OBSERVATIONS OF F-REGION CRITICAL FREQUENCY VARIATION OVER BATU PAHAT, MALAYSIA, DURING LOW SOLAR ACTIVITY

SABIRIN BIN ABDULLAH

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Universiti Tun Hussein Onn Malaysia

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ABSTRACT

Wireless radio in the HF band still uses the ionospheric layer as the main medium for communication. Critical frequencies are important parameters of the ionosphere. Due to the activities of the sun, the critical frequency varies diurnally, following the pattern of day and night. The critical frequency for the Parit Raja station is determined using an ionosonde at latitude 1° 52' N and longitude 103° 48' E which is close to the geomagnetic equator at geographic latitude 5° N. This work analyses the dependence of the critical frequency during the solar minimum of Solar Cycle 23. The median critical frequency value is used to develop a model using regression and polynomial approaches because it is more accurate than using average values. From the observations, the critical frequency observed in 2005 is the highest, corresponding to a higher sunspot number of between 11 and 192. In contrast, the critical frequency is lower in 2007 due to the decrease in the sunspot number of between 11 to 63. The general trend of the daily critical frequency is 6.8 MHz to 12.0 MHz from 00:00 to 17:30 UTC and decreasing to 7.0 MHz from 18:00 to 23:00 UTC. The average value of the critical frequency for 2005 to 2007 is 7.5 MHz, with a minimum of 1.8 MHz and a maximum of 11.0 MHz. In addition, the daily observed virtual height for the F-layer is 200 to 480 km except during the months of January, February, November and December, during which it is much higher up to 550 km. The Parit Raja model showed good agreement for the 3rd degree polynomial fitted between the measured values. This model can be used as a reference ionospheric profile over southern Malaysia.

ABSTRAK

Penggunaan Frekuensi Tinggi (HF) dalam komunikasi masih bergantung kepada lapisan ionosfera sebagai medium utama. Frekuensi kritikal merupakan parameter penting lapisan ionosfera. Disebabkan oleh aktiviti matahari, frekuensi kritikal akan berubah – ubah pada waktu pagi hingga ke petang mengikut pola siang dan malam. Frekuensi kritikal untuk stesyen Parit Raja ditentukan menggunakan ionogram Parit Raja dari nilai pemerhatian pada kedudukan latitud 1° 52' N dan longitud 103° 48' E yang terletak berdekatan dengan khatulistiwa geomagnet pada latitud 5. Kajian ini melihat kebergantungan frekuensi kritikal semasa Kitar Solar 23 yang merupakan solar minimum yang rendah. Nilai frekuensi kritikal dalam bentuk median digunakan untuk menghasilkan model berpandukan pendekatan regresi dan polinomial memandangkan ianya adalah lebih tepat dibandingkan dengan penggunaan nilai purata. Dari keputusan pemerhatian yang diperolehi, frekuensi kritikal yang diamati pada 2005 adalah yang tertinggi, berpadanan dengan nilai bintik matahari yang tinggi di antara 11 dan 192. Sebaliknya, frekuensi kritikal adalah lebih rendah pada 2007 kerana penurunan nilai bintik matahari di anatara 11 hingga 63. Kecenderungan umum frekuensi kritikal harian ialah 6.8 MHz hingga 12 MHz dari 00:00 hingga 17:30 UTC dan menurun ke 7 MHz dari 18:00 hingga 23:00 UTC. Nilai purata frekuensi kritikal dari 2005 hingga 2007 ialah 7.5 MHz, dengan nilai minimum 1.8 MHz dan nilai maksimum 11 MHz. Selain itu, ketinggian maya harian yang diamati bagi lapisan-F ialah 200 km hingga 480 km kecuali pada bulan Januari, Februari, November and Disember, di mana ketinggian maya pada bulan ini adalah jauh lebih tinggi sehingga 550 km. Model Parit Raja menunjukan keputusan yang baik pada polinomial darjah tiga yang dipadankan antara nilai pengukuran. Model ini boleh digunakan sebagai rujukan untuk profil ionosfera merentasi bahagian selatan Malaysia.

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LIST OF SYMBOLS

f_oF_1	Critical Frequency in the F_1-layer
f_oF_2	Critical Frequency in the F_2-layer / Ordinary Wave
f_xF_2	Extraordinary wave
f_N	Plasma frequency
f_c	Critical frequency
f_o	Critical frequency of ordinary wave
f_x	Critical frequency of extraordinary wave
f	Frequency
R	Sunspot Number
N, N_e	Electron number density (per meter ^{3})
n_x	Electron density of the ionized layer
N_{max}	Total electron density
h'	Virtual Height
t	Time of Flight
μ'	Group Refractive Index
μ	Refractive index
χ	Solar zenith angle
h	Height

LIST OF ABBREVIATIONS

GPS	Global Positioning System
HF	High Frequency
SSR no.	Sunspot Relative Number
SC	Solar Cycle
JUPEM	*Jabatan Ukur dan Pemetaan Malaysia*
TEC	Total Electron Content
EUV	Extreme Ultra Violet
UTHM	Universiti Tun Hussein Onn Malaysia
LT	Local Time
UT	Universal Time
UTC	Coordinated Universal Time
WARAS	Wireless and Radio Science

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CHAPTER I

INTRODUCTION

1.1 Introduction

After the existence of the ionospheric layer was discovered, HF communication is one of the traditional long range communications that have been used widely. The capability of HF communication to communicate over long distances and as an emergency means of wireless communication (Maslin, 1987). Under extreme disaster, HF communication also provides the ability to communicate within the disaster area. An HF radio user can communicate to another HF radio user with no other requirements for any infrastructure beyond the equipment itself, namely radios and associated antennas. Once initial investment of equipment is made, there is no cost for calls and no monthly equipment rental cost.

In HF communication frequency variation, the ionospheric layer plays an important role. In Malaysia, the ionosphere over Penang, Malaysia, was studied at middle to high latitude in 1946 by a researcher from Japan (Maeda, 1986). However, there was not much ionospheric research related to Malaysia since then. Nevertheless, research on HF propagation and total electron content (TEC) observations began in the early 1990s (Zain, 2005).

1.2 Background

The earth's atmosphere contains several layers from 90 to 1000 km. Each layer has a different characteristic and profile. In daily life, the sun gives plenty of resources to our earth. The sun's radiation is transferred to the earth in different forms. One of the radiations of the sun is in the form of extreme ultraviolet (EUV) which can affect the earth's atmosphere especially on ionospheric irregularities. The ionosphere is formed when EUV light from the sun strips electrons from the neutral atoms of the earth's atmosphere. The ionosphere is composed of a number of ionized regions above the earth's surface which plays a very important part in the propagation of radio waves.

The presence of free electrons in the ionosphere can influence the propagation of radio waves through the open space. The density of the electrons in the ionosphere plays the role of bending the radio waves in the layer. Electron density which is also known as Total Electron Content (TEC) is much higher during high solar activity.

1.3 Ionospheric Research in Malaysia

Early research in Malaysia focused on TEC using GPS receiver which was studied by Zain and Abdullah (1999). In their study, the measurements of TEC in Arau, Malaysia were used from four different times of the observation value. The observation value is collected using the GPS (Global Position System) receiver from Jabatan Ukur Pemetaan Malaysia (JUPEM)'s station in Malaysia (Zain and Abdullah, 1999).

The work that was carried out in the previous research by Zain *et al.*(2002) showed that the relative variation from the GPS storm had a time range of about -20%

to 25% and there was a positive phase which exceeded 25% TEC enhancement during the main phase of the storm. The variation of TEC during the geomagnetic storm was from 15 until 17 July 2000 (Zain *et al*., 2002), and the phenomena of the TEC near the solar maximum activity was the subject of further study of the research (Hassan *et al*., 2002 and Ho *et al*., 2002). In the study, most of the TEC values from Sarawak for the research purpose were provided by JUPEM. The interesting feature in the study is the shift in TEC maximum from 12:00 to around 14:00 (Zain and Abdullah, 2000). Besides the GPS receiver, the ionosonde can also provide to the study on ionospheric investigation using a ground based system.

As mentioned, previously the research on TEC in Malaysia was mainly carried out using GPS. However, the design of the magnetic observatory terminal which is considered as the first attempt to set up an observatory in Malaysia has led to ionospheric and geomagnetic research activities being carried out using a digital ionosonde and magnetometer in 2001

1.4 Problem Statement

Ionospheric research in Malaysia is quite scarce and is limited to TEC studies. It has only been 20 years since Malaysia started conducting research in this area whereas other countries have been carrying out this research for up to 100 years (Rishbeth and Davis, 2001). The latest study in Malaysia utilised ground equipment to examine the ionospheric layer. With the availability of this equipment, it gives opportunity to conduct research specifically in Parit Raja, Malaysia in developing an ionospheric profile model in Malaysia. The study of the ionospheric profile is the first step to determine the profile of the trend in Batu Pahat, Malaysia. This study provides the first profile of the ionospheric critical frequency in the region of Malaysia, especially over Batu Pahat, Johor where the decline of the solar activity period was used in this research.

This research studied the observation value of the ionosphere based on the f_oF_1 and f_oF_2 critical frequencies. The results from this research are expected to assist the researcher in improving the modeling of the ionospheric region of Malaysia.

1.5 Aim and Objectives

The aim of the research is to analyze and model the trend of critical frequency variation over Parit Raja, Johor during low solar activity using the observation values in the form of theoretical and measurement value.

The objectives of the research are as the following:

i. To determine the critical frequency from the ionogram interpretation using the observation values.

ii. To analyze the daily, monthly and yearly critical frequency variation using the observation values.

iii. To develop an empirical model using the observation values.

1.6 Motivation

Ionospheric research began in 1920 and is still continuing in the United Kingdom, Alaska, Canada, Australia and Japan. Ionospheric research is important in HF communications because it depends highly on the ionospheric variations. Advantages of the HF communication is that it allows communication over long distances, provides the ability to communicate within disaster areas with no requirements for infrastructures like telephone land lines, cellular telephones, and satellite telephones. Additionally, an HF radio user can communicate with another HF radio user with no necessity for any infrastructure beyond the equipment itself which is radios and associated antennas. HF provides a cost effective solution to emergency wireless communication as once initial equipment investment is made, there is no cost for calls and no monthly equipment rental cost.

Because of the advantages of HF communication, the critical frequency variation over Parit Raja can contribute to a reliable frequency which can be used based on the ionospheric profile study. The initial model of the critical frequency over Parit Raja can show the trend of the critical frequency variations for Malaysia, in particular at Parit Raja, Johor.

1.7 Research Contribution

The research has characterized the critical frequency variation for the year 2005 to 2007. The analysis of the research contributes to the initial model of the critical frequency variation for Parit Raja, Malaysia. The empirical model of the observation value can be used as a reference of the ionospheric profile of the critical frequency variation in Malaysia and for future improvement.

1.8 Summary

This research is a study on the variation of critical frequency profile over Parit Raja from 2005 to 2007 using analysis and modeling. The approach presented used several analyses from daily, monthly and yearly observation values. Based on the statistical modeling, the fitting value of the formulations is determined from the observation value. This is additional knowledge which the researcher could never gain from the research using the variation of the critical frequency in Malaysia. The measurement values were compared with the IRI (International Reference Ionosphere) and the ionosonde station at Darwin obtained from the official website for validation purposes.

This thesis contains five Chapters. This chapter introduces the topic of the study. Chapter II describes the related works in ionospheric study and the relationship between the ionosphere and the activity of the sun. It starts by outlining the fundamental characteristics and concepts regarding the atmospheric layer. A short review of the important research works related to this study is then presented. The critical frequency is determined mostly based on the measurement from the ionospheric layer while the analysis of the critical frequency uses statistical modeling.

Chapter III presents the methodology that was used for this study, which is equipment setup and the parameter used for the measurement. It describes the methodology used to determine the critical frequency from the ionogram interpretation. The IRI model is used to compare with the model.

In Chapter IV, the explanation of the empirical model using the observation values is presented, including a description on the regression and polynomial approach used in this model.

The analysis of the results is explained in Chapter V. The analysis of the ionospheric critical frequency is presented in the form of diurnal variation results and seasonal variation results. The diurnal and seasonal result determined the trend of the daily and monthly ionosphere. The result on the maximum electron density from the critical frequency and maximum usable frequency ascertained the difference of the ionospheric profile during high solar activity. The monthly regression analysis results from 2005 to 2007 and the polynomial results from the 6th, 5th, 4th, and 3rd degree are also presented. The conclusion from the study and future work is in this chapter.

CHAPTER II

LITERATURE REVIEW: THE IONOSPHERE

2.1 Introduction

The basics of ionospheric layer is introduced in this chapter. The previous works undertaken which are related to the ionospheric work is also presented here. Finally, this research work is put in context with the research activities in the equatorial region.

2.2 Ionosphere

The importance of this research lies in the ionospheric layer. Ionization of the ion particle in this layer is produce highly only during the day when the sun is above the horizon (MacNamara, 1994).

Ionospheric research began after the existence of the layer was discovered in the 20th century. Since then, research on the ionosphere has started to increase due to the development of the measurement equipment. For prediction and study of the nature of the ionospheric layer, the vertical and oblique sounding of the radio wave from the ground system is used (Fenwick and Barry, 1966). The sounding system was used widely by researchers to study the ionospheric layer in the temperate countries. The new design of the equipment to study the ionosphere makes it much more convenient because of the modern design of the system.

The capability of the measurement equipment in the vertical and oblique sounding can determine the critical frequency variation and virtual height from the ionosonde. However, oblique sounding shows group delay dependence over a certain frequency range. This work was done by Krasheninnikov *et al*. using the ray-tracing technique (Krasheninnikov *et al*., 1996).

Due to the variations of the ionosphere through time and day, a long – term and short – term trend can provide information on the variation of the ionosphere. J. Bremer had investigated the parameter of the ionosphere from the E – layer and F – layer and his study showed that the trend of the E – layer is in qualitative agreement with the increasing greenhouse effect from the lowering of virtual height of the E – layer (Breamer, 2004).

The ionospheric effect from the solar wind conditions can lead to storm event and this is associated with F2 peak height enhancement. Tsagouri and Belehaki's study showed that height enhancements are wavelike disturbances that most probably originate in the auroral oval region and propagate toward the equator – like travelling ionospheric disturbances (TID) (Tsagouri and Belehaki, 2002).

Recently, the technique for studying the TEC in the ionospheric region involves GPS observation and a similar study was also initially carried out in Malaysia using JUPEM's observation values. The ionospheric measurement parameter is the critical frequency and the height of the reflection. The critical frequency is the most important of the ionospheric parameter. The difference of the ionospheric variation is based on the disturbed and undisturbed condition of the activity of the sun. The increase in the temperature of the layer causes the electron density of the ionosphere to change. Mendillo *et al*. (2002) has carried out a research on the modeling of the ionosphere of F2 – layer for seasonal trends and day – to – day variability using ionosonde. The day – to – day variability results showed that the relation of the variability is due to variations in the wind rather than the variation of thermosphere composition.

The trends of the ionosphere for long-term trend can also be affected by the earth's magnetic field and geomagnetic activity. This was studied by Elias and Adler (2006) who estimated the trend of the ionosphere using several stations (Elias and Adler, 2006). On the other hand, Karpachev *et al*. investigated ionospheric response to large-scale internal gravity waves where the use of large scale data set in the analysis showed the quiet and disturbed condition of the ionosphere (Karpachev *et al*., 2007).

Additionally, the hysteresis of f_oF_2 was studied for several European stations over the whole 24-hour diurnal interval for the equinoctial month of the years just before and just after the solar cycle minimum for solar cycle 20 and 21. The hysteresis development study is best in the equinoctial month and it is better in spring than in autumn. The noontime hysteresis was found to be sufficiently representative for most of the spring time studies. The hysteresis is much stronger in the night due to the considerably lower f_oF_2 at night. In autumn, the hysteresis is much lower at night compared to in spring. The frequency for spring is estimated at 0.5 MHz (Buresova and Lastovicka, 2000).

The development of an empirical model with no densities is used to construct a physically reasonable model for the diurnal, seasonal and solar-cycle changes in the upper atmosphere under different conditions. The model represents the condition of the e-layer with the seasonal and solar changes (Titheridge, 1997). There is rapid increase at sunrise, and a maximum near 14 h which is typically about seven times pre-sunrise minimum.

The high latitude ionosphere is more often disturbed than quiet, for example flux charged particles dominate over solar controlled ionization. The three experimental methods to determine the absorption of the quiet ionosphere at high latitude are riometer, rocket data and simulation using true quiet ionosphere (Harrich *et al*., 2003).

The seasonal variation study is the result of the Earth revolving around the sun that is the relative position of the sun as it moves from one hemisphere to the other with changes in seasons. Seasonal variations of the D, E, and F_1-layers correspond to the highest angle of the sun; thus, the ionization density of these layers is greatest during summer. The F_2-layer, however, does not follow this pattern; its ionization is greatest in winter and least in summer, the reverse of what might be expected. As a result, operating frequencies for F_2-layer propagation are higher in winter than in summer. Several stations had been used to determine the long-term trend of the critical frequency using the seasonal observation value. For the majority of the stations, there is also a pronounced seasonal effect with the trend magnitude being higher in summer than in winter (Danilov *et al*,. 1999).

The principal systematic feature, found mainly at subauroral stations but to some degree elsewhere, is the semiannual pattern, with peaks at the equinoxes. There are differences between the solstices; in general, variability at night is greater in winter than in summer, but by day the variability is greater in December than in June in both hemispheres. In general, variability is somewhat greater at subauroral and equatorial latitudes than at mid-latitudes. The examination of the day-to-day variability at Slough with various lengths of 1-56 days showed that it is fairly constant for lengths of 5-20 days while at equinox the seasonal trends increase it at longer lengths. Rishbeth and Mendillo (2001) suggest that the greater variability at night, especially in winter, is partly due to the lower electron density and partly due to the lack of the strong photochemical control that exists in the daytime F_2-layer, but occurs largely because the auroral sources of magnetic activity become stronger and move to lower latitudes at night. This effect is enhanced in winter when nights are longer. The magnetosphere can also affect the ionospheric variation. The magnetosphere is formed by the intersection of the solar wind with the earth's magnetic field as shown in Figure 2.1.

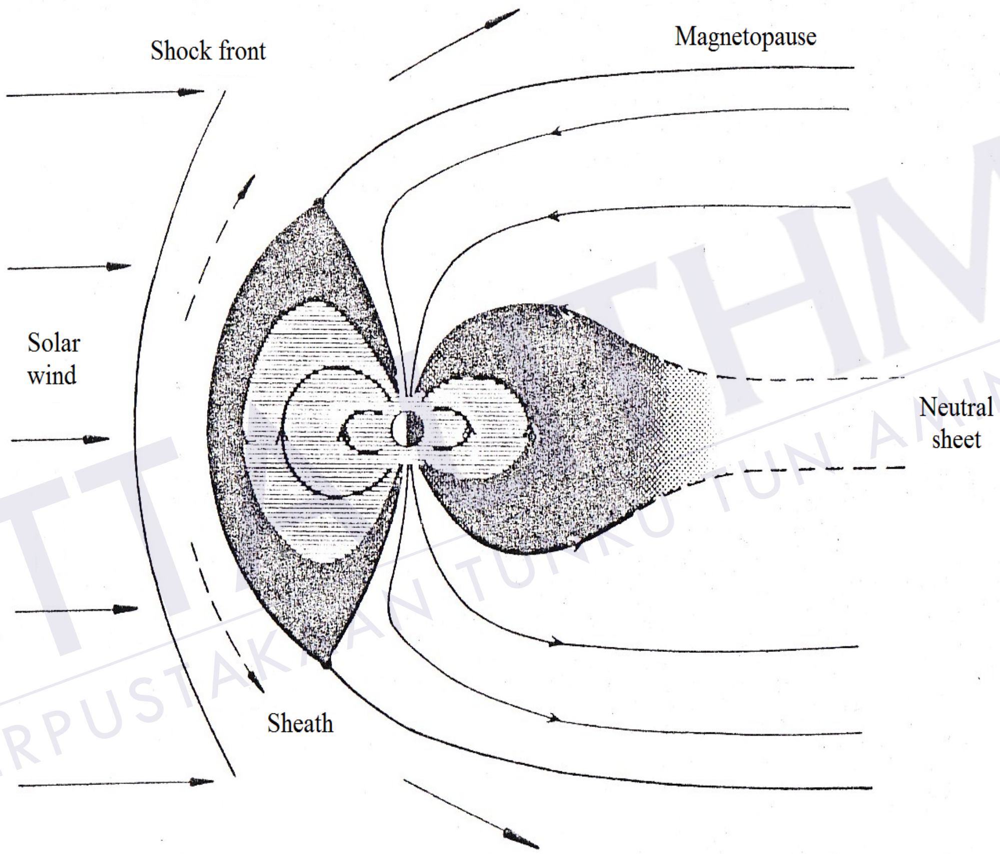

Figure 2.1: The Earth's magnetosphere. Source: Rishbeth and Garriot, 1969

The atmospheric region is affected by the sun and the interesting part of the sun is the small dark patches that can be seen in the white light image. These are called sunspots and have been recorded for a long time. Just after the invention of the telescope, Galileo showed that the sunspots were actually on the surface of the sun. Later, the number of the sunspots on the surface of the sun became a good indicator of the general level of the ionospheric effect from the sun. The solar flux value is also used as an indicator of the general level of the solar activity if the sunspot number is unavailable.

Sunspot numbers affect the ionospheric layer variation daily through the years. The sunspot number plot for 2005 to 2007 is shown in Figure 2.2 while the sunspot number value for 2005 to 2007 is listed in Appendix C to Appendix E. The sun consists of the solar interior, the visible surface or photosphere, the chromospheres or lower solar atmosphere, and the corona outer solar atmosphere. Studies on the ionosphere involving the sunspot number have been used as an indicator of the sun activity. The work that was done by Belehaki *et al.*(2000) using the hourly local ionospheric index f_nF_2 was proposed to define the normal level of the undisturbed ionosphere. Multiple regression analysis was used to determine the model. For each month of the year, for a given station, a set of 48 or 72 coefficients were calculated, depending on the monthly sunspot activity. In general, the data analysis showed the f_nF_2 index varies only with the daily sunspot number R_z and is independent of the magnetospheric activity, approaching the level of the normal ionosphere with a high degree of confidence (Belehaki *et al.*, 2000).

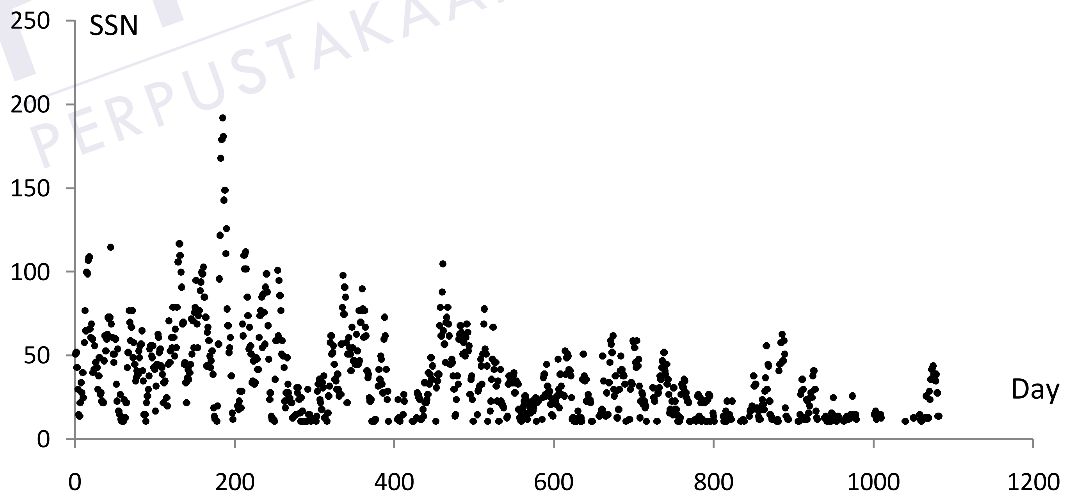

Figure 2.2: Sunspot Number in 2005 to 2007

Solar flare is also used as an indicator for ionospheric variation (Davies, 1996). Flare durations vary from about 3 min up to 2 h and Figure 2.3 shows the solar flare from 2005 to 2007.

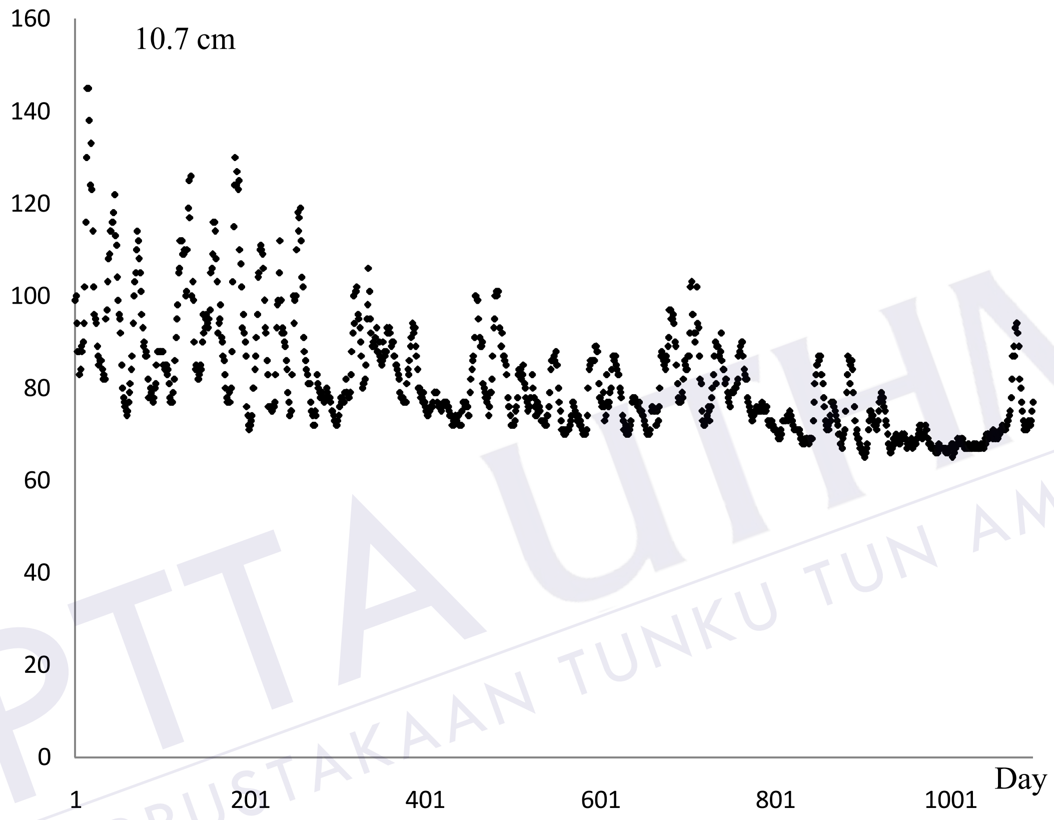

Figure 2.3: Solar flux in 2005 to 2007

The ionospheric layer can reflect the electromagnetic wave with HF frequency. The frequency reflection that occurs from this layer is known as the critical frequency. The critical frequency variation is determined from the sounding equipment used to study the ionospheric variations.

2.3 Critical Frequency of the Ionospheric Layer

This research mainly focuses on the critical frequency because it involves radio wave propagation. The critical frequency is used as the communication frequency at a certain range of reflection from the ionosphere. The critical frequency is f_oF_1 and f_oF_2 for F-layer and f_oE for E-layer, respectively.

The critical frequency is obtained by sending a signal pulse such as an electromagnetic wave launched vertically into the ionosphere. This is reflected back and the highest frequency at which the reflection occurred is obtained. This equation can be written as:

$$n_x = \sqrt{1 - \left(\frac{81N_x}{f^2}\right)} \qquad (2.1)$$

where n_x is the electron density of the ionized layer.

The electromagnetic wave can be reflected from the ionospheric layer if $n_x = 0$. The equation can be written as:

$$n_x = \sqrt{1 - \frac{81N_x}{f^2}} = 0 \qquad (2.2)$$

The highest frequency can be obtained at which the reflection will occur when N_x is a maximum:

$$f_c = 9\sqrt{N_{max}} = \frac{\omega_c}{2\pi} \qquad (2.3)$$

where,

f_c = critical frequency

N_{max} = total electron density

The critical frequency from the observation value can be used to determine the electron density. The derived equation can be written as:

$$N_{max} = (f_c/9)^2 \qquad (2.4)$$

The critical frequency is sometimes called plasma frequency. Each of the ionospheric layer has a specific N_{max} at a given location and time, and the maximum frequencies at which reflection is made by the various layers are often labeled foE, foF$_1$, and f_oF$_2$. These are not constant but vary diurnally, seasonally and with other solar pattern (Griffiths, 1987).

The f_oF_1 critical frequency in the ionosphere is affected by the high solar activity. The sunspot number can also affect the f_oF_1 critical frequency. The frequency of f_oF_1 is much lower than f_oF_2 and it can be given as:

$$f_oF_1 = (4.3 + 0.01R)\cos^{0.2}\chi \qquad (2.5)$$

The f_oF_2 critical frequency is the notable frequency in the F-layer. The f_oF_2 critical frequency is much higher than the f_oF_1 critical frequency. The f_oF_2 has larger values corresponding to high soalr high solar activity during the year 1957-58 and 1968-70 (Zhang and Teo, 2004).

The critical frequency is the parameter used to predict severe geomagnetic activity (Perrone *et al*., 2006). The analysis was conducted during negative ionospheric storm and this is important for successful radio communication. The critical frequency can decrease below its mean value during negative storm or increase during positive storm.

The effect of the critical frequency is also due to sun phenomena. In his study, Yurdanur showed the possible effect of the interplanetary magnetic field (IMF) on the ionospheric region (Tulunay, 1994). Additionally, the ionospheric fitting method has been suggested by Yan Zhao-wen which described the anti-parabolic model for joining the electron layer density (Yan Zhao-wen and Han Yi-feng, 2008). Furthermore, as explained by Forbes *et al*. (2000), ionospheric variability is mainly due to meteorological influences, solar ionizing flux, and changing of solar wind conditions (Forbes *et al*., 2000). Another way to determine the variability of the critical frequency is through a comparison of the measurement observation values between the IRI models. This work has been done by Adeniyi and Radicella, where seasonal variability of the ionosphere was included in the result (Adeniyi and Radicella, 2002).

2.4 Equatorial Region

The height of the F_2 peak varies across the equatorial zone. In general, hmF_2 is highest at the equator, falling off slightly towards summer side and more rapidly towards the winter side; the summer/winter difference being around 100 km by day and 50 km at night. It is remarkable that the day/night variation of the height hmF_2 at equatorial latitudes though similar in amplitude to that at mid-latitudes (of order 100 km), is completely opposite in phase. At mid-latitudes, hmF_2 is higher at night than by day because of the effect of the poleward thermospheric wind by day and equatorward wind at night. At the equator, *hm*F2 is largely controlled by the electromagnetic drift, which is upward by day and downward at night. The formation of equatorial trough has something to do with plasma diffusion along magnetic field lines and this was realized during early development of F-layer dynamics (Rishbeth, 2000).

The ionospheric research in equatorial region is different due to solar wind contribution to F2 layer ionization. Chaman Lal (1997) explained that in the equatorial region, the electromagnet wave radiation in the UV EUV range does not appear for maximum F2 layer ion density because of the fountain anomaly effect (Chaman Lal, 1997).

A 3D raytracing model was employed to study the effect of the equatorial ionosphere on HF radio propagation. Three scenarios of the ionosphere are used as the propagation media for comparison, the homogeneous ionosphere (parabolic), inhomogenous ionosphere and inhomogenous ionosphere with magnetic field (Zhang *et al*., 2004). Characterized as the occurrence of a trough in the ionization concentration at the equator and crests at about 17° in magnetic latitude (Appleton, 1946) in each hemisphere, the equatorial anomaly has been well described as arising from the electrodynamics at the equator. Tidal oscillations in the lower ionosphere move plasma across the magnetic field lines which are horizontal at the magnetic equator. The resulting E-Region dynamo sets up an intense current sheet referred to as the equatorial electrojet. The zonal current flows Eastward during the day and Westward at night. Since an electric field is established perpendicular to the magnetic field, an ExB/B^2 drift moves the ionization vertically upwards during the day and downwards at night. The upward motion of ionization during the day is termed the equatorial fountain since ionization rises above the magnetic equator until pressure forces become appreciable that it slows down and under the force of gravity moves along the field lines and is deposited at higher tropical latitudes. The resulting enhancement of ionization at tropical latitudes and a trough in ionization concentration at the magnetic equator is termed the equatorial anomaly.

Walker and Chan (1989) presented the modeling of the ionosphere in East Asia under solar minimum in the seasonal months of January, April and July for East Asia. Comparisons have been made between the computer simulation and various experimental measurements of the f_oF_2, m(3000)F2 and n_t obtained in East Asia during a period of low solar activity. The model covered a restrictive latitude range of 40º N-20º S (~40º N-30º S dip latitude) and it was considered that these boundaries were too near to the equatorial anomaly region and might affect the numerical solution. In January, maximum f_oF_2 values of ~13.5 MHz occur at about 1400 lst in the southern hemisphere and slightly later at 1500 lst in the northern hemisphere. In April, at 1200 lst the Southern crest closest to the magnetic equator, first, attains full development with a f_oF_2 value of 11 MHz at about 12º s dip latitude (Walker and Chan, 1989).

The asymmetry of the equatorial ionospheric anomaly has been investigated using the critical frequency (f_oF_2) and virtual height (hpF_2 / $h'F_2$) results obtained from the chain of East Asian ionosonde station (at longitude ~120ºE) during the sundial-87 campaign. Although the equatorial ionospheric anomaly has been under experimental investigation for several years, the ionospheric data base and the spatial and temporal resolution of the phenomena have been mainly poor. The investigation presented the relative behaviors of both the northern and southern ionization crest of the equatorial ionospheric anomaly to explain the observed differences. The crest asymmetries existed in the morning and late afternoons. The results were explained by the effect of the trans-equatorial meridional wind, blowing from the Northern (summer) to the Southern (winter) hemisphere. During the afternoon, both ionization crests were similarly affected by reduction of the daytime equatorial electrojet intensity, as indicated by the magnetic field H-component near the magnetic equator (Walker *et al*., 1991a).

Periodic structure was observed in the E- and F-Regions of the ionosphere throughout South East Asia during the sundial campaign, on 29 May to 7 June 1987. The propagating modulation of the critical frequency was observed from different ionospheric and geomagnetic station. The moving Northward and Southward of the propagating wave structure from the observation station became difficult to distinguish because of the interfering problem of this propagating wave. The high value of the critical frequency of the E-layer which is 18 MHz was discovered during this campaign (Walker *et al*., 1991b). On the quiet day of 5 June, evidence was found of an upward propagating acoustic gravity wave modulating both E-region (sporadic-E, f_oEs) and F-region (virtual height, h'F).

The equatorial region E-layer contains highly irregular structures that are associated with the electrojet, and cause equatorial sporadic E. The variations at sunset are generally accompanied by the instability phenomena known as equatorial spread F. The trough exists from mid-morning to late evening, and is aligned with the geomagnetic dip equator, where the peak electron density NmF_2 is typically 30% or so, less than at the crests which lay 15º-20 º to north and south. Ionospheric behavior is controlled by physical processes which are largely expressed in terms of conservation equations for mass, momentum and energy. The equatorial ionosphere is special because of the constraint imposed on charged particle motions by the geomagnetic field. The results from this can make the equations complicated because of the magnetic field geometry that must be incorporated in them

The variability of the critical frequency for an equatorial station has been investigated in Africa. The high solar activity varies between 10 to 30 percent during the day time. The result showed that the magnetic storms increase in variability at both high and low solar activities (Adeniyi *et al*., 2007).

2.5 Low Solar Activity

The sun completes its cycle in 11-years and the activity of the sun depends on the spot produced every year. The solar cycle in 2005 to 2007 is Solar Cycle (SC) 23 and the decrease of the solar activity continued until 2009. According to the smoothed sunspot relative number (SSR no.), Solar Cycle 23 began in May 1996.

Based on many prediction methods, SC23 was originally expected to reach a magnitude comparable to SC 21 (SSR21 max = 164.5) and even higher. SSR23 max was expected to be between 140 and 200, with the exception of a climatologycal method, which had an estimation of 115. SC 23 maximum level was SSR23 max =

120.8, reached in April 2000, with a second (smaller) maximum in Nov. 2001, of 115.5. The SC 23 current data are only for 90 months from its minimum (May 1996 - Dec. 2003). The SSR of SC 23 is lower than for SCs 21 and 22 and closer to SC 20.

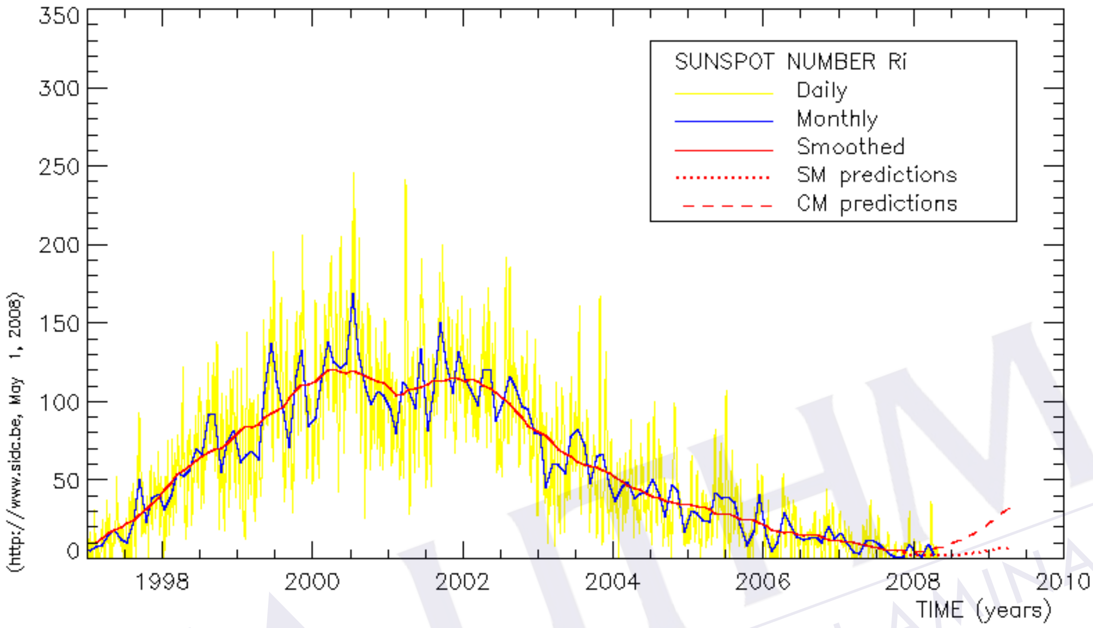

Figure 2.4: Solar Cycle 23

Previous SCs with similar SSRmax had lengths between 9 yr and 1 month (SC 2) and 11 yr and 10 months (SC 11). SC 23 seems to be much alike SC 17, which had a length of 10 yr and 6 months. The first SC 23 active region (AR) emerged in May 1996 – late, in comparison with previous SCs; therefore, it might give a hint on the cycle's slow amplification and low activity level. SC 23 ARs became predominant over the ones of SC 22 after February 1997. Its ascending phase starts to develop in September 1997. SC 23 had a series of long duration ARs, efficient in high energy eruptive events. They took place in July 2000, March - April 2001, May - June 2002 and October - November 2003 (Maris *et al.*, 2004). In the descending phase of the pulses which are more obvious in flare energy release indices than in SSR, information can be obtained about the activity in the current cycle, and even of the appearance of the following one.

Those ARs might appear because of the interaction between the magnetic fields, belonging to the old and to the new solar cycle, with a reversed dipole. This behavior of flares could explain the "abnormal" and unpredicted appearance of SC 23. The new magnetic dipole, responsible for SC 23 activity, began to lose part of its energy even during the descending phase of SC 22 so that the activity of SC 23 proves to be well below predicted values.

The investigation of the f_oF_2 using a long series of solar observations indicates that f_oF_2 at mid-latitudes increase linearly with the 12 month running average of the sunspot number (Sethi *et al*., (2002).

2.6 Summary

The ionospheric layer is highly affected by the sun's activities. The sun consists of the solar interior, the visible surface or photosphere, the chromospheres or lower solar atmosphere, and the corona outer solar atmosphere. The ionization of electron density in the ionosphere enables the reflection of radio wave through open space.

The long-term and short-term trend can provide information of the ionosphere daily. The parameter used for the long-term and short-term analysis is the E-layer and F-layer. The critical frequency can be determined from the study of the E-layer and F-layer. The critical frequency variation is an important parameter of the ionospheric layer during day and night.

The critical frequency is affected by the activity of the sun. The solar cycle of the sun also shows the variation of the critical frequency. The critical frequency variation is determined from the diurnal variation and seasonal variation. The variation of the ionosphere is also a result of the sun phenomena such as geomagnetic storm and IMF. This is mainly due to meteorology influences, solar ionizing flux and changing of solar wind condition.

The ionosphere in other countries has been studied beginning right after the measurement equipment was invented. The measurement equipment is used for prediction and to study the nature of the ionospheric layer. The sounding system uses the vertical and oblique sounding of radio wave from the ground system. Research in European countries have used parameters such as the sunspot numbers to investigate the daily effect of the ionosphere layer variation throughout the years. The study of the TEC in the ionospheric region involving GPS observation and similar study have been carried out in Malaysia using JUPEM's observation values. The ionosonde measurement equipment using the ground base system gives the advantage for ionospheric research in Malaysia. Ionospheric study has been done in the equatorial region where the ionospheric variation was studied using the profile and the critical frequency.

Equatorial anomaly plays an important role in the changes of electron density at the equatorial region. Because of the magnetic field line, concentration of the electron density is lower at the magnetic equator. This is also known as the equatorial fountain anomaly. The investigation of the equatorial region is based on geomagnetic storm event.

Every 11 years, the sun completes a solar cycle and the sun's activity depends on the spot produced every year. Solar cycle 23 began in 1996 and continued until 2009. In this study, the investigation of the critical frequency variation is based on solar cycle 23 during the decrement period of 2005 to 2007.

CHAPTER III

METHODOLOGY: EXPERIMENTAL SETUP

3.1 Introduction

This chapter discusses the equipment setup which consists of several hardware and antenna. There are two types of sounding that can be used to measure the ionosphere reflection: vertical incidence sounding and oblique incidence sounding, but in this study, the vertical incidence sounding was used. The parameter was used in the measurement and the interpretation of the ionogram to determine the critical frequency. The International Reference Ionosphere model was used to compare the model with the observation value. This chapter explains the theoretical and measurement value of the critical frequency that been used in this research. The error and uncertainty from the observation and equipment is also explained. The critical frequency is the parameter that was used for analysis and for developing the modeling.

3.2 Equipment Setup

The equipment used in the measurement is a ground sounding system (MacDougall *et al*., 2000). The digital ionosonde uses the Barker Codes for noise improvement in the receiving system. The vertical incidence sounding was used at the observation station. The system uses a computer to control and store the observation value from the reflection of the ionospheric layer. Four receivers are used for the system to give the ionogram and drift value of the ionosphere. The transmitter card is connected from the amplifier and the amplifier will boost the signal to the transmitting antenna. The receiving card is connected from the pre-amplifier to the receiving antenna to the card (MacDougall, 2003).

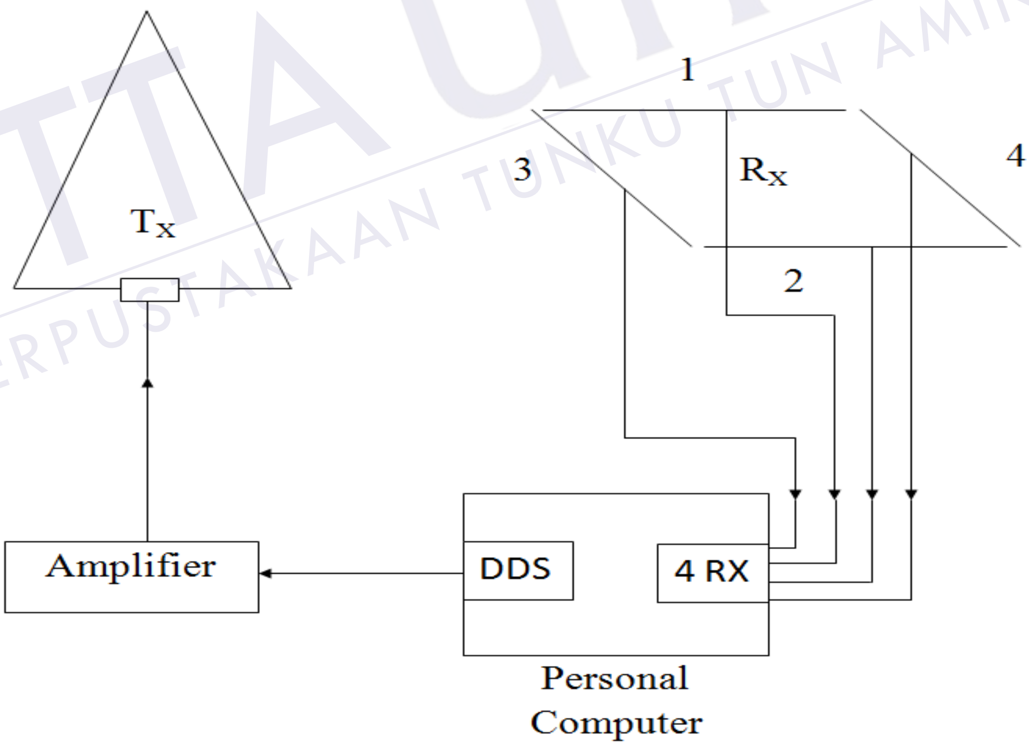

Figure 3.1: Equipment setup for the measurement consisting of PC, transmitter, transmitter antenna and receiver antenna.

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