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# Implementation of a low-energy VLF data logger for characterizing the lower ionosphere at Ibadan

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## ABSTRACT

This study implemented a very low frequency (VLF) data logger for monitoring the local ionosphere. The VLF data logger was built around a Raspberry Pi 3B+. A 1 $m^2$ loop antenna with a sensitivity of $5.86 \times 10^{-4}$ $V/s^{1/2}m^{-1}$ was built to receive the VLF signal. The system recorded three frequencies: 19.2, 19.58, and 19.8 kHz from South Vijayanarayanam (India), Anthorn (UK), and Exmouth (Australia), respectively, at Ibadan, Nigeria. Three months (June–August 2019) of data were reported in this study. The results revealed that the data logger saves up to 83% energy compared to an average laptop. The system was able to characterize the diurnal morphology of the D-layer. The diurnal morphology shows the sunrise and the sunset effect (signature). It was noted that variations exist in the average signal strength on quiet days; therefore, further study is recommended to investigate the geophysical conditions that are responsible for these variations.

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## 1. Introduction

Very low frequency (VLF) is a band of radio waves with a frequency of 3–30 kHz (Pal et al., 2017). Known sources of VLF are usually from military submarines located around the world (Sulic et al., 2016). VLF is propagated in the Earth–ionosphere waveguide (Devi et al., 2008) as skywaves and ground waves (ITU-R, 2017) with the ionosphere and the earth surface forming the upper and lower boundaries, respectively.

The ionosphere responds to the dynamics of the sun, therefore, VLF propagation is influenced by space weather. The study of space weather is important because it affects communication systems, satellites, power grids, and oil exploration (Ezekoye and Obodo, 2007). Hence, since the amplitude of the VLF signal strength is affected by the dynamics of the lower ionosphere, the signal is being used as a proxy to study the lower ionosphere (Dahlgren et al., 2011). The use of VLF to study the lower ionosphere (D-layer) is important because the D-layer is located such that *in situ* measurement is challenging; thus, the VLF signal is used as a remote sensor to probe the D-layer and study the space weather.

Adimula (2005) has earlier shown that a large discrepancy has been found between standard models and observations in the equatorial stations in the West Africa region, partly due to the low representation of the Africa region in the computation of such models. This problem informs the need to increase the number of observations in Africa. Power is one of the major factors mitigating the deployment of instrumentation in the Africa.

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Thus, the general aim of the study is to implement a low-energy VLF data logger for characterizing the local ionosphere at Ibadan. The specific objectives of this study is to (1) construct and install a loop antenna to receive VLF signals; (2) implement energy-saving hardware and software to record and store VLF data; and (3) validate the data collected and present the quite day diurnal morphology of VLF signal as received at KolaDiasi University, Ibadan (KDU-I). The result of the study will increase the number of observations in Africa and also help us to understand the morphology of the local ionosphere around this region.

## 2. Materials and Methods

Stanford University distributes a low-cost VLF preamplifier to track solar flares. Figure 1 shows the block diagram of a VLF data logger. The antenna receives the signal and sends it to the preamplifier to amplify the signal. The analogue digital converter converts the analogue output from the preamplifier to a digital signal that can be processed and stored by the computer (data analyzer). The main software produced for the VLF hardware was for windows; however, a modified version that can work on Raspbian has being implemented by Abdullah et al. (2016). This study will also implement the Raspbian version because Raspberry Pi consumes low energy.

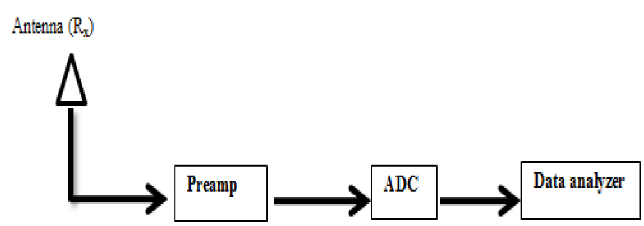


**Figure 1.** Block diagram of the sudden ionospheric disturbance (SID) tracking system.

**Figure 2.** Loop antenna.

### 2.1. Antenna design and construction

A square-shaped loop antenna was constructed on a wooded frame of an area of 1 m$^2$ (see Figure 2); the antenna has 31 windings with 24 American Wire Gauge (AWG) (diameter 0.511 mm) wire.

When a VLF signal passes through a loop antenna, a voltage will be induced. The magnitude of the induced voltage $V_0$ is given by

$$V_0 = j2\pi fNA\cos\theta \quad (1)$$

where $f$ is the frequency of the signal (Hz), $B$ is the magnetic flux density ($T$), $A$ is the area of the loop antenna (m$^2$), $N$ is the number of turns, and $\theta$ is the angle of the magnetic field from the axis of the loop (Zakaria et al., 2018).

The antenna sensitivity can be obtained using

$$S = \frac{c\sqrt{(4kTR)}}{2\pi NA} \quad (2)$$

where $k$ is the Boltzmann's constant, $T$ is the temperature ($K$), and $R$ is the Direct Current (DC) impedance of the loop.

At room temperature $4kT = 1.61 \times 10^{-20}\ J$ (Tan, 2015). The DC resistance of the loop antenna is 8.98 Ω. Therefore, the sensitivity of the antenna is $5.86 \times 10^{-4}$ V/s$^{1/2}$m$^{-1}$.

### 2.2. Hardware deployment

The resources needed to set up the hardware of the VLF data logging system are as follows: Raspberry pi 3B+, preamplifier (the preamplifier used in this research was provided by Stanford Solar Centre), SD card (32 GB), 7.1" Liquid Crystal Display (LCD), USB sound card, 5 V power supply (two units; one for Raspberry Pi and one for the LCD module each), acrylics board (to construct a stand for the LCD), standard keyboard, mouse, loop antenna, and access to the Internet.

The Raspberry Pi device can run on various operating systems (OS), but the Raspbian OS was chosen because it is energy efficient (Astudillo-Salinas et al., 2016). The Raspbian image was downloaded from the official Raspberry Pi website (https://www.raspberrypi.org/downloads/). The image was "Unzip" using *7zip* software, and then the image was etched into a 32 GB SD card using balenaEtcher-Portable-1.5.56 software. The SD card was inserted into the Raspberry Pi board, and then the keyboard, the mouse, and the LCD module were connected. The sound card was inserted into a USB port on the Raspberry pi and the preamplifier was connected to the recording jack on the sound card. The loop antenna was then connected to the preamplifier. The preamplifier was powered using the 5 V from the USB port of the Raspberry Pi. Upon completing the connections, the Raspberry Pi and the LCD were powered using a 5 V power supply.

### *2.3. Configuring Raspberry Pi (software configuration)*

The Raspberry Pi was powered on and connected to the Internet for necessary software update. Raspbian OS version of SuperSID software was downloaded from https://github.com/ericgibert/supersid as SuperSID_Master. However, to run the SuperSID_Master Matplotlib, wxPython, NumPy, and alsaaudio modules need to be installed on the Raspberry Pi (Abdullah et al., 2016). The instructions to install these dependencies can be found on https://geoffboeing.com/2016/03/scientific-python-raspberry-pi/.

The configuration files of the SuperSID_Master software were edited to execute the command in the Graphics User Interface (GUI) mode. Additionally, the data path, the audio sampling rate, and the USB sound card were also edited in the configuration files. Upon executing the SuperSID_Master software, spikes were seen on the waveform. Figure 3a shows the frequency spectrum with the spikes representing the list of stations available.

The frequency associated with each spike represents the signals available. Available frequencies were compared to the list of VLF stations on https://

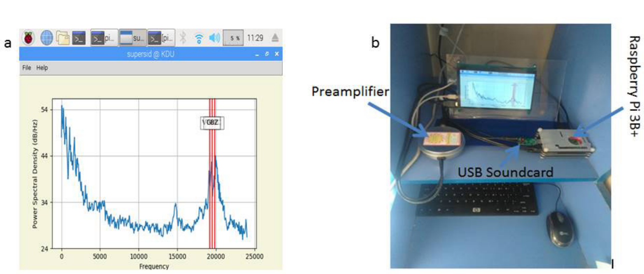


**Figure 3.** VLF data logger. (a) Spectrum showing the available stations at KDU-I. (b) Raspberry Pi-based VLF data logger.

**Table 1.** List of VLF transmitters.

| Country | Call sign | Frequency (Hz) | Location | Latitude | Longitude |
|---|---|---|---|---|---|
| India | VTX4 | 19,200 | South Vijayanarayanam | +08.38 | +077.75 |
| UK | GBZ | 19,580 | Anthorn | +54.91 | −003.28 |
| Australia | NWC | 19,800 | Exmouth | −21.82 | +114.17 |

sidstation.loudet.org/stations-list-en.xhtml; https://www.mwlist.org/vlf.php, and then three stations were added by editing the configuration files. Figure 3b shows the complete instrumentation setup.

Table 1 shows the list of stations recorded for this study. The SuperSID_Master software samples data every 5 seconds for each station. The data collected are stored on a virtual memory.

### *2.4. Data collection*

The SID monitor was installed at KDU-I, Ibadan, Nigeria (+7.6248°, +3.9131°). It recorded the amplitude of three VLF signals. The data reported in this study were collected from June to August 2019.

## 3. Results and Discussion

### *3.1. Power saving*

The data logger assembled demonstrated high efficiency at saving energy. In order to determine the power consumption of the constructed data logger and how much energy it saves; the Peacefair power meter (Model PZEM-061) was used to take readings.

The Raspberry Pi 3B+ and other components excluding the screen consume ≈ 3 W, the system consumes an additional ≈ 0.4 W while taking the readings (VLF signal was recorded every 5 seconds). The 7" screen consumes ≈ 5 W, also, ≈ 2 W is used when connected to the Internet. Therefore, the total power consumption of the VLF data logging system with the screen is ≈ 10.5 W. Replacing a conventional monitor with the 7" screen made a big difference. A laptop consumes about 32 W of energy (Desroches et al., 2014). Therefore, the energy-saving VLF data logger (E-VLFr) constructed saves about 83% of energy compared to an average laptop. The E-VLFr constructed in this study consumes 252 Wh per day; this is an improvement on earlier work (Abdullah et al., 2016) which needs an estimated 960 Wh power per day. This improvement makes E-VLFr energy-friendly and suitable for battery power backup.

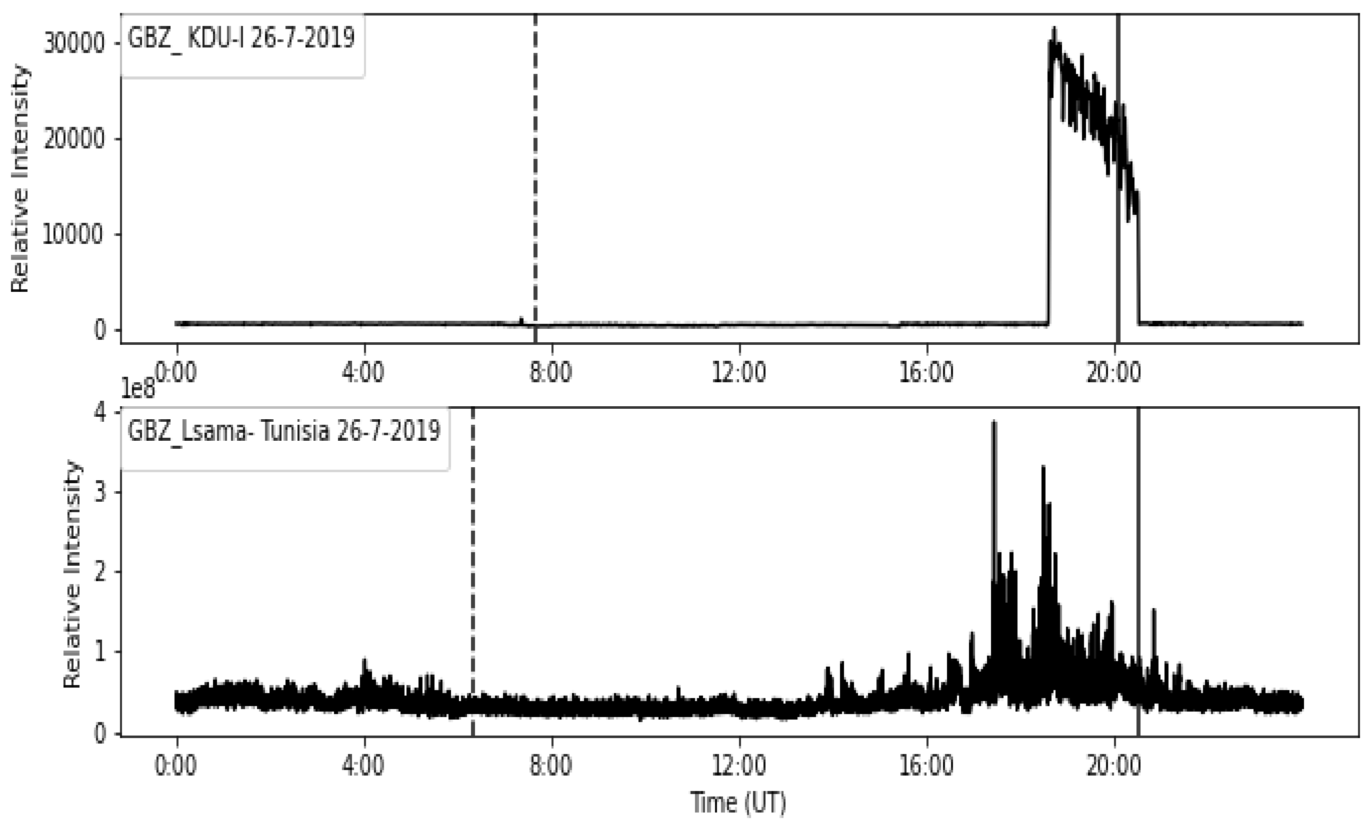


**Figure 4.** Diurnal morphology of VLF signal from GBZ station recorded at KDU-I and Lsama-Tunisia on 26/07/2019.

### *3.2. Data validation*

For validation, data recorded by the E-VLFr was compared with data from Lsama-Tunisia station (10.14°, 36.83°), which is available on http://sid.stanford.edu/database-browser. Among the stations monitored, only the GBZ station was available on both monitors, so data for the GBZ station was compared. The data collected in July were used for the validation because Lsama-Tunisia does not have data for June when the data collection started. A day was arbitrarily selected to compare the data from the two locations. The local time of Tunisia is GMT +1 which is the same as Ibadan during the period the data were recorded. Thus, we expected variations which are mainly due to longitudinal variation between Ibadan, Nigeria, and Lsama-Tunisia.

Figure 4 shows the plot of GBZ stations recorded at KDU-I and Lsama-Tunisia. The dashed line indicates the local sunrise time, while the continuous line indicates the local sunset time (https://www.timeanddate.com/sun/). The plots show pre-sunset enhancement in the two stations (7:20 UT at KDU-I and 4:33 UT at Lsama-Tunisia). Although the pre-sunset enhancements were small, they were noticeable. The enhancements indicate the sunrise signatures.

Also, there was a more prominent enhancement around the sunset time on both monitors. The enhancement at both stations started before sunset time. The perturbation gradually reduced through the local sunset and ended after the local sunset time. In addition to the above similarities, using Pearson's correlation, the correlation between the hourly average of both stations was found to be $r = 0.63$. This is a moderate correlation. Hence, the comparison confirms that the data being recorded is valid and a representation of the GBZ–KDU-I propagation path.

### *3.3. Diurnal morphology*

Figure 5 shows the diurnal morphology of the VLF signal from three stations: NWC, VTX4, and GBZ. The data plotted were recorded on 30/06/2019 at KDU-I using the E-VLFr. NWC station was enhanced between 5:00 UT and 8:00 UT (6:00–9:00 LT), while GBZ stations had a depression during the same time frame. Furthermore, there was a depression in the relative signal intensity of VTX4 around 5: 00 UT, but then

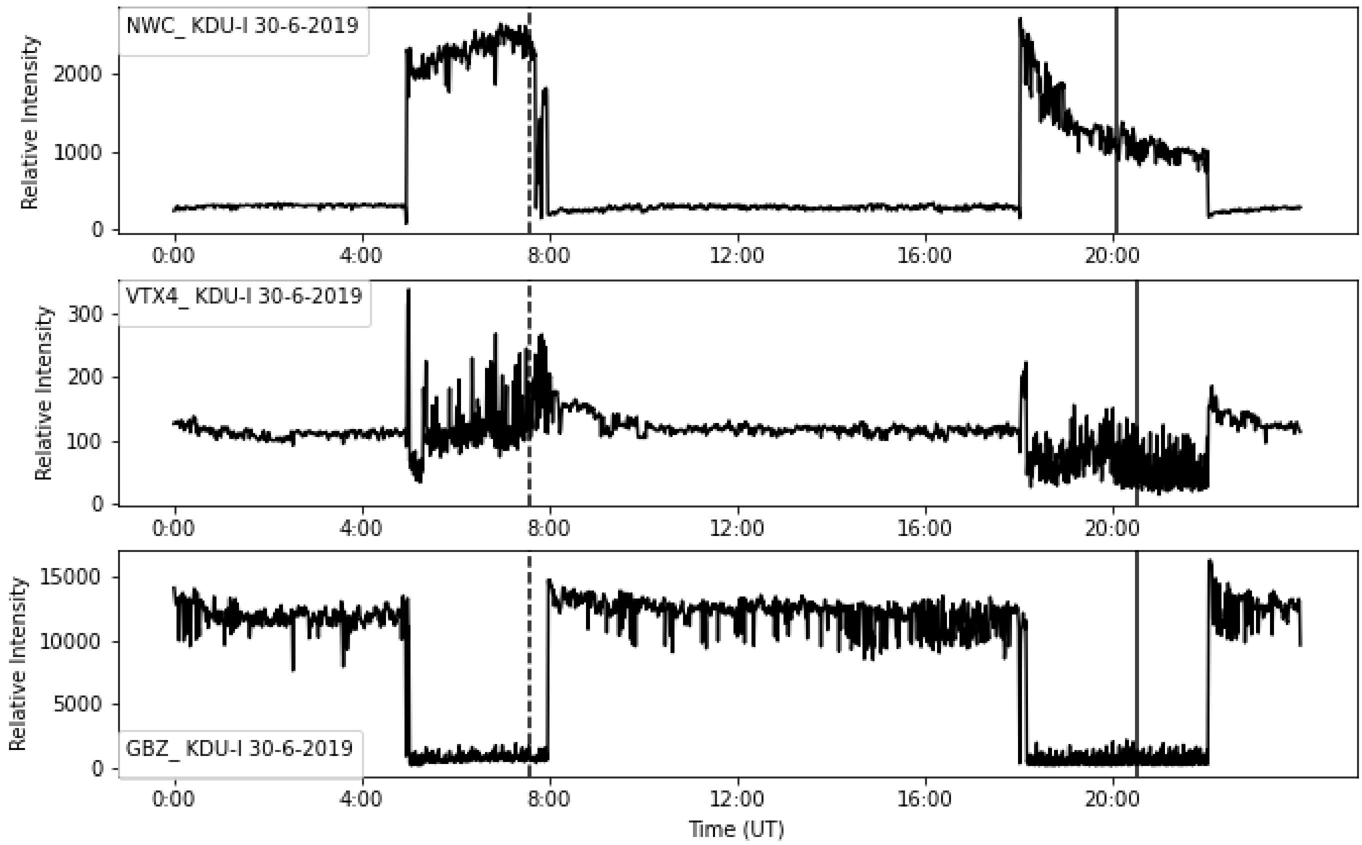


**Figure 5.** Diurnal morphology of VLF signal at Ibadan.

the signal would gradually increase till after sunrise (8:00 UT).

During the evening time, there was a similar depression for VTX4 and GBZ and an enhancement for NWC around 18:00 UT (19:00 LT) which gradually subsides till 22:00 UT (23:00 LT) on the same day. It was observed that the sunset signature precedes actual sunrise time; however, this observation is not strange, as similar observation has been reported by Sulic et al. (2016).

The VLF data logger is also known as a SID monitor because it can be used for monitoring SID (Scherrer et al., 2010). Because the period under consideration is a low solar activity period, so no SID was recorded. But the sunrise and sunset signatures are a major feature of the diurnal morphology of the SID monitor (Scherrer et al., 2010). Therefore, since the sunrise and sunset signatures were prominent, the installation was successful.

## 4. Conclusion

This study implemented a low-energy VLF receiver. The receiver was built around a Raspberry Pi. The data recorded were validated using data from an existing station. The success of the receiver in characterizing the local ionosphere was further validated in the quiet day diurnal morphology which shows prominent sunrise and sunset signature.

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