Ionospheric Disturbances due to Solar Activity Detection using SDR

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Abstract – This paper focus on disturbance occurring in ionosphere due to certain phenomena's like solar flare Coronal Mass Ejection(CME),Sudden Ionospheric disturbances(SID),sunspots etc. The observation from VLF receiver is the keystone for numerous experiments, studies and results on Earth's ionosphere. The Sun is capable of producing strong radio emission which may directly affect the wireless communication and navigational system without any warning. Using recent techniques different equipment's can be builtto accomplish these observation using a unified hardware and software. To detect the real time condition of ionosphere, SDR technique and Gnu Radio framework is used.

Keywords – Ionosphere, Spectrum Lab Gnu Radio, SID Receiver

I. INTRODUCTION

The ionosphere is a part of upper atmosphere where large number free ions and electrons are present which is ionized by solar and cosmic rays[1]. This layer ranges from 70-100 km above the Earth. Due to the high ionization from the Sun the atoms are ionized and positively charged. The ionosphere is one of the most important layers because if there is any change in ionosphere it will directly affect the radio propagation. Ionosphere is made up of different gases like Nitrogen (78%), oxygen (21%) and some traces of gases and aerosol which is approximately 1%. The ionosphere has higher concentrations of charged particles (ions) which mostly consist of electrically neutral atoms and molecules. These ions are created when energetic photons from the Sun collide with atoms and molecules in the atmosphere, knocking electrons out of the atoms and molecules in a process called photoionization. It has several layers created at different altitudes and of different densities. Each layer has its own properties, and existence and number of layers change daily under the influence of Sun and also depends on wavelength of the solar radiation absorbed in that region. The different layers are D, E and F layer. The D is the lowest known ionized region which lies between 60-90kms. This is the most dense part of atmosphere which is produced by Lyman series alpha radiation (λ= 121.6 nm) ionizing Nitric Oxide (NO). This layer is weakly ionized and has a pressure of 2Pa. The electron density is $10^7 - 10^{10} \, e/m^3$ .The temperature of this layer is 76^0 C .The E layer is formed by the X-ray and far ultraviolet radiation ionizing molecular oxygen (O2). It is useful for long distance communication. It ranges from about 100-150km from the Earth. The rate of ionization rapidly increases after the sunrise reaches maximum at noon and drops after sunset. The electron density is about $10^{11} \, e/m^{-3}$ and the temperature is 50^0 C. The F layer may range from 160-500km. This layer is also known as Appleton layer. Above 160km the ions and electrons recombine more slowly. During day time this layer is divided into two F1 and F2 layer. During the day time a deformation is formed in F1 layer. The F2 layer remains for both day and night. This layer is responsible for occurrence of skywave radio propagation and it facilitates the high frequency waves in long distance.[1]-[3]
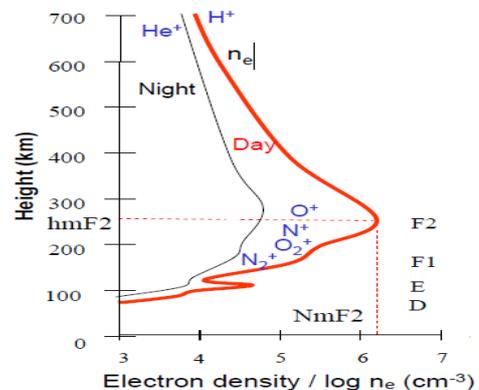

Fig. 1 : Different Layers of ionosphere[3]

An ionospheric model is the mathematical expression of ionosphere as a function of location, sunspot and geomagnetic activity. The ionospheric plasma is defined in terms of four parameters like electron density, electron temperature, ion temperature and ionic composition [1]. The ionosphere is mainly affected by certain natural phenomena's like solar flare, sunspot and sudden ionospheric disturbances.

Solar flare is the explosion which occurs at the surface of the Sun which releases about 6×10^{25} Joules of energy[5]. During the solar flare a large amount of electrons, ions, atoms from the surface of Sun (Corona) is ejected to the surface of Earth. The X-rays and UV radiation emitted from the Sun affects the ionosphere. Due to solar flare there will be a sharp rise in intensity of the VLF signal transmitted through ionosphere.[6] This rise is because the signals are reflected by the high ionized D layer instead of E layer. There are different types of flare which are classified depending upon the intensity of X-Ray wavelength is in between 1-8 A^{0}. The largest flare is the X-flare. M-Class flares are smaller and C-Class flares are tenth the intensity of the M-flares[6]. The X-ray produced due to the solar flare increases the ionization in the lower region of ionosphere (D layer). This change in the electron profile of ionosphere is known as Sudden Ionospheric Disturbances (SID)[7]. Here in this paper the focus is on the study of D layer .This is because in this layer the penetration of solar flare and X-rays is easy. During the daytime the wavelength of VLF are so long that radio waves can be conducted between the Earth and the ionosphere D layer. In this layer the propagation is stable and the attenuation is very low. During night time the D layer disappears and is reflected from E and F layer. The reflection coefficient is very high and the signal strength will be more. The sunrise and sunset signal patterns depend on the transition between the nighttime reflection of signal at high altitude and the waveguide propagation mode.[5]-[9]

II. TRANSMISSION STATIONS

In this paperthe VLF signals are used for the measure of ionospheric changes. There are two station mainly received are INS station (call sign VTX3) at South Vijayanarayanam village and AUS station at Exmouth, Western Australia (call sign NWC).The INS VLF transmitter grid is in the form of Six pointed star with a main transmitter at center and the transmission at the points. There are 13 transmission stations. The grid is made up of central mast and two concentric circles of six mast each. The inner radius of circle is 730 meter and the outer circle is 1300 meter. Table1 gives overall information about the Indian Navy Station VTX[10].

The NWC transmitter grid has thirteen tall radio tower. The tallest tower is known as tower Zero and the height is about 387m. Six towers are evenly placed around the Tower Zero in hexagonal shape which is having a height of 304m. The other six towers are placed evenly around the tower Zero in hexagonal shape at a height of 364m. [11].

ID/ Call sign	VTX
Location	08°23'N 77°45'E
Frequency allocations	16 KHz (VTX1) / 17 KHz (VTX2) / 18.2 KHz (VTX3) / 19.2 KHz (VTX4)
Locator	MJ88vj
Modulation	Modulation
Mode	Active
Power	1MW

Table 1 : INS Station Details

III. EXPERIMENTAL SET UP

1. SID detection using Spectrum Lab

The solar flare and coronal mass ejection may cause huge emission from the Sun .This interact with Earth ionosphere which changes the path of the reflected radio waves. Continuous monitoring of the signal from the radio beacon and some transmitters the possible changes can be detected. The requirement is a PC with 16 bit, 44100Hz sound card microphone that detects small voltages at small frequencies from few Hertz to 20kHz.An antenna is plugged in the microphone socket that makes the sound card as the Very Low Frequency Radio Receiver. The antenna used is 1 meter diameter square-loop antenna with about 120 meters of 17 gauge wire wound onto it. The software used for data logging and displaying the signal is Spectrum Lab. The screenshot of the water fall is taken on 2nd May 2012. This display is obtained when we start the sound thread. This graph shows the spectrum in line plot. One axis is the frequency domain and another is amplitude.[13]

The pink line in the waterfall shows the peak at 18.2 kHz, VTX3 IND station, Tirunelveli. At 19.7 kHz there are some traces of signal received from NWC Station, operated by Australia, US Navy Station. Fig 3 depicts the watcher plot of Spec Lab. The numerical expressions are as follows, [13][14]

Fig. 2 : Screen shot of Spec Lab on 20th September 2012.

(a) Time that returns the current time (date+ time. Here, a 'now' command is used which returns the current time (including the date.

(b) noise(freq1, freq2) that calculates the noise in frequency range. It returns the noise level in a specified frequency range. It uses an algorithm suggested by G4JNT .

(c) avrg(freq1, freq2) that calculates the average in frequency range .This function adds the value from all the FFT bins of specified frequency and divides the sum by the number of FFT bins. This function is used to determine the relative strength of broad-band signals with known modulation patterns. This will give an estimate for the signal strength of that particular station.

(d) peak_a(freq1,freq2) that calculates the peak AMPLITUDE in frequency range. This function returns the maximum amplitude in frequency domain in decibel if the FFT output is logarithmic. This function checks the contents of all FFT bins in a specified frequency range, and returns the amplitude of the strongest peak using interpolation method.

(e) peak_f(freq1,freq2) that calculates the peak FREQUENCY in frequency range. It returns the audio frequency of the highest peak in the specified frequency range.

The file can be saved as text file in any directory In File Export, Filename and Activation tab. There is Export File #1, Export File #2 Tabs. Give the directory of our choice in Export File #1 text box. Text file will contain all the data mentioned earlier. Next, the text file is exported to MS-EXCEL.[13],[14]

2. GNURADIO

Gnuradio is a open source software which works in Linux platform by using C++ program one can create our own blocks Modulation and demodulation schemes can be done by connecting the signal processing blocks. The advantage of SDR is reconfigurabilty, cost–effective, portability, flexibility The Gnu Radio architecture is a suite of applications and libraries designed to facilitate the construction of sophisticated signal-processing systems, based on the notion of Software Defined Radio—the movement of signal-processing elements of a radio design into the software domain, usually on a general-purpose computing platform.[15]

3. SDR SID RECEIVER USING GNU RADIO FRAMEWORK

With minimum hardware one can track the solar flare and changes in ionosphere. In SID receiver, the VLF signals is transmitted from different transmitters After transmission these signals bounce off from Earth's ionosphere and is picked up by VLF receivers. An SID antenna, loop antenna is used here to pick up the reflected radio signals. Antenna is connected to the soundcard of the PC which does the ADC conversion. Using software signal-processing techniques in Gnu radio frame work the captured signal is analyzed.[16]

The signal is received using a SID antenna which is directly plugged into the MIC input of 48 kHz sound card of the PC. Without an amplifier between antenna and audio card we can obtain the desired result due to the modern sound cards which are remarkably sophisticated signal processors. Once the signal reaches the soundcard, it digitizes the signal. The signal is carried out to the speaker through Audio Sink. This audio goes to multiplier and to a filter that transforms the signals into complex (I and Q) signals. To convert the signal to complex form the Hilbert transform is used. Each channel is defined by its own spectral occupancy. To extract each channel FIR filter is used. Once the channel is extracted find the received power of that particular channel. For that RMS block can be used which calculates the root mean square power and an integrator stage, inorder to adjust the integration time[16].

The rate of RMS block is twice the selected channel bandwidth. This data is then sent to an external file. The channel is demodulated using a GMSK de-modulator. The output is given to another external file and by adding extra blocks different VLF channels can be extracted. To display the signal, RMS power output can be given to a Scope block. Data written to the external files are then finally read out to a text file to plot the SID graphs.[16]
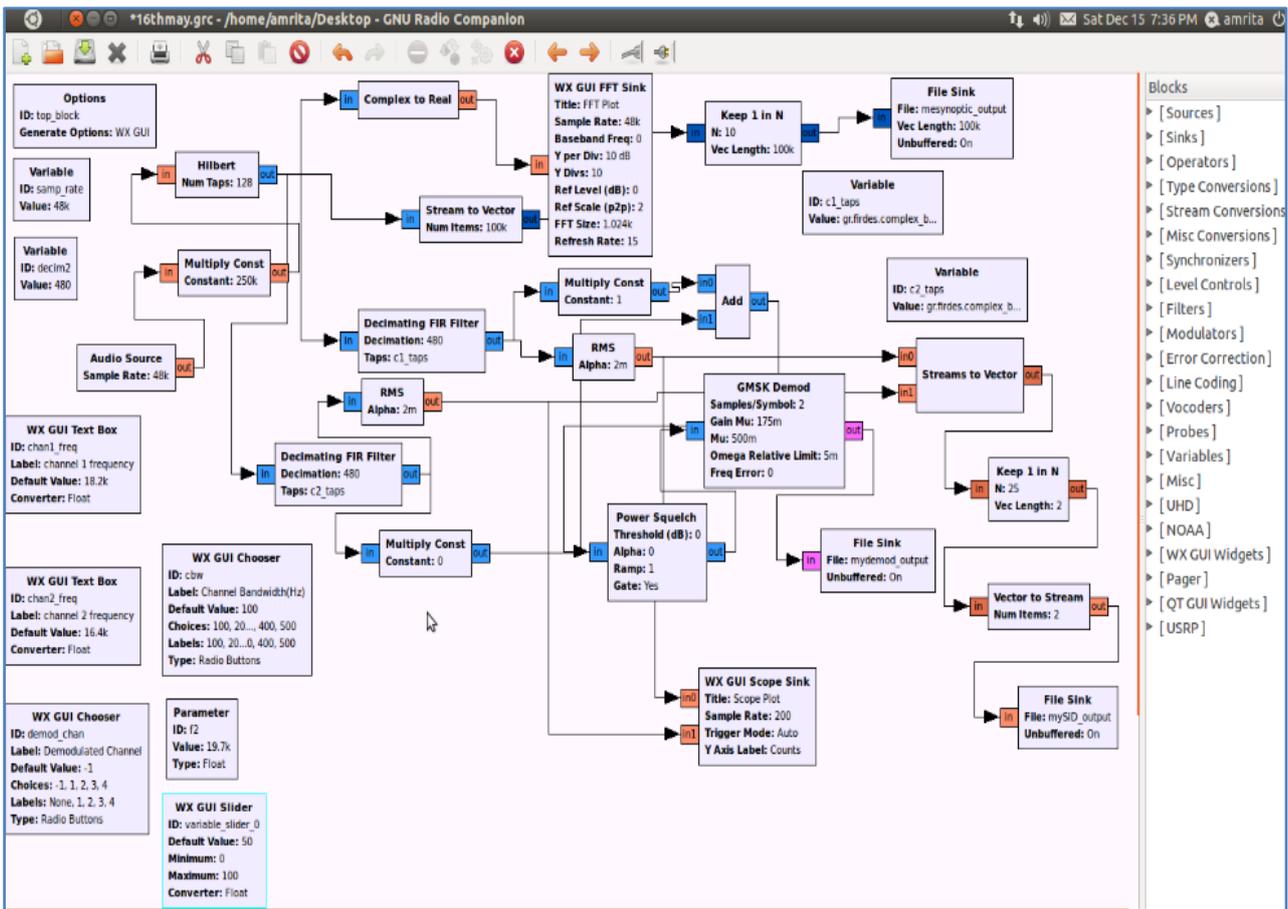
Fig. 3 : Flow Graph of SID Receiver [16]

IV. RESULTS

Figure 4 shows the FFT plot of the flow graph of SID SDR receiver. In the FFT plot we can see the peak of signal at 18.2 kHz and 19.8 kHz frequencies.
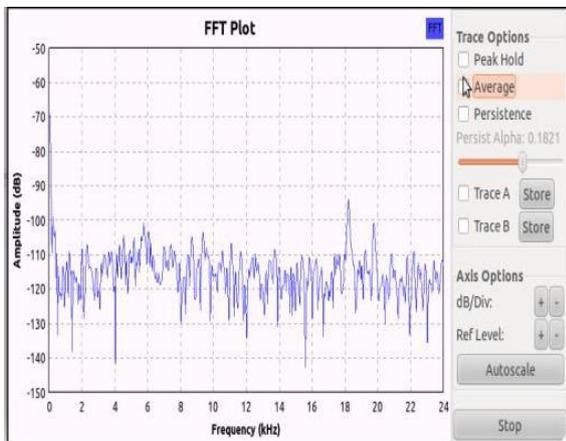

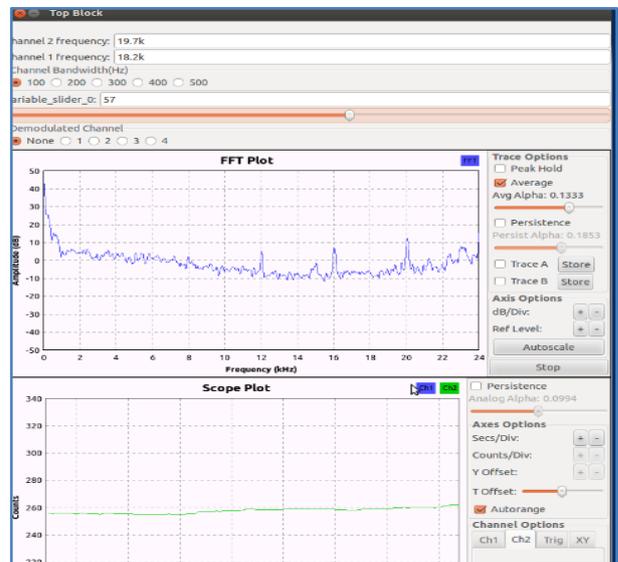
Fig. 4 : FFT plot of SDR SID Receiver

Fig. 5 : FFT and Scope Plot of SID SDR receiver

When this flow graph is running, three data files are written into the Computer directory. This is done by File sink block of GRC. By using Python language one can write these data to a text file and plot the graph. The continuous monitoring of the signal is done using this SID Receiver. The signals of 15th December and 31st May 2012 are plotted here.
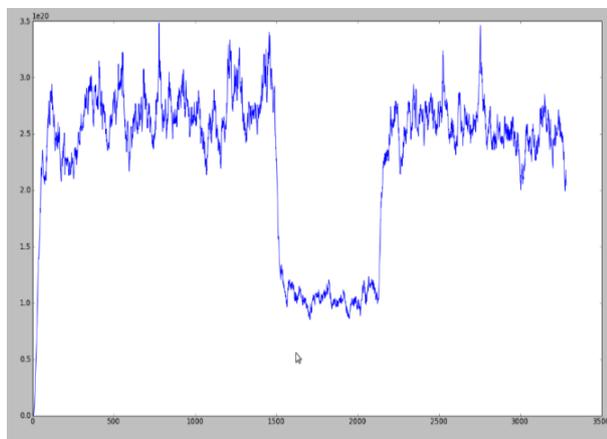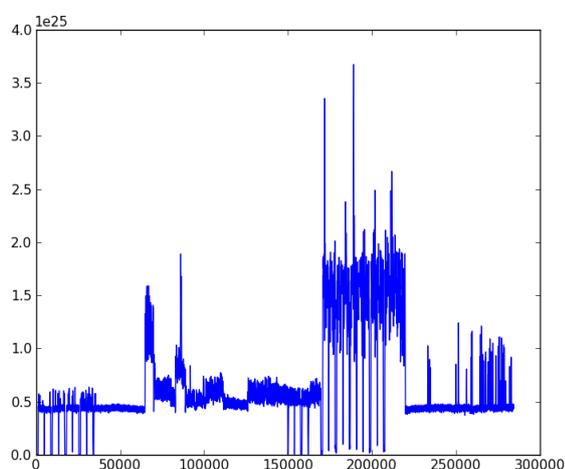

Fig. 6 : SID data of 15th December 2012

Fig. 7: SID output of 31st May 2012

V. CONCLUSION

Ionospheric disturbances can be viewed with the help of certain software and an antenna. SDR is a powerful technology in the field of communication. The SID antenna is built to capture signals from different transmittingstations. The SID receiver was built in software defined platform and Gnu radio framework. The signals are received using this receiver.Finally the graphs were plotted and compared with NOAA satellite solar flare report.

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