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INTRINSIC RESTRAINING FACTORS IN PRECISE EXTRATERRESTRIAL RADIO SIGNAL RECEPTION

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Abstract

In electromagnetic signal reception Gabor uncertainty is one of the fundamental concepts. A finite limitation has been noticed while we are receiving Jovian busts and analyzing it at our observatory set at Bidhannagar College. Due to time-frequency restriction there is more than 0.1 µs uncertainty in recording Jovian signal through Radio Jove Project or by spectrum analyzer. It also noted precise observation is largely limited by time synchronization through client computer and instrumental selection circuit choice. It challenges this backlash is hidden into modern days signal reception procedure.

Keywords:

Uncertainty, Radio Signal, Jovian Burst, Spectrum Analyzer

1. INTRODUCTION

We have crossed a long way in science and technology field throughout our civilised era. Despite our tremendous progress, we are still behind in time, namely for reception of galactic and extragalactic radio signals [1]-[2].

After the discovery of radio bursts from Jupiter, careful analysis of extraterrestrial signal to understand the cause behind. Most of the observed radio waves from Jupiter are polarized. Information wrapped in Jovian signal consists of meteorological conditions of Jupiter and about the medium in space between Jupiter and Earth through which signal travels. Polarized radio waves implied that Jupiter had a very intense magnetic field and when charged particles move through that magnetic field their paths are distorted. The particles are accelerated and move in spirals around magnetic field lines towards either the north or the south pole. Accelerated charged particles emit radiation in radio frequency range depending up on their energy. and called cyclotron emission. In our endeavour to receive Jovian radio emissions we need to know about the source of the radio signal as well as actually when it was detected. The time correlation is very important to distinguish Jovian bursts from ordinary radio frequency interference [3].

2. CONSTRAINS IN PRECISE DETECTION

Two major points may be considered for precise detection of radio signals from extra-terrestrial sources. They may be categorised as: Instrumental limitation and Time-frequency uncertainty.

2.1 INSTRUMENTAL LIMITATION

Data quality is a major criterion in any signal processing module [4]-[5]. Accuracy over precision is carrying more importance in our observation. A typical personal computer uses a quartz crystal oscillator for timestamp which is sensitive to temperature and drifts with time. So, we need to synchronize it regularly. During this synchronization an estimation of time to communicate with reference and the time taken to process the request and response by reference plays a crucial role in updating computer clock. A few ms errors in assumptions accumulate to a second in result. We assume general PC quartz crystal has tolerance about 20 ppm when averaged over 1 day. At the end of a 24-hr time, the clock could diverge by ~ 1.8 second. To some extent a PC clock is seems to be responsible for its own accuracy. The Network Time Protocol (NTP) is widely used for synchronizing PC clocks by exchanging messages between a time server and client PC containing information about time offsets and delays. We may consider that time in local computer consists of real time and a symmetric offset δ. Computer sends a request to a time server with local time stamp ($T_{in}+\delta$). Server receives it at time T and responses it which get processed by client with time stamp ($T_f+\delta$). From observed relation

$$(T_{in} + \delta) < T < (T_f + \delta) \tag{1}$$

Client computer evaluates symmetric time offset.

$$\delta = T - (T_{in} + T_f)/2 \tag{2}$$

NTP can provide synchronization at the sub-tens of millisecond level. Sub-microsecond level precision can be achieved by using Precision Time Protocol (PTP), which is based on Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems standard [6].

3. TIME-FREQUENCY UNCERTAINTY

According to uncertainty principal energy of any function and its Fourier transform cannot be simultaneously localized [7]. Hence there is no suitable technique that can simultaneously localized a Jovian signal in both the time and frequency domain. When we analyse the signal received for a long window, we can have a good frequency resolution at the cost of temporal resolution. It causes a drop in accuracy. Let the signal and its Fourier transformation (FT) are respectively denoted by $s(t)$ and $s(\omega)$ in $L_2(\Re)$; where, $L_2(\Re)$ is Hilbert space of all integrable signals in real domain [8]. Here,

$$s(t) = \int_{-\infty}^{+\infty} s(\omega)^{j2\pi\omega t}\, d\omega \tag{3}$$

and from Plancherel's theorem

$$s(\omega) = \int_{-\infty}^{+\infty} s(t)^{-j2\pi\omega t}\, dt \tag{4}$$

In our problem, we assume Jovian signal as either continuous or pulse shaped for an adjustable length of time. Using the usual notations, we have,

$$\left[\int_{-\infty}^{\infty}(t-t_0)^2|s(t)|^2\,dt\right]^{0.5}\left[\int_{-\infty}^{\infty}(\omega-\omega_0)^2|s(\omega)|^2\,d\omega\right]^{0.5} \geq \frac{1}{4\pi}\left[\int_{-\infty}^{\infty}|s(t)|^2\,dt\right]^{0.5} \quad (5)$$

where $(t\text{-}t_0)$ and $(\omega\text{-}\omega_0)$ are time spread around a fixed time t_0 and frequency spread around a fixed frequency ω_0 respectively.

4. OBSERVATIONAL TECHNIQUE AND RECORDED SIGNAL

Uncertainties can be infused in planetary signal reception through different intrinsic procedures [9]. We have set up our observatory at Bidhannagar College (22º35.06’ N, 88º24.33’E) with the help of NASA Radio Jove project. It is built of fixed dipole array antenna for receiving signal at 20.1 MHz. Radio signal from Jupiter is very weak. It produces less than 1 µV at the antenna terminals of the receiver [10]. Such a weak radio frequency signal must be amplified by the receiver and should be converted to audio signals of sufficient strength for eminent detection of bursts. According to principle of the fixed dipole antenna, it can receive signal without temporal frequency spread [11] but in Radio Jove receiver RJ1.1 direct converter NE602 has a frequency spread of about 150 kHz around tuned frequency 20.1 MHz. Radio Jove Receiver is equipped with a low pass filter which strips all unnecessary signals [12]. When electromagnetic signal strikes antenna it travels down to band pass filter where JFET amplifies it and sends to local oscillator of Radio Jove Receiver RJ1.1 as described in Fig.1.

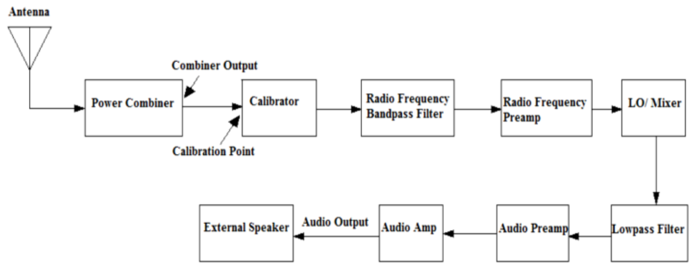

Fig.1. Block diagram of the Jovian receiver [10]

Local oscillator converts it into audio frequencies and mixer converts all those frequencies into a new signal with a typical frequency set by the arithmetic difference in frequency between the incoming signals from Jupiter, and the frequency at which the local oscillator is set. Intermediate frequency is fed to low pass filter having few kHz windows at 20.1 MHz. Finally Audio amplifiers amplify the resultant signal and process it to display through computer by striping audio information off the RF signal.

To tune up this particular frequency of 20.1 MHz, receiver uses two variable capacitors (4-40 pF and 3-20 pF) and two variable inductors (1.5 µH) [11]. Each of these components has at least 5% tolerance that broaden frequency spectrum. Audio low pass filter response is down 3 dB at 3.5 kHz and hence the RF bandwidth becomes 7 kHz. All these contributions from selective filter towards bandwidth sum up to about 200 kHz spread around meridian 20.1 MHz.

With a view to analyze the signal we have used Skypipe software at our observatory, Bidhannagar. Audio signals from the receiver are sent to a computer sound card where they are processed and displayed as a strip-chart record using SkyPipe software. Data files consist of a header file and a series of groups of Date and Sample values [6]. Header file has parameters like Start time, End time, Latitude, Longitude, maximum and minimum Y-scale, Time zone, Source, Local name, Location, Channels and for additional parameter NoteLength. Timestamp in data series can either be pursued directly from client computer each time a data is recording or by dividing time interval between start and end time equally for each data point. In both cases we cannot overrule time synchronization issue completely. A typical record of the recorded Jovian radio signal taken at our observatory is shown in Fig.2.

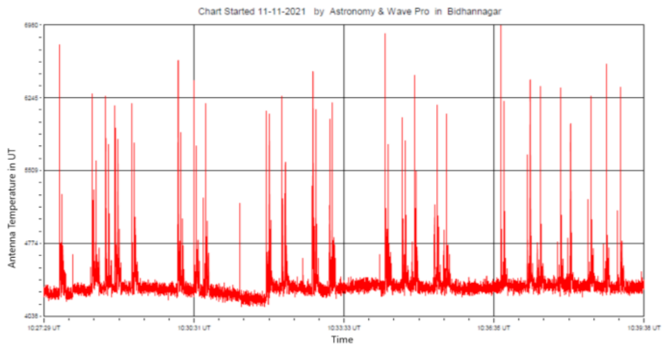

Fig.2. A sample time profile of recorded Jovian signal at Bidhannagar on 11th November 2021

5. RESULT AND DISCUSSION

As discussed before, Jupiter emits cyclotron radiation from electrons trapped; more specifically, in its strong magnetic field. The decametric radio waves have frequencies between 1 MHz to ~40 MHz with a peak at about 10 MHz.. These types of radio waves from Jupiter are never heard above 40 MHz. This seems to be the maximum frequency. However, the frequencies below ~15 MHz are unsuitable to penetrate the ionosphere of the Earth and again the intensity of the emissions drops off rapidly if we go at higher values. To get whole observable Jovian spectrum we use spectrum analyzer and it also has same limitation. In spectrum analyzer amplitude of signal is displayed over a wide range of frequencies. For the spectrum analyzer used, frequency range is from 150 Hz to 1 GHz with a minimum frequency scan width 100 kHz/div [13]. A good spectrum analyzer works according to the triple super-heterodyne receiver principle [14] The signal $x(t)$ to be measured is applied to the 1st mixer where it is mixed with the signal of 1st local oscillator with varying frequency f_0 (say). The difference between the oscillator and the input frequency is the first intermediate frequency, which passes through a waveband filter tuned to a center frequency f_i at almost half of its maximum range. This frequency is repeatedly scanned over a range, so that the frequency component $x(f)$ is shifted to f_i and passed by the filter. It then enters an amplifier, and this is followed by two additional mixing stages of oscillators and amplifiers. In the third IF stage, the signal can be selectively transferred through a filter having bandwidth of the order of 100 kHz before arriving at an AM demodulator. The logarithmic output is transferred via a low pass filter to another amplifier. This amplifier output is connected to the Y deflection plates of the CRT. The resolution bandwidth of filter determines distinguishability of closely spaced signals, but its value is predetermined for any analyzer. A simple block diagram of super-heterodyne spectrum analyzer used for the purpose is shown in Fig.3.

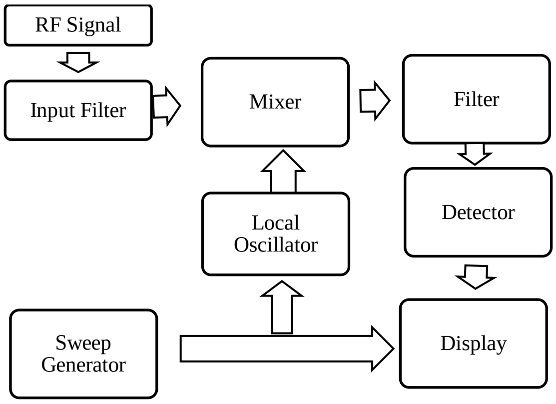

Fig.3. A simple process diagram of Super-heterodyne spectrum analyzer

Resolution of one spectrum analyzer determines its utility over other and the important factor for resolution of a spectrum analyzer is shape factor of filter [15]. It defines as the ratio of the 60 dB bandwidth to the 3 dB bandwidth of IF filter. Shape factor is inversely proportional to resolution factor. Other than that noise sidebands, it can also reduce the resolution by reducing the off-band rejection of the IF filter. The resolution of the analyzer is limited by bandwidth and it seems that by reducing the IF bandwidth mathematical infinite resolution can be achieved. But practically the usable IF bandwidth is limited by the stability (residual FM) of the analyzer.

6. CALCULATION

Since, it is impossible to sharply localize a signal in both time domain and frequency domain simultaneously; we must sacrifice both high temporal resolution and frequency resolution to some extent to achieve a representative result. If we measure the signal having frequency ν MHz with an instrument having tolerance of $\Delta\nu$ Hz then by Heisenberg's uncertainty principle, variance over time precision Δt will be given by

$$\Delta t \geq \frac{1}{4\pi\Delta\nu} \tag{6}$$

For our dual dipole Jove antenna with receiver fixed at frequency 20.1 MHz has tolerance of 200 kHz. So, any event recorded by that arrangement has variance more than 0.4 μs. In case of spectrum analyzer recording, since frequency scanwidth is about 100 kHz/div so any recorded events have variance more than 0.8 μs. Since, to observe Jovian burst we generally sweep from 10 MHz to 40 MHz with minimum scanwidth 1.5 MHz. This introduces 0.05 μs uncertainty in recorded timestamp. It obviously established superiority of mighty spectrum analyzer to fix tuned Jove receiver for precise Jovian radio observation. The spectrum analyzer's resolution is usually adjusted to few tens of Hz so that it doesn't take too long to analyze and display the frequency spectrum. Result of that the individual spectral lines spaced at lower frequencies than scanwidth display only the overall envelope.

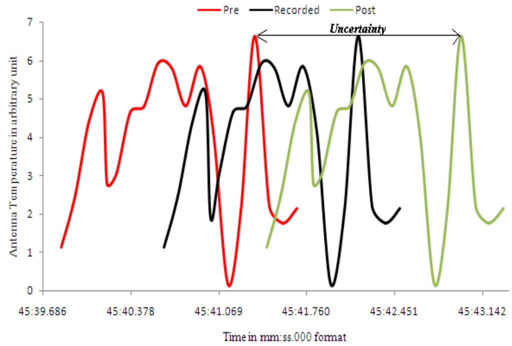

Fig.4. Typical time profile of the recorded Jovian radio signal taken at our Bidhannagar College observatory around 10 PM (IST). Horizontal axis showing timestamp only in sec. *Pre* and *Post* in Figure indicates assumed deviated timestamps from *Recorded* timestamp due to total uncertainty

As the uncertainty is reduced in determining the burst width (which is typically few ms for Jovian S bursts), the frequency spectral-energy density is seen to spread out and flatten. Other than that, if we consider client computer can update its time with server daily by once then there is a possibility of error in any recorded event timing by 1.8 sec which is much larger than uncertainty variance. A typical application of deviation on the recorded Jovian radio signal timestamp is shown in Fig.4. Vertical axis representing signal strength is taken as arbitrary unit. Collected data has finest possible resolution in time domain. Recorded data was stripped and calibrated with theoretical value to represent uncertainty.

7. CONCLUSION

Uncertainty is a key term in understanding risk and risk assessment. Formulation from Heisenberg doesn't limit to single stream but its significance in any discipline lies under its application. Whatever probes we are using to register Jovian radio bursts, fixed tuned receiver or spectrum analyzer are essentially introducing uncertainty to measurement. It is also true for many solar emissions and sudden ionospheric disturbances due to solar flares. From our study it reveals a major part of this uncertainty due to client computer time synchronization can be removed by regular server time protocol synchronization but intrinsic contribution according to Gabor limit is always there. Hence for two or more bursts happening within specific time interval that is less than Gabor uncertainty limit cannot be distinguished whereas they can interfere to each other, and we can have a resultant signal.

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