Emergency Communications System Via Ionosphere
For Connection ANPC-BV Pedrógão Grande

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Abstract — This work was inspired by the tragedy that devastated the country in 2017, when, as a result of failures in the existing communications system, thousands of people ended up being victims of a fire of gigantic proportions.

As such, the idea arose of creating an alternative communications system, so that communication between responsible entities in Portugal could be safeguarded if the current system fails again.

This dissertation aims at the study of a communications system that allows a viable and quality communication between various parts of the country, both in natural disasters and in possible conflict scenarios. It will then be verified whether it is possible to make a connection between the ANPC headquarters in Amadora and the BV headquarters in Pedrógão Grande through a NVIS communication.

In this study we used a half-wave dipole to transmit the signal, and an AS-2259/GR antenna to receive the signal. The data concerning the desired connection were calculated and, after calculations of the elevation angle and attenuation for the connection under study, it was concluded that, for a power supply of 20 W, it will be possible to connect the ANPC and Pedrógão Grande with great viability, since the sensitivity calculated in the reception turns out to be relatively superior to the sensitivity necessary for communication to be made with quality.

Keywords — NVIS, Emergency Communications, Ionosphere, Civil Protection, Attenuation, Radiopropagation

I. INTRODUCTION

With the increasing number of catastrophic situations, whether natural or man-made, there is also a growing need for effective communication in these situations. There must be a viable communication without interruption, either in cases of conflict, such as in war scenarios, or in natural disasters, so that the number of casualties is as low as possible or preferably zero.

Regarding natural disasters, in the case of our country, the study of this topic may be applicable more specifically to the cases of forest fires, which often devastate Portugal, as well as floods, which victimize thousands of people every year, either through moral, physical or collateral damages, but also to a hypothetical scenario of conflict that may come to grips with the country.

This work was inspired by the tragedy that devastated the country in October 2017, more specifically the center region, where, as a result of failures in the existing emergency communications system, SIRESP, thousands of people became victims of a fire of proportions never seen before in Portugal. As such, the idea was to create an alternative communication system to the existing one, to be used in emergency situations, so that communication between the responsible entities in Portugal could be safeguarded if the current system fails again, through a NVIS communication. NVIS communication is widely used, especially in war scenarios, since it allows HF communication at short and medium distances, allowing even the connection when obstacles are present, not requiring many material means for the system to be assembled.

NVIS depicts the radio propagation mode that uses antennas with a very high radiation angle, approaching 90 degrees vertically, combined with the use of a frequency below the critical frequency, in order to establish reliable communications within a radius of approximately 320 kilometres. This propagation mode is normally used to make close contacts.

There are two types of HF propagation, known as groundwave and skywave. The groundwave propagation occurs when the receiving station is sufficiently close to the transmitting station, and is able to receive the percentage of the transmission signal that "grabs" the ground. The range of the groundwave propagation varies with the type of antenna present at the transmitting station, with the characteristics of the ground between the transmitting station and the receiving station, among other factors. It can be anywhere from a few kilometres to a few tens of kilometres. Distances that go beyond the reach of the groundwave signal are covered by the skywaves. These are the waves that radiate towards the atmosphere, at an angle that allows them to be reflected by the atmosphere and return to the surface of the Earth at a point a little further on.

The idea of NVIS is then, as discussed above, radiate a signal at a frequency that is lower than the critical frequency, at an almost vertical angle, and have that signal reflected by the ionosphere at a very high angle of incidence, returning to earth at a relatively close distance from where the signal was radiated. Since it is impossible for an antenna to radiate its signal at an exact angle, what you get is a set of angles, ranging from almost vertical to perfectly vertical. The part of the signal that is radiated at vertical or near vertical angles reflects back to earth at a radius that is determined by the lowest angle from which the antenna radiates more signal. Taking into account layer D, its absorption, among other factors, determines a minimum frequency below which the signal will not be able to be used, as well as a distance in which, beyond the same, the signal will also not be able to use.

For areas that are within the groundwave range of the broadcast station, the presence of the station may interfere with skywave reflection. However, it can also serve as an aid, depending on whether they arrive in phase, out of phase, or something between the two, depending also on the relative powers of the signals. If the groundwave arrives with the same power of the skywave and both are out of phase, the signal will disappear. Since the height of the ionosphere varies over time, the phase alignment may drift between being in phase or out of phase, resulting in fading of the signal. For this reason, it is
necessary to minimize groundwave radiation when using NVIS techniques, so that it is less likely to interfere with skywave.

As regards receiving signals, there is an advantage, in addition to the advantages of signal transmission already mentioned, that if the antenna favors high transmission angles, it will also favor high reception angles. In addition, an optimized high-angle radiated antenna used for NVIS will also be optimized to receive skywaves that will arrive from the ionosphere at a high angle. Also, an antenna that does not radiate many groundwave signals will also probably not receive many groundwave signals. When both stations use antennas that are optimized for NVIS, this mode is favored in both transmission and reception, and these advantages together increase the likelihood of more reliable communication.

There is also an inherent advantage of the use of NVIS-type antennas which applies only to reception. The range of frequencies (between 2 and 10 MHz) that is advantageous to NVIS is also the same range of frequencies that is most susceptible to atmospheric noise, where one of the largest sources of this is distant storms. Obviously the nearest storms are worse, of course, but the noise of all possible sources joins. Unless there is a coming storm, most of the noise will be the sum of the noise from distant sources that will all propagate to the receiving antenna. Since NVIS-optimized antennas capture most propagated signals from relatively close areas, and do not favor reception of signals, static faults, and other sources of noise or interference from more distant sources, it will not capture as much noise as an optimized antenna to operate in DX. This results in a better SNR.

Usually, measures are performed that optimize the capabilities of NVIS stations and substantially lower their noise level. At other times, the noise reduction can be maximized at the expense of some signal strength, and result in a communication circuit having low signal levels but still lower noise levels for an even better signal-to-noise ratio achieved by focusing solely on maximizing signal levels. It is therefore essential to select a frequency below the critical frequency but not far below it by selecting an antenna that radiate skywaves at a high angle and minimizing groundwaves and noise reception to establish reliable communication within a radius of 320 kilometers, which is a challenge for high frequency operation.

II. PROPAGATION VIA IONOSPHERE

A. The Ionosphere

The ionosphere is defined as the layer of the atmosphere that is ionized by cosmic and solar radiation. It is located between 50 and 1000 km above the Earth’s crust. This layer of the atmosphere includes the thermosphere, as well as some parts of the mesosphere and the exosphere. It is a layer in which, because of the high energy of the sun and the cosmic rays, the atoms lose one or more electrons, and are positively charged, that is, they become ionized. Ions behave as free particles.

At night, without the interference of the Sun, the cosmic rays ionize the ionosphere, though not as strongly as the UV rays. These cosmic rays come from various sources, being present in our Galaxy or the rest of the Universe - such as supernovas, quasars or black holes. It is due to the fact that the ionosphere is much less charged during the night than some phenomena that happen in the day to ease to observe.

The ionosphere is of great importance because, among other things, it influences radio propagation to distant sites on Earth, and propagation between satellites and Earth. For very low frequency waves, the ionosphere and ground produce a waveguide by which the radio signals can protrude and trace their way around the Earth, as shown in Figure 1.

Figure 1 - Reflection of VLF waves in the ionosphere (obtained from [16])

B. Ionosphere Layers

Historically, it was thought that the ionosphere was composed of a number of relatively distinct layers identified by the letters D, E and F. The layer F was later divided into F1 and F2. The nomenclature was attributed by Edward V. Appleton, a pioneer in radio propagation, who used the letter E because he was accustomed to using that letter to describe the electric field of the wave reflected by the first layer of the ionosphere he studied. He later identified a second layer at a higher altitude and used the letter F for the reflected wave. Suspecting that there was a layer at a lower altitude, he decided to use the letter D to characterize it. As time went on, the letters became associated with the layers themselves, not the field or reflected waves. It is now well known that the electron density increases more or less evenly with the height from the D layer, reaching the maximum at the layer F2.

Figure 2 shows the existence of the different layers of the ionosphere during the day and at night. It is possible to verify that all the layers are present in the ionosphere during the day, but at night there are only the layers E and F.

Figure 2 - Ionosphere layers

C. D Layer

The D layer is the lowest layer of the ionosphere, present approximately between 50 and 90 km altitude. This layer differs from the layers E and F in that the free electrons disappear almost completely at night because they are recombined with oxygen ions and form electrically neutral oxygen molecules. During this period, the radio waves cross the D layer and reflect in layers E and F. During the day, some reflection in the D layer may occur, however, the power of the radio waves is reduced. This is the cause of the reduction of radio transmissions during the day.

During proton storm events, this layer may reach unusual levels of ionization. These events, by increasing the ionization, also increase the absorption of the radio signals that
pass in the layer. In fact, absorption levels may increase by tens of dB's in this period, which is sufficient to absorb all HF signals. These events typically occur between 24 and 48 hours.

D. E Layer

This layer extends through an altitude between approximately 90 and 140 km altitude. Unlike the D layer, the ionization of the E layer remains overnight. However, it is considerably lower than during the day. This layer was responsible for the reflections involved in the first transatlantic radio communication, made by Guglielmo Marconi in 1902. The ionization density of this layer is typically $10^5$ electrons per cubic centimeter during the day, being possible that there are periods of greater ionization. Usually, at an oblique incidence, this layer can only reflect radio waves at a frequency range below 10 MHz and can contribute to wave absorption at a higher frequency range. During sporadic events in this layer (Es), it is possible for waves of frequency ranges exceeding 50 MHz to be reflected.

E. F Layer

The F layer is present above 140 km altitude. This layer has the highest concentration of free electrons. Although its degree of ionization persists with little change at night, there is a change in ion distribution. During the day, it is possible to distinguish two layers: a smaller layer known as F1, and above this a more ionized dominant layer called F2. During the night, these layers fuse at the level of layer F2. This layer reflects radio waves with frequencies that can reach 35 MHz. The exact value depends on the peak of the electron concentration, which typically reaches the value of $10^6$ electrons per cubic centimeter. This is the layer responsible for most skywave propagation of radio waves and high frequency radio communications over long distances.

F. Sporadic Layer Es

The sporadic layer Es refers to the unpredictable formation of regions with a large electron density in the E layer. This region can be formed at any time of day or night and, occurring in layer E, lies between 90 and the 140 km of altitude. It can vary a lot in the area it occupies, be it a few kilometers or a few hundred kilometers, and also in the time that this region holds (can be present between only minutes to several hours). This region may have electron density comparable to the F layer, which means that it may reflect the high frequency ranges that are used for F-layer communications. Sometimes the sporadic layer is transparent and allows most of the radio waves to pass through, and reflect in the F layer. However, at other times this layer is able to completely block the layer F, and cause the signal not to reach the receiver, and consequently to the receiver. Since the layer is partially transparent, the radio wave can sometimes reflect in the F region and sometimes in the Es layer. This may lead to a partial or intermittent transmission of the signal, or even lead to fading.

G. Variations in the Ionosphere

The ionosphere does not allow the same frequency to be used for year-round or even 24-hour communications since the electron density in the ionosphere is not always the same. It can vary due to several factors, such as altitude, latitude, solar cycle over several years, the daily solar cycle, as well as the season (seasonal variation).

H. Variations with altitude

At low altitudes, air has a very high density of particles, and therefore it is practically impossible to obtain ion densities comparable to the density of neutral particles. As the height increases, the air density becomes lower, and the ions that are present in these regions tend to travel long distances before recombining, and this causes the life of the ions to increase, and, since the intensity of the radiation is higher, the ion density also increases and reaches values much higher than the density of neutral particles. Figure 3 shows the constitution of the various layers of the atmosphere, as well as the variation of the electron density present in the ionosphere.

![Electron density according to height](image3)

I. Variations with the daily solar cycle

Early in the morning, the sun is relatively low, so the radiation must penetrate a large column of air before reaching a certain level in the atmosphere. As a result, ionization rates are lower, and the location of ionized layers is transferred to higher altitudes. As the sun goes away, layers D, E and F1 change in altitude. At noon, the layers are lower and the electron density is the highest of the day. On the other hand, at night, ionization in layers D, E and F1 tends to disappear as electrons and ions recombine to form neutral gases, as shown in figure 4.

![Maximum frequencies for the layers E, F1 and F2](image4)

J. Variations with the solar cycle

The sun varies in a period of rise and fall in its activity that ends up affecting HF communications. These solar cycles can range from 9 to 14 years. At its minimum, only the low frequencies of the HF band are reflected by the ionosphere, while at their maximum, the high frequencies also propagate successfully, as shown in figure 5.

This is because there is greater radiation to be emitted by the sun at its solar peak, producing more electrons in the ionosphere, which allows the use of high frequencies. But there are other consequences of this solar cycle. During this peak
there is a greater probability of occurring solar flares. This phenomenon involves huge explosions of the sun emitting radiation that ionizes the D layer, causing an increase in the absorption of HF waves. Since this layer is only present during the day, only the paths that pass through the daylight are affected. The absorption of HF waves traveling through the ionosphere after a solar flare is called a fade-out. Fade-outs occur instantly and mostly affect low frequencies. If a fade-out is suspected, then it is advisable to use high frequencies. The duration of this phenomenon can vary from 10 minutes to a few hours, depending on the duration and intensity of the solar flare.

K. Seasonal Variation

Seasonal variations are the result of the translation of the Earth around the Sun. The frequencies in layer E are higher in summer than in winter. However, the variation of frequencies in the F layer is more complicated. In both hemispheres, the frequencies in the F layer generally peak around the equinoxes (March and September). Around the solar minimum in the summer, the frequencies are, as expected, generally higher than those presented in winter, but around the solar peak, the frequencies in winter tend to be higher than in the summer. In addition, the frequencies around the equinoxes are higher than those of the summer and winter for the peak and for the solar minimum. The observation of the winter frequencies is usually larger than the summer is called a seasonal anomaly.

L. Variations with latitude

Figure 6 shows the variations in layers E and F of the maximum frequencies at noon (Hemisphere-Day) and at midnight (Hemisphere-Night) from the pole to the equator. During the day, with increasing latitude, solar radiation reaches the atmosphere more obliquely, so the intensity of radiation and the daily production of free electrons decreases. In the F layer, this latitude variation continues at night due to the action of atmospheric currents.

The deviations from latitude from low to high latitudes are also notorious. The peak frequencies in the F layer are not at the geomagnetic equator, but 15 to 20 degrees north or south of the same. This is called an equatorial anomaly. In addition, at night, the frequencies reach a minimum around 60 degrees north or south of the geomagnetic equator. This is the so-called depression latitude. Communicators who require communications near the equator during the day and a latitude of 60 degrees at night should be aware of these characteristics.

M. Ionospheric Plasma

Two fundamental properties of a plasma, the plasma frequency and the refractive index, determine the interactions between plasma and electromagnetic radiation. Figure 7 shows these same interactions.

N. Attenuation Constant in an Ionospheric Plasma

The ionosphere is composed essentially of a plasma, which presents a variation in the density of electrons, depending on several factors.

The plasma frequency is a characteristic frequency defined in the absence of the imposed magnetic field and is observed when introducing an initial perturbation that separates the charged particles in the presence. This frequency is given by

$$ f_p = \frac{w_{pe}}{2\pi} = \frac{q^2 N_e}{m_e e \varepsilon_0} $$

A very simple model is considered to obtain the attenuation constant, which despises the collision losses and the magnetic field, being the force due to the electric field the only one to exert attenuation on the electrons.

The constant attenuation is then given by the expression

$$ \alpha = \frac{\omega_p^2 \theta}{2c(\omega^2 + \theta^2)} $$

O. Virtual Height

The virtual height is the height above the earth’s surface from which a refracted wave appears to have been reflected. The expression is given by

$$ h_v = \frac{3 \times 10^8 \times \Delta t}{2} $$

P. Maximum Usable Frequency

MUF is the highest frequency that can be used in transmission between two points, through reflection in the
ionosphere, at a certain time, regardless of transmission power. This frequency is given by the expression

\[ MUF = \frac{f_c}{\cos \theta} \]

Where \( f_c \) is the critical frequency, which is given by

\[ f_c = \sqrt{80.55 N_{\max}} \]

III. ATTENUATION IN A COMMUNICATION VIA IONOSPHERE

The ionosphere acts as a reflecting layer for radio waves in some frequency ranges, although only for frequencies not very high (at most frequencies in the order of magnitude between 3 and 30 MHz). As such, for a connection to be made, it is necessary for the signal to be transmitted by the transmitting antenna, and to reach the ionosphere, at an angle, called the angle of fire, oblique. For frequencies above 30 MHz, the signal, even if transmitted at an oblique angle, "pierces" the ionosphere, not being reflected. When the signal is reflected by the ionosphere, it returns to the Earth's surface, allowing communication to take place. This phenomenon is called by jump, and is represented in figure 8.

After being reflected in the ionosphere, and returning to the earth’s surface, the signal can be reflected back to the ground and back to the ionosphere, thus obtaining more than a jump, as represented in the figure. Thus there may be several reflections, which may correspond to n jumps, which allow the signal to propagate over long distances. These various reflections that the signal can suffer end up causing an additional attenuation in the link.

Since there may be more than one jump in communication via the ionosphere, a study will be done for two cases - the first, in case there is only one jump, and the second, in case there are two jumps. The distance to be considered will be 200 km between the transmitting antenna and the receiving antenna in the first case, and 400 km in the second. The study of both cases aims to calculate the total attenuation suffered by the signal in the ionosphere communication between two points on the Earth’s surface.

For the first case, the link is represented in figure 9.

The frequencies to be studied will be 3, 5, 8 and 10 MHz.

A. Take-off Angle

To precisely define the path travelled by the signal sent by the transmitting antenna, it is necessary to calculate the relation between the jump distance \( d \), the virtual height \( h' \) and the fire angle \( \psi \). The approximation of the flat earth will be used to calculate the fire angle at a given frequency \( f \), which is represented in figure 10.

The expression of the take-off angle is given by

\[ \psi = \tan^{-1}\frac{2h'}{d} \]

Figure 19 presents a graph which makes the study of the take-off angle \( \psi \) according to the virtual heights \( h' = 80 \text{ km}, 100 \text{ km}, 250 \text{ km} \) and 350 km.

B. Free space attenuation

The free space attenuation is the loss of signal strength that occurs when an electromagnetic wave propagates in free space. The antennas are isotropic, and the free space attenuation is then expressed in dB and is given by the formula

\[ A_0 = 32.44 + 20 \log(d_{[\text{km}]} \) + 20 \log(f_{[\text{MHz}]} \) \] [dB]

Taking into account the estimated range of 200 km, and sweeping the previously defined frequencies, the values obtained are presented in table 1.

<table>
<thead>
<tr>
<th>Frequency [MHz]</th>
<th>( A_0 ) [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>99.28517199</td>
</tr>
<tr>
<td>5</td>
<td>103.722147</td>
</tr>
<tr>
<td>8</td>
<td>107.8045466</td>
</tr>
<tr>
<td>10</td>
<td>109.7427469</td>
</tr>
</tbody>
</table>

Table 1 – Free space attenuation

C. Ionospheric Attenuation

Taking into account that the stratification of the layers of the ionosphere is considered flat, the attenuation in each layer is given by the expression

\[ A_l = e^{-2\pi \alpha} \]
In which $\propto$ corresponds to the attenuation constant, and $\kappa$ corresponds to the distance travelled by the signal within the ionosphere, which is given by the expression

$$\kappa = \frac{\text{esp}}{\sin \psi}$$

Where esp represents the thickness of each layer (40 km for layer D, 50 km for layer E, 70 km for layer F1 and 190 km for layer F2) and $\psi$ is given by figure 11. The values for the ionospheric attenuation are given in table 2.

For the calculation of the total attenuation in the ionosphere, the sum of all the layers of each of the frequencies is given in table 3.

### Table 2 – Ionospheric attenuation

<table>
<thead>
<tr>
<th>Layer</th>
<th>$f = 3$ MHz</th>
<th>$f = 5$ MHz</th>
<th>$f = 8$ MHz</th>
<th>$f = 10$ MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer D</td>
<td>0.0817</td>
<td>0.0295</td>
<td>0.0115</td>
<td>0.0074</td>
</tr>
<tr>
<td>Layer E</td>
<td>0.0090</td>
<td>0.0033</td>
<td>0.0013</td>
<td>0.0008</td>
</tr>
<tr>
<td>Layer F1</td>
<td>0.0096</td>
<td>0.0035</td>
<td>0.0014</td>
<td>0.0009</td>
</tr>
<tr>
<td>Layer F2</td>
<td>0.0025</td>
<td>0.0009</td>
<td>0.0004</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

### Table 3 – Total ionospheric attenuation

<table>
<thead>
<tr>
<th>$A_{\text{total}}$ [dB]</th>
<th>$f = 3$ MHz</th>
<th>$f = 5$ MHz</th>
<th>$f = 8$ MHz</th>
<th>$f = 10$ MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1029</td>
<td>0.0371</td>
<td>0.0145</td>
<td>0.0093</td>
</tr>
</tbody>
</table>

### D. Ground Attenuation

The communication with two jumps, in which the signal will be reflected by the terrestrial surface, one has to consider the attenuation suffered by the signal when it is reflected in the ground, considering that it is a rough surface. The schematic of this connection is shown in figure 12.

The attenuation suffered by the signal, when reflected by the earth’s surface, is given by the expression

$$A_z = |\Gamma|^2 e^{-\kappa^2 D}$$

Where $\Gamma$ is the polarization value, $g$ is the Rayleigh parameter, and $D$ is the divergence factor. Since the use of the flat Earth approach is considered, the value of the divergence factor is $D = 1$.

Polarization is defined by horizontal and vertical polarization, as represented in figure 13.

The reflected fields are given by the "Fresnel coefficients" which have as expressions

$$\begin{align*}
\text{HP: } \Gamma_h &= \frac{E_{\text{reflejado}}}{E_{\text{incidente}}} = \frac{\sin \psi - \sqrt{n^2 - \cos^2 \psi}}{\sin \psi + \sqrt{n^2 - \cos^2 \psi}} \\
\text{VP: } \Gamma_v &= \frac{H_{\text{reflejado}}}{H_{\text{incidente}}} = \frac{n^2 \sin \psi - \sqrt{n^2 - \cos^2 \psi}}{n^2 \sin \psi + \sqrt{n^2 - \cos^2 \psi}}
\end{align*}$$

The attenuation values, for the horizontal polarization and for the vertical polarization, are presented in table 4.

### Table 4 – Ground attenuation

<table>
<thead>
<tr>
<th>$f$ = 3 MHz</th>
<th>$f$ = 5 MHz</th>
<th>$f$ = 8 MHz</th>
<th>$f$ = 10 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>4,577045</td>
<td>4,862568</td>
<td>5,558533</td>
</tr>
<tr>
<td>VP</td>
<td>4,930047</td>
<td>5,215571</td>
<td>5,911536</td>
</tr>
</tbody>
</table>

### E. Total Attenuation

For the case where there is only one jump, it is considered the free space attenuation and the attenuation suffered when the signal reflects in the ionosphere. For this situation, the expression that gives the total attenuation is given by the expression

$$A_{\text{1\ jump}} = A_0 + A_{i\ total}$$

And the results are presented in table 5.

### Table 5 – Total attenuation for one jump

<table>
<thead>
<tr>
<th>$f$ = 3 MHz</th>
<th>$f$ = 5 MHz</th>
<th>$f$ = 8 MHz</th>
<th>$f$ = 10 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{total\ 1\ jump}}$ [dB]</td>
<td>99,3880666</td>
<td>103,759242</td>
<td>107,819044</td>
</tr>
</tbody>
</table>

For the case where there are two jumps in the connection, it is considered the attenuation in free space, the attenuation suffered by the signal when reflected in the terrestrial surface, for the horizontal polarization and for the vertical polarization, and the attenuation suffered by the signal when reflected in the ionosphere, twice. The expression giving the total attenuation suffered by the signal, in this particular case, is given by

$$A_{\text{total\ 2\ jumps}} = A_0 + 2A_{i\ total} + A_{\text{ground}}$$

And the results are presented in table 6.

### Table 6 – Total attenuation for two jumps

<table>
<thead>
<tr>
<th>$A_{\text{total\ 2\ jumps}}$ [dB]</th>
<th>$f$ = 3 MHz</th>
<th>$f$ = 5 MHz</th>
<th>$f$ = 8 MHz</th>
<th>$f$ = 10 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>203,1926</td>
<td>211,9349</td>
<td>220,0545</td>
<td>223,9205</td>
</tr>
<tr>
<td>PV</td>
<td>203,5456</td>
<td>212,2879</td>
<td>220,4075</td>
<td>224,2735</td>
</tr>
</tbody>
</table>
IV. NVIS ANTENNAS

NVIS antennas are one of the types of antennas that provide much of their radiation at an extremely high angle, allowing for excellent omnidirectional communication.

To make reliable communications that need to travel a distance of a few tens or hundreds of kilometres, the answer is not to use groundwaves, increase transmission power, or to install repeaters or other more drastic measures. The solution is to use NVIS antennas, select appropriate operating frequencies, and make it possible to make reliable communications up to approximately 320 km away.

A. Antennas Selection

Selecting an antenna for NVIS propagation is complex. First, it is necessary to establish the distance at which the communication is to be made so that the appropriate angle of fire is chosen.

It is then necessary to determine the coverage required. A radio link with mobile stations or several stations in different directions of the transmitter requires omnidirectional antennas. A point-to-point connection uses a bidirectional or directional antenna.

B. Type of Antennas

After all antenna characteristics are determined, the antenna required for the connection must be chosen. Table 7 shows the various types of antennas that can be used in NVIS communications, as well as their characteristics.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Directivity</th>
<th>Polarization</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS-2259/GR</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Half-wave dipole</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inverted V</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inverted L</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 7 – Type of NVIS antennas

C. AS-2259/GR

The AS-2259 / GR antenna is the most commonly used antenna by military personnel, and provides NVIS propagation for short distance connections. An example of its assembly is represented in figure 14 and its radiation pattern is represented in figure 15.

D. Half-wave Dipole

The horizontal half-wave dipole is used for short and medium distances. Since it is relatively easy to build, this is the most commonly used antenna. Its assembly example is represented in figure 16. It is a very versatile antenna, and adjusting its height relative to the ground, its maximum gain varies between medium fire angles (for medium distances) and high fire angles (for short distances).

When this antenna is built to a height of half the wavelength, it turns out to be a bidirectional antenna, as presented in figure 17.

If the antenna is built to a height of a quarter of the wavelength, it is an omnidirectional antenna, presented in figure 18.

Figure 19 presents the radiation patterns of three frequencies of a half-wave dipole built to 8 meters height, obtained through the software MMANA-GAL.
E. Inverted V

The inverted V antenna is similar to the dipole, but only uses a single support at the center, as presented in figure 20.

Figure 20 – Inverted V example of assembly (obtained from [4])

Figure 21 presents the radiation pattern of an inverted V antenna, obtained through the software MMANA-GAL.

Figure 21 – Radiation pattern of an inverted V antenna

F. Inverted L

An Inverted L antenna is a combination of a vertical and a horizontal section, as shown in figure 22.

Figure 22 – Example of an inverted L antenna assembly (obtained from [4])

This antenna provides omnidirectional radiation for ground wave from the vertical element and high-angle radiation from the horizontal element for short-range skywave propagation. The vertical section is a quarter-wave length and the horizontal section is a half-wave length, and its used for a very narrow range of frequencies. Figure 23 presents the radiation pattern of an inverted L antenna with 45.72 meters length, obtained through the software MMANA-GAL.

Figure 23 – Radiation pattern of an inverted L antenna 45.72 meters long

G. Choice and theoretical study of the transmitting antenna

Although 4 types of antennas compatible with NVIS propagation are presented, the AS-2259 / GR antennas and the half-wave dipole are the only antennas that meet all the requirements of NVIS communication. While they have a fairly take-off angle, the inverted V and L antennas also exhibit a large groundwave radiation, which can interfere with NVIS communications. These antennas will be used only in situations where the protection provided by the ground prevents the interference of groundwave radiation to the station with which it is intended to communicate. As such, to ensure that the connection isn’t affected by groundwave radiation, a horizontal half-wave dipole will be studied to transmit the signal and the AS-2259 / GR antenna will serve as the receiving antenna.

The electric field of a half-wave dipole is given, by the expression

\[ E_\theta = \frac{j n l_m e^{-j k r} \cos \left( \frac{\pi}{2} \cos \theta \right)}{2 \pi r} \sin \theta \]

And the magnetic field by the expression

\[ H_\phi = \frac{E_\theta}{\eta} = \frac{j l_m e^{-j k r} \cos \left( \frac{\pi}{2} \cos \theta \right)}{2 \pi r} \sin \theta \]

V. ANPC – PEDRÓGÃO GRANDE CONNECTION

The features in the signal propagation give the operator the ability to communicate through mountains or dense vegetation. For example, in combat situations, a valley can give the operator hostile interception protection and protect the link from interference exert by groundwave and skywave waves from long distances. NVIS antennas need a high radiation angle with very little groundwave radiation. Figure 24 demonstrates a NVIS communication.
The values of the attenuation suffered by the emitted signal, calculated by the sum of the free space attenuation and the ionospheric attenuation are presented in table 8.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{total}$ [dB]</td>
<td>99.20</td>
<td>101.6</td>
<td>103.5</td>
<td>105.1</td>
<td>106.4</td>
<td>107.6</td>
</tr>
</tbody>
</table>

Table 8 – Total attenuation in the link between Amadora and Pedrógão Grande

To obtain the sensitivity of the communication, the transmitter antenna will be fed with a power of 20 W. Obtaining the gain of the antennas through the analysis of their radiation patterns, and using the Friis equation, which is given by


The values of the sensitivity obtained for this communication, are given in the table 9.

<table>
<thead>
<tr>
<th>$f$ [MHz]</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_r [dBm]$</td>
<td>-62.096</td>
<td>-61.610</td>
<td>-62.542</td>
<td>-63.224</td>
<td>-63.780</td>
<td>-63.035</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

The main objective of this study was to find an alternative emergency communication system in Portugal. As such, it was found that a type of communication of easy assembly and using HF frequencies would be a possible solution to the problem found, and since it is intended to make connections at relatively short distances, the NVIS communication was the ideal system to make the connection between key locations in the country. It is also a type of communication widely used, successfully, in war scenarios, reasons that led to consider to apply it to this specific case.

As such, a theoretical study was made of the atmosphere layer to be used to make the bond, as well as its layering, and of all the factors that influence the density of electrons present in the ionosphere, which have an effect on the communication made through it, adding to it the effect that solar disturbances have on it.

Then, the attenuation in a short-distance ionosphere connection was calculated, taking into account the theoretical study done previously. It was started by finding the appropriate fire angle for a 200 km link, and the attenuation was calculated for a range of frequencies appropriate to an NVIS communication, between 3 and 10 MHz. Then, the attenuation a two-hop connection was calculated, which led to the conclusion that, when reflecting on the ground, the attenuation on this connection turns out to have a value of approximately 100 dB’s more than a connection with only one hop.

The next thing to do was to study the existing antennas that allow a NVIS communication, and all the features of the antennas were studied in order to choose the best for this particular link. It was concluded that the best antenna to use to transmit the signal is a half-wave dipole.

After collecting the data of the link and applying the features of the antenna, it came to conclude that the dipole, fed by a power of 20 watts, is enough to make a viable communication between Amadora and Pedrógão Grande, with good quality, once the sensitivity value calculated in the reception is considerably higher than the one necessary.

A. Calculation of the connection sensitivity

Figures 25 and 26 show the connection between Amadora and Pedrógão Grande, as well as the communication profile, obtained through the software Google Earth.

To establish communication between the two points, first one has to define the take-off angle. This angle has a value of $\psi = 76.2232$ and the distance traveled by the signa lhas a value of $d = 718,727$ km. These values were obtained through the sketch presented in figure 27.
REFERENCES

[6] N3AE and N3IDX, "Improving the AS-2259 NVIS Antenna".