

## MEASUREMENT OF A SHIELDING EFFECTIVENESS OF COMPOSITE MATERIALS ACCORDING TO MIL-STD 285 AND IEEE STD 299-2006

*Martin Pospisilik*<sup>1</sup>, *Josef Soldan*<sup>1</sup>, *Vojtech Kresalek*<sup>1</sup>, *Milan Adamek*<sup>1</sup>,  
*Rui Miguel Soares Silva*<sup>2</sup>

<sup>1</sup>Faculty of Applied Informatics, Tomas Bata University in Zlin, Zlin, Czech Republic,  
pospisilik@fai.utb.cz

<sup>2</sup>UbiNET – Computer Science Security and Cybercrime, Polytechnic Institute of Beja, Portugal,  
rusilva@acm.org

**Abstract** – This paper describes an equipment being developed at the Department of Electronics and Measurement of the Faculty of Applied Informatics of Tomas Bata University in Zlin that is designed to process measurements of shielding efficiency of composite materials according to standards MIL-STD 285 and IEEE Std. 299-2006. This kind of measurement is demanded by aircraft industry that develops new, lightweight materials for construction of aircrafts with reduced weight and dimensions and increased number of electronic devices. Besides the fact, that it is necessary to ensure mutual electromagnetic compatibility of the equipment mounted on the aircraft's board, all the devices must also sustain interferences caused by High Intensity Radiated Field (HIRF). This is important all the more, as in the past, there were several aircraft crashes recorded as a result of interference of their equipment with terrestrial transmitters. The hereby described measuring station enables measurement of the shielding efficiency of various materials by means of a comparative method, using a steel plate as a default material.

**Keywords:** Shielding Effectiveness, Composite Materials, Electromagnetic Compatibility

### 1. INTRODUCTON

Not only in the past, the aircraft industry has been one of the driving forces in the area of electromagnetic compatibility. The constructors had to face many problems raising at the field of mutual electromagnetic compatibility of devices that had to be in a concurrent operation. For example, as described in [1], in 1984 the NATO airplane "Tornado" crashed in Germany after its circuits interfered with a powerful transmitter in HolKirchen.

In the framework of the latest trends in the production of small aircrafts, the demand on their electronic equipment is increased, whilst there is a legitimate pressure on decreasing of their weight. The constructors endeavour to use composite materials, creating a pressure on their intensive advancements. One of the intensively tracked parameters of

the new materials is their shielding effectiveness, defined as follows:

$$SE = 10 \cdot \log \frac{P_1}{P_2} [dB] \quad (1)$$

Where:

$P_1$  – Power generated by the source of the interference [W],

$P_2$  – Power being spread behind the shielding material [W].

The shielding effect of the material is generally ensured by three concurrently acting effects [5], as described below:

$$SE_{dB} = R_{dB} + A_{dB} + M_{dB} \quad (2)$$

Where:

$R$  – Attenuation on the interface with different impedances,

$A$  – Attenuation caused by the absorption of the material (heat loss),

$M$  – Attenuation caused by multiplied reflections.

The attenuation  $R_{dB}$  describes how much energy is reflected back from the shielding material. In case the shielding material creates a partition  $M$  between two different environments  $A$  and  $B$ , the attenuation caused by the reflection can be described as follows:

$$R = 20 \cdot \log \left| \frac{Z_A + Z_M}{2 \cdot Z_M} \cdot \frac{Z_M + Z_B}{2 \cdot Z_B} \right| [dB] \quad (3)$$

Where:

$Z_A$  – impedance of the environment  $A$  [ $\Omega$ ],

$Z_B$  – impedance of the environment  $B$  [ $\Omega$ ],

$Z_M$  – impedance of the shielding material  $M$  [ $\Omega$ ].

The attenuation due to absorption of the energy by the material can be described on the basis of the calculation of the intrusion depth  $\delta$ :

$$A = 20 \cdot \log \left| e^{\frac{t}{\delta}} \right| [dB] \quad (4)$$

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \quad (5)$$

Where:

- t – material thickness [m],
- $\delta$  – intrusion depth [m],
- $\sigma$  – material conductivity [ $S \cdot m^{-1}$ ],
- $\mu$  – material permeability [ $H \cdot m^{-1}$ ],
- $\omega$  – wave frequency [ $rad \cdot s^{-1}$ ].

The principle of the attenuation by means of multiple reflections does not apply if ( $t \gg \delta$ ), but if ( $t \ll \delta$ ), its value can be negative, decreasing the total shielding effect of the material. To make the theoretical background complete, the relevant equation is enlisted below, as well as a diagram describing its principle.[5]

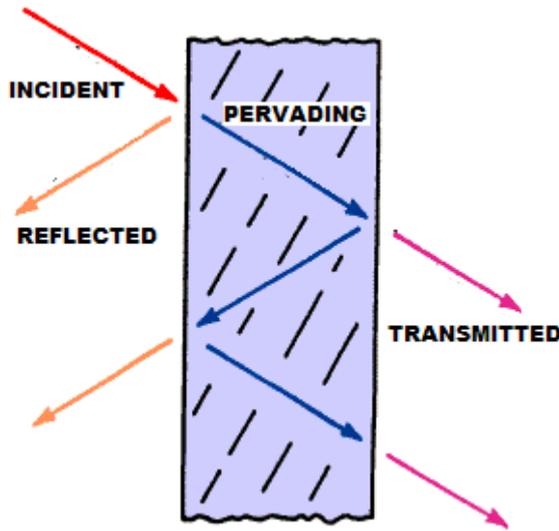


Fig. 1 Principle of attenuation caused by means of multiple reflections. Incident, reflected, pervading and transmitted waves are shown. [5]

$$M = 20 \cdot \log \left| 1 - \left( \frac{Z_0 + Z_M}{Z_0 + Z_M} \right)^2 \cdot e^{-\frac{2t}{\delta}} \cdot e^{-j\frac{2t}{\delta}} \right| [dB] \quad (6)$$

Where:

- $Z_0$  – impedance of the surroundings of the material [ $\Omega$ ],
- $Z_M$  – impedance of the material [ $\Omega$ ],
- t – material thickness [m],
- $\delta$  – intrusion depth [m].

## 2. MEASURING STATION

The measuring station consists of a steel box in which an antenna, electromagnetic power absorbers and a window for clamping of the measurement sample are incorporated, one external antenna on a tripod, a set of instruments and a

computer on which the controlling software is run. The description of these items is provided below in this chapter.

### 2.1 Shielded steel box

The construction of the shielded steel box can be observed in Fig. 2. The standards define only dimensions of the window for clamping of the measured material and the method of its mounting. As it is expected to process the measurements on the frequencies around 1 GHz and above, the dimensions of the box were chosen in that way so its dominant resonant mode was safely below the lowest operating frequency of the measurement site. According to [4], the resonant modes of a closed box can be calculated as follows:

$$f_{ijk} = \frac{1}{2\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{i}{a}\right)^2 + \left(\frac{j}{b}\right)^2 + \left(\frac{k}{c}\right)^2} [Hz] \quad (7)$$

Where:

- $\mu$  – material permeability [ $H \cdot m^{-1}$ ],
- $\varepsilon$  – material permittivity [ $F \cdot m^{-1}$ ],
- i, j, k – mode indexes,
- a, b, c – dimensions of the box [m].



Fig. 2 Construction of the shielded steel box

When the length of the box is 2 m and other dimensions are chosen proportionally, the dominant resonant frequency according to the equation (7) is approximately 170 MHz. The higher resonant phenomena are suppressed by the internal absorbers. On one of its sides, the box is equipped with a strongbox type door in order to enable manipulation with the sensors mounted inside the box. The door employs Cu-Be shielding seal. At the back side of the box, a penetration panel is mounted, incorporating the following equipment:

- Grounding screw,
- 16 A single phase power mains filter with high attenuation,
- N-type connectors for connecting of coaxial cables,
- circular waveguide.

The measured materials are attached by means of a flat frame that is mounted to the body of the box by 20 clamping screws. This facilitates the manipulation with the material

samples and enables uniform pressing force around the perimeter of the samples.

## 2.2 Antennas

For the basic measurement, two equal horn antennas are used, as depicted in Fig. 3. SAS 571 or HF 906 horns are utilized. Both antennas must be in the same height, placed at a distance of 0.3 m from the measured sample.

The external antenna is mounted on a tripod, while the internal antenna is mounted on a non-conductive support.

A brief description of the antennas is provided in the table below.

Table 1. Brief description of the antennas

Parameter	Value	
	SAS 571	HF 906
Frequency range	700 kHz to 18 GHz	1 GHz to 18 GHz
Gain	1.4 to 15 dBi	7 to 14 dBi
Impedance	50 $\Omega$	50 $\Omega$
Polarization	Linear	Linear
VSWR	< 1.6:1 (typ.)	1.5:1 (typ.)
Max. transmitting power	300 W	300 W
Manufacturer	A.H.Systems	Rohde & Schwarz

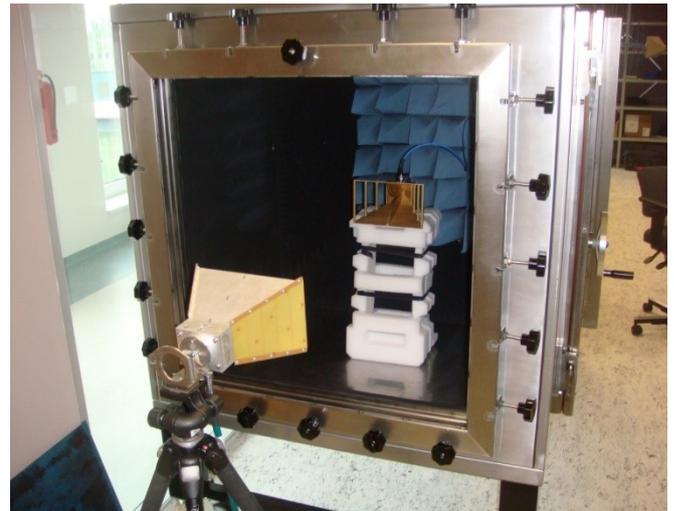


Fig. 3 Antennas for shielding effectiveness measurements

## 2.3 Measuring instruments

For the purposes of the basic measurement, remotely controlled generator Rohde & Schwarz SMR 20 and spectrum analyser Rohde & Schwarz FSP 40 are used. The settling time of the instruments for measurement at a constant frequency and a constant transmitted power is approximately 0.25 s.

A brief description of the instruments is provided in the tables below.

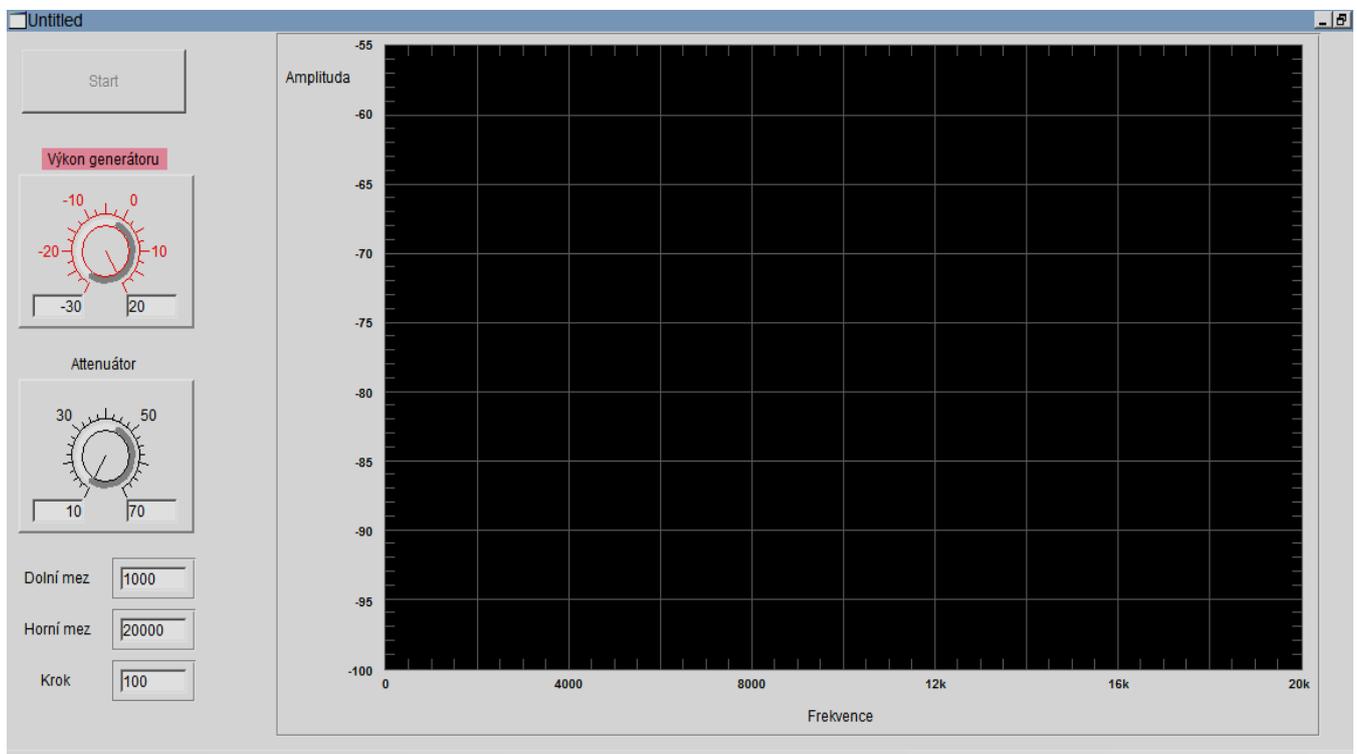


Fig. 4 User's panel of the first version of the controlling software

Table 2. Description of the generator SMR 20

Parameter	Value
Frequency range	10 MHz to 20 GHz
Output power	+ 10 dBm @ 20 GHz
Output impedance	50 $\Omega$
Settling time	< 10 ms
Spectral purity	< -55 dBc

Table 3. Description of the receiver FSP 40

Parameter	Value
Frequency range	9 kHz to 40 GHz
Attenuator	10 dB step up to -70 dBu
Detectors	Max, Min, Auto-Peak, Sample, RMS, Average, Quasi-Peak

### 2.4 Controlling of the measurement

Controlling of the measurement is processed by means of a laptop on which a controlling software developed in Agilent VEE is run. The abovementioned instruments are connected via a GPIB bus that is connected to the laptop by means of GPIB/USB converter.

A screenshot of the user's panel in Fig. 4.

The initial version of the controlling software operates as follows:

1. At the control panel, the user can set up several parameters prior the measurement is run. This includes setting of the minimum and maximum frequency in MHz, step of the measurement, setting of the output power of the generator and setting of the spectrum analyser's attenuator.
2. By clicking the button "START", a delay of several seconds is applied, while the instruments are being set to the required configuration.
3. The measurement is processed for a pre-defined time period at each of the frequencies, chosen from the pre-defined sequence (minimum, maximum, step). In each step, the signal generator and the spectrum analyser are tuned to the same frequency, a time delay of 0.25 s is applied and then the value measured by the spectrum analyser is read and stored to the table. A graph of the measured frequency response of the environment between the transmitting and the receiving antenna is plotted on the user's screen.
4. Once the measurement is finished, the results are stored to a file, from which they can be imported to Microsoft Excel or another data processing software.

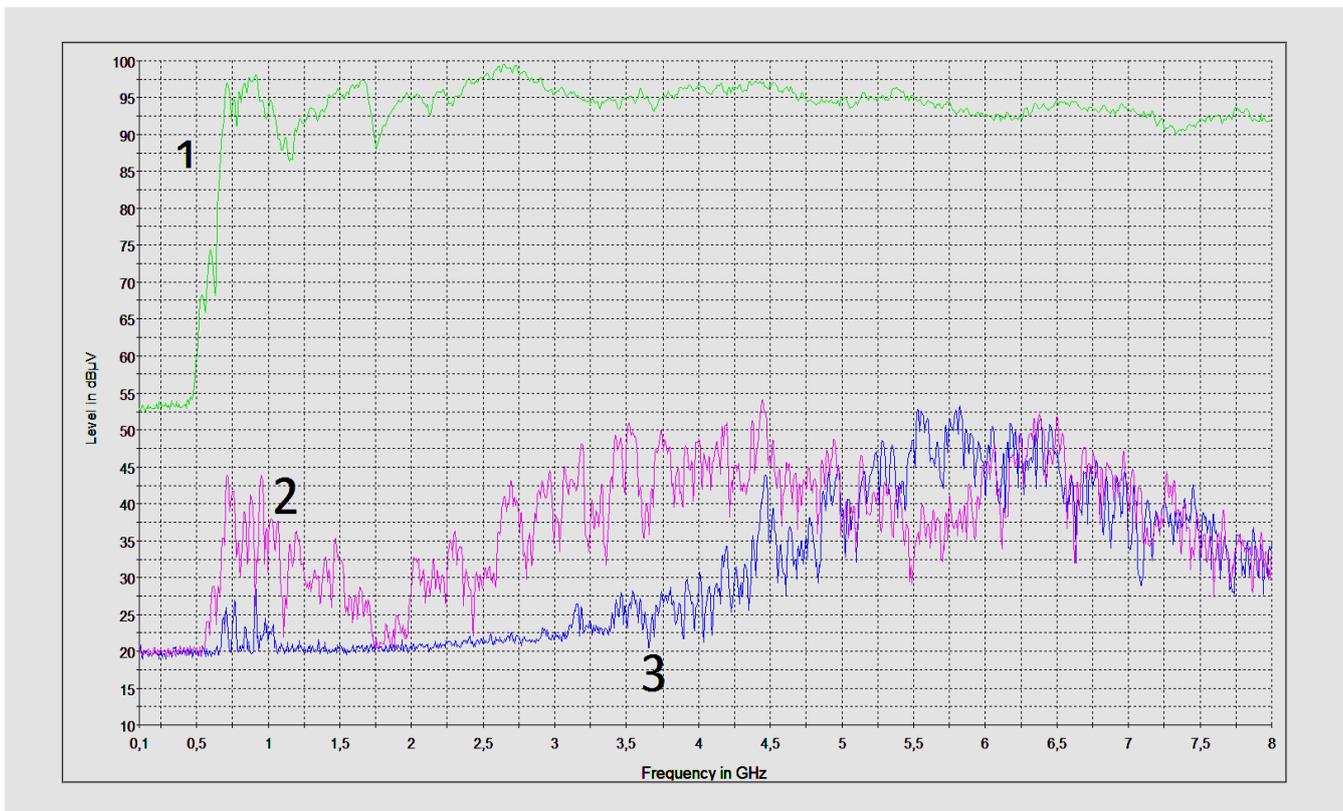


Fig. 5 Example of the measured data (see text for description)

### 2.5 Configuration of the measurement station

The physical configuration of the measurement station is depicted in Fig. 6. All devices, including the shielded box, are grounded in one point. The controlling computer and the instruments are placed on a table next to the shielded box. The shielded box is equipped with small wheels so it can be moved around the laboratory.

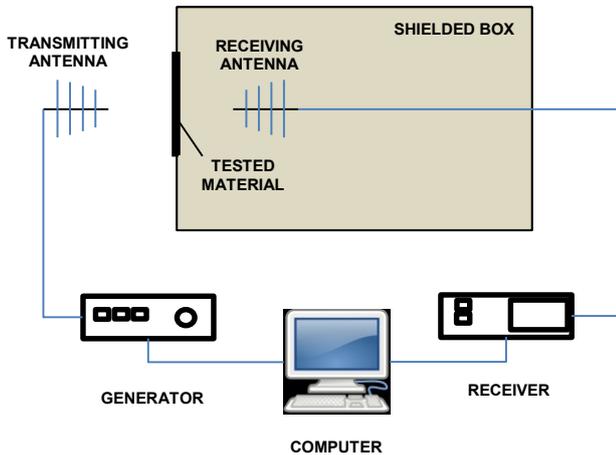


Fig. 6 Schematic diagram of the measurement station

### 3. OBTAINED RESULTS

An example of the results obtained by means of the hereby described measurement station is depicted in Fig. 5. The diagram shows three different spectra indicated by numbers. Their meaning is described in Table 1.

Considering the steel plate (spectrum No. 3 in Fig. 5) is a reference, between the frequencies 0.75 and 4 GHz the dynamic range of the measuring station is higher than 65 dB, which is sufficient for many applications.

Below the frequency of 0.75 GHz both the transmitting and the receiving antennas are out of their operating frequency range and the measured intensity of the electrical field falls to the level of the receiver's noise. Above the frequency of 4 GHz the shielding effectiveness is partially decreased and currently the efforts to find the cause of this phenomenon are undertaken.

Table 4. Description of spectra depicted in Fig. 5

Spectrum No.	Description
1	Reference frequency response. No material was inserted between the measurement antennas.
2	Frequency response measured when a sample of composite material was attached in the window of the measurement box.
3	Frequency response measured when a steel plate was attached in the window of the measurement box.

On the basis of the experience gained with the measurement station it can be stated, that reliable results can be obtained in the frequency range from approximately 0.8 GHz to 4 GHz. Currently, further research is conducted with the aim of increasing of the operating frequency range. Although high quality steel was used and the weld tightness was checked by means of transition resistance meter (see [3] for the theoretical background) and by means of sealed radionuclide sources, the shielding effectiveness of the steel box is decreased at the frequencies above 4 GHz. Intensive research is performed to find the cause of this phenomenon. The currently achieved shielding effect is approximately 80 dB at 1 GHz and drops to approximately 50 dB at 5 GHz. It is expected that at the higher limit, the frequency range can be widened by changes in the construction of the shielded chamber. Moreover, the lower frequency limit can be slightly adjusted by employment of different antenna types but still it must be considered, that the lowest applicable frequency must be considerably higher than the dominant resonance mode that was, according to equation (7), calculated at 170 MHz.

Another issue was observed at repeated measurement at different power levels of the electromagnetic field. When the transmitting power was decreased and the receiver's attenuator was adjusted properly, the shapes of the frequency response curves changed. This phenomenon have been mainly observed at those levels at which the input level was too close to the maximum level that the receiver was able to process, and at the levels where the noise could have exhibited.

### 4. DISCUSSION ON FURTHER RESEARCH

On the basis of the obtained results and experience gained with the measurement station, both described in the previous chapter, the several different targets of the further research have been specified:

- There is a need to modify the sample mounting frame in order to increase the tightness of the seal.
- Changes in the controlling software should be done in order to implement additional the features mentioned in the subchapters below.

#### 4.1 Seal tightness increasing

As mentioned above, the performance of the shielded chamber decreases with the frequencies above 4 GHz. It is expected that there is a weak point in the construction, based on the existence of a small waveguide from the outside to the box. The length of the electromagnetic waves with the frequency of 4 GHz in a free space is approximately 75 mm which can be put into correspondence with the spacing between the nuts by means of whose the sample holding frame is mounted. The distance between the nuts is approximately 66 mm. The effort is to achieve more uniform pressure to the sealing around the window in which the measured sample is mounted.

#### 4.2 Controlling software modifications

Based on the experience with the controlling software, the following modifications are processed:

- Capability of automated measurement process consisting in the following steps:
  - measurement of the reference level,
  - measurement of the reference sample,
  - measurement of the measured sample,
  - data processing and direct export to Excel.
- Capability of automated transmitting level selection and receiver's attenuator setting in order to eliminate the effect of noise and/or overload of the receiver.
- Capability of repeating the measurement in order to eliminate random errors.

### 5. CONCLUSIONS

The paper presents a method of measurement of the shielding efficiency of materials for a minor aircraft industry as well as the construction of the measuring station that is being developed in the Laboratory of the electromagnetic compatibility that is run under the Faculty of Applied Informatics at Tomas Bata University in Zlin. The paper presents the mechanical construction of the steel shielded box, the instrumentation of the measuring station and the controlling software developed in Agilent VEE environment that employs a GPIB bus.

On the basis of the hereby presented results that have been obtained by the measurement station prior the date of publishing of this paper it can be stated that although the results are satisfactory and applicable within a limited frequency range, there is a space for innovations that should take two directions:

1. Increasing the applicable frequency range of the shielded box consisting in improvements in its ports' shielding,
2. Improvements in the controlling software that would increase the reliability of the results as well as the user's comfort.

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