The Influence of Sunspot Number on High Frequency Radio Propagation

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Abstract—This paper aims to study the influence of sunspot number on High Frequency (HF) radio communications in Peninsular Malaysia for the years 2009 to 2011. Sunspots, which are a natural phenomenon that occurs due to magnetic activities on the Sun's surface, can be counted using smoothed sunspot number (SSN). HF signal propagates through the ionosphere where the ionospheric properties have been ionized by flares and prominences from sunspot number. This has significant effect on the stability of the ionosphere, resulting in the frequencies that can be used for HF communications to vary depending on the time of day, season, year and the 11-year solar cycle. This study was carried out during a period when the sunspot values rose from a low level in 2009 to a much higher level in 2011, making it suitable to observe the influence of sunspot number values on the HF frequencies employed. Maximum Usable Frequency (MUF) was determined based on HF transmission tests that were conducted from April 2009 to September 2011. It was observed that as the SSN values increase, the range of the operating HF frequencies and the numbers of frequencies that can be used also increase. This will, therefore, affect the median frequency that can be used for daily and monthly HF communications.

Keywords—High frequency; maximum usable frequency; radio propagation; ionosphere; sunspot number

I. INTRODUCTION

British physicist's Edward Appleton discovered that a blanket of electrically charged or ionized particles in the ionosphere is capable of reflecting radio waves. By 1920s, scientists around the world have applied this theory in their research to investigate and predict the refractive properties of the ionosphere[1–5]. Their research revealed that frequencies from High Frequency (HF) radio have strong correlation with the ionized ionosphere.

HF radio communications is dependent for most of its applications on the use of the ionosphere [6]that enables HF radio communication signals to be reflected and refracted back to earth so that they can travel over great distances around the world. HF that is affected by ionized layers is called Maximum Usable Frequency (MUF), i.e. the highest possible frequency that can be used to transmit over a particular path under given ionospheric conditions [1][2][7], with the median value of MUF working 50% of the specific time [8]. MUF is important for HF users in order to achieve better frequency management [9] and for determining the best frequency to use in the communication between two locations [10].

The ability of the ionosphere to reflect and refract the radio waves is caused by the notable phenomenon of the solar indices from the sun, i.e. sunspots that occur on the Sun's surface (photosphere) that is caused by magnetic activity. Sunspots affect radio propagation by ionizing the layers of the ionosphere. Large concentrations of ionization in the ionospheric layers increase its ability to bend the HF radio waves and to return the signal back to earth at huge distances from the transmitter to the receiver. Therefore, when the photosphere is active with magnetic activity, the HF transmission between the two points is better.

This paper aims to evaluate the influence of sunspot number on MUF in Peninsular Malaysia for the years 2009 to 2011. The evaluation of the frequencies can then be used to determine, or estimate the HF frequencies in Peninsular Malaysia for those years. This study was carried out at the beginning of solar cycle 24 when the sunspot number values rose from a low level in 2009 to a much higher level in 2011, making it suitable for observation of the influence of sunspots on HF propagation in the equatorial region. This research is well established in other parts of the world, but in Malaysia this kind of research is scarce and in need of in-depth study.

II. HF RADIO PROPAGATION

HF transmission using skywave propagation plays an important role especially in the military as HF radio is used by

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the military for tactical and strategic purposes, and certain military scenarios. In contrast, for civilian users, HF radio is used in the event of any disasters such as hurricanes, tornados and earthquakes [1][2][6][11]. The biggest problem in HF radio communication is the rapid change in the ionospheric characteristics; hence, the operating frequencies need to be changed from time to time to get satisfactory performance [12]. Therefore, it is important to use the right frequencies or channel to convey information.

The ionosphere is an uncertain and highly variable region on a variety of time scales, ranging from hours, days, season to season up to the 11-year solar cycle. Hence, the variation of the ionosphere plays a significant role in the HF propagation in that a frequency which may provide successful communication presently may not achieve similar results an hour later. Sunspots have significant effect on the stability of the ionosphere, and this is due to the radiation of the sun's activities that produce flare and prominence, resulting on a direct impact to the ionosphere [10].

Basically, MUF reflection is dependent on ionospheric parameters, namely critical frequency and peak height. Previous researches of these parameters in this area have been carried out by [13–15]. The relationship between MUF and critical frequency and peak height is shown below:

$$MUF = \frac{f_{cr}}{\sqrt{1-\left(\frac{R}{R+h}\right)^2}} \qquad (1)$$

where,

f_{cr} = Critical frequency

R = Radius of the earth

h = Height of the ionosphere

Sunspot is crucially important in determining and predicting the HF frequencies. Sunspots can be predicted according to the 11-year solar cycle and it can be counted as smoothed sunspot number (SSN). The relationship between HF propagation and SSN is shown in Fig. 1. HF radio frequency can be predicted based on sunspot number and predictions are made using a variety of computer programs including IONCAP, PROPMAN, REC533, MINIMUF and ASAPS. By knowing the SSN values, MUF can be predicted or expected. Prediction of HF frequencies using prediction software shows the approximate range of frequencies that can be used to transmit. Other than the time of day, month, longitude and latitude of the transmitter and receiver stations, and type of antenna, SSN has been used as the input parameter for prediction software [7][16].

In this study, ASAPS (Advanced Stand Alone Prediction System) software developed by Ionospheric Prediction Service (IPS) Australia [17] was used as the computer prediction.The user interface of ASAPS is quite advanced, including databases of transmitter and receiver positions, type of antenna used, time and date of prediction, transmitter power, and SSN.

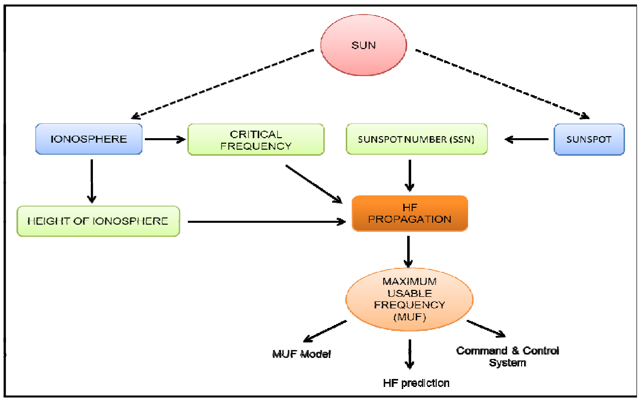

Fig. 1. Relationship between SSN and MUF

III. DATA AND METHOD

In this study, sunspot number data for the years 2009 until 2011 was obtained from IPS, Australia. The MUF data was obtained from actual HF transmissions from the Science and Technology Research Institute for Defence (STRIDE), Malaysia. The locations of the transmission tests are between Kajang (2°59'N, 101°48'E), BatuArang (3°32'N, 101°47'E) and Lumut (4°13'N, 100°37'E). The transmission tests were conducted from April 2009 to September 2011, at the beginning of Solar Cycle 24, where the monthly SSN values, rose from low levels in 2009 and 2010 to a much higher level in 2011 [18]. The transmission tests were done in the morning (LT 0800 to 1200), evening (LT 1200 to 1900) and at night (LT 1900 to 2400). Frequency selections were based on computer prediction by ASAPS software.

IV. RESULTS & ANALYSIS

A. HF transmission in July 2009, July 2010 and July 2011

These results of the successful frequencies (MUF) for transmissions in July 2009, July 2010 and July 2011 during the morning (0800 to 1200) and evening period (1300 to 1900) are shown in Fig.2.The SSN for July 2009, 2010 and 2011 are illustrated in Fig. 3 where SSN for July 2009 was the lowest while the SSN values increased slightly in July 2010, and rose higher in July 2011.

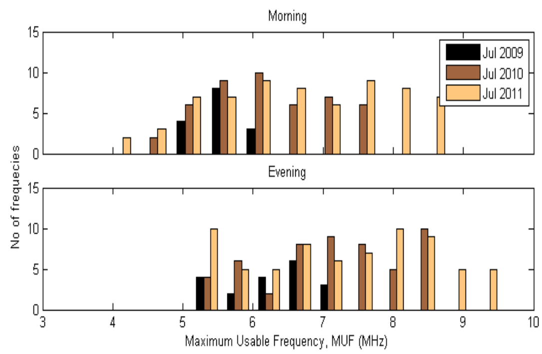

Fig. 2. MUF in the morning and evening for July 2009, July 2010 and July 2011

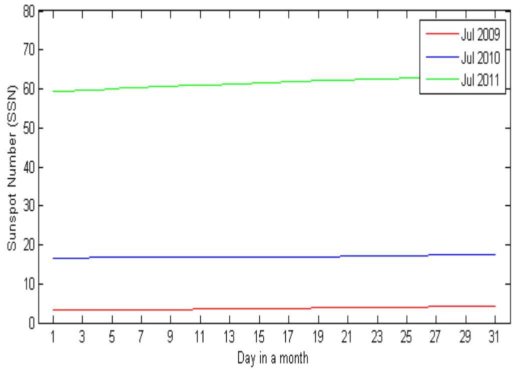

Fig. 3. SSN for July 2009, July 2010 and July 2011

In the test conducted in the morning of July 2009, the frequency range was between 5 to 6 MHz and achieved only 12% of the overall frequencies in the morning. The very low SSN values in 2009 resulted in low operating HF frequency range. However, in 2010, the SSN values increased slightly, enabling more frequencies through the ionosphere. The test conducted in July 2010 indicated that 36% of the frequencies achieved successful transmission, and the frequency range was between 4 to 7 MHz. Contrastingly, for the test conducted in July of 2011, the number of successful frequencies for communication increased to 52% and the frequency range also increased between 3 to 8 MHz.

For the tests conducted in the evenings, it was observed that in July 2009 only 13% of the frequency made it through for communication, and the frequency range was between 5 to 7 MHz. Then in July 2010, the successful frequencies increased to 37%, and the frequency range also increased to nearly 9 MHz. Subsequently for July 2011, 50% of the frequencies achieved successful transmission, and the frequency range increased to 9.5 MHz.

Frequencies used in July 2011 for the morning and evening improved because in 2011, the SSN values had essentiallyincreased. Higher SSN means more radiation from flares and prominences to the ionosphere, resulting in more ionized ionosphere and increased penetration of energy into the ionosphere.

The plots in Fig. 4 show the MUF median values for July 2009, 2010 and 2011 with its predicted values using ASAPS software. Analysis of error using RMSE between the predicted and actual MUF is shown in Table 1. Fig. 4 shows that MUF prediction for year 2011 is higher compared with 2009 and 2010. The actual MUF for 2011 is also higher compared with 2009 and 2010. These plots show the median MUF is higher when SSN is higher. During the day time, the solar activity increases, thus the ionized layer in the ionosphere also increases, allowing high frequencies to be propagated over long distances. Subsequently, the lower frequency tends to be absorb by the ionosphere because of the enhanced ionization in the lower ionosphere caused by solar radiation [8][19]. This is in contrast with the night time when the solar activity is low; hence, radio energy is absorbed less. Thus, lower frequencies are propagated better than high frequencies [8]. As concluded by [20], this is consistent with the plots in Fig. 4, i.e. during the day time, the median MUF is higher and at night and dawn, the median MUF is lower.

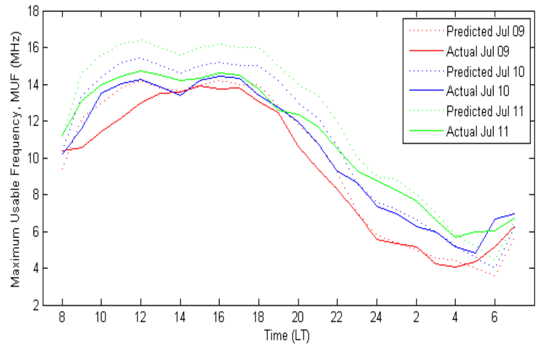

Fig. 4. Median MUF from July 2009 to July 2011

TABLE I. RMSE BETWEEN PREDICTED AND ACTUAL MUF

Month / Year	RMSE
July 2009	0.89
July 2010	1.09
July 2011	1.39

B. HF transmission for 2009 to 2011

Fig. 5 shows the operating HF frequency for the year 2009 to 2011. From the diagram, it is shown that the MUF range for 2009 is lower compared with 2010 and 2011. Meanwhile, the MUF range for 2011 is higher because SSN for 2011 is higher among the three years as shown in Fig. 6. The SSN value for 2009 is almost 0 and the maximum value is approximately 10. Therefore, the number of successful frequency for transmission is also less compared with 2010 and 2011. Meanwhile, the SSN values for 2011 are higher, where the maximum value is more than 60, and hence the number of successful frequencies for transmission mainly increased.

The usage of HF frequencies for communication varies when radio waves strike the ionized layers. This is due to the changes in the ionosphere's free electron density which depends on radiation from the sunspots. The ionised ionosphere allows the radiated wave to be refracted and reflected through it, and with appropriate frequencies and other factors, the transmission can be successful 90% of the time. In addition, the low power can often achieve extremely long range distance when proper transmission frequency is used [1].

From these analyses, HF frequency can be determined or estimated based on the prediction of SSN. These analyses can be used not only for the period of 2009 to 2011, but they can also be used as a reference for future studies and predictions with similar SSN.

Consequently, from all the results, the HF frequency is influenced by SSN. This is because SSN modifies the transmission properties of the ionospheric medium [21–22]. However, SSN values that are too high will interfere with the transmission of HF signals[16][22].

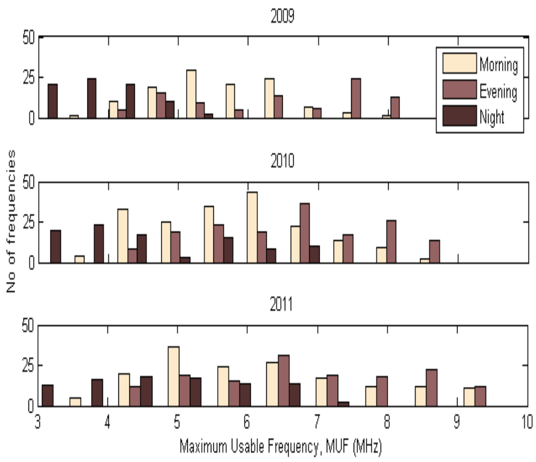

Fig. 5. Median MUF from 2009 to2011

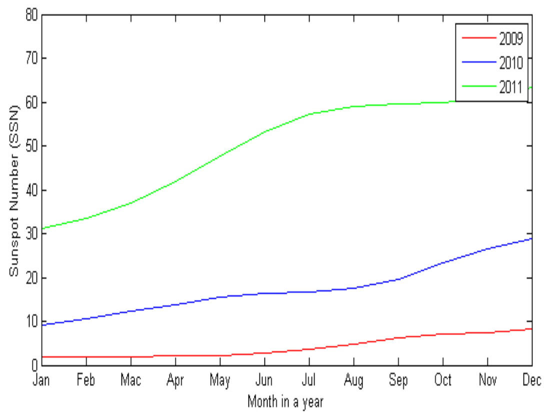

Fig. 6. Monthly SSN for 2009 to 2011

V. CONCLUSION

Based on the transmission tests that have been conducted, it is observed that SSN has a large influence on HF communication systems. In the day time, higher frequency is used for transmission because SSN radiates flares and prominences to ionize the ionospheric layers. Contrarily, at night time, lower range frequency is important for transmission because the ionized layer decreases due to the decrease in solar activity.

This study can also be used to observe the behaviour of HF frequencies in Malaysia because this present study can be drawn upon in the future to develop the MUF model for the Malaysian environment. Moreover, predictions can be made more accurately using the MUF model, and thus better HF frequencies can be utilized for transmission.

ACKNOWLEDGMENT

This research study was carried out as part of the research of the Communication Branch, Instrumentation & Electronics Technology Division, Science & Technology Research Institute for Defence (STRIDE), Ministry of Defence, Malaysia. The research was also supported by ANGKASA grant DPP-2014-052.

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