U.P.B. Sci. Bull., Series A, Vol. 80, Iss. 1, 2018 ISSN 1223-7027

DETERMINATION OF THE ELECTROMAGNETIC WAVE PROPAGATION FOR THE DETECTION OF THE CHERENKOV RADIATION CONE IN SALT ENVIRONMENT

Valeriu SAVU[1], Octavian FRATU[2], Madalin Ion RUSU[3]*, Dan SAVASTRU[4], Daniel TENCIU[5], Alexandru VULPE[6], Razvan CRACIUNESCU[7]

Knowing the noise level measured in saline medium of -118dBm we designed and constructed a complex antenna system with which we measured the signals injected from a generator in this environment. Measurements made with the antenna system in saline environment, have highlighted the signal level of -61.5dBm, much lower than until now. Thus, the attenuation of the saline medium was determined for the horizontal plane compared to the previous measurements made for the vertical plane.

Keywords: Cherenkov, electromagnetic wave, radiation, antenna, saline environment.

1. Introduction

The study of cosmic radiation began almost 100 years ago, from 1911 to 1913. Then the Austrian physicist Victor Hess measured the variation of ionization present in the air with altitude after balloon flights [1]. For this discovery, Victor Franz Hess and Carl David Anderson received the Nobel Prize in Physics in 1936 [2]. Since that time a series of experiments have been directed at the study of these cosmic radiations. The used experimental methods were more and more complex, so high energy particles ($10^{12} \div 10^{18}$) eV and very high energies ($10^{18} \div 10^{20}$) eV (neutrinos) were analyzed. The detection of high energy cosmic radiation (particles with energies > 10^{14}eV) is accomplished by indirect experiments, that is, no direct primary particle is detected, but the effect of the

[1] Dr. Eng., NR&D Institute for Optoelectronics - INOE 2000, Romania, e-mail: savuv@inoe.ro
[2] Prof., Faculty of ETIT, UP of Bucharest, Romania, e-mail: ofratu@elcom.pub.ro
[3] Dr. Eng., NR&D Institute for Optoelectronics - INOE 2000, Romania, e-mail: madalin@inoe.ro
[4] Dr. Eng., NR&D Institute for Optoelectronics - INOE 2000, Romania, e-mail: dsavas@inoe.ro
[5] Dr. Eng., NR&D Institute for Optoelectronics - INOE 2000, Romania, e-mail: daniel@inoe.ro
[6] Lect., Faculty of ETIT, UP of Bucharest, Romania, e-mail: alex.vulpe@radio.pub.ro
[7] Asist., Faculty of ETIT, UP of Bucharest, Romania, e-mail: razvan.craciunescu@radio.pub.ro
*Corresponding author e-mail: madalin@inoe.ro

secondary particles generated by the interaction of the primary particle with the environment through which it passes are measured.

The phenomenon by which high energy particles can be detected by interacting with the environment is called the Askaryan effect (the name of the one who described it for the first time) and consists of the emission of coherent Cherenkov radiation (in the case of particles moving through a medium at a speed higher than the phase light velocity through that medium) in the radio frequency domain by the excess electrical charge that occurs during the development of a cascade in that environment [3].

The principle of the Cherenkov detectors is based on the fact that when a particle passes through an environment and moves at a speed higher than the phase light velocity through that medium, an electromagnetic radiation (the Cherenkov Effect) will be emitted. Cherenkov detectors have the property of being able to discriminate between particles with different speeds. Since it is possible to measure the impulses of these particles, then we can say that it is possible to discriminate after the mass of the particles [4], [5] and [6].

The detection of neutrinos with energies higher than 10^{20}eV in saline environment requires their interaction with the environment, thus generating the Cherenkov cone of electromagnetic radiation. The detection of Cherenkov cosmic radiation cone in saline environment requires the knowledge of the attenuation of the propagation of electromagnetic waves in such an environment. In order to determine environmental attenuation, it is necessary to know the electrical parameters of the antennas that can detect the Cherenkov cone of cosmic radiation in saline environment.

The detection of the Cherenkov cone in saline environment is done by measuring the energy levels of the electromagnetic radiation in this environment. The volume of a cosmic radiation detector for detecting the electromagnetic component of the Cherenkov cone is very high: (500x500x500) m^3 [7]; (1000x1000x1000) m^3 [8]; (3000x3000x3000) m^3 [9].

The noise level measured in saline medium for the 187.5MHz frequency is -118dBm [7]. This noise level represents a voltage level of 0.398μV per an impedance of 50Ω for this frequency, but for the saline environment the antenna has an impedance of 13.46Ω and then the voltage level from which the noise starts is 0.206μV for the frequency of 187.5MHz. Knowing these data we have developed a complex system for determining the cosmic radiation Cherenkov cone in saline environment.

This article is organized as follows. In the second section we describe the complex system for determining the propagation of electromagnetic waves through saline environment for detecting the Cherenkov cone of electromagnetic radiation in this environment. The third section presents the design of the main elements of the system. The fourth section analyzes the results of the measurements with the complex system in saline environment and the fifth section presents the conclusions of the measurements and future perspectives.

2. Description of the complex system

The block diagram of a complex system for determining the propagation of electromagnetic waves through the saline environment for detecting the Cherenkov cone of electromagnetic radiation in this environment works on the central frequency of 187.5 MHz and is presented in Fig. 1 [10].

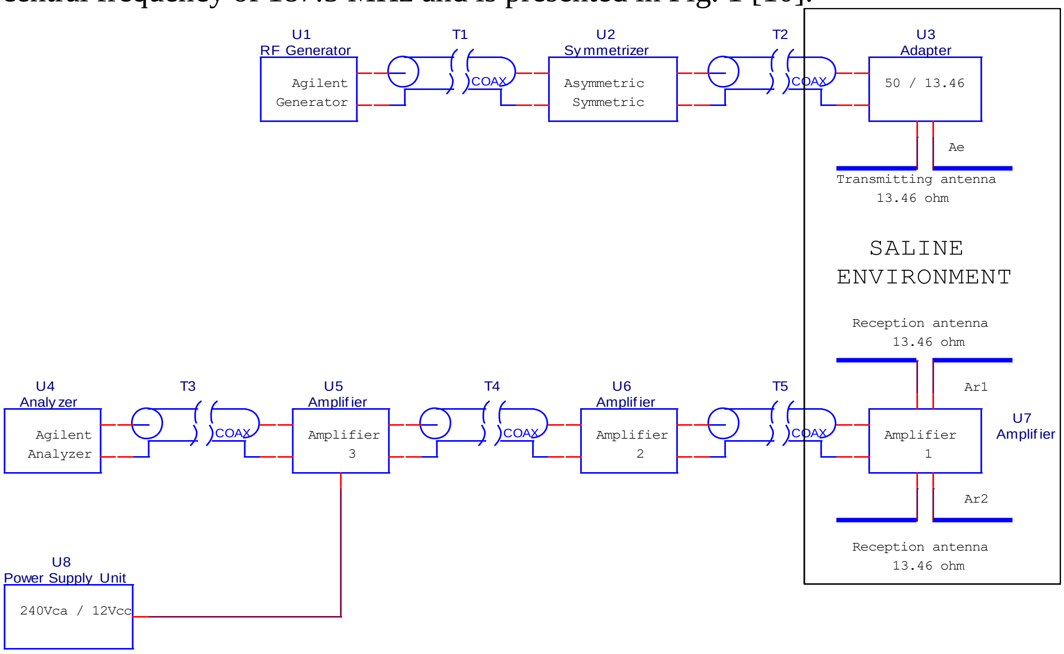

Fig. 1. The block diagram of the complex system for determination of the dielectric parameters of the saline environment for detecting the Cherenkov cone of electromagnetic radiation in this environment for a working frequency of 187.5MHz.

The complex system consists of the following blocks: U1 - Agilent Radio Frequency (RF) Generator; T1 - 50 Ω shielded cable for radiofrequency signal injection; U2 - Balun for transmitting antenna; T2 - 50 Ω shielded cable for connection of the impedance adapter to the transmitter, U3 - impedance adapter; Ae - Transmitting antenna; Ar1,2 – Receiving antennas; U4 - Agilent Radiofrequency (RF) Analyzer; T3 - 50 Ω shielded cable for transmitting signal from U5 unit to the U4 analyzer; U5 - Third amplifier (Amplifier 3) for receiving signal, T4 - Shielded 50Ω cable for connection between U6 and U5 amplifiers; U6 - Second amplifier (Amplifier 2) for the reception signal; T5 - Shielded 50 Ω cable for connection between U7 and U6 amplifiers; U7 - The first amplifier (Amplifier 1) for the signal received by the pair of receiving antennas Ar1,2 of receiving; U8 - 12Vcc Power Supply for amplifiers.

The U2 block (Balun) transforms the asymmetrical impedance into symmetrical impedance for equally loading the dipole antenna arms. The circuit diagram of the balun is shown in figure 2. The balun is used at the transmitter and receiver.

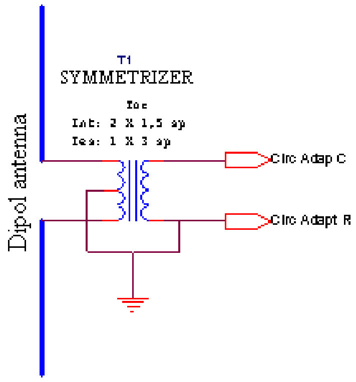

Fig. 2. The electrical diagram of balun (symmetrizer).

The transmitting antenna (Ae) is connected to the U1 unit via an adapter circuit since the antenna impedance in the salt is less than 50Ω. Figure 3 shows the electrical layout of the emission block.

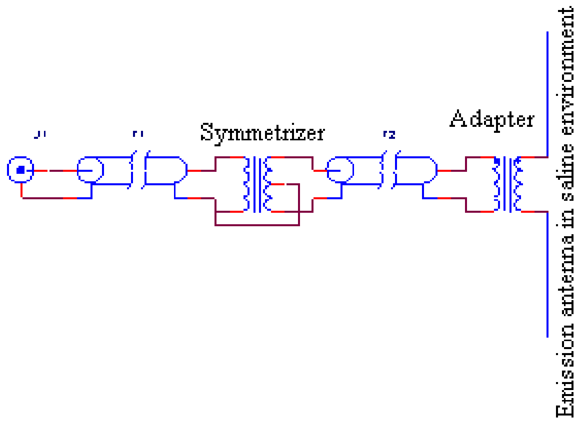

Fig. 3. The adapter and the balun (symmetrizer) used for the emission antenna.

Fig. 3 shows the electrical connection diagram of the transmitting antenna (Ae) with the Agilent radiofrequency signal generator (U1). The U1 unit connects to the J1 connector with the 50 Ω T1 connection cable of about 2m and the signal is injected into the balun (U2). Thus, the impedance of the asymmetric 50Ω generator is passed to the symmetrical 50Ω impedance that is found at the input of the 50Ω shielded T2 cable. The adapter (U3) converts the 50Ω impedance that is found at the output of the 2.5m T2 connection cable in the impedance of the 13.46Ω antenna working in saline environment.

3. Designing system elements

In order to build the complex system for determining the propagation of electromagnetic waves through the saline environment for detecting the Cherenkov cone of electromagnetic radiation in this environment it is necessary to calculate the main elements.

a) Calculation of antenna parameters:

$$L_{a[\lambda/2]} = \frac{c}{2f\sqrt{\varepsilon_{r\,salt}}}, \text{ antenna length in } \lambda/2 \text{ [m]}, \qquad (1)$$

and $c \cong 3*10^8$ m/s; f = the resonance frequency of the antenna [Hz];

$\varepsilon_{r\,salt} = 5.981 + j0.0835$, the real part was taken in calculation $\Re(\varepsilon_r) \cong 6$.

Result: $f = 187.5\text{MHz} \Rightarrow L_{a187.5\text{MHz}} \cong 0.327\text{m}$

b) The formula for calculating the radiation resistance of the antennas for working in salt environment is:

$$R_{a\,salt} = \frac{2\pi}{3\sqrt{\varepsilon_{r\,salt}}} Z_0 \left(\frac{L_a}{\lambda}\right)^2 \qquad (2)$$

where: $\varepsilon_{r\,salt} \cong 6$, $Z_0 \cong 377\Omega$ and $\lambda = \frac{c}{f}$ the wavelength in the air, then for the frequency f = 187.5MHz the radiation resistance of the transmitting and receiving antennas: $R_{a\,salt187.5MHz} \cong 13.46\Omega$.

c) The summation block is actually a coupling circuit for the two receiving antennas Ar1,2. Summing the signals of the two receiving antennas Ar1,2 represents the sum of the attenuating powers to 3dB.

The relationships are valid for the summation block:

$$C = \frac{1}{2\pi fZ_c} \text{ and } L = \frac{Z_c}{2\pi f} \text{ where } Z_c = \sqrt{2 \cdot Z_{ac} Z_s} \qquad (3)$$

where: $Z_{ac} = 50\Omega$ and is the impedance seen at the output of the adaptation circuit, $Z_s = 50\Omega$ is the load impedance of the summating block.

Therefore: $Z_c = 70.7\Omega$, $C = 0.00707\,(\pi f)^{-1}$ [F], $L = 35.35\,(\pi f)^{-1}$ [H] (4)

d) The band-pass filter with central frequency of 187.5MHz is a 3 poles Butterworth filter. This filter is shielded and partitioned for each pole. The electrical scheme of the band-pass filter, with three poles, is shown in Figure 4. For the calculation filter, the following relations are valid:

$$L_1 = \frac{Z_0}{\pi(f_2 - f_1)} \qquad (5)$$

$$L_2 = \frac{Z_0(f_2 - f_1)}{4\pi f_1 f_2} \tag{6}$$

$$C_1 = \frac{f_2 - f_1}{4\pi Z_0 f_1 f_2} \tag{7}$$

$$C_2 = \frac{1}{\pi Z_0(f_2 - f_1)} \tag{8}$$

where Z_0 represents the input and output impedance of the filter, f_1 represents the minimum bandwidth frequency and f_2 represents the maximum bandwidth frequency. In these formulas L_1 and L_2 are expressed in [H], C_1 and C_2 are expressed in [F], Z_0 is expressed in [Ω] and f_1 and f_2 are expressed in [Hz].

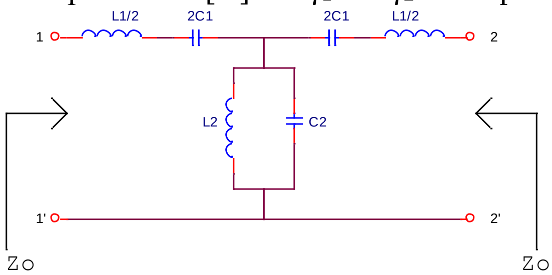

Fig. 4. The electrical calculation scheme of the band-pass filter, with three poles.

The form factor for the 3-poles filter is the following:

$$F_{3poli} = \frac{B_{60dB}}{B_{6dB}} \tag{9}$$

4. Experimental results

The measurements made in saline environment led to determining the permittivity of this environment at the frequency of 187.5MHz, in order to detect the Cherenkov cone of electromagnetic radiation in this environment. The complex system for determining the propagation of electromagnetic waves through saline environment for detecting the Cherenkov cone of electromagnetic radiation in this environment is made up of 3 units of cascaded amplifiers on the central frequency of 187.5MHz (U7, U6 and U5).

The receiving antennas were inserted into saline environment in specially made holes.

The location of the measuring points with the complex system in the saline environment is presented in figure 5. At point R, the unit U7 with the two receiving antennas was maintained. At points E1 and E2, the unit U3 with the transmitting antenna was placed at a time.

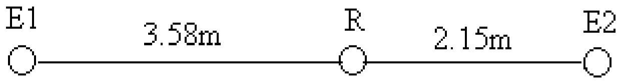

Fig. 5. Placement of the measuring points.

The total loss on the connection cables for the reception block is 0.216dB and for the emission block is 0.252dB. The total loss introduced by the connecting cables for the complex system is 0.468 dB. The signal injected into the system by the Agilent radiofrequency generator will be considered, in calculations, less with 0.468dB.

The frequency mitigation feature of the 3-poles BPF (band-pass filter) is shown in Figure 6. The shape factor of the 3-poles BPF filter is $F_{3\,poles\,60dB/6dB} = 5.99$.

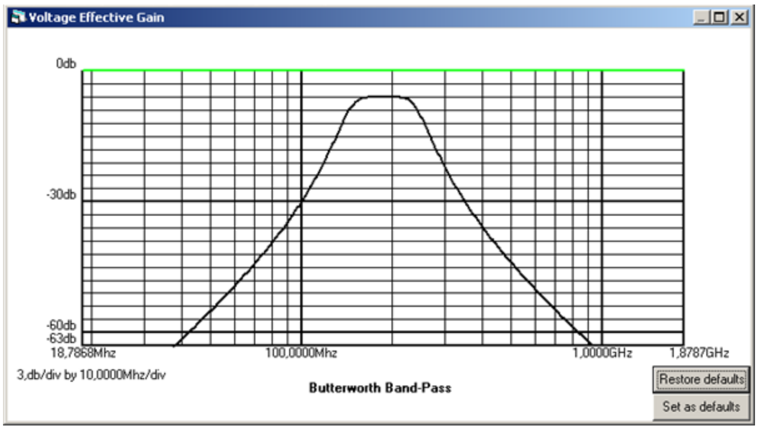

Fig. 6. The frequency attenuation characteristic for the band-pass filter with three poles.

The frequency mitigation feature for cascading three filters with three poles, and 187.5MHz center frequency is shown in Figure 7.

The shape factor of the three 3-poles BPF filters in cascade is: $F_{3\,poles\,casad\;\;60dB/6dB} = 2.04$. This form factor is well suited for measurements with the complex system.

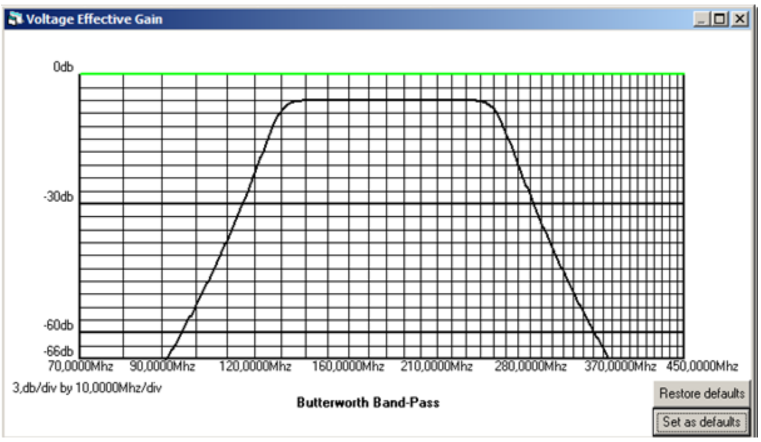

Fig. 7. The frequency attenuation characteristic for the three 3-poles BPF filters in cascade and the center frequency of 187.5MHz.

Fig. 8 shows the complex system prepared for measurements in saline environment.

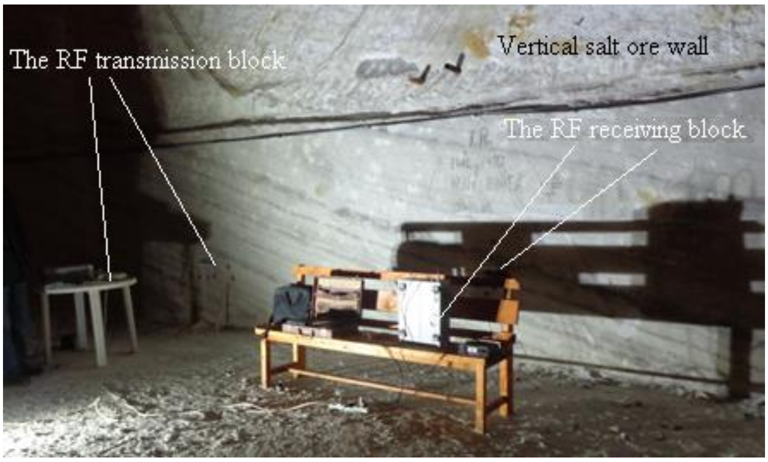

Fig. 8. The complex system of the determination of the dielectric parameters in saline environment for detecting the Cherenkov cone of electromagnetic radiation in this medium at the frequency of 187.5MHz with the two blocks (emission and reception).

Signal level of 0dBm, 10dBm and 20dBm was injected into the emission antenna. The measurements were made for the frequency 187.5MHz and two in-band frequencies of the 3-poles BPF filter (175MHz and 200MHz). The results are shown in Tables 1 and 2.

Table 1

RF level measurement for saline environment in two directions for central frequency of 187.5 MHz.

Output signal from generator	Level at reception (3.58m)	Level at reception (2.15m) in opposite direction
0 dB	-46.68 dBm	-51.78 dBm
10 dB	-36.28 dBm	-42.33 dBm
20 dB	-27.33 dBm	-33.9 dBm

Table 2

RF level measurement for saline environment at two frequencies in the 3-poles BPF filter band.

Output signal from generator	175 MHz	200 MHz
	Level at reception (3.58m)	Level at reception (3.58m)
0 dB	-61.5 dBm	-59.5 dBm
10 dB	-52.5 dBm	-49.6 dBm
20 dB	-42 dBm	-41.4 dBm

Following the calculations of the data in Tables 1 and 2 and considering the attenuations introduced by the complex system, the values of the imaginary part of the dielectric rigidity of the saline environment were obtained. The data are presented in Table 3.

Table 3

The value of the imaginary part of the dielectric rigidity of the saline medium and the calculation of the corresponding value for *tan δ*.

***f* = 187.5MHz**	
d = 3.58m	*d* =2.15m
$\Im(\varepsilon_r)$= 0.11346; *tan δ* = 0.01891	$\Im(\varepsilon_r)$= 0.073656; *tan δ* = 0.01228
***d* = 3.58m**	
f = 175MHz	*f* = 200MHz
$\Im(\varepsilon_r)$= 0.50562; *tan δ* = 0.01719	$\Im(\varepsilon_r)$= 0.106629; *tan δ* = 0.01777

Analyzing the measured values in Tables 1 and 2, we determined the attenuation length for the saline environment, for two directions and three frequencies. The data calculated for the attenuation length for the saline environment are shown in Table 4.

Table 4

Determination of attenuation length for saline environment.

Measurement direction	*f* [MHz]	3,58m	2,15m
Attenuation length [m]	187,5	0,671	0,361
	175	0,506	–
	200	0,523	–

For the detection and measurement of the effect of the passage of neutrinos through a massive salt block it is necessary to measure under a very low radiation background. The noise level measured in saline environment for a 600MHz frequency band is of -118dBm [11].

The input resistance at the terminals and the length of the dipole antenna in $\lambda/2$ will be modified with the actual value of permittivity of the saline environment where the antenna working.

The saline environment attenuation length in the vertical wall case, where measurements were made with the antennas in the horizontal plane (Table 4), is much less than attenuation length in the horizontal wall [11]. The attenuations in the horizontal plane measurement with the antennas, in relation to the vertical plane, are higher because the saline environment in which were made measurements may contain a higher density of impurities. The results are shown in Table 3 for *tan δ*.

6. Conclusions

The complex system for frequency of 187.5MHz opens the premises for the realization a cosmic radiation detector based on the Cherenkov cone of electromagnetic radiation in saline environment. Measurements made in saline environment with the complex system can lead to a system for simulating the Cherenkov cosmic radiation cone in this type of environment, greatly reducing the cost of developing and operating a Cherenkov detector in saline environment.

Acknowledgements

This work has been carried out on the Core Programme of the Romanian Ministry of Education and Research, National Authority for Scientific Research, 5N/9.03.2016, PN16 40 01 02.

R E F E R E N C E S

[1]. *V.F. Hess*, Convection phenomena in ionized gas-ionwinds, Phys. Zeit. 13, pp. 1084, November 1912.

[2]. *Angelo Joseph A*, Nuclear Technology, Greenwood Press, ISBN 1-57356-336-6, 2004.

[3]. *Engel R., Sekel D., Stanev T.,* Neutrinos from propagation of ultra-high energy protons, Phys.Rev. D64, 093010, 2001.

[4]. *Th.Farbel*, Experimental Techniques in High Energy Nuclear and Particle Physics, World Scientific, Singapore, 1991.

[5]. *W.R.Leo*, Techniques for Nuclear and Particle Physics Experiments, Springer Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, 1995.

[6]. *W.H.Tait*, Radiation detection, Butterworths, London, Boston, Sydney, Wellington, Toronto, Durban, 1980.

[7]. *Valeriu Savu, Razvan Craciunescu, Octavian Fratu, Simona Halunga, Ion Marghescu*; Cosmic Radiation Detector Performances in Salt Mines; 11th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services, Telsiks 2013, Serbia, Nis, October 16-19, 2013.

[8]. *Toshio Kamijo and Masami Chiba*, Microwave Properties of Rock Salt and Lime Stone for Detection of Ultra-High Energy Neutrinos, SPIE, Vol. 4858, 2003.

[9]. *Chiba Masami, et. all*, Radar for salt ultra-high-energy neutrino detector and contribution of W-gluon fusion process to collision of neutrinos against protons, Nuclear instruments & methods in physics research, ISSN 0168-9002, 2009.

[10]. *Savu Valeriu, Fratu Octavian, Craciunescu Razvan-Eusebiu, Halunga Simona Viorica, Vulpe Razvan-Alexandru, Voicu Carmen,* Sistem hardware de detectie a radiatiei cosmice de tip neutrin electron in sare, Cerere de brevet de inventie A/00959 din 05-12-2016.

[11]. *Valeriu Savu, Ion Marghescu, Octavian Fratu, Simona Halunga, Alina-Mihaela Badescu*; Antenna Design for Electromagnetic Waves Propagation Studies Through the Salt Ore*;* U.P.B. Sci. Bull., Series C, Vol. 75, Iss. 2, 2013, ISSN 2286 – 3540.