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RESEARCH ARTICLE

Statistical Analysis of Radio Frequency Interference (RFI) Caused by Solar Radiation During Wet and Dry

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Abstract Radio frequency intereference study is crucial in radio astronomy field of research in managing the background noise to avoid signal mitigation from celestial object of interest. This paper describes a correlation between solar radiation and radio signal within ultra-high frequency (UHF), which statistically deduced using Spearman correlation method. The observation was done in several location including Balai Cerap KUSZA (BCK) during dry and wet season. Solar radiation is one of meteoparameters that measured simultaneously with radio signal data using weather station. This data was analysed and compared to power level (radio signal) recorded in dBm during wet and dry seasons. Findings show that telecommunication services occupy the UHF band. Hence, it can be concluded that, there are still some frequencies available for radio astronomical sources including that below 400 MHz. This allocation is suitable for solar observation, Jupiter observation, continuum observation, solar wind observation, as well as pulsar and deuterium observation and VLBI application. Statistical analysis indicate that solar radiation was significantly prominent during peaks of 382.5 MHz, 1800.0 MHz and 2160.0 MHz. It is largely related with a correlation of 0.6252, 0.6769, 0.5965 during the wet season and only small and moderate correlation at all peaks during the dry season. This important information could be a significant contribution for radio astronomers when trying to identify the best allocation for observing radio astronomical sources in the future.

Keywords: Statistical Analysis, Radio Frequency Interference, Solar Radiation, Astronomical Sources, Wet and Dry seasons

Introduction

Investigating Radio Frequency Interference (RFI) is a continuing concern in the field of radio astronomy. Due to rapid development in technologies and telecommunications, overcrowding of frequency users often become a challenge to radio astronomical observation (Abidin *et al.*, 2015; Hamidi *et al.*, 2012; Umar et al., 2015). Proper mitigation initiatives have been suggested and developed so that the astronomical radio service can still be protected (Liu *et al.*, 2019; Pinchuk *et al.*, 2020). The RFI monitoring system in Malaysia is yet to be developed for an extended period, as there is still no radio telescope available in the east coast of Peninsular Malaysia. Since Malaysia is located at the equator, it is consistently cloudy even during the drought season. Climate is a concern when choosing a perfect site for establishing a radio telescope in order to avoid future technical issues. A previous study on RFI in Malaysia had considered meteoparameters, such as rain, humidity, solar radiation and wind speed as some of the external RFIs for a radio telescope since it has the ability to attenuate the ambient radio signal. The effect of solar radiation on radio signal has been exemplified by (Ezekoye., 2007). The study found that the increase in attenuation depended on the seasons, Earth's surface, frequency and time. Protection of the radio astronomy service from unwanted emissions resulting from the application of wideband digital modulation should be lower, as recommended in Rec. ITU-R RA.1237-1. Details of the study regarding the levels at which interfering signals become harmful to radio astronomy observation can be found in Recommendation ITU-R RA.769. For radio astronomical observation in specific bands, for example deuterium (322.0-328.6 MHz), hydrogen (1400-1427 MHz) dan hydroxyl lines (1610.6-1613.8 MHz), the frequency must be below the astronomical line threshold power flux-density (pfd) value -204 dB(W/m^2), -196 dB(W/m^2) and -194 dB(W/m^2) (Abidin *et al.*, 2010; ITU, 2003).

Most RFI studies were carried out in the western part of Peninsular Malaysia, such as in Kuala Lumpur, Negeri Sembilan, Langkawi, Perak, and Selangor, which was carried out by University of Malaya since 2005 (Abidin *et al.*, 2010; Hamidi *et al.*, 2011; Hamidi *et al.*, 2014; Hamidi *et al.*, 2012; Umar *et al.*, 2011; Umar *et al.*, 2013; Umar *et al.*, 2014; Umar *et al.*, 2015; Umar *et al.*, 2018). Several studies have studied the effect of solar radiation on radio signal attenuation (Mat *et al.*, 2016; Sabri *et al.*, 2017; Marhamah *et al.*, 2018; Afifah *et al.*, 2016). However, these studies have failed to show that solar radiation has a significant effect on radio signal. Afifah *et al.*, 2016 found that radar signals are affected by ionised particles emitted by heat energy from the Sun. The signals received were lower during the day compared to the night. The variation was seen starting from sunrise and sunset as there were changes in signal strength. Collectively, this study outlines a critical role for the robustness of the VHF and UHF in a solar radiation environment. The higher frequency is more sensitive compared to the lower frequency due to its lower wavelength. In this case, VHF is more robust because of its low sensitivity. This study indicates that there is a relationship between solar radiation and the transmission signal, taking into account external factors that might affect the radio signal in the troposphere, which consists of meteoparameters such as wind, rainfall and atmospheric reflection. Meteoparameters that are usually associated with the attenuation of radio transmission signals are rain, wind, humidity and sometimes fog. More specifically, wet foliage causes attenuation to radio signal, whereby an increase in the system's temperature changes the signal polarization compared to dry foliage (Joshi *et al.*, 2005).

The objective of this study is to investigate the available knowledge about the effects of the solar radiation on radio signal attenuation using a statistical method, with a focus on the UHF band. This study should serve as a reference for future studies pertaining to choosing suitable sites for establishing a radio telescope in Malaysia. This paper consists of four sections. The methodology of the study is stated in Section Methodology, while the effect of solar radiation on radio signal is proposed, and verified in Section Result. This is followed by the findings and conclusions in Section Conclusion.

Methodology

Instrumentation and Procedure

The experimental setup, shown in Fig. 1 comprises an antenna, a 1.4 GHz low noise amplifier (LNA) and a spectrum analyser. A discone antenna optimized at 1240 MHz was mounted on a tripod and connected via a 50 ohm coaxial cable to the 28 dB gain/0.34 dB NF spectrum analyser. The antenna was designed and properly measured by (Umar *et al.*, 2018) for this purpose. The setup was fully portable and easy to assemble. It was powered by a 12V battery for the spectrum analyser. The Davis Vantage Pro2, shown in Fig. 2, was used to obtain solar radiation data at BCK. The weather station was mounted on the rooftop of the observatory and connected to the processing software running on a computer.

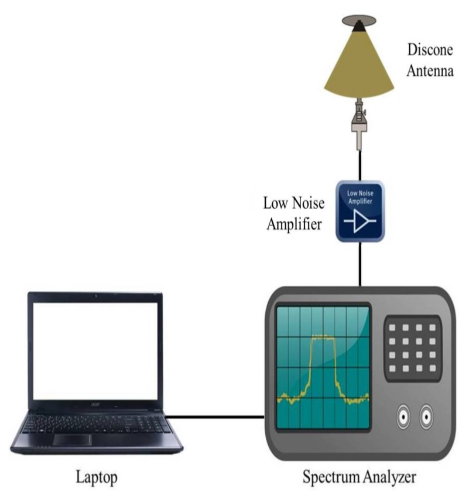

Fig. 1 Instrument Setup for RFI observation.

Fig. 2 Davis Vantage Pro2 device in BCK.

Based on the studies by (Mohd *et al.*, 2017; Shafie *et al.*, 2017), the observation period was extended to 24 hours during the wet season (January) and dry season (May) at BCK (5º 32' 10" N 102 º 56 ' 55" E), which is situated in the coastal area of Merang. The wet season in the east coast of Peninsular Malaysia is brought about by the North-East (NE) monsoon, while the dry season is brought about by the South-West (SW) monsoon. The power level in dBm, strength for all frequencies between 300 MHz and 3000 MHz were observed and recorded every one minute for an hour using the spectrum analyser (Keysight FieldFox Microwave Analyzer N9915A 9GHz) and compared for both the seasons.

Site Survey

Before data taken in BCK, preliminary studies had obtained brief RFI pattern and information to get a general idea before the main observations were conducted. Due to limited instruments and time constraint, the preliminary was done to observe radio environment below 1000 MHz, which is still within the UHF band range. As a lot of RFI monitoring have been carried out by Malaysian researchers in other places, such as Hentian Serdang (HSRDG), ESERI (ECE), Sungai Chantek (SGC) and BCK. The site selection criterion was applied for various populations; from remote areas to urban areas. It indicates the frequency allocated by telecommunication services and radio communication. It is important that the site is not off-grid and has enough facilities and infrastructure for the observer, especially power demand and internet connection.

BCK is located in a remote area 24 km from Gong Badak. The observatory is situated on a Merang Hill 40 m (160 feet) above mean sea level and nearby Merang jetty and beach of Merang less than 1 km. This jetty provides tourist access to Redang Island, which is one of the most beautiful islands in the world. Meanwhile, ECE is located in the Universiti Sultan Zainal Abidin's (UniSZA) main campus. Another site is HSRDG, which is located in a residential area in Serdang City, Selangor where highways are present nearby. In contrast, SGC is located 10 km away from Jerteh City. It is located nearby a forest, old residential area and is surrounded by foliage. The average power level measured at selected sites differed from each other, as illustrated in Figure 3. In the same bandwidth, it was noticed that several radio astronomy observations below 1000 MHz are pulsar, deuterium line (DI), solar radio burst Type I, II and III, stationary solar radio burst and moving Type IV, solar burst continua and solar burst Type V. The frequency users in HSRDG are more crowded compared to ECE, BCK and SGC.

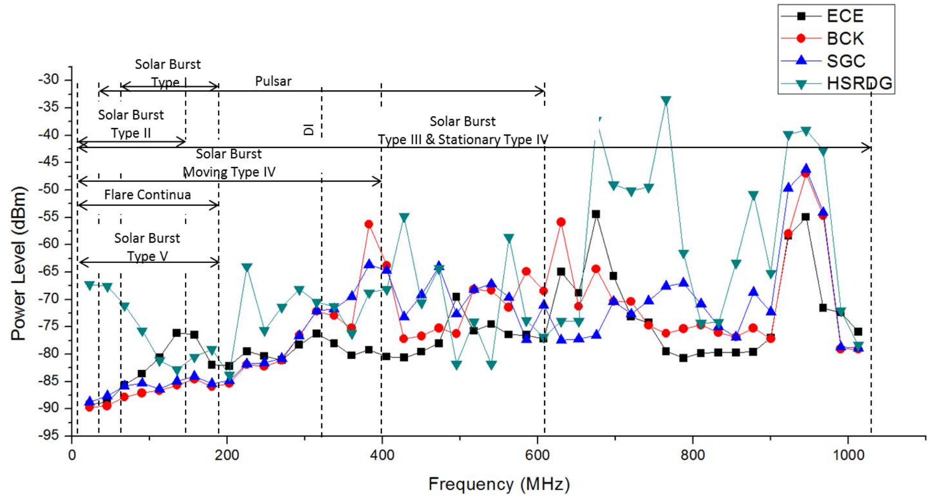

Fig. 3 Spectrum monitoring at ECE, BCK, SGC and HSRD.

According to the Malaysian Population and Housing Census (2010), the population density in Kajang, where HSRDG is located, was 342,657 people. There is a hospital located nearby the observation site, thus, increasing the population density in HSRDG due to high-traffic loads and high-end medical equipment. The population for ECE, BCK and SGC were 83,793 population/km^2, 3,274 population/km^2 and 5,655 population/km^2 respectively (DOSM, 2010). Overall, these results indicate that BCK is considered as one of the suitable places for radio astronomical observation due to its low population density and low spectrum pollution, which is 47.9707 population/km^2 compared to other sites even though power level at all these sites is low l. The high population density should increase the level of human-made RFI (Sabri *et al.*, 2017).

Results and Discussions

Radio Environment at BCK

The spectral measurements are shown in Figure 4. In the plots, the region with no prominent peaks are labelled as region 1 (R1), region 2 (R2), region 3 (R3) and region 4 (R4). R1 is between 427.5 MHz – 900.0 MHz, R2 is between 990.0 MHz – 1777.5 MHz, R3 is between 1912.5 MHz – 2092.5 MHz and R4 is between 2227.5 MHz – 3000.0 MHz. The average power level difference between the wet season and dry season is 11.3923 dBm.

It is important to identify the prominent peaks as well as it sources in the UHF band because there are allocated bands for radio astronomical observations. Although Malaysian Communications And Multimedia Commission (MCMC) has allocated certain bands, it should be protected for the study of astronomy, while the existence of ground-based RFI still exists as it comes from human-made RFI sources. Many researchers who study radio astronomy have experienced this problem (Eatough *et al.*, 2010; Otto *et al.*, 2016). Another problem arises when solar radiation and some meteoparameters cause attenuation the ground base RFI, causing the average power level to be amplified.

Throughout the observation period, prominent peaks were found and identified as RFI contributors towards nearby radio astronomical objects. These prominent peaks were labelled as peak I (382.5 MHz), II (945.0 MHz), III (1800.0 MHz) and IV (2160.0 MHz), while users of these frequencies were identified based on MCMC. Most of these prominent peaks had originated from telecommunication systems from the nearby base station as there were users from nearby residences. The source of these peaks are shown in Table 1. There are peaks detected in the R1 until R4, however the signal power level are low. There are normally comes from the telecommunication sources such as radio and television transmission, radar, radio amateur communication, military communication, air traffic control, flight communication and many more. Each of them communicates in their specific spectrum allocated by the authorities (e.g. MCMC).

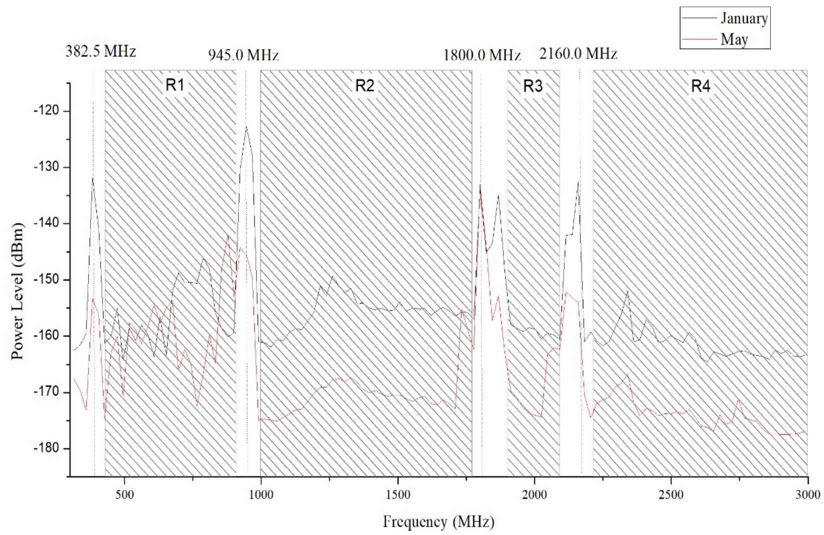

Fig. 4 Average power level at BCK and low RFI region (R).

Table 1 Peaks & Malaysia Allocation.

Peaks	Malaysia Allocation	Sources
I	FIXED MOBILE MLA34 5.254 MLA3 MLA14 MLA84 MLA93 MLA102	Digital trunked radio
II	FIXED MOBILE 5.317A MLA91 BROADCASTING 5.320 MLA3 MLA96 MLA102	Cellular mobile services [EGSM/GSM]/ [IMT]
III	FIXED MOBILE 5.384A 5.388A MLA53 MLA89 MLA91 MLA92 MLA99 5.149 5.341 5.385 5.386 MLA3 MLA81 MLA90	Cellular mobile services [EGSM/GSM]/ [IMT]
IV	FIXED MOBILE 5.388A MLA53 MLA92 5.388	Cellular mobile services IMT

Correlation between Solar Radiation and Radio Signals

Based on observations, the solar radiation measured was higher during January (226.2535±3 W/m^2) compared to May (200.9688±3 W/m^2). Although January was considered to be a dry season and May was a wet season, it is noted that there was rainfall on the days of the observation (January only). where the rain rate was 0.3909±2.9265 mm/h, while there was no rain in May. It was also observed that both days had a 74% RH. The temperature only differed slightly in January (29.06±1.0235 ^{o}C) and May (28.93±1.4273 ^{o}C).

Based on Table 2, solar radiation had a significant effect on the observed peaks (Peak I, II, III and IV) and it had a large correlation with Peak I, III and IV with values of r=0.6252, r=0.6769 and r=0.5965, while Peak II had a small correlation (r=0.1192) in January. Moreover, only small correlations were calculated for Peak I, II, III and IV, which yielded values of r=-0.2860$, r=0.2745, r=-0.0196 and r=0.3393 respectively, during May.

Table 2 Correlation of solar radiation and radio signal.

Month	Peak I	Peak II	Peak III	Peak IV
January	0.6252	0.1192	0.6769	0.5965
p-value	0.0000	0.0017	0.0000	0.0000
May	-0.2860	0.2745	-0.0196	0.3393
p-value	0.0000	0.0000	0.6581	0.0000

These positive and large correlations indicate that the attenuation of radio signals change as the solar radiation changes, whereby the ionised particles produced by the heat energy from the Sun effects radio signals (Taat *et al.*, 2016). This is also consistent with the curve fit shown in Figure 5. The power level increases when solar radiation increases. This may affect RFI by making it unstable and causing interference to radio astronomical observations within the UHF range, especially DI, HI and OH. At higher frequencies (Peak III and IV), more signals were observed and they were largely correlated compared to lower frequencies (Peak I and II). This may be due to the existence of rainfall in January. According to Joshi *et al.* (2005), wet foliage causes more interference compared to dry foliage in the form of attenuation to radio signals, increasing the system's temperature and changing the signal's polarization.

Conclusions

This study determined the frequency window for UHF (300-3000MHz) and found that there is RFI-free allocation that exists in between (i) 427.5 - 900.0 MHz, (ii) 990.0 - 1777.5 MHz, (iii) 1912.5 - 2092.5 MHz and (iv) 2227.5 - 3000.0 MHz. This is a very important window for radio astronomers on the ground for line and continuum observations (Hamidi *et al.*, 2012).

The correlation between solar radiation and radio signal in an UHF band at BCK was calculated and the relationship was deduced using the statistical analysis and polynomial curve. Solar radiation is significant for prominent peaks at 382.5 MHz, 1800.0 MHz and 2160.0 MHz. It has a correlation of 0.6252, 0.6769 and 0.5965 during the wet season and only small and moderate correlation peaks in the dry season. Although well-protected, the radio observatory is still prone to satellite emissions. Therefore, unwanted releases from satellites is the most serious threat to radio astronomy services due to the rapid development of satellites today. In the future, MCMC and radio astronomers need to suggest, share and discuss the details of managing the radio astronomy spectrum.

UniSZA had started investigating RFI in Terengganu since 2015. The aim of the study was to examine the RFI pattern and to observe possible radio astronomical sources, such as solar observation, Jupiter observation, solar ionospheric disturbance (SID) and solar wind observation. UniSZA had also began collaborating with Christian Monstein, which is the Compound Astronomical Low-Cost Low-Frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) spectrometer founder, to study solar bursts.

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