A first study into the propagation of 5 MHz (60 m) signals using the South African ionosonde network

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The SARL has purchased two 5 MHz test frequencies from ICASA. These frequencies are intended for experimental and research purposes. One of the frequencies is allocated for two-way communications (5.260 MHz) while the 5.250 MHz frequency is used for beacon transmissions for propagation research purposes. Ionograms from the South African ionosonde network was used to analyse short range propagation on these frequencies, especially for the near vertical incidence scenario.

Introduction

Amateur radio has a long and proud history of providing South Africa with skilled radio operators in times of conflict and war as well as providing communications and assistance in times of disasters and tragedies (natural or man-made). To hone these skills radio amateurs often provide communications during public events such as motor rallies, cycle races, marathons, etc.

In South Africa we are fortunate not to suffer so much from natural disasters (earth quakes, tsunamis, tornadoes, mud-slides, etc.) as some other countries but we are not exempt from forest fires, boats and planes that go missing or people that get lost or trapped in mountains or deserts. During these emergencies radio amateurs contribute greatly by being able to provide supplementary (or primary) communications where the cell-phone and official communication network coverage is inadequate. All that a radio amateur need is a radio, battery and an antenna in the form of a wire to be able to assist when events become challenging.

A typical scenario is a search party in a deep ravine needing to communicate with the base station or search coordinators. The distances involved may be relatively short in terms of how the crow flies, but in remote, hilly terrain or with a mountain in between “normal” communication channels (e.g. the cellular network) may fail.

Under the conditions depicted in Figure 1 steep radiation angle, HF communications are very effective. (This is quite the opposite of long distance HF communications where low radiation angles are typically required.) Central to successful short range communications is the selection of an antenna with the required high angle radiation characteristics and an
operational frequency that will be refracted back to Earth and not penetrate the ionosphere to be lost in space. An ionosonde is the ideal instrument to help determine the correct frequency to be used for NVIS communications.

The South African ionosonde network

The ionosphere has been extensively studied using measurements from satellites, rockets, incoherent scatter radars and ionosondes. For this investigation it is necessary to define the behaviour of the ionosphere in terms of the propagation of radio waves and therefore the focus is on the characterisation of the ionosphere with the aid of radio probes, specifically ionosondes.

The South African ionosonde network consists of 4 ionosonde stations located at Grahamstown (Eastern Cape, 33.3°S, 26.5°E), Louisvale (Northern Cape, 28.5°S, 21.2°E), Madimbo (Limpopo, 22.4°S, 30.9°E) and Hermanus (Western Cape, 34.4°S, 19.2°E). All 4 ionosondes are Digisondes produced by the University of Massachusetts, Lowell Centre for Atmospheric Research (UMLCAR). The Grahamstown ionosonde has been operating since 1996, and Madimbo and Louisvale since 2000. The installation of the Hermanus ionosonde was completed in July 2008 and was the first DPS-4D operational in the field throughout the world.

The Hermanus ionosonde was donated by the South African Department of Communications and is operated and maintained by the South African National Space Agency (SANSA). The other three ionosondes are owned by the South African National Defence Force (SANDF) with the maintenance of the Grahamstown station and the data archiving and distribution of all ionospheric data being the responsibility of SANSA. The Department of Physics and Electronics at Rhodes University partners the SANSA in the South African ionospheric data collection, archiving and distribution.

All of the South African ionosondes operate continuously on a vertical incidence program set at a 15 minute resolution.
An ionosonde is an instrument that transmits a burst of HF radio energy vertically upwards towards the ionosphere. The time taken for the echo to return to Earth is measured and the (virtual) height of the ionospheric reflection point is calculated. The delay of the echo is frequency dependent and the output of the ionosonde is typically a graph of virtual height versus frequency. The virtual height is what the height of reflection would have been had the radio wave continued to travel at the speed of light all the way to the point of reflection. This graph is known as an (vertical incidence) ionogram. An ionosonde can be thought of as a long distance radar operating in the HF frequency range, transmitting and receiving vertically away from the Earth.
Vertical incidence ionograms as shown in Figure 3 have been used to study and quantify the ionosphere for more than 60 years or more than five solar cycles.

As the operating frequency of the ionosonde is increased, the time delay for the echo of a signal travelling vertically increases until the operating frequency is equal to the critical frequency of the \( \text{E} \) layer. At this point the layer will just be penetrated with virtually no reflection. This happens at 3.26 MHz in Figure 3. For frequencies just above \( f_{\text{OE}} \), the time delay decreases with frequency since the signals at these frequencies find it increasingly easy to penetrate the \( \text{E} \) layer. However as the critical frequency for the \( \text{F1} \) layer is reached, the signals start to slow down again as they approach penetration. In Figure 3, \( f_{\text{OF1}} \) is at 4.37 MHz. The same decrease followed by an increase in delay time happens for the \( \text{F2} \) layer. When the operating frequency exceeds the critical frequency for the \( \text{F2} \) layer, \( f_{\text{OF2}} \) (7.23 MHz in Figure 3) the signals penetrate the total ionosphere and go on into space. Visa-versa, if the frequency is too low (e.g. <2.2 MHz in Figure 3), there will be no returning signal due to absorption by the \( \text{D} \) layer.

When a pulse of HF radio wave energy is vertically transmitted, it is reflected from the ionosphere and returned to the receiver some time \( T \) later. The group height or virtual height can be calculated by

\[
h' = \frac{cT}{2}
\]

where \( c \) is the speed of light in free space.
The ionosphere is however not free space and the velocity of a signal travelling through it is related to the velocity of light by

\[ V = \frac{c}{\mu'} \]  

(2)

Where \( \mu' \) is the group refractive index.

Along the ionospheric propagation path \( \mu' \) (and \( V \)) change in proportion to the electron density. By working in small segments and integrating over the whole path it is possible to calculate the true height versus frequency. This is automatically done in modern ionosondes and displayed as part of the ionogram. In Figure 3 there are two black lines. The broken black line just below the red ordinary layer echoes is used for curve fitting calculations and the solid black line starting at the minimum frequency and at a height of just more than 90 km and finally reaching a height of 580 km is the true height profile.

There are two traces for each layer of the ionosphere due to the Earth's magnetic field giving rise to the ordinary (O) and extraordinary (X) rays. In Figure 3 the O-ray is depicted in red and the X-ray in green. When a plane polarised radio wave hits the ionosphere, it splits into two characteristic waves (ordinary and extraordinary) that propagate independently through the ionosphere. The Earth's magnetic field, or geomagnetic field, has important effects on both the ionosphere and HF propagation. The strength of the geomagnetic field is measured in terms of the electron gyro-frequency. Charged particles such as electrons cannot move across a magnetic field line but are forced to spiral or rotate around them. The rate at which they rotate is called the gyro-frequency and depends on how heavy they are, their electric charge and the strength of the magnetic field. For electrons in the geomagnetic field, the gyro-frequency is typically less than 2 MHz and varies with latitude and longitude over the surface of the Earth. The vertical asymptotes for \( f_{O}F2 \) and \( f_{E}F2 \) are separated by approximately half the gyro-frequency, \( f_{b} \). For Grahamstown this is approximately 0.38 MHz according to Figure 3.

**Assimilating short range 5 MHz (60 m) propagation from vertical ionograms**

Under the conditions depicted in Figure 3 it is clear that short distance NVIS propagation is possible in the Grahamstown area on the 3.5 (80 m), 5.25 (60 m) and 7 MHz (40 m) amateur bands. Higher frequency band signals (10 MHz, 14 MHz, 18 MHz, etc.) will penetrate the ionosphere and be lost in space.

From Figure 3 it is also clear that NVIS sky wave propagation on the 1.8 MHz (160 m) band (and lower bands) will not be possible due to absorption from the D layer.
From Figure 4 it can be seen that the atmospheric noise levels are lower on the higher frequency bands and under the conditions depicted in the ionogram of Figure 3, the 7 MHz band will be the preferred band for short distance (e.g. < 200 km) sky wave communications. This is typical for communications during the middle of the day. (The ionogram was generated at 12h45 Central African Time.)

Example of when the 7 MHz (40 m) band fails to support short range, skywave communications

A study of the ionograms produced by the South African ionosonde network reveals that the 40 m band will not always support the short range NVIS (day-time) propagation typically required during emergency communications.
In the Louisvale ionogram of Figure 5 it can be seen that the highest vertical incidence frequency that will be reflected by the ionosphere is around 5.5 MHz (Red and green traces.) (The other traces on the ionogram are oblique results from the other ionosondes in the network, giving an indication of propagation over a ~700 km path.) From Figure 5 it is clear that NVIS communications will not be possible on the 7 MHz band under the applicable conditions and at 08h00 CAT when the ionogram was generated. Under these circumstances 5 MHz will provide the most reliable communications as the noise levels will be considerably lower than that experienced on 3.5 MHz (as depicted in Figure 4).

Figure 5: (Vertical and oblique incidence) Ionogram as generated by the Louisvale ionosonde indicating NVIS failure on 7 MHz but good propagation on 5 MHz

Example of when the 5 MHz (60 m) band fails to support short range, skywave communications

At night and just before sunrise short range sky wave communications are mostly only possible on the 3.5 MHz (80 m) and 1.8 MHz (160 m) bands. Under the conditions depicted in Figure 6 it can be seen that the 5 MHz band is then not suitable for NVIS communications.
Figure 6: (Vertical and oblique incidence) Night time ionogram as generated by the Louisvale ionosonde indicating NVIS failure on 5 MHz but good propagation on 3.5 MHz

During times of high solar activity the absorption of the D layer can cause the Lowest Usable Frequency (LUF) to extend beyond 5 MHz, ensuring that no sky wave communications will be possible on 5 MHz over any distance. In the ionogram of Figure 7 the lack of any echoes below 6 MHz indicates very high absorption by the D layer and a corresponding LUF of 6 MHz. Under these conditions the higher amateur bands (7 MHz or even 10 MHz) will produce the most successful NVIS communications.
Figure 7: (Vertical and oblique incidence) High solar activity, day time ionogram as generated by the Louisvale ionosonde indicating NVIS failure on 5 MHz but good propagation on 7 and 10 MHz

Summary

The ionograms generated by the South African ionosonde network clearly illustrates the supremacy of the 5 MHz band for short range, NVIA communications under certain conditions. These typically happens during the morning and late afternoon when the 7 MHz band does not support short range, sky wave communications and the 3.5 and 1.8 MHz bands suffer from high noise levels.

During the middle of the day the 7 MHz (and 10 MHz during high solar activity) band is typically the most effective medium for short range, sky wave communications.

Permanent access to the 5 MHz band will ensure that the amateur radio community can efficiently contribute to emergencies requiring short distance communications beyond line-of-sight as typically required in hilly and mountainous terrain.

The South African ionosonde network is unique in Africa and place South African radio amateurs in the very fortunate position to monitor reigning, short range propagation conditions and to improve their skills and experience accordingly.

Useful web address