The Absorption Capability Measurements of the Free Space Absorbers

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Abstract—The article refers to problems related to the absorption measurements of materials absorbing electromagnetic waves (Radar Absorbing Materials — RAM). The methodology of measurements, description of the original laboratory stand for measuring the absorption characteristics of the examined materials as a function of the testing signal angle of incidence and for measuring radar cross section (RCS) were introduced. Results of the above mentioned measurements for a metal plate covered with a sample absorbing material were also published.

1. INTRODUCTION
The article introduces the original methods of measurement and results of the measurement of the electromagnetic waves absorption level of the sample absorbing material. A metal plate (50 × 54) cm covered with absorbing material formed by a sponge saturated with graphite compounds was an object of research. As a reference material for evaluating absorption of the respective materials a metal plate not covered with absorbing material was used. Fig. 1 shows the appearance of the respective samples.

2. DESCRIPTION OF THE MEASURING METHOD
The article introduces two methods for measuring absorption level of the tested materials. One of them is based on a parameter, in the radar technique defined as a Radar Cross Section (RCS), which is a measure of the signal level refracted by an object at a given testing signal level. The second method is based on measuring absorption characteristics of the tested materials as a function of the testing signal angle of incidence.

2.1. The Measurement of the Characteristics of Tested Materials as a Function of the Testing Signal Angle of Incidence
The measurement of the characteristics of tested materials as a function of the testing signal angle of incidence is divided into two stages. The first stage is a reference measurement where a signal reflected from a reference plate, which wasn’t covered by the absorbing material, is measured. In the second stage, the measurement of the signal level reflected from a plate covered with an absorbing material is performed. In the processed methods of measurement a relative difference between signals measured in these two stages is the measure of the material electromagnetic waves absorption.

The absorption level of different absorbing materials placed on the metal plate is evaluated comparing to the level of the signal reflected from a metal plate not covered with the absorbing material. The absorption level is heavily dependent on the angle of the plate surface covered with the absorbing material in relation to the transmitting (receiving) antenna aperture and the obtained results allow to estimate at which angle the maximum absorption value of the tested material can be achieved. Block scheme of the laboratory stand is shown in Fig. 2.

Figure 1: An appearance of the respective testing samples. Sample No 1 — a metal plate not covered with absorbing material (reference material). Sample No 2 — a metal plate covered with absorbing material (RAM).
The measurement methodology is based on measuring the signal reflected from the surface covered with the tested absorbing material. The testing signal is generated by a microwave generator with a horn transmitting antenna. The signal reflected from the surface covered with the absorbing material is measured with a horn reception antenna and a microwave receiver. Measurements are performed in an anechoic chamber covered with absorbers to avoid reflecting from the floor and walls (Fig. 3). Measurements involved the following equipment:

- high frequency signal source — HP 8362 series generator,
- high frequency amplifier, operating at the testing frequency (the frequency at which the absorbing material is tested),
- two horn antennas,
- Agilent 8511A frequency converter,
- HP 8530 microwave receiver,
- rotary head for measuring absorbing characteristics.

2.2. Radar Cross Section Measurement

The measurement of radar cross section of absorbing materials placed on the metal plate (50×54) cm was executed in a measuring arrangement shown in Fig. 2. In contrast to measuring the absorption characteristics of examined materials as a function of the testing signal angle of incidence, in case of the RCS measurement no change of the plate angle is performed.

A precise arrangement of the plate with absorbing material in relation to the testing signal source was performed by means of a laser beam placed on the transmitting (receiving) antenna aperture and a mirror placed on the plate with tested material. The arrangement of the transmitting (receiving) antenna in such a way that the generated laser beam reflects from the mirror and covers the point where it was originally generated, proves that the aperture of the transmitting (receiving) antenna is parallel to the surface of the metal plate covered with absorbing material.

The radar cross section defines a measure of the electromagnetic wave reflection from a given object. A theoretical value of RCS for a flat, rectangular and perfectly reflecting surface can be
evaluated with the following equation [2]:

\[ \sigma = \frac{4\pi a^2 b^2}{\lambda^2}, \]  \hspace{1cm} (1)

where:

- \( \sigma \) — radar cross section in \([\text{m}^2]\),
- \( \lambda \) — wavelength in \([\text{m}]\),
- \( a, b \) — height and width of the rectangular reflecting surface in \([\text{m}]\).

\( \sigma \) value for a metal plate reflecting the incident electromagnetic wave can be calculated with the following equation [2]:

\[ \frac{P_{RX}}{P_{TX}} = \sigma \cdot \frac{G^2 \lambda^2}{(4\pi)^2 R^4}, \]  \hspace{1cm} (2)

where:

- \( P_{RX} \) — power of the signal reflected from a metal plate in \([\text{W}]\),
- \( P_{TX} \) — power of the transmitted signal in \([\text{W}]\),
- \( G \) — antenna gain (transmitting and receiving antenna have the same value of gain),
- \( R \) — antennas distance from the metal plate in \([\text{m}]\).

In order to evaluate \( \sigma \) value, \( P_{RX} \) value of the signal refracted from the metal plate should be measured as well as \( P_{TX} \) power of the transmitted signal value. For evaluating \( \sigma \) value also \( K \) coefficient is necessary:

\[ K = \frac{G^2 \lambda^2}{(4\pi)^2 R^4}, \]  \hspace{1cm} (3)

The above dependency is a component part of Eq. (2). \( K \) value defines parameters of the measuring system and depends on the testing signal wavelength. Having a reference object with a known \( \sigma \) value, \( K \) coefficient value can be evaluated with the following dependency:

\[ \frac{P_{RX}}{P_{TX}} = \sigma \cdot K, \]  \hspace{1cm} (4)

In the above dependency \( P_{RX} \) and \( P_{TX} \) values are obtained as a result of measuring the reference object. In this case a metal plate \((50 \times 54)\text{ cm}\) not covered with RAM (radar absorbing materials) was used as a reference object. \( \sigma \) parameter value for the tested metal plate should be evaluated with Eq. (1).

\( K \) coefficient value describing the laboratory stand with the metal reference plate with \( \sigma \) value as well as \( P_{RX} \) and \( P_{TX} \) values obtained from measurements, should be evaluated from Eq. (4) after executing the following transformations:

\[ \frac{P_{RX}}{P_{TX}} = \sigma \cdot K/10 \log \]
\[ 10 \log \frac{P_{RX}}{P_{TX}} = 10 \log \sigma + 10 \log K \]
\[ 10 \log K = 10 \log \frac{P_{RX}}{P_{TX}} - 10 \log \sigma \]
\[ K = 10^{10 \log \frac{P_{RX}}{P_{TX}} - 10 \log \sigma} \]  \hspace{1cm} (5)

\( K \) values, characteristic for the measuring system, were used to count \( \sigma_{RAM} \) parameter value for the metal plate \((50 \times 54)\text{ cm}\) covered with RAM. Eq. (4) should be used to count \( \sigma_{RAM} \) parameter
after executing the following transformations:

\[
\frac{P_{RX}}{P_{TX}} = \sigma_{RAM} \cdot K / 10 \log
\]

\[
10 \log \frac{P_{RX}}{P_{TX}} = 10 \log \sigma_{RAM} + 10 \log K
\]

\[
10 \log \sigma_{RAM} = 10 \log \frac{P_{RX}}{P_{TX}} - 10 \log K
\]

\[
\sigma_{RAM} = 10^{\frac{10 \log \frac{P_{RX}}{P_{TX}} - 10 \log K}{10}}
\]

(6)

In the above equation the value calculated with Eq. (5) should be taken for \( K \). \( \sigma_{RAM} \) parameter values obtained for the metal plate (50 \( \times \) 54) cm, covered with RAM are given in the table with measurement results in the next point.

3. MEASURING RESULTS

3.1. The Absorption Characteristics of the Examined Materials as a Function of the Testing Signal Angle of Incidence

The results of the absorption characteristics measurements of the tested material as a function of the testing signal angle of incidence and its frequency are presented below. The following characteristics are presented in polar coordinates (Fig. 4).

Because of the laboratory stand construction, the tested material was illuminated by the transmitting antenna only in range of the rotary head turning angle (\(-90^\circ \div 90^\circ\)). On the basis of the obtained measuring results it should be found that the bigger the testing signal angle of incidence on the plate covered with a tested material is, the bigger refraction it proves. The phenomenon of absorption is dominating for parallel angles of the transmitting (receiving) antennas aperture and the surface covered with the tested material. For this value of the angle the absorption phenomenon is dominating. In relation to the above, the absorption readings taken are representative results, which can be used for comparative analyzing using other materials. The value of absorption describes the difference between two signals: reflected from the tested material and the metal plate. For the signal’s frequency of 3 GHz it is 12 dB, while it’s 11 dB for 4 GHz.

![Figure 4: The absorption characteristics of the examined materials as a function of the testing signal angle of incidence in polar coordinates.](image)

Table 1: The value \( \sigma_{RAM} \) and indirect parameters for sample No. 2 and the measurement distance \( R = 2 \text{ m.} \)

<table>
<thead>
<tr>
<th>Testing signal frequency ( f ) [MHz]</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
<th>4000</th>
<th>4200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar cross section ( \sigma ) of a rectangular, perfectly reflecting surface ( [m^2] )</td>
<td>40.69</td>
<td>63.59</td>
<td>91.56</td>
<td>124.62</td>
<td>162.78</td>
<td>179.46</td>
</tr>
<tr>
<td>Radar cross section ( \sigma_{RAM} ) for a metal plate covered with RAM ( [m^2] )</td>
<td>5.62</td>
<td>2.11</td>
<td>1.53</td>
<td>1.50</td>
<td>1.45</td>
<td>1.24</td>
</tr>
</tbody>
</table>
3.2. Radar Cross Section Measurement
The results of the radar cross section measurements are presented in Table 1. The measures were taken for the rotary head angle where the phenomenon of absorption dominates. The presented results allow to conclude that RCS decreases along with the tested signals frequency increase.

4. CONCLUSIONS
The standpoint for measuring material absorption described in this article can be efficiently used for comparative testing of different materials. The presented measures of absorption fairly define electromagnetic waves absorption of varying materials.

REFERENCES