The Use of Raspberry Pi and High Resolution Sound Card for Very Low Frequency Signal Detection

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***Abstract*— Space weather research is an important aspect in studying and monitoring the effects of extraterrestrial forces outside the earth on human activities. Stanford University under International Space Weather Initiative (ISWI) program has developed first generation of sudden ionospheric detection named as SuperSID. To enable the usage of this system for community outreach space science education program, a portable and low cost system need to be developed. Raspberry Pi can be used as the main processor for the SID system. It can be easily operated without the need of a personal computer. However, the available sound card are limited and sampling rate is on 48 kHz. This limit the detection of the VLF frequency detection to approximately 22 kHz. Thus it become a limiting factor to view the VLF spectrum in a full range (3-30 kHz). To overcome this problem, a VLF receiver system with a better sound card (Audio Injector) was proposed to detect the signal in a full VLF spectrum with the objective for a better data analysis. The hardware aspects including an antenna, a pre-amplifier, a sound card (Audio Injector) and a microprocessor (Raspberry Pi) with LCD Touchscreen as its monitor display. The VLF acquisition software part consists of an acquisition software executable by Python programming language with additional modules that runs in Raspberry Pi. Finally a portable VLF receiver system with maximum sampling rate of 96 kHz has been developed to capture VLF signal between 3-30 kHz.**

Keywords-component; SuperSID, VLF Receiver, Audio Injector, Raspberry Pi, Python, ionosphere

I. INTRODUCTION

Earth' sky contain several layers generally called the Atmosphere, Ionosphere and Magnetosphere. Ionosphere is located at altitude between 60 and 1000 km. Ionosphere consists of three layers namely D-layer (60-90km), the E-layer (90-140km) and F-layer (above 140km) [1]. The numbers of ionosphere layers are depending on the electron density. Solar flares with strong hard UV and X-rays component will increase ionization process in the D region. It increases VLF phase velocity because the reflection height is lower [2]. The VLF wave has unique characteristics due to their efficient global propagation (attenuation rates of only a few dB/Mm) and deep penetration properties into seawater which enable the communications between submarines [3]. The propagation conditions of the VLF signal have a significant modification due to severe changes of electron density in the lower ionosphere layer induced by solar X-ray flares, leading to the increase of electron density in the D-layer by 1-2 orders of magnitude. This condition can change the conductivity of the upper waveguide edge and the other propagating of the VLF signals. These changes can be detected by the VLF field strength variation [2]

Sudden Ionospheric disturbances (SID) can affect radio communications and navigations using radio spectrum [4]. The variation through periodic pattern which can be differentiate from the empirical data is known as first group. Daily variation, seasonal variation, dependence in geomagnetic field and climatology in outer space weather are the example of the first group of variation. The second group of variation is SID that does not showed any behavior pattern to the magnitude and period of occurrence [5].

An inexpensive space weather monitor system has been design and developed by Stanford University's Solar Center to encourage school students explore and understand Space Sciences. It can detect changes in the Earth's ionosphere caused by solar flares and other disturbances [6]. This system can measure effects of solar flares on Earth by tracking the changes in a VLF signal as it bounce off in the Earth's ionosphere. The VLF signals emits from the transmitter stations set up by various country for submarines communication purposes. The VLF signal strength in the Earth ionosphere affected by the Sun and change the waves propagation in this layers [6]. Under International Space Weather Initiative [6] and International Heliophysical Year, these SID monitors have been place in many countries.

In 2012, University Kebangsaan Malaysia (UKM) had developed a VLF receiver system known as UKM-SID. It uses for SID detection and SuperSID Introductory Project teaching kit [7]. In 2015, a portable VLF data acquisition system using Raspberry Pi has been designed and developed. It successfully acquired VLF signal transmitted from NWC (19.8 kHz) from Australia. This system can be operated without the need of a large and expensive computer [8]. This system used a USB external sound card (Creative Sound Blaster X-Fi Go! Pro) to acquire amplified VLF signal at a sampling rate of 44.1 kHz. As such, it can only can acquire VLF signals with maximum frequency of 22.05 kHz [8].

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The paper describe the development of a portable VLF receiver system using the latest model version of Raspberry Pi with a sound card that has a higher sampling rate and compatible to the Raspberry Pi kernel. The Audio Injector sound card with a sampling rate capability of 96 kHz was chosen to replace the previous UKM-SIDπ external USB sound card. The system consists of antenna, pre-amplifier, analog to digital converter (sound card), Raspberry Pi and LCD touchscreen display as its monitor display. SuperSID software is an open source software and written in Python by Eric Gibert [9]. It can be retrieved from the GitHub website to record the pre-amplified signal received by the antenna.

II. METHODOLOGY

This project can be categorized into the hardware and the software aspects. The hardware aspects including an antenna, a pre-amplifier, a sound card, a microprocessor and a LCD touchscreen display. For the software aspect comprises the SuperSID software written in Python and can be obtained from GitHub [9].

From Fig. 1, the diagram shows the components of the VLF receiver system. It consists of a loop antenna to acquire the VLF signal being transmitted, typically the signal is a very low induced output voltage and need to be amplified using a pre-amplifier. The amplified signal is sampled at a sampling rate of 96 kHz using the Audio Injector sound card. The signal data captured was processed and stored in the microSD card connected to the microprocessor (Raspberry Pi) using the SuperSID software.

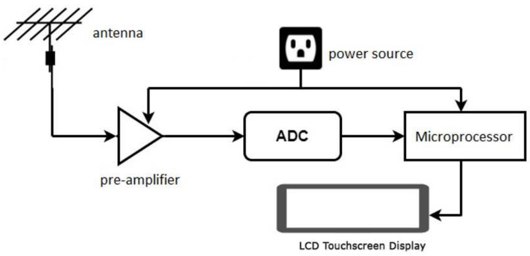

Fig. 1. Block diagram of VLF receiver system

A. Loop Antenna

The loop antenna used in Fig. 2 was already been built by high school students (SMK Pantai Sepang Putra). It was used to retrieved the VLF signal transmitted by the VLF transmitter station in Australia. The component used to build this antenna consist of a PVC frames and 24 turns of single core wire, with the size of approximately one-meter square. As for the antenna output, RG58 coaxial cable was used to connect the antenna output to the pre-amplifier.

Fig. 2. Loop antenna

B. Pre-amplifier

The pre-amplifier was redesigned using the software Altium Designer as shown in Fig. 3 based on the schematic of SuperSID pre-amplifier developed by the Stanford Solar Center. Fig. 4 shows the design of the pre-amplifier with a double layer layout PCB. Through-hole Technology (THT) components were chosen to solder on the board due to its bigger form factor than the previous UKM-SIDπ pre-amplifier.

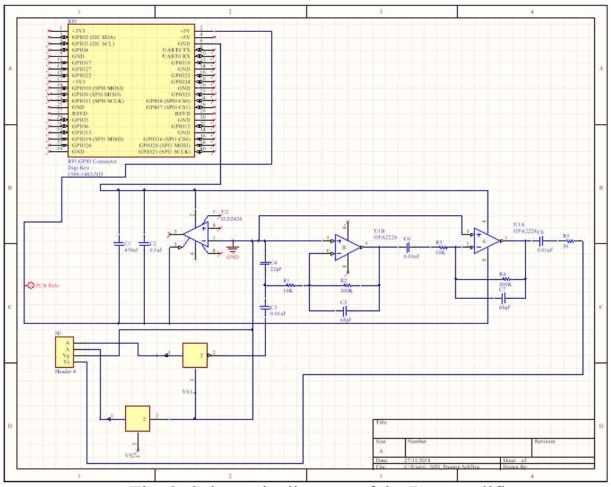

Fig. 3. Schematic diagram of the Pre-amplifier

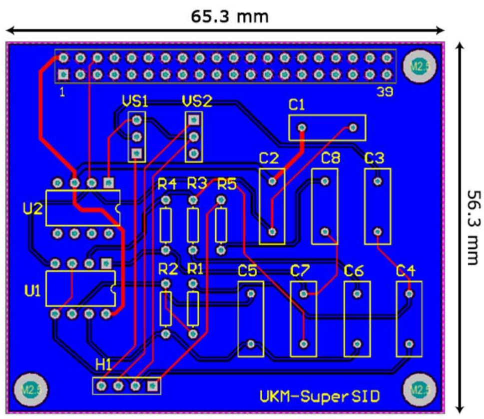

Fig. 4. PCB layout of the Pre-amplifier

C. Sound card

The VLF signal must be convert from analog to digital for the software to process the data. Fig. 5 shows the Audio Injector sound card by Flatmax Studios which was used to capture and sampled the signal received.

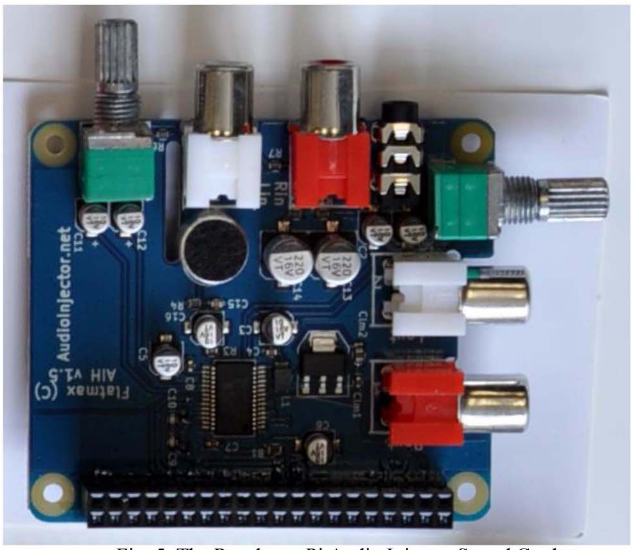

Fig. 5. The Raspberry Pi Audio Injector Sound Card

The sound card is capable of sampling the signal received with a sampling rate of 96 kHz, which mean we can view the maximum frequency spectrum up to 48 kHz which can be calculated using Eq. 1. The benefit of using this sound card is that the driver is already integrated into the Raspberry Pi kernel and the installation steps are easy to follow [10].

$$fMAX = \frac{fs}{2} = \frac{96000}{2} = 48000Hz \quad (1)$$

D. Raspberry Pi and Display

The Raspberry Pi is a small and compact computer that in general has all of the basic function of a computer system. The difference is only in the specifications and the components to build it which is not very high spec compared to a desktop computer. It has the basic specifications of a standard desktop computer, for example an Ethernet port, SD card slot, USB slot, HDMI port, 3.5mm input jack and many more. The version of the Raspberry Pi that was used in this project was Raspberry Pi 3 Model B+ shown in Fig. 6 which is the current latest version.

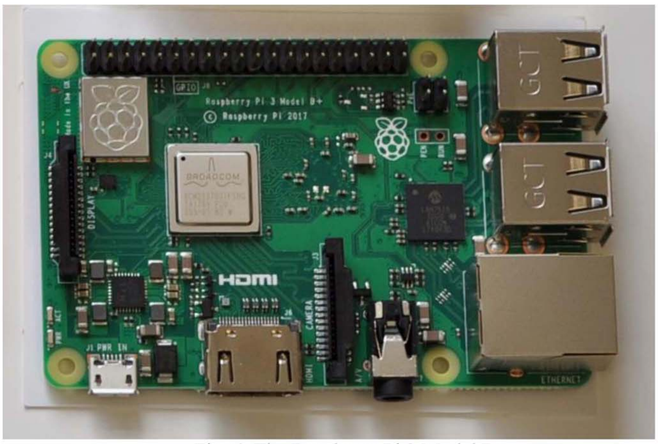

Fig. 6. The Raspberry Pi 3 Model B+

For this project, a 16 GB microSD card was used to store the image file of the Raspbian operating system, the SuperSID software and the Audio Injector sound card driver. The installation process of the Raspberry Pi 3 Model B+ is the same as the standard installation process shown by the Raspberry Pi Foundation. The version of the image file used was (2018-10-09-raspbian-stretch.zip) which can be retrieved in the official website Raspberrypi.org. A 7-inch LCD touchscreen display was used as the output display for the Raspberry Pi using the DSI ribbon cable and jumper wires connection and the whole setup are as shown in Fig. 7.

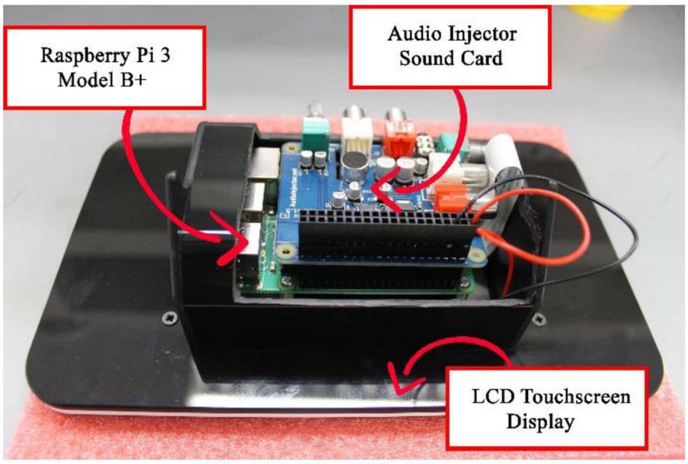

Fig. 7. The whole UKM-SIDπ setup

E. SuperSID Software in Raspberry Pi

The software is an open source and can be obtained from the GitHub website “https://github.com/ericgibert/supersid.git”. It was written in a Python language, executable with the Raspberry Pi which runs on Linux environment. There are additional modules installed for this software to run and that is matplotlib, wxPython (wxgtk 2.8), numpy, scipy and alsaaudio [8].

Matplotlib module was installed in the Raspberry Pi to plot the acquired VLF signals. The alsaaudio is the driver for external sound card in the Linux environment. Numpy or Scipy has the function which in general to process the array package to manipulate the large multidimensional arrays of arbitrary records. The wxPython has been used to create a user friendly graphical user interface [8].

Before running the SuperSID software, the input command line in the configuration file (supersid.cfg) need to be changed according to the setup of the system. For example, the command "viewer=tk" was used to enable the graphical user interface (GUI) mode. The "audio_sampling_rate" was changed to 96 kHz which is currently supported by the sound card. The command "data_path = /home/pi/supersid/Data" need to be set to save the data in that directory and the Audio Injector sound card was chosen to process the VLF signal by changing the command line "Card= audioinjectorpi".

III. RESULT AND DISCUSSION

A. UKM-SIDπ Pre-amplifier PCB

The new design of the pre-amplifier board in Figure 8 has a bigger form factor (56.26×65.26mm) compared to the previous UKM-SIDπ pre-amplifier.

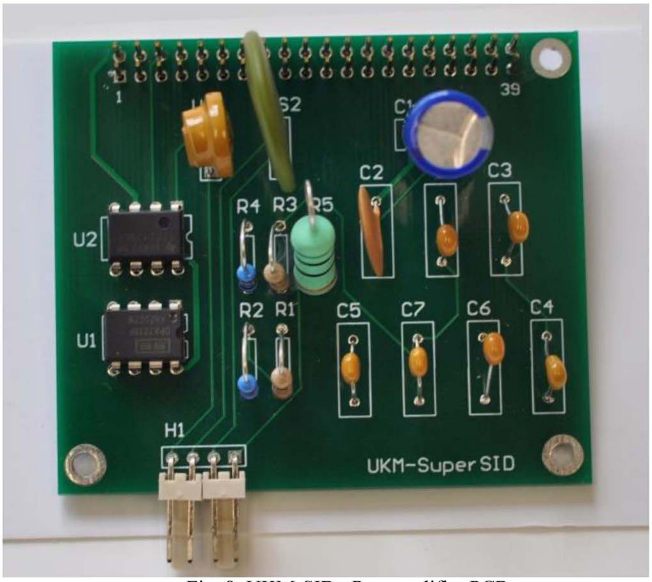

Fig. 8. UKM-SIDπ Pre-amplifier PCB

The original SuperSID pre-amplifier can amplify VLF signal about a thousand times [6]. An experiment has been conducted to calculate the gain using a function generator with a frequencies range from 2-100 kHz with voltage input (V_{in}) of 500 mV. The amplifier gain is calculated based on Eq. 2.

$$Gain = 20\log\left(\frac{V_{pp}}{V_{in}}\right) \qquad (2)$$

where Vpp = peak-to-peak output voltage

The data obtained was used to plot the gain versus frequency plot as shown in Fig. 9, the graph show that the new UKM-SIDπ pre-amplifier has a low pass filter characteristic.

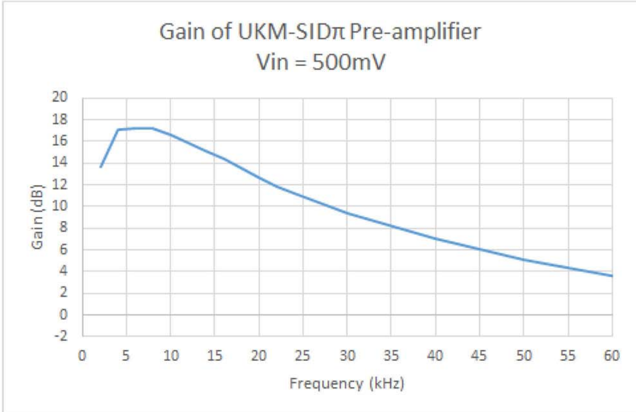

Fig. 9. Graph plot of Gain vs Frequency for the UKM-SIDπ Pre-amplifier

B. VLF Receiver System Test

The overall VLF receiver system in Fig. 10 consists of loop antenna connected to the pre-amplifier via RG58 coaxial cable connection to amplify the VLF signal received and the pre-amplifier output was transfer to the UKM-SIDπ system in which it was processed by the Audio Injector sound card. We can monitor and capture the signal being received using the SuperSID software [9].

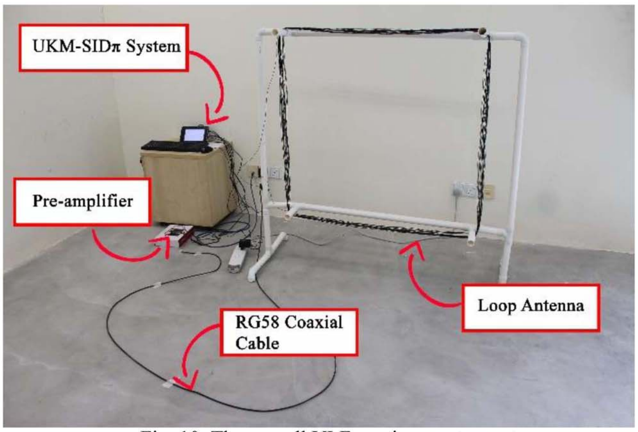

Fig. 10. The overall VLF receiver system setup

The system was installed at level 7, Research Complex, UKM and the data is being logged daily (every 24 hours) into the Data directory in the microSD card for future analysis. The SuperSID software was pre-coded to monitor and capture VLF signal of 19.8 kHz that are being transmitted by the transmitter station at North West Cape (NWC), Australia. A clear and stable peak of 19.8 kHz has been detected by the VLF receiver system as shown in Fig. 11 using the SuperSID software.

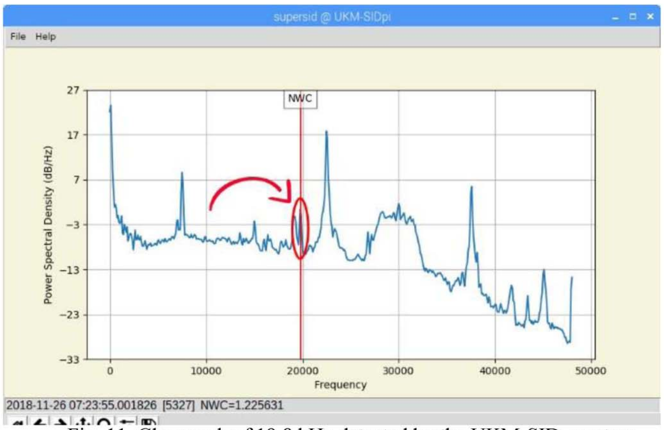

Fig. 11. Clear peak of 19.8 kHz detected by the UKM-SIDπ system

Fig. 12 and Fig. 13 shows the diurnal variation of NWC VLF signal acquired during 25 November 2018 on a typical quiet day. The data plot has a low-signal-strength of the VKF signal during daytime, sunrise and sunset signatures and a high-signal-strength during the night time. At day time, the field strength changes smoothly with a maximum at noon due to the reflection position of D-layer changes with zenith angle of the Sun [2]. After sunset, the thinning of D-layer follows by the reflection occur from the F-layer. It cases the VLF signal strength varies r as the F layer is not stable during nighttime.

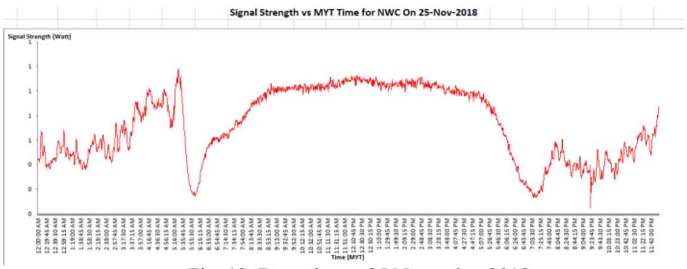

Fig. 12. Data plot on 25 November 2018

Local sunrise (7:01 am) and sunset time 7:00 pm) is shown Fig. 13 respectively. It is the prayer times for the Muslims (Syuruk and Maghrib) and verified by JAKIM – Putrajaya.

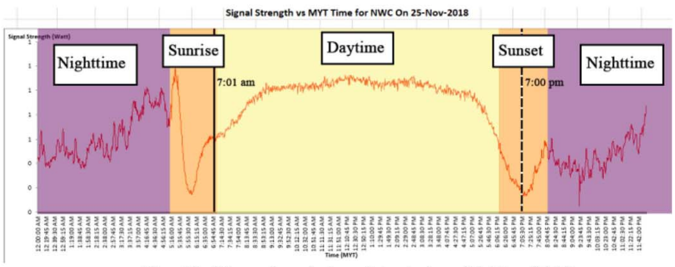

Fig. 13. Diurnal variation detected on 25 Nov 2018

C. Comparison between previous UKM-SIDπ and latest UKM-SIDπ

Comparison between SuperSID (original system), UKM-SIDπ version 1 and the UKM-SIDπ Version 2 system is shown in Table 1. The new UKM-SIDπ system has twice the processor clock speed and RAM size which mean it has better performance than the previous system. It also has Wi-Fi and Bluetooth technologies, expanding its capabilities for the user to operate. But the main point to highlight is the system sound card (Audio Injector) in which the new UKM-SIDπ system has a higher sampling rate which mean we can view the VLF spectrum in full range (3-30 kHz).

TABLE 1. COMPARISON BETWEEN THE OLD & NEW UKM-SIDΠ SYSTEM

SuperSID Monitor	UKM-SIDπ Ver. 1	UKM-SIDπ Ver. 2
Dekstop / Laptop PC	Raspberry Pi Model B	Raspberry Pi 3 Model B+
Sufficient to run windows	CPU Clock 700 MHz	CPU Clock 1.4 GHz
Sufficient to run windows	RAM 512 MB	RAM 1 GB DDR2
Ethernet port	No Wi-Fi & Bluetooth	Support 2.4 GHz and 5 GHz Wi-Fi & Bluetooth 4.2
Sound card with sampling rate of 96 kHz	External sound card with sampling rate of 44.1 kHz	External sound card with sampling rate of 96 kHz
Windows OS	Linux OS	Linux OS
500 Watt	10 Watt	10 Watt
RM 1500.00	RM 120.00	RM 200.00

IV. CONCLUSION

A portable VLF receiver system using the latest model of Raspberry Pi and a better sound card (Audio Injector) has been design and developed. The latest UKM-SIDπ system has been tested and able to acquired VLF signal transmitted by NWC station (19.8 kHz) from Australia. This system show its capability to be part of the global space weather sensor network and it can be easily operated by a high school student or teacher without the need of a large and expensive computer. Besides that, it could also use as teaching kit for promoting science, technology, engineering, mathematics and space science education to the high school students in pursuing the course for a better generation to come in a modern and technology-driven nation in the future.

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