Dual-Band Polarization-Independent Absorber Based on Resistive Frequency Selective Surface

Anamaria S. Maia, Antônio L. P. S. Campos, Maurício W. B. Silva, Ruann V. A. Lira and Alfredo Gomes Neto

***Abstract*—In this paper, a three-layered frequency-selective absorber (FSA) that can efficiently absorb electromagnetic waves (EM) in a double-band is proposed. The proposed structure is designed so that signals reflected from the frequency selective ground plane are located at 2.4 and 5.5 GHz (ISM and UNII bands) and absorbed by the front resistive layers. Simulation results show that the proposed absorber not only blocks transmission in the desired bands but absorbs the signals reflected from the conductive layer. Reflective FSS unit cells are composed of double square loops printed on an FR-4 substrate and the resistive layers are formed of OhmegaPly material with a resistivity of 50 ohms per square. Furthermore, the proposed absorber is 0.17λ thick at the lowest frequency of absorption. The experimental results agree with the numerical simulations and show an absorptivity of more than 90% at 2.4 and 5.5 GHz, covering entirely ISM and UNII bands.**

***Index Terms*—Frequency selective surfaces, frequency selective absorber, microwave absorption.**

I. INTRODUCTION

ELECTROMAGNETIC wave absorption refers to the ability of a structure or material to attenuate the energy of an impinging wave. Full control of the received radiation is desirable since many phenomena are inherent to electromagnetic disturbances such as interference, spurious radiation, leakage, and susceptibility, to name a few [1], [2]. Conventional broadband absorbers are designed using gradual impedance matching techniques so that they can gradually attenuate energy over the length of the structure. However, these traditional approaches have specific thickness restrictions and usually lead to bulky configurations [3]–[5]. Therefore, even though these absorbers have bandwidths that cover different operating frequency ranges, their application in microwave technology is inherently limited by its bulky feature. Resonant absorbers can be an alternative to the weight and volume limitation found in broadband absorbers, but their application is limited to confined environments, due to their complete conductive grounding plane. Furthermore, these structures cannot operate in more than one frequency band [6], [7], and, in some applications, could be interesting operate in two different bands, allowing the transmission of another bands of interesting.

There are several techniques for designing absorbers. Recently, the use of metamaterials has enabled the development of ultrathin absorbers, which can be synthesized by a subwavelength periodic array of resonators, which also allows reducing the structure size [8]–[10]. However, this approach also suffers from the same limitations on the full-ground plane. To provide more freedom for the construction of absorbers, many studies have proposed the development of frequency selective surface (FSS)-based absorbers, named frequency-selective absorber (FSA). As an example, an ultra-wideband frequency-selective absorber with an adjustable notch band was achieved by stacking a lossy and lossless FSS [11]. Qu *et al.* proposed a graphene-based dual-polarization switchable rasorber/absorber, which can be controlled by the chemical potential of graphene. The proposed multifunctional device was obtained by combing the absorber with SRRs and reconfigurable FSS [12]. Although these proposed absorbers operate in a relatively wide frequency band and have a low profile, it suffers from the same problems of those

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reported absorbers on the full ground plane. Kiani *et al*. designed and experimentally verified an absorb/transmit frequency selective surface using a two-layer cross dipole array, which can absorb waves at 5 GHz while allowing out-of-band signal transmission [13].

Considering the above discussion, in this paper, we propose a based-FSS dual-band absorber composed of a square ring array. We show that the different layers, composed of conductive and resistive square loops arrays, are capable to absorb an impinging wave and exhibit -10 dB absorption bandwidth in the 2.4 and 5.5 GHz frequency bands, with fractional bandwidths of 3.4% and 15.9%, respectively. A sample of the proposed absorber is fabricated, and it is shown that the measured results match well with the simulated response. When compared with other types of absorbers, the proposed structure presents absorption in the two desired and allows out-of-band EM-wave propagation. The novelties of the proposed absorber are the simple design, compact size, covers maximum ISM- bands, it does not use full-metallic ground plane, nor metal in the resistive layer. Thus, the absorber only blocks the frequency bands of interest, letting the others through.

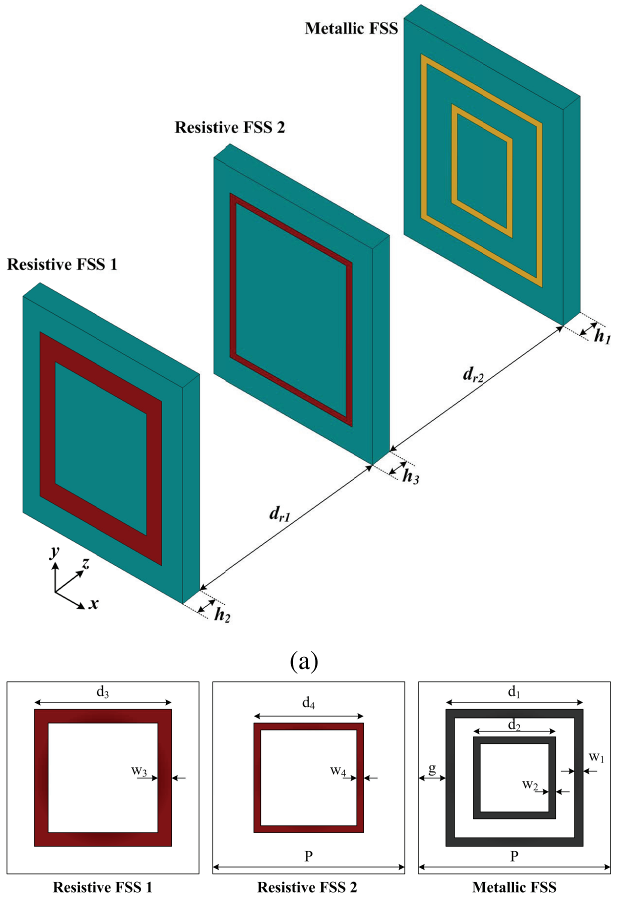
II. THEORY ANALYSIS AND DESIGN

A resonant electromagnetic wave absorber is usually a single band, consisting of a resistive FSS at the top layer, an intermediate dielectric layer, and a bottom full conductive layer. The structure formed by periodic arrangement of symmetrical cells can be treated as a Salisbury screen with the difference that Salisbury Screens are engineered with the (377 ohms/sq) resistive layer and ground plane separation fixed at a quarter wavelength, whereas the spacer for the former is much thinner to make use of the transformed inductance of the ground lane. So, the engineering design and principle of operation of the two structures is quite different.

When a plane wave hits, it is reflected from the ground plane and reaches the resistive layer 180° out phase, and, thus, causing cancellation, since the distance covered by the second wave is $\lambda/4$ or an odd multiple of it. In other words, the absorption in the Salisbury screen occurs due to the cancellation of the waves reflected on the resistive sheet and on the ground plane. Thus, the wave is absorbed by the resistive sheet if the matching condition with the free space impedance is satisfied. The dielectric thickness, air spacer, and resistive sheet values increase the design degrees of freedom for controlling location and absorption level. Therefore, we can add one more absorption band to the three-layer structure, optimizing the dielectric spacer and the resistive sheet.

Based on the above explanation, we emphasize two important issues regarding the design. The choice of the square loops is because this geometry has a very good angular stability and polarization independence. The three layers were separated by air gaps using Teflon spacers. The first one is related to the air spacing d_1 and d_2, which must be correctly assigned because of the phase shift of EM waves due to reflections. Second, considering that the lossy layer is not uniform, since it is composed of an FSS, an ideal surface resistance must be defined [14]. Furthermore, the conductive FSS design is composed of unit cells using double-square loops, which means that two resonant frequencies are obtained in the bands of interest. The fulfilling of this requirement ensures that the incident electromagnetic wave can be reflected in the metallic FSS layer and properly absorbed in the two front resistive layers. By carefully choosing the physical dimensions of the unit cells and the gap between the FSSs, it is possible to tune the frequencies in which the absorption peaks occur, resulting in double-band absorption. Therefore, the double-square loop structure is chosen as the unit cell of the metallic layer, and a single square loop comprises the two resistive layers, as shown in Fig. 1. The novelty of this design is the use of two resistive layers to adjust the frequency response more precisely.

The metallic layer proposed in this work uses a low-cost FR-4 substrate, which has a thickness h_1 = 1.6 mm, the dielectric constant of 4.4, and the loss tangent of 0.02, which provides a zero transmission (T(ω) = 0) to the bands of interest. The resistive layers are composed of simple square loops and are placed in front of the conductive layer. The geometrical dimensions, in mm, are presented in Fig. 1(a) and (b), in which $d_{r1} = 11$, $d_{r2} = 10$, $d_1 = 21$, $d_2 = 13$, $d_3 = 21$, $d_4 = 16$, $w_1 = w_2 = 1$, $w_3 = 2$, $w_4 = 1$, and $g = 1.5$. Furthermore, the surface resistance of the first layer (resistive FSS 1) is equal to 50 ohms/square, placed on an FR-4 substrate with a thickness h_2 = 0.15 mm. The second layer (resistive



(a)

(b)

Fig. 1: Illustrative configuration of the proposed absorber: (a) perspective view, and (b) unit cells of the different layers.

FSS 2) is developed on Nelco N4000 substrate with relative permittivity of 3.65, loss tangent 0.009, thickness h_3 = 0.254 mm, and surface resistance of 50 ohms/square. The periodicity of the structure is P = 24 mm. In this work, due to lack of availability, it was not possible to use the same substrates for both the resistive layers.

To understand the working principles of the proposed structure, we can consider the absorptivity, defined from the following equation:

$$A(\omega) = 1 - R(\omega) - T(\omega) \tag{1}$$

where $R(\omega)$ = $|R_{xx}|^2$ + $|R_{yx}|^2$ is the reflected power and $T(\omega)$ = $|T_{xx}|^2$ + $|T_{yx}|^2$ is the transmitted power. The co- and cross-polarized components are represented by “xx” and “yx”, respectively. The reflectance $R(\omega)$ and the transmittance $T(\omega)$ are minimal, providing an absorptivity close to the unit over the frequency range of interest. The presence of a ground plane provides a null transmittance $T(\omega)$, and the reflectance $R(\omega)$ is minimal due to the cancellation of waves in the resistive sheet, arising from the ground plane reflection.

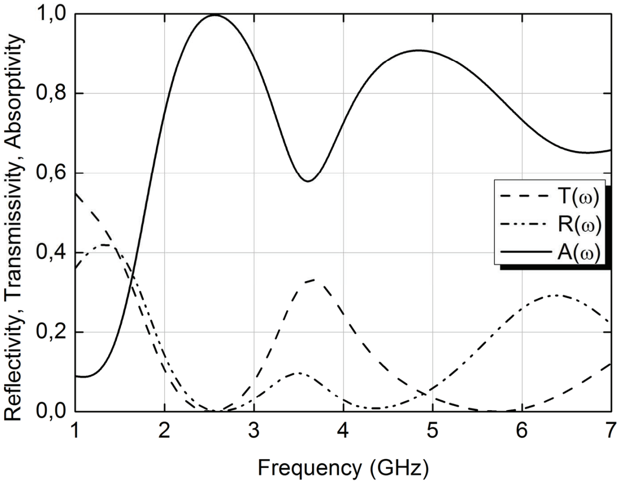
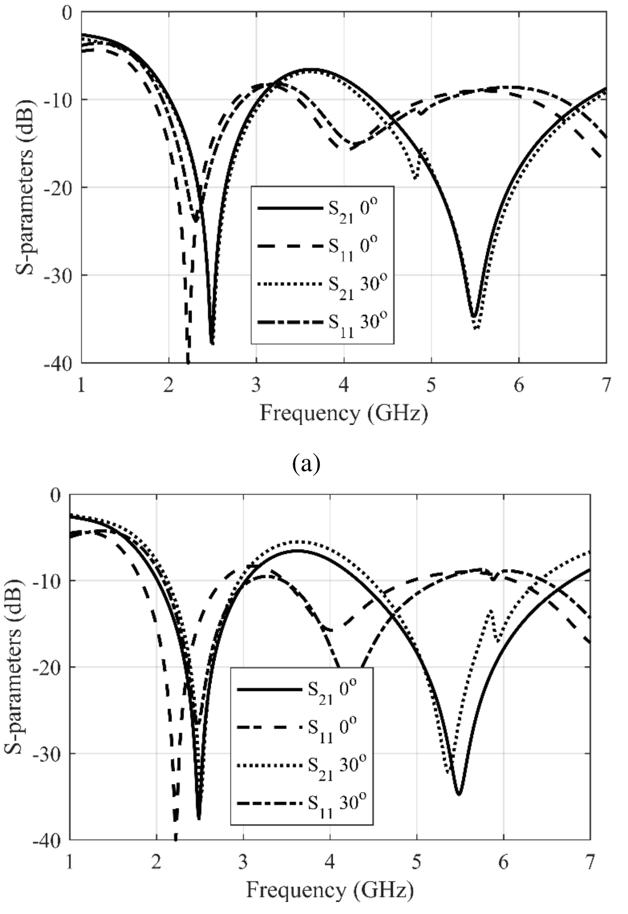


Fig. 2: Simulation results of the proposed structure showing absorptivity as a function of the co-polarized and cross-polarized reflection and transmission.

Considering that the air spacing of the structure it has distance closes to a quarter of a wavelength at each operating band, the impedance of the grounded dielectric becomes capacitive [15]. In addition, the impedance of the FSS layers, composed of resistive arrays, behaves as a capacitor. Therefore, the geometrical dimension values of the resistive array elements are determined to provide maximum absorption, as the design begins from a fixed surface resistance (50 ohms/sq). In this sense, the working principle of the proposed structure is the same as that of a conventional Salisbury screen, with the difference of both conductive and resistive layers are composed of periodic elements. To verify this, numerical simulations of the transmissivity and reflectivity were carried out. The results are presented in Fig. 2, and as can be observed, $T(\omega)$ is zero only in the vicinity where the structure operates, differently from a conventional absorber with a complete ground plane. As expected, $R(\omega)$ is small only in the vicinity of the operating bands. The structure presented an absorptivity of 99.7% at 2.5 GHz and 91% at 5.5 GHz, as it can be seen in Fig. 2.

To analyse the signal absorption ability of the



(a)

(b)

Fig. 3: Simulated S-parameters for oblique incidence for (a) horizontal and (b) vertical polarizations.

proposed structure, we investigate the absorber by Ansys Designer software, by simulating the reflection coefficients. For the simulation, it was assumed a single unit cell with periodic boundary conditions along the x- and y-directions. The EM wave propagates into the interface in the +z direction and reaches the unit cell in the xy-plane [see Fig. 1(a)].

We investigated the influence of the incidence angle (θ) on reflection, transmission, and absorption. Figs. 3(a) and (b) shows the transmission and reflection coefficients under oblique incidence for the horizontal as well as vertical polarization, respectively. It is clear, from Fig. 3, that the designed absorber presents angular stability up to 30° for both polarizations. It is considered that the absorber has wide angular stability, once the proposed model maintains absorption above 80% for both orthogonal polarizations, maintaining the absorption bandwidth (see Fig. 4).

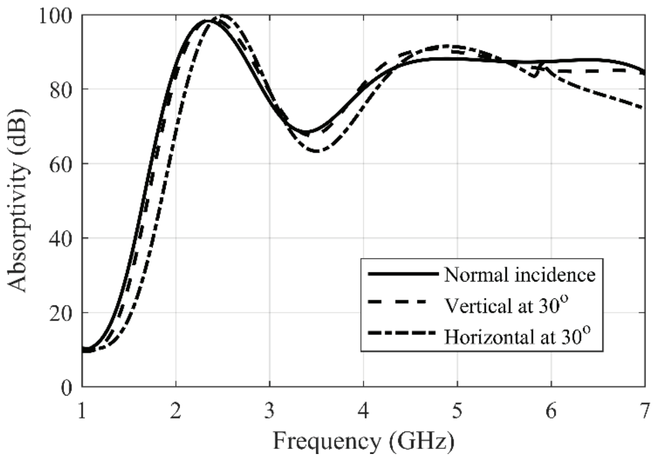


Fig. 4: Absorption for oblique incidence for horizontal and vertical polarizations.

III. Results Analysis and Discussions

To experimentally analyse the proposed absorber, the three layers were built, and the prototype was assembled. The metallic layer has an overall size of 250 mm x 250 mm and contains 9 x 9 unit cells. The first resistive layer (resistive FSS 1) has 200 mm × 200 mm size and 8 x 8 unit cells. A 220 mm x 220 mm prototype, comprising 9 x 9 cells (resistive FSS 2) was fabricated and the final structure is shown in Fig. 5. In the sample preparation, patterns were etched onto a thin 50 ohm/square Ohmega Ply layer through a conventional printed circuit board fabrication process. The measurement setup is shown in Fig. 5, in which two standard gain horns antennas are connected to an Agilent vector network analyser (model N5230A).

The sample is placed on the front of the horn antennas, surrounded by pyramidal absorbers, and then tested with the free space method. For both reflection and transmission measurements, the transmission horn antenna emits signals with vertical polarization, while the receiving horn antenna is used for receiving waves with vertical and horizontal polarization. The signals reflected by the sample, as shown in Fig, 5, are used to obtain the reflective coefficients R_{xx} and R_{yx}. On the other hand, the configuration shown in Figure 5(c) is used to compute the transmissive coefficients t_{xx} and t_{yx}. The reflection measurements are calibrated against the reflection response of a 2 mm thick aluminium plate having the same dimensions as the absorber. So,

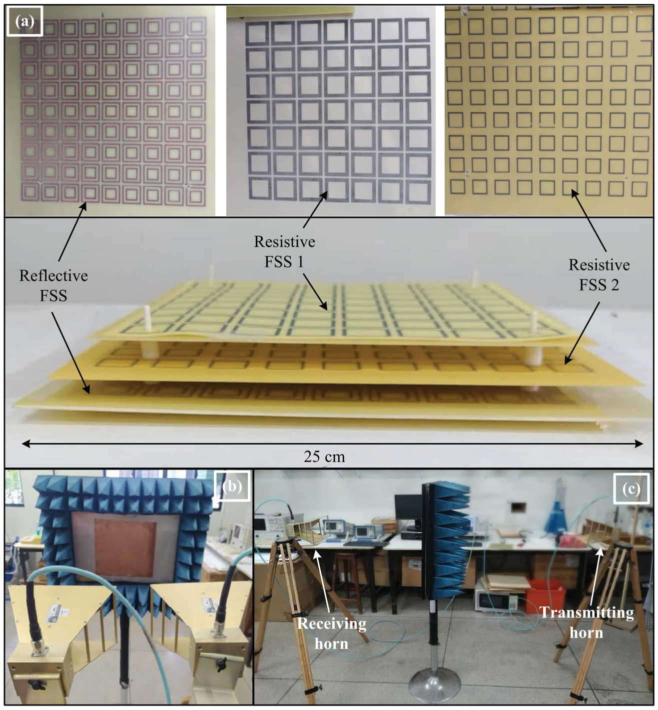
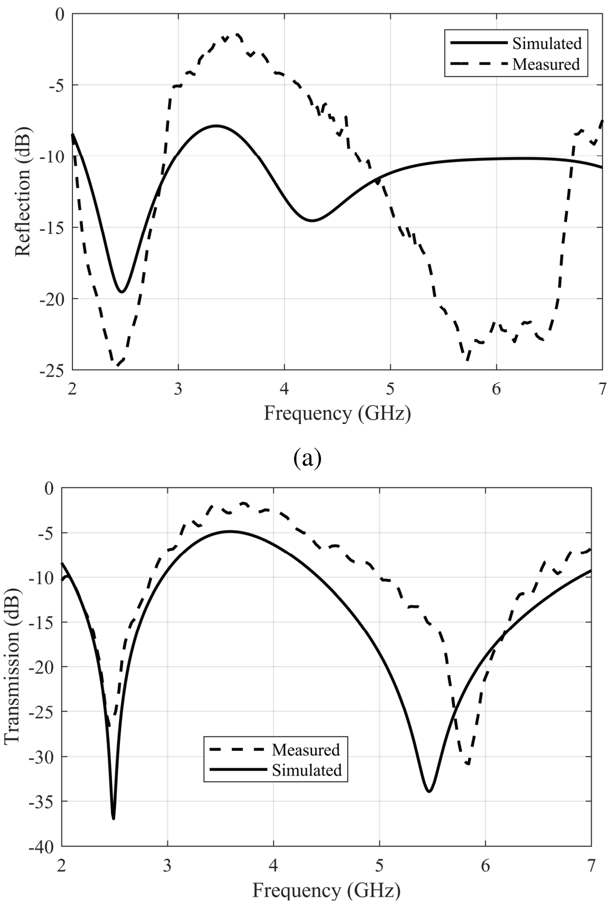


Fig. 5: Photo of the assembled absorber, and experiment setup for reflection and transmission measurements.

the real reflection from the absorber was computed by subtracting the two measured reflected signals. Transmission measurements are calibrated against the transmit response of the receiving antenna when the FSS panel is removed (empty frame measurement).

Fig. 6(a) and (b) show the comparison between the numerical data with the reflection and transmission spectrum measured from the fabricated sample, while the absorptivity is shown in Fig. 7.

The measured absorption rates are better than 90% from 2 to 3 GHz and from 5 to 6 GHz, respectively. It is seen from Fig. 6 that two absorption peaks close to the unity occur in the desired frequency bands. This result confirms what appears in eq. (1), showing that, although the reflection result (shown in Fig. 6(a)) does not have very well-defined peaks, both parameters (*T* and *R*) are important to measure the structure efficiency through absorptivity. It is seen from Fig. 7 that two absorption peaks close to the unity occur in the desired frequency bands. This result confirms what appears in eq. (1), showing that, although the reflection result (shown in Fig. 6(a)) does not have very well-defined peaks,



(a)

(b)

Fig. 6: Comparison between simulated and measured results for (a) reflection and (b) transmission.

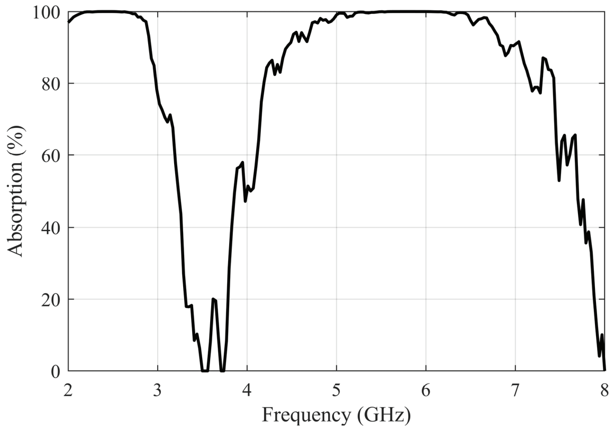


Fig. 7: Measured absorptivity at normal incidence.

both parameters (T and R) are important to measure the structure efficiency through absorptivity. Compared with the simulation results, the experimental results show some disagreement on the bandwidth at 5.5 GHz, although the bandwidth for simulated and measured results comprises the band of 5 to 6 GHz, in booth results, so for - 10 dB line, frequency in experiments matches well with that in simulations, for the desired application. There is an obvious disagreement between simulated and measured results on the bandwidth at 5.5 GHz, although the frequency in experiments matches well with that in simulations. In experiments, some measurable parameters are the same as in simulations. However, due to the manufacturing and assembly tolerances of the board, the distance between the layers (d_{r1} and d_{r2}) as well as $Im(\varepsilon_d)$ are uncertain parameters. In our opinion, these may be the main contributors to the difference between simulations and experiments.

Table I compares the proposed FSS with other work given in [8] - [13], considering the aspects of employed technology, frequency response, angular stability, polarization independence, and presence of ground plane. As seen in Table 1, our proposed FSS has dual-band response, angular stability up to 30°, polarization independence, and has no ground plane. No proposed structure in the other works assembly all of these characteristics, which proves the novelty of our FSS.

TABLE I: Comparison of the proposed absorber and previously reported absorbers.

Ref.	Operation freq.	Emp. tec.	Freq. resp.	Ang. stability	Ground plane
[8]	8 GHz	Metamat.	Single	-	Yes
[9]	6–15 GHz	Chaos surf.	Single	-	Yes
[10]	8.2–25 GHz	Metamat.	Single	Up to 60°	Yes
[11]	6–9 GHz 11–22 GHz	FSS	Dual	Up to 40°	Yes
[12]	0.55–0.95 THz	FSS and metamat.	Single	-	Yes
[13]	5.5 GHz	FSS	Single	No	No
Our work	2.5/5.5 GHz	FSS	Dual	Up to 30°	No

IV. CONCLUSION

A dual-band, polarization insensitive and with angular stability absorber was presented in this paper. By introducing two different resistive layers, composed of square loops in front of a frequency-selective reflector plane, we obtained a dual-band frequency selective absorber. With a thickness referring to 0.17λ, the proposed structure can be considered thin and up to the limit of knowledge of the authors, it is the first reported dual-band frequency selective absorber without a full ground plane. Numerical results show that the proposed dual-band absorber exhibits high absorption up to a 30° angle of incidence (above 90% for both TE and TM polarization, respectively). To verify the absorption performance of the proposed design, a 250 mm x 250 mm sample of the absorber has been fabricated and measured. Both the numerical and measurement results show that the proposed structure can absorb waves in two different frequency bands, while allowing out-of-band signal traffic. Measured results of the fabricated prototype have been a good match with the simulated result and presented absorptivity above 90% at 2.4 and 5.5 GHz, demonstrating the validity of the proposed design strategies.

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