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Attached are two papers associated with Prof. Abdullab and SID monitors for space weather applications.

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Development of UKM-SID teaching module for space science education

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Abstract

This paper highlights the development of UKM-SID teaching module for solar flare detection utilizing VLF technique. This module consists of three segments namely, the antenna development, preamplifier and data logger. It was introduced in selected high schools in Selangor, Malaysia, where students need to build the antenna, assemble the preamplifier and analyze the data. They were also required to keep a log book of their activities. With the aid of the teaching module, the students gained hands-on experience in carrying out a team project and indirectly enhance their knowledge in space science.

Keywords: SID; VLF; solar flare; space science; teaching module;

1. Introduction

Space science program was conducted at the international level through the United Nations Office for Outer Space Affairs (UNOOSA) since 1970 and more actively expanded to developing countries through the declaration of Vienna "The Space Millennium: Space and Human Development" in 1999 (Wamsteker, Albrecht, & Haubold, 2004). In Malaysia, this awareness was realized with the establishment of the Planetarium Division, Department of the Prime Minister in 1989 and continued until the establishment of the National Space Agency in 2002. Space weather is an increasingly important research in space science in recent years in studying the effects of the sun in the environment of the earth, satellite, communication and others. Space science research has been conducted in the Faculty of Engineering, UKM since 1999 (Abdullah & Zain, 2000).

Through collaboration between the Institute of Space Science (ANGKASA) UKM and Stanford University, U.S. under the International Heliophysical Year (IHY), research in remote sensing using Very Low Frequency receiver (VLF) was initiated in 2009 at the university using Atmospheric Weather Electromagnetic System for Observation, Modelling and Education (AWESOME) monitor (Salut, Abdullah, & Graf, 2010; Suryadi, Abdullah, Husain, & Siang, 2009). Following the success of the IHY program, the International Space Weather Initiative (ISWI) was formed that focuses mainly on space weather. One of the objectives of ISWI is education and public outreach. Through this program and continuing collaboration with Stanford University, a low cost version of the AWESOME monitor designed for high school named Sudden Ionospheric Disturbance (SID), was obtained (Scherrer, et al., 2008). Based on this monitoring tool, the UKM-SID teaching module has been developed not only focus on the science of space weather but also provide hands-on activities than can stimulate experiential learning.

This paper reports the development of UKM-SID teaching module to be used in high schools in Selangor, Malaysia. The purpose of this project is to provide exposure and early space weather education to high school

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students. This teaching module consists of both educational and research components used to detect the presence of solar flares which is one of the solar activities utilizing VLF signals reflected from the ionosphere.

2. Space Weather

Natural phenomena such as solar flares affect the space weather conditions that surround the Earth (Wamsteker, et al., 2004). Disturbances to the space weather condition have been known to affect human activities on Earth such as disruption of electrical power grid system, navigation system and radio communication systems, as well as interfering with activities in space, such as satellite systems and other technological systems and endanger astronauts (Lanzerotti, 2001). In order to overcome these problems, space weather research and education need to be intensified to ensure that space technology system is well functioned. A remote sensing technique using very low signal frequency (VLF) in the range of 3-30 kHz has been widely used to study the disturbances in the D region of the ionosphere (40-90 km from ground level) (Inan, Cummer, & Marshall, 2010). This disturbance is referred as Sudden Ionospheric Disturbance (SID).

The occurrence of the solar flares that cause the disturbance can be detected by tracking the changes in VLF signal as it is reflected from the Earth's ionosphere (Scherrer, et al., 2008). The signal comes from transmitters that were set up by various nations to communicate with their submarines. Rapid ionization due to the effects of the Sun on Earth's ionosphere changes the signal strength of the VLF that can be detected by the SID monitor (Space Weather Monitors, 2008).

3. Development of UKM-SID module

Based on the support from Stanford University, we constructed our own SID system named UKM-SID teaching module. This teaching module consists of 3 main segments; VLF antenna development, preamplifier assembly and data logger. The antenna will receive VLF signals from various transmitters and this signal will be boosted by the preamplifier and stored in the data logger.

3.1. VLF antenna development

The first segment of the teaching module is the development of the VLF antenna. This antenna is used to pick up the VLF signals reflected from the ionosphere that are transmitted from all over the world. The antenna is a wire loop antenna that can be built in various shapes and sizes. The shape can be rectangular, square, circle, hexagon and others. Larger antenna will have better signal reception. Figure 1 shows the antenna that has been built in UKM which is a rectangular loop antenna with 1 meter square in diameter and with 29 turns.

Figure 1. UKM VLF antenna

3.2. Preamplifier assembly

The second segment is a preamplifier. The preamplifier 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 a thousand times so that it can be detected by the sound card in the data logger. The original preamplifier designed by Stanford University is in the form of double layer printed circuit board (PCB). This type of layout is not suitable for manual assembly, therefore, we simplified the PCB to a single layer layout. Figure 2a shows the PCB layout while Figure 2b shows the PCB after being assembled with the components.

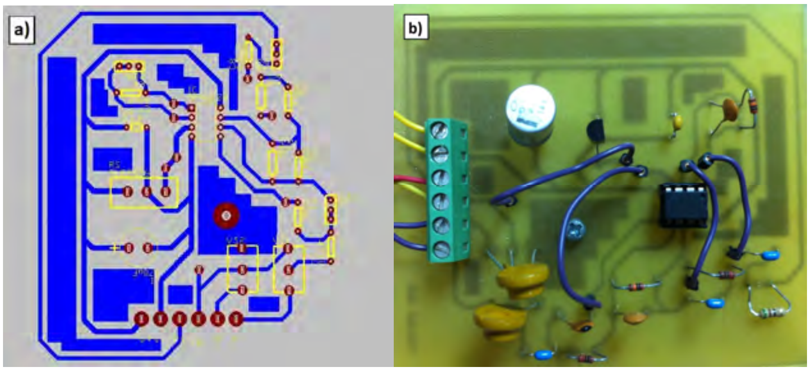

Figure 2. PCB layout a) before assembly and b) after assembled with components

3.3 Data logger

The third segment is a data logger which consists of a computer with sound card and configuration software. The sound card is recommended to be a High Definition audio card with a minimum sampling rate of 96 kHz. This sound card will convert the received analog VLF signal into digital signal. This signal will be processed by the software and the output signal will be plotted. Figure 3 shows an example of the signal detected by the antenna and plotted by the software. The peak shown in Figure 3 indicates the detected VLF signal from the North West Cape (NWC) station located at Exmouth, Australia. The received signal in Figure 3 needs to be converted to local time (LT). The occurrence of solar flare can be seen from the existence of spikes in the converted signal as shown in Figure 4.

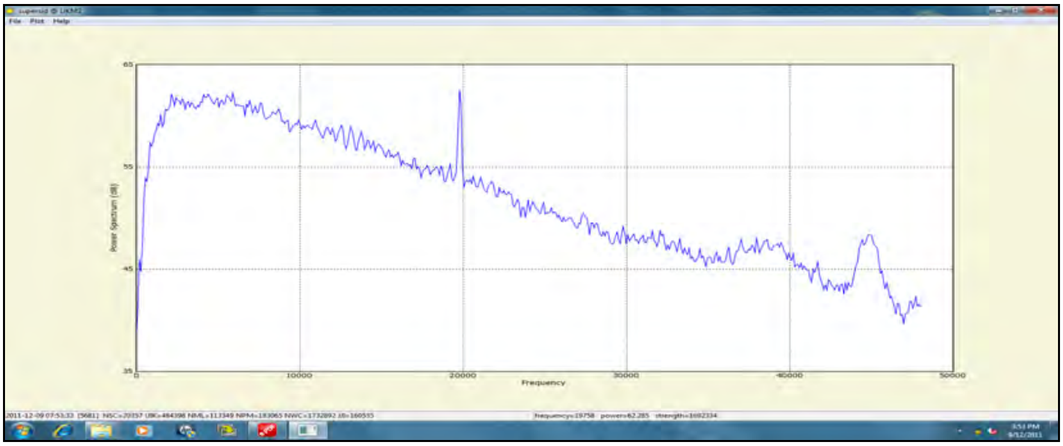

Figure 3. Receiving VLF signal from NWC station (freq: 19.8 kHz)

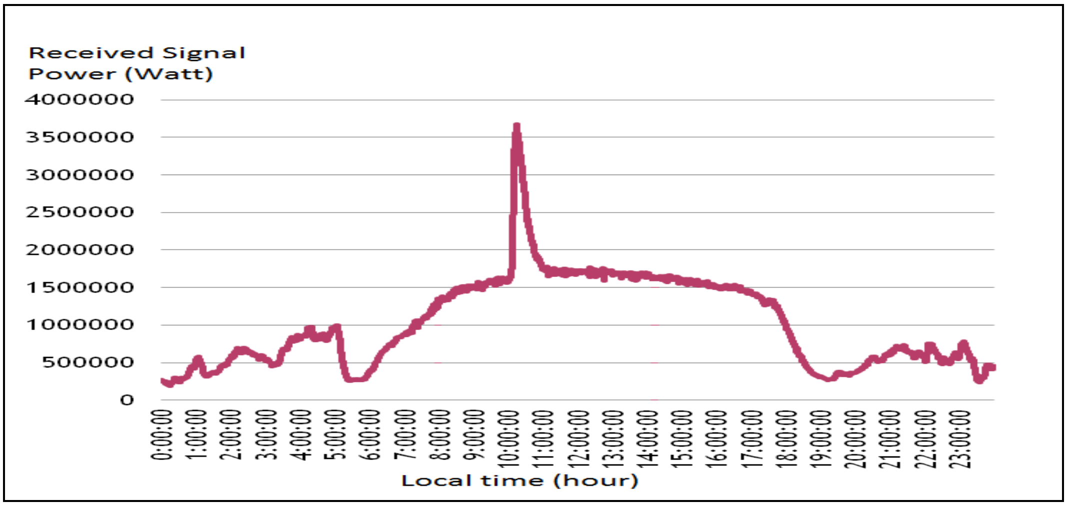

Figure 4. The spike showing the detected solar flare

4. UKM-SID system

In order to develop the UKM-SID system, the 3 segments mentioned in section 3 need to be built and integrated. A teaching kit, inclusive of software, electronic components, PCB, user manual, and related information were also provided. Figure 5 shows the steps in developing the UKM-SID system. First, the antenna should be designed and built according to the specification provided. Then, the electronics components should be assembled on the PCB and soldered to build the preamplifier. Next, the antenna will be connected to the preamplifier which is then connected to the data logger. This is followed by the software installation and testing. Lastly, data will be collected continuously to monitor the occurrence of the solar flare.

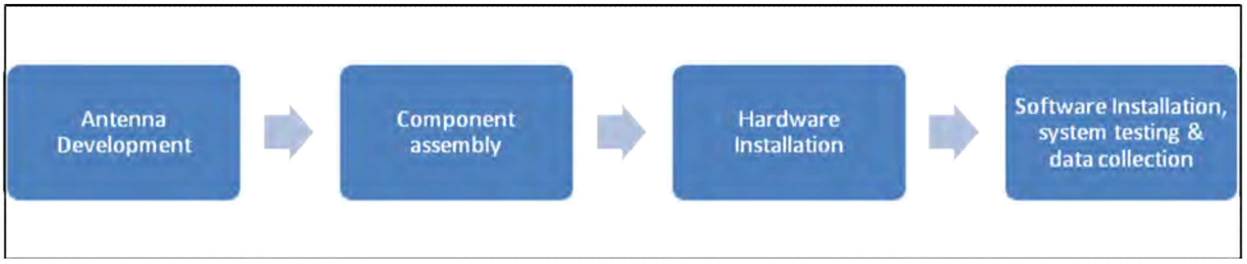

Figure 5. UKM-SID system development

5. Way forward

The UKM-SID teaching kit has been introduced as a pilot project to Sekolah Menengah Agama Persekutuan, Kajang and Sekolah Seri Puteri, Cyberjaya. Several meetings and workshop have been conducted in order to brief the students and teachers about the UKM-SID system. Students are required to build the UKM-SID system according to the specified schedule. They are also facilitated by UKM post and undergraduate students who are actively involved in space science research.

Through the antenna development, preamplifier assembly and data processing, the students' technical skills, critical thinking and their ability to work in team will be enhanced. They are also required to record their activities in a log book, complete their assignments and present their work. These activities will help strengthen their communication skills. As for data analysis, students utilize various software programs which will keep them abreast of the current development in information technology. In addition, the students are also required to do information searching in order to complete the task given. These activities will harness the students self-learning skills and enhance their knowledge in space science.

The hardware development will enable students to apply what they have learned in schools and stimulate their interest in space science. This also indirectly supports the government's intention to establish a Young Malaysian Aerospace Exploration Association (MyACE).

6. Conclusion

UKM-SID teaching module has been developed at UKM with the collaboration of Stanford University under the ISWI program. This module is capable in detecting solar flare using VLF technique. This module has been deployed to selected high schools in Selangor to expose and educate them on space science. It is hoped that the skills and knowledge gained from the project will cultivate students' interest in space science.

Acknowledgements

We would like to thank teachers and students of Sekolah Menengah Agama Persekutuan, Kajang and Sekolah Seri Puteri, Cyberjaya for their participation in this project. We also would like to thank Stanford Solar Center and Society of Amateur Radio Astronomers of Stanford University for the donation of the SID monitor and components. Special thanks to Prof. Dr. Deborah Scherrer for the kind support. This project is partially funded by UKM internal grants (Komuniti-2011-014 and OUP-2012-122).

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Development of A VLF Receiver System for Sudden Ionospheric Disturbances (SID) Detection

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***Abstract*— Sudden Ionospheric Disturbances (SID) are transient changes in the ionosphere caused by enhancement in X-ray and EUV fluxes during solar flare events. The SuperSID space weather monitor has been developed by Stanford University Solar Center to detect SID via VLF remote sensing. In this paper, a receiver system named as UKM-SuperSID has been developed to detect SID in the equatorial region. The system, which consists of loop antenna, preamplifier and a computer, is able to detect VLF signals with frequency of 19.8 kHz transmitted from North West Cape station (NWC), Australia. The data obtained showed repetitive diurnal variation. During the observation period from 11 December 2011 until 17 January 2012, M and C class solar flares events have been detected, with a class M1.5 flare observed as the largest detected flare. The results showed that the effectiveness of the UKM-SuperSID in detecting SID in the equatorial region thus enables it to be part of the global space weather sensor network.**

Keywords - SuperSID, VLF Remote Sensing, Solar Flare, VLF Receiver

I. INTRODUCTION

Solar activities such as solar flares, coronal mass ejection and solar wind are hazardous events in space, i.e. space weather, which could damage space-borne and ground-based technology systems, may threaten safety of astronauts and affect human life on Earth [1]. The study of solar activities is vital due to their potential harmful impact. Solar flares are defined as a sudden, rapid and intense variation in brightness which result from abrupt release of large amount of magnetic energy that being stored in the corona [2]. Occurrences of solar flares are characterized by emission of electromagnetic radiation particularly Extreme Ultraviolet (EUV) and X-ray together with ejection of charged particles [3].

The ionosphere consists of D, E and F layers which are present at height about 50 – 90 km, 90 – 150 km and above 150 km respectively [4]. The presence of free electrons due to ionization by solar radiation allows Very Low Frequency (VLF) radio signal (3 – 30 kHz) transmitted by various transmitter for radio and navy communication to propagate in the Earth-ionosphere waveguide [5]. During solar flare events, large amount of EUV and X-ray fluxes penetrate down the D layer and increase ionization rate hence electron density. These fast and brief changes in ionospheric condition, known as Sudden Ionospheric Disturbances (SID) could be detected by monitoring perturbation in VLF signal amplitude using VLF receiver, i.e. VLF remote sensing method [6, 7].

Stanford University Solar Center has developed a low cost but sensitive space weather monitor, named as SuperSID for SID detection via VLF remote sensing [8]. It is being deployed in developing countries worldwide in conjunction with International Space Weather Initiatives (ISWI). Signal processing is done via soundcard instead of data logger as in conventional SID-VLF [8]. However, there is no record of deployment of SuperSID in Malaysia and its effectiveness still needs to be determined. The purpose of this experiment was to build a VLF receiver system, known as UKM-SuperSID in Universiti Kebangsaan Malaysia (UKM) for SID detection, effectiveness determination and development of teaching kit for SuperSID Introductory Project to secondary school students in Malaysia.

UKM-SuperSID was installed at UKM, Malaysia (3.13 °N, 101.7 °E). The receiver is tuned to receive the 19.8 kHz VLF signal from a transmitter station at North West Cape (NWC), Australia (21.8 °S, 114.2 °E). In this paper, the authors present the development of the system, detection of diurnal variation, SID and solar flares as well as comparison of data with that of Geostationary Operational Environmental Satellites (GOES) [9].

II. METHODOLOGY

The experiment done is divided into four main parts, i.e. built of loop antenna and preamplifier PCB, setup of monitor station as well as analysis and validation of data. Fig. 1 shows the block diagram of the UKM-SuperSID VLF receiver system which consists of loop antenna, preamplifier and computer with sound card. Distant VLF signal is received by the loop antenna and very low induced output voltage is amplified by the preamplifier. Analog to digital conversion is done by high definition audio sound card which sampled the amplified analog signal at 96 kHz. Thus, UKM-SuperSID is able to detect signals with maximum frequency up to half of the sampling rate, i.e. 48 kHz. The received VLF signal is sampled every 5 s, processed and stored in computer using the SuperSID software developed by Stanford University Solar Center [8].

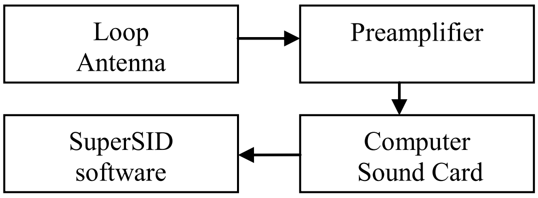


Figure 1. Block diagram of UKM-SuperSID

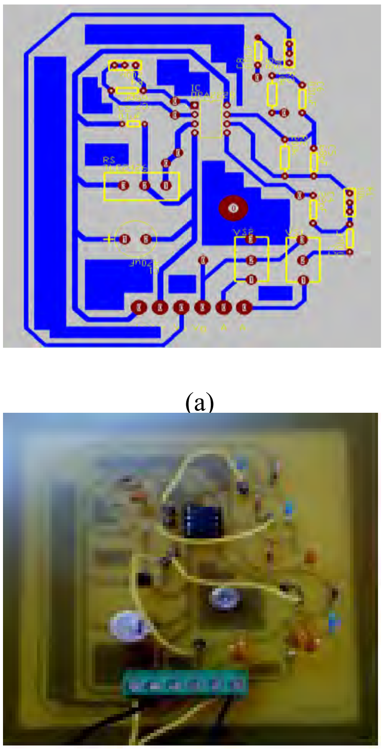
A. Loop Antenna

The loop antenna as shown in Fig. 2 is made up of low cost PVC frame and 25 loops of #26 AWG wire, with size of 1 meter square. The antenna output is connected to the UKM-SuperSID preamplifier using RG58 coaxial cable.

Figure 2. Loop antenna

B. UKM-SuperSID Preamplifier

The UKM-SuperSID preamplifier is built based on the design of the SuperSID preamplifier. The original double layer board is redesigned into a single layer PCB as shown in Fig. 3. The fabricated board housed components identical to that of SuperSID, supplied by Society of Amateur Radio Astronomers. The less compact and easy-to-solder board acts as a user-friendly and adequate teaching aid for secondary school students in SuperSID introductory project.



(a)

(b)

Figure 3. (a) UKM-SuperSID PCB layout & (b) UKM-SuperSID board

Two tests were conducted to verify the performance of UKM-SuperSID board, i.e. gain test and selective test with the result obtained by SuperSID board as benchmark. For both test, loop antenna was replaced by function generator at the preamplifier input terminal. Sine wave output from function generator at frequency of 16.11 kHz with amplitude 0.159 V is further reduced to 0.159 mV via voltage divider, as in

$$V_{IN} = \frac{200}{200+(2\times 100\times 10^3)}\times 0.159 = 0.159 \text{ mV}, \tag{1}$$

where V_{IN} = preamplifier input voltage.

1) Gain Test: The test is done to verify that UKM-SuperSID board could amplify the signal to a level detectable by the sound card. For SuperSID board, the output voltage at the preamp was 0.133 V whereas that of UKM-SuperSID was 0.147 V. The gain of SuperSID board is found to be 836.48, as in

$$\text{Gain} = \frac{V_{OUT}}{V_{IN}} = \frac{0.133}{0.159 \text{ m}} = 836.48, \tag{2}$$

where V_{OUT} = preamplifier output voltage. Whereas UKM-SuperSID was proven to functional by amplified the input signal by 924.53 times, as in

$$\text{Gain} = \frac{V_{OUT}}{V_{IN}} = \frac{0.147}{0.159 \text{ m}} = 924.53. \tag{3}$$

2) Selectivity Test: The test is done to verify that the pre-amplifier of the UKM-SuperSID has been correctly assembled. Preamplifier output was fed into "line in" of sound card. Fig. 4 and 5 show the spectrum displayed by SuperSID software when signal at frequency 16.11 kHz was fed into SuperSID and UKM-SuperSID preamplifier respectively. It was shown that UKM-SuperSID could display a clear peak at that 16.11 kHz, similar to the one of SuperSID. Based on the test results, UKM-SuperSID was proven to be able to detect and amplify signal in VLF range. The board is used in the VLF receiver system built.

C. Setup of Monitor Station

The UKM-SuperSID VLF receiver system was installed in Kolej Pendeta Zaba, UKM as shown in Fig. 6. Fig. 7 shows that distinct peak at 19.8 kHz has been detected by the monitor station. The station was configured to monitor VLF signal at 19.8 kHz transmitted by NWC from Australia.

D. Analysis and Validation of Data

Analysis of data is done by plotting the data in local time to detect its diurnal variation. SID is detected as sudden increase in signal strength received during daytime. Comparison with GOES data, which is available online from SWPC [9] is done to validate SID with occurrence of solar flares event.

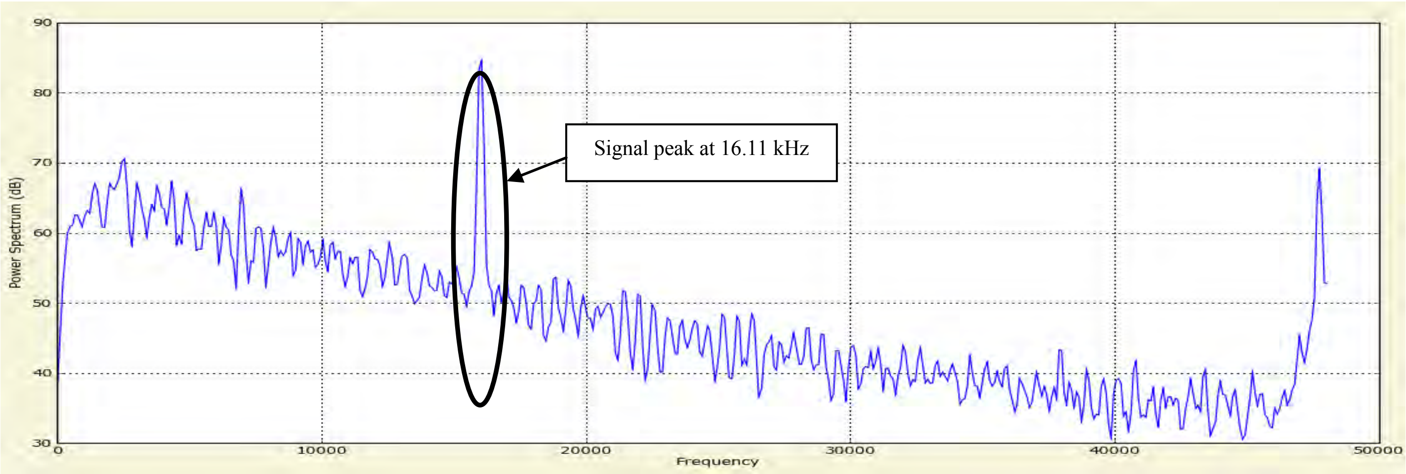


Figure 4. Clear peak at 16.11 kHz with amplitude 84.3 dB using SuperSID

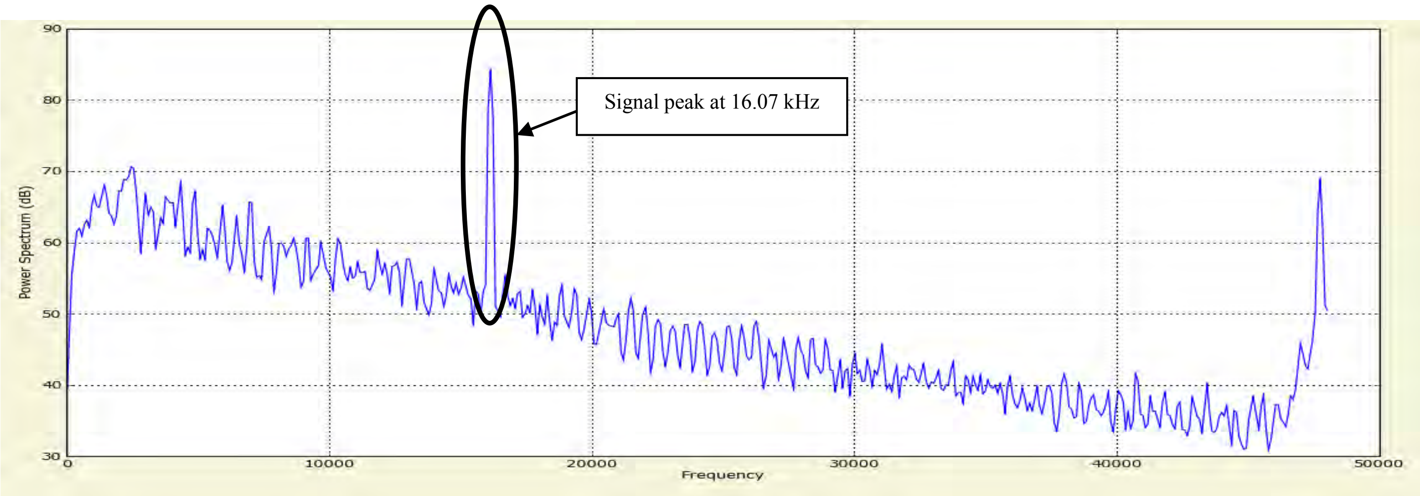


Figure 5. Clear peak at 16.07 kHz with amplitude 84.7 dB using UKM-SuperSID

Figure 6. UKM-SuperSID monitor station setup

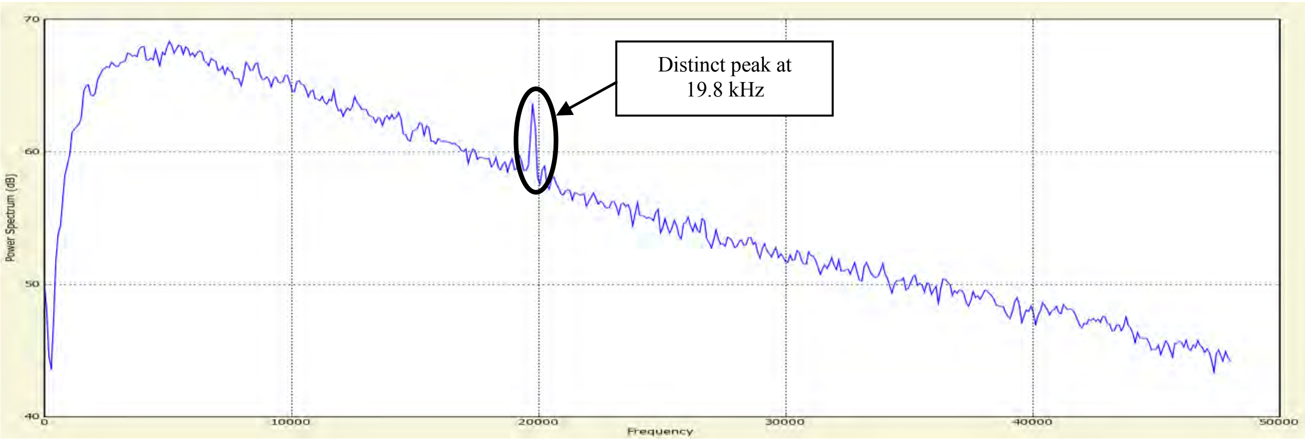


Figure 7. Clear peak detected at 19.8 kHz by UKM-SuperSID

III. RESULT AND DISCUSSION

A. Diurnal Variation

The great circle distance between NWC, Australia and UKM, Malaysia is around 3089 km. An earth ionospheric waveguide mode of propagation is assumed since single hop VLF reflection via D-layer is less than 2000 km [10, 11]. The variation is affected by VLF wave reflection height which changes with ionospheric condition throughout the day.

Fig. 8 shows the diurnal variation of NWC VLF wave received during 31 Dec 2011, which is a quiet day. During daytime, the field strength changes smoothly with a maximum at noon because the reflection height of the wave changes with zenith angle of the Sun [11].

In Fig. 8, the first minimum (SR1) observed at 4:50 AM indicates that the sunrise terminator was approaching NWC. The sunrise terminator then moved in northwest direction along the signal propagation path from NWC to UKM. The second minimum (SR2) is observed at 5:30 AM. Subsequently, an increase in signal strength is observed as development of temporary C layer began when electrons from negative ions built up during night time were released [10]. Changes of slope at SR3 (7:00 AM) indicates the development of D layer and fading of C layer. Maximum signal strength is observed at noon when the sun reaches its highest solar zenith angle. Another minimum (SS1) is observed at 7:14 PM at sunset. The minimum is due to the modal interference generated at the sunrise and sunset height discontinuities in reflection height [10, 11]. After sunset, disappearance of D-layer follows and reflection occurs from F layer. The received signal strength varies randomly as the F layer is not stable during night time. Fig. 8 also shows the local sunrise and sunset time at 7:18 AM and 7:14 PM respectively. Somewhat similar daynight pattern was observed on a NWC-Khatav, India path on 19.8 kHz in More [11]. Fig. 9 shows repetitive diurnal variation in the field strength of NWC signal received by UKM-SuperSID from 26 until 30 Dec 2011.

B. SID and Solar Flares Detection

SID due to occurrence of solar flares is observed as distinct peaks during day time, as in Fig. 9. They are characterized by sudden increase in signal strength followed by slow reduction to normal level. This is because ionization rate at D layer is enhanced during solar flares events due to increase in EUV and X-ray fluxes. This leads to lowering of effective reflection height and increase of sharpness or rate of change of electron density with height at the lower edge of the D layer [12]. The lowering of reflection height increases amplitude of received signal. Moreover, the wave does not experience loss of energy as it is reflected from the sufficiently ionized D layer [11, 12].

During the period from 11 Dec 2011 until 17 Jan 2012, 18 M class and strong C class solar flares events were detected. Four of the flares are shown in Fig. 9. The details of the flares from GOES data are tabulated in Table I. Difference in time when SID detected and time recorded by GOES is shown in Fig. 10 for M1.5 and M1.2 flares detected on 26 and 30 December respectively. It was found that SID detected on 30 Dec 2011 has a lead time as compared to that of GOES, because the computer clock did not synchronize with Worldwide Time Network. However, SID detected which showed observable peaks at reasonable timing are acceptable. In future work, synchronization with computer clock will allow more accurate data to be obtained.

TABLE I. DETAILS OF SOLAR FLARES EVENT DETECTED

Date	**Solar Flares Events**			
	Start Time (Local)	***Peak Time (Local)***	***End Time (Local)***	***Class***
26 Dec 2011	10:13 AM	10:27 AM	10:36 AM	M1.5
30 Dec 2011	11:03 AM	11:09 AM	11:13 AM	M1.2
27 Dec 2011	12:11 PM	12:22 PM	12:31 PM	C8.9
29 Dec 2011	3:12 PM	3:18 PM	3:22 PM	C7.3

IV. CONCLUSION

The objectives have been achieved through the development of UKM-SuperSID receiver system. SID and solar flares have been detected. Thus, the effectiveness of SuperSID in equatorial region has been determined and a teaching aid for SuperSID Introductory Project has been developed.

ACKNOWLEDGEMENT

The authors wish to thank Stanford Solar Center and Society of Amateur Radio Astronomers of Stanford University Stanford University for the provision of the SID monitor and components. Special thanks to Dr. Deborah Scherrer for the kind support. This project is partially funded by UKM internal grants (Komuniti-2011-014 and OUP-2012-122).

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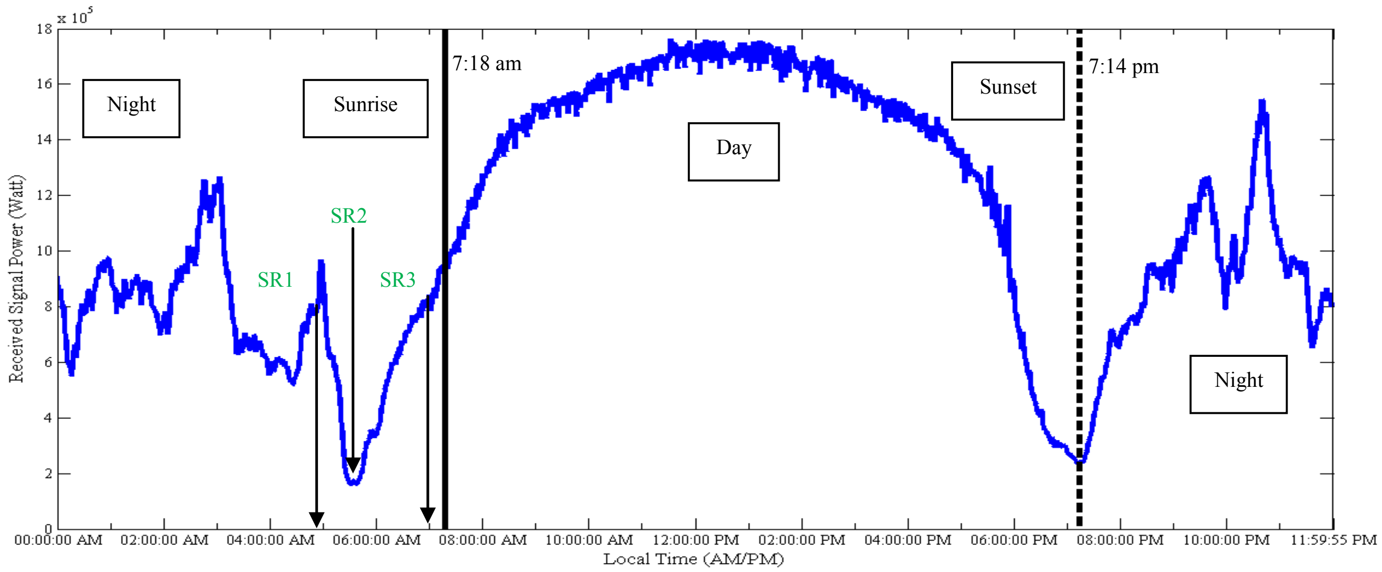

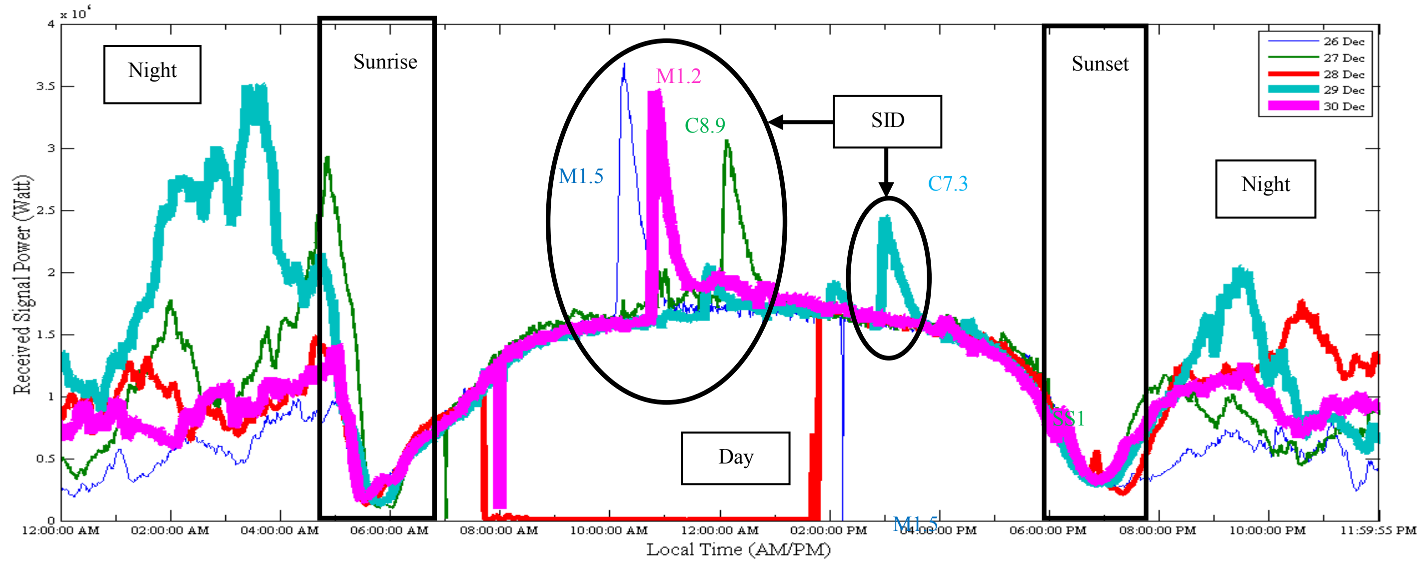

Figure 9. Diurnal variation and solar flares detected from 26 – 30 Dec 2011

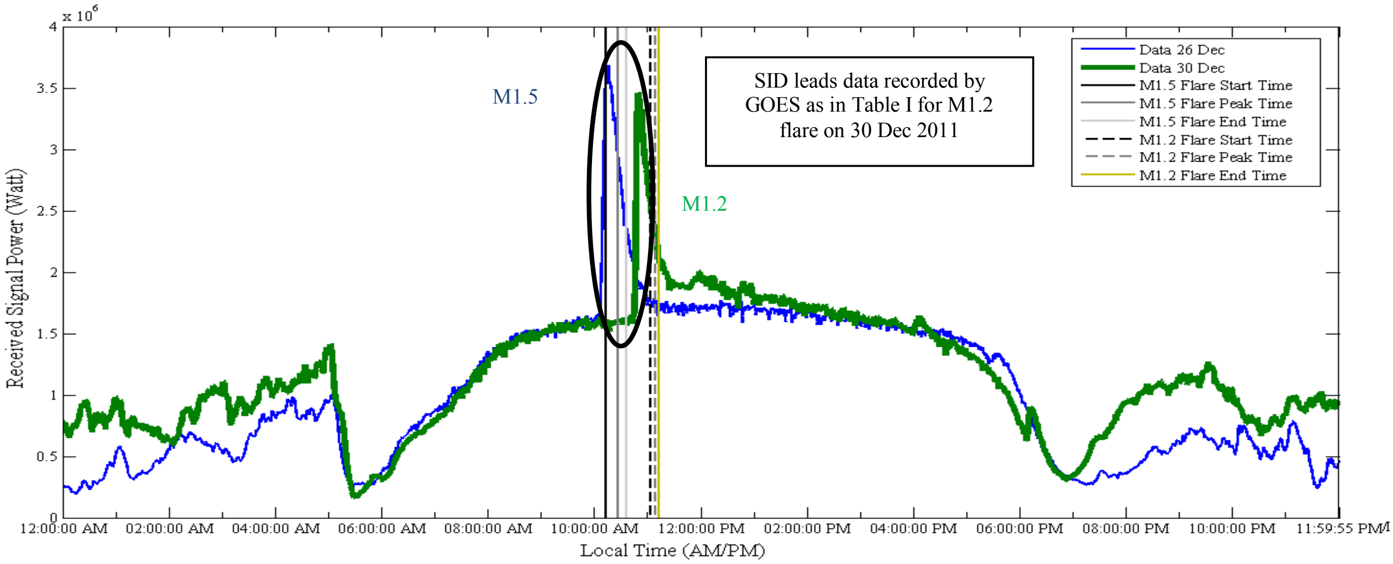

Figure 10. Comparison between SID detected time and GOES recorded time for M1.5 and M1.2