GPS Interference detected in Sydney-Australia

Asghar Tabatabaei Balaei
Cooperative Research Centre for Spatial Information Systems and
School of Surveying and Spatial Information at the University of New South Wales/Australia
+61 2 93854206/asghart@student.unsw.edu.au
Beatrice Motella
Electronics Department at the Politecnico di Torino/Italy
+390112276413/Beatrice.motella@polito.it

Andrew G. Dempster
Cooperative Research Centre for Spatial Information Systems and
School of Surveying and Spatial Information at the University of New South Wales/Australia
+61 2 93856890/a.dempster@unsw.edu.au

ABSTRACT

Radio frequency interference affects the integrity, continuity and availability of the GPS system. These are the highly important parameters for critical applications like aviation. Interference also has an adverse impact on accuracy. Continuously operating reference stations (CORS) networks are employed to improve the accuracy of GPS position measurements used by surveyors. Interference can affect the normal operation of these stations. The goal of this work was to find if there is an interference source for GPS L1 in Sydney. It was shown that the third harmonic emission from a TV station lies within the L1 bandwidth. This source of interference is characterized in terms of frequency and power and the effect that it can have on the RF front-end of the receiver.

KEYWORDS: GPS, Interference, Detection, TV station

1. INTRODUCTION

Radio frequency (RF) interference is amongst the most disruptive events in the operation of GPS receiver. Detection of interference will enable us to make timely alerts once this disruption exists and this will improve integrity of the service. Interference can be generated either intentionally or unintentionally. There is a number of different potential sources for unintentional interference. The third harmonic of a TV station transmission has been shown to be a source for unintentional GPS L1 interference [1]. Several authors have already reported GPS interference in different countries [2, 3, 4, 5, 6]. This is the first time, however, that such disturbances are reported from Australia. There are several TV channels generating harmonics of order smaller than 10 which cause interference problems for GPS receivers. By studying the "Draft License Area Plan for Sydney Analogue Television" [12], it was found that the third harmonic of a transmitter station located in Artarmon easting 331560 Northing 6257750 (Figure1) is within the GPS receiver bandwidth. This interference was found in some specific locations and at particular times to be strong enough to saturate the Automatic Gain Control (AGC) in the RF front-end of the receiver. In section 2 the location and the hardware to detect the interference is described. In section 3, the source and the effect of the interference is characterized. Section 4 is dedicated to applying a detection algorithm to find the interference. The paper concludes in section 5.

2. LOCATION DESCRIPTION AND HARDWARE SETUP

The data collection took place in Artarmon, a suburb of northern Sydney. The data sets were collected in Ampden Road near the TV transmitter tower at about 6 km from the city centre (see Figure 1).

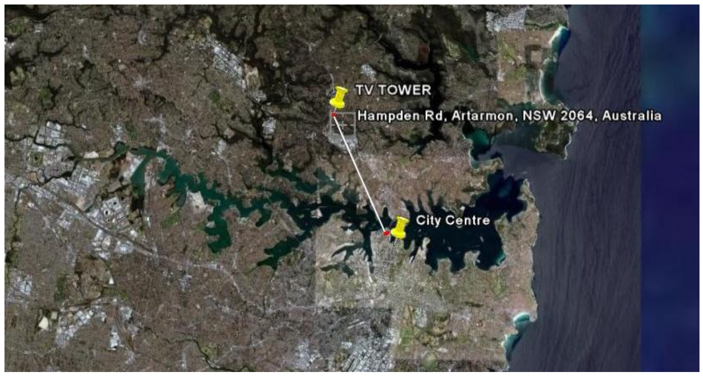

Figure 1 The distance between Sydney city centre and Hampden Road, Artarmon, where the data collection took place from Google Earth

The tower hosts the TV transmitter of Channel 28 (SBS) , which has the carrier frequency at 527.25 MHz in the band IV of Ultra High Frequencies (UHF) [7].
The TV transmitter power and the detection of the TV channel 28 transmission by means of the spectrum analyser are shown in Figure 2.

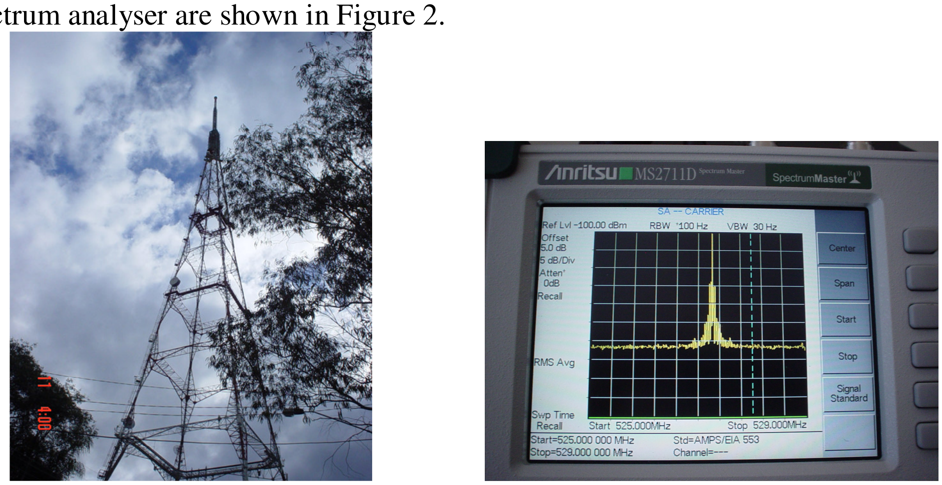

Figure 2 TV Tower in Hampden Road - Artarmon (left hand side) and the detection of the TV transmission (at 527.25 MHz) by means of the spectrum analyzer (right hand side)

The interferer is an analogue TV channel (Phase Alternation Line - PAL), which means that it is characterized by a vestigial sideband 8 MHz wide. The lower band edge is at -1.75 MHz from the carrier frequency and the upper band edge is at +6 MHz.
The transmitter we considered has the carrier frequency at fc = 527.25 MHz. This means that its 3rd harmonic is at 1581.80 MHz. Consequently the lower frequency of the 3rd harmonic is at 3*1.75 MHz = 5.25 MHz from 1581.80 MHz. Its distance from L1 central frequency is only 1 MHz from L1 GPS central frequency (1581.80 – 5.25 – 1575.42 MHz), which means that it falls within the front-end filter bandwidth of the receiver used in this test: the 3 dB bandwidth of the NordNav filter is 3.78 MHz.
The data were collected on 12th July 2006 at 11.30 am.

For the data collection the NordNav R-30 GPS software receiver has been used. The NordNav R-30 is a software receiver that allows us to save the raw data and post-process them. The data are stored at the output of the AD converter using a sample frequency of 16.3676 MHz. The Intermediate Frequency is at 4.1304 MHz and the front end -3dB bandwidth is 3.78 MHz. During the experiment a patch antenna was used.

3. SOURCE AND EFFECT CHARACTERIZATION

In this section the effect of the interference on the NordNav R-30 GPS receiver is analyzed. The first step in detecting the presence of undesired electromagnetic sources is the evaluation of the signal spectrum. By analysing the spectrum of the signal it was possible to detect the presence of several spikes that distort the shape of the signal spectrum at the front end output. The spectra have been evaluated using a 4096 sample Fast Fourier Transform (FFT) and 256 windows for the Welch technique [8]. Because the sampling frequency is 16.3676 MHz, the resolution bandwidth is equal to 4 kHz.

Starting from the data collection start time, the spectrum has been evaluated versus time every 5''. Figure 3 shows three different snapshots for the spectrum evaluated respectively at 1'15'', 1'50'', and 2'55'' with respect to the start time of the data collection. The spectrum is estimated using the data extracted at the output of the Analogue to Digital Converter (ADC) block. It is possible to recognize the shape of the front end filter that has a 3dB bandwidth of about 3.8 MHz.

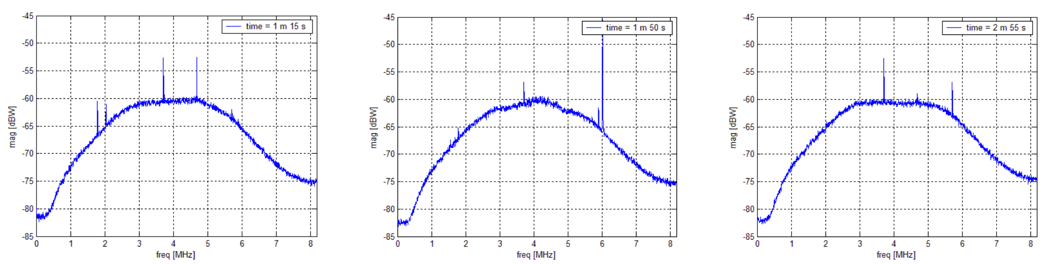

Figure 3 Spectrum of the received signal at different times

Over time several peaks were detected. The strongest and most frequent are at the frequencies:

- 3.7163 MHz;
- 4.6913 MHz;
- 6.0260 MHz.

Further investigation about the impact of these peaks on the working of the receiver has been done. Figure 4 examines the relationship between the height of the spikes and the behaviour of the Automatic Gain Control (AGC) level. The height of the peaks was measured with respect to time and the noise floor level for about 3 minutes. The spike at 3.7163 MHz (in pink) is the most frequent one and it is present for almost the whole time interval; its height varies up to 11 dB above the noise floor. It is strongest in the time interval between 42 and 64 seconds. The spike at 4.6913 MHz (in red) is less frequent and weaker. It is present in the time interval 18-100 seconds and it is has a maximum of 6 dB at around sec 45. The spike at 6.0260 MHz (in green) is the least frequent, but the strongest one. Its presence is limited to around second 80, but it emerges from the noise up to 13 dB.

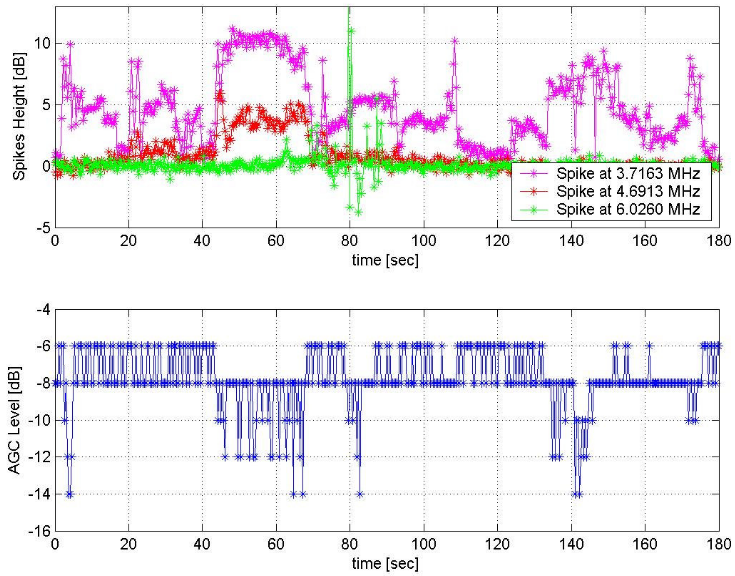

Figure 4 Height of the spikes w.r.t. the noise level vs time (above) – AGC gain vs time (below)

Comparing the behaviour of the height of the peaks with the AGC level vs time (Figure 4), it is easy to observe how the AGC gain is affected by the presence of interference sources within the received signal. In order to allow the ADC to work properly, the aim of the AGC is to maintain the incoming signal within a certain amplitude range. To do that, when the interferer is present, the AGC modifies its gain, compensating for the increasing/ decreasing power level of the received signal. In detail, it is possible to observe how the AGC changes its gain in the time interval 42-64 sec (when the peaks at 3.7163 and 6.4913 MHz occur), around the second 80 (when the peak at 6.0260 MHz is on) and in the interval 135-145 sec (when the peak at 3.7163 MHz is on again).

In the absence of interference, the AGC would normally not change value in the period observed in this experiment.

Since the automatic gain control has the aim of maintaining the power of the incoming signal, the presence of undesired sources makes its behaviour affect also the power of the useful signal, i.e. when interference is strong, the wanted signal is attenuated. In order to have a quantitative measure of such a loss, the average of the spectrum within 1 MHz of bandwidth has been evaluated. This is the portion of band where the GPS signal has the strongest frequency components. Figure 4 shows an example between sec 70 and sec 100. It indicates the relationship between the average of the spectrum (evaluated within 1 MHz around the central frequency) and the behaviour of the AGC. Within this time interval, due to the presence of the strong spike at 6.0260 MHz, the AGC adjusts its gain, increasing the attenuation. This affects the received signal. The consequence is a loss of up to 7 dB (from -62 to -69 dB) within the frequency band where the GPS signal is present. This effect is shown in Figure 4 (seconds 80-85).

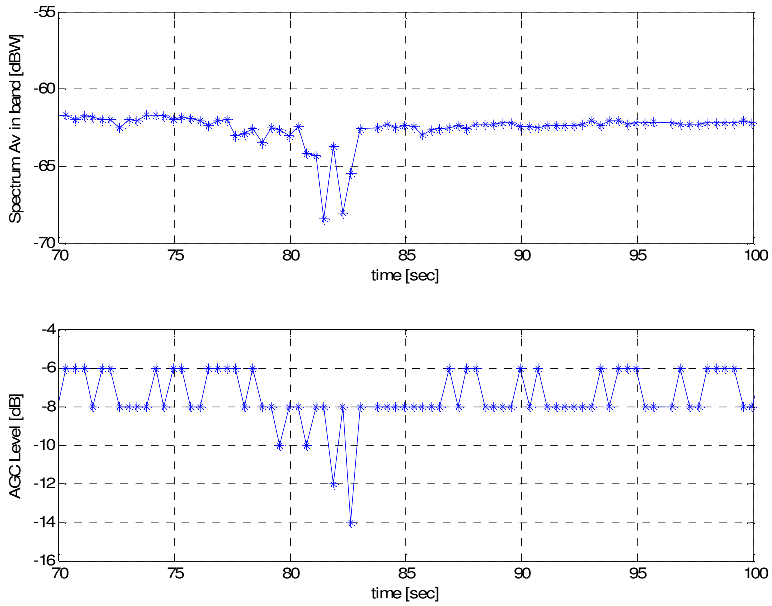

Figure 5 Spectrum average within a band of 1 MHz around the central frequency (above) – AGC level versus time (below)

4. DETECTION OF THE RFI

For detecting this interference, the same algorithm is used that has been used in [9, 10]. Depending on where the interfered data is collected, different levels of interference can be received by the GPS receiver antenna. If the receiver antenna is in the location where it can receive the main lobe of the transmitted signal, then the received power can be enough to saturate the RF front-end of the receiver and consecutively stop the normal operation of acquisition and tracking of the receiver. The power spectral density of the received signal in this situation is shown in Figure 6. It can be seen that the interferer is spread across the band and the reason it looks stronger in the band centre may be that the NordNav receiver bandwidth is 2 MHz around the IF frequency which is 4.130 MHz.

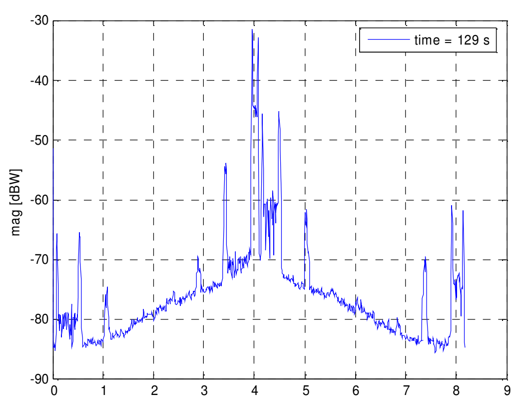

Figure 6 Interference-affected data collected in a location from where the main lobe of the transmission is received in a specific time (time = 129s from the collected data)

To get an idea of how much power is received by the receiver antenna, the Automatic Gain

Control (AGC) level of the receiver was recorded. The AGC is the first component in the receiver that reacts to the input signal power. If the interference power is higher than the environmental thermal noise power, then the AGC, by changing the gain, will try to keep the signal to noise ratio at its optimum value [11]. It will continue decreasing the gain with the increasing input signal power till it saturates. This also attenuates the GPS signal. The characterization of the behaviour of this component in the NordNav receiver RF front-end in the presence of wideband noise within the L_1 band is investigated. This characterization will allow us to estimate the amount of interference power that the receiver is receiving at each moment. To do this experiment the hardware setup of Figure 7 is used.

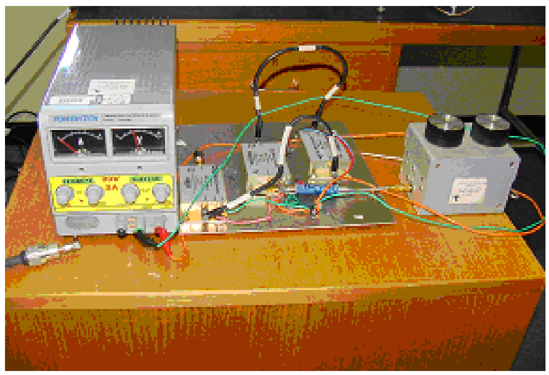

Figure 7 The hardware setup to characterize the behavior of AGC level of NordNav software receiver

In Figure 7, there is a DC power supply, a three stage amplifier with each stage having a gain of 27 dB providing in total a gain of 81 dB. In the output of this amplifier there is a REACTEL filter with a bandwidth of 20 MHz and a central band of 1575.42 MHz. This amplified and filtered signal is passed through a programmable attenuator to control the input noise power. This signal is finally fed into the GPS receiver.

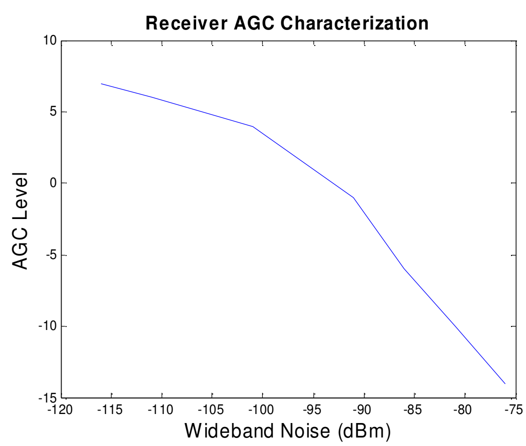

Figure 8 Characterization of the behavior of AGC level w.r.t the received in-band power in the NordNav software receiver

This experiment is performed in a few steps where the input noise power changes by adjusting the programmable attenuator. Figure 8, shows the level of the AGC versus the input power. The figure shows that the AGC decreases the gain once the input power is high.

Figures 9 and 10 show the histograms of the IF data when the input power is less than the thermal noise and also in the situation when the AGC is saturated because of the high amount of received signal is shown.

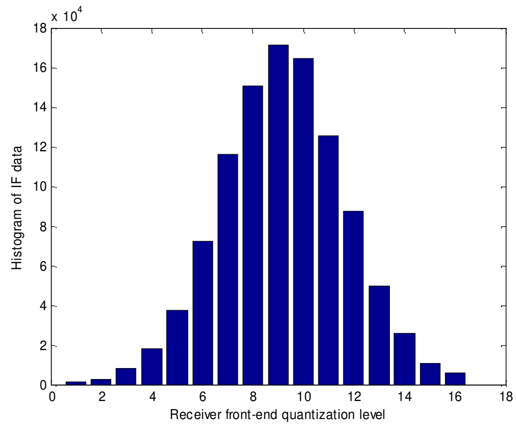

Figure 9 Normal histogram of the IF data when the AGC is in its linear operation

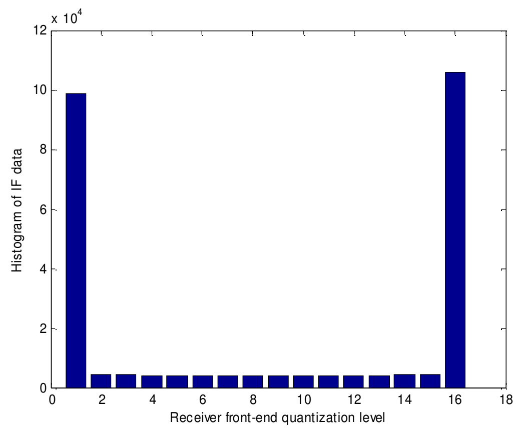

Figure 10 histogram of the IF data when the AGC is saturated by interference

The intermediate frequency (IF) data from the receiver radio frequency (RF) front-end is sampled by a four-bit ADC, giving 16 levels of quantization. Figure 9 shows that the histogram in the situation in which the AGC is working in its linear normal operation looks like a Gaussian distribution, as can be expected given the signal appears simply to be "noise". Alternatively if the interference or the noise power received by the receiver is high it can saturate the AGC in a way so that it can no longer keep the histogram in a Gaussian shape. In an extreme situation the histogram can become like that shown in Figure10. This histogram is for real data suffering from interference collected from the TV transmitter antenna where the received power of interference is very strong. Considering the AGC behaviour in terms of input power noise (Figure 8), the IF data histogram in the presence of interference (Figure 10) and the changing AGC level shown in (Figure 11) it is clear that the interference received in this area is strong. This interference actually stopped the normal operation of the NordNav software receiver and no GPS satellite signal was acquired or tracked in those particular locations at the time when interference was present.

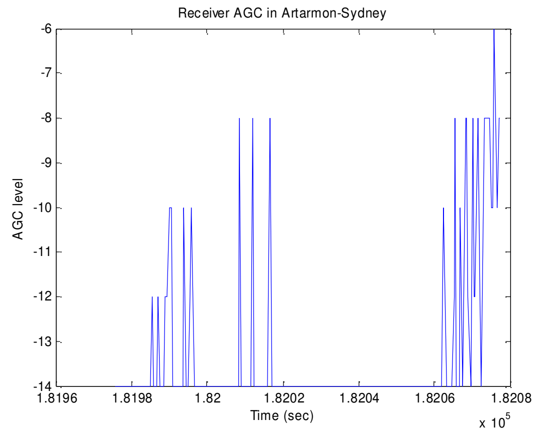

Figure 11 AGC level in the strongly interfered area versus time

The interference detection technique used here in this paper is sensitive enough to detect CW interference when its power is below the power of the environmental noise. In situations where the AGC is significantly affected by the power of the interference, then this will affect the statistical behaviour of the signal in each frequency bin. This will prevent the algorithm from working properly. As is clear from Figure 6, in these cases the RFI can be detected simply by analysing the signal spectrum or by observing the AGC. Figure 12 shows the log10 of "p _value "in the presence of the interference of Figure 6. It clearly shows that no decision can be made based on this figure regarding the existence of RFI and its frequency.

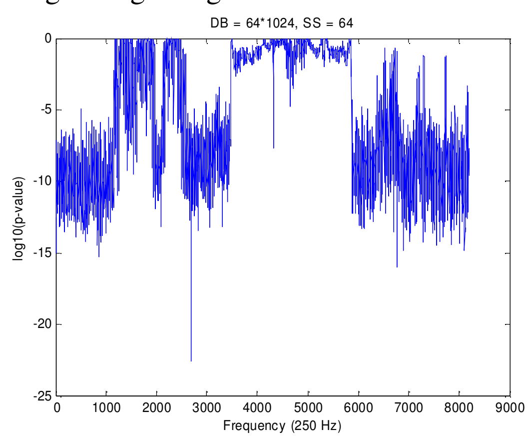

Figure 12 p-value across the bandwidth in the presence of strong interference in a specific time {large negative values indicate a high likelihood of the presence on interference}

Based on the the previous discussion, data is collected in the place where interference is very weak and it therefore does not affect the AGC level. The histogram of data for this case is like the one in Figure 9 has a Gaussian shape. The power spectrum of data is shown in Figure 13, with no large spikes visible. From this power spectrum, no distinguishable anomaly is recognizable to be interference.

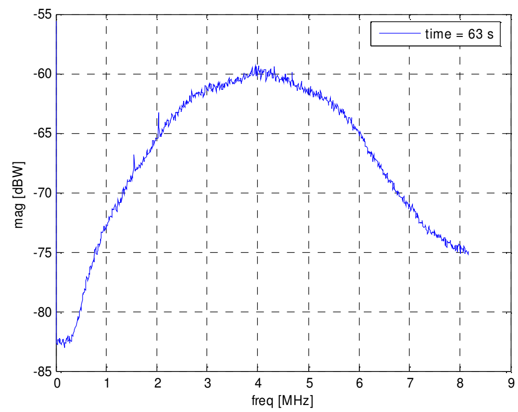

Figure 13 Power Spectral Density of the Received Signal at time...

The result of applying the RFI detection technique to this data is shown in Figure 14. In this figure, the log10 of "p-value" is shown across the 1MHz bandwidth for almost 40 seconds.

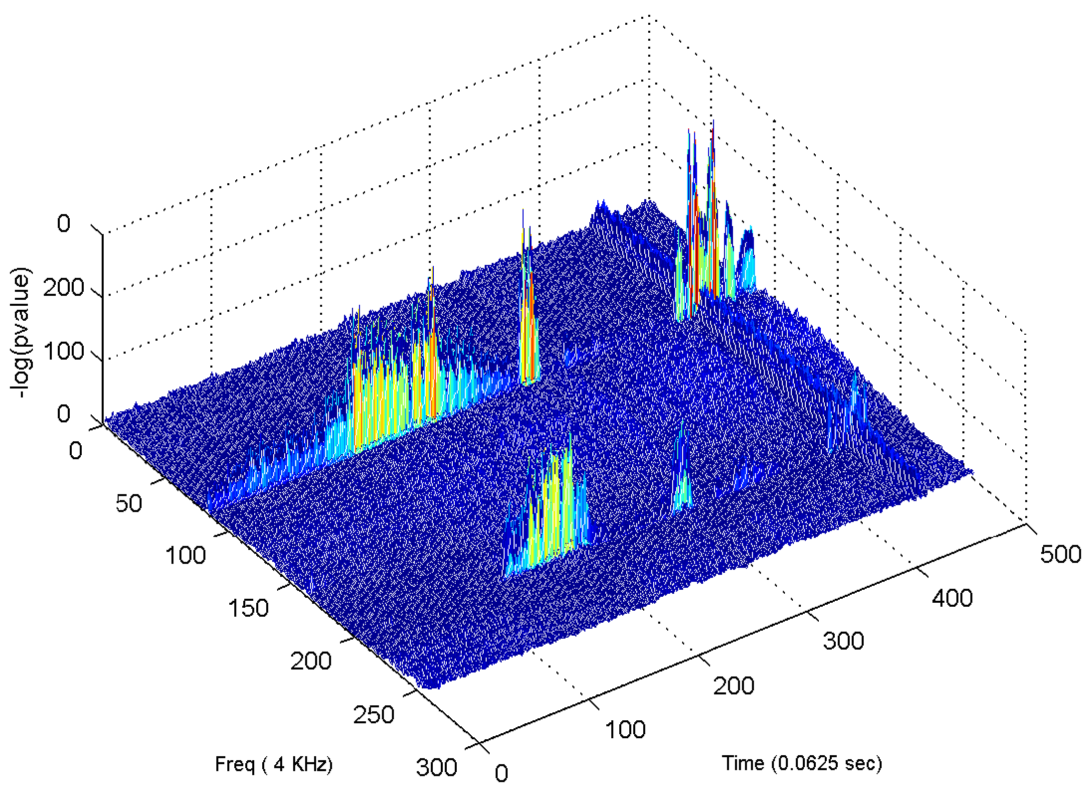

Figure 14 log10 (p-value) versus time and frequency

In this figure, the hypothesis test is performed using a window size of 62.5 ms. In the time axis each step corresponds to 62.5 ms. Also the data block size is chosen to be 2*1024 samples of data meaning that each step in the frequency axis corresponds to 8 KHz. This figure shows that there are two CW interferences within the 2 MHz bandwidth. There are moments like those are point 370 (23 sec) in which no interference is recognized from this figure. In fact interference in those moments is not strong enough to be detected by a 62.5ms window size. Figure 15 shows that by using a 256 ms window size this interference is recognizable. With a longer window size we can have both more SS (sample size) and DB (data block) size.

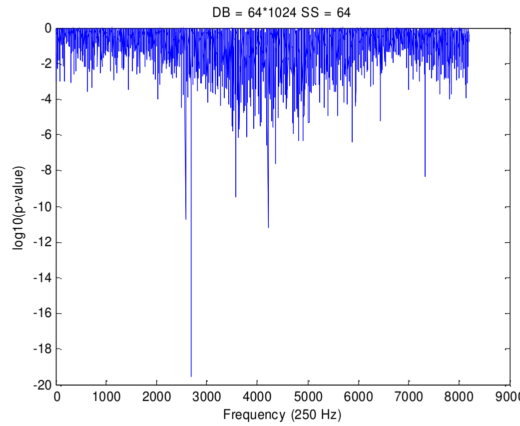

Figure 15 P-value across the L1 bandwidth for time 23 sec

Around time step 450, a big wave can be seen all across the 2 MHz band width. This wave is the result of momentarily receiving a high power signal. This phenomenon can be the result of two situations; the AGC fails to cope with the situation because of high dynamic wideband noise or it actually reacts to the high power narrowband noise.

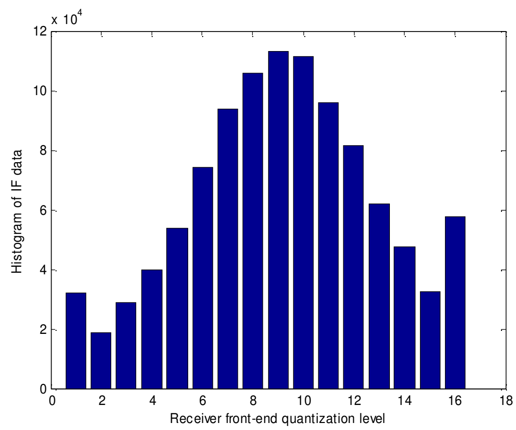

Figure 16 Histogram of the IF data at time 28 sec

In Figure 16, the histogram of the data is shown for a window size 62.5 ms. It can be seen that the histogram is different from the normal histogram shown in figure 9.

5. SUMMARY

An interference generated by a TV transmitter tower within the bandwidth of GPS (L1) is reported in this work. The location is Artarmon in in Sydney, Australia. This interference in some points was strong enough to saturate the AGC completely and stop the test software receiver from tracking the satellites. The effects of this interference on AGC were analysed. Also using a statistical inference technique, this same interference source was detected when below the level of the noise. The plan is to repeat this measurement in other areas and to generate a radio map from Sydney in terms of radio frequency interference within the GPS bandwidth.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the CRC for Spatial Information in funding this project (CRC-SI Project 1.1).

REFERENCES

[1] Johannessen R, Gale S.J, Asbury M.J.A, ”Potential Interference Sources to GPS and Solutions Appropreate for Applications to Civil Aviation” IEEE AES Magazine 1990

[2] Hutchinson, A.D. and Weitzen, J., “Television interference to GPS”, Input to the RTCA SC 159 AD HOC Subgroup on GNSS interference, June 1994

[3] Buch, F., “GPS Interference in Germany, Experiences during the ISAN project”, Workshop notes, RIN workshop on interference – is there any problem?, London, 12-13 October 1995, pp215-227

[4] Borza, T., Fejes, I.,“GPS interference in Hungary” 5th International Seminar on GPS in Central Europe, 5-7 May 1999, Penc, Hungary Reports on Geodesy, 5(46), 215 (1999)

[5] Berggraf, O., Electro magnetic interference observed with a GPS receiver in Staganger Harbour”, Workshop notes, RIN workshop on interference – is there a problem?, pp112-121 London, 12-13 October 1995

[6] Scaramuzza, M., Geiger, A., “Use of digital terrain models for detection of potentially interfering zones”, Proceedings of the Workshop “GPS Interfeernce – is it a problem?”, London, October 1995, pp144-165

[7] *Licence Area Plan*, Sydney Analog Television, Australian Broadcasting Authority Canberra, November 2002

[8] J.G. Proakis, M. Salehi, *Communication System Engineering,* Prentice Hall, 1994

[9] Marti L., Van Grass F., “Interference Detection by Means of the Software Defined Radio” ION GNSS 17th International technical meeting of the satellite division, (2004)

[10] Tabatabaei Balaei A, Dempster A G (2006b) A Statistical Inference Technique for GPS Interference Detection Submitted to the IEEE Transaction on Aerospace and Electronic systems. November 2006

[11] Spilker J. and Natali F., “Interference Effects and Mitigation Techniques”, Chapter 20 of ‘Global Positioning System: Theory and Applications’, AIAA. (1996)

[12] “Draft Licence Area Plan – Sydney Analogue Television” Australian Broadcasting Authority Canberra Octber 2002