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Design of an Anechoic Chamber at the Faculty of Electronic Engineering in Niš

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Abstract - **The project of an anechoic chamber realization at the Faculty of Electronic Engineering in Niš, is presented in this paper. The chamber is intended for measurements in the frequency range of 0.8 – 20 GHz. Selection of suitable geometry is performed, dimensions are calculated and the strategy of covering the chamber internal surface with RF absorbing material is analyzed. The most important results are discussed.**

Keywords – **Anechoic chamber, Antenna measurements, EM propagation, EMC characterization**

I. Introduction

Recent development in wireless communication systems requires efficient electromagnetic characterization. Methods providing high - accurate measurements of antenna radiation pattern, radar cross section, EM immunity and the leaking radiation intensity are the most important. By reducing interference signals, they must enable precise evaluation of the direct signal level at the receiver. All of the signals reflecting from the obstacles near the radiation source and the test region, reaching the receiver at the same time, are causing undesirable interference. However, this effect can also be a result of receiving a number of EM signals that belong to the other radiation sources, which radiate at the approximately the same frequency, as the observed source. Several methods for characterization of EM radiation are able to significantly reduce interference and to provide the required accuracy of the performed measurements. Depending on the conditions for EM characterization, these methods can be divided into outdoor and indoor measurements.

Outdoor measurements are performed far away from the urban settlements and sources of the interfering electromagnetic radiation [1]. In the wide area surrounding the radiating source and the test region, there should be no obstacles that could cause signal interference or diffraction. Outdoor measurements provide long distance between transmitting and receiving antenna that is essential condition for accurate measurements and good approximation of EM plane wave at the receiver. This is very important in cases when the large antennas are evaluated and/or antenna radiation pattern at high frequencies is measured. It is considered that the real spherical wave illuminating the antenna can be approximated by an ideal plane wave at the receiver, if the distance between antennas is equal to, or greater than the Rayleigh range.

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The boundary between the near-field and the far-field zone is given by

$$r \leq \frac{2D^2}{\lambda}, \tag{1}$$

where D is the aperture of the largest antenna under test and λ is the wavelength of the EM wave. For instance, radiation pattern of a 0.5 m diameter parabolic antenna can be measured if the antenna is located at least 34 m away from the transmitting antenna at the operating frequency of 20 GHz. Outdoor measurements are strongly influenced by atmospheric conditions and undesirable radiations from distant transmitters or mobile communication base stations. Also, the flat areas used for performing these measurements are quite far from the laboratories and development centers where components for wireless communication systems are fabricated. On the other hand, specialized anechoic chambers are able to eliminate all of these disadvantages [1, 2].

The research at the Department of Telecommunications focuses on development of devices for application in wireless communication systems. Since there is no specialized anechoic chamber at universities in Serbia, required measurements cannot be performed. Finally, it is decided to design and construct an anechoic chamber at the Faculty of Electronic Engineering.

II. RF Anechoic Chamber

RF anechoic chamber is a shielded room intended to simulate a free-space environment. Reflected waves inside the chamber are attenuated by covering the chamber walls with special material having significant absorbing effects at the radio frequencies (RAM – Radio Absorbing Material). Although anechoic chambers of different geometry are present, the rectangular chamber is mostly used. It provides measurements of antennas and antenna arrays, radar cross section and EM compatibility. In addition to this type of chamber, there are chambers of specialized architectures which are utilized for measuring antennas (tapered chamber, TEM chamber and double horn chamber [2, 4]), radar cross section of the military missiles, and more.

At one end of the chamber, a source of electromagnetic radiation is placed, and at the other end, an antenna which has to be evaluated (receiving antenna), is located. The antenna data acquisition system enables one to plot the radiation pattern of antenna and determine its important parameters. The antenna to be tested is usually mounted on the pedestal that can be rotated under the control of the positioner. By rotating the antenna, the incidence angle of EM wave illuminating the antenna surface is changing and the level of

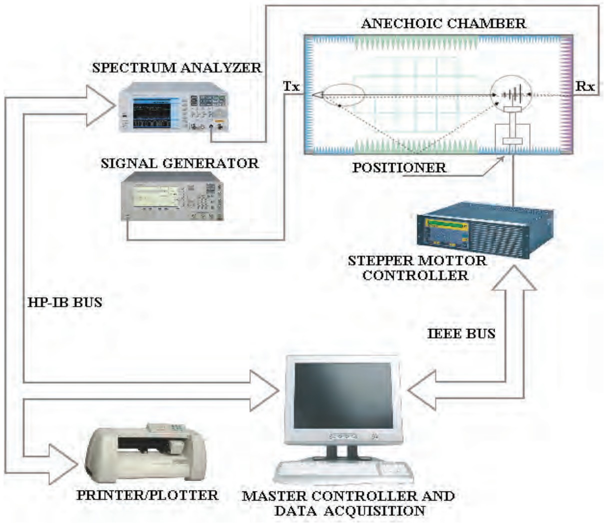

Fig. 1. Antenna data acquisition block diagram

the received signal is measured (Fig 1). The resulting signal amplitude data is plotted against the angle-of-arrival to provide a graphical representation of the signal components received by the AUT (Antenna Under the Test).

III. Radio Absorbing Material

In order to attenuate EM waves reflected from the walls, floor and ceiling, the entire internal surface of the anechoic chamber is covered with the radio absorbing material. There are two basic types of RAM elements: the first one is used to attenuate reflections at low frequencies while the second one absorbs high-frequency EM waves. Low-frequency RAM elements (30 MHz – 1000 MHz) are typically made of ferrite materials. At the higher frequencies (0.1 GHz – 50 GHz), absorbers made of the carbon impregnated polyurethane foam are used [2-6].

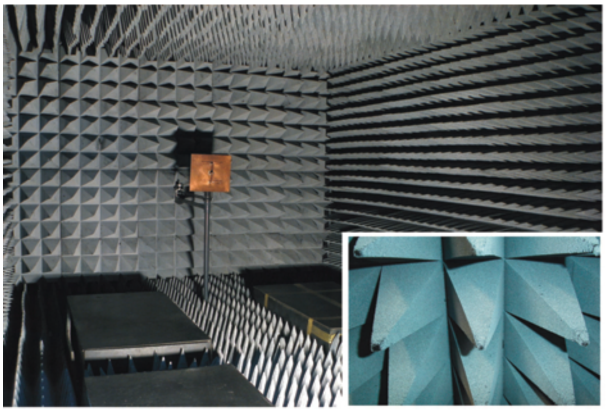

Fig. 2. The internal appearance of the anechoic chamber

Typical physical realization of high-frequency RAM elements is in the form of square based pyramids. A number of pyramids are fastened to the square panel which is also made of the same radio absorbing material. Depending on the manufacturer, standard panel dimensions are 0.5 m x 0.5 m or 0.61 m x 0.61 m. The height of the pyramids depends on the

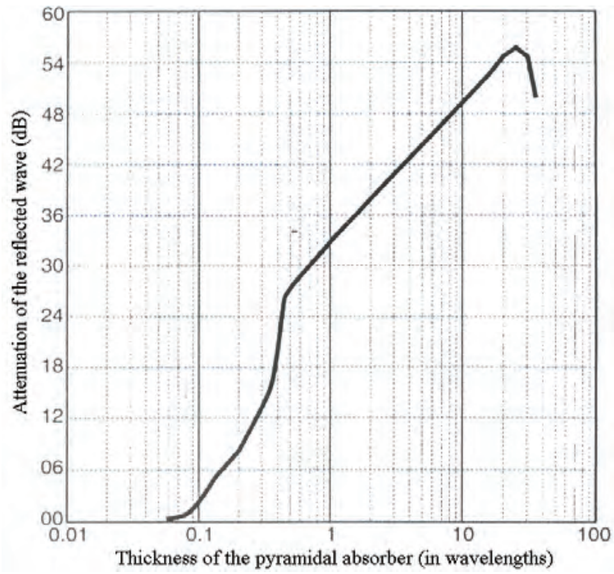

Fig. 3. Attenuation of the reflected wave as a function of the thickness of pyramidal RF absorber at normal incidence

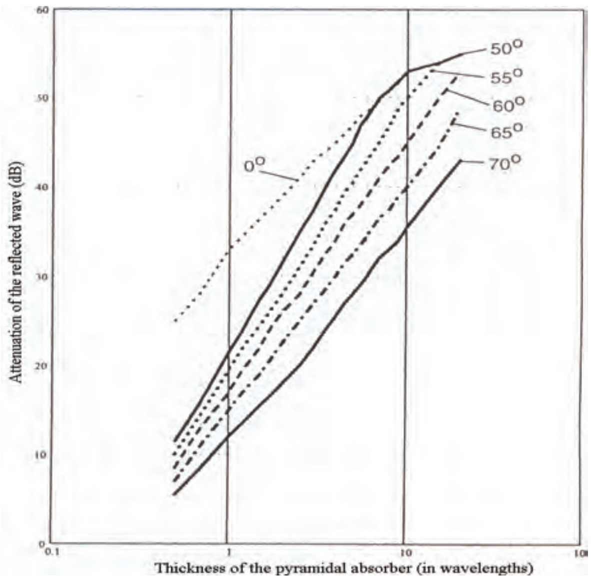

Fig. 4. Attenuation of the reflected wave as a function of the thickness of pyramidal RF absorber at various incidence angles

lowest operating frequency and the amount of the absorption required. Generally, RAM elements have good performance when the absorber thickness is greater than the wavelength of the incident EM wave. RAM elements are mounted on the metal surface of the internal chamber walls. For that purpose, low-permittivity adhesives are used.

RAM performance depends on the pyramidal absorber thickness and the EM wave angle-of-arrival. Fig. 3 shows attenuation of the reflected EM wave against the thickness of the pyramidal absorber (in wavelengths), at normal incidence. The same dependence, for various angles of incidence, is shown in Fig. 4. If the higher pyramids are used, the chamber reflectivity performance is improved. However, RAM elements are very expensive and their cost depends on the amount of RAM material used for their fabrication. Depending on the manufacturer, pyramid–shaped RAM elements 200 mm high cost 95$ - 120 $ per square meter, while the pyramidal absorber height of 400 mm costs 160$ - 220$ per sq meter. The RAM performance deteriorates rapidly with increasing incident angle.

IV. RECTANGULAR ANECHOIC CHAMBER

Rectangular anechoic chamber is mostly utilized in the measurements of antenna radiation pattern, radar cross-section and EMC. Electromagnetic characteristics of this architecture are not too difficult to analyze, allowing efficient planning and construction of the chamber. When starting the process of the rectangular anechoic chamber design, the most important information is related to the minimum and maximum operating frequency, and the aperture size of the largest object under test. The text that follows analyzes a scenario of an antenna radiation pattern measurement, in order to evaluate chamber dimensions. For that purpose, a directional antenna is used as a transmitter (usually a horn antenna at high frequencies or a log-periodic antenna at low frequencies) and an antenna whose characteristics are measured, as a receiver (AUT). Usually, Ray Tracing method is utilized in the EM analysis. This method is based on the evaluating of all possible paths of EM wave propagation from the transmitting to the receiving antenna. The signal level at the receiver is determined. In the measurement process, only direct signal is valuable for AUT characterization. Signals received by AUT after one or a few reflections from the side walls, floor and ceiling of the chamber, are unwanted signals which cause interference in the measurement process. These signals are usually called the anechoic chamber noise. In Fig. 5, direct signal is drawn with the solid line (DW), while the reflected signals are presented with the interrupted lines. There are six reflected signals reaching AUT after only one reflection. In Fig. 5, four of them are shown: reflection from the wall at the back of the transmitting antenna (SRT), reflection from the wall at the back of receiving antenna (SRB), reflection from the right side wall (SSR1) and reflection from the left side wall (SSR2). Reflections from the floor and ceiling could not be presented in this two-dimensional cross section. However, they are identical to the reflections from the side walls. Fig. 5 also presents a signal which is reflected from the both side walls (MSR) and those one reflected from the side wall and then, from the wall at the back of the receiver (MRB), into the quite zone. As it can be seen, beside these two reflections, there are a large number of multiple reflections. Since levels of these signals are very low at the receiver (AUT), they are not included into the consideration. Reflection of the signal radiated by the back lobe of antenna radiation pattern (SRT), has low level at the receiver, due to the use of very directional antennas and it does not affect the evaluation of AUT, too.

If the chamber geometry is designed such that an EM signal from the transmitter reaches the receiving antenna after a few reflections, the EM energy may be sufficiently decreased after a few bounces from the absorbing walls, floor and ceiling. Since the single reflections (except SRT), entering the test region, can affect the measurement accuracy, they should be maximally attenuated by lining the chamber walls with the appropriate RAM elements.

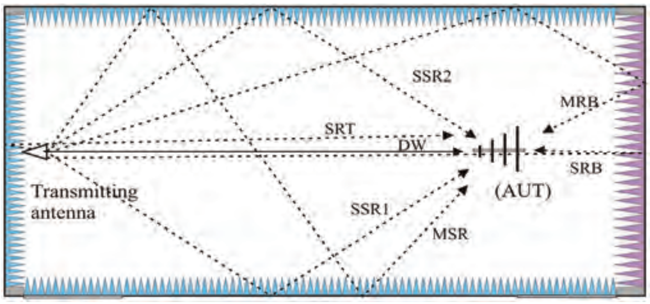

Fig. 5. Propagation of EM waves inside the rectangular anechoic chamber

The quite zone of the anechoic chamber is a defined volume within the chamber where AUT is to be placed for evaluation. Dimensions of the quite zone are equal to the aperture of the largest AUT, or greater. Suitable architecture of the chamber will result in the lowest noise level in this volume. In order to reduce reflections from the side and back walls, the quite zone diameter Q is usually determined as follows

$$Q \approx \frac{1}{3} \cdot W \qquad (2)$$

In addition, distance between the quite zone and the back wall at the receiver should be equal to the quite zone width ($G \approx Q$).

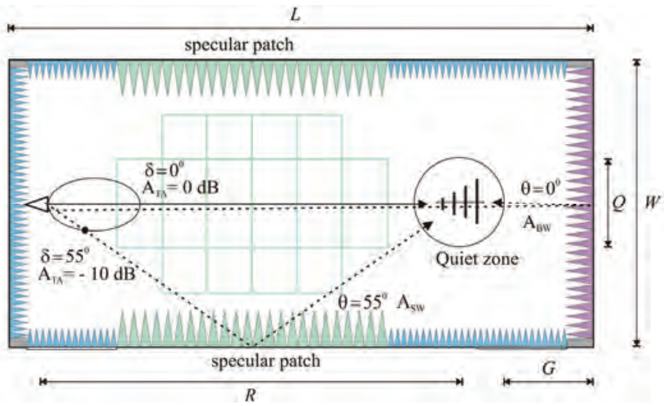

Fig. 6. Effect of EM signal specular reflection into the quite zone in the rectangular anechoic chamber

The first phase of an anechoic chamber design is related to evaluation of its size. For a given operating frequency and maximum antenna aperture, distance between transmitting and receiving antenna must meet the far-field condition according to Eq. (1). If the transmitting antenna is placed very close to the back wall, the minimal length of the anechoic chamber can be calculated as follows

$$L_{\min} \approx R + \frac{3}{2} \cdot Q = R + \frac{W}{2} \cdot \qquad (3)$$

Good performance in attenuation of reflected signals can be achieved for angles of incidence less than 60º. This condition can be satisfied if the width and the height of the chamber are equal to, or greater than the half of the chamber length (W, $H \geq L/2$). Therefore, the minimal anechoic chamber length can be written by

$$L_{\min} \approx \frac{4}{3} \cdot R \qquad (4)$$

The second phase of the anechoic chamber design is related to the evaluation of RAM elements to cover the chamber walls. A great deal of care must be taken to reduce the effects of the reflected signals. For every part of the chamber, type of RAM elements to be used is determined. In order to achieve satisfying performance with reasonably saving of cost, complete internal surface must be lined. The noise level in the quite zone, which is a result of reflected and diffracted signals inside the chamber, should be below the specified value. Attenuation of the reflected signals is better if the higher pyramids are utilized. Since the use of these RAM elements results in the higher cost, specified signal-to-noise ratio in the quite zone must be obtained using pyramidal absorber whose thickness is reduced as much as it is possible. Calculation of the minimal height of the pyramid elements is performed at the chamber lowest operating frequency. The RAM performance improves as the frequency goes higher due to the relative increase of the pyramidal absorber thickness (in wavelengths).

The accurate measurements in the anechoic chamber are obtained when the reflectance level of the signals entering the quite zone is 30-40 dB below the direct signal level (at the lowest operating frequency). Since single reflections have the greatest influence on the quite zone noise, they must be sufficiently reduced by RAM elements. In this case, multiple reflections would be negligible. The attenuation of the direct signal, propagating from the radiating source to the receiver, is equal to the free-space path loss $A(R)$ (Fig 6). The attenuation of the signal, reflected from the back wall at the receiver, is the sum of free-space path loss $A(R+3Q)$ and the attenuation of the back wall RAM elements A_{BW}. The attenuation of the signals reflected from the side walls, floor or ceiling, is determined as a sum of the attenuation of antenna radiation in the δ direction A_{TA} (which is different from the maximum antenna radiation), free-space path loss $A(\sqrt{R^2+W^2})$ and the attenuation of RAM elements of the side walls, floor and ceiling A_{SW}. If the differences in the free-space path losses, caused by the various propagating paths, are small, then the relative attenuation of the signal reflected from the back wall into the quite zone has value of A_{BW}. The relative attenuation of the signals reflected from the side walls into the quite zone is equal to $A_{TA}+A_{SW}$ (relative to the direct signal). The required values for A_{BW} and A_{SW} are determined in regard to the relative attenuation of the specular reflections entering the quite zone and the antenna radiation pattern. In Fig. 3, the height of the back wall RAM elements can be determined.

In order to evaluate the thickness of the pyramidal absorber needed to cover the side walls, floor and ceiling, the angles of incidence must be determined. For the side walls, these angles have value of *arctan*(R/W), while for the floor and ceiling the incidence angles can be calculated as *arctan*(R/H). Required height of the pyramidal absorber can be evaluated on the basis of data in Fig. 4.

V. Calculations of the Specular Zones of the Rectangular Anechoic Chamber

When the minimum height of RAM pyramidal elements is determined, the complete interior surface of the chamber is usually not covered with one type of the pyramidal absorber. If these elements are used for lining the chamber surfaces that cause single reflections into the quite zone, significant cost savings can be achieved. Less expensive absorber can be used to cover the rest of the chamber surface that can only cause multiple reflections into the test region. The height of these pyramids is two times smaller than of those in the specular zone [2].

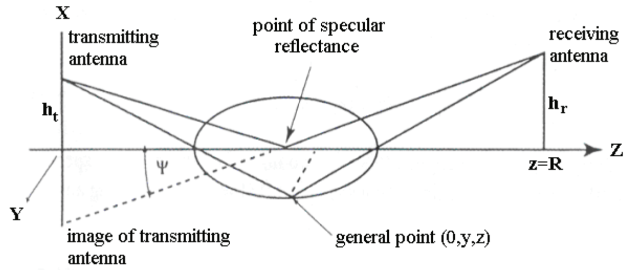

Fig. 7. The Fresnel zone boundary at the surface of the chamber wall

Techniques of geometrical optics are used to evaluate the size of specular zones. Their boundaries are determined by single reflections that are tangent to the quite zone. However, since diffraction effect is not included in the calculation, the specular zones surfaces should be larger. Due to these effects, RAM elements close to these zones are able to send some amount of EM energy into the quite zone.

Applying the concept of Fresnel zones at the area of the wall illuminated by the transmitting antenna, boundaries of the Nth Fresnel zone can be determined as follows

$$[h_t^2 + y^2 + z^2]^{1/2} + [h_r^2 + y^2 + (R-z)^2]^{1/2} - [R^2 + (h_r + h_t)^2]^{1/2} = N\lambda/2 \quad (5)$$

The successive outer boundaries of the Fresnel zones on the surface of the chamber wall describe a set of ellipses whose major axis lies along the longitudinal chamber axis (Fig. 7).

Introducing new parameters

$$\varphi = \tan^{-1}[R^2 + (h_r + h_t)^2]^{1/2}, \quad (6)$$

$$F_1 = (N\lambda/2R + \sec(\varphi)), \quad (7)$$

$$F_2 = (h_r^2 - h_t^2)/[F_1^2 - 1)R^2], \quad (8)$$

$$F_3 = (h_r^2 + h_t^2)/[(F_1^2 - 1)R^2], \quad (9)$$

expressions for calculating the center of the Nth Fresnel zone, the zone length and width can be derived

$$C_N = R(1 - F_2)/2 \quad (10)$$

$$L_N = RF_1(1 + F_2^2 - 2F_3)^{1/2} \quad (11)$$

$$W_N = R[(F_1^2 - 1)(1 + F_2^2 - 2F_3)]^{1/2}. \quad (12)$$

Experience has shown that minimum six Fresnel zones (N=6) need to be covered to achieve good reflectivity in the anechoic chamber.

VI. ARCHITECTURE OF THE ANECHOIC CHAMBER

In order to perform required measurements for the Laboratory for antennas, propagation and EM compatibility, a rectangular anechoic chamber will be designed and implemented at the Faculty of Electronic Engineering. High - accuracy measurements of a large number of antennas for modern wireless communication systems will be performed in the frequency range of 0.8 – 20 GHz.

Considering the available space inside the building of the Faculty of Electronic Engineering and the budget limitations, distance between transmitting and receiving antenna is selected to be 4.6 m. In Fig. 8, the antenna aperture size is shown as a function of the operating frequency (which is calculated based on the condition for far-field radiation). As it can be seen, at the lowest operating frequency of the chamber, antenna with the maximum aperture of 0.93 m can be evaluated, what is suitable for measurements of antennas for mobile communication base stations. According to Eqs. (3) and (4), the anechoic chamber dimensions are determined as follows: length 6.5 m (L), width 3.2 m (W) and height 3.2 m (H). Since the maximum antenna aperture decreases as the frequency goes higher, AUT can be placed closer to the back wall and still remain in the test region.

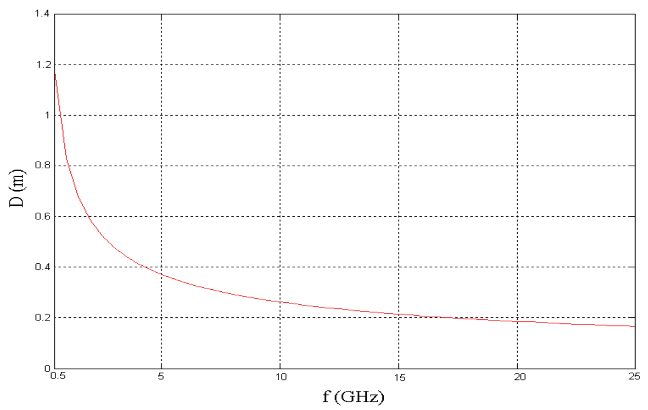

Fig. 8. Frequency dependence of the AUT aperture for *R* = 4.6m

The level of reflected signal entering the quite zone is the initial criteria for the selection of radio absorbing material. In the quite zone, this level should be at least 30 dB below the direct signal level. This condition is completely satisfied at the higher frequencies.

As it is stated before, noise level in the test region mainly depends on the single reflections from the side walls, floor and ceiling. Reflection from the back wall at the incidental angle of θ=0° propagates from the transmitting antenna in the direction of the antenna maximum radiation. Since δ=0°, relative attenuation of the signal is given by

$$A_{TA}(0°)+A_{BW}(0°) = 0\ dB+A_{BW}(0°) = A_{BW}(0°) \geq 30\ dB \quad (13)$$

Reflections from the side walls, floor and ceiling are carried out under the incidental angle of θ = *arctan*(4.6/3.2) ≈ 55°. Reflected wave is previously radiated by the transmitting antenna in the direction δ = 90°-55°= 35°. Relative attenuation of the wave can be written as

$$A_{TA}(35°) + A_{SW}(55°) = 10\ dB + A_{SW}(55°) \geq 30\ dB \quad (14)$$

For the chamber operating frequency range, the source antenna is usually a standard horn antenna, having attenuation of radiation around 10 dB and greater (in E and H plane), in the direction of 35°. In Eq. (14), A_{TA} (35°) is assumed to be 10 dB.

According to (13), required attenuation must be A_{BW} (0°) ≥ 30 dB. From the graphic in Fig. 3, the minimal height of pyramidal absorber that meets this condition is equal to 0.7λ, or 265 mm, at the operating frequency of 0.8 GHz. Therefore, RAM elements, whose base dimensions are 0.5 m × 0.5 m and height of 300 mm, are selected to cover the back wall of the anechoic chamber.

Attenuation of specular zones at the side walls, floor and ceiling is A_{SW} (55°) ≥ 20 dB. From the graphic in Fig. 4 (angle of incidence is 55°), the minimum height of the pyramidal absorber is calculated. At the operating frequency of 0.8 GHz, it is equal to 1.05λ, or approximately 393 mm. For lining the specular zones, RAM elements with base dimensions of 0.5 m × 0.5 m and height of 400 mm are selected.

TABLE I. THE ANECHOIC CHAMBER SPECIFICATIONS

Frequency range	0.8 GHz – 20 GHz
Dimensions of the chamber	6.5m (L) × 3.2m (W) × 3.2m (H)
Distance between antennas	4.6 m @ 0.8 GHz 5.0 m @ 20 GHz
Aperture of the largest AUT	0.93 m @ 0.8 GHz for *R* = 4.6 m 0.19 m @ 20 GHz for *R* = 5.0 m
Quite zone dimension	diameter 1 m @ 0.8 GHz
Quite zone reflectivity performance	- 30 dB and below @ 0.8 GHz - 33 dB and below @ 1.0 GHz - 35 dB and below @ 1.5 GHz - 38 dB and below @ 2.0 GHz - 40 dB and below @ 3.0 GHz - 44 dB and below @ 4.0 GHz

TABLE II. SPECULAR ZONE DIMENSIONS FOR N=6 AT DIFFERENT OPERATING FREQUENCIES

Frequency[GHz]	Specular zone length [m]	Specular zone width [m]
0.8	5.1	3.7
1.6	3.9	2.6
2.4	3.3	2.0
5	2.4	1.4
10	1.7	1.0
20	1.2	0.7

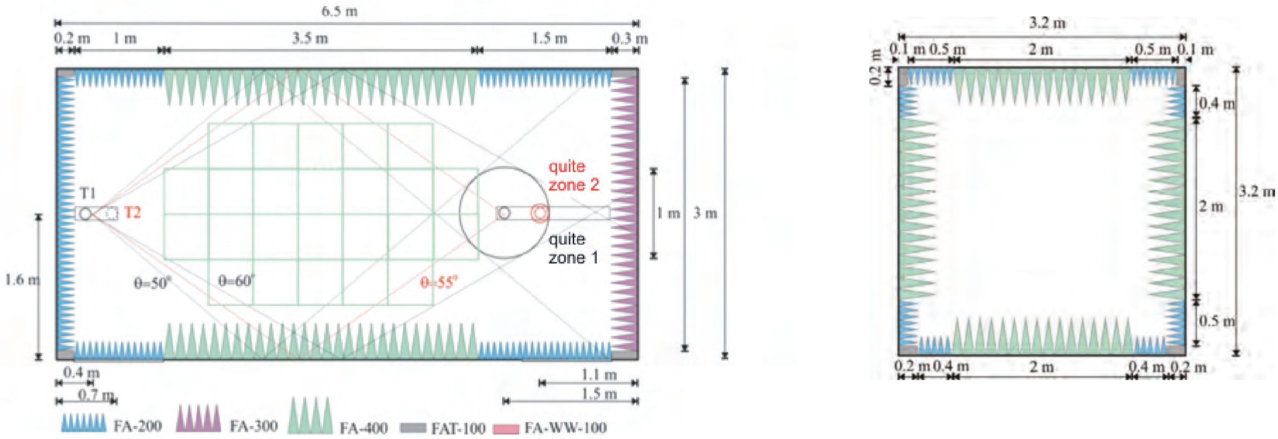

Fig. 9. Horizontal and vertical cross-sectional views of the anechoic chamber to be constructed at the Faculty of Electronic Engineering

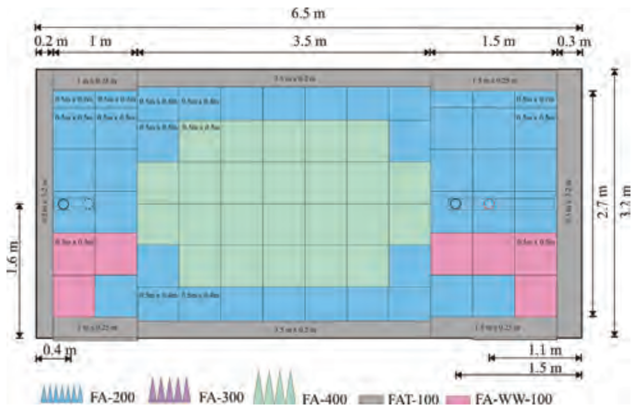

Fig.10. The anechoic chamber floor covered with RAM elements

TABLE III. REFLECTION COEFFICIENTS OF RAM ELEMENTS AT DIFFERENT FREQUENCIES

f [GHz]		0.8	1	1.5	2
Absorber	θ ()				
FA-400	0°	- 33 dB	- 36 dB	- 40 dB	- 44 dB
	55°	- 20 dB	- 23 dB	- 28 dB	- 32 dB
FA-300	0°	- 31 dB	- 33 dB	- 36 dB	- 40 dB
	55°	- 16 dB	- 19 dB	- 25 dB	- 28 dB

In Table II, calculated dimensions of the specular zone covering the first six Fresnel zones are given. FA – 400 RAM elements will be used to line the specular patch with dimensions of 3.2 m x 2 m. At the lowest operating frequency, this patch will cover the first two Fresnel zones. Covering all six Fresnel zones will be provided at the operating frequency of 2.4 GHz and higher. Figs. 9 and 10 illustrate specular patch at the side walls, floor and ceiling. The rest of the chamber internal surface can be lined with RAM elements that have two times smaller height of the pyramids (Fig. 9). Standard 100 mm high flat absorber, FAT -100, is utilized to cover the chamber corners. Fig. 10 illustrates the floor lined with special flat absorber FAT-WW-100 (100 mm thick), in the vicinity of the antenna. This is a solid absorber which allows approach to the antennas. At the selected operating frequency, the quite zone performance depends on the reflected signal maximum level (evaluated in relation to the DW level). Attenuation of SRT, SSR and SRB signals can be evaluated on the basis of reflection data from Table 3 (or taken from Figs. 3 and 4 or manufacturers specifications). It can be concluded that these results completely correspond to the quite zone performance given in Table I.

VII. CONCLUSION

Specialized electromagnetic anechoic chambers are widely used for efficient EM characterization One RF anechoic chamber, having a performance and construction as well as the other modern microwave chambers, will be realized at the Faculty of Electronic Engineering, in Niš. This implementation is very important for intensive research activities in the area of antennas, propagation and EM compatibility. In addition, the anechoic chamber will significantly improve the teaching process through the modern laboratory exercises and active participation of students in the research projects. Finally, the Laboratory for antennas, propagation and EMC will take a great part of the activities of the National laboratory for electromagnetic compatibility, which is now in the process of establishment.

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