# 40 years an anechoic chamber for automatic antenna measurements in Department of Communication Engineering and Technologies at Technical University of Varna

**Georgi T. Chervenkov, Lyubomir P. Kamburov, Georgi S. Kirov**

*The creation and development of the anechoic chamber for automatic antenna measurements in the Department of Communication Engineering and Technologies at Technical University of Varna since mid 1970's to now days is described in this paper. Information related to the anechoic chamber requirements is given. The state and the basic technical characteristics of the chamber during the period between 1974 and 2004 are considered. The improvement of the anechoic chamber characteristics in the last decade (2005 –2014) is described. Obtained performance characteristics of the chamber are: frequency range: 1-13 GHz, dynamic range: 80-50 dB, step of an azimuth variation: $0.1^0$, time of measurement of the radiation pattern: 6 min, reflection coefficient range of the absorbers: -20 to -48 dB and maximum dimension of the test antenna: 0.77-0.21 m. The most important achievements of the members of the High Electrodynamics and Optoelectronics Group in Department of Communication Engineering and Technologies are also considered.*

***40 години безехова електромагнитна камера за автоматизирани антенни измервания в катедра „Комуникационна техника и технологии" в Технически университет - Варна, (Георги Ц. Червенков, Любомир П. Камбуров, Георги С. Киров).*** *В статията е описано създаването и развитието на безеховата камера за автоматизирани антенни измервания в катедра „Комуникационна техника и технологии" в Технически университет – Варна от средата на 70-те години на миналия век до днес. Дадени са сведения за изискванията към безеховите камери. Разгледани са състоянието и основните технически характеристики на камерата през периода 1974-2004 г. Описано е подобряването на характеристиките на безеховата камера през последното десетилетие (2005-2014 г.). Постигнатите технически характеристики на камерата са: честотен обхват: 1-13 GHz, динамичен обхват: 80-50 dB, стъпка на изменение на азимута: $0.1^0$, време за измерване на диаграмата на насоченост: 6 min, диапазон на изменение на коефициента на отражение на поглъщащите елементи: от -20 до -48 dB и максимален размер на изследваната антена: 0.77-0.21 m.Разгледани са също най-важните постижения на членовете на групата Високочестотна електродинамика и оптоелектроника.*

## Introduction

The antenna measurements are outdoor and indoor [1]. The outdoor measurements are performed in two cases: in the first one the antenna under test operates in its natural environment. In the second one the antenna dimensions are rather large or the frequencies of measurement are low, for example – metric waves (30-300 MHz). The outdoor measurements are not protected from environmental conditions. The indoor measurements are used in investigations at high frequencies of antennas with small dimensions or of antenna models. These measurements are preferred if one does not want to reveal the antenna under test for reasons of commercial or military security.

The indoor measurements are performed in anechoic chambers. These measurements use two types of techniques. In the first case the near-field signal distribution is measured and from this data the far-field antenna characteristics are computed [2]. In the second case the source antenna is placed at one end of the anechoic chamber and the antenna under test is mounted on a turntable or multi-axis positioner at the other end. The distance between the both antennas must correspond to the requirements for a far-field zone.

The anechoic chambers are lined with radio absorbing material (RAM) from within and with metal (usually copper) sheet from outside. The RAM minimizes reflections from the walls, floor and ceiling. Sometimes the chambers are tapered to prevent the creation of standing waves. The RAM is made from carbon-impregnated polyurethane foam or similar materials, and usually has a tapered pyramidal shape (Fig.1) to provide a gradual transition between the impedance of free space and the metal sheet.

*Fig.1. Radio absorbing material.*

Reflection coefficient of the order of -20 to -40 dB is obtained for absorber thickness more than one wavelength. More sophisticated absorbers can be made from multilayer structures, but these are only used in specialized applications.

The first absorber was patented in mid 1930's [3]. Important investigations in the field of the absorbers were accomplished during the Word War II from German and American research teams [4]. In the mid 1970's more than 400 anechoic chambers are used for antenna measurements. It is impossible to obtain accurate results from antenna measurements without use of an anechoic chamber.

**Anechoic chamber requirements**

1. *Minimum distance between the source antenna and the antenna under test.* Some of the antenna characteristics are measured in the receiving mode and this measurement requires an uniform plane wave incident upon the test antenna. To obtain a perfect plane wave the distance between the both antennas should be infinitely long. For practical purposes usually a criterion such that the phase error at the edge of the curved wavefront should not exceed π/8 radians ($22.5^0$) is adopted. In this case the minimum distance between the both antennas for far-field measurement is given by the expression

$$r_{\min} = 2D^2 / \lambda, \quad (1)$$

where $D$ is the larger aperture dimension of the both antennas and $\lambda$ is the wavelength. This distance is known in the antenna measurements as the Rayleigh distance.

It is seen from (1) that the distance $r_{min}$ increases with the frequency. On the other hand it should be taken into account the influence of the frequency on the dimension $D$.

2. *Minimum distance between the source and test antenna at low frequencies (f < 1 GHz).* There are two other values of the minimum distance between the source and test antenna that need to be considered, particularly at low frequencies. *Firstly*, the reactive near field is significant within about one wavelength of the antenna, thus

$$r_{\min} = \lambda. \quad (2)$$

*Secondly*, when the antenna is rotated the distance from its end to the source antenna varies from $r + D/2$ to $r – D/2$. The $1/r$ field dependence leads to pattern errors. For example, if ±0.5 dB amplitude error is acceptable, then

$$r_{\min} = 10\lambda \quad (3)$$

is required.

3. *Absorber thickness*. Usually, pyramidal absorbers are used in the anechoic chambers. It is mentioned above that a pyramidal absorber thickness of one wavelength assures values of the reflection coefficient of the order of -20 to -40 dB. If the pyramidal absorber is 2 wavelengths thick, it can achieve a -40 dB reflection level for normal incidence. It is very difficult to be carried out these requirements at low frequencies. For example, for low values of the reflection coefficient ($S_{11}$ < -40 dB) the pyramidal absorber thickness at frequency 100 MHz should be more than 6 m.

4. *Dynamic range of the measurement*. The usable dynamic range of the measurements in an anechoic chamber is limited by three main factors:

- Level of external electromagnetic interferences. Nowadays the electromagnetic environment is characterized by various power and multispectral radiations, particularly in the big towns. In order to minimize the level of these external noises it is obligatory for the anechoic chamber to be shielded and grounded;
- Level of internal reflections. It depends on the chamber shape, quality of the absorber and mutual disposition of the equipment used in the measurement;

- The source transmit power and receiver sensitivity. This is not a serious limitation provided that the signal is detected in a narrow bandwidth and a wide dynamic range low-noise amplifier is used at the test antenna. If the peak power received by the test antenna is $X$ dB and the required dynamic range of the measurement is $Y$ dB, then the minimum detectable signal must be at least ($X - Y$) dB, and preferably slightly more if measurement of nulls between sidelobes are not be corrupted by noise.

### The anechoic chamber at Technical University of Varna during the period between 1974 and 2004

The anechoic chamber at Technical University of Varna (TU-Varna) was created in the mid 1970's (1974) [5], [6].

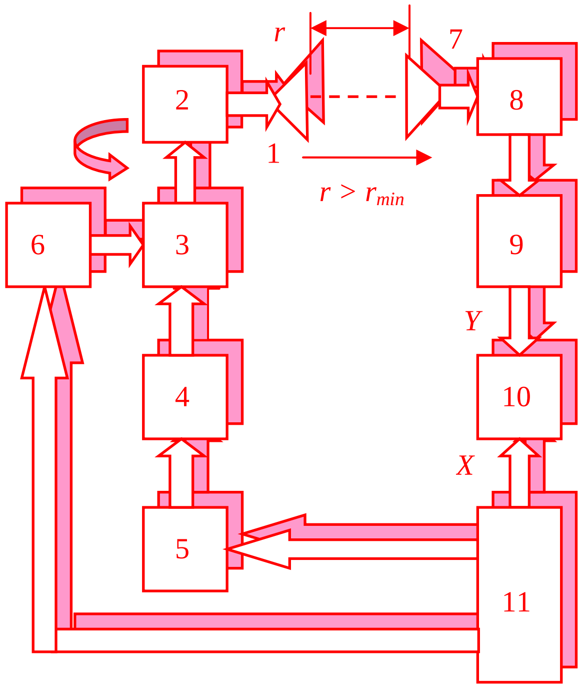



*Fig.2. Block scheme of a system for automatic antenna measurements with test receiver and plotter:1 – antenna under test; 2 – positioner; 3 – reducer; 4 – speed box; 5 – motor; 6 – microwave generator; 7 – receiving antenna; 8 – polarization positioner; 9 – test receiver; 10 – plotter;11 - control panel.*

It is of rectangular shape with dimensions $L$ x $W$ x $H$ = 5.6m x 3.3m x 3.1m. The pyramidal absorbers for the chamber were fabricated in the university. The chamber was not lined with a metal sheet.

The block scheme of the system for automatic antenna measurements is shown in Fig.2. As microwave generators were used generators of series Г3-21 to Г3-26 with frequency range from 840 MHz to 12.09 GHz and output power from 1 W to 12 mW. The test receiver of the system was Rohde & Schwarz USU3.BN15233 with frequency range 1 to 13 GHz and dynamic range of 70 dB (from -85dBm to -15dBm), and as plotter a XY-Recorder endim 620.02 was used.

The system allows automatic measurement of the antenna radiation pattern and computing the directivity from measured data. In the anechoic chamber can be measured also and the other antenna characteristics such as input impedance, reflection coefficient, axial ratio and gain. The basic technical characteristics of the system for automatic antenna measurements with test receiver and plotter are shown in Table 1.

**Table 1**

*Basic technical characteristics of a system for automatic antenna measurements with test receiver and plotter*

| No | Technical characteristic | Dimen-sion | Value |
|---|---|---|---|
| 1 | Minimum angular speed | deg/s | $2x10^{-3}$ |
| 2 | Maximum angular speed | deg/s | > 60 |
| 3 | $P_{Gout}$ (1-3GHz)/(3-12GHz) | W | $1/10^{-2}$ |
| 4 | Frequency range | GHz | 1-12 |
| 5 | Dynamic range | dB | 50/30 |
| 6 | Max. signal level error | dB | 0.2 |
| 7 | Maximum angular error | deg | 0.1 |
| 8 | Max. test antenna weight | kg | 50 |

*Fig.3. Department of Radioengineering 1973.*

In the period 1974-2004 Department of Radioengineering (Fig.3) accomplished scientific researches in the following six fields:

- High frequency electrodynamics and optoelectronics (HFEDOE);
- Television and video engineering;
- Radionavigation and radar engineering;
- Radio and optic communication systems;

- Audio engineering;
- Radio engineering circuit and signals and maritime electronics.

In this period in the HFEDOE Group participated the following lecturers – Prof. H. Hristov, Prof. E. Ferdinandov, Assoc. Prof. G. Entchev, Assoc. Prof. G. Kirov, Assoc. Prof. R. Georgiev, Assoc. Prof. J. Urumov, Assoc. Prof. S. Savov, Assist. Prof. N. Kirov, Assist. Prof. L. Kamburov, Assist. Prof. R. Todorova, Assist. Prof. P. Yankova, Assist. Prof. Z. Zheynov, Assist. Prof. L. Haralambiev, and PhD students – I. Gatzov, B. M. el Jacqies, A. M. Jassim, A. Georgieva.

Head of the HFEDOE Group between 1967 (the year of a creation of the Department of Radioengineering at TU-Varna) and 2000 was Prof. H. Hristov and from 2000 to 2012 – Assoc. Prof. G. Kirov. Since 2012 head of the HFEDOE Group is Assoc. Prof. J. Urumov.

**Improvement of the anechoic chamber characteristics in the last decade (2005-2014)**

In this period some important improvements (changes) were accomplished.

1. *Grounded metal shielding*. The whole surface ($S$ = 92 m$^2$) of the anechoic chamber was lined with 0.4 mm (400 μm) copper sheet from outside. According to copper skin data from Table 2 this metal thickness fully satisfies the requirements for shielding at the whole microwave range. The reduction of the external noise level leads to improvement of the chamber dynamic range.

**Table 2**

*Copper skin depth*

| Frequency, GHz | 1 | 3 | 5 | 10 | 15 |
|---|---|---|---|---|---|
| Skin depth, μm | 2.09 | 1.21 | 0.93 | 0.66 | 0.54 |

2. *Pyramidal absorbers*. The pyramidal absorbers with high reflection coefficient were substituted with three types of commercial pyramidal absorbers as follows (Fig.4):

- The middle part of the walls was lined with pyramidal absorbers SA-150. This band of width $H_2$ = 1.5 m has the same height $H_4$ = 1.55 m as the both antennas (source and test antenna) and determines the maximum values of the reflections for the strongest radiations produced by the main lobe of the radiation pattern.

- The lower and the top parts of the walls with dimensions: width $H_1$ = 0.6 m, thickness $h_1$ = 90 mm,

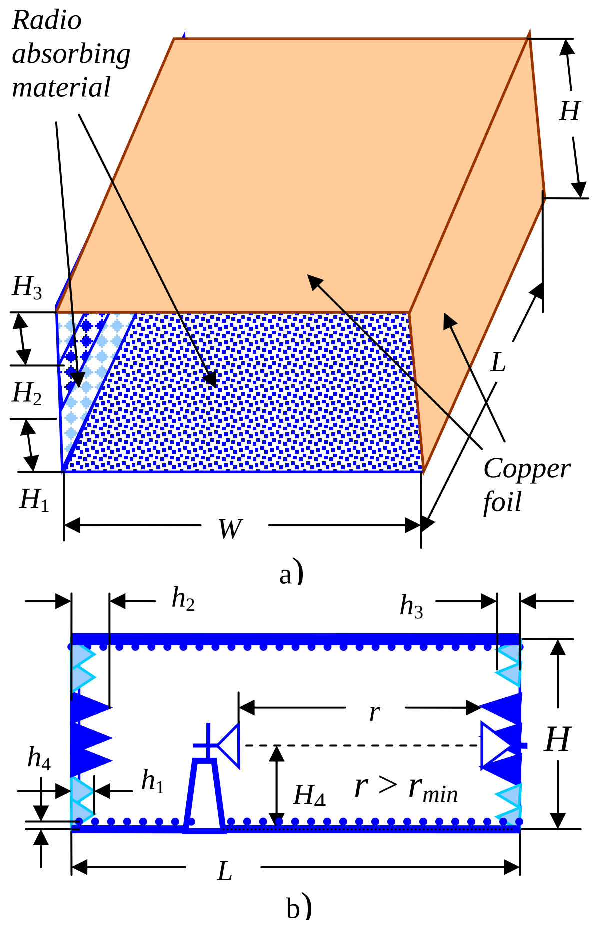



*Fig.4. Geometry of an anechoic chamber for automatic antenna measurements: a) General view; b) Longitudinal section.*

and width $H_3$ = 1 m, thickness $h_3$ = 90 mm, respectively, were lined with pyramidal absorbers TORA-9.

- The floor and ceiling were lined with 30 mm ($h_4$) pyramidal absorbers SA-30. The technical characteristics of the three types of absorbers are shown in Table 3. Thus the level of the reflections in the chamber was additionally decreased.

3. *Generator accuracy*. The generators of series Г3-21 to Г3-26 were substituted with more accurate models of series Г4-78 to Г4-83 and Г4-195 with frequency range from 1.16 to 18 GHz and output power from 1 to 10 mW.

4. *Computer*. The plotter XY-Recorder endim 620.02 was replaced with a personal computer. It records automatically the measured radiation pattern and from this data computes the antenna directivity.

5. *Dynamic range*. The Г4 - generators have low output power (1-10 mW) and the measurements of the

**Table 3**

*Technical characteristics of the used pyramidal absorbers*

| Characteristic \ Model | f, GHz | SA-150 | TORA-9 | SA-30 |
|---|---|---|---|---|
| Producer | | China | ZAO TORA | China |
| Thickness, mm | | 150 | 90 | 30 |
| Weight, kg/m$^2$ | | 4.8 | 2.9 | 1.1 |
| Refl. coef. in normal inci-dence,dB | 1 | -20 | -12 | -8 |
| | 3 | -35 | -20 | -17 |
| | 5 | -40 | -30 | -20 |
| | 10 | -45 | -40 | -30 |
| | 15 | -50 | -45 | -35 |
| Panel size, mm x mm | | 500 x 500 | 490 x 490 | 500 x 500 |

co-polar radiation pattern nulls and the whole cross-polar radiation pattern, particularly of low directive test antennas (with gain lower than 5 dBi) can not be accomplished. To increase the dynamic range of the system for automatic antenna measurements two schemes are used:

- Frequency range 1-6 GHz. The block scheme of the system for automatic antenna measurements at this frequency range is shown in Fig.5.

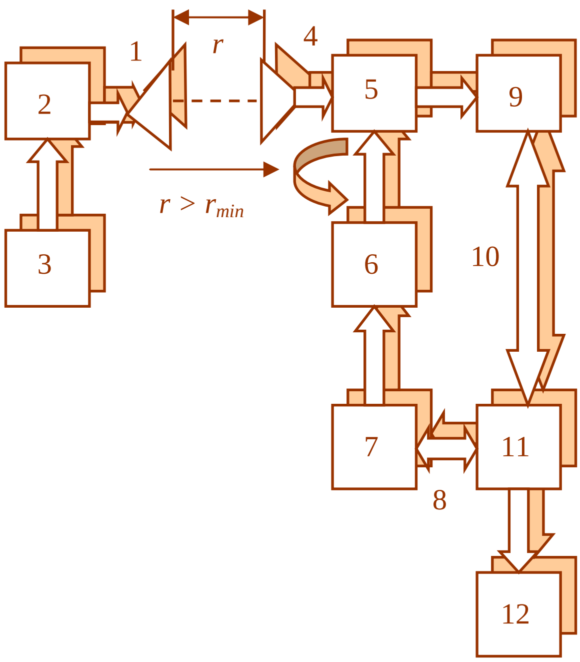



*Fig.5. Block scheme of a system for automatic antenna measurements at frequency range 1-6 GHz with spectrum analyzer and personal computer:1 – transmitting antenna; 2, 5 – positioners; 3 – microwave generator; 4 – test antenna; 6 – DC motor; 7 – DC motor controller; 8, 10 – USB interfaces; 9 – spectrum analyzer;;11 – personal computer; 12 – monitor.*

There are two essential differences in this scheme in comparison with the scheme of Fig.2: Firstly – the test receiver is replaced with a remote controlled USB spectrum analyzer SPECTRAN HF-6060 V4X with frequency range 10 MHz to 6 GHz and dynamic range of 145 dB (from -135 dBm to +10 dBm); Secondly – instead of a plotter a personal computer is used. The usable dynamic range obtained at frequency range 1 to 6 GHz by means the scheme with a spectrum analyzer and a personal computer is more than 80 dB;

- Frequency range 6-13 GHz. The block scheme of the system for automatic measurements at the frequency range 6 to 13 GHz is shown in Fig.6. It is obtained from the scheme of Fig.5 by inclusion of a test receiver Rohde & Schwarz USU3.BN15233, 1-13 GHz in order to cover the frequency range 6-13 GHz. Its output voltage with intermediate frequency $f_{IM}$ = 21.4 MHz is at the frequency range of the spectrum analyzer input voltage.

The improvements of the anechoic chamber in the period 2005-2014 were supported by some research projects [7], [8] and the Technical University of Varna.

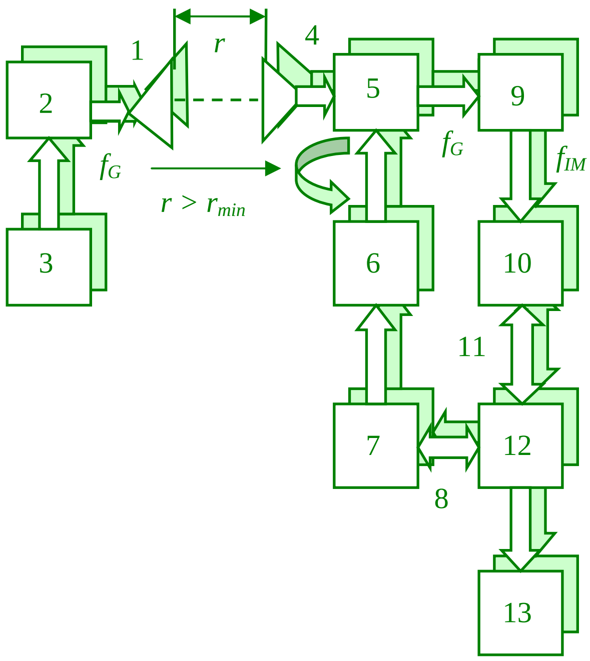



*Fig.6. Block scheme of a system for automatic antenna measurements at frequency range 6-13 GHz with test receiver, spectrum analyzer and personal computer: 1 – transmitting antenna; 2, 5 – positioners; 3 – microwave generator; 4 – test antenna; 6 – DC motor; 7 – DC motor controller; 8, 11 – USB interfaces; 9 – test receiver; 10 – spectrum analyzer; 12 – personal computer, 13 – monitor.*

**Technical characteristics of the anechoic chamber**

The basic technical characteristics of the anechoic chamber for automatic antenna measurements at TU-Varna are shown in Table 4.

**Table 4**

*Basic technical characteristics of the anechoic chamber*

| No | Technical characteristic | Dimen-sion | Value |
|---|---|---|---|
| 1 | Azimuth range | deg | 0-360 |
| 2 | Azimuth variation step | deg | 0.1 |
| 3 | Time measurement of the radiation pattern | min | 6 |
| 4 | $P_{Gout}$ (1-8GHz)/(8-18GHz) | mW | 1/10 |
| 5 | Frequency range | GHz | 1-13 |
| 6 | Dynamic range 1-6 GHz<br>6-13 GHz | dB<br>dB | 80<br>50 |
| 7 | Reflection coefficient of the absorbers (1/13GHz) | dB | -20/-48 |
| 8 | Dimensions of the chamber *L* x *W* x *H* | m | 5.6x3.3 x3.1 |
| 9 | Surface of the chamber | $m^2$ | 92 |
| 10 | Maximum dimension of the test antenna (1/6.5/13GHz) | cm | 77/30/ 21 |

In Fig.7 a radiation pattern in plane $\varphi$ = $45^0$ of a circularly polarized aperture coupled microstrip short backfire antenna at central frequency $f_0$ = 11.668 GHz measured in the anechoic chamber is shown. It is seen from the figure that the dynamic range of the measurements is more than 50 dB.

The general view of the anechoic chamber is shown in Fig.8.

In the period 2005-2014 in the HFEDOE Group participated the lecturers Assoc. Prof. G. Kirov, Assoc. Prof. J. Urumov, Assoc. Prof. R. Georgiev, Assist. Prof. N. Kirov, Assist. Prof. L. Kamburov, Assist. Prof. Z. Zheynov, Assist. Prof. G. Chervenkov and the PhD students A. Georgieva, D. Mihaylova, and K. K. Abdoula (Fig.9). There was very fruitful mutual cooperation in common research projects between HFEDOE Group and Universidad Técnica Federico Santa Maria (UTFSM) Valparaiso, Chile.

Now, in 2014 the HFEDOE Group in Department of Communication Engineering and Technologies consists of eight researchers as follows: four permanently appointed lecturers – Assoc. Prof. J. Urumov, Assist. Prof. L. Kamburov, Assist. Prof. G. Chervenkov and Assist. Prof. Z. Zheynov, two honorary members – Prof. H. Hristov and Assoc. Prof. G. Kirov and two PhD students – D. Mihaylova and K. K. Abdoula.

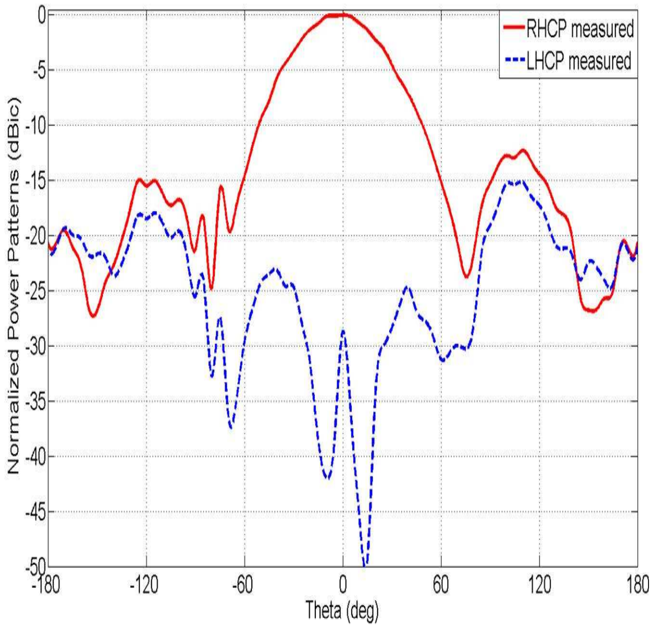



*Fig.7. Measured $\varphi$ = $45^0$ radiation pattern of a circularly polarized aperture coupled microstrip short backfire antenna at central frequency $f_0$ = 11.668 GHz in the anechoic chamber: ____ copolarization (RHCP); - - - - crosspolarization (LHCP).*

*Fig.8. An anechoic chamber at TU-Varna.*

*Fig.9. Department of Radioengineering 2010.*

**Some of the most important achievements of the HFEDOE Group**

1. *Great numbers of successfully carried out research projects* including national and international projects [9-11].

2. *17 certificates and patents of invention* [12-14] *and 6 patent applications* [15]. In Fig.10-12 some of the created and investigated microwave antennas by the HFEDOE Group are shown.

3. *Hundreds of papers*, many of them published in ISI (with impact factor) journals.

4. *25 books and manuals* for students including two books edited by world leading book publishers [16, 17].

5. *Successfully defended 1 Doctor of Science thesis and 13 PhD theses*.

6. *Hundreds of reviews* of habilitation, theses, books, research projects, and scientific papers, many of them intended for publication in ISI journals.

7. *Many citations* of the scientific publications of the HFEDOE Group including in ISI journals.

8. *The members of the HFEDOE Group have been awarded many national and international prizes*. Their names are listed in many international encyclopedias such as Marquis Who's Who in the World (USA), Marquis Who's Who in Science and Engineering (USA), Great Minds of the 21$^{st}$ Century (American Biographical Institute (ABI), USA), International Dictionary of Professionals (ABI, USA), 2000 Outstanding Intellectuals of the 21$^{st}$ Century (International Biographical Centre (IBC) Cambridge, England), Dictionary of International Biography (IBC Cambridge, England), etc…

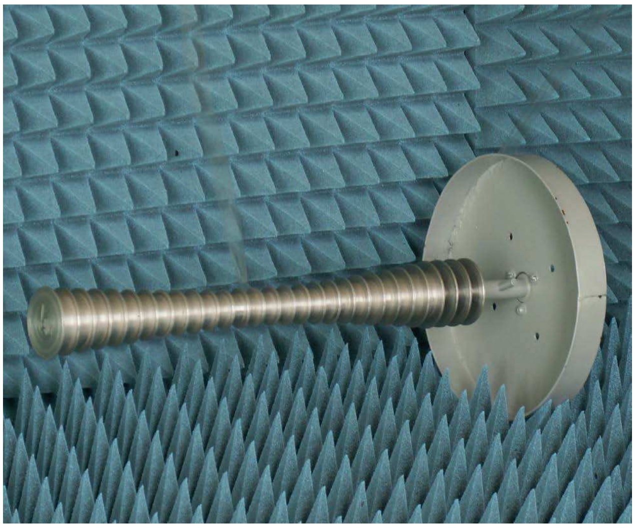


*Fig.10. Impedance disk-on-rod antenna. BPO. Certificate of invention No. 26 928/12.07.1979.*

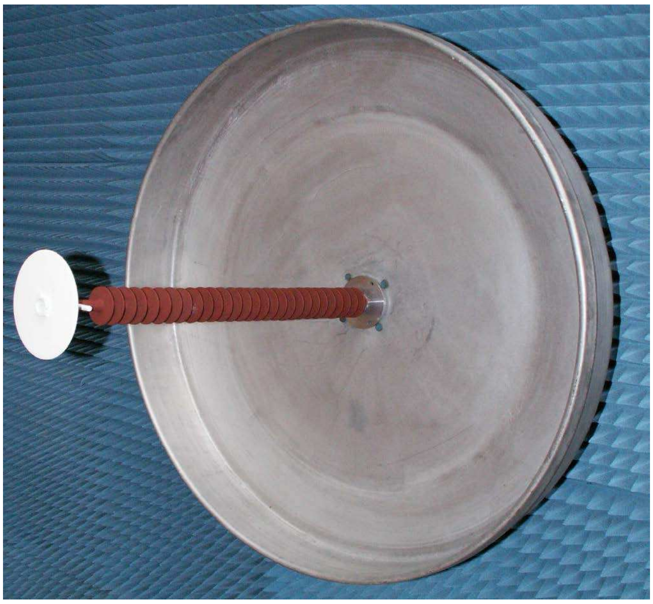
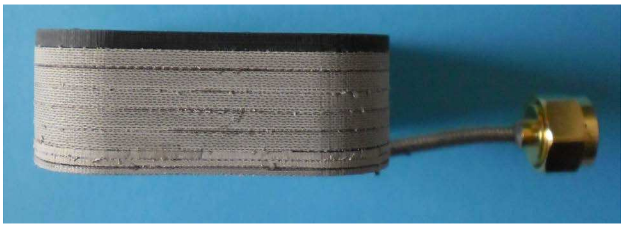


*Fig.11. Backfire disk-on-rod antenna.*



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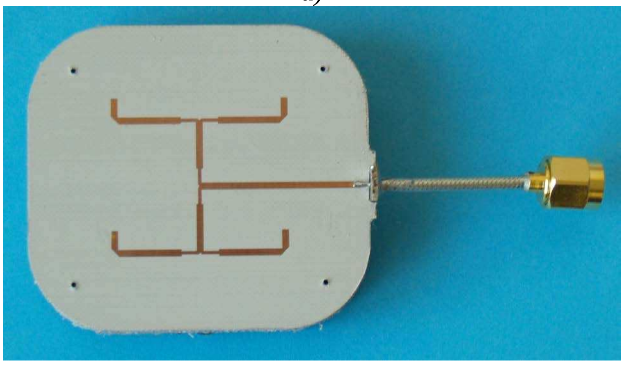

*b)*

*Fig.12. 4-element antenna array of microstrip short backfire antennas. BPO. Patent application Reg. No. 110 818/16.12.2010: a) Side view; b) Bottom view.*

**Conclusion**

During the past 40 years the anechoic chamber in Department of Communication Engineering and Technologies contributed the research activity of the HFEDOE Group enhancing its level and practical applications. Now the HFEDOE Group is leading national research center in the antenna engineering and desirable partner in international research projects in this field.


### Acknowledgements

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***Assist. Prof. Dr. Georgi T. Chervenkov*** *received his MSc degree in telecommunication engineering from the National Military University of Veliko Tarnovo, Bulgaria in 2001 and his PhD degree in communication engineering from the Technical University, Varna, Bulgaria in 2013. He has over seven years experience in the field of microwave radio relay and optical link maintenance. He is currently an assistant professor in Department of Communication Engineering and Technologies at Technical University, Varna. Dr. Chervenkov is a member of IEEE and IET. His research interests include microstrip lines and antennas, microwave devices, radio wave propagation, wireless communications and electromagnetic compatibility.*

*tel.: +359-52-383-252 e-mail: lz2gec@abv.bg*

***Assist. Prof. Dr. Lyubomir P. Kamburov*** *received his MSc degree in radio electronic devices from Baltic State University, Sankt Peterburg, Russia in 1987 and his PhD degree in communication engineering from the Technical University, Varna, Bulgaria in 2013. He has been with the company for radar and radar systems Tcherno More, Varna from 1987 to 1990. Since 1990, he has been with the Department of Radioengineering at Technical University, Varna. He is currently an assistant professor in Department of Communication Engineering and Technologies at the same university. Research interests of Dr. Kamburov include antennas, microwave devices and optical communications.*

*tel.: +359-52-383-674 e-mail: lkamburov@mail.bg*

***Assoc. Prof. Dr. Georgi S. Kirov*** *received his MSc and PhD degrees in radioengineering from the Technical University, Varna, Bulgaria in 1968 and from the Technical University, Sofia, Bulgaria in 1980, respectively. In 1969, he joined the Department of Radioengineering, where he has been a head of the department from 1992 to 2011. He was a lecturer at the University of Setif, Algeria and a researcher at the Moscow Technical University of Communications and Informatics, Russia, Otto von Guericke University of Magdeburg, Germany and the University of Luxemburg. Dr Kirov is currently a honorary associate professor in the Department of Communication Engineering and Technologies at the Technical University, Varna. He is a member of IEEE. His research interests include surface wave antennas, modulated antennas, backfire antennas and microstrip antennas.*

*tel.:+359-52-385-724 e-mail: gkirov@abv.bg*



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