Ionospheric Critical Frequency Observation From Ionosonde Data for GPS Positioning Improvement over Malaysia

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Abstract. This research work was done to determine the critical frequency, f_c, variation over Advanced Telecommunication Research Center (ATRC) UTHM by identifying the variability of the ionosphere from Ionosonde. The ionospheric variability was analyzed on diurnal variation basis at Low Solar Activity (LSA) and High Solar Activity (HSA). Ionosonde that was placed in ATRC was used to detect the f_c of the ionosphere. Observation data in the form of Ionogram than was used to identify thef_c and then the plotted using Matlab. The comparison was done for 2 diurnal solar activity variation data for 2 consecutivemonths from the year 2011. The results then was compared with the International Reference Ionosphere's (IRI) f_c. Overall,the solar activity has direct effect to the f_c during daytime than after Sun set over the equatorial region. By knowing the ionospheric condition, this will be helpful to improve the position of train when applying the European Rail Traffic Management System (ERTMS) in Malaysia later.

Keywords: Ionosphere, Critical Frequency, Ionosonde, Solar Activity.

1 Introduction

The Earth's atmosphere is divided in few layers and ionospheric layer is ionized by radiation from the Sun [1]. Ionosphere layer is situated from about 60 to 2000km from the surface of the Earth. The ionosphere is consists of freeelectrons and ions that being produced by the extreme ultraviolet radiation from the Sun. This layer is divided furtherinto D layer, E layer and F layer (which can be split further into F_1 and F_2 layers).

The composition of the ionosphere is strongly influenced by the solar activity and the amount of electron densitydepends on latitude, longitude and the altitude [2]. Since the solar activity is very active on the equatorial region, theamount of electron density is always greatest over this region. The five main variations are diurnal variations, seasonalvariations, latitudinal variations, altitudinal variations and sunspot number. In order to study the ionospheric variations, all these 5 elements has to be considered.

In this work, the critical frequency, f_c, of the ionosphere has been determined using Ionosonde (Canadian Advanced Digital Ionosonde (CADI)) in ATRC UTHM. Ionosonde is pulse radar that operates in between 1 to 20 MHz of frequency range. The f_c is equal to the maximum reflection frequency at vertical incidence from the ionospheric layer[4]. In other word, the f_c correlates very well with the solar activity and it is the measure of maximum electron densityin the ionospheric layer [5].

1.1 Critical Frequency

The ionospheric f_c varies with time of a da y, altitude, season and location and it correlates with the on the maximumamount of electron density. The f_c is equal to the vertical incidence reflection from the ionospheric layer due to the maximum frequency [7]. Normally, the highest frequency signal can be obtained from the reflected point at the transmission location, which is located at the F-layer – which sometimes termed as f_oF_2 (critical frequency reflected from the F_2 layer).

The f_c depends on the ultra-violet (UV) radiation intensity from the Sun. It varies continuously with the time of the day, which correlates well with the local activity of the Sun. Since the f_c correlates with the solar activity, it can be used to calculate the electron density composition in the ionospheric. This is where the role of Ionosonde comes in. The Ionosonde is used to transmit sequence of varying frequency pulses and the reflection signal frequency will be used to measure the composition of the ionosphere in the unit of f_c. For this, need a proper structured antenna farm – which we have at UTHM.

From here, by using the Ionogram, the maximum electron density and the f_c (in the function of height) can be obtained. It depends very much on the reflection frequency value, which represent the f_c value. However, if the transmission frequency value is very high, the refraction index will be finite. Due to this, there is no any vertical reflection. Therefore, rather than using higher frequency value, a minimum value is sufficient to obtain the f_c at whichthe vertical reflection will take place to determines the maximum electron density from the ionospheric layer. The reflection height is determined by the frequency of the Ionosonde signal that being transmitted up in the sky [8]. Thevertical asymptote corresponds to the critical frequency of the F_2 layer, f_oF_2.

Every ionospheric layers has its own f_c and it correlates with the maximum electron density from the ionospheric layer. The relationship between electron density and the f_c can be obtained using equation (1) below;

$$fc = 9\ x\ 10^{-6}\sqrt{Nmax} \tag{1}$$

where f_c = in MHz, and $N_{max} = N_mF_2 = electron$ per m^3

Other than that, the variation of f_c can be obtained by comparing it with the the International ReferenceIonosphere's (IRI) data base [9]**.** IRI is a database that being developed to determine the ionospheric data at any part of latitude, longitude and altitude. Most of the time, it correlates very well with the observed values.

2 Methodology

To conduct this research work, the understanding and the knowledge on how to 'read' (interpret) the Ionogram (inthis case, CADI diagram) is very important. CADI is a low cost, state of art, flexible, full featured Ionosonde ideal for both routine ionospheric monitoring and research. This system provides sounding capability using high power RF pulses at vertical incident. The reflection frequency range of CADI is from 1 to 20 MHz.

2.1 Interpretation of the Ionogram

The transmitter provides power amplification of the RF signals. The required transmitter power is only 600 wattsused to send the frequency range 1 to 20 MHz. Barker pulse coding provides an 11 dB S/N improvement which is equivalent to having 13 times more transmitter power [10]. The amplifier unit is a solid state and includes monitors for forward and reverse power.

The receiver cards amplify and demodulate the return signals. The system can incorporate from one to four receivers for spaced antenna measurements. The receiving signal will be displayed in the form of Ionogram and savedata storage in the hard disk.

To operate the Ionosonde, two main programs are needed;

(i) CADIRUN – to check the function of the CADI system to make sure it works properly. When this program executes, it reads the CADI configuration data from the file LOCATION.INI.

(ii) CADITEST - the program used for collecting data. When this program executes, the instructions will be given forthe system to identify which data to collect and when to collect.

The Expert System for Ionogram Reduction (ESIR) CADI Analysis software allows CADI Ionograms to be scaled. ESIR is an approach to automate Ionogram scaling. It uses a combination of knowledge-based pattern recognition and physics-based modeling techniques to extract traditional ionospheric parameters such as f_oF_2 and h_mF_2. ESIR also generates electron density profiles. If the Ionogram has adequate quality, the virtual height trace will be utilized to obtain a true height for given electron density profile.

The analysis of the Ionograms provides an extended database of EDP that contains the ionospheric variability asa function of latitude, local time (UT) and season. Fig. 1 below shows the sample of Ionogram and from here, the f_c and the virtual reflection height can be determined.

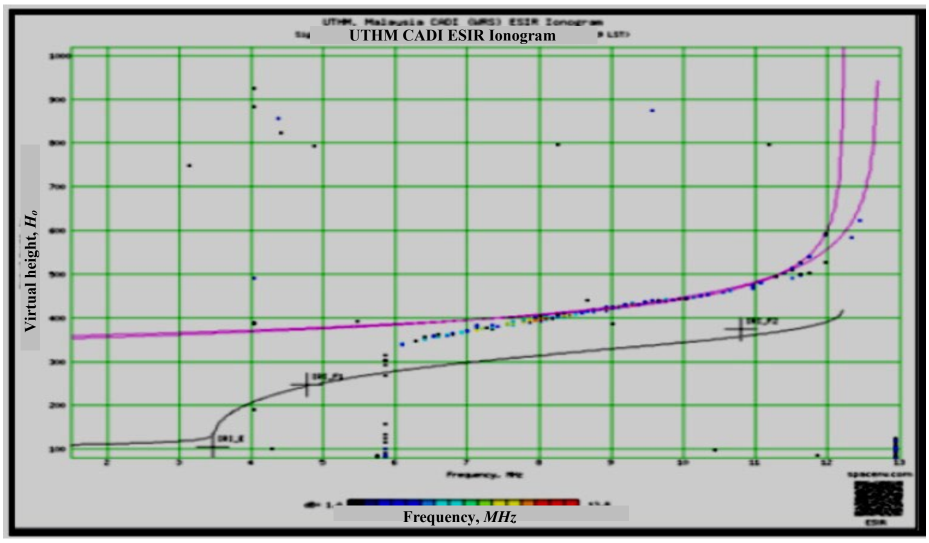

Fig. 1. Sample of ESIR Ionogram from ATRC UTHM.

3 Results and Analysis

In this work, the f_c of the ionosphere over equatorial region was observed, estimated and analyzed. The analysis was done for two levels of solar activity: local time LSA and HSA. The approach that was made in this work is that LSA is when the solar activity is not active at local time and HSA is when the solar activity is active at local time. So,to fulfil this, two different time periods have been chosen; which is 10:00-14:50 LT (HAS), and 01:00-04:50 LT (LSA). The Ionogram data that was obtained are for the months of October and November 2011 respectively. Only 2 months of data has been taken for this work to show the relationship between consecutive data set. Data from 2011 was chosen because 2011 was the year where the solar activity was in up-trend mode.

Although the ESIR Software can record the data at 15 minute interval but for this project, a 30 minute interval is selected for analysis purposes. The difference between the f_oF_2 observations and the f_oF_2 values from IRI model werecomputed using equation (1) above. Analysis has been made by showing the similarity in f_oF_2 between observed (Ionosonde) and measured (IRI).

3.1 Variation Due to Solar Activity on October 2011

The comparison between the f_c in four days in October 2011 is shown in Fig. 2 during HSA. It can been seen that the f_c develops gradually during the day between 10:00 to 14:50 hours LT.

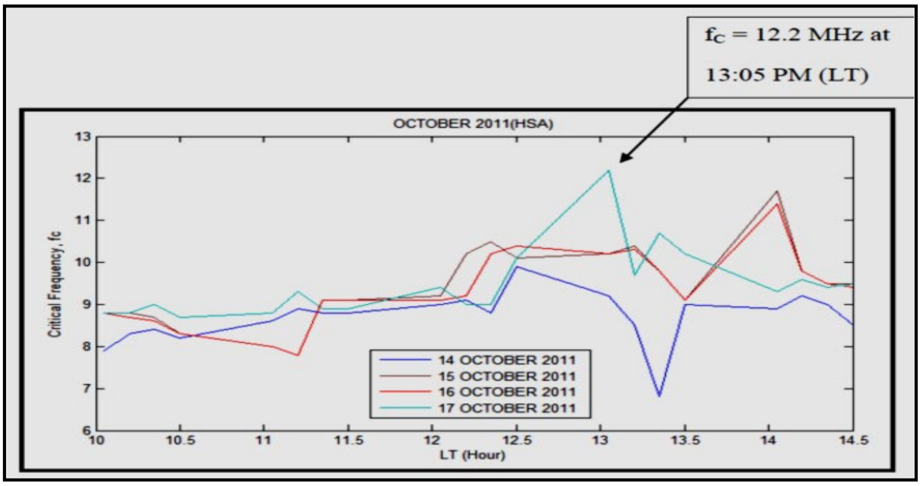

Fig. 2. The *foF2* values on October 2011 from the Ionogram.

The observed and model f_oF_2 rise and reach the maximum value on 17 October 2011 at 13.05 PM (LT) compared to 14, 15 and 16 October 2011. This is due to the photoionization process that can occur during the day when the Sun is above the horizon. The f_c of ionospheric layer will be greater at higher level solar activity.

On 14 October 2011, f_oF_2 is much lower than other observation days. It happens because when the Sun is disturbed(due to solar flares and high solar wind streams), it can affect the ionosphere. Most of the solar flares occur during high solar activity and it will cause only a small effect to the ionosphere.

Fig. 3 shows the comparison between the f_oF_2 observed and the IRI value. It has been proved that the IRI's f_oF_2 are very close to the observed f_oF_2 values.

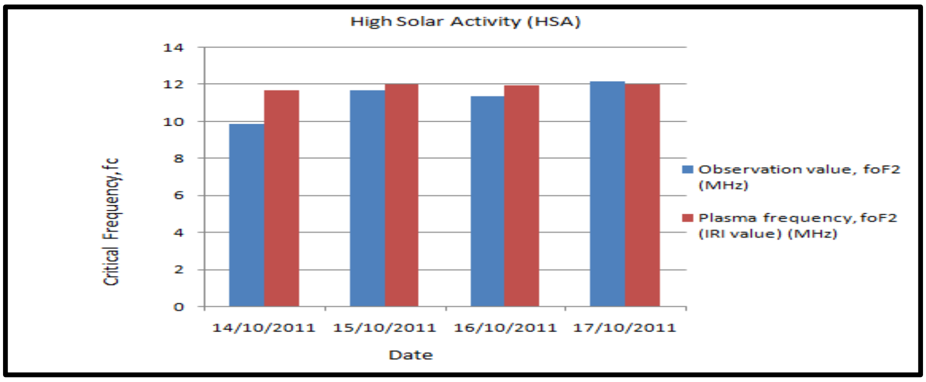

Fig 3. Comparisons of the *foF2* between the observed and the IRI during HSA in October 2011

Fig. 4 shows the comparison between the f_c for four days in October 2011 at LSA. The frequency of the F_2 layervaries with the time of the day at 1:00 AM until 4:50 AM (19:00 UTC to 22:50 UTC). The maximum value of f_c on 14 October 2011 is 5.9 MHz.

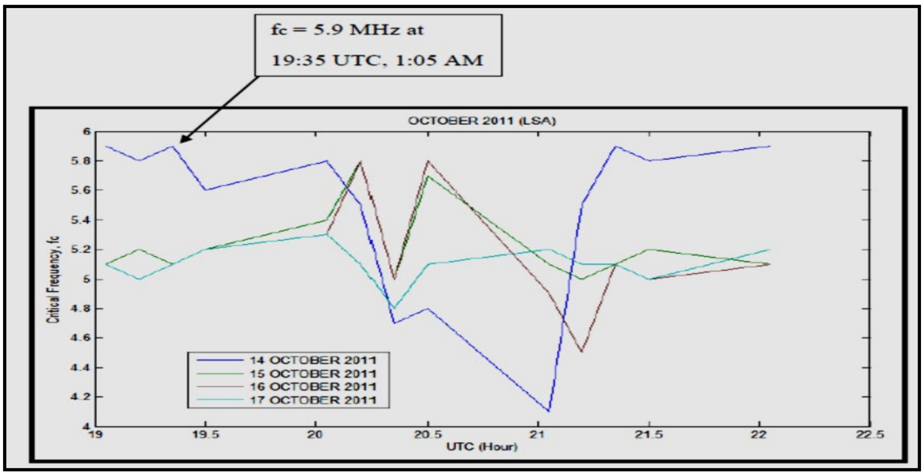

Fig. 4. The *foF2* values on October 2011 from the Ionogram.

From the observation, f_c is 5.9 MHz. However, from the IRI model, the f_c is 5.04 MHz. The variation between these 2 data is very small than the calculated f_oF_2. The f_c also very low (from the plot) after the Sun set. This phenomenacould be due to the recombination process that takes place in the ionospheric layer. Fig. 5 below shows that the IRI's f_oF_2 value which is quite closer to the observed f_oF_2 values.

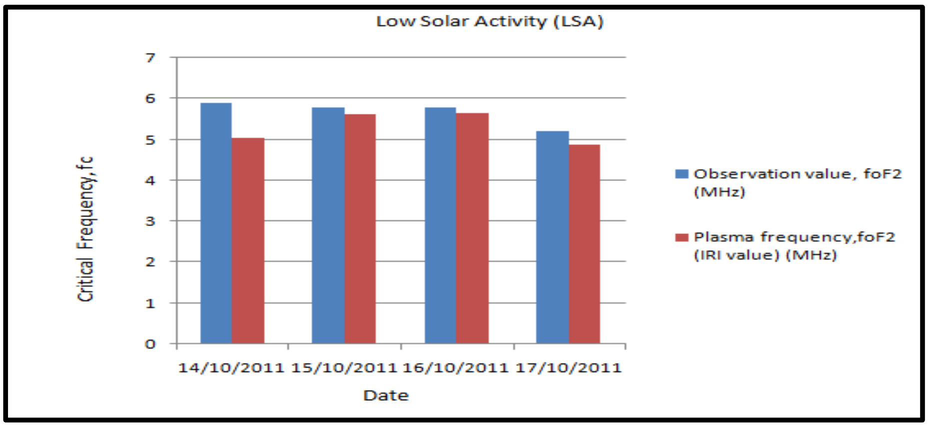

Fig. 5. Comparisons of the f_oF_2 between the observed and the IRI during LSA in October 2011.

3.2 Variation Due to Solar Activity on November 2011

Fig. 6 shows the f_oF_2 for 4 consecutive days. It is shown that the value of the f_c develops gradually in the day where the peak value falls in between 10:00 AM to 14:50 PM. The maximum f_c is on 16 November 2011 at 10:35 AMLT. For this condition, the f_c vary with time and correlates closely with the solar activity. Other than that, increased in ultra-violet (UV) radiation also would increase the f_c of the F-layer.

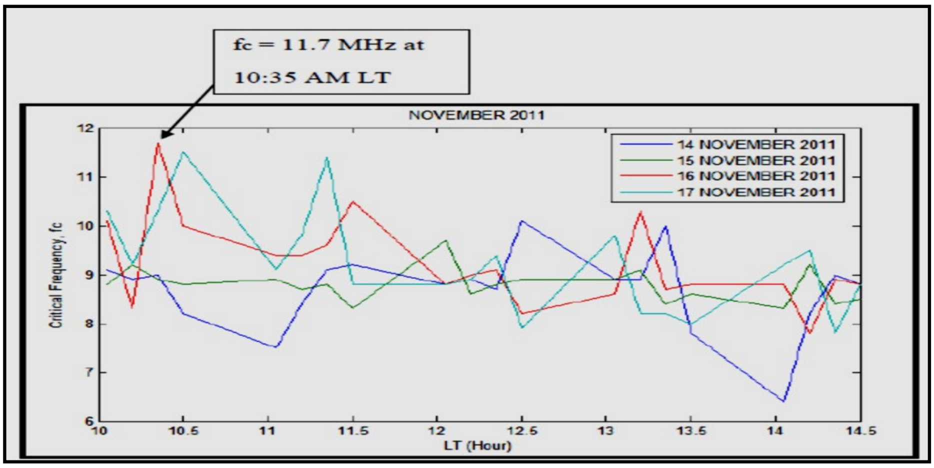

Fig. 6. The $foF2$ values on November 2011 from the Ionogram.

Fig. 7 below shows that the correlation between IRI's f_oF_2 and the observed f_oF_2. Both of them shows very good correlation.

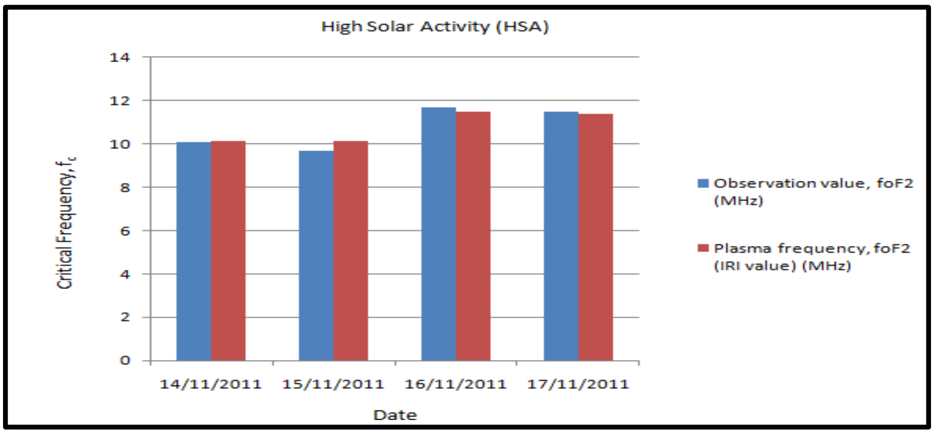

Fig. 7. Comparisons of the f_oF_2 between the observed and the IRI during HSA in November 2011.

Fig. 8 below show the comparison between f_c from 14 until 17 November 2011. The f_c is lower and weak at this time could be because it is the period of time without sun shine.

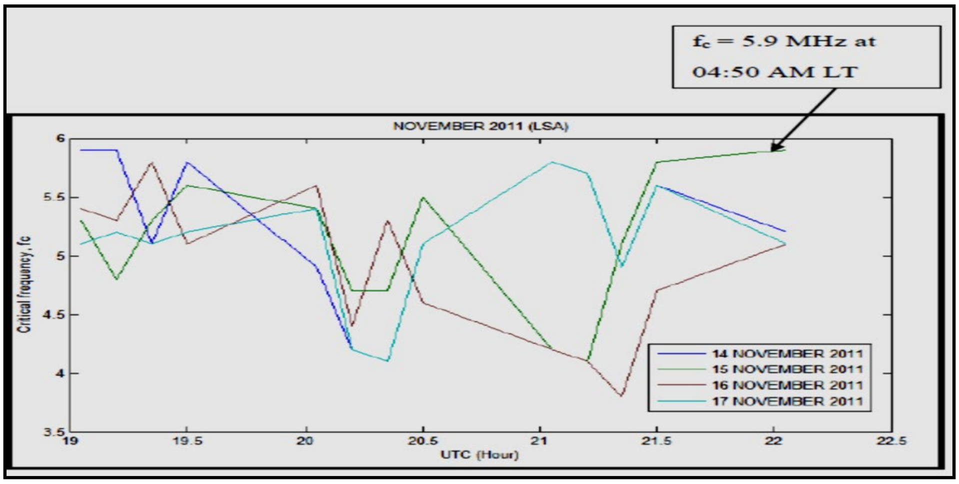

Fig. 8. The *foF2* values on November 2011 from the Ionogram.

During night, the density of the ionosphere is low. It will continue to decrease, reaching its lowest point just before dawn. So, the f_c is usually well below 6 MHz.

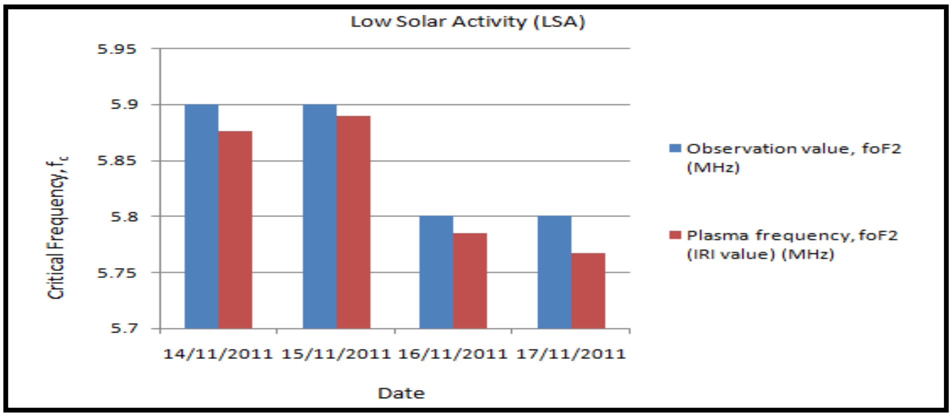

Fig. 9. Comparisons of the f_oF_2 between the observed and the IRI during LSA in October 2011.

Fig. 9 also show good correlation between the IRI's f_oF_2 and the observed f_oF_2 values.

4 Conclusion

In this work, the Ionogram variation at different solar activity has been shown. The Ionosonde datawas analyzed based on short-term (diurnal) variability on hourly, daily and monthly basis to determine the f_c at local time (UTC) for the month of October and November 2011.

The results showed that on October and November 2011, the value of the f_c of the ionosphere is somehow maximum within the period of 10:00 AM to 3:00 PM (04:00 UTC to 09:00 UTC) while somehow minimum within the period of 1:00 AM until 4:50 AM (19:00 UTC to 22:50 UTC). Solar activity affects the ionosphere more during day-time than night time. The highest f_c is 13 MHz and it keep decreasing to 6 MHz as night approaches. This variationof the ionosphere directly influenced by the variation in the Sun's activity.

The f_c that was obtained also has been compared and proved by using the IRI data. The correlation between thesetwo data are quite close, close to more than 90%. That shows the CADI Ionosonde in ATRC gives very accurate and reliable f_c data.

This observation will be useful for improving the Global Positioning System (GPS) positioning which will be useful for the implementation of ERTMS for Malaysian railway network in the future.

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