Magnetic Reconnection of Solar Flare Detected by Solar Radio Burst Type III

Z.S. Hamidi, N.N.M. Shariff, Z.A. Ibrahim, C. Monstein, W.N.A. Wan Zulkifli, M.B. Ibrahim, N.S. Arifin, N. A. Amran
School of Physics and Material Sciences, Faculty of Applied Sciences, MARA University of Technology, 40450, Shah Alam, Selangor, Malaysia
Academy of Contemporary Islamic Studies (ACIS), MARA University of Technology, 40450, Shah Alam, Selangor, Malaysia
Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia
Institute of Astronomy, Wolfgang-Pauli-Strasse 27, Building HIT, Floor J, CH-8093 Zurich, Switzerland

E-mail: zetysh@salam.uitm.edu.my

Abstract. The Sun is an ideal object of a blackbody with a large and complex magnetic field. In solar activity specifically solar flare phenomenon, the magnetic reconnection is one of the most significant factors of the Sun that can simplify a better understanding of our nearest star. This factor is due to the motion of the plasma and other particles through the convection mechanism inside the Sun. In our work, we will highlight one of the solar burst events that associated with solar flares. This event occurred on 13th November 2012 from 2:00:03 UT till 2:00:06 UT. It peaked with M2.0 solar flare at 2.04 UT. Within short time intervals of about $10^2$ to $10^3$ s, large quantities of energy of $10^{22}$ to $10^{26}$ J are emancipated. The changing magnetic field converts magnetic potential energy into kinetic energy by accelerating plasmas in the solar corona. It is believed that the plasma is channelled by the magnetic field up and away from the Sun. It is also accelerated back down along the magnetic field into the chromosphere. In conclusion, we showed that the structure of the solar radio burst type III is an indicator of a starting point of magnetic reconnection.

1. Introduction
The Sun, a main sequence star with spectral type of G2V is considered as one of the strongest radio sources and observation in this widely region can provide evidence on structures throughout the solar atmosphere. It is widely known that the transportation of energy from the central regions of the Sun is primarily through photon radiation, although electron conduction contributes in the innermost region and convection dominates near the surface. However, the dynamical behaviour of the Sun exhibits a variety of physical phenomena, some of which are still not at all or only barely understood due to the complexity of the structure of the Sun. Along the process, many research works have done to fulfill the objectives of this study.

1 School of Physics and Material Sciences, Faculty of Applied Sciences, MARA University of Technology, 40450, Shah Alam, Selangor, Malaysia
Meanwhile, the corona extends from the top of a narrow transition region to Earth and beyond has a temperature millions of degrees which is still considered as a mysteries properties. It is composed by protons, electrons an uncertain amount of helium nuclei and a small portion of highly ionized heavier atoms. It can be observed clearly during eclipse and where the solar wind originates. A multi-wavelength observation is believed a good approach in order to understand the variability of solar wind [1].

Before going into details of observations, it would be instructive to give some basic information on solar activities such as solar flares and Coronal Mass Ejections (CMEs). These phenomena can stimulate plasma oscillations which can release radiation at metric and decametric wavelengths. Solar flare is considered as a high energetic and complicated phenomenon in which mass eruptions occur, energetic particles are generated and highly energy radiations are emitted. In general, there are 3 types of acceleration commonly quoted in solar flares which is (i) Direct electric field acceleration [2,3] can boost a particle to high energies simply via the Coulomb force from the electric field and may drive in the current sheet or in the reconnection site, but it is hard to maintain a large-scale coherent direct current, DC electric field. (ii) Shock or first-order Fermi acceleration can energize particles by making them repeatedly pass through the shock front back and forth and this mechanism may be present in the fast shock produced by the super-magnetosonic outflow jet from the reconnection region. However, it would be difficult to reflect the particles in the upstream region. (iii) Stochastic (second-order Fermi) acceleration by turbulence or plasma waves is the most likely mechanism [4,5] for solar flares, compared with the shortcomings of the other 2 mechanisms.

During a flares, large quantities of energy are transferred between the corona and chromosphere through thermal conduction, non-thermal particle beams, radiation transport and the mass motions [6]. This event is triggered by fast drift of the individual active region proper motion within the complex magnetic configuration due to instabilities of equilibrium of coronal magnetic field [7]. Since the magnetic force is much stronger than other forces in the corona, any coronal structure is mainly controlled by magnetic field.

Meanwhile, metric radio burst is normally a non-thermal particles accelerated and trapped during those events [6]. In the presence of flares, strong solar radio burst type III is observed over a broad frequency range. It is generally believed that the conversion of Langmuir wave to electromagnetic wave is the generating mechanism of solar type III bursts [8]. The Langmuir wave can be easily excited by the instability of the electron-beam current, and the interaction of the forward and backward Langmuir waves are considered to be the cause for the second harmonic of a type III burst, however, the generating mechanism of the backward Langmuir wave is not easy to be understood. Whereas it is well established that flares do not drive CMEs, both of them correspond to different aspects of the same magnetic energy release [6].

In the currently widely accepted scenario, the basic physical processes involved and the observational signatures are as follows. Magnetic reconnection, as the primary energy release mechanism occurring high in the corona, rapidly heats the plasma and accelerates particles. It is well known that process by which magnetic lines of force break and re-join into a lower-energy configuration, which magnetic energy is converted into plasma kinetic energy. The impulsive phase of the flare coincides with the acceleration phase of the CMEs Some particles escape along the open magnetic field lines into the interplanetary space, with electrons producing various radio bursts and some electrons [9] and ions being detected at 1 AU. In what manner and when the magnetic reconnection in the solar flare occur is remain as one of the longest outstanding questions in solar physics, holding clues about the onset of structure formation in the first light of solar burst detection. It is believed that metric radio observation
plays an important role in understanding the behaviour of magnetic reconnection due to solar burst type III characteristic [10,11].

Since the corona is a good conductive medium, still it has a finite resistivity[12]. The magnetic energy can be released in the diffusion process. The region where the energy release works efficiently is known as a current sheet, in which a certain component of the magnetic field is abruptly changed across the sheet. This energy is thought to be released high in the corona and produces emission across the entire electromagnetic spectrum, from radio to gamma ray energies and heats the surrounding plasma to tens of Kelvins. Roughly, around 50% of the energy released in a flare goes into accelerating particles [13,14]. It is thought that the energy required for a flare is stored as ‘free’ magnetic energy in the corona in the form of a current.

2. Experimental Setup and Observations
The Compound Low Cost Low Frequency Transportable Observatory (CALLISTO) system has been operating routinely at the National Space Centre, Sg Lang Selangor (3.083333°N 101.533333°E ) since March 2012 funded by the National Space Centre, Malaysia[15,16]. This is one of the radio quiet zone candidate sites in Malaysia. It obtains the minimum Radio Frequency Interference (RFI) with average -102 dBm [17]. E-Callisto networking is an internationalization research collaboration that investigate the phenomena of solar flares and Coronal Mass Ejections based on solar burst characteristics in a broadband radio region from 45 -870 MHz [18]. This collaboration has achieved the objective to monitor the Sun within 24 hours all over the world; the precise data will lead to an understanding of the causes of spectacular ejection of material from flare region that associated with the coronal magnetic field [19]. So far, we have 2 spectrometers that will be installed at INSTUN, Perak and Jelebu, Negeri Sembilan. Figure 1 shows the schematic diagram of CALLISTO system [20].

![Figure 1. Schematic diagram CALLISTO system](image)

3. Results and Discussion
In this section, a comprehensive analysis of solar radio burst Type III observation of short-duration in association with eruptions on the sun and appear like a radio burst Type II is presented. This observation allows for the mechanisms of evolution Type II and local environment of the burst to be characterized. Yet, the burst is quite unique and interesting to be tackled. The burst is classified as a
solar radio burst type III. However, a clear structure of fundamental solar radio burst Type II can be observed.

This event occurred on 13th November 2012 from 2:00:03 UT till 2:00:06 UT. It peaked with M2.0 solar flare at 2.04 UT. From the earliest prediction, there is a possibility a Coronal Mass Ejections (CMEs) will eject directly to the Earth. This is due to a continuous monitoring within few days period. Based on the results, it is associated with type M 6.0 solar flares from active region AR1613 and AR1614. It was found that the sunspot number is 188 and radio flux exceeds 144 sfu. There are 8 active regions and with a density of 9.1 protons/ cm$^3$. During that event, solar wind also reached up to 369.7 km sec$^{-1}$. Those parameters provided an alert with Sun’s activities. The potential of a big explosion of CMEs is considered very high. Based on observation, the formation of solar radio burst Type III is due to multiple radio blackout storms.

As can be seen from Figure 2, there is a group of solar radio burst Type III (at the background of the intense burst) that formed intermittently with a wide range frequency from 220 MHz till 380 MHz. In conjunction with constraints on the spectrum, it is believed that the burst is drifting in a wide range. This burst actually has been observed intermittently in the last a few hours since 00:22 UT. The groups of solar radio burst Type III until 5:30 UT can still be observed. This proved that a meter solar radio burst will take a long period to decay and AR1613 and AR1614 potentially active within a few day comparison, the dynamic spectra in the X-ray region beginning from 1:00 UT till 7:00 UT is shown in Figure 3.

![Figure 2. Solar Radio Burst Type III on 13th November 2012](image-url)
In particular, an observed random variable may be represented as instability of the magnetic field of the active region. There was a CME event (~383 km/s) that has been detected at 1:28 UT from LASCO data. As can be seen, the X-ray flux is approximately to the 10^{-4} Watts m^{-2} during 2:00 UT. This is the highest point within six hours period of time. The sun remains active with 2 solar flares class M can be detected.

Overall, the Sun tends to be consistent with multiple storms, however, not huge CMEs explosion. Based on LASCO observation, the CME explosion with a speed of 419 km/s can be detected at 3:12 UT which means that almost after 1 hour and 10 minutes after the formation of this burst. In conclusion, this event is one fine example of tendencies solar radio burst Type III, which makes it possible to form solar radio burst Type II. The burst is formed between 2 events of CMEs in the same day.

4. Conclusion
It is undeniable that solar flare plays an important role in the Sun-Earth connection due to sudden changes of strong magnetic fields in the Sun’s corona. Within short time intervals of about 10^{2} to 10^{5}s, large quantities of energy of 10^{22} to 10^{26}J are emancipated. The changing magnetic field converts magnetic potential energy into kinetic energy by accelerating plasmas in the corona. The plasma is channelled by the magnetic field up and away from the Sun. It is also accelerated back down along the magnetic field into the chromosphere. In the chromosphere, the plasma crashes into denser gas and releases its kinetic energy into thermal energy, sound, and light energy. The burst impulsive phase onset could occur at first lower frequencies, although there are also examples with delays in the
opposite sense. It is hoped that we could possible to find a latest data that might answered the mechanism of type III burst based on solar flare events. Still, it is not fully understood how the energy is released and converted into thermal heat and into non-thermal particle acceleration energy. It should be noted; however, there are many complex models which propose how this occurs, yet most models at some point invoke magnetic reconnection. There are also other models which do not feature magnetic reconnection as the main cause of energy release. One particular model suggests electrons are accelerated in the corona to energies of up to 10 - 100’s of keV. These electrons then propagate down the newly connected field lines. Upon reaching the loop foot points the electrons encounter an increased plasma density where they undergo Coulomb collisions and emit the hard X-ray emission.

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