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Development of a flexible thin-film radio-absorbing structure for UHF and SHF microwave range

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A broadband printed thin-layer radio absorbing structure based on an array of coupled dipole antennas has been developed and created. The resulting material can be used to solve the problems of shielding electromagnetic waves and reduce the level of electromagnetic emission from various devices in the 4−7 GHz frequency range, as well as to create building radio shielding materials.

Keywords: radar absorbing screen, magnetron sputtering, array of printed antennas.

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Introduction

The issue of reducing the electromagnetic emissions from radio electronic devices is of great importance due to the negative impact of electromagnetic waves (EMW) of UHF and SHF bands on sensitive radio equipment [1–4] and the human organism [4–8]. Effective reduction of electromagnetic emission from radio electronic devices can be achieved by placing wide-range radio-absorbing screens (RAS) placed inside the housing of the devices, and these screens provide the necessary level of electromagnetic shielding.

Wide-range radio-absorbing screens are created abroad on the basis of flat thin-film antenna structures [9–16], on foil materials such as fiberglass RF/SHF boards [9]. However, these radio-absorbing screens have a rather significant weight with a large area of the shielded housing of the radiating device, and there is also the problem of creating large arrays of extended dipole elements of large size for UHF-band frequencies [9,13–16]. A more promising direction should be the direction of creating flexible wide-range RASs using metal-screen printing technologies [17]. Such structures fabricated by thin-film technology (mask magnetron or electron-beam sputter dep[osition, printing with metallized ink, etc.) can have both pronounced wide-range radio absorption and wide-range radio screening.

The objectives of this paper are the development and study of the thin-layer radio-absorbing and radio-shielding structure based on the array of coupled dipole antennas to obtain a wide-range RAS suitable for effectively reducing the level of electromagnetic radiation from radio devices in the frequency range 2−7 GHz in mechanical engineering and specialized construction.

1. Mathematic simulation

At the first stage, the simulation of the electromagnetic parameters of a certain configuration of the thin-layer radio-absorbing structure based on the array of coupled paired triangular dipole antennas was performed. To accomplish this task, the AWR Design Environment software package was used, which allows designing and studying various SHF structures. Passive wide-range RAS structures based on copper triangular dipoles placed on the surface of dielectric substrate were simulated.

The first simulated sample is the array of uncoupled copper triangular dipoles with a jumper on a 75 μm thick polymer Mylar substrate (Fig. 1, a), for which the dependence of the calculated complex transmission coefficient S_{21} on the frequency of electromagnetic radiation (Fig. 1, b) is given.

The maximum value of radio screening obtained by simulation for the described structure is −19.0 dB at a frequency of 3.82 GHz.

The second simulated sample is the array of electrically coupled copper triangular dipoles with a jumper on a 75 μm thick polymer Mylar substrate (Fig. 2, a), for which the dependence of the calculated complex transmission coefficient S_{21} on the frequency of electromagnetic radiation (Fig. 2, b) is given. The maximum value of radio screening obtained by simulation for the described structure is −20.5 dB at a frequency of 3.72 GHz. It was decided to use this structure further as the basis for the RAS creation.

The analysis of the publications on approaches and methods for creating thin-layer RASs showed [9–17] that the most common and effective ways to create RASs are chemical etching, printing using 3D printer, or a metallized pattern sputtering of the array of absorbing elements onto the surface of dielectric substrate. When creating a thin-layer RAS, we chose the method of magnetron sputtering

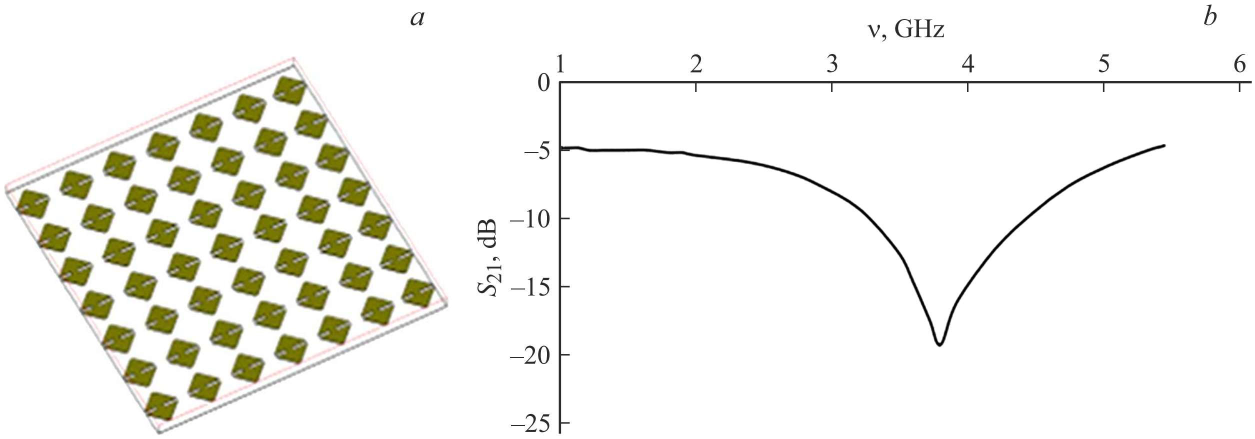

Figure 1. The RAS model based on the array of uncoupled copper triangular dipoles on a Mylar substrate (a) and the frequency dependence of the parameter S_{21} (b).

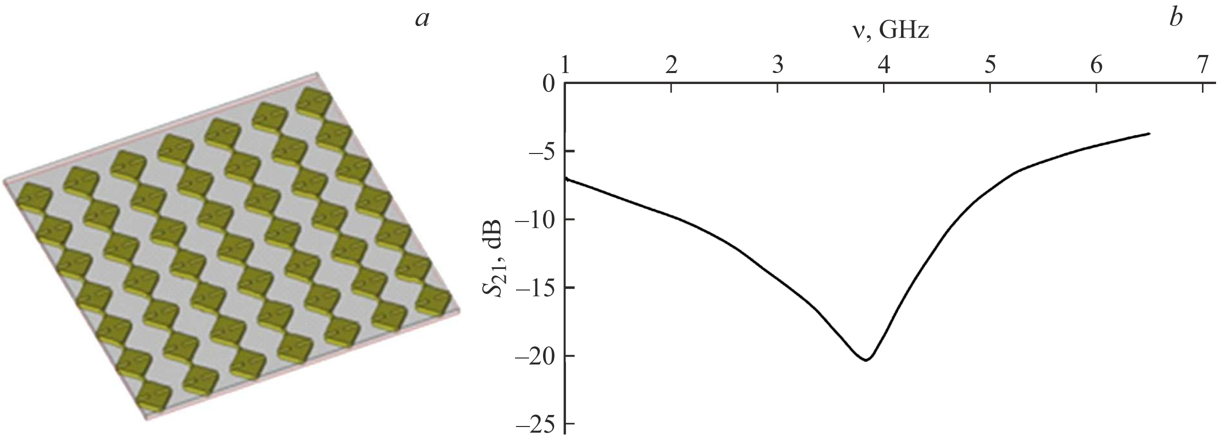

Figure 2. The RAS model based on the array of coupled copper triangular dipoles on Mylar substrate (a) and the frequency dependence of the parameter S_{21} (b).

of metallized circuits as more promising than the method of etching printed circuit boards in relation to the mass characteristics of the created RAS.

2. Experimental part. RAS manufacturing

In this paper the following materials were used: copper foil 0.3 mm thick (purity 99.99%, China) as a target for magnetron sputtering; nichrome foil Kh20N80 0.35 mm thick (RF) as a target for magnetron sputtering, Mylar 75 μm thick (China), acetone (technical, RF), vinyl film (China). To create RAS based on triangular coupled dipoles a special stencil mask from a vinyl film (Fig. 3, a) was designed and manufactured using a cutting plotter, which was used when sputtering copper metal layer 300 nm thick in the magnetron sputtering unit Quorum Q150T. The current strength for magnetron sputtering with argon plasma was 80 mA at a sputtering rate of 40 nm/min. The resulting RAS structure (Fig. 3, b) was protected from oxidation by two layers of acrylate varnish with a total thickness of about 10–12 μm applied by the spray method.

As you know, most modern smartphones can show the level of the incoming signal in „dBμV/m" units, which makes it possible to study the throughput of the created RAS based on coupled copper triangular dipoles on a flexible Mylar substrate using improvised means (Fig. 4). The smartphone digital indicator shows the power level of the incoming signal of 3G-cellular communication at frequency of 2.145 GHz in the range of -40 to -130 dB μV/m.

Experiments conducted ten times shown that the smartphone shielding with RAS based on coupled copper triangular dipoles on flexible Mylar substrate reduces the level of 3G-signal reception by 15–22 dBμV/m, and on average by 17.9 dBμV/m.

It was found that over time (more than a week) an undesirable effect of copper film oxidation is observed despite the presence of a protective layer of acrylate varnish, which reduces the efficiency of 3G-signal radio shielding by the fabricated screen to average level of 14.2 dBμV/m. To

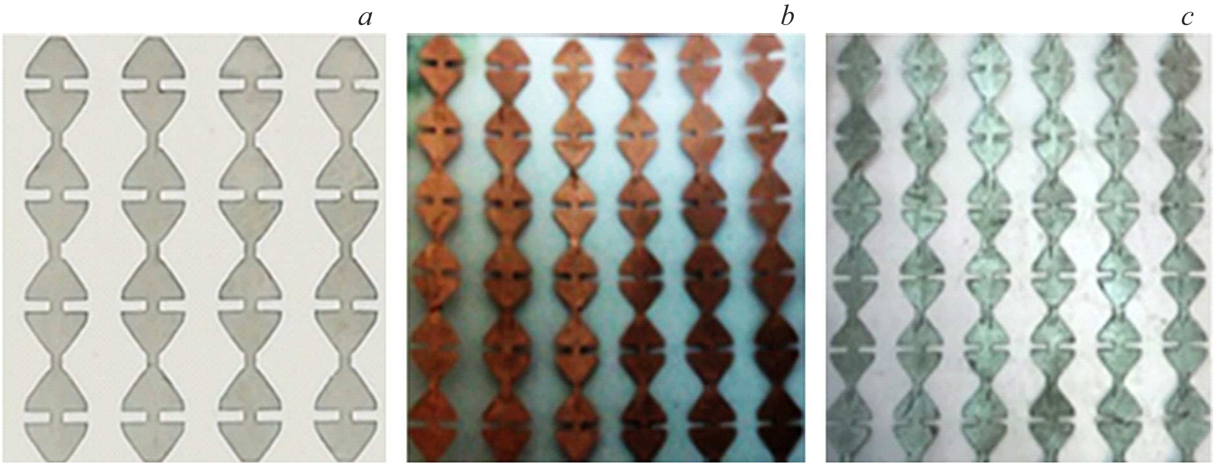

Figure 3. Fragments of components for RAS manufacturing: *a* — stencil mask for RAS manufacturing, lying on an aluminum substrate; *b* — RAS sample based on coupled copper triangular dipoles on Mylar substrate; *c* — RAS sample based on coupled copper triangular dipoles on Mylar substrate with a protective nichrome coating.

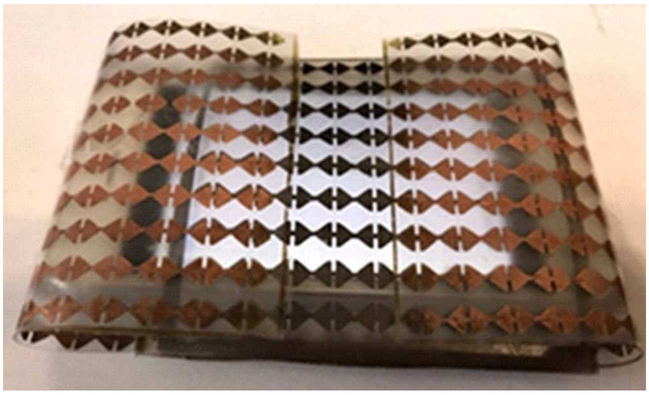

Figure 4. Measurement of 3*G*-signal level of a smartphone with shielding by manufactured thin-layer RASs.

eliminate the effect of copper oxidation on newly created RAS samples based on coupled copper triangular dipoles on the flexible Mylar substrate the protective anticorrosion layer of Kh20N80 nichrome 50 nm thick was sputtered on top. The obtained sample of the modified RAS is shown in Fig. 3, *c*.

The frequency dependences of the reflection loss parameter S_{11} in free space were measured for the created RAS on Mylar substrate with a 300×300 mm aluminum plate placed behind it and with perpendicular irradiation of the RAS. As a signal generator and spectrum analyzer we used vector network analyzer KC901V (Deepace Technology, China) and wide-range log-periodic printed antennas KC R100B for the 0.38–8 GHz band with 50 Ω coaxial power line. The measuring channel was calibrated without RAS using a radio-reflecting aluminum plate located on a radio-absorbing sheet ECCOSORB® AN (Laird Technologies, USA). The result of measuring the parameter S_{11} for the array 2×2 of fabricated RASs with total size of 200×200 mm based on coupled metallized dipoles with vertically polarized signal is the following frequency dependence (Fig. 5).

According to the data in Fig. 4, RAS made on the basis of metallized dipoles has pronounced radio absorption peaks in the frequency range from 4 to 6 GHz.

The transmission parameter S_{21} vs. frequency in free space were measured for the manufactured RAS on Mylar substrate. When creating the measuring setup, we used the recommendations in [18]. As a signal generator and spectrum analyzer we used vector network analyzer KC901V (Deepace Technology, China) and wide-range log-periodic printed antennas KC R100B for the 0.38–8 GHz band with 50 Ω coaxial power line. The electromagnetic shielding efficiency of the shield under study was determined from the measured values of S_{21}, determined by the method of circuit vector analysis, using the following formula [19]:

$$SE_{\square} = 20 \cdot \log_{10} |S_{21}|. \qquad (1)$$

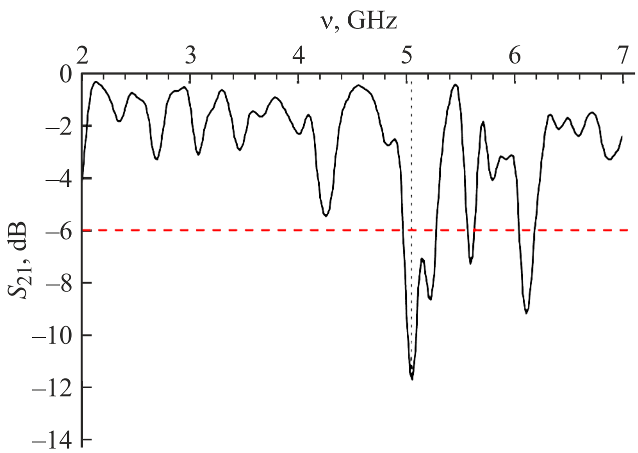

Figure 5. S_{11} parameter vs. frequency for 2×2 array of the manufactured RASs.

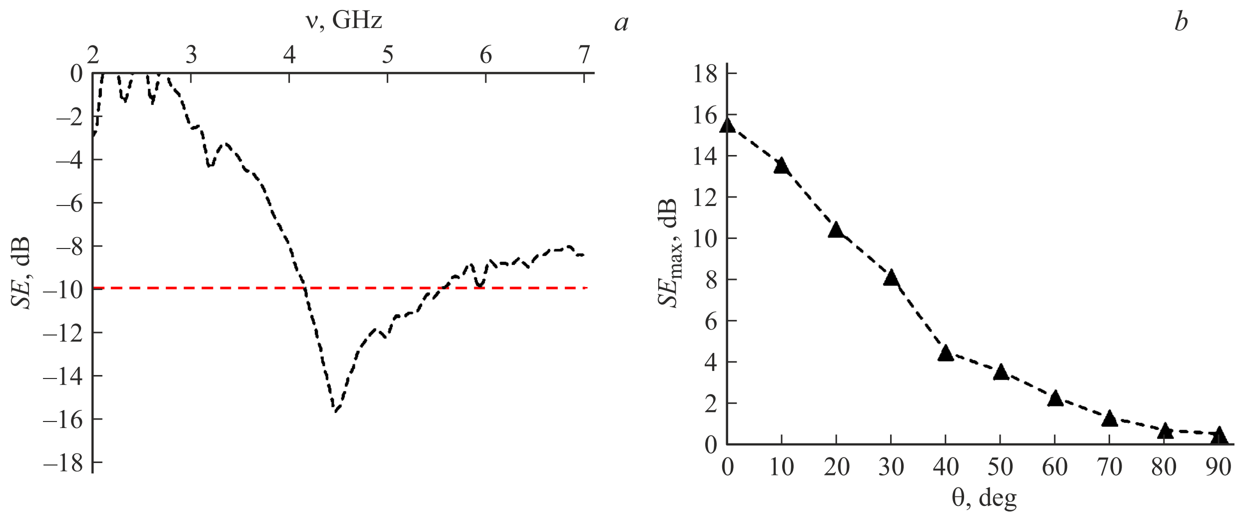

Figure 6. Characteristics of 2×2 array of manufactured RASs: S_{21} parameter vs. frequency for 2×2 array of manufactured RASs (*a*); the maximum level of signal attenuation vs. angle of rotation of RAS with respect to the antennas (*b*).

The result of measuring the parameter S_{21} for the array 2×2 of fabricated RASs with total size of 200×200 mm based on coupled copper dipoles with vertically polarized signal is the following frequency dependence (Fig. 6).

According to the experimental data of measurements with wide-range log-periodic antennas in the studied frequency range of 2−7 GHz, the fabricated printed radio-absorbing structure has a signal transmission coefficient with loss level of > -10 dB at frequencies of electromagnetic radiation in the range from 4.17 to 5.56 GHz (Fig. 6, *a*). The observed discrepancy between the type of frequency dependence of the calculated (Fig. 2, *b*) and experimental transmission loss modulus (Fig. 6, *a*) of the created radar absorbing screen is connected, in our opinion , with the following reasons: 1) inaccurate knowledge of the required electrodynamic parameters, which were used in the simulation of thin-film metal materials produced by magnetron sputtering; 2) technical problems in the manufacture of the printed array of coupled dipole antenna elements; 3) neglect of the effect of the used protective anti-corrosion layer of nichrome 50 nm thick.

Conclusion

This type of shielding frequency-selective structure has a transparency window in the range of 2−3 GHz and wide-range radio shielding in the frequency range of electromagnetic waves from 4 to 7 GHz, which depends on the type of polarization of electromagnetic wave and on irradiation angles. In this case, radio shielding from 4 to 7 GHz is mainly due to the radio absorption of EMW in thin films of copper and nichrome in the form of rhomboid dipoles with a gap. When the position angle of the RAS changes with respect to the polarization of the incident electromagnetic radiation from the log-periodic irradiating antenna, the efficiency of the observed radio shielding of the RAS decreases (Fig. 6, *b*). Based on the calculated electromagnetic parameters, the proposed crossed radio-absorbing screen structure can be classified as a metamaterial [20].

Thus, as a result of the work execution, a flexible thin-layer printed radio-absorbing structure was designed, optimized and manufactured, it is suitable for effective reduction of the level of electromagnetic radiation from radio devices in the frequency range of 4−7 GHz.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] R.R. Gainutdinov, Z.M. Gizatullin. Tekhnologii elektromagnitnoj sovmestimosti, **3**, 44 (2010). (in Russian)

[2] R.P. Bystrov, V.G. Dmitriev, A.A. Potapov, Yu.M. Perunov, V.A. Cherepenin. RENSIT, **6** (2), 129 (2014). (in Russian)

[3] A.A. Akbashev, N.B. Balyuk, L.N. Kechiev. *Zaschita ob'ektov telekommunikatsij ot elektromagnbitnykh vozdejstvij* (Grifon, M., 2014) (in Russian)

[4] S.S. Schesnyak. *Metody rascheta sredstvzaschity radioelektronnykh sistem ot electromagnitnogo izlucheniya* (SVVM, SPb, 2016), 310 s. (in Russian)

[5] V.A. Bannyj, V.A. Ignatenko, A.S. Azarenok, L.A. Evtukhova. *Problemy zdorov'ya i ekologii*, **56** (2), 4 (2018). (in Russian)

[6] S. Batool, A. Bibi, F. Frezza, F. Mangini. European Review For Medical And Pharmacological Sciences, **23** (7), 3121 (2019). DOI: 10.26355/eurrev_201904_17596

[7] N. Wongkasem Electromagnetic Biology and Medicine, **2** (40), 236 (2021). DOI: 10.1080/15368378.2021.1874976

[8] K. Karipidis, R. Mate, D. Urban, R. Tinker, A. Wood. J. Exposure Science & Environmental Epidemiology, **31**, 585 (2021). DOI: 10.1038/s41370-021-00297-6

[9] Y. Shang, S. Xiao, B.Z. Wang. Microwave Optical Technol. Lett., **56** (5), 1200 (2014). DOI: 10.1002/mop.28288

[10] W. Chen, C.A. Balanis, C.R. Birtcher. IEEE Transactions on Antennas and Propagation, **63** (6), 2636 (2015). DOI: 10.1109/TAP.2015.2414440

[11] W. Jiang, Y. Liu, S. Gong, T. Hong. IEEE Antennas and Wireless Propagation Lett., **8**, 1275 (2009). DOI: 10.1109/LAWP.2009.2037168

[12] M.Z. Joozdani, M.K. Amirhosseini, A. Abdolali. Electron. Lett., **52** (9), 767 (2016). DOI: 10.1049/EL.2016.0336

[13] Y. Chang, W. Che, Y. Han, Y. Chow. IEEE Antennas and Wireless Propagation Lett., **13**, 1084 (2014). DOI: 10.1109/LAWP.2014.2327961

[14] B.-Y. Wang, S.-B. Liu, B.-R. Bian, Z.-W. Mao, X.-C. Liu, B. Ma, L. Chen. J. Appl. Phys., **116**, 094504 (2014). DOI: 10.1063/1.4894824

[15] D. Sood, C. Tripathi. Appl. Phys. A, **122** (4), 332 (2016). DOI: 10.1007/S00339-016-9884-2

[16] J.C. Iriarte Galarregui, A.T. Pereda, J.L.M. de Falcón, I. Ederra, R. Gonzalo, P. de Maagt. IEEE Transactions on Antennas and Propagation, **61** (12), 6136 (2013). DOI: 10.1109/TAP.2013.2282915

[17] W.-J. Lee, J.-W. Lee, C.-G. Kim. Compos. Sci. Technol., **68** (12), 2485 (2008). DOI: 10.1016/J.COMPSCITECH.2008.05.006

[18] E.A. Shtager, A.S. Schesnyak, V.P.Belov, D.O. Khabirov. Tehnologii EMS, **67** (4), 40 (2018) (in Russian).

[19] S. Geetha, K.K.S. Kumar, C.R.K. Rao, M. Vijayan, D.C. Trivedi. J. Appl. Polymer Sci., **112**, 2073 (2009). DOI: 10.1002/app.29812

[20] P.N. Kaleeba, A. Tennant, B. Chambers, J.P. Idez. Antennas and Propagation Society International Symposium IEEE, **4**, 295 (2003). DOI: 10.1109/APS.2003.1220178

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