

## A BROADBAND METAMATERIAL ABSORBER CONSTRUCTED OF SQUARE METALIZED SEGMENTS

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The aim of this paper is to study an absorber constructed of square metalized segments arranged on Arlon AD350 foil dielectric. The paper shows that the absorbing metamaterial possesses a broad operational absorption bandwidth of 1.5 GHz to 18 GHz, with an absorption coefficient of 0.9. The absorber also possesses the complete polarization independence at incidence angles ranging from 0° to 90°.

**Keywords:** *absorber, metamaterial, bandwidth, equivalent circuit.*

### Introduction

Metamaterial [1–3] is an artificially engineered material with electromagnetic properties. It is indeed difficult to obtain and not found in the natural environment at all.

A group of Iranian scientists have recently developed an absorber based on split ring resonators (SRR). It has triple resonance 8.6, 10.2, 11.95 GHz with absorption of more than 84% [4]. The results show that the parasitic element can provide new capacitance and inductance to create a new resonance. The current distribution determined new capacitance within the structures.

Scientists are working actively on developing layered structures. Chinese scientists have defined and measured a layered structure, 2.2 mm thick. Their structure consists of a conventional printed circuit board affixed by means of a cross-matrix method on the surface of a powdered carbonyl iron substrate, filled with powdered silicone rubber [5], and a magnetic substrate supported by a metal plane. Measurement results show that the absorption bandwidth of the proposed structure is 2.55–5.68 GHz.

Other recent developments include a thin absorber composed of four dielectric layers, as well as metal microstructures of double split ring resonators (MDSRR) and a set of lumped resistors [6]. Numerical results show that the proposed absorber achieved ideal absorption with an absorptivity of more than 80% at normal incidences within 4.52–25.42 GHz, corresponding to a bandwidth of 139.6%.

The main problem with existing absorbers is their relatively low absorption range, about 10% of the bandwidth. However, a group of Chinese scientists have developed a broadband, polarization-insensitive absorber of a three-layer structure with a resistive film of different shapes on each substrate layer [7]. Numerical simulations show that the absorption capacity of the normal incident wave exceeds 90% within the range of 2.34–18.95 GHz. This corresponds to a relative absorption bandwidth of 156%. A broadband symmetrical metamaterial absorber, which is angle and polarization independent, has also been developed for the X and Ku bands [8]. The bandwidth was extended by

introducing a quadruple resonator. This structure has absorption peaks at 11.31, 14.11, 14.23, and 17.79 GHz with absorption of 94.63, 95.58, 97, and 75.58%, respectively.

The problem of narrow-band absorption has been solved by adding extra layers. Turkish scientists proposed a multiband absorber design based on a multilayer structure with a square split ring [9]. This was designed for frequency bands such as WIMAX, WLAN, as well as satellite communications. The absorption levels of the proposed structure exceed 90% for all resonant frequencies.

Chinese scientists have proposed and developed a metamaterial absorber with an almost perfect absorption peak. This can be magnetically tuned within 0.2–7.6 GHz, by combining ferrite with a megastructure [10].

Structures with a very difficult conductive pattern have also been studied. They include the absorber based on a U-shaped hinge [11] design with an O-shaped double split. This also contains a square split in the centre and a double negative-gain property (DNG). The design of this structure exhibits two consecutive absorption peaks in the X and Ku bands at 11.56, 12.27, and 14.19 GHz with absorption of 82.31, 98.91, and 97.79%, respectively.

The development of ultra-thin absorbers is another area of research. Vietnamese scientists have recently developed an ultra-thin broadband metamaterial absorber for C-band applications by utilizing a single layer of metal-dielectric-metal structure [12] on an FR-4 substrate. The proposed metamaterial has a wide absorption band, ranging from 4 to 8 GHz with absorptivity above 90% [13].

A structure of an ultrathin triple-band polarization-independent metamaterials absorber with two resonators has also been developed. They are referred to as structure A and structure B. It is based on an FR4 substrate [14]. The proposed absorber structure provides three distinct absorption peaks of 99.67, 99.48, and 99.42% with a bandwidth of 170 MHz (4.11–4.28 GHz), 350 MHz (9.17–9.52 GHz), and 480 MHz (11.24–11.72 GHz), respectively.

This article presents a compact size absorber consisting of square segments with excellent absorption in the L, S, C, X, and Ku frequency bands.

## 1. Absorber design and equivalent circuit

The absorber being studied here consists of square metalized segments of electroplated copper foil, 0.018 mm thick, on a dielectric base plate. Arlon AD350 foil dielectric was used as the printed circuit board base. This laminate has a dielectric layer, 1.524 mm thick, dielectric permittivity equal to 3.5, and a dielectric loss tangent value equal to 0.0033.

The structure is square in shape and with the following main dimensions  $A = 30$  mm,  $B = 10$  mm,  $C = 10$  mm,  $D = 70$  mm (see Fig. 1).

Two variants of the cell design will be considered in the simulation. The first variant is the structure on the dielectric base. On the reverse side of the dielectric there is no resistive layer (see Fig. 2 (a)). In the second variant, however, a copper electroplated foil is applied to the reverse side of the foil dielectric (see Fig. 2 (b)).

The absorber being studied here is a resonance circuit with inductance and capacity (Fig. 3).

The metalized square segments are characterized by certain inductivities  $L1$  and  $L2$ , depending directly on the size of the square segments. The gaps between the metalized

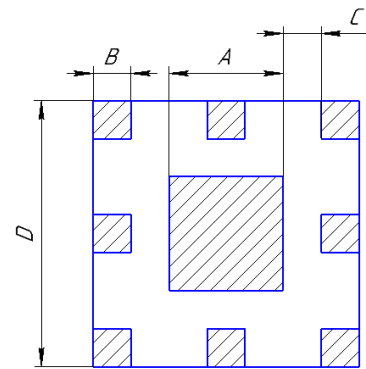


Fig. 1. Metamaterial absorber dimensions

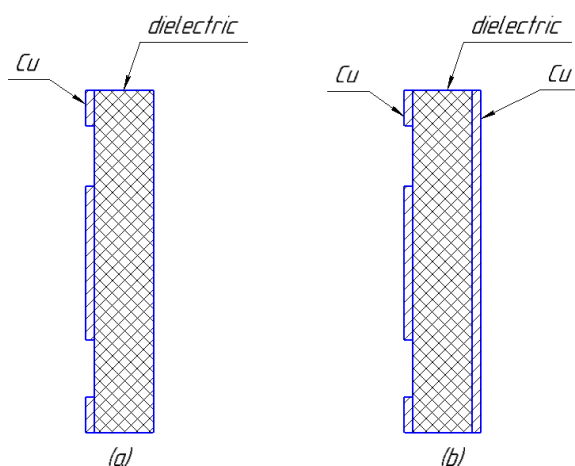


Fig. 2. Variants of the structure under study

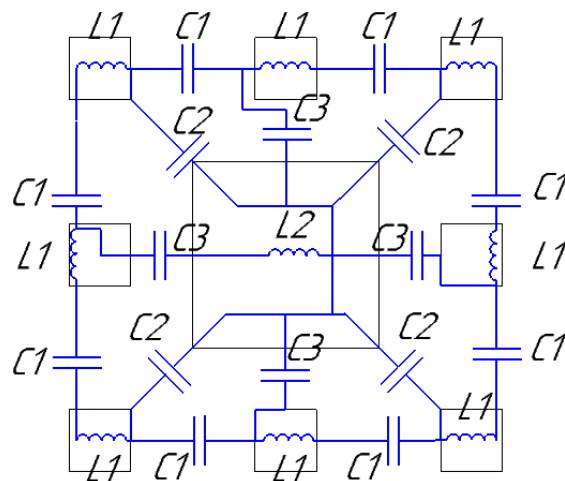


Fig. 3. Absorber equivalent circuit

square segments are characterized by capacitive components  $C1$ ,  $C2$  and  $C3$ . Thus, it is possible to obtain a structure that absorbs electromagnetic waves at a certain frequency by selecting certain sizes  $A$ ,  $B$  and  $C$ . The structure can be calculated according to the following formula.  $f = 1/2\pi\sqrt{LC}$ . The thickness of the dielectric substrate, as well as its dielectric permittivity directly affect resonant frequency.

## 2. Simulation of the metamaterial absorber

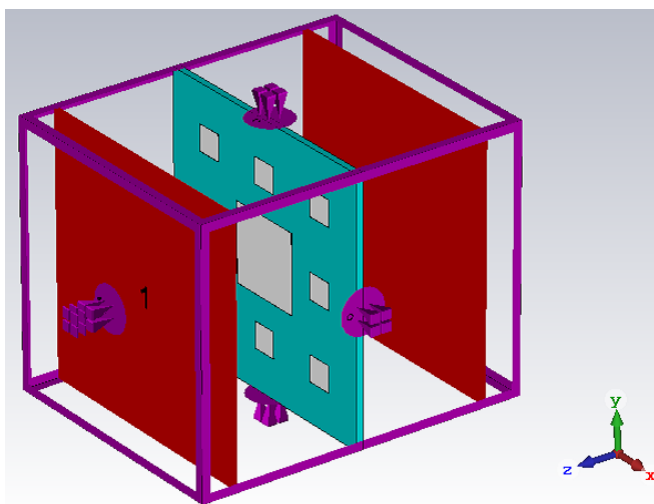


Fig. 4. A model of the absorbing structure by Ansys HFSS

Simulation was performed by the Ansys HFSS program with the time method applied. For the purposes of calculation, the waveguide ports were set in the far zone, in order to meet the condition  $r \geq 2D^2/\lambda$  [15], where  $r$  is the distance from the phase centre of the antenna,  $D$  is the maximum overall size of the antenna (the aperture size),  $\lambda$  is the wavelength.

In the simulation, boundary conditions — open (add space) were used on the front and back sides of the cell under study, and boundary conditions — open were imposed along the edges of the board (along the  $x$  and  $y$  axis, respectively).

Fig. 5 shows the calculated absorption parameters. The absorption  $A(\omega)$  parameter is determined using the equation  $A(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2$  [16]. In order to increase the absorption value, both the reflection coefficient value ( $S_{11}$ ) and the transmission coefficient value ( $S_{21}$ ) of the electromagnetic waves must be reduced. If there is a screen on the reverse side of the absorber, the transmission coefficient may be ignored, since the board is covered with copper foil on the reverse side. In this way the transmitted wave will be very weak and can be considered as zero:  $A(\omega) = 1 - |S_{11}|^2$ . According to Fig. 5, our prototype has wide electromagnetic energy absorption bands and ranges from 0.1 to 1.8 GHz and from 3 to 18 GHz, with absorption coefficients of 0.97 and 0.99, respectively.

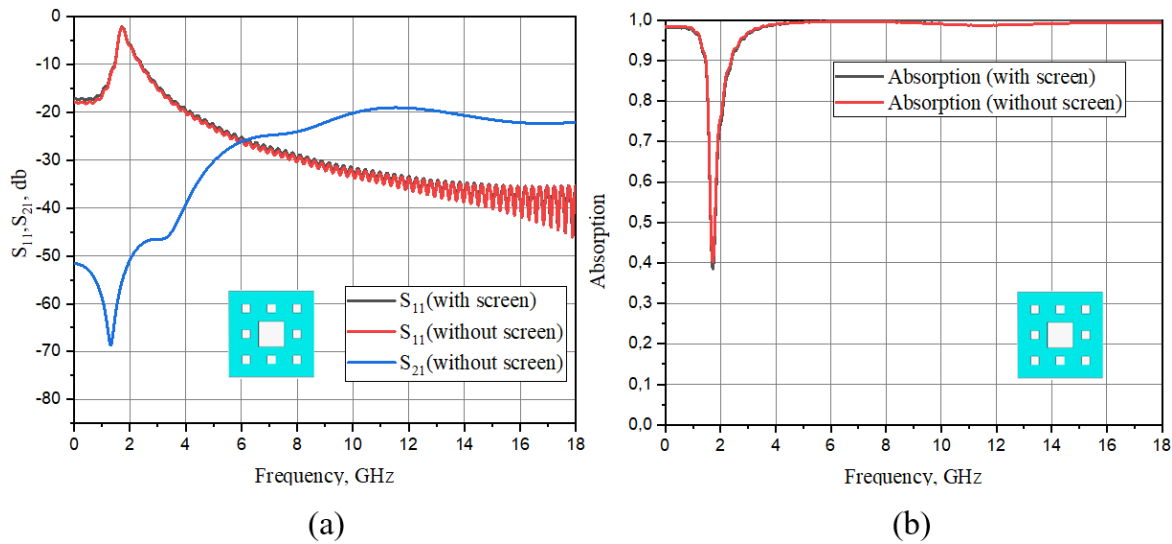


Fig. 5. a) Frequency dependence plot of reflection and transmission coefficient for one unit cell, b) frequency dependence plot of absorption coefficient for one unit cell

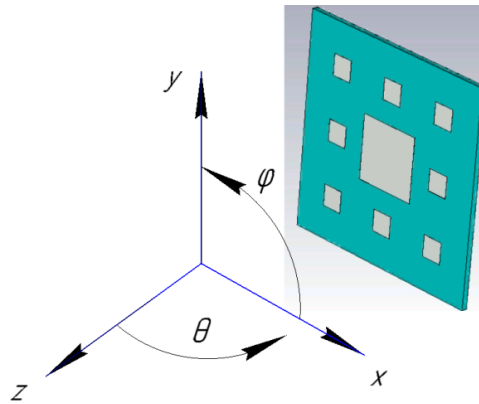


Fig. 6. Angles  $\varphi$  and  $\theta$  in the spherical coordinate system

The presence or absence of a screen on the back side of the metamaterial absorber has almost no effect on the S parameters. Thus, this absorber shows excellent absorptivity in the L, S, C, X and Ku frequency bands. The corresponding graphs were calculated (Figs. 7, 8) to confirm that the investigated absorber is independent of polarization angles  $\varphi$  and  $\theta$  (Fig. 6). Based on Fig. 7 and 8, we can conclude that with the change of polarization angles, the structure with the screen (Fig. 2 (b)) shows a constancy of absorption parameters.

Moreover, a certain deviation of the characteristics from the initial ( $0^\circ$ ) can be observed in the absence of a screen on the reverse side of the PCB (Fig. 2 (a)), when changing the polarization angles  $\varphi$  and  $\theta$  between 0 and  $90^\circ$ , (Fig. 8). This is primarily due to the lack of additional re-reflection of the incident wave from the screen, as well as an additional capacity C4 between the structure and the screen (Fig. 9).

Let us look at a simulation of the structure of 4 and 9 elementary unit cells. These structures are also interesting because simulation produces mutual inductance-capacitance couplings which affects the final absorption parameter. Fig. 10 shows that for an array of 4 unit cells, the absorption also remains high in the frequency range of 2–18 GHz with an absorption coefficient of 0.99. The band at higher frequencies has expanded by about 1 GHz compared to one unit cell, while the band in the L band has narrowed by half. It now ranges from 0.1 to 0.7 GHz with absorption of 96%. Most likely, this is caused by the mutual influence of individual parts of the unit cells, as well as by the lack of a gap between individual cells.

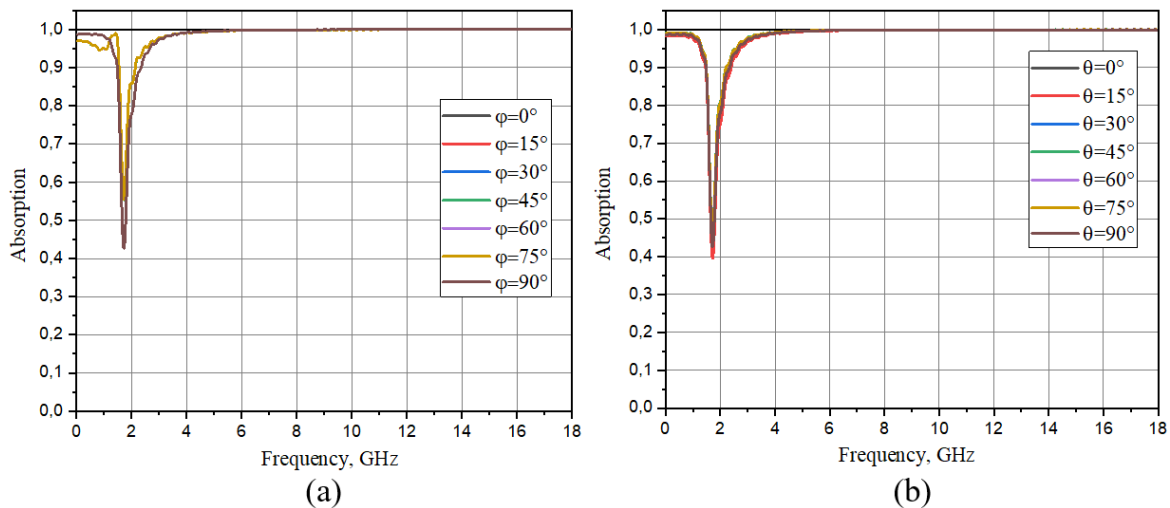


Fig. 7. a) Frequency dependence plot of the absorption coefficient for a unit cell with a screen when  $\varphi$  changes from 0 to  $90^\circ$ ; b) Frequency dependence plot of the absorption coefficient for a unit cell with a screen when  $\theta$  changes from 0 to  $90^\circ$

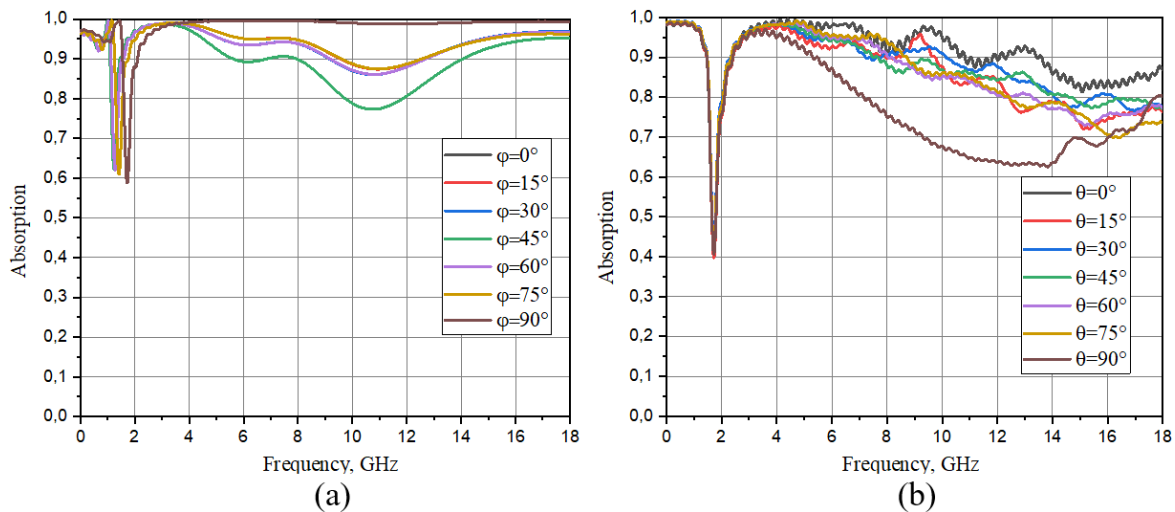


Fig. 8. a) Frequency dependence plot of the absorption coefficient for a unit cell without a screen, when  $\varphi$  changes from 0 to  $90^\circ$ ; b) Frequency dependence plot of the absorption coefficient for a unit cell without a screen, when  $\theta$  changes from 0 to  $90^\circ$

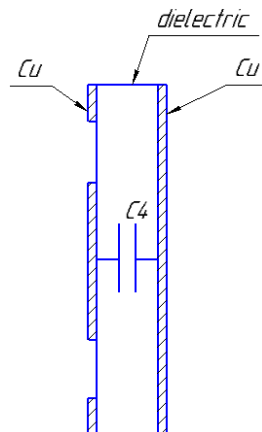


Fig. 9. Capacity due to the screen

Fig. 11 shows that increasing the number of array cells to 9 leads to better absorption in the frequency range from 0.1 to 0.5 GHz and from 1.5 to 18 GHz with absorption coefficients of 0.96 and 0.99, respectively, with a screen. However, we can observe a decrease of absorption from 1.5 to 18 GHz without a screen. This is primarily due to the appearance of the  $S_{21}$  transmission coefficient, which worsens the overall absorption at higher frequencies.

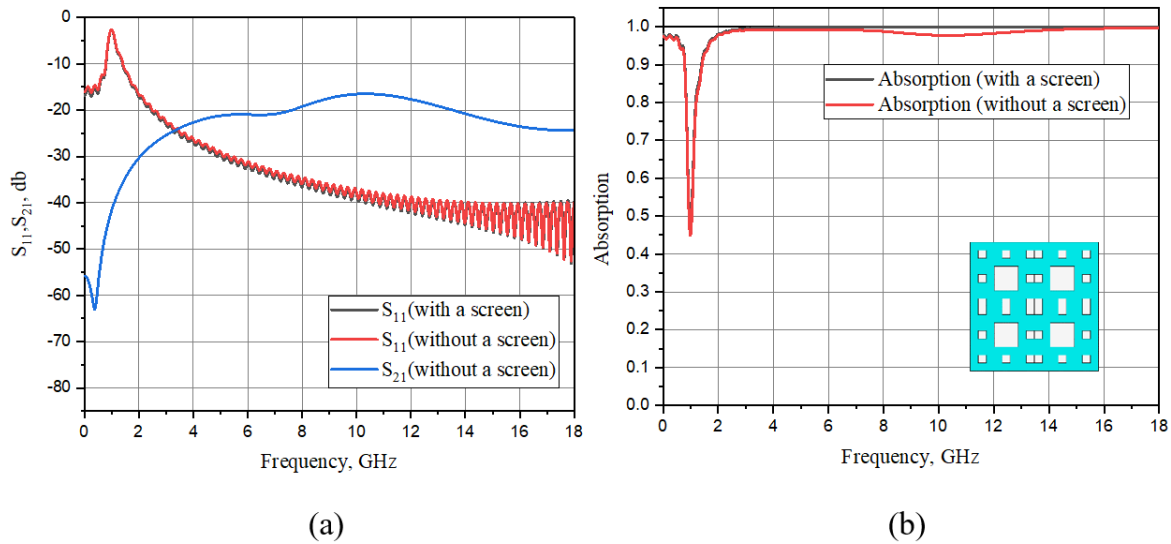


Fig. 10. a) Frequency dependence plot of reflection coefficient and transmission coefficient for an array of  $2 \times 2$  cells; b) frequency dependence plot of absorption coefficient for an array of  $2 \times 2$  cells

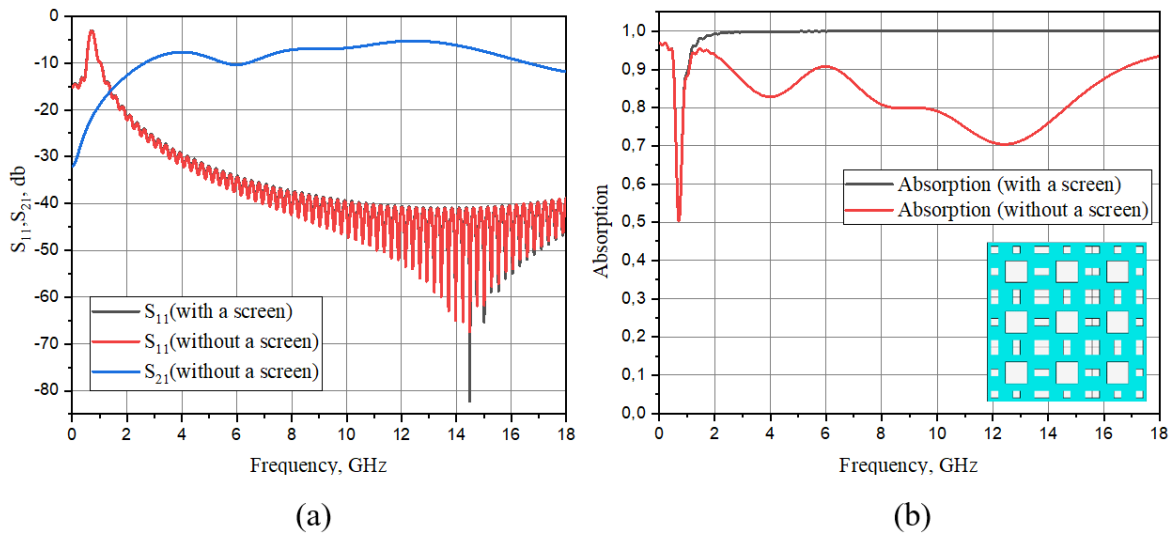


Fig. 11. a) Frequency dependence plot of a reflection coefficient and a transmission coefficient for an array of  $3 \times 3$  cells; b) frequency dependence plot of an absorption coefficient for an array of  $3 \times 3$  cells

### 3. Experimental results

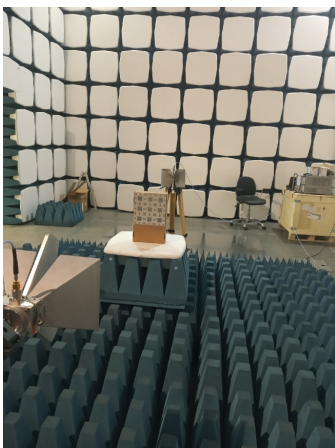


Fig. 12. Measuring of S-parameters in an anechoic chamber

A metamaterial absorber was produced on the  $215 \times 215$  mm Arlon AD350 foil dielectric base. The absorber was tested in an anechoic chamber (Fig. 12). During the experiment, electromagnetic waves were transmitted and received with two horn antennas across the range of 1–18 GHz. They were placed at a distance of 1000 mm from the measured absorber. A Rohde & Schwarz ZVA24 vector analyzer was connected to the horn antennas to measure S-parameters. Then the S-parameters were transformed in the Microsoft Excel program and absorption plots were drawn according to them (Fig. 13).

The absorption parameters thus obtained show a good convergence of absorption plots for the structure with a screen. For the structure without a screen, the absorption parameters obtained in both

the simulation and the experiment differ. This was caused first of all by the fact that the boundary conditions were set along the contour of the investigated absorber while simulated by the Ansys HFSS (see Fig. 4) program. This did not take into account the real dimensions of the anechoic chamber. Another reason for the discrepancy in the results for the structure without a screen is that the receiving and transmitting antennas were set for the simulation by means of ideal waveguide ports. These do not take into account all the inhomogeneities of the real antennas.

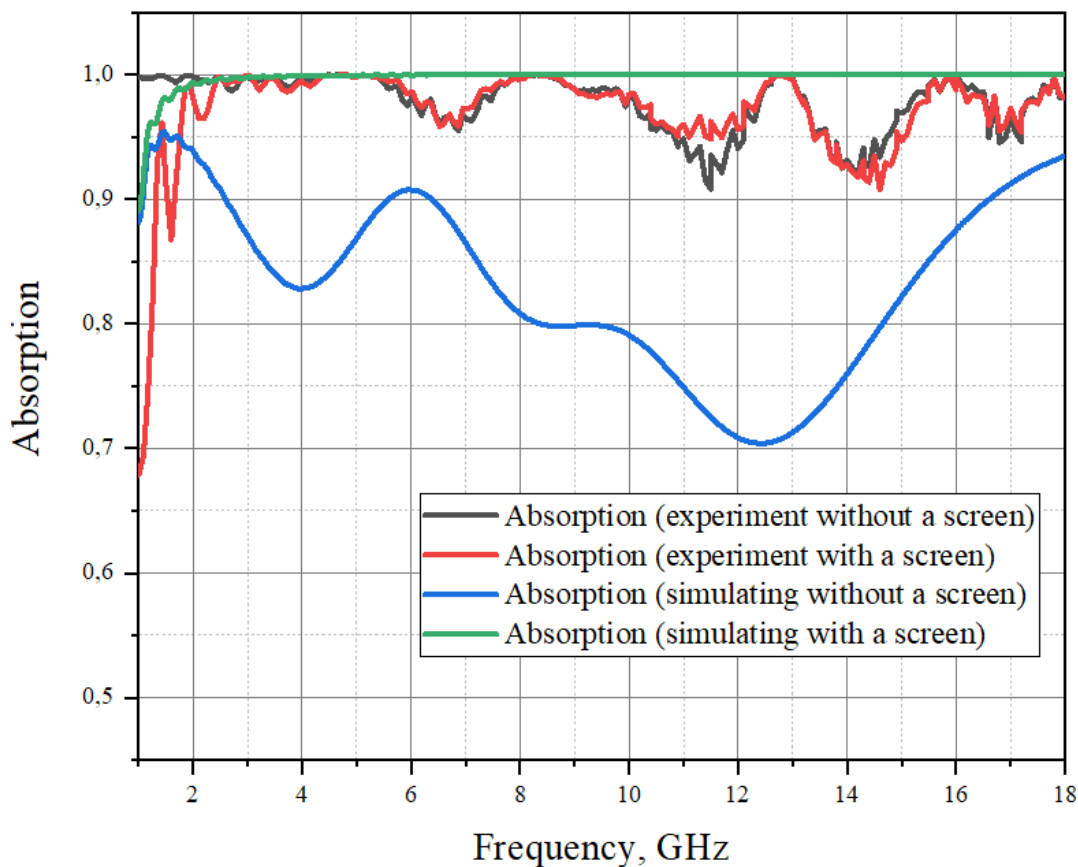


Fig. 13. Frequency dependence plot of an absorption coefficient of the investigated absorber

## Conclusion

In this paper, we designed an absorber of square metalized segments arranged on the Arlon AD350 foil dielectric. The paper has shown that the absorber design exhibits excellent absorption across the frequency range of 1.5–18 GHz with 90% absorption. This absorber thus works across the L, S, C, X and Ku frequency ranges.

Increasing the number of the unit cells narrowed the absorption range at lower frequencies, while at higher frequencies the band was widened in practical terms by 1 GHz.

The absorber design exhibits excellent polarization independence at incident wave angle from 0 to 90°.

Finally, the metamaterial absorber thus developed will be useful for communications and medical applications.

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## ШИРОКОПОЛОСНЫЙ ПОГЛОТИТЕЛЬ НА ОСНОВЕ МЕТАМАТЕРИАЛА, ВЫПОЛНЕННЫЙ ИЗ КВАДРАТНЫХ МЕТАЛЛИЗИРОВАННЫХ СЕГМЕНТОВ

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Целью данной работы является исследование поглотителя, состоящего из квадратных металлизированных сегментов, расположенных на фольгированном диэлектрике Арлон АД350. В статье показано, что поглощающий метаматериал обладает широкой рабочей полосой поглощения от 1.5 до 18 ГГц с коэффициентом поглощения 0.9. Поглотитель также обладает полной независимостью от поляризации при углах падения от 0 до 90°.

**Ключевые слова:** поглотитель, метаматериал, полоса пропускания, схема замещения.

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