Quality Production Improvement and System Safety: QPI 16 - CZOTO 10 Materials Research Forum LLC
Materials Research Proceedings 34 (2023) 169-177 https://doi.org/10.21741/9781644902691-21

Radar Recognition: Paint Coatings with Absorption Properties in the Microwave Range

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Keywords: Radar, Coatings, Absorption, Microwave

Abstract. The article presents the characteristics of modern reconnaissance systems in the radar range and camouflage methods for this range. Two absorbers of electromagnetic radiation in the 4-18 GHz range were tested, measuring their attenuation properties. Carbonyl iron and thin-walled hollow microspheres based on soda-lime-borosilicate glass were tested, on the basis of which paint coatings with different shares of absorbers and different coating thicknesses were produced. The attenuation properties of both absorbers were determined and attention was paid to the maximum values and frequencies for which they occur. Further directions of research were also proposed in order to obtain varnish coatings that are an effective camouflage agent in radiolocation.

Introduction

On the contemporary battlefield, as shown by recent full-scale conflicts, artillery, both barreled and rocket artillery, as well as armored forces with accompanying mechanized infantry units, still play a decisive role. On the fronts of modern conflicts, the improvement of means of destruction is observed, increasing the share of "intelligent" weapon components. However, what ensures their effective attack, even for the most modern system, is effective reconnaissance. In close range and direct combat, the human eye is still the basic reconnaissance device, but since the invention of the rifle, later cannons, then rockets and airplanes, the area of direct combat has been constantly increasing. For reconnaissance purposes, a number of sensors are used that operate in different ranges of electromagnetic radiation (Fig.1).

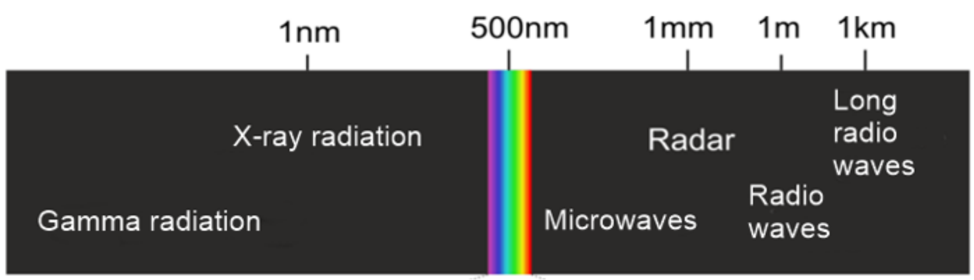

Fig.1. *Scheme of the electromagnetic radiation spectrum*

Sensors in the optical and thermal bands are commonly used – especially for closer distances. On the other hand, for longer distances, radars operating in the microwave band up to hectometer waves are used. Due to various properties, e.g. reflection or absorption by water vapor, penetration through selected media, etc., they find various applications: telecommunications, meteorological, SAR or military reconnaissance. Therefore, the frequency was divided into different bands (Table 1),

Table 2. *Frequency division into bands (source: [1])*

Band name	**Frequency range [GHz]**	**Wavelength range [cm]**	**Band's symbol**
VHF	0.1 - 0.3	300 - 100	A
UHF	0.3 - 0.5 0.5 - 1.0	100 - 60 60 - 30	B C
L	1 - 2	30 - 15	D
S	2 - 3 3 - 4	15 - 10 10 - 7.5	E F
C	4 - 6 6 - 8	7.5 - 5 5 - 3.75	G H
X	8 - 10 10 - 12	3.75 - 3 3 - 2.5	I J
Ku	12 - 18	2.5 - 1.67	J
K	18 – 26.5	1.67 - 1.1	J (do 20 GHz)
Ka	26.5 - 40	1.1 - 0.75	K
Millimeter wave	40 - 100	0.75 - 0.3	L (do 60 GHz) M (>60 GHz)

Several bands are used in reconnaissance applications. Here are some example uses:
- S band – NUR-15 – three-coordinate complementary radar for radar coverage and detection of low-flying targets; the AN/APY-2 radar station of the E-3/AWACS aircraft;
- Band C – LIWIEC artillery reconnaissance radar set;
- Band X – AN/APG-66 radar station of the F-16 aircraft; RPW-10 – battlefield radar (Figure 2);
- Ku-band – AN/PPS-5C – battlefield radar;
- L band – 59N6E Protiwnik-GE – long range radars.

Fig.2. *PGSR-3i Beagle battlefield reconnaissance radars (source: [2])*

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The main task of the radars is to raise the situational awareness in the theatre of war by detecting, locating and identifying ground and air objects, thanks to the registration of their radar echoes by the antennas. Some of them that use the Doppler effect can also contain information about the speed of a moving object. Others using synthetic aperture radar (SAR) are able to produce a three-dimensional image of the terrain, and sometimes also determine the type of material, shape and size of the object. Currently, the most modern radars are AESA – Active Electronically Scanned Array, whose antenna consists of many independently, electronically controlled modules, which makes it possible to track many targets. They are also characterized by greater resolution and accuracy (Fig.3).

Fig.3. *C-band AESA radar used in the ZDPSR BYSTRA radiolocation station (source: [3])*

The vast majority of radars are equipped with receiving antennas as well as emitting electromagnetic pulses, which makes them easy targets to track. Passive radars, which do not send their own signals, do not have this handicap, and they receive the radar echo from other sources, which may be, for example, telecommunication transmitters (telephony, radio, terrestrial or satellite TV).

An important element of the modern battlefield is to hide your own forces from the enemy's radar reconnaissance. One way to achieve this goal is to construct your own objects in such a way that their radar echo is as small as possible. The measure used to determine and compare the size of signals in echolocation is the Radar Cross Section (RCS). It describes the measure of the energy that would be reflected from the object in relation to the total energy incident on the object and referred to a unit sphere with an area of 1 m^2 and perfectly reflecting waves in all directions. Thus, this quantity is described in m^2 or in dB. Table 3 shows estimated RCS values for sample objects.

Table 3. *Example RCS values for selected objects (source: [4])*

Object	RCS [m^2]	RCS [dB]
Bird	0.01	-20
Human	1	0
Motorboat	10	10
Passenger car	100	20
Truck	200	23
corner	20379	43.1

Thus, the basic features affecting the RCS are: the size of the object, its shape and material properties in terms of absorption and reflection of electromagnetic waves. Already today there are constructions in the stealth technology, which, thanks to their construction (specific shape) and the materials used for the outer shells, are able to effectively reduce the RCS, and thus the radar echo, so as to become almost invisible to radars or significantly reduce the detection distance. For example, B-2 Spirit heavy bomber with a wingspan of 52 m has RCS approx. 0.1 m² [5]. Table 4 shows a few selected RCS for modern military aircraft.

Fig.4. *B-2 Spirit heavy bomber, constructed in stealth technology (source: [6])*

Table 4. *RCS for selected modern models of military aircraft (source: [7])*

Aircraft model	RCS	Rmax
	[m²]	[km]
F-15C; Su-27	10–15	450–600
MIG-29	5	370–450
F/A-18C	3	330–395
F-16C	1,2	260–310
Su-47	0.3	185–220
F-18E	0.1	140–170
F-35A	0.0015	50–60

The authors of the article are also working on reducing RCS. They focus on material properties and, in this article, they tested and compared sets of paint coatings that were selected as potential radar echo reducing. Wave absorbers were sought, which, as thin varnish coatings, would attenuate electromagnetic waves in the C, X, Ku ranges, which are used in radiolocation, as previously mentioned.

Radiation energy in the paint coating is decomposed into 3 components: reflection, absorption and multiple reflection [8].

$$SE = SE_R + SE_A + SE_{MR} \quad (1)$$

Due to the study of attenuation, only the absorption part of the SEA was considered in this article. The presence of magnetic and electric dipoles enables the conversion of electromagnetic energy into energy dissipated in the layer (e.g. heat), which contributes to increasing electromagnetic attenuation.

Paint coatings were tested - a lossy, absorbing layer with a thickness of s and the assumed reflection coefficient $\Gamma = 0$ and wave impedance Zn = 1, applied to metal plates (reflective layer). Thus, the model system can be described by the equation:

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$$\Gamma = \frac{Z_n - 1}{Z_n + 1} \quad (2)$$

For a plane wave it was assumed:

$$Z_n = \sqrt{\frac{\mu_r}{\varepsilon_r}} \cdot \tanh\left(j \cdot \frac{2 \cdot \pi}{\lambda} \cdot \sqrt{\varepsilon_r \cdot \mu_r} \cdot s\right) \quad (3)$$

λ – wavelength in free space

$\varepsilon_r(f) = \varepsilon'(f) - j\,\varepsilon''(f)$ – complex permittivity

$\mu_r(f) = \mu'(f) - j\,\mu''(f)$ – complex magnetic permeability

j – imaginary part $\sqrt{-1}$

Two different materials were tested as absorbers:

- BASF's spherical carbonyl iron, designated EB, with a particle size of 3 - 4 μm (Table 5 contains basic properties)
- Thin-walled empty microspheres manufactured by 3M marked as S22 with particle size D50 - 35 μm (Table 6 contains basic properties).

Table 5. *Properties of the carbonyl iron used in the study*

Type	Form	Size	Bulk density [kg/m³]	Fe atom content [%]	C atom content [%]	N atom content [%]	O atom content [%]
BASF EB	powder	3 ÷ 4 μm with a wider grain size distribution	4 200	> 97,3	< 1	< 1	< 0,4

Table 6. *Properties of the glass microspheres used in the study*

Type	Form	Particle size D_{50} [μm]	Density [kg/m³]	Scrush test [MPa]	Minimum survivability [%]
3M S22	Powder	35	0.22	2.76	80

On the basis of these absorbers, varnish pastes were made, which were used to paint aluminum plates with dimensions of 300 × 300 × 4 mm.

In the case of carbonyl iron, Epikote 828 epoxy resin and Ancamine 1618 hardener were used as a binder. The composition also included additives produced by Amepox Microelectronic Co Ltd.: AX-R, reducing viscosity, and AX-S - increasing flexibility.

For 3M S22 glass microspheres, XX0606 polyurethane resin was selected as a binder, with XPH80002 hardener and BYK 969 dispersant additive.

The share of carbonyl iron as an absorber in the varnish paste was 75% for the first series of samples and 80% for the second series of samples. The thickness of the applied paste layer is 05, 1, 1.5, 2.0 mm for each series, respectively.

On the other hand, in the samples with the participation of 3M S22 glass microspheres, 3 series of samples with the absorber content of 20.5%, 35.0 and 54.0%, respectively, were made. The thickness of the applied paint layer was for 20.5% 4w - 0.814mm, 6w - 1.041mm, 8w - 1.273 mm.

For 35% 4w - 0.987mm, 6w - 1.416mm, 8w - 1.803mm and for 54% 4w - 1.457mm, 6w - 1.798mm, 8w - 2.278mm.

The tests consisted in measuring the radar signal reflected from the samples with coatings and comparing them to the reference sample - without the varnish coating. The tests were carried out on a measuring stand consisting of a reflectometer operating in the 4-18 GHz range and a control computer (Figure 5).

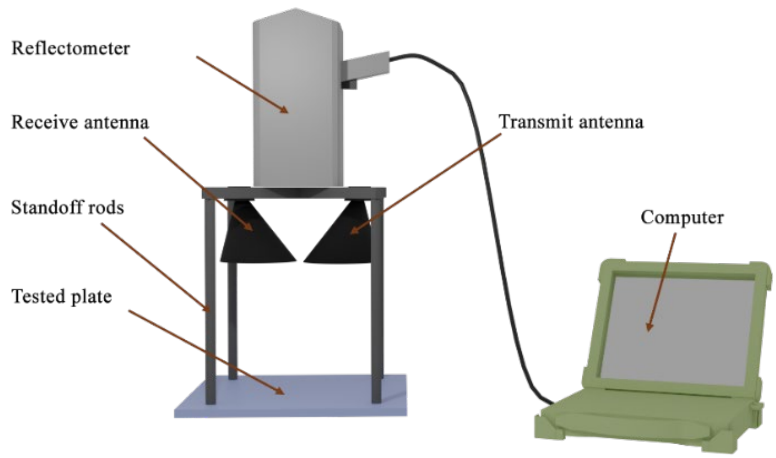

Fig.5. *Scheme of the measuring station (description of individual elements in the diagram).*

The results of attenuation measurements for carbonyl iron as an absorber are presented in Table 7, while the graphs in Fig.6 and Fig.7 show the attenuation tendency depending on the thickness of the paint layer with the absorber.

Table 7. *Results of attenuation measurements for EB carbonyl iron*

Frequency [GHz]	content 75%				content 80%			
	0.5mm	1.0mm	1.5mm	2.0mm	0.5mm	1.0mm	1.5mm	2.0mm
4	-4.5	-5.0	-4.5	-18.0	-1.7	-2.6	-5.0	-6.0
6	-4.5	-7.0	-7.0	-12.5	-1.9	-3.0	-7.5	-8.0
8	-7.0	-12.0	-12.0	-9.0	-2.1	-5.0	-11.5	-14.0
10	-7.0	-13.0	-11.0	-7.0	-2.3	-7.0	-12.5	-12.0
12	-5.0	-10.0	-7.0	-5.0	-2.5	-9.0	-11.0	-6.0
14	-4.5	-5.0	-4.5	-4.0	-2.8	-10.0	-7.0	-5.0
16	-4.0	-4.5	-4.0	-4.0	-5.0	-10.0	-6.0	-5.0
18	-4.0	-4.5	-4.0	-4.0	-6.0	-10.0	-6.0	-5.0

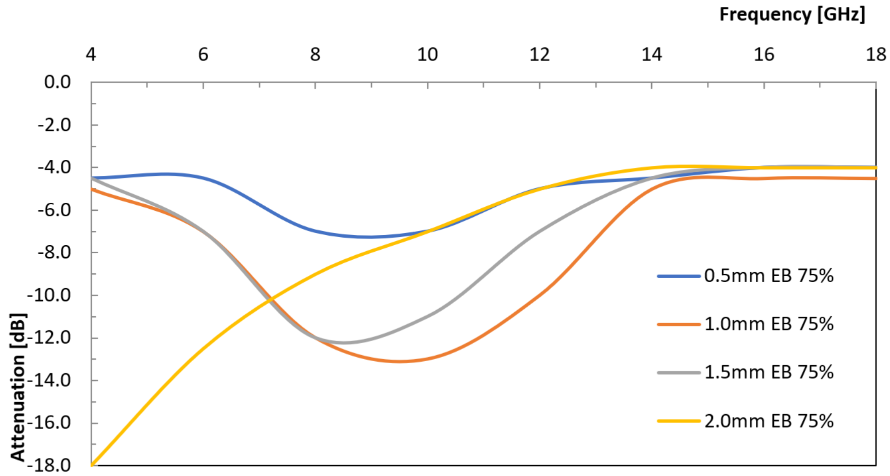

Fig.6. *Influence of thickness on attenuation - EB absorber, 75% share*

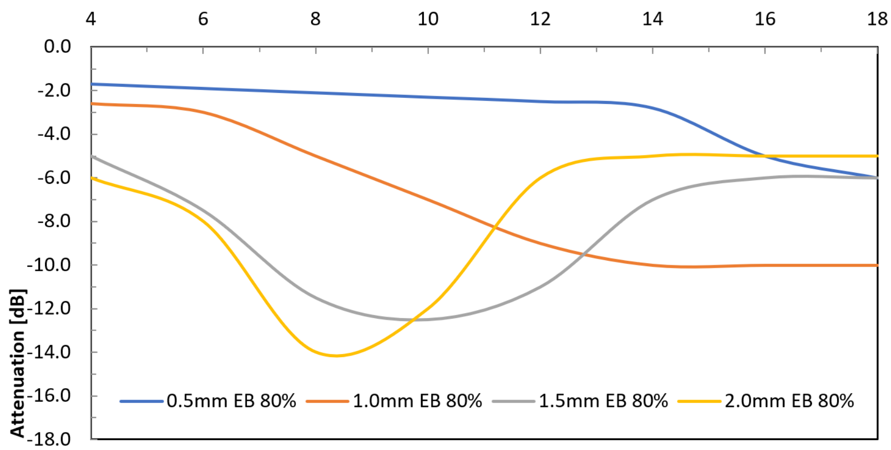

Fig.7. *Influence of thickness on attenuation - EB absorber, 80% share*

For 3M S22 glass microspheres, the results are presented in Table 8, and the damping tendency in Fig.8, Fig.9 and Fig.10.

The thickness of the applied paint layer was for 20.5% 4w - 0.814mm, 6w - 1.041mm, 8w - 1.273 mm. For 35% 4w - 0.987mm, 6w - 1.416mm, 8w - 1.803mm and for 54% 4w - 1.457mm, 6w - 1.798mm, 8w - 2.278mm.

Table 8. *Results of attenuation measurements for S22 glass microspheres*

Frequency [GHz]	Content 3M S22 20.5%			Content 3M S22 35%			Content 3M S22 54%		
	4w 0.814 mm	6w 1.041 mm	8w 1.273 mm	4w 0.987 mm	6w 1.416 mm	8w 1.803 mm	4w 1.457 mm	6w 1.798 mm	8w 2.278 mm
4.0	-0.282	-0.200	-0.380	-0.252	-0.222	-0.371	-0.256	-0.310	-0.481
6.0	-0.706	-0.096	-0.176	-0.097	-0.120	-0.165	-0.112	-0.733	-0.179
8.0	-0.074	-0.100	-0.183	-0.096	-0.141	-0.257	-0.142	-0.228	-0.172
10.0	-0.086	-0.153	-0.313	-0.204	-0.215	-0.335	-0.182	-0.282	-0.289
12.0	-0.102	-0.269	-0.376	-0.177	-0.362	-0.454	-0.267	-0.484	-0.506

14.0	-0.073	-0.200	-0.312	-0.117	-0.310	-0.596	-0.244	-0.479	-0.656
16.0	-0.459	-0.671	-0.891	-0.519	-0.787	-0.657	-0.830	-0.650	-0.403
18.0	-0.538	-0.746	-0.948	-0.554	-0.711	-1.250	-0.849	-0.989	-1.726

From the presented results, it can be seen that the absorbers used show attenuation properties in the range of the tested frequencies (4-18GHz). It should be added that carbonyl iron has 10 times better damping properties than S22 glass microspheres, achieving a reduction of even -18 dB for selected frequencies and coating thicknesses (4GHz, 2mm, 75% EB) compared to a sample without a paint coating with an absorber. The S22 glass microsphere absorber reached a maximum value of -1.73 dB for a share of 54% and a coating thickness of 2.278 mm. At the same time, it can be stated that the maximum attenuation for both absorbers depends on the thickness of the layer - usually for a thicker layer there is greater attenuation and the type, share and thickness also affect the position of the maximum attenuation in the spectrum of the tested frequencies.

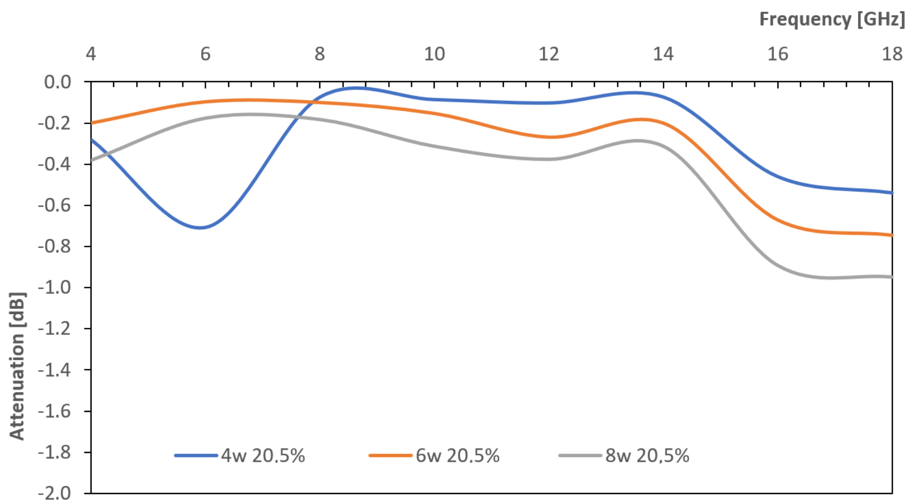

Fig.8. *Influence of thickness on attenuation - 3M S22 absorber, share 20.5%*

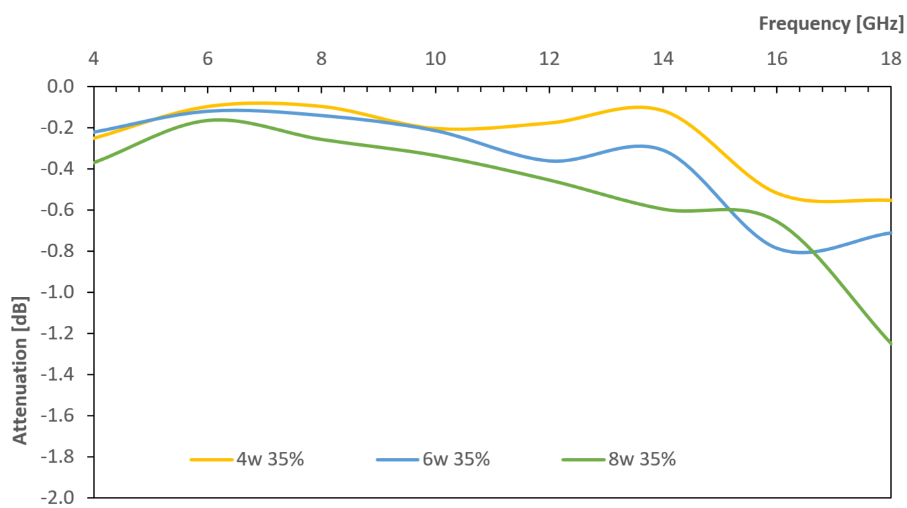

Fig.9. *Influence of thickness on attenuation - 3M S22 absorber, share 35%*

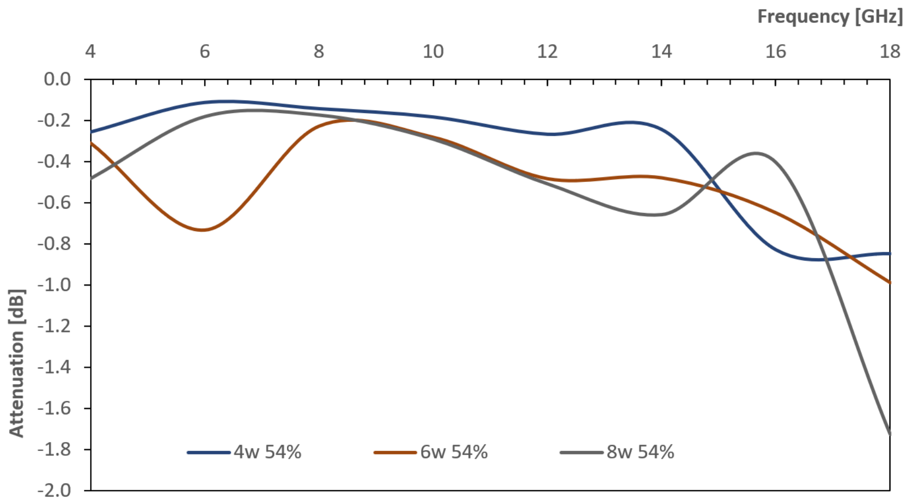

Fig.10. *Influence of thickness on attenuation - 3M S22 absorber, share of 54%*

Conclusions

Carbonyl iron as an absorber provides good attenuation properties (-18dB), which cannot be stated in relation to S22 glass microspheres, for which the highest attenuation was -1.73 dB. At the same time, good attenuation properties for carbonyl iron occur in a fairly narrow frequency range and do not cover the C, X, Ku bands, but occur for different frequency values depending on the thickness of the layer and the share of the absorber. In connection with the above, it can be assumed that attenuation in a wider range could be obtained by using multi-layer systems with different shares of absorbers, as well as different thicknesses of individual layers forming the paint coating. In addition, further research with greater precision and a wider frequency range would be advisable to confirm the trends of "shifting" of the maximum attenuation.

In conclusion, carbonyl iron has great potential to be used as a radar absorber in paint coatings in camouflage applications.

References

[1] Based on IEEE, https://www.radartutorial.eu/07.waves/wa04.po.html, 2023-01-23

[2] https://polska-zbrojna.pl/Mobile/ArticleShow/30589, 2023-01-23

[3] Materiały producenta – PIT-RADWAR, https://www.pitradwar.com/oferta/425,zdolna-do-przerzutu-stacja-radiolokacyjna-bystra#, 2023-01-20

[4] M. Skolnik, « Introduction to radar systems », wydanie drugie, McGraw-Hill Inc, 1980, strona 44.

[5] D. Richardson: Stealth Warplanes, Zenith Press, 2001

[6] https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104482/b-2-spirit/

[7] Prasad N.E., Wanhill R.J.H., Aerospace Materials and Material Technologies Volume 1: Aerospace Materials, Springer Nature, 2016, s. 1-343. https://doi.org/10.1007/978-981-10-2143-5

[8] Sankaran S., Deshmukh K., Ahamed M.B., Khadheer Pasha S.K., Recent advances in electromagnetic interference shielding properties of metal and carbon filler reinforced flexible polymer composites: A review, Composites Part A: Applied Science and Manufacturing, t. 114, 2018, s. 49-71. https://doi.org/10.1016/j.compositesa.2018.08.006