panel suppresses reflection (below – 10 dB) from 1.79 GHz to 3.15 GHz. The resistive FSS design clearly provides absorption for the

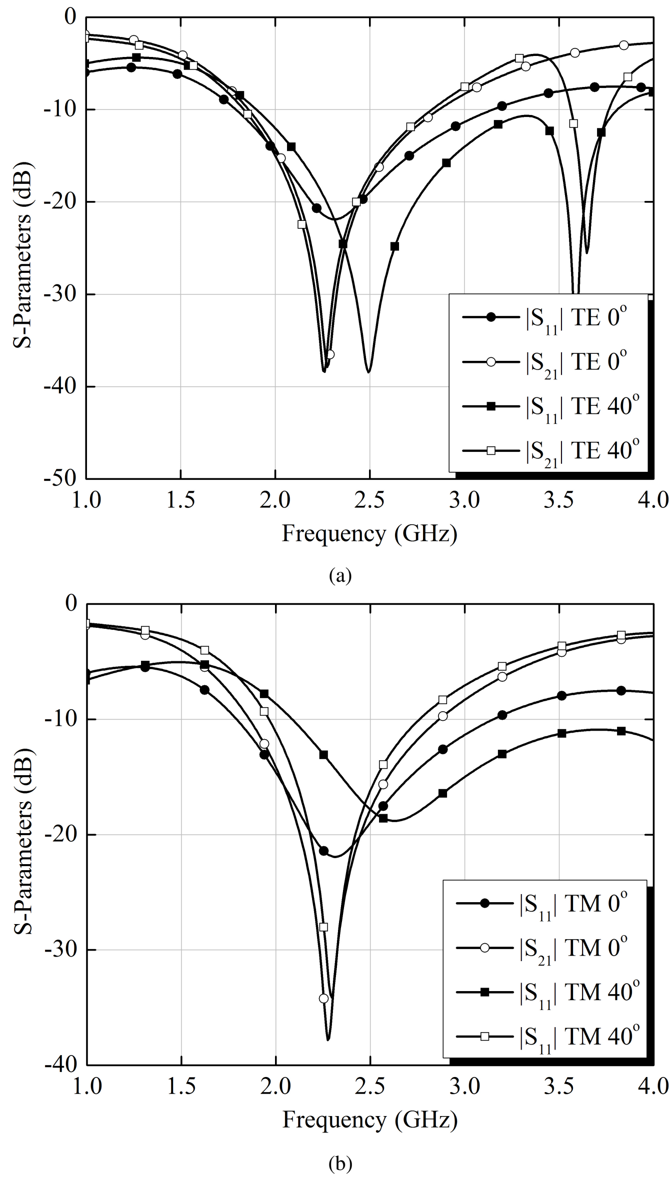

Fig. 11. S-Parameters under normal and oblique incidence for both (a) TE and (b) TM polarization.

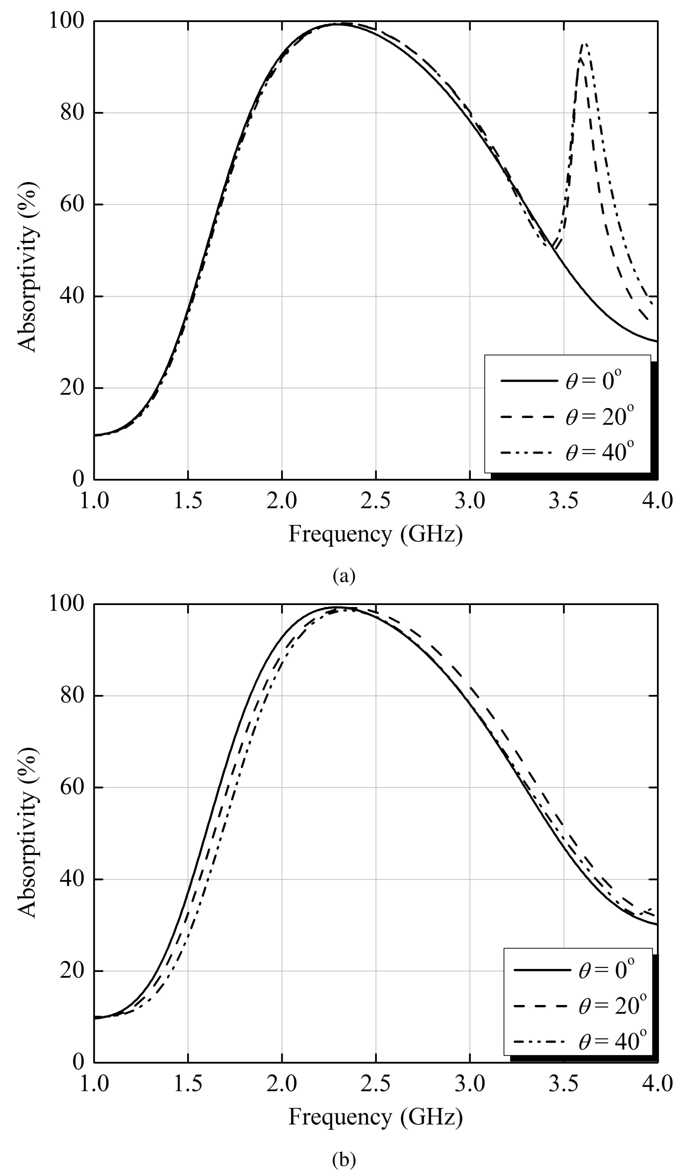

Fig. 12. Simulated absorptivity under normal and oblique incidence for both (a) TE and (b) TM polarization.

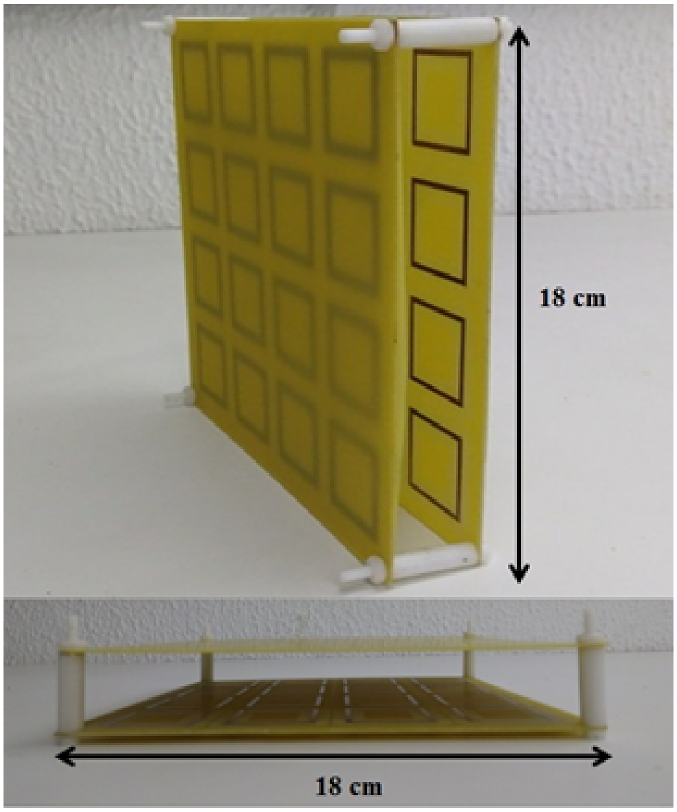

Fig. 13. Built absorber/transmit structure.

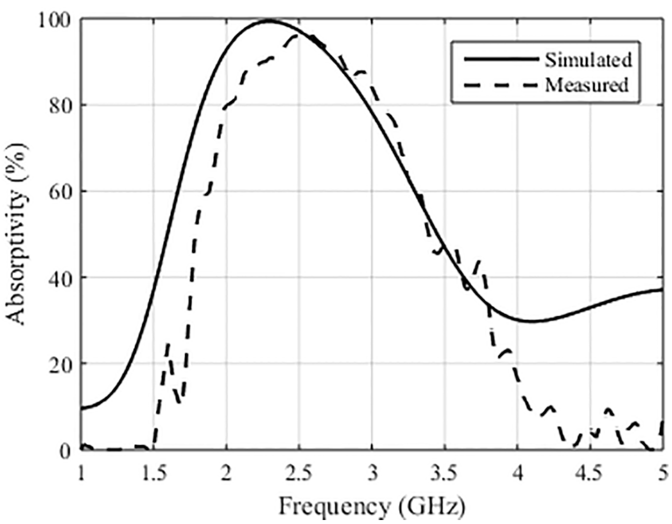

Fig. 14. Comparison between measured and simulated results for absorptivity.

reflected signals from the conducting FSS layer with maximum attenuation of 22 dB achieved at 2.28 GHz. The structure has a – 10 dB transmission bandwidth of 1.02 GHz. The absorber structure presents transmission coefficient magnitude of – 37.8 dB at 2.28 GHz. To verify the angle stability of the proposed structure, the response under oblique incidence was investigated. Fig. 11 shows the absorptivity for different incidence angles, for TM as well as TE polarization. As it can be observed in Figs. 11(a) and (b), the proposed absorber presents angular stability up to 40° for the TE and TM polarizations, respectively, with a frequency shift of the reflection coefficient in both polarizations.

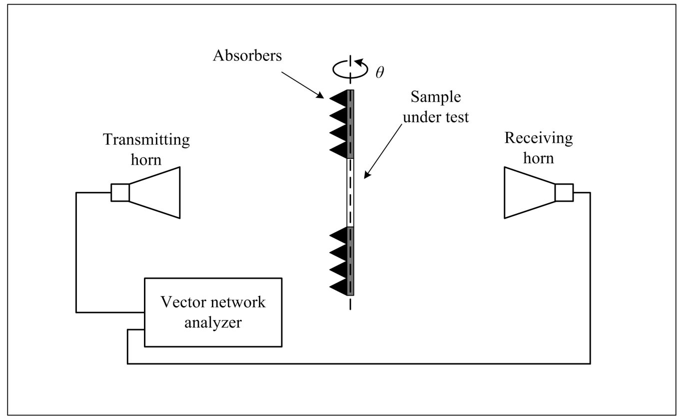

Fig. 15. Transmission coefficient measurement setup.

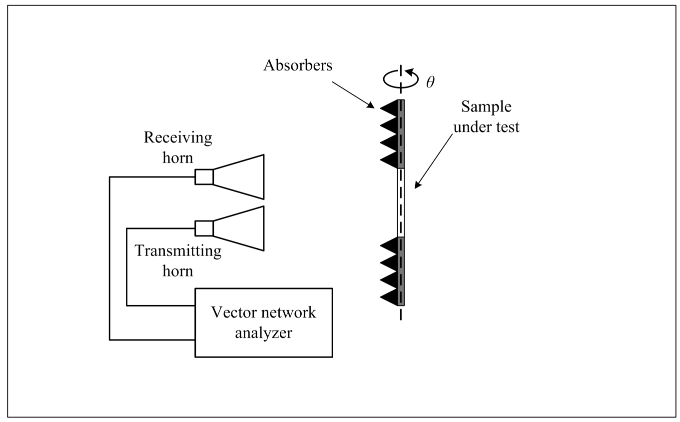

Fig. 16. Transmission coefficient measurement setup.

To confirm the efficiency of the proposed absorber, we present the structure response in terms of the absorptivity. The total absorption can be quantified as follows [25]:

$$A = 1 - R(\omega) - T(\omega) \quad (1)$$

Where $R(\omega) = |R_{xx}|^2 + |R_{xy}|^2$ is the reflected power and $T(\omega) = |T_{xx}|^2 + |T_{xy}|^2$ is the transmitted power.

The co- and cross-polarized components are represented by “xx” and “yx”, respectively. In some absorbers the transmission can be ignored due metallic layer on the backside of the substrate. However, the proposed structure is composed of two frequency selective surfaces, therefore the co- and cross polarized components of the transmitted power cannot be ignored in the absorptivity calculation, using (1).

Fig. 12 shows the absorptivity for different incidence angles, θ, for TM as well as TE polarization. The structure presents high absorption for normal incidence with peak at 2.28 GHz, corresponding to a maximum absorptivity of 99.66%. Moreover, it is important to point out that the high absorptivity (>90%) goes from 1.95 to 2.74 GHz, covering the entire ISM band. It is observed the structure maintains high absorption levels for oblique incidence angles up to 40° for TE and TM polarizations, respectively, which shows wide-angle stability.

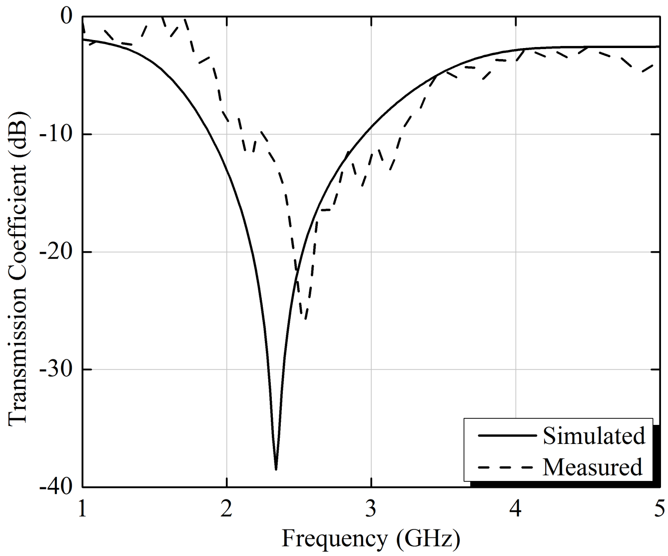

Fig. 17. Comparison between simulated and measured results for S_{21} parameter.

The proposed unit cell is compact, once its periodicity and thickness are, in terms of the longest wavelength of the bandwidth of the absorption λ_L, $0.27\lambda_L$ and $0.19\lambda_L$, respectively.

For validation purpose we built a conducting and a resistive FSS. The two FSS were cascaded using Teflon screws. Fig. 13 shows the built absorber.

Measured results were accomplished with the use of a vector network analyser from Agilent, model E5071C, and two horn antennas operating in the range of 0.7 – 18 GHz with 16 dBi of gain. To confirm the validity of the proposed structure, absorptivity measurements were performed and shown in figure 14, where it can be seen the agreement between measured and simulated curves. Reflection and transmission coefficients were measured. For transmission coefficient a traditional setup was used, as shown in Fig. 15. For reflection coefficient the setup shown in Fig. 16 was used. This kind of setup limits measurements of angular incidence.

In Fig. 17 we can see the comparison between simulated and measured results, for normal incidence and for the transmission coefficient. A good agreement between the results is observed. The simulated results show that the absorber panel suppresses reflection (below – 10 dB) from 1.86 GHz to 2.87 GHz. The measured results show that the absorber panel suppresses reflection (below – 10 dB) from 1.97 GHz to 3.15 GHz. So, this absorption band is appropriated for the entire ISM band.

In Fig. 18 we can see the comparison between the simulated and measured results, for normal incidence and for the reflection coefficient. Again, a good agreement between the results is observed. Simulated results show that the absorber panel suppresses reflection (below – 10 dB) from 1.79 GHz to 3.15 GHz. Measured results show that the absorber panel suppresses reflection (below – 10 dB) from 1.98 GHz to 3.08 GHz. So, this absorption band is appropriated for the entire ISM band. Small differences between simulated and measured results are from the fabrication defects, because of an air gap between the very thin resistive layer and the dielectric superstrate.

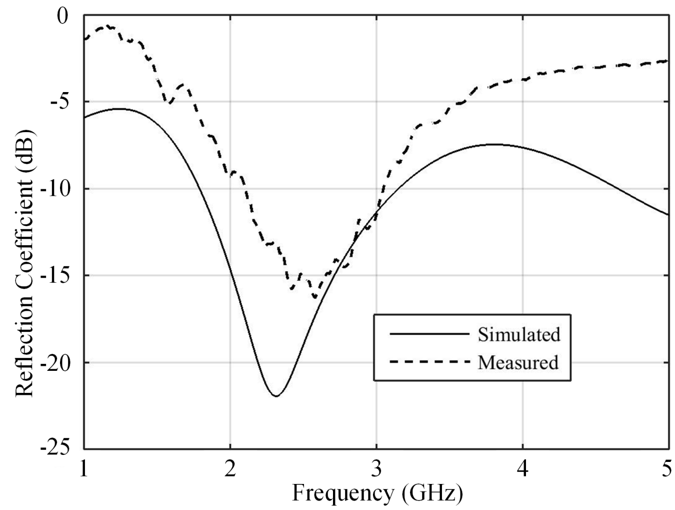

Fig. 18. Comparison between simulated and measured results for S_{11} parameter.

VI. Conclusion

The absorb/transmit frequency selective surface with a conductive FSS and resistive FSS, using square loops, presents a good performance, confirming the expected selective results in frequency of the ISM band and small dimensions. It is important to mention that although there was a high absorption in unwanted frequencies it does not generate any significant effect, because in this region there is no reflection, so the structure is totally transparent in other bands, such as Global System for Mobile Communication (GSM) and Universal Mobile Telecommunication System (3G). None multipath are produced in ISM band. The influence of each parameter on the response of the structure was shown through a wide parametric analysis. Moreover, simulated results demonstrated angle stability up to 40° for the TE and TM polarization. The absorptivity of the absorber, under normal incidence, is the same for TE as well as TM polarization, which means that the structure is polarization insensitive. Measured results showed that the absorber suppresses reflection (below – 10 dB) from 1.97 GHz to 3.15 GHz. So, this absorption band is appropriated for the entire ISM band. Experimental results confirm the analysis developed.

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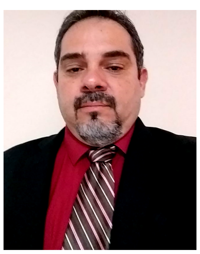

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