# MEASUREMENT AND DESCRIPTION OF VERY LOW-FREQUENCY SIGNAL IN THE IONOSPHERE AT THE ILORIN STATION

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**Abstract**

This research presents the results of a very low frequency (VLF) signal received by a VLF receiver at the University of Ilorin, Ilorin (ILR) station (4.68° N, 8.49° E), from 23rd of January 2021 to 17th May 2021. Using a square-shaped loop antenna (Rx) of 7.2 meters perimeter, the VLF receiver tracks transmitting signals from three selected VLF transmitter stations namely VTX (19.2 kHz), India, NWC (19.8 kHz), Australia and GBZ (19.5 kHz), United Kingdom. A comparison was made with the VLF amplitude signal with an electron density of the D-region that was obtained from the International Reference Ionosphere (IRI) model. The result of the work shows a period of sunrise time (SRT) and sunset time (SST) on the VLF amplitude signal for some selected days. The solar quiet day morphology at the ILR station reveals that the VLF signal strength is high at night than in the daytime. This shows evidence of 24 hours of solar radiation and the signature of the appearance and disappearance of the D-region.

**Keywords:** Ionosphere, very low frequency, D-region

## Introduction

Very low frequency (VLF) propagation is broadly characterized by low attenuation, high phase and high signal-to-noise ratio and frequency stability (Saccuan et al., 2018) Thus, VLF radio propagation can be employed for sustainable long-distance radio communication and can be used as a way of understanding characteristics of the height, sharpness, and electron density profile of the ionospheric D layer (Šulić et al., 2016). The presence of free electrons in the ionosphere is due to ionization by solar radiation which allows VLF radio signal in the frequency range of 3 to 30 kHz, transmitted by the various transmitter for radio and communication to propagate in the Earth-ionosphere waveguide (Wah et al., 2012). The ionosphere is the part of the Earth's atmosphere where there is enough ionization to affect radio signal transmission. The structure of the ionosphere fluctuates dramatically with altitude (ionospheric layers), time (seasonal fluctuations and day-night cycles), geographic location (poles, geomagnetic equatorial areas), and solar activity that affect the propagation of radio signals (Saccuan et al., 2018). The ionosphere is formed when high energy ultra-violet light from the sun interacts with the molecules of gases and the atoms in the atmosphere which result in abundant electron and ions. This ionization of different constituents takes place at different altitudes resulting in the formation of different regions in the ionosphere. Being higher at greater altitudes and decreasing downward. The ionosphere consists of D, E and F layers which are present at the height of about 50 – 90 km, 90 – 150 km and above 150 km respectively (Rastogi et al., 1999). Long-distance communication in the high-frequency bands between 3 and 30 MHz, and slightly beyond, is accessible by the ionosphere (Bensky, 2019). Radio communication is highly dependent on the time of day, season, longitude, and the sun's multiyear cycle creation of sunspots.

The Earth-ionosphere waveguide is defined by the lower D-layer between 50 to 90 km and the Earth's surface. In this Earth-ionosphere waveguide, VLF radio waves propagate over the Earth's surface. The attenuating behaviour of the D layer is analogous to the reflecting feature of the E layer during the daytime when X-ray and UV become greater (Sasmal et al., 2015). After sunrise, VLF sky waves coming from long distances after sunrise are damped and ground wave propagation dominates. As the free electrons in the D layer vibrate due to the interaction of these radio waves, the electrons collide with molecules, and at each collision, there is a small loss of energy. The high density of air molecules in the region means that the collision frequency is very high. In the daytime, the low-density D layer absorbs and attenuates radio waves (Scherrer et al., 2010, Onah & Okeke, 2013). At night, the lower layers largely disappear by recombination, and thus, the layer becomes transparent to radio waves for the first time (Sasmal et al., 2015).

The study aims to characterize very low-frequency signals in the ionosphere with the objectives of replacing and configuring the VLF radio receiver system with a low-voltage device using Raspberry Pi, to investigate the variation of the VLF radio signal in the ionosphere and to compare the VLF radio signal with the electron density of the D-region.

## Materials and Methods

In this study, the amplitude of the VLF signal was obtained from the VLF receiver located in the Department of Physics, University of Ilorin, Ilorin (ILR), Nigeria (4.68°E, 8.49°N). The VLF receiver system records signal frequency from 0-50 kHz which is maintained by SuperSID software that constantly logs the intensity of the three (3) different VLF transmitter stations. The VLF receiver system has four units namely, an antenna, a pre-amplifier, an analogue-digital converter (ADC) and a data analyser (Raspberry Pi). The block diagram of the VLF radio receiver system consisting of the important units of the system is shown in Figure 1. The incoming VLF signal is received by the loop antenna at a very low induced output voltage which is amplified by the pre-amplifier. The analogue to digital conversion is done by a high-definition audio sound card that sampled the amplified analogue signal.

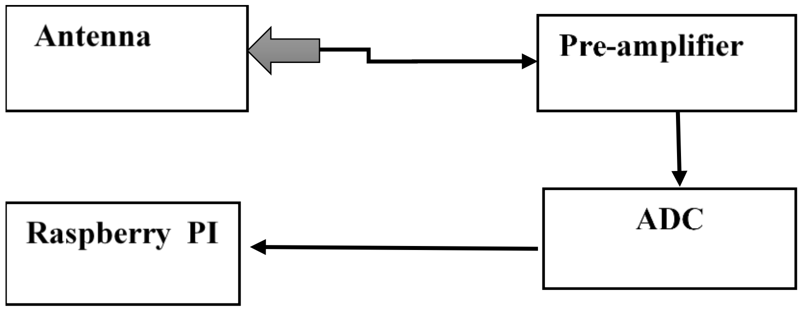


**Figure 1:** Block diagram of SuperSid

The VLF radio receiver system pre-amplifier is of the type Super-SID (Šulić et al., 2016) being an endowment from the Stanford University Solar Center. The received VLF signal is sampled every 5 seconds, processed by the SuperSID program and stored on Raspberry Pi. The Super-SID program is written in Python language and was developed by Stanford University Solar Centre.

The VLF signal being transmitted from VTX, NWC, and GBZ stations located in India, Australia and the United Kingdom respectively is the sole input to the receiving system and the stored data are the main output of the data acquisition (DAQ) system. The VLF signal captured is amplified by the SuperSID preamplifier and converted to digital signals by the soundcard for further processing by the computing device which runs the SuperSID program. The location of these transmitter stations monitored by the ILR VLF radio receiver is listed in Table 1.

**Table 1: List of VLF Transmitter Stations**

| Country | Call Sign | Freq. (kHz) | Location | Latitude | Longitude |
|---|---|---|---|---|---|
| India | VTX | 19.20 | South Vijayanarayanam | 8.38° | 77.75° |
| Australia | NWC | 19.80 | Exmouth, Western | -21.82° | 114.17° |
| United Kingdom | GBZ | 19.58 | Anthorn | 54.91° | -3.28° |

The photo of the VLF radio receiver system at the ILR station is shown in Figure 2. The antenna receives a VLF signal reflected from the ionosphere that is transmitted by the three transmitting stations given in Table 1. The antenna is a wire loop antenna as can be seen in Figure 2(a). The loop antenna can be built in various shapes like rectangular, square, circle, hexagon or any other shape and size.

The pre-amplifier is used to amplify the VLF signal as the signal received from the antenna is typically very low in amplitude (0.1mV). This will amplify the signal thousand times so that it can be detected by the sound card in the data logger. This type of layout is not suitable for manual assembly; therefore, we simplified the PCB to a single-layer layout.

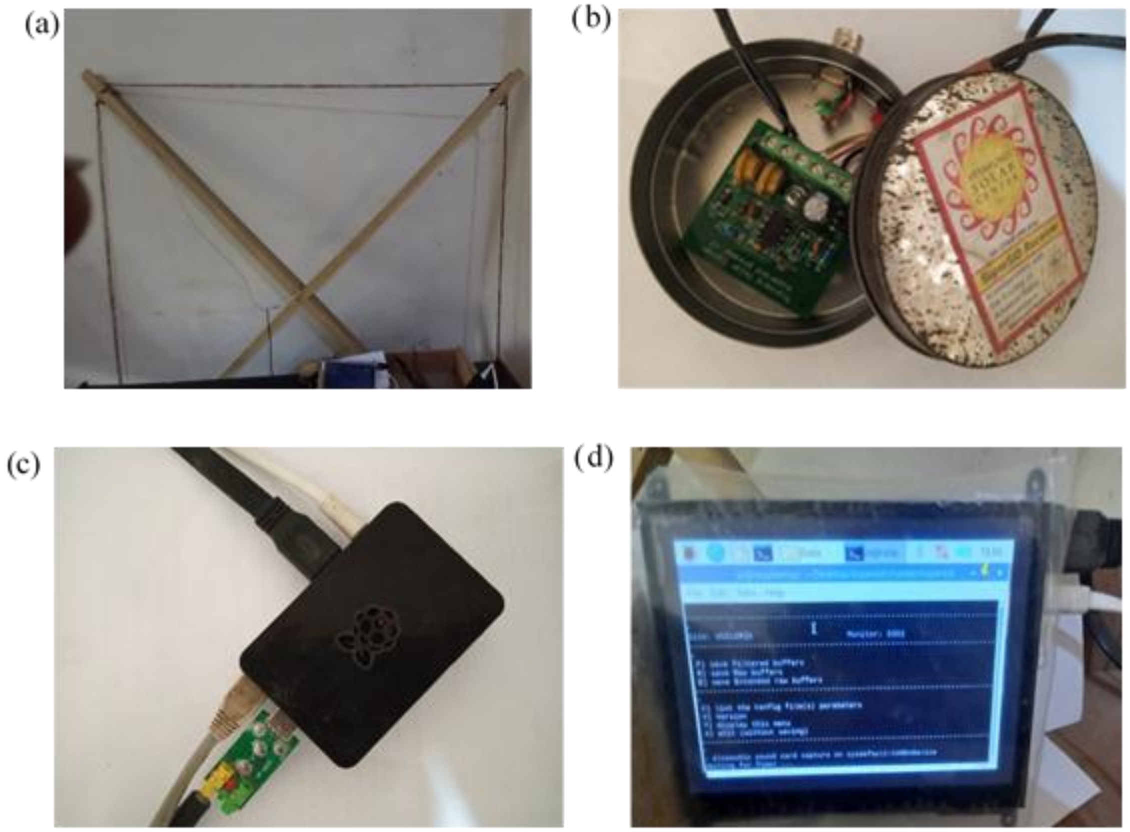

**Figure 2:** The VLF radio receiver system is shown (a) loop antenna (b) Super-SID pre-amplifier (c) Raspberry Pi (d) display-monitor

The third segment of the receiver system is the data acquisition unit which serves as the data logger. It consists of Raspberry Pi with a sound card and the SuperSID program. The sound card is a high-definition audio card with a minimum sampling rate of 96 kHz. This sound card will convert the received analogue VLF signal into a digital signal. The signal is then processed and logged in the Raspberry Pi. Our usage of the Raspberry Pi in place of a computer unit is to mitigate the epileptic power supply problem bedevilling Nigeria at the moment. The Raspberry Pi is a low-power-consuming device that is useful in this situation (Mardina Abdullah et al, 2016). Thus, the cost of backing up the system becomes lower compared to using a personal computer or laptop.

## Results and Discussion

### Diurnal Variation of VLF

The VLF signal recorded from the ILR VLF receiver station for some selected days is presented in this section. The receiver tracks transmitting the signal from three selected VLF transmitters namely South Vijayanarayanam (VTX, 19.20 kHz), India, Exmouth, Western Australia (NWC, 19.80 kHz) and Anthorn, United Kingdom (GBZ, 19.58 kHz). The data were recorded at ILR station from 23$^{rd}$ of January 2021 to 17$^{th}$ May 2021. Here are the observations from ILR, an equatorial station. The amplitude of the VLF signal for 24 hours at the ILR VLF observatory on January 23, 2021, is shown in Figure 3.

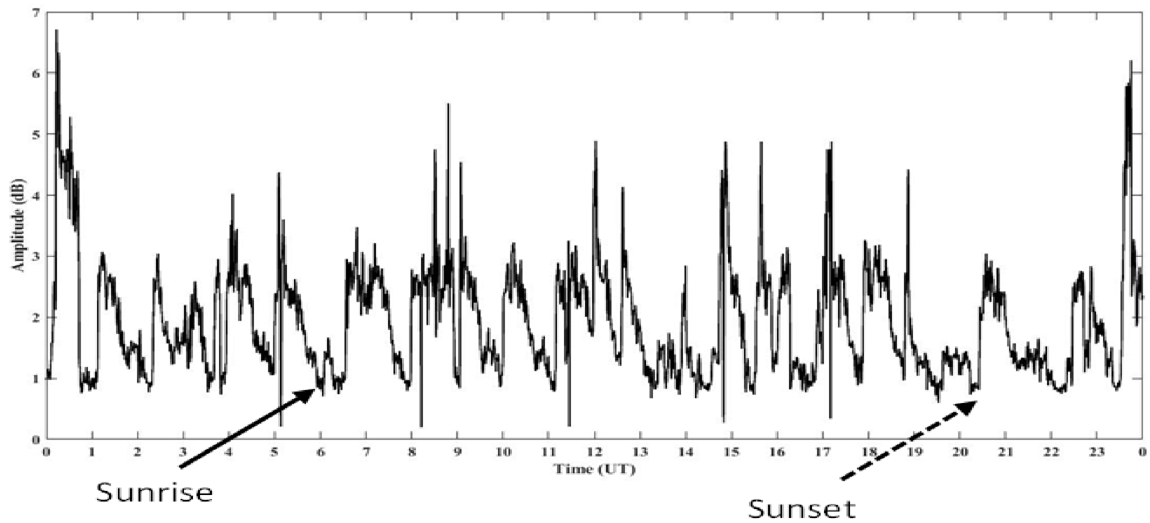


**Figure 3:** A typical diurnal variation of the signal amplitude of the VTX transmitter on a quiet day (24 hours) at the ILR observatory.

Figure 3 shows the amplitude of VLF for VTX station on a solar quiet day at ILR station, an equatorial observatory. The term 'solar quiet' here means the period in which there is the absence of geomagnetic and solar disturbances. The variation of VLF amplitude (dB) against time in UT for 24 hours on January 23, 2021. The sunrise signature is shown by the continuous black arrow, while the sunset signature is shown by the dashed line arrow. The period after the dawn (sunrise) signature and the after the sunset signature represent the daytime and nighttime, respectively. The daytime is the interval between the sunrise and sunset signatures (Sasmal et al., 2014, Oladipo *et al.*, 2021).

There is a need to observe the comparison of the VLF signal from VTX, NWC and GBZ stations which are at a distance of 7,649 km, 11, 807 km and 5,681 km respectively from the receiver at ILR station. Figure 4 shows the plot of SID on the 28th of February 2021.

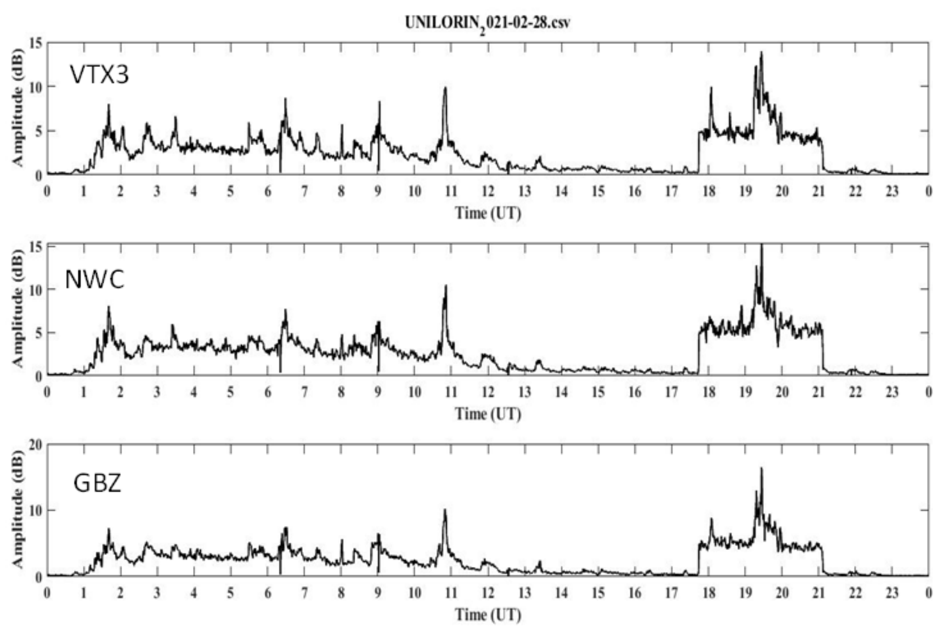


**Figure 4:** Samples of the narrow-band data from three stations on 28th February 2021

From Figure 4, it can be observed that the NWC transmitter, though more powerful than the VTX transmitter, the received signal is weaker and less varying than the VTX data perhaps because of the propagation distance of NWC (~12,000 km) as compared to VTX (~8,000 km). The GBZ (~6,000 km) signal is also stronger than the NWC transmitter. This could be because a major portion of the NWC-ILR path is characterized by a very low conductivity (Sasmal et al., 2014).

The result of the VLF amplitude for some selected days in the year 2021 is illustrated in Figure 5. The results indicate the expected morphology of the VLF signal which is important in flagging the occurrences of the solar flare.

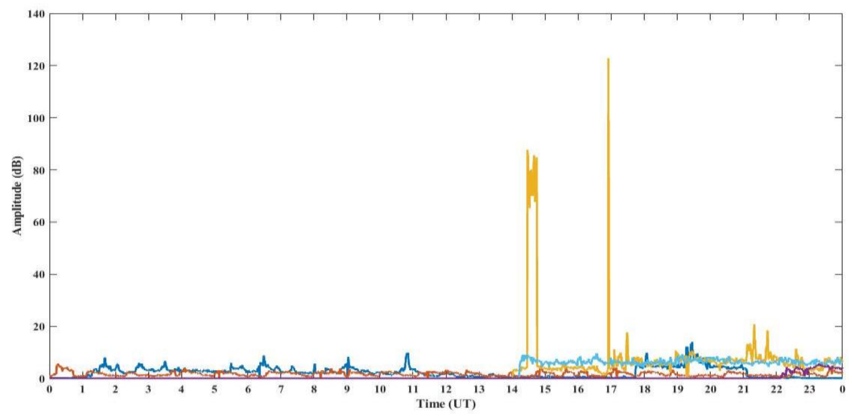


**Figure 5:** The diurnal variation of the signal amplitude of the VTX transmitter for several weeks of data. Each of the lines with colours represents the VLF signals for the different epochs.

The appearance between 07.0 UT and 18.0 UT represents the sunrise and sunset fading associated with the sunrise and sunset along the propagation path. Due to the long VLF path, the duration of the sunrise and sunset fading is very long (~5 hours) giving rise to shallower dips due to the terminators. Generally, in long paths, a series of minima are expected around the time of sunrise along the transmission path which is associated with modal conversion effects as the sunrise terminator crosses the transmitter-receiver path, which is associated with modal conversion effects as the sunrise terminator crosses the transmitter-receiver path (Moral et al., 2013).

***VLF and NmD Variation***

Figure 6 shows the plot of data samples by Rx on the 28th of February, 2021, it is 24 hours of data recorded at UT time, and an electron density of the ionospheric D-layer (NmD) obtained from the IRI model.

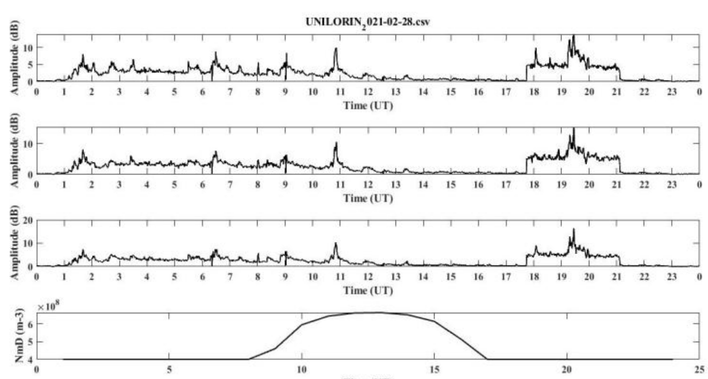


**Figure 6:** Variation of NmD values corresponding to VTX, GBZ and NWC signals.

From figure 6, a comparison was made with the VLF amplitude signal with an electron density of the D-region that was obtained from the (IRI) model. The result of the work shows a period of sunrise time (SRT) and sunset time (SST) on the VLF amplitude signal for some selected days.

**Conclusions**

Having presented the result and analysis of this research, the following conclusion was inferred:

The diurnal variation observed at ILR shows that the quiet day ionization is highest at noon. Thus, signal strength is always high around noon compared to other times of the day.

By comparing the VLF amplitude signal with an electron density of the D-region that was obtained from (the IRI) model. The result of the work shows a period of sunrise time (SRT) and sunset time (SST) on the VLF amplitude signal for some selected days.

The quiet day morphology at the ILR station reveals that the VLF signal strength is high at night than in the daytime. This shows evidence of 24 hours of solar radiation and the signature of the appearance and disappearance of the D-region.

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