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# Optimization of Cosmic Radiation Detection in Saline Environment

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## Abstract

Following the interaction of a neutrino with saline environment, the Cherenkov cone will be generated. The electromagnetic effect of the Cherenkov cone is perpendicular to the cone generator and it has the energy directly proportional to the neutrino energy. In the saline environment, neutrinos with very high energies (noise – 115 dBm) can be determined. Investigation of these neutrinos will lead to the construction of a Cherenkov detector. The construction of a Cherenkov detector involves the design and the construction of a very large number of detection elements and of cascade amplifiers. Another necessary condition is to know exactly the distribution of the dielectric parameters of the saline environment. In order to know the distribution of the dielectric parameters of the saline environment, it is necessary to make a map of their distribution. Under these conditions, the number of detection elements will be optimized and also the optimal position of the future Cherenkov detector will be determined. In this chapter, we will present the methodology of calculating the detection elements and a method to determine the dielectric parameters. Measurements of attenuation of the propagation of electromagnetic waves in this environment will be presented. We will detail how to optimize a Cherenkov detector.

**Keywords:** netrins, radiation, cone, Cherenkov, electromagnetic

## 1. Introduction

Following the interaction of a neutrino with saline environment the Cherenkov cone will be generated. This cone has the height in the prolongation of the neutrino's direction and the base of the Cherenkov cone is forming in the continuation of the neutrino's direction, keeping its angle at the top of the cone. The base of the Cherenkov cone moves further in the same direction as the neutrino that produced the Cherenkov Effect. The electromagnetic effect of the Cherenkov cone is perpendicular to the lateral surface of the cone and it has the energy directly proportional to the energy of the neutrino. It is this neutrino that produced this effect. By determining the energy and the direction of the neutrino that produced the electromagnetic effect of the Cherenkov cone, information about the phenomena in the Universe that generated this neutrino is discovered. In the saline environment, neutrinos with very high energies can be determined. These neutrinos provide information about the phenomena in the Universe that occurred at great distances from Earth. These distances are much larger than the distances at which the most efficient telescopes can work, so that the information obtained from neutrinos will

increase the horizon of knowledge and contribute to the improvement of information about the Universe. Thus, we can say that this information makes a significant contribution in the field of astrophysics and astronomy.

The study of cosmic radiation began between 1911 and 1913. During this period, the Austrian Physicist Victor Hess, following balloon flights, measured the variation of ionization present in the air with the altitude [1]. The neutrinos carried by cosmic radiation have very high energies of the order  $(10^{15} \div 10^{23})$  eV, those with energy between  $(10^{15} \div 10^{21})$  eV can be detected in saline environment and those with energies greater than  $10^{21}$  eV cross the terra.

The investigation of the interactions of high-energy neutrinos of cosmic origin in a dense environment (natural salt) will lead to the construction of a cosmic radiation observer in this environment. The phenomenon by which particles charged with high energies are detected due to the interaction with the environment is called the Askaryan effect and consists in the coherent emission of Cherenkov radiations in the radio frequency domain, through an excessive electrical charge that occurs during the development of an electron cascade in that environment. Cherenkov radiation occurs in the case of particles moving through an environment at a speed greater than the speed of light through that environment [2].

An avalanche of relativistic particles [3] represents the interaction between a very high-energy neutrino and a dense and dielectric environment (salt block). For neutrinos with energy greater than  $10^{15}$  eV, only about 20% of it appears as a hadronic particles cascade, and this cascade has an electromagnetic component [3]. The electromagnetic cascade consists of electrically charged particles (about 70% of the particles) [4]. These particles contribute to the generation of the total electromagnetic energy of the cascade [4]. Particles with a speed of travel greater than the speed of light through a transparent and dense environment (the salt block) will produce the Cherenkov radiation effect (in our electromagnetic case) in this environment [2].

The phenomenon, by which the interaction with the environment can detect particles charged with high energies, is called the Askaryan effect and consists in the emission of Cherenkov radiation (in the case of particles moving through an environment at a speed greater than the speed of light through that environment) coherent in the radio frequency domain by the excess load that appears during the development of a cascade in that environment [2]. Determination of neutrinos with energies greater than  $10^{12}$  eV can lead to the discovery of new astrophysical systems and new physical processes [3]. The direction, from which these very high energy neutrinos come from, is a direct indicator of the source that generates them, thus a cosmic radiation observer from a saline will have to fulfill this goal [3]. The result of the interaction of a very high energy neutrino with a dielectric, transparent and dense environment (salt block), is an avalanche of relativistic particles [3] which by Cherenkov effect will cause the information obtained to generate new aspects about astro-particles and they create the premises for a deeper understanding of the cosmic phenomena of high energy in the Universe [3]. These particles contribute to the generation of total electromagnetic energy in the form of a Cherenkov cone [4]. Knowing the effects related to the propagation of electromagnetic waves in dielectric environments with impurities (saline environment) [5], then, by eliminating the influences of the parameters of the propagation environment (saline environment), one can deduce the basic parameters of the flexible transmitting and receiving antennas. By performing a sufficient number of measurements, these basic parameters of the flexible transmitting and receiving antennas can be determined. Knowing these parameters, the detection of the electromagnetic radiation of the Cherenkov cone (which is known to be perpendicular to the generator of the cone) can be performed with much greater accuracy. Then it will be possible to determine

the direction and energy level of the neutrinos generating the Cherenkov cone with the same precision level. Considering these aspects, the special importance of designing and realizing a complex system for determining the electrical parameters of the antennas for the detection of Cherenkov cone of electromagnetic radiation in saline environment, is deduced. The determination of the electrical parameters of the antennas for the detection of the Cherenkov cone of electromagnetic radiation in saline environment will be thought out so that it can determine these parameters in such environments. The basic parameters of the antennas [6, 7] will be determined: the radiation diagram, the directivity, the gain, the polarization, the input impedance, the frequency band, the effective surface, and the effective height.

In order to determine the Cherenkov cone in saline environment (the noise does not influence the energy measurement because the maximum noise level measured in saline environment is  $-115$  dBm [8]), it is necessary to make a Cherenkov detector in this environment. The implementation of a Cherenkov detector in saline environment involves the design and construction of a very large number of detection elements together with the related devices and a very large number of cascade amplifiers as well [5]. Under these conditions the price of a Cherenkov detector in saline environment is very high. Another necessary condition (it is of particular importance since it can reduce the costs of producing a Cherenkov detector in saline environment) is the accurate knowledge and distribution of the dielectric parameters of the saline environment in the salt volume in which a Cherenkov detector will be made. The realization of a map of the distribution of the dielectric parameters of the saline environment in the entire volume of a salt rock implies the elaboration of a complex system for determining the dielectric parameters of the saline environment for the detection of the Cherenkov cone of cosmic radiation in this environment. With this system, measurements can be made in saline (on-site) environment in order to make this map. The use of this system in the measurements will increase the possibility to implement a Cherenkov detector in saline environment. Until now, this system has not been used in saline environment for the detection of cosmic radiation, which brings a novelty in the field. The novelty in the field of cosmic radiation detection in saline environment has led to patent applications A/00959/05.12.2016 [9], A/00404/07.06.2018 [10] and A/00354/12.06.2019 [11].

So far, a number of studies were carried out in different environments in order to perform a Cherenkov cosmic radiation detector. The studies were conducted in environments such as: air, ice, salt rock [12, 13], limestone rock, etc. For saline environment the SalSA detector is known, under water (ANTARES, Baikal, NEMO, NESTOR, AUTECH etc.), under ice (AMANDA, ICECUBE and RICE), for atmosphere (ASHRA, AUGER, EUSO and OWR), between soil and air (GLUE, Forte'NuTel and ANITA) [14]. The "Salt Sensor Array" (SalSA) detector has as reference parameters,  $10 \times 10$  rows of square surfaces, placed  $250$  m horizontally between them for a depth of  $2000$  m and placed at  $182$  m vertically between them, with  $12$  knots per row and for each row  $12$  detection elements, resulting in  $14,400$  detection elements. In the SalSA (saline environment) project, a  $250$  m attenuation length of the electromagnetic waves was obtained for a frequency band of  $100 \text{ MHz} \div 300 \text{ MHz}$  using antennas with horizontal and vertical polarity [15]. Cherenkov 3D type detector with a geometry  $20 \times 20 \times 20$  where the number of sub-bands is  $1$  and the number of antennas with the same polarization type is  $2$  has a size of  $500 \text{ m}^3$ , uses  $32,000$  detection elements and a number of  $400$  wells in the salt block and it uses the neutron electron cosmic radiation detection system [5, 9]. In these studies, there was no question to determine the dielectric parameters of the environments, in which the measurements were performed.

In saline environment, two projects were carried that studied the way of detecting the Cherenkov cone of electromagnetic radiation in saline environment,



but in these projects, there was no search for flexibility and adaptability of the antennas for the most accurate detection of the Cherenkov cone of electromagnetic radiation in saline medium.

The study of the detection of cosmic neutrinos began almost 20 years ago. Several specific telescopes have been developed that have attempted to identify these particles. The results were not the ones expected. On 23-02-1987, a radiation source of cosmic neutrinos was identified for the first time. This was called “Supernova 1987A” and opened a new stage in the theory of cosmos evolution. For ice detectors (ANITA) [16] with an SNR > 1 allowance, all events occurring in the frequency band (100 ÷ 1000) MHz can be considered detectable. In another paper dealing with the detection of cosmic radiation at the ice surface in Antarctica [17], it is mentioned that if SNR = 1 is considered, then the number of events can be estimated. Nor does this work address the reflections, attenuations, and characteristic of the antennas. Another paper dealing with the interaction of neutrinos (UHE) [18] and referring to a constant detector volume, does not take into account the effects related to the signal-to-noise ratio, antennas, propagation through the study environment, aspects that we want to achieve in this project. Due to an inhomogeneous distribution of impurities in the saline environment, a theoretical approach to the propagation phenomenon of electromagnetic waves in this environment cannot be realized [19, 20].

In order to obtain the most accurate dielectric parameters of the saline environment, it is necessary to improve the system of measurement and the determination of these parameters. In order to reach the proposed objective it is necessary to minimize the errors introduced by adapting the detection elements (transmission and reception antennas) to the saline environment (the electrical parameters of the antennas: the working impedances, the directional characteristics in horizontal and vertical plane, the gain, etc. of the transmitting and receiving antennas that are affected by the saline environment), it is necessary to make a band-pass filter with the lowest insertion attenuation resulting in a uniform bandwidth and it is also necessary to make an amplifier with the amplification as much as possible constant in the working band (central frequency 187.5 MHz, amplification band at 3 dB greater than the bandwidth filter by at least 10% and the amplification can compensate for the losses introduced by the connection cables).

The determination of the Cherenkov cone in saline environment presents as a result the determination of the energy, the direction and the sense that the neutrinos, which interact with a saline environment, possess. These neutrinos provide information about the phenomena in the Universe that occurred at great distances from Earth. These distances are much larger than the distances at which the most efficient telescopes can work, so that information obtained from neutrinos will increase the horizon of knowledge and will contribute to the improvement of information about the Universe. Thus, we can say that this information makes a significant contribution in the field of astrophysics and astronomy.

## **2. Data measurement systems in saline environment**

The generation of radiation pulses that arise from the interaction between high energy neutrinos (Ultra High Energy, UHE) and a dense dielectric medium has been studied first by Askaryan [21], who also presented the first results based on laboratory tests.

Askaryan also identified several natural materials that can be used as neutrinos detectors: the salt blocks present in saline mines, the ice from polar region, and the soil of moon [22, 23]. It was proven that a solid block of salt is a very good candidate

for such detectors, since it suffers important changes of its electrical properties, based on which, the neutrinos that pass through the block can be detected.

Based on the Askaryan effect [24–26] the radiation that passes through a dense dielectric generates a cone of coherent radiation in the radio or microwave frequency domain, known as Cherenkov radiation [27–29]. In order to detect this radiation, one has to determine the frequency domain in which those radio impulses have maximum intensity and the parameters of an antenna that can be used in a conventional receiver.

In an experimental setup with a particular configuration of transmitter and receiver antennas, one can measure the level and the range of the radiation generated and, based on those results, can evaluate the neutrinos energy. The system proposed in this paper consists in an Anritsu MS2690A signal analyzer, with an incorporated signal generator, coupled to the transmitting and receiving antennas [30].

With this system, the dielectric parameters of the saline environment are determined first and, by knowing these parameters, the distance of attenuation of the propagation of electromagnetic waves through the saline environment can be determined (the distance at which the module of the electromagnetic field decreases to  $1/e$ ). Thus, it is possible to determine, following a package of measurements for the vertical plane [8], and for the horizontal plane [31], the distribution of the attenuation of the electromagnetic waves through the saline environment (the map of the distribution of the electromagnetic waves in the saline environment leading to the determination of the optimal position of placement in a saline environment of a Cherenkov detector), the determination of the minimum number of detection elements, and the optimal position of their placement in saline environment [10]. Based on the use of dedicated software, one can determine the extreme situations of the generation of the Cherenkov cone outside the volume of the Cherenkov detector [11].

In order to determine the dielectric parameters of the saline environment, two methods were studied, a direct and an indirect one.

**The direct method** involves the injection of a radio frequency signal into the measuring medium (saline medium) in order to determine the electrical parameters of the radio frequency antennas. Thus, this method involves performing a measuring assembly. This will include a radio frequency signal generator nozzle that will inject the signal into an emission antenna, the electrical parameters of which are known, an antenna for the reception of the injected signal, the electrical parameters of which will be determined, a signal analyzer block received from the measuring antenna. The antennas will be introduced in saline environment.

According to IEEE standard no. 145–1983 [32], which states that “the antenna is a means of transmitting or receiving radio waves”, i.e. the antenna is that part of a radio equipment that, by means of electromagnetic exchange of power with the environment, ensures communication between at least two telecommunication equipments. The antenna can also be regarded as an element that adapts between the environment and the receiver or transmitter. It actually performs a transformation of the power of the electromagnetic field into a signal received as electrical power. Also, the antenna transforms the electric emission power into the power of the radiant electromagnetic field [6, 33].

The transmitting and receiving antennas, from a constructive point of view, are identical. The basic parameters of the antennas are [6, 7]:

- radiation diagram,
- directivity,

- gain,
- polarization,
- the input impedance,
- the frequency band,
- the actual area,
- the effective height.

**The radiation diagram** of the antenna represents the space surface for which the vectors leaving the antenna towards this surface have the module proportional to the intensity of the radiation in the respective direction. The direction, in which the field intensity is zero, is called null. The region between two nulls is called the lobe. The maximum of the lobe is called the level of the lobe and the direction, in which it is maximum, is called the orientation of the lobe. If we represent the lobes in relative sizes, then an antenna can have one or more level 1 (0 dB) lobes - called main lobes, - and less than 1 level lobes (negative in dB) - named secondary (lateral or auxiliary) lobes. The back lobe of an antenna (180° to the main lobe) is related to the main lobe (in dB) and it is called the front/back ratio of the antenna [6, 7].

We can define the radiation diagram of an antenna if we take into account the electric component module  $E$  for the electromagnetic field radiated by the antenna. The other parameters and their definitions are kept. A decrease in 3 dB of the electric field module represents a decrease of its times ( $1/\sqrt{2} \approx 0.707$ ) [6, 7].

The maximum radiation intensity is given by:

$$P_{\Omega max} = \left| P_{\Omega} \left( \theta = \frac{\pi}{2} \right) \right| = \left| \frac{\eta_0 k_0^2}{32\pi^2} \left( \sin \frac{\pi}{2} \right)^2 \right| = \frac{\eta_0 k_0^2}{32\pi^2} \quad (1)$$

and the relative radiation intensity is given by:

$$P_{\Omega rel} = \frac{|P_{\Omega}|}{P_{\Omega max}} = \frac{\frac{\eta_0 k_0^2}{32\pi^2} (\sin \theta)^2}{\frac{\eta_0 k_0^2}{32\pi^2}} = (\sin \theta)^2 \quad (2)$$

where:  $P_{\Omega}$  represents the radiation intensity,

$\theta$  represents the angle under which the radiation intensity is determined,

$\eta_0$  represents the vacuum impedance,

$k_0$  represents the vacuum propagation constant.

From these equations, the radiation pattern of the antenna can be determined.

**Directivity** is the ratio of radiation intensity in a given direction to the average radiation intensity that is calculated for all directions in space. The average radiation intensity is calculated as the total radiated power divided by  $4\pi$ . The approximate formula for calculating directivity is as follows [6, 7]:

$$D(\theta, \phi) = 10 \log \left[ 4\pi \frac{P_{\Omega}(\theta, \phi)}{P_{rad}} \right] [dB] \quad (3)$$

**The absolute gain** of an antenna, for a given direction, represents the radiation intensity in that direction relative to the radiation intensity that could be obtained if

the antenna would radiate isotropically all input power. The radiation intensity, corresponding to the isotropically radiated power, is equal to the ratio of the input power to  $4\pi$ . For an approximate calculation, the formula [6, 7] can be used:

$$G_{max} \approx \frac{3 \cdot 10^5}{\theta_E \theta_H} \quad (4)$$

where:  $\theta_E$  and  $\theta_H$  represents the angular openings (in degrees) at 3 dB in the planes of vectors  $E$  and  $H$ .

**The polarization** of an antenna is determined by the polarization of the electromagnetic field radiated by it. The propagation of the electromagnetic field is given by a transverse plane wave (components  $E$  and  $H$  are perpendicular to each other and in turn are perpendicular to the propagation direction). The polarization of an electromagnetic field is determined by the curve of the vector  $E$  described in time at the observation point. This curve can be an ellipse (elliptic polarization), a circle (circular polarization) or a straight line (linear polarization). Apart from linear polarization, the other polarizations are characterized by the direction of travel of the curve (right or left) [6, 7].

**The input impedance** of an antenna is, in fact, the impedance presented at the antenna terminals. The impedance of the antenna is given by the ratio between the voltage and the current at the terminals or the ratio between the electrical and magnetic components determined at a conveniently chosen point. The formula for calculating the impedance of the dipole antenna of length  $l$  is much smaller than  $\lambda$  and traveled by a constant current  $I$  is as follows [6, 7]:

$$R_{rad} = P_{rad} / \left( \frac{1}{2} I^2 \right) = \frac{\eta_0 k_0^2 l^2}{6\pi} \quad (5)$$

The frequency band is defined as “the frequency range, in which the antenna performance associated with a predetermined parameter, is maintained in a specified range” [6, 7].

The actual surface area of an antenna, for a given direction, is represented by the ratio of the power available at the antenna terminals, being considered as the receiving antenna and the power density for the plane wave incident in that direction. The electromagnetic wave and the antenna are considered to be adapted from each other in terms of polarization. If no specific direction is indicated, then the maximum antenna radiation direction is taken by default [6, 7].

The effective height of an antenna, with a linear polarization and receiving a plane wave from a given direction, represents the ratio between the voltage determined with the open circuit at the antenna terminals and the intensity of the electric field determined by the antenna polarization direction.

An issue that interests us is the input resistance of the dipole antenna. This antenna will be calculated to work in a saline environment. In order to determine the parameters of the antenna in saline environment, we must know the input resistance of the dipole antenna in the free space. In order to determine the input resistance of the dipole antenna, we will start from the cylindrical dipole, which is a direct materialization of the concept of thin wire antenna. The parameters of the cylindrical dipole are slightly different from those provided by a theoretical analysis. This fact is given by the condition imposed on the length of the dipole, which must be much larger than the diameter. But this condition is not strictly fulfilled.

Considering that the dipole radiates in the free space, we will have approximate formulas for calculating the input resistance. If we make the notation  $G = n\pi$ , then [6, 7]:



$$R_{in} = \begin{cases} 20G^2 & 0 < n < 1/4 \\ 24.7G^{2,5} & 1/4 \leq n < 1/2 \\ 11.4G^{4,17} & 1/2 \leq n < 0.6366 \end{cases} \quad (6)$$

The behavior of the dipole antenna in dielectric mediums for propagating the electromagnetic waves is similar to the behavior in vacuum or air, except that the impedance and the calculation of the antenna arm lengths change according to the relative permittivity of the environment, in which the antenna is located. If a group of antennas is inserted into a salt block, then the input resistance and the length of the dipole antenna in  $\lambda/2$  will be changed with the real value of the permittivity of the salt ( $\epsilon_r = 5.981 + j0.0835$ ) and the penetration depth of the waves. Electromagnetic will depend on  $\tan\delta$ , which is precisely the ratio between the imaginary and the real part of the permittivity.

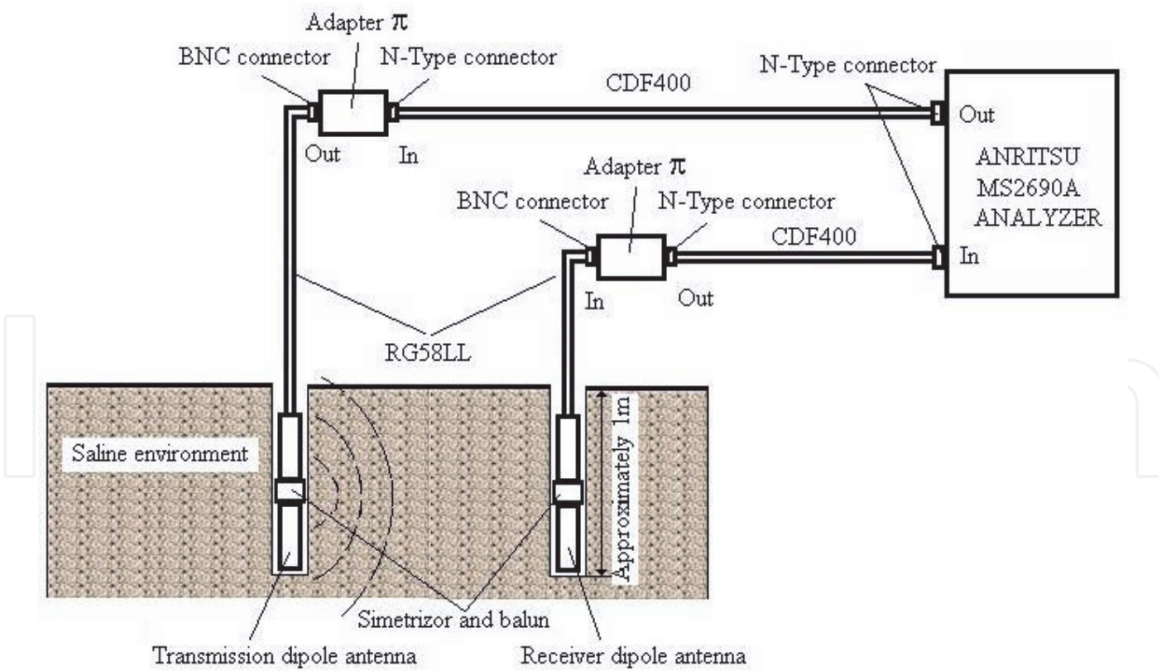
The antenna parameters are influenced when the antenna passes from work in vacuum or air to work in environment with different permittivity of vacuum. Therefore, in calculating the antennas working in environments with different permittivity than the vacuum (generally higher), the permissibility of the environment, in which the antenna works is taken into account. Averages such as salt constitute an unconventional environment for antennas and therefore the dielectric parameters of the salt, for a frequency range between 100 MHz and 5 GHz, must be known.

The direct method is performed by a system of generation and analysis of radio signals in saline environment and it is made from an emission antenna, a receiving antenna, and a signal analyzer. Two pairs of antennas are used for two working frequencies  $f_1$  and  $f_2$ , in order to determine the dielectric parameters of the salt, in order to determine the transfer of electromagnetic waves through the salt block, and in order to determine the electrical parameters of the radiofrequency antennas in saline environment.

The system is made of two identical antennas of the dipole type in  $\lambda/2$  for the wavelength corresponding to the frequency  $f_1 = 450$  MHz and  $f_2 = 750$  MHz, each provided with a symmetrical and an impedance adapter of a transformer type with transmission lines mounted in the immediate vicinity of antenna, coaxial cables with small losses of type RG58LL, an impedance adapter of type CD, connecting cables of type CDF400 with small losses between signal analyzer Anritsu MS2690A (generator part with emission antenna), two antennas (one for transmission and one for reception), and the signal analyzer Anritsu MS2690A (analyzer part with the receiving antenna). The schematic diagram of the system, for generating and analyzing radio signals in saline environment, is shown in **Figure 1** [8].

The indirect method involves the determination of the electrical parameters of the radio frequency antennas in saline environment, knowing the electrical parameters of these radio frequency antennas in air and measuring their parameters introduced in a saline environment when the dielectric parameters of the saline environment are known. This method involves performing a measurement installation of the electrical parameters of the radio frequency antennas in the air and repeating the measurements in a saline environment with the same installation. For this, dielectric parameters of the saline environment must be known.

Knowing the conclusions of the measurements in a saline environment, we can determine the electrical parameters of the radiofrequency antennas in such an environment. Numerous measurements have been made in massive salt blocks by RADAR penetration technology (GPR) [34]. From the conclusions of the measurements, we mention:



**Figure 1.**  
 The system of generation and analysis of radio signals in saline environment.

- the propagation of radio waves through a saline environment is not affected by scattering phenomena;
- no depolarization phenomena were observed;
- no significant dispersion phenomena were observed for the frequency range (0.1 ÷ 1) GHz.

Other empirical properties of salt blocks are [35]:

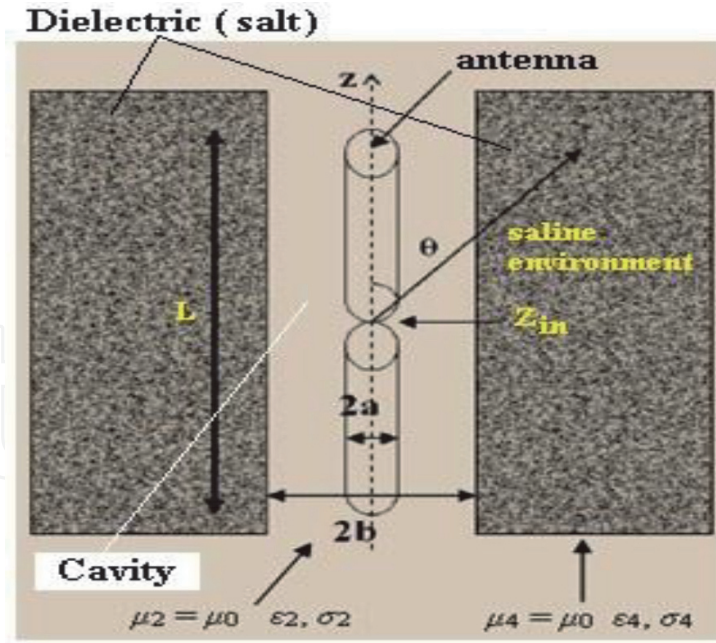
- a decrease in the tangent of the loss angle with frequency;
- the attenuation length is dependent on the percentage of impurities the salt block contains;
- no significant phenomena of double salt refraction were reported.

To perform the indirect method, the behavior of the antenna, introduced in a saline environment, will be analyzed when we have an interleaved element (air) between the antenna and the medium. By analyzing the following figure, we can determine the influence of the electrical parameters of the radio frequency antennas in saline environment when there is no perfect contact with this environment.

**Figure 2** shows a cavity in a dielectric medium (salt), in which an emission or reception antenna (dipole antenna in  $\lambda/2$ ) is introduced.

If we analyze the **Figure 1** where the cavity is cylindrical with the length  $L$  and the radius of the base of  $r = b$  and considering the continuity of the tangential component of the electric field ( $E_0 = E_1$ ), we will find the equation below:

$$\frac{\Delta\omega}{\omega_0} = \frac{(\epsilon_0(\epsilon_r - 1))|E_{00}|^2\pi b^2L}{4W_0} \quad (7)$$



**Figure 2.**  
Cavity in a dielectric medium (saline medium), in which a dipole antenna is inserted in  $\lambda/2$ .

where:  $E_{00} = 1$  and  $W_0 = \pi \epsilon_0 L \int_a^b J_0(k_0 r)^2 r dr$  represents the energy found in the cavity. The resonant frequency of the empty cavity is:

$$\omega_0 = k_0 c = 2.405 \left( \frac{c}{a} \right) \quad (8)$$

and  $E_0 = J_0(k_0 r)$  is the energy in the empty cavity and  $J_0$  represents the Bessel function of the first order for which  $r = a$ . Then, we will obtain:

$$\frac{\Delta \omega}{\omega_0} = 1.856(1 - \epsilon_r) \left( \frac{b}{a} \right)^2 \quad (9)$$

If we use the last two formulas, then we can deduce the relative dielectric permittivity for the salt measurements:

$$\epsilon_r = 5.981 + j0.0835 \quad (10)$$

The loss angle tangent is related to the attenuation coefficient of the field ( $\alpha$ ) and it represents the distance at which the electromagnetic field module decreases to  $(1/e)$ . The formula, associated with the loss angle tangent, is [36]:

$$\tan \delta = \sqrt{\left[ \frac{2}{\epsilon'} \left( \frac{ac}{2\pi f} \right)^2 + 1 \right]^2 - 1} \quad (11)$$

where:  $f$  represents the frequency and  $c$  is the speed of light in a vacuum. Then the attenuation length becomes:

$$L = \frac{1}{\alpha} = \frac{\lambda_0}{2\pi} \sqrt{\frac{2}{\epsilon'(\sqrt{1 + \tan^2 \delta} - 1)}} \quad (12)$$

or an approximate value:

$$L \cong \frac{\lambda_0}{2\pi(\epsilon)^{\frac{1}{2}} \tan \delta} \quad (13)$$

where:  $\lambda_0$  is the wavelength in vacuum.

For the study of the propagation of electromagnetic waves through saline environment it is necessary to know the dielectric parameters of the medium, through which they propagate (of the saline environment).

For this we will consider the propagation equation in linear, homogeneous, and isotropic environments for the electromagnetic waves [37–39]:

$$\nabla \cdot \bar{E} - \mu\sigma \frac{\partial \bar{E}}{\partial t} - \mu\epsilon \frac{\partial^2 \bar{E}}{\partial t^2} = \nabla \left( \frac{\rho}{\epsilon} \right) \quad (14)$$

and we consider the dissipative (absorbing) environment in which  $\sigma \neq 0$ .

We can assume that, if the environment contains free electric charge ( $\rho \neq 0$ ), then it will exponentially decrease in time to zero.

We can determine the intensity of the wave at a certain depth  $z$ , which will be [37, 38]:

$$I(z) = \frac{1}{2} \sqrt{\frac{\epsilon}{\mu}} (\bar{E}_0(z))^2 = \frac{1}{2} \sqrt{\frac{\epsilon}{\mu}} (\bar{E}_0(0))^2 e^{-\beta z} \quad (15)$$

or otherwise:

$$I(z) = I_0 e^{-\beta z} \quad (16)$$

where:  $I_0$  represents the intensity of the wave upon entering the environment ( $z = 0$ ),  $\beta$  represents the absorption coefficient.

The salt from the mines of North America showed dielectric constants in the 5–7 range and the loss angle tangent between 0.015 and 0.030 at 300 MHz [40].

An important problem is to determine the penetration length of electromagnetic waves in saline environment (attenuation length.) Thus we will define the depth of penetration of the wave into the environment. We will note the distance  $d$  as representing this depth. This depth is the decrease of the intensity of the field  $e$  times from the initial one. Then the intensity of the wave at depth  $d$  becomes:

$$I(d) = I_0 e^{-\beta d} \quad (17)$$

where:

$$d = \frac{1}{\beta} \quad (18)$$

We will consider the case of an almost dielectric environment ( $\sigma$  – small,  $\epsilon$  – big). In this case the ratio ( $\sigma/\epsilon$ ) will be much smaller than the unit [37, 38]:

$$\frac{\sigma}{\epsilon\omega} \ll 1, \frac{\omega_c}{\omega} \ll 1 \text{ and } v \cong \frac{1}{\sqrt{\epsilon\mu}} \quad (19)$$

which means that the electromagnetic wave has the same propagation speed for whatever its frequency is. This means that there is no dispersion (this is the case for salt).



Then the depth of penetration will be given by the relation:

$$d \cong \frac{1}{\sigma} \sqrt{\frac{\varepsilon}{\mu}} = \frac{1}{\sigma Z} \quad (20)$$

where:  $Z$  is the impedance for the pulse of the wave.

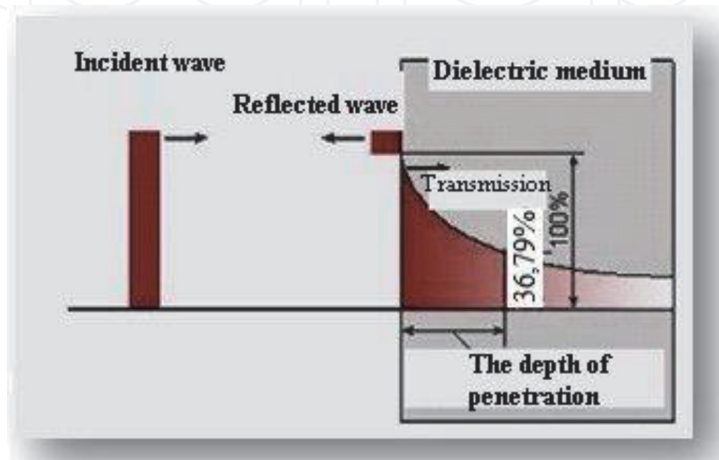
In most practical cases  $\tan \delta \ll 1$ , so for the calculation of the penetration depth the formula is used (**Figure 3**):

$$d = \frac{3 \cdot 10^8}{2\pi f (\varepsilon_r)^{\frac{1}{2}} \tan \delta} \quad (21)$$

The 36.79% percentage represents a  $1/e$  decrease of the electromagnetic field in the dielectric environment (the incident field from which the reflected field is subtracted is taken into account).

The two methods do not differ much from each other. The difference is that, in the indirect method, there will be two packages of measurements. Starting from the package of measurements in air, continuing with the measurements in saline environment and knowing the dielectric and attenuation parameters of the electromagnetic waves of the saline environment, the electrical parameters of the radiofrequency antennas in saline environment can be determined by calculations. Taking into account these considerations, the indirect method can generate errors, because the determination of the electrical parameters of the radio frequency antennas in saline environment is based on the measurements of these parameters in the air (where small errors can occur), then measurements of these parameters are made in saline environment (where there also can occur small errors) and following the calculations, the errors can be added, which means a greater error. Thus, the indirect method involves high degree errors in determining the electrical parameters of radio frequency antennas in saline environment.

For the direct method, a system for measuring the electrical parameters of radio frequency antennas in saline environment will be used. The measurements being direct, we deduce that the errors are given only by these measurements (by the measurement system, analyzer – the generator part and the analyzer part). No additional calculations are required. So, the direct method is a method with smaller errors, although a measurement system, adapted to the saline environment is needed, compared to the indirect method that uses the same system of measurement in the air and in the saline environment.



**Figure 3.**  
Illustration of the penetration of electromagnetic waves in a dielectric environment [41].

3. Data collection in saline environment

In order to be able to collect the data from the saline environment, we will use the system presented in **Figure 1**. An important problem is the design of the antennas to work in the saline environment. The first problem, that arises, is the determination of the antenna length for working in saline environment.

Calculation of antennas [8]:

$$L_{a[\lambda/2]} = \frac{c}{2f\sqrt{\epsilon_r}} \tag{22}$$

And it represents the antenna length in  $\lambda/2$  [m] and  $c = 3 \cdot 10^8$  m/s and  $f$  = the resonance frequency of the antenna [Hz],  $\epsilon_r = 5.981 + j0.0835$ , taking into account the real part  $\Re(\epsilon_r) \cong 6$ . **Figure 4** shows the shape and dimensions of the antenna determined by the above formula.

The antennas are made of Copper pipe with  $\Phi = 6$  mm and have the following dimensions (**Table 1.**) for salt work.

A second problem that arises is the determination of the radiation resistance of the antennas in saline environment. As shown in **Figure 4**, the antenna is a dipole antenna in  $\lambda/2$  and then the formula for calculating the radiation resistance is:

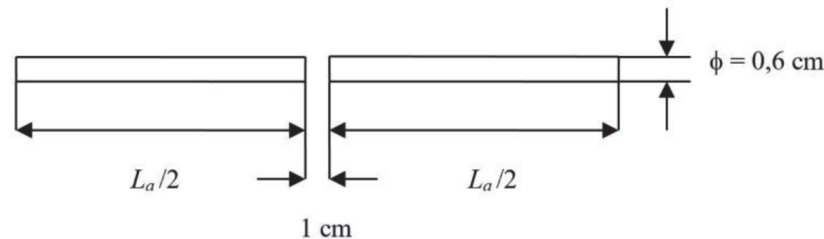
$$R_{rad} = 0.19397\sqrt{\frac{\mu_0}{\epsilon_0 \times \epsilon_r}} \tag{23}$$

where:  $\mu_0 = 4\pi 10^{-7}$  [N/m<sup>2</sup>] and  $\epsilon_0 = 8.859 \times 10^{-12}$  [F/m].

Then the radiation resistance is about 29.853  $\Omega$ . Following the analysis of **Table 1**, it is found that the antenna length is much smaller than  $\lambda$  and then we can say that the antennas are of Hertzian type and the radiation resistance of the antennas will be calculated with the formula:

$$R_{a\,sare} = \frac{2\pi}{3\sqrt{\epsilon_{r\,sare}}}Z_0\left(\frac{L_a}{\lambda}\right)^2 \tag{24}$$

Then, for salt work, a radiation resistance of about 13.5  $\Omega$  will be obtained. In these conditions, it is necessary to adapt the radiation resistance of the antennas to the characteristic impedance of the Anritsu MS2690A 50  $\Omega$  analyzer. For the



**Figure 4.**  
Antenna dimensions.

$f$ [MHz]	300	400	500	600	700	800	900	1000
$L_a$ [m]	0.204	0.153	0.122	0.102	0.087	0.077	0.068	0.061

**Table 1.**  
The dimensions of the transmitting and receiving antennas at different frequencies for working in saline environment.

frequencies  $f_1 = 450 \text{ MHz}$  and  $f_2 = 750 \text{ MHz}$ ,  $L_{a450\text{MHz}} = 0.136 \text{ m}$  and  $L_{a750\text{MHz}} = 0.082 \text{ m}$  were obtained and for the radiation resistance the following values were obtained:

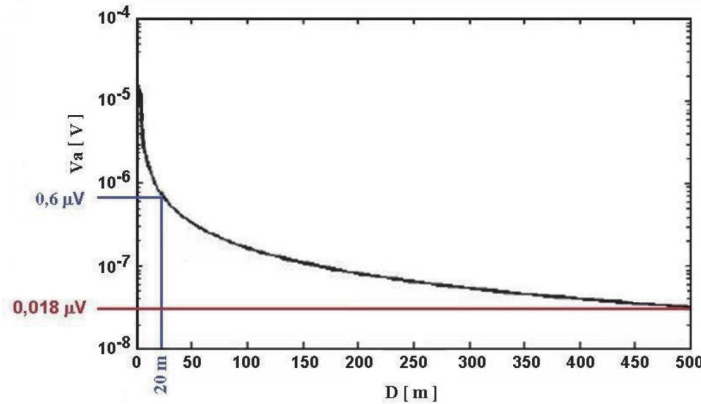
$$f_1 = 450\text{MHz} \Rightarrow R_{a \text{ save } 450\text{MHz}} = \frac{1}{\sqrt{6}} \cdot 789.586 \cdot \left( \frac{0,136}{0,667} \right)^2 = 13.401\Omega \quad (25)$$

$$f_2 = 750\text{MHz} \Rightarrow R_{a \text{ save } 750\text{MHz}} = \frac{1}{\sqrt{6}} \cdot 789.586 \cdot \left( \frac{0,082}{0,400} \right)^2 = 13.546\Omega \quad (26)$$

The frequency, at which the best propagation of electromagnetic waves, was determined in saline environment (Cantacuzino Mine from Slănic Prahova), is 187.5 MHz. The noise level in saline environment (Mina Cantacuzino from Slănic Prahova) is  $-115 \text{ dBm}$  and at an impedance of  $13.5 \Omega$ , a noise level of  $0.20662 \mu\text{V}$  is obtained. **Figure 5** shows the graph determined theoretically according to the distance of the variation of the radio frequency voltage level at the receiving antenna level. An electromagnetic emission event of a neutrino with the energy of  $10^{18} \text{ eV}$  that generated a Cherenkov cone in saline environment was taken into account in this graph.

Analyzing the graph in **Figure 5**, we determine that for a neutrino with the energy of  $10^{18} \text{ eV}$  that generated a Cherenkov cone in saline environment, a radio frequency signal at the terminals of a receiving antenna comparable to the noise level measured in saline environment will be produced as an effect at a distance of 50 m. So, for longer distances it is necessary that the energy of the neutrino be greater than  $10^{18} \text{ eV}$  ( $10^{23} \text{ eV}$ ).

Thus, a “Hardware system for detecting cosmic radiation of electron neutron type in salt” was designed [9]. This system is used to measure the level of attenuation of the electromagnetic waves introduced by the saline environment. Also with this system, the dielectric parameters of the saline environment can be determined in order to create a map with the distribution of the attenuations introduced by the saline environment. This system is, in fact, a radio detection station [5],  $SR_{mk}$  where m is equivalent to the Cartesian x coordinate, k is equivalent to the Cartesian y coordinate, and n is equivalent to the Cartesian z coordinate. Each radio station will include two antennas for horizontal polarization and two for vertical polarization, one impedance adjustment circuit for each antenna, one adder for each polarization, one band pass filter to select the desired spectral components, five amplifiers followed by one band pass filter (minus the last amplifier) with full chain amplification from the first band pass filter to the 120 dB anti-alloy filter, an anti-alloy filter, an analog-to-digital converter, a FIFO memory (first input – first output).

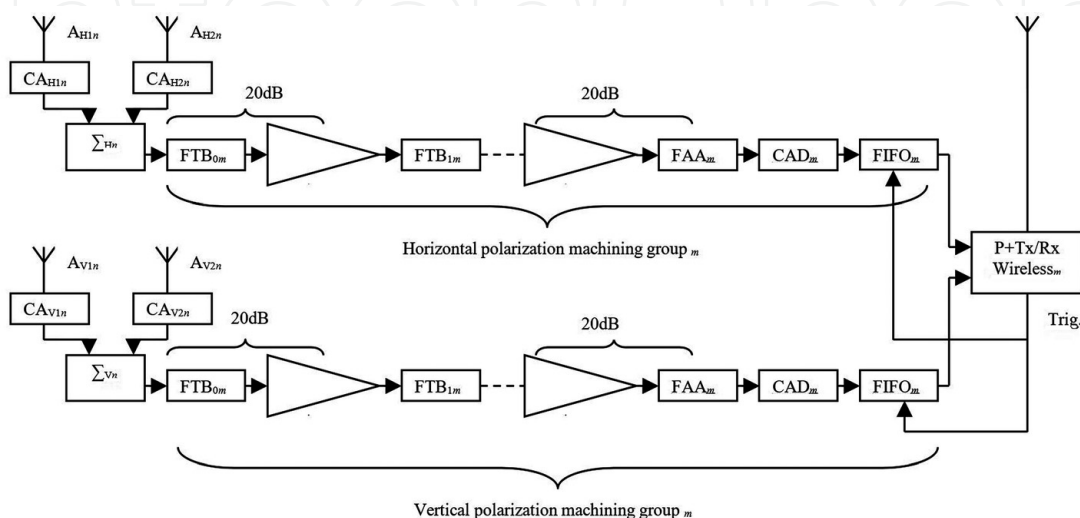


**Figure 5.**

The graph of the variation of the radio frequency voltage level at the receiving antenna level.

There follows a local processing station  $SR$  with a Wireless transceiver and, at the other end, another transceiver with a processing system to connect with the computer system. The total amplification of 120 dB is required to bring a signal of  $0.6 \mu\text{V}$  (20 m) at the level of 0.6 V that can be processed by  $CAD_m$  (analog-to digital converter). It consists of the following blocks (**Figure 6**):

- $A_{H1n}$  and  $A_{H2n}$  is the pair of antennas for horizontal polarization in the vertical group  $n$ ;
- $A_{V1n}$  and  $A_{V2n}$  is the pair of antennas for vertical polarization in group  $n$  on the vertical;
- $CA_{H1n}$  and  $CA_{H2n}$  are the circuits for adapting the impedance of the antennas with the horizontal polarization to the impedance of the  $50 \Omega$  cable;
- $CA_{V1n}$  and  $CA_{V2n}$  are the circuits for adapting the impedance of the antennas with the vertical polarization to the impedance of the  $50 \Omega$  cable;
- $\sum_{Hn}$  and  $\sum_{Vn}$  are the sums of the signals coming from the antennas  $A_{H1n}$ ,  $A_{H2n}$  respectively  $A_{V1n}$ ,  $A_{V2n}$ ;
- $FTB_{0m}$  is the first band pass filter to select the desired spectral components;
- $A_{1m}$ ,  $FTB_{1m} - FTB_{4m}$ ,  $A_{5m}$  represents the 100 dB amplification chain together with  $FTB_{0m}$  and  $FAA_m$ ;
- $CAD_m$  is the converter from analog signal after amplification, to digital signal;
- $FIFO_m$  is the memory of the digital signal maintained as a buffer until the arrival of the trigger signal from the  $P + Tx/Rx$  Wireless (transceiver) system;
- $P + Tx/Rx$  Wireless is the local information processing system that includes the hard and soft trigger circuit, the  $Tx/Rx$  Wireless transceiver and the receiving broadcast antenna, which is used to improve the noise signal ratio and to calibrate the system processing from  $PC$  computer.



**Figure 6.**  
 Block diagram of the system for receiving, local processing and wireless transmission of the measured data to the computing system.



For the correct analysis of the data it is necessary that the temporal relation and the absolute value of the electric field be known, that is to say, all the instrumental errors must be corrected before working with the involved physical quantities. This implies a correction of the delays, which occur in the system, and a calibration of the amplitude.

For the correction of these events it is necessary that a well-known signal be present in all data and that it will provide us the necessary temporal information. There is no need for an absolute time scale, as the measurements are not compared to external events. For this reason, only the relative temporal delays between the antennas should be known.

It is necessary to determine the attenuations introduced by the connection cables.

We used two types of cables:

- type CFD400-E (blue) with a length of 5 m.
- type R-6763, O400 (black) with a length of 21 m.

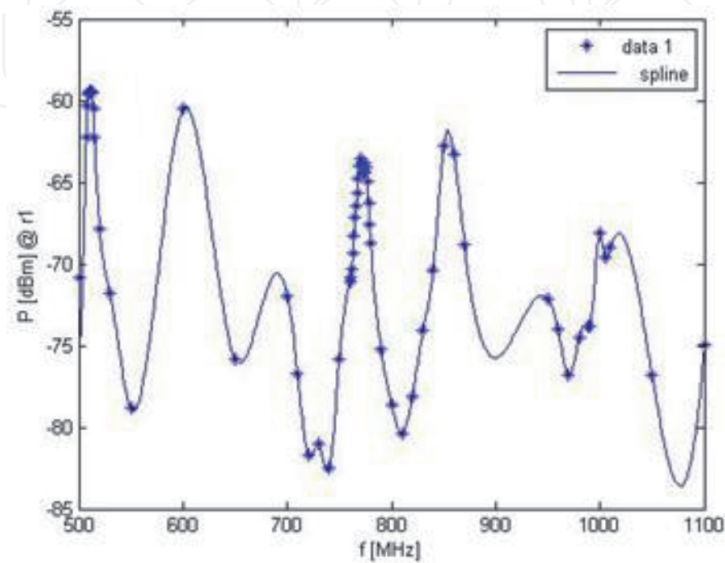
The measured attenuations are presented in **Table 2**.

Following the measurements, the graph of variation of the power of a signal with a constant level measured at a fixed point at a distance of 20 m from the emission antenna was determined (**Figure 7**). The transmitting and receiving antennas were introduced in saline at a depth of 1 m from level 0.

Following the analysis of this graph, it is deduced that the attenuation of the electromagnetic waves is great for frequencies greater than 500 MHz, but it has a variation of about 20 dBm for a spectrum of 600 MHz. These attenuations fall for lengths of approximately 20 m. For the same signal levels introduced in the

$f$	Cable CFD400-E	Cable R-6763, O400
450 MHz	−0.31 dBm	−3.05 dBm
750 MHz	−0.6 dBm	−4.22 dBm

**Table 2.**  
*The attenuations measured on the connection cables used in the measurements in saline environment.*



**Figure 7.**  
*The power received at a fixed point 20 m from the transmitting antenna for various frequencies emitted.*

broadcast antenna placed at a depth of 1 m from level 0 and received with an identical antenna placed at the same depth, attenuations of about 50 m are obtained for the frequency of 187.5 MHz.

At the output of the system, the signal is processed by  $CAD_m$ , which is made with the RD-143 development board. It consists of an ADC083000 analog-to-digital converter (CAN), an amplifier for improving the signal/noise ratio achieved with the LMH6555 low-distortion differential amplifier, a tact signal generator, a Field Programmable Gate Array (FPGA) block, a local processor, a PLL loop frequency synthesizer, VCO oscillator made with LMX2531 LQ1500E, and a USB interface for direct communication with the PC made with CY7C6801BA.

The analog-numeric converter ADC083000 produced by National Semiconductor is an 8-bit converter that has a working power consumption of 1.9 W at a supply voltage of  $V_{cc} = 2.2$  V, the maximum input signal on the Wine + and Wine- inputs is 2.5 V and the maximum conversion rate is 3GSPS (3 gigabytes per second). The resolution of the analog-numerical circuit, in this case, is:

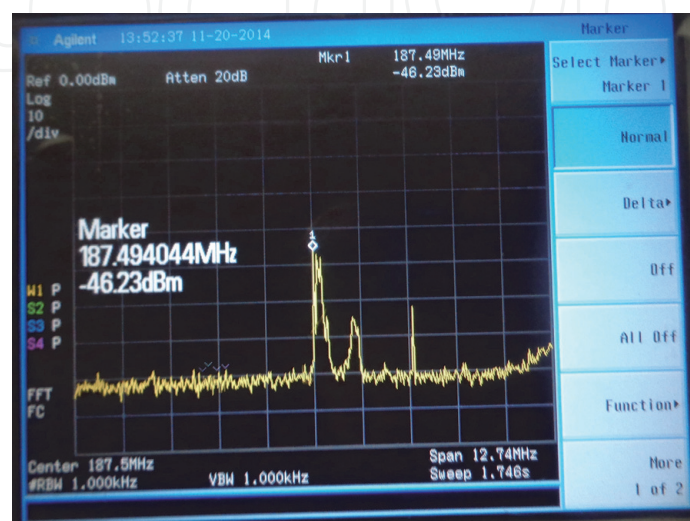
$$Rez = 1LSB = \frac{V_{max}}{2^n} = \frac{2.5}{2^8} = 9.8mV \quad (27)$$

It also offers a bit error rate of the order of  $10^{-18}$ .

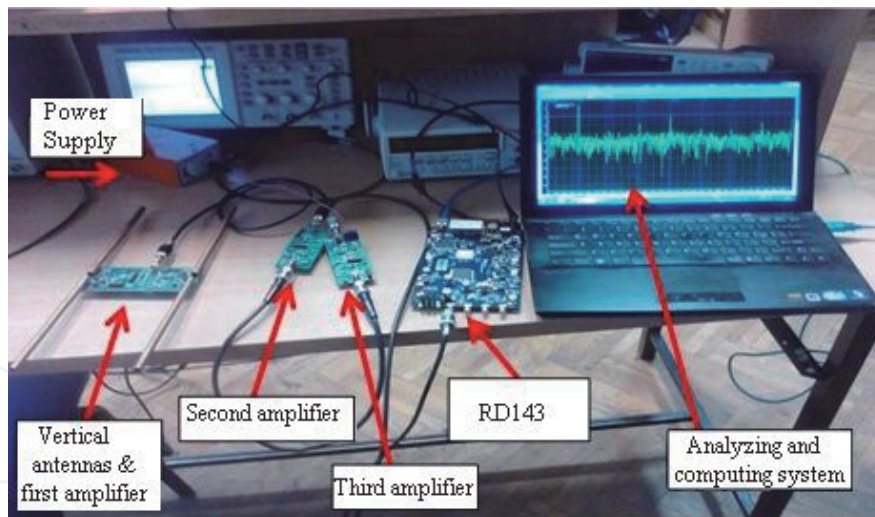
Following the laboratory tests, it was found that the actual number of bits used by RD143 for quantization, around 187.5 MHz (the signal value from the CAN input – analog-to-digital converter) is 7.3 bits, which means that the noise introduced by the CAN is very small. In fact, this noise increases as the frequency of the signal processed by CAN increases.

Another important feature, determined by laboratory measurements, of this CAN is the low power consumption, reaching a consumption of 1.9 W at the maximum sampling frequency (3 GHz). Moreover, a linear characteristic of the power consumption, characteristic between 1.4 and 1.9 W. is observed. The signal processed by RD143 is on a frequency of 187.5 MHz.

The dipole antenna of the system was found to pick up the radio signal generated by the USRP (Universal Software Radio Peripheral). The signal reached in the signal processing unit (e.g. laptop) is a distorted sinusoidal signal with the fundamental on 187.49 MHz and the amplitude 66.23db (the input signal was -50 dB), which means an amplification of 116.23 dB (a close amplification of the theoretical one) (**Figure 8**).



**Figure 8.**  
 The signal at the input of the RD143 digital processing system.



**Figure 9.**

The system shown in **Figure 6** at the laboratory level.

Distortions due to the existence of 3rd and 4th harmonics offer a distortion factor of 10%. The receiver design was performed for saline environment, medium with relative permeability different from that of the air. This could be one of the causes of a fairly large distortion factor. **Figure 9** shows the spectrum of the radio signal generated by the USRP and processed with the proposed experimental model.

#### 4. Methods for determination and detection of Cherenkov cone in saline environment

Following the studies and articles published so far, it can be deduced that in order to make a Cherenkov detector in saline environment, many detecting elements and correspondingly many holes in saline environment, many chains of amplifiers (to bring the level detected by the workable TTL level detection (transistor-transistor logic), to compensate for losses on connection cables, etc.), many radio stations ( $SR_{mk}$ ) etc. Under these conditions, an optimization of the number of detection elements of a Cherenkov detector in saline environment and implicitly of all corresponding component elements is required.

To optimize a Cherenkov detector, it is necessary to carry out a study in order to achieve the objective. Following the study it was concluded that the optimization of a Cherenkov detector in saline environment is necessary in order to determine the optimal positions by placing the detection elements for to obtain the maximum information. Thus, it is necessary to know the attenuation of electromagnetic waves in saline environment. This aspect involves a large number of measurements in the volume of the entire salt block in which the future Cherenkov detector will be placed. Because of the attenuation of the electromagnetic waves (the product of the interaction of a neutron with sufficiently high energy with a saline environment that generates the Cherenkov cone) is given by the dielectric permittivity of the saline environment, it is necessary to create a map with the distribution of the dielectric parameters of the saline environment. Knowing this map will determine the optimal positions of the detection elements and their number as well.

In these conditions, two patents have been proposed, which deal with the methods of determining the Cherenkov detector inside and outside the volume of the Cherenkov detector [10, 11].



4.1 Inside the volume of the Cherenkov detector

Determination of the Cherenkov cone inside the volume of the Cherenkov detector involves the design of a method to optimize the Cherenkov detector of electromagnetic radiation in the saline environment by determining the optimal points of placement of the detection elements and the Cherenkov detector in the saline environment, in order to minimize the number of measurement points and number of electromagnetic radiation sensing elements generated to reduce costs and simplify the measurement chain.

The first problem that occurs is the creation of a map with the distribution of the dielectric parameters of the saline environment. For this, a sufficiently large number of measurements of the dielectric parameters of the saline environment will be executed in order to interpolate and extrapolate the measurement results.

The problem solved by the optimization method of the Cherenkov detector of electromagnetic radiation in the saline environment removes the disadvantages of the Cherenkov detectors in the saline environment that have been proposed so far.

Thus the method minimizes the number of detection elements and implicitly of the measurement chain, being also an economical and much faster method, characterized in the fact that it determines the optimal points of placement of the detection elements for the determined volume of the Cherenkov detector in saline environment through iterations.

An iteration formula is used to obtain the optimal volume of the future Cherenkov detector placed in saline environment:

$$Lc_i^3 = p[i + \alpha(i - 1)] \tag{28}$$

where  $\alpha, i \in N$ ,  $p \in R$  and  $p, \alpha, i > 0$ ;  $Lc_i^3$  represents the length of the side of the cube with iteration  $i$ ;  $i$  represents the number of the iteration;  $\alpha$  represents a coefficient that is dependent on the attenuation length of the electromagnetic waves through saline environment and adjusts to whole values;  $p$  represents the iteration step and it is between 20 m ÷ 500 m.

This results in a Cherenkov detector consisting of at least two or more cube-shaped detectors in the cube and it also determines the optimal position of the future Cherenkov electromagnetic radiation detector in saline environment (**Figure 10**).

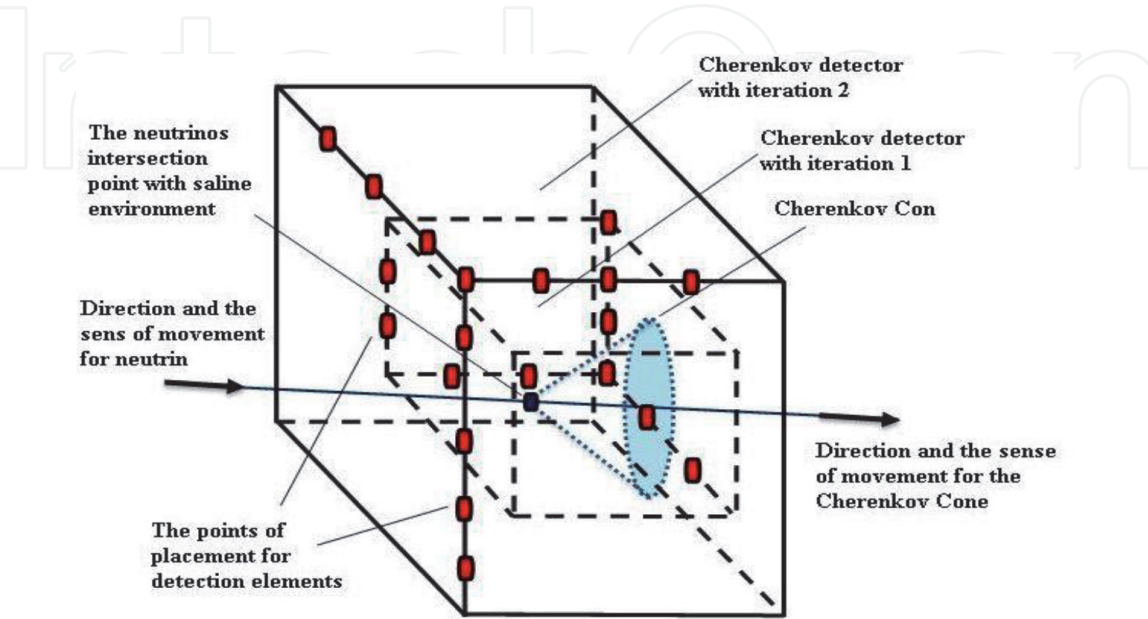


Figure 10.  
An example of optimal placement of the detection elements of a Cherenkov detector for two iterations.



The method of optimization of the Cherenkov detector of electromagnetic radiation in the saline environment has, as first stage, the determination of the imprint of the saline environment, in which the future Cherenkov detector is placed, which is realized by measurements in order to determine the dielectric parameters of the environment and its attenuation length at the frequency of work set (187.5 MHz). In order to reach the first stage, measurements will be made to determine the propagation of the electromagnetic waves at different points of the volume of the environment in a vertical and horizontal plane [8, 31] and function of the measurement results, the measurements can be resumed or multiplied for to determine entirely the real distribution of the environmental attenuation for the propagation of the electromagnetic waves. These measurements will be performed using antennas whose electrical parameters (directivity characteristic, radiation resistance, loss resistance, antenna efficiency, front-to-rear ratio) are very well known to work in saline environment. These measurements will be performed horizontally and vertically, storing the data in a database, which from their processing they will lead to drawing a map with the distribution of the attenuation lengths of the electromagnetic waves. The second step consists in configuring the electrical parameters of the detection elements at this frequency (187.5 MHz), by determining the directivity characteristics, radiation resistance, loss resistance, efficiency and front-to-back ratio, for the horizontal and vertical plane. This data will be stored in another database, which represents the information regarding the detection elements of the Cherenkov detector. The determination of the electrical parameters of the detection elements of the Cherenkov detector will be carried out by resuming or multiplying the measurements so that the actual values of the electrical parameters for the detection elements can be determined as accurately as possible. The two databases (the environmental footprint and the electrical parameters of the detection elements) and the use of a dedicated software will determine the optimal placement points of the detection elements for the volume determined by each iteration. Thus, the minimum number of iterations can be determined to optimize the Cherenkov detector.

This method has the following advantages:

- Determination of the optimal positioning of the Cherenkov detector in the total volume of the saline environment;
- Determination of the optimal placement points of the detection elements for the volume determined by each iteration;
- Minimization of the number of detection elements and the measuring chain, which implies very low labor and material prices compared to the known methods and minimization of the number of wells necessary for the detector;
- Software processing time is short compared to other methods;
- Determination of Cherenkov Cone under real conditions.

This method determines the positions of the optimum measurement points, which lead to the minimization of the number of measurements, the number of electromagnetic radiation detection elements and implicitly of the measurement chain and it also determines the optimal position of the future Cherenkov detector in the total volume of the saline environment. All these aspects lead to cost reduction. In order to determine the Cherenkov cone in saline environment, the method requires the use of a dedicated software that uses a database containing the footprint of the saline environment for which a cosmic radiation detector is desired.

4.2 Outside the volume of the Cherenkov detector

The determination of the Cherenkov cone of electromagnetic radiation in the saline environment outside the volume of the Cherenkov detector is determined by placing at optimum points some detection elements outside its volume in all the x, y, z and positive and negative directions knowing the attenuation fingerprint in the electromagnetic wave field of the saline environment in order to determine the possible Cherenkov Cones that could form outside the detector volume depending on the energy determined by the detection elements in the vicinity of the detector.

So far, no method for the determination of a Cherenkov Cone outside the detector volume is known, even though some of the energy emitted by the cone reaches the detector elements of the detector.

This method determines the Cherenkov cone regardless of the position in which it is generated outside the detector volume, being an economical and predictable method, because outside the detector there are a minimum number of detection elements placed in optimal positions determined by their placement surfaces (planes) and obtained by using the formula:

$$Lc_{exi}^3 = p[1 + i(\alpha + 1)] \tag{29}$$

where:  $\alpha, i \in N^*, p \in R$   $\forall i, p, \alpha, i > 0$ ;  $Lc_{exi}^3$  represents the length of the side of the cube delimited by the planes outside the volume of the Cherenkov detector;  $i$  represents the number of the iteration;  $\alpha$  represents a coefficient that is dependent on the attenuation length of the electromagnetic waves through saline environment and it adjusts to whole values;  $p$  represents the iteration step and it is between  $20 \div 500$  m and it is chosen larger than the iteration step of the Cherenkov cone determination resulted inside the Cherenkov detector volume (Figure 11).

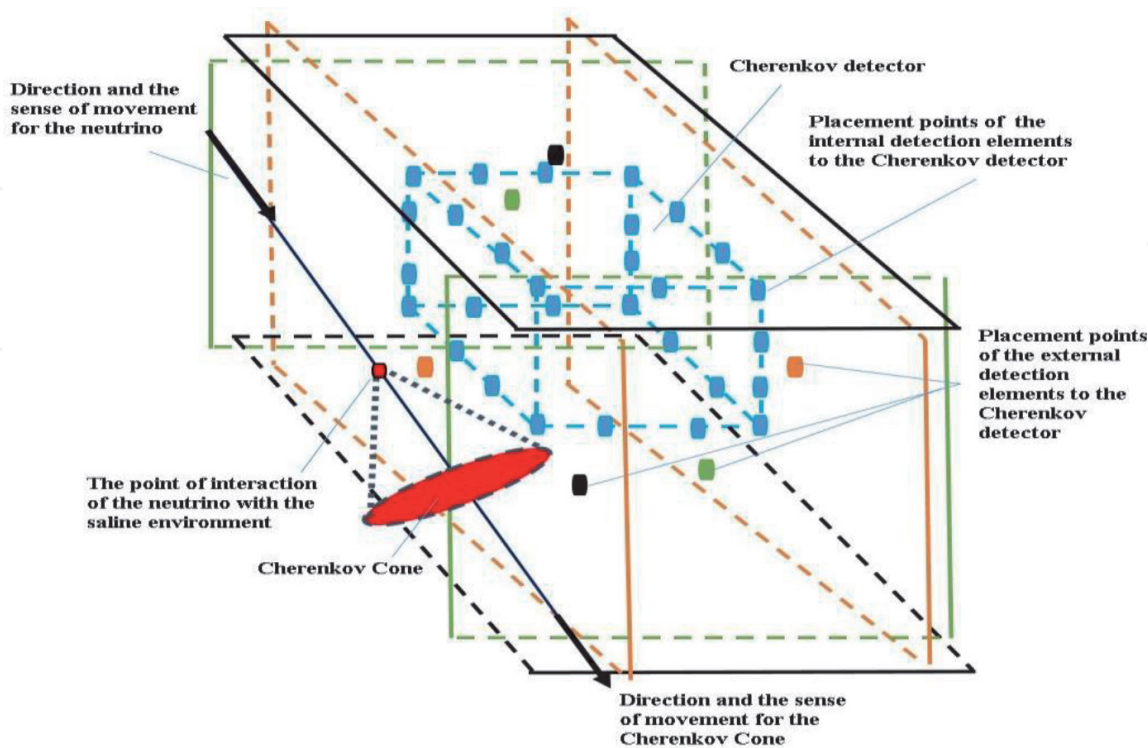


Figure 11.  
An example of determination of the spatial positions of the placement plans of the detection elements external to the volume of the Cherenkov detector for a higher iteration of the determination of the volume of the Cherenkov detector in saline environment.

The method is based on the determination of the attenuation fingerprint of the saline environment (the map of the spatial distribution of the electromagnetic waves attenuation in the saline environment) in the field of the electromagnetic waves and it leads to the increased probability to determine the generation of the Cherenkov Cone from outside the detector volume by determining the energy levels measured by the external detection elements providing that they are higher than the energy levels measured by the detection elements inside the Cherenkov detector.

The determination of the Cherenkov cone in saline environment outside the volume of the Cherenkov detector consists in determining the optimal position of placement of the external detection elements, using a dedicated software.

For this, a minimum number of detection elements are placed outside the detector volume, which have very well established positions on the external surfaces of the detector, calculated by a higher iteration ratio than the detector volume calculation in all positive, negative  $x$ ,  $y$ ,  $z$  directions (Eq. (29)).

Then the attenuation of the saline environment (the map/fingerprint of the attenuation of the electromagnetic waves in the saline environment) will be calculated in the field of the electromagnetic waves [5, 8, 10, 31] as a result of measurements made outside the Cherenkov detector volume. In order to determine the Cherenkov cone outside the Cherenkov detector volume, the energy levels given by the sensing elements located outside the detector volume will be measured and if the energy measured by the external sensing elements is greater than the energy measured by the internal elements of the Cherenkov detector, then it is decided that a real Cherenkov cone outside the volume of the Cherenkov detector was generated. Thus we obtain the position in space of the Cherenkov Cone generated outside the detector in real situations using the dedicated software.

The method has the following advantages:

- determination of the Cherenkov cone generated outside the Cherenkov detector volume;
- determination of the optimal positioning of the detection elements outside the volume of the Cherenkov detector in the saline environment by using a dedicated software;
- it establishes the plans (surfaces) for placing the detection elements outside the Cherenkov detector volume obtained by an iteration higher than the detector volume determination;
- it minimizes the number of external detection elements and it optimizes the measurement chain, which implies very low labour and material prices and it minimizes the number of wells required outside the detector;
- it minimizes the data processing time with the help of the dedicated software;
- it determines the Cherenkov cone generated outside the detector under real conditions;
- this method can be used for any type of environment as long as the environmental mitigation footprint in the field in which the Cherenkov detector works in the respective environment does not change during the determination period.

The application of the method for the determination of the Cherenkov cone in saline environment outside the volume of the Cherenkov detector requires three steps prior to the method.

The first step consists in determining the dielectric parameters of the saline environment in which the detection elements from outside the volume of the Cherenkov detector are to be located and it represents precisely the footprint of the respective saline environment.

In the second stage, for the working frequency of the detection elements in the saline environment (187.5 MHz), the directivity characteristics, the radiation resistance, the loss resistance, the efficiency, and the front-to-back ratio are determined.

The third stage consists in processing the real data obtained when a Cherenkov cone is generated as a result of an interaction of cosmic radiation of the neutron nature with the saline environment in which the whole system (the Cherenkov detector and its external sensing elements) is located together with the two databases from the previous stages and depending on the energy levels measured by the external and internal elements the spatial position, in which the Cherenkov Cone was generated, is deduced. If the energy measured by the external sensing elements is greater than the energy measured by the internal elements then the Cherenkov Cone was generated outside the detector volume.

## 5. Conclusions

The information, “decoded” from the analysis of the electromagnetic energy generated by the Cherenkov cone (which is in a directly determined relation by the energy of the neutrino, which produced the Cherenkov phenomenon), are transmitted by the nuclear phenomena (fusion, fission, nuclear diffusion), which took place in the Universe at astronomic distanced (much larger than the detection possibilities known so far). This information brings an important contribution to the knowledge of the Universe.

The determination of the Cherenkov cone in salt spray (in salt spray the neutrinos with energies of the order  $10^{12} \div 10^{23}$  eV are determined, which represent phenomena in the Universe that are generated by solar, galaxies, quasars, pulsars etc. systems), implies the implementation of a system, which measures the distribution of the density of the environment dielectric permittivity, which occurs in order to reduce the electromagnetic waves generated following the interaction between the environment with a neutrino. Thus a map, of the distribution of the “attenuation lengths” of the electromagnetic waves in the environment in which the measurement were done, is carried out.

The maximum distance between the detection elements placed in salt spray at Slănic Prahova is given by the noise level, which was measured here (−115 dBm) and it is of 50 m (0.2  $\mu$ V, the graph from **Figure 5**). The detection of this level requires amplifications of about 129.5 dB on the frequency 187.5 Mhz (120 dB + 9.5 dB or an amplification of  $3 \times 10^6$ ) in order to bring the signal at digital processing level with a DAC system (digital-analog converter). Thus we deduce that the attenuation length of the saline spray determines the placement points of the detection elements of a Cherenkov detector.

In order to minimize the costs of implementation of a Cherenkov detector for the determination and detection of the Cherenkov cone in saline spray (and in other environments where a map of the distribution of the spatial density of the dielectric permittivity in the volume of the entire environment, can be carried out), we need two stages: - the implementation of the map of the spatial density distribution of the dielectric permittivity in the volume of the entire salt spray and the determination of the optimum number of detection elements of the future Cherenkov detector and their optimum spatial placement position. In this regards, two methods for the



determination and detection of the Cherenkov cone in salt spray are noticed: - inside and outside the volume of the detector.

The Cherenkov cone in salt spray is generated following the interaction of a UHE neutrino (Ultra High Energy,  $10^{12} \div 10^{23}$  eV) with the saline environment. The detection of the information generated by the Cherenkov cone in salt spray implies knowing the energy, the direction, and the direction of travel of the neutrino, which interacted with this environment. The generation of UHE neutrinos may be due to some nuclear-related phenomena, which have a very high energy and give these neutrinos energies equivalent to the phenomena and provide information about these violent phenomena in the Universe. Thus, we can determine the nuclear phenomena in the Universe.

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