PROJECT REPORT

Report of Lab GNU Radio, course ET4394, Wireless Networking

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Contents

1. Introduction

With the increasing number of users of wireless network, the available frequency spectrum is running out. Thus, technology such as Dynamic Spectrum Access (DSA) and Cognitive Radio (CR) are developed to make use of the white space in the frequency spectrum. CR is the technology that makes DSA possible. It is the radio that can sense and autonomously reason about its environment and adapt accordingly [1]. The use of the white space frequency spectrum should not influence the use of the primary users.

In this project, a simple signal detector is established using GUN Radio. Signals received by RTL dongle are sampled and processed to detect digital television channels (DVB-T) under varying channel conditions. The receiver operating characteristic (ROC) of the detector can thus be generated and the detection mechanism tested can be further improved.

The RTL dongle used in this project is RTL2832U and the software used is GNU Radio Companion. Besides, Gqrx is used as an assistant tool.

2. Project Description

The goal of this project is to establish a signal detector using GNU Radio. Detection of the DVB-T channel signals is made to search for empty channels available in broadcast television frequency band. The detector should be able to judge from its detection to decide whether there exists a signal or not. Based on the detection performance, ROC of the detector will be generated.

2.1. RTL2832U

The RTL2832U is a high-performance DVB-T COFDM demodulator that supports a USB 2.0 interface. It supports 2K or 8K mode with 6, 7, and 8MHz bandwidth. Modulation parameters, e.g., code rate, and guard interval, are automatically detected.

Features of RTL2832U is shown in Table 1.

Table 1. Features of RTL2832U

Features
COFDM complying with Nordig Unified 1.0.3, D-book 5.0, and ETSI 300-744
Supports multiple IF frequencies (4.57MHz or 36.167MHz) and spectrum inversion
Includes ISDB-T(SBTVD-T) 1-Seg
Supports Zero-IF input
Single low-cost crystal for clock generation (±100ppm)
Automatic transmission mode and guard interval detection
Impulse noise cancellation circuits
Automatic carrier recovery over a wide range offset (±800KHz)
Superior performance with pre/post/long echo profiles
Embedded adjacent and co-channel interference rejection circuit
Delayed AGC with programmable Take-Over Point (TOP)
7-bit ADC for RF signals level measurement
Hardware MPEG-2 PID filters
Infra-red port for remote control and wake-up, protocols supported are:
Microsoft RC6 protocol
NEC, Sony, SIRC, RC-5 protocol
Eight general purpose I/O ports
USB 2.0 Interface
Supports USB Full/High speed
Configurable vendor information via external EEPROM
Passes USB-IF certification
Signal 3.3V external power is required
48-pin QFN (6x6 mm2) Green Package

2.2. Cognitive Radio

A cognitive radio (CR) is an intelligent radio that can be programmed and configured dynamically. It automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management [2].

The spectrum management framework for cognitive radio networks consist of spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. In this project, spectrum sensing is applied.

2.3. White Space

In cognitive radio networks, systems operating in digital television white spaces are particularly interesting for practical applications. In this project, single-antenna spectrum sensing of real DVB-T signals under different channel conditions is considered. The five DVB-T channels of Delft is shown in Table 2.

Table 2. DVB-T channels of Delft [3]

	Transmitter location	UHF channel	Freq. (MHz)	kW (ERP)	COFDM	Bandwidth (MHz)	Code/Rate
RTS Bouquet 1	Delft	52	722	1	8k	8	HP 1/2; LP-1/2
NTS1 Bouquet 2	Delft	49	698	1	8k	8	HP 1/2; LP-1/2
NTS1 Bouquet 3	Delft	57	762	1	8k	8	HP 2/3; LP-1/2
NTS1 Bouquet 4	Delft	24	498	1	8k	8	HP 2/3; LP-1/2
NTS1 Bouquet 5	Delft	27	522	1	8k	8	HP 1/2; LP-1/2

2.4. Power/Energy Detection

In this project, power/energy detection is used for detection of signals. Formula used to convert the power of a signal to dB unit is shown as follows and it is the formula used in this project.

Logarithmic power measuring:

$$P(dBW) = 10 * log10(\ P(W)\ /\ 1W)$$

3. Implementation

The basic infrastructure of this simulation module is shown in Figure 1.

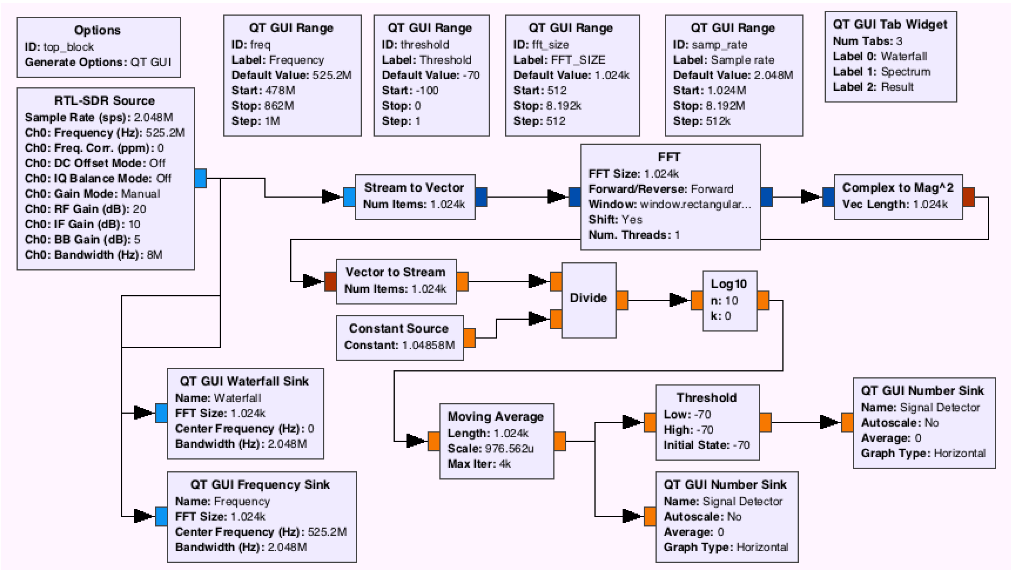

Figure 1. GNU blocks for signal detection

Blocks used in this infrastructure is shown in Table 3.

Table 3. GNU blocks explanation

Block	Description	Parameters
RTL-SDR Source	Get signal from RTL2832U dongle	Sample rate: samp_rate, RF Gain: 20dB, IF Gain: 10dB, BB Gain: 5dB, BW: 8MHz
QT GUI Frequency Sink	Display untreated signal from RTL2832U dongle using the Power-Frequency diagram	FFT Size: fft_size, Center Frequency: freq, Window type: rectangular, BW: 4*samp_rate
QT GUI Waterfall Sink	Display untreated signal from RTL2832U dongle using the Time/Power-Frequency Waterfall	FFT Size: fft_size, Center Frequency: freq, Window type: rectangular, BW: 4*samp_rate
Stream to Vector	Convert input signal to vector for FFT transformation	Num Items: fft_size
FFT	FFT transformation	FFT Size: fft_size, Window: rectangular,
Complex to Mag^2	Used for the formula P(dBW) = 10 * log10(P(W) / 1W)	Vec Length: fft_size
Vector to Stream	Convert FFT transformation result to stream	Num Items: fft_size
Constant Source	Used for the formula P(dBW) = 10 * log10(P(W) / 1W)	Constant: fft_size*fft_size
Divide	Used for the formula P(dBW) = 10 * log10(P(W) / 1W)	/
Log10	Used for the formula P(dBW) = 10 * log10(P(W) / 1W)	n: 10, k: 0
Moving Average	Moving average filter	Length: fft_size
Threshold	Used for determine signal detection	Initial State: -70
QT GUI Number Sink	Display the power level of a signal and show the result of detection	Signal Detector
QT GUI Range	Change the value of sample rate, frequency, FFT size, and threshold during detection	samp_rate=2,048Msps, freq.min=478MHz, freq.max=862MHz, fft_size=1024, threshold.min=-100, threshold.max=0
QT GUI Tab Widget	Set taps of display	3 taps: Waterfall, Spectrum, Result

The Moving Average [4] block is not added in the first place, but is used as the improvement for the signal detection. Before implementing the Moving Average filter, signal coming from the FFT block contains much noise that influences the detection accuracy of a certain frequency channel. The Moving Average filter is used as a simple way to smooth out noisy signal.

The value of sample rate, FFT size, threshold and other parameters can all influence the performance of the detector. In this project, changes of sample rate, target frequency, FFT size and threshold can all be configured.

4. Results & Analysis

4.1. DVB-T Channel Signal Detection

The 5 signals shown in Table 2 can all be detected using GNU Radio. Besides the 5 DVB-T signals, 5 other frequencies in which signals exist are tested. Also, 10 frequencies in which no signal exists are tested.

In this project, signals are detected at 4 different locations to generate a more accurate ROC of the detector. The result of the detection is shown in Table 4. Note that the level is just an instantaneous average value of the power of the signal.

Table 4. Signal detection result

	Central Freq. (MHz)	Freq. Rage (MHz)	TUD Library (Indoors)		TUD Library (Outdoors)		Michiel de Ruyterweg 8 (Indoors)		Michiel de Ruyterweg 8 (Outdoors)	
			Detection	Level (dB)	Detection	Level (dB)	Detection	Level (dB)	Detection	Level (dB)
RTS Bouquet 1	722	718.2 - 725.8	No	-72.3	Yes	-66.6	Yes	-61.3	Yes	-67.6
NTS1 Bouquet 2	698	694.2 - 701.8	No	-72.8	Yes	-65.9	No	-71.9	Yes	-64.8
NTS1 Bouquet 3	762	758.2 - 765.8	No	-74.2	Yes	-69.1	Yes	-68.3	No	-72.0
NTS1 Bouquet 4	498	494.2 - 501.8	Yes	-71.4	Yes	-61.0	Yes	-61.4	Yes	-60.3
NTS1 Bouquet 5	522	518.2 - 525.8	Yes	-70.6	Yes	-63.5	Yes	-62.3	Yes	-67.3
Unknown #1	480	/	No	-73.9	No	-75.5	No	-72.4	No	-71.9
Unknown #2	600	/	No	-75.2	No	-76.4	No	-74.3	No	-74.9
Unknown #3	796	791.5 - 800.5	Yes	-57.4	Yes	-45.0	Yes	-70.6	Yes	-67.4
Unknown #4	806	801.5 - 810.5	Yes	-61.5	Yes	-64.5	No	-74.4	No	-74.0
Unknown #5	816	811.5-820.5	Yes	-73.2	Yes	-71.8	No	-74.3	No	-73.6
	Average level: -68.67dB, Std. Deviation: 6.42									
Empty #1	550	/	No	-75.3	No	-76.5	No	-75.1	No	-75.3
Empty #2	650	/	No	-75.2	No	-76.7	No	-75.3	No	-75.2
Empty #3	750	/	No	-75.3	No	-76.5	No	-75.2	No	-75.1
Empty #4	850	/	No	-75.6	No	-76.5	No	-75.3	No	-75.5
Empty #5	635	/	No	-75.3	No	-76.3	No	-75.0	No	-75.2
Empty #6	504	/	No	-75.5	No	-76.3	No	-74.6	No	-75.0
Empty #7	533	/	No	-75.3	No	-76.4	No	-75.0	No	-75.0
Empty #8	547	/	No	-75.3	No	-76.3	No	-75.0	No	-75.1
Empty #9	589.5	/	No	-75.4	No	-76.7	No	-74.8	No	-75.2
Empty #10	778	/	No	-75.4	No	-76.7	No	-75.6	No	-75.3
	Average level: -75.53dB, Std. Deviation: 0.60									

The detection result (Yes/No) shown in Table 4 is with respect to the threshold of -70dB. It can be seen from the table that when using the same threshold, the detection result can be different. This is due to the method used in the detection, i.e., power/energy detection. Signals received in different places have different levels of power, which results in different detection results.

According to the data gathered in Table 4, the average power level of the existed signal is -68.67dB and the average power level of the noise signal is -75.53dB.

4.2. Bandwidth Detection

Take the detection of 522MHz signal as an example, the frequency spectrum of the signal is shown in Figure 2. When central frequency is set to 522MHz, Signal Detector shows one detected signal. When central frequency is decreased to 518MHz, there shows no detected signal. The same happens when the central frequency is increased to 526MHz. Also, the waterfall plots shown in Figure 3 indicate that the boundary is 518.2MHz and 525.8MHz, which implies the bandwidth to be 7.6MHz. This is a little bit smaller than the real bandwidth, which is 8MHz. However, if the noise level can be lowered, the measured bandwidth could be closer 8MHz. Also, Figure 4 shows the signal detection using Gqrx, which gives the same result.

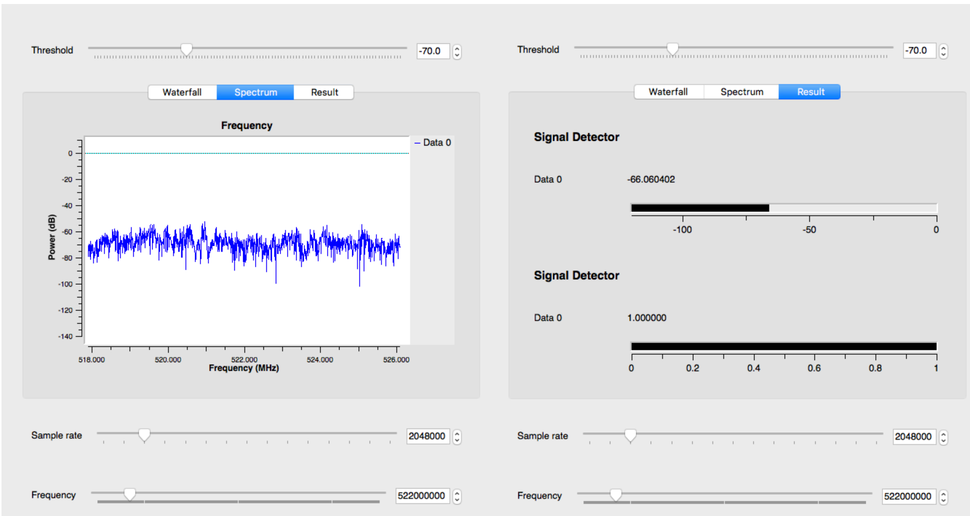

Figure 2. Detection of signal in Freq. 522MHz

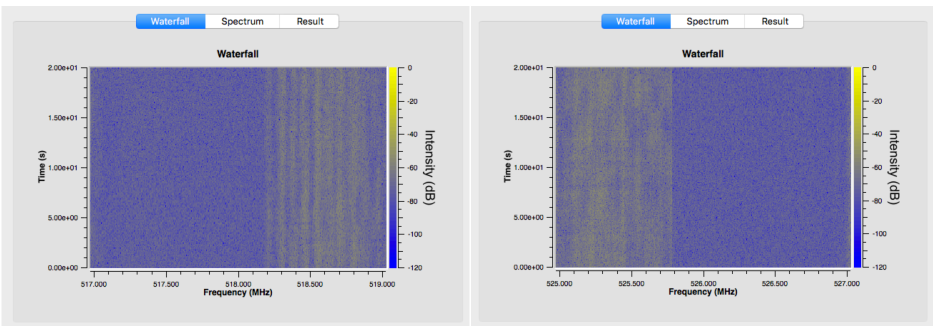

Figure 3. Waterfall diagram of the signal edge

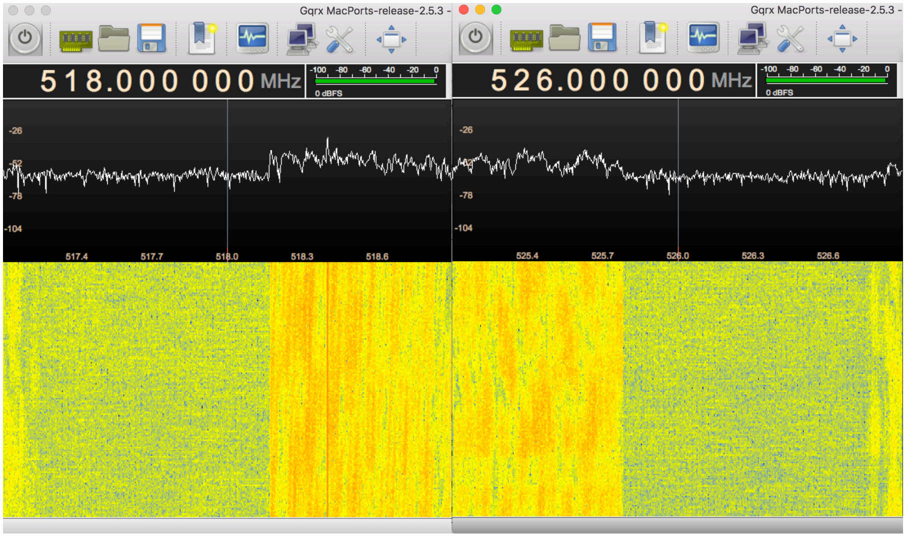

Figure 4. Signal edges detection using Gqrx

4.3. Unknown Signal Detection

One of the unknown signals that have been detected is in Freq. 480MHz. The frequency spectrum and waterfall plot of this signal is shown in Figure 5 and the detection result is shown in Figure 5. This signal cannot be detected when the threshold is set to -70dB. Another unknown detected signal is around Freq. 795MHz, which is shown in Figure 6 and 7. This signal has a bandwidth of approximately 9MHz.

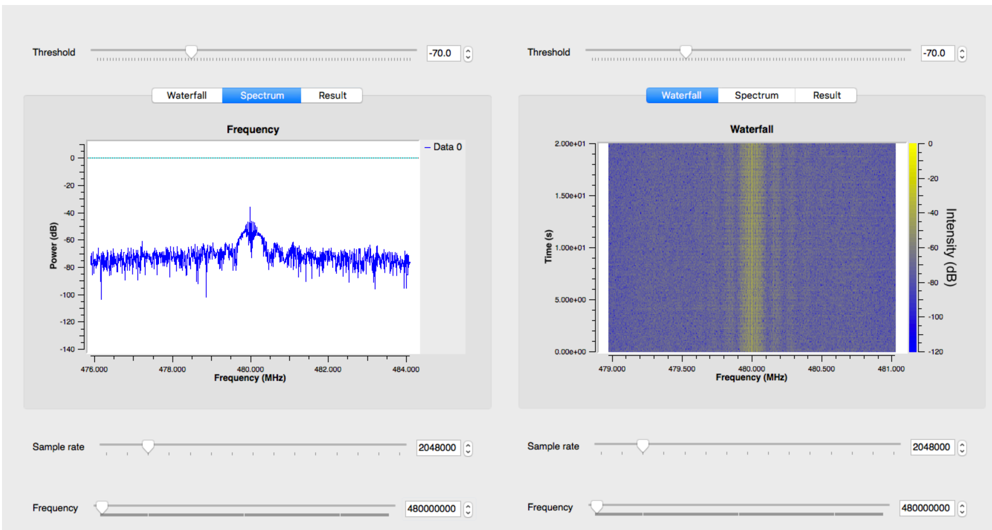

Figure 5. Detection of signal in Freq. 480MHz

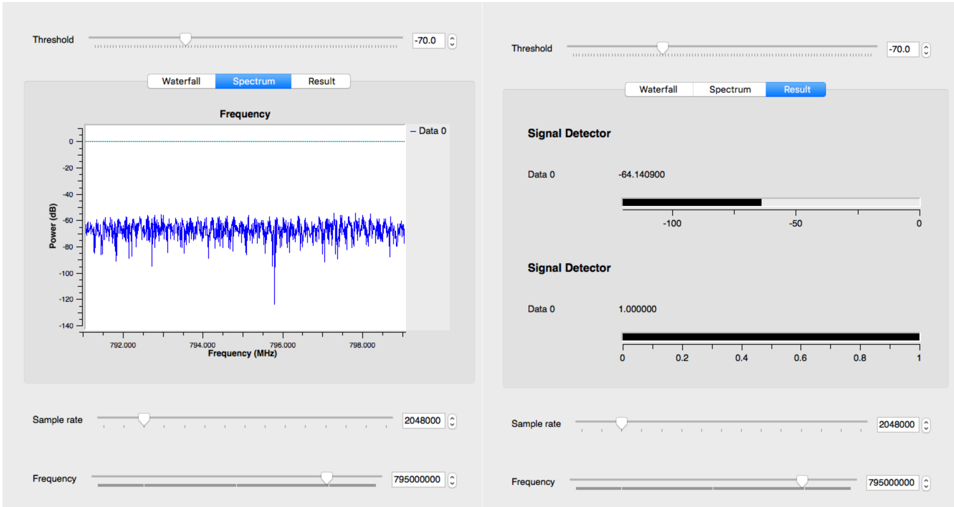

Figure 6. Detection of the signal around Freq. 795MHz

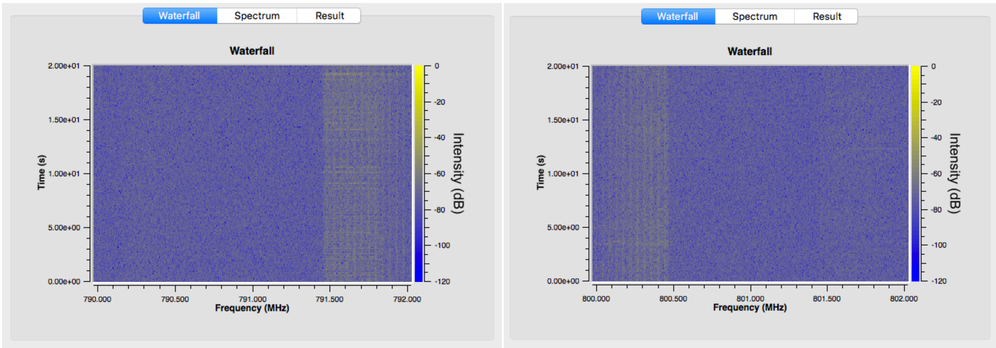

Figure 7. Detection of the signal around Freq. 795MHz

4.4. No Signal Detection

Figure 8 and 9 show a detection example of the detector when there exists no signal. The detector result is correct when the threshold is set to -70dB.

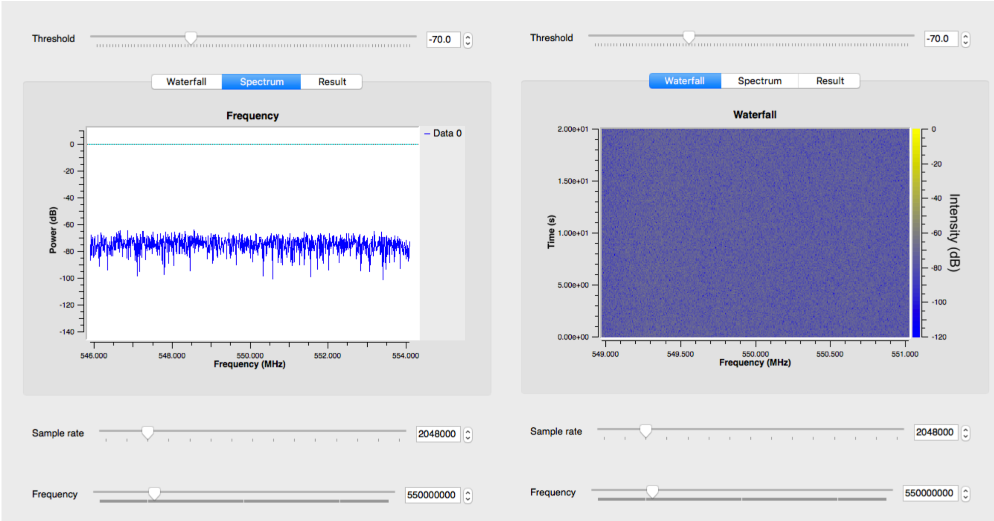

Figure 8. Example of no signal detected in Freq. 550MHz

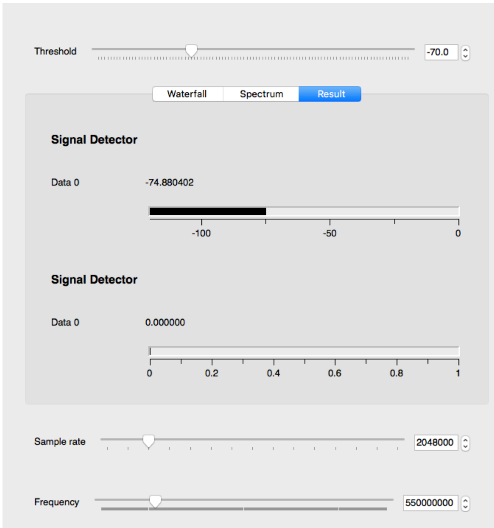

Figure 9. Example of no signal detected in Freq. 550MHz

4.5. False Alarm

It is said in section 3 that the Moving Average block is not added in the first place. The absence of this block induces more false alarms. As shown in Figure 10 to Figure 12. These three figures show 2 false alarm examples in Freq. 550MHz and Freq. 650MHz.

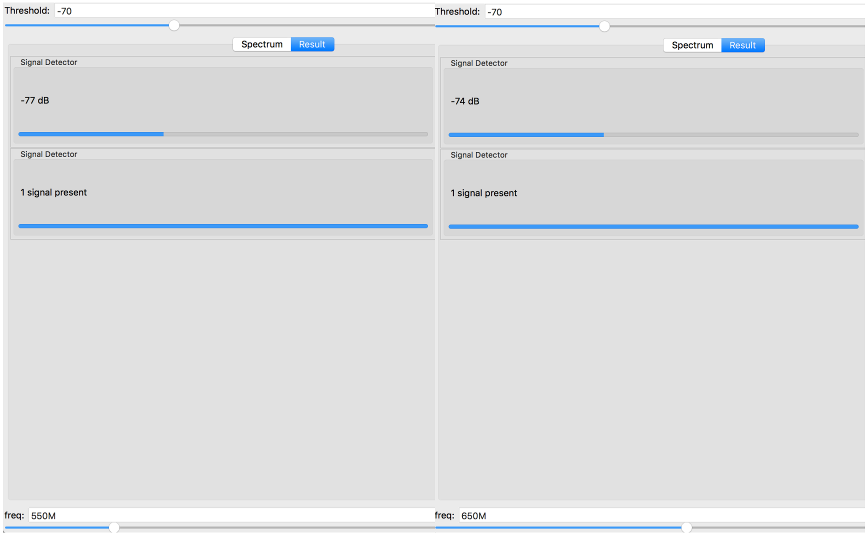

Figure 10. Example of false alarms in Freq. 550MHz and Freq. 650MHz

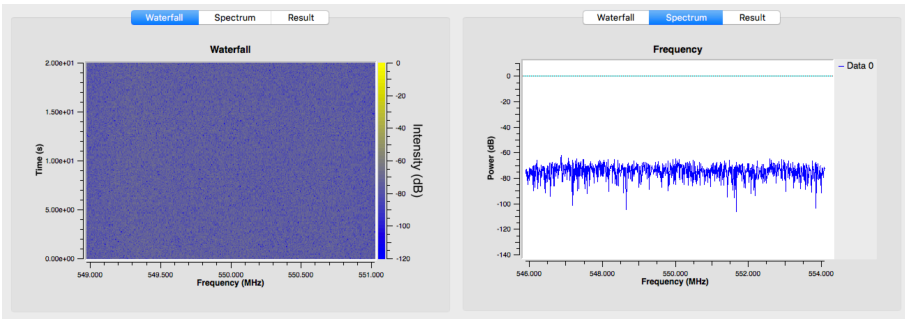

Figure 11. Waterfall and Frequency spectrums in Freq. 550MHz

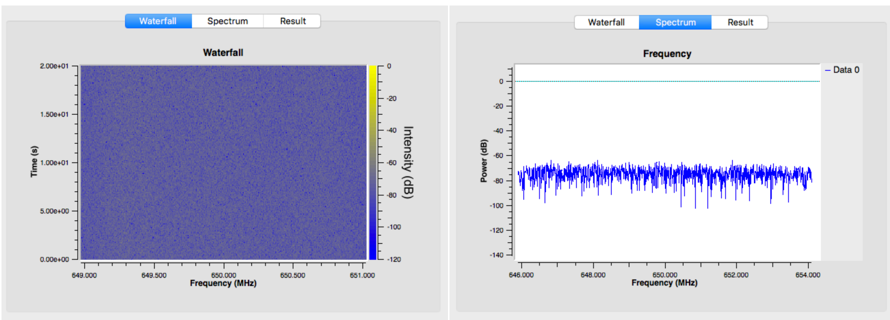

Figure 12. Waterfall and Frequency spectrums in Freq. 650MHz

This induction of false alarm is due to the strong power level of noise signal and relatively low threshold. However, after adding the Moving Average block into the project, the number of false alarms reduce greatly.

4.6. Performance Analysis

Base on the detection result shown in Table 4, the RTL-SDR detection probability plot can be generated using MATLAB, as shown in Figure 13, as well as the ROC curve of the detector, as shown in Figure 14. It can be seen from Figure 13 (left) that when the threshold is set to -70dB, the probability of false alarm is 0 and the probability of correct detection of existed signals is only 58.21%, as shown in Figure 14 (left). However, the threshold can be improved to -73dB. In this case, the probability of false alarm is 1.1033e-05, which is very close to zero, and the probability of correct detection of existed signals is improved to 75.00%. As shown in Figure 14 (right).

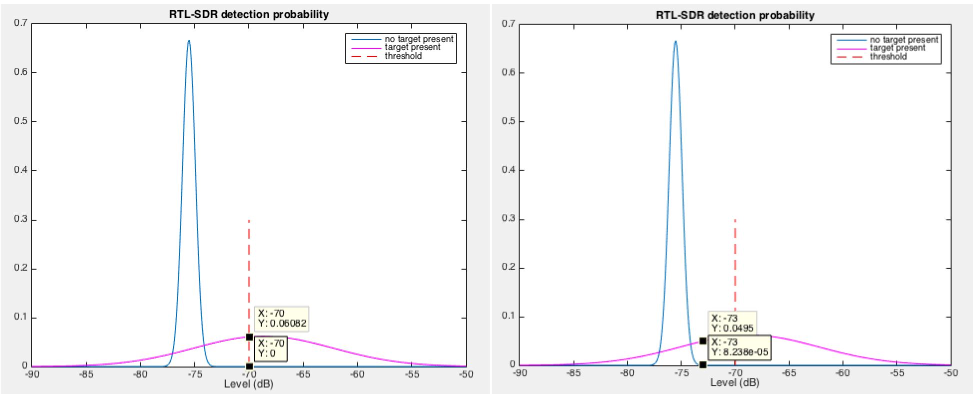

Figure 13. RTL-SDR detection probability curve

```
>> GNU

Pfa =

     0


Pd =

    0.5821
```

```
>> GNU

Pfa =

   1.1033e-05


Pd =

    0.7500
```

Figure 14. Calculation result

The ROC curve of the detector shows the relationship between the probability of false alarm and the probability of existed signals detection.

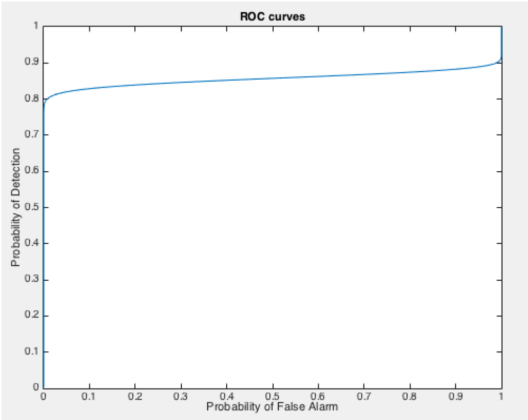

Figure 15. ROC curve of the detector

5. Conclusion

Base on the result and analysis of the above, conclusions can be made as follows.

The designed signal detector is feasible of detection of DVB-T signals. The power/energy detection mechanism used in this design performs well on signal detection.

Locations have influence on signal detection. Signal is stronger at some location and weaker at other locations. In this project, signals detected at Michiel de Ruyterweg 8 is stronger than signals detected inside the Library. Thus, the detector should be able to adjust its threshold when used in different places.

Threshold has influence on signal detection. A lower threshold will induce more false alarms while a higher threshold may not recognize an existing signal. Trade off between the reliability and sensibility should be made when designing a signal detector.

The power level of noisy signal has influence on signal detection. A stronger noise may induce false alarm. Thus, when designing a signal detector, a better signal processing method should be made to filter the noise signal.

Reference

[1] Zurutuza N. Cognitive Radio and TV White Space Communications: TV White Space Geo-location Database System[J]. 2011.

[2] https://en.wikipedia.org/wiki/Cognitive_radio

[3] http://radio-tv-nederland.nl/dvbt/digitenne-kpntv.html

[4] http://www.ece.uvic.ca/~elec350/grc_doc/ar01s01s07.html

Appendix

Source code of the calculation and plotting using MATLAB is shown below. It can also be found on GitHub (https://github.com/yjgong/WirelessNetworking). The source code is based on the code written by Rizqi Hersyandika of last year.

```
% no target present distribution mean = -75.533 dB & stdev = 0.597
Pnotarget = makedist('Normal', 'mu', -75.533,'sigma',0.597);
% target present distribution mean = -68.67 dB & stdev = 6.420
Ptarget = makedist('Normal','mu', -68.67,'sigma',6.420);
threshold = -70 ;
Pfa = 1 - cdf(Pnotarget,threshold) % prob of false alarm
Pd = 1 - cdf(Ptarget,threshold) % probability of detection

Level=-90:0.1:-50;
figure(1);
plot(Level,Pnotarget.pdf(Level));
hold on
plot(Level,Ptarget.pdf(Level),'m');
title('RTL-SDR detection probability')
hold on
Y = 0:0.1:0.3;
X = threshold * ones(size(Y));
plot(X, Y, 'r--')
legend('no target present', 'target present','threshold')
xlabel ('Level (dB)')

Pfa_ROC = 1 - cdf(Pnotarget,Level); % prob of false alarm
Pd_ROC = 1 - cdf(Ptarget,Level); % prob of detection

figure(2);
plot(Pfa_ROC,Pd_ROC);
title('ROC curves')
ylabel ('Probability of Detection')
xlabel ('Probability of False Alarm')
```