AUTOMATIC DETECTION AND CLASSIFICATION OF RF SIGNALS

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(JUNE , 2023)

CERTIFICATE OF CORRECTNESS AND APPROVAL

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DECLARATION

No part of the effort submitted in this paper has been presented in endorsement of another award or qualification in either this institution or somewhere else.

ACKNOWLEDGEMENTS

الْحَمْدُ للَّهِ رَبِّ الْعَلَمِينَ

We are thankful to Allahﷻ, as He is the one who directed us in completion of this effort at each phase. He is the one who blessed us with this idea and made possible for us to come up with new ideas and process new thoughts to complete this project.

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Devoted to our remarkable parents, much-loved sisters, supportive brothers and encouraging wives whose incredible assistance and support led us to this brilliant accomplishment.

Plagiarism Certificate (Report)

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Abstract

Electronic Warfare is one of the major deciding factors in the success of conventional and unconventional warfare. As RF technology is advancing with a very high pace, the conventional Electronic Warfare equipment are getting obsolete along with. Pakistan Army has indoctrinated a large quantity of Electronic Warfare equipment and still more is required to compete current requirement, owing to high tension scenario at borders and operational areas. This high-cost equipment are prone to frequent upgradation and maintenance as well as being highly resource dependent. Considering above mentioned issues related to the EW equipment that Pak Army is using, they are seldom utilized for difficult terrains and border areas and are to be kept as reserve for conventional warfare. Automatic detection and classification of radio frequency (RF) signals is a critical task in modern communication systems. [1] With the increasing complexity of wireless communication systems and the growing demand for spectrum usage, it has become increasingly important to develop efficient and effective methods for detecting and classifying RF signals. This paper presents a novel approach for automatic detection of RF signals based on GNU radio software. The proposed method uses a combination of feature extraction and classification techniques to identify different types of RF signals. [1]

GNU Radio is an open-source software-defined radio framework that is used to develop signal processing applications. It provides a range of signal processing blocks that can be used to build signal processing pipelines. These blocks are used to perform a variety of signal processing tasks, including filtering, modulation, demodulation, and decoding. To implement automatic detection and classification of RF signals using GNU Radio, one can use the software to build a signal processing pipeline that includes blocks for signal acquisition, feature extraction, and classification. The signal acquisition block can be used to capture RF signals from a radio receiver, while the feature extraction block can be used to extract relevant features from the captured signals. These features can include signal frequencies, bandwidth, modulation type and other relevant parameters.

Key Words: *Electronic Warfare, GNU Radio, RF fingerprinting.*

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CHAPTER 1: INTRODUCTION

The research work in this dissertation has been presented in two main parts. First part is related to the wireless spectrum monitoring and investigation of unknown signal frequencies. The objective of this part is to formulate possible methods for wireless spectrum monitoring and interception of any unencrypted analogue and digitally modulated signal Finally, second part revolves around signal identification of radio sets by various techniques that can be adopted using Universal Software Radio Peripheral (USRP).

1.1 Background, Scope and Motivation

Universal Software Radio Peripheral (USRP) are highly dynamic radio sets that can perform any digital signal processing via computer attached to them with USB or ethernet interface. Since the signal processing is done using a computer software, this gives the fluidity to software defined radios in comparison to traditional hardware radios in which signal processing is usually done using analogue elements and circuitry. A traditional hardware RF device can fulfill a single purpose for which it was manufactured, for example a Wi-Fi modem cannot demodulate FM radio signals and same applies for an FM radio. But a single circuitry of USRP can perform both functions because the signal processing depends only on software and is independent of hardware. Computational power, being cheaper than complex hardware radios provide very cost-effective alternatives to its counterparts[2].

This feature or dynamicity in Software Defined Radios motivated us to research methods that could aid EW particularly detection and classification. As only software is required to change its function, a single SDR and a laptop is enough to provide all functions that were required. Moreover, new methods of encoding and modulating data over wireless signal can be adopted easily by few amendments in software.

The radio selected for this project is USRP and it has ability to transmit as well as receive signals and is full duplex in nature.

1.2 SDR and USRP

Concept of SDR is briefly explained above. In this paragraph I would like to explain conceptual working methodology of SDR, which will further improve overall understanding of this equipment. An ideal SDR converts desired signal into bits of information and feeds it to computer for further processing, the computer is mainly responsible for all digital signal processing. Responsibility of SDR lies with catching, pre-filtering, pre-amplifying, and converting an analogue signal into digital signal and then packing digital signals into predefined bits. After this, it sends these signals to computer via USB interface[2].

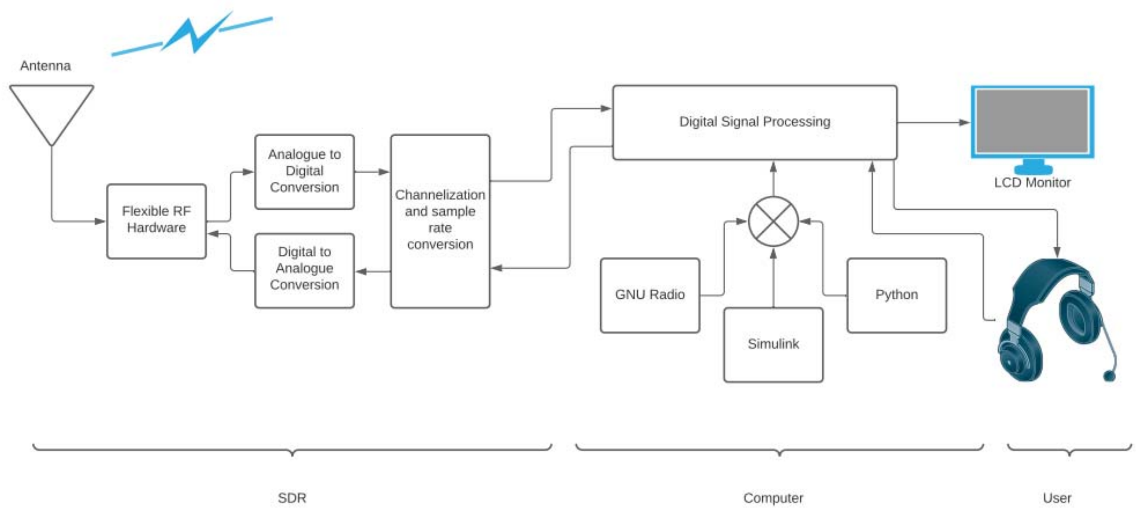


Figure 1.2.1 SDR workflow

The Universal Software Radio Peripheral (USRP) line of software-defined radios was created and is offered by Ettus Research and National Instruments, which is Ettus Research's parent company. The USRP product line was created by a team led by Matt Ettus and is frequently utilized by research facilities, academic institutions, and hobbyists.

Most USRPs include a high-speed link that they use to connect to a host computer, which the host-based software uses to operate the USRP hardware and send/receive data. Some USRP devices combine an embedded CPU with the general features of a host computer to enable stand-alone operation of the USRP device.

Many of the items in the USRP family are open-source hardware, and the family was created with accessibility in mind. All USRP products are controlled by the free and open-source UHD driver, which is available for download and includes the board schematics for a few USRP models. Complex software-defined radio systems are frequently built using USRPs in conjunction with the GNU Radio software library.

Figure 1.2.2 USRP 2

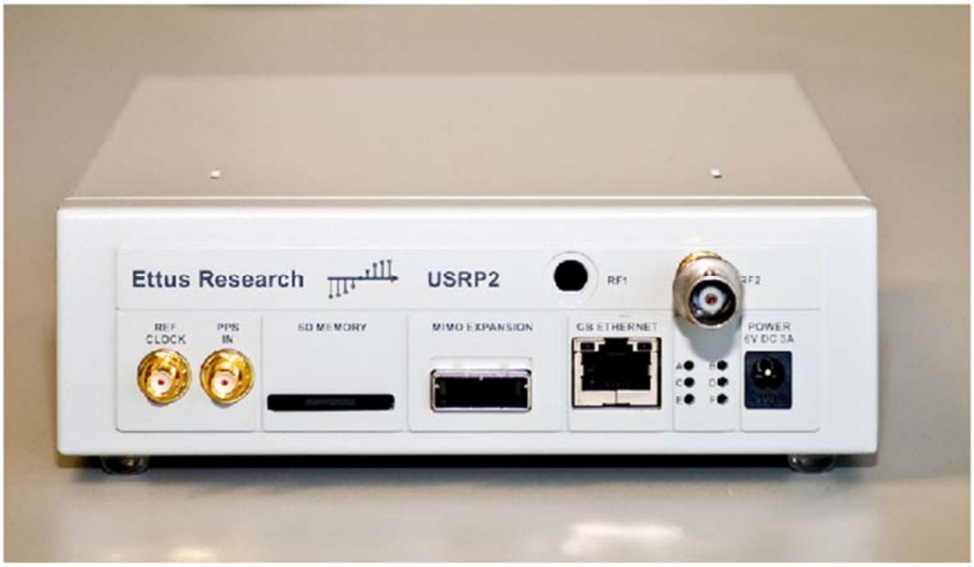


Figure 1.2.3 USRP 2

Following table explains important features of USRP 2

Table 1.1 USRP 2 features

Operating Frequency	400Mhz – 4.4GHz
Mode of Operation	Full Duplex
Frequency Accuracy	2.5 ppm
Frequency step	< 1 khz
Compatibility	GNU Radio, SDR#, GQRX
Gain Range	0-31 dB

1.3 GNU Radio

GNU Radio is a software system that provides graphical interfaced signal processing blocks to implement software defined radios. It is open-source programme that provides python based codes in the form of blocks specifically for signal processing. It works with python as Simulink works with Matlab. It is important to introduce functions of some commonly used blocks to provide better understanding of its ability and its importance in respect to SDR[3].

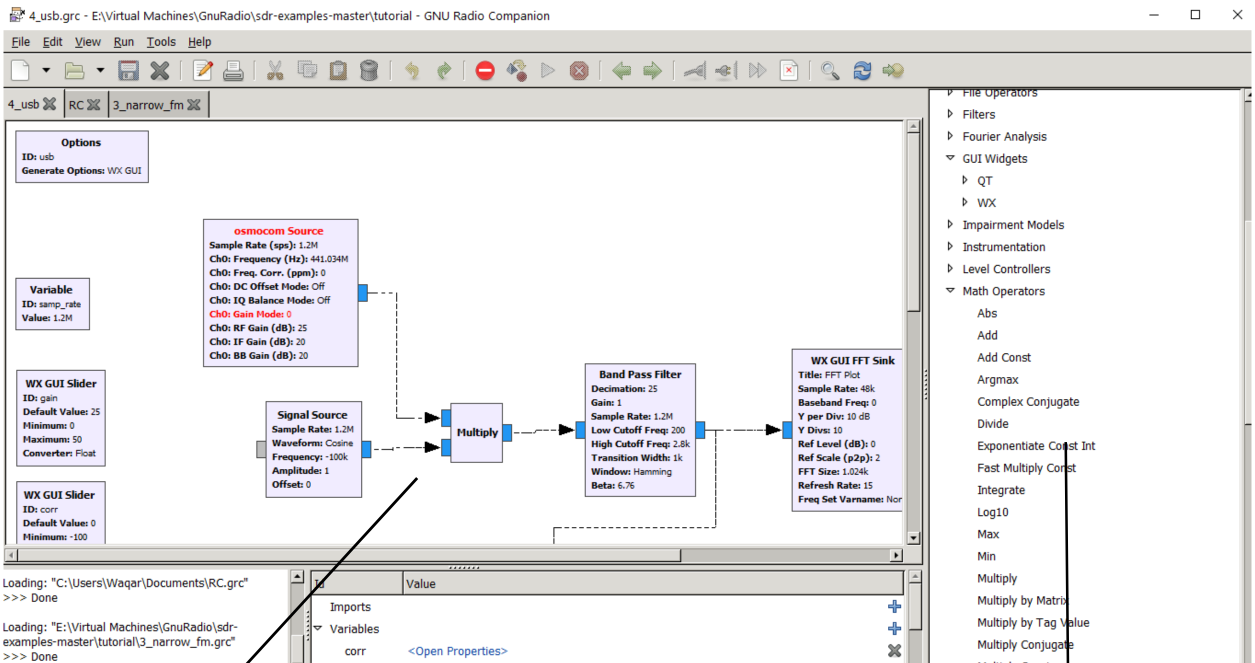
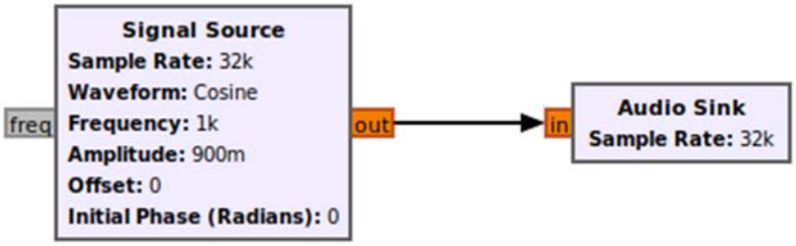


Figure 1.1.3.1 GNU Radio

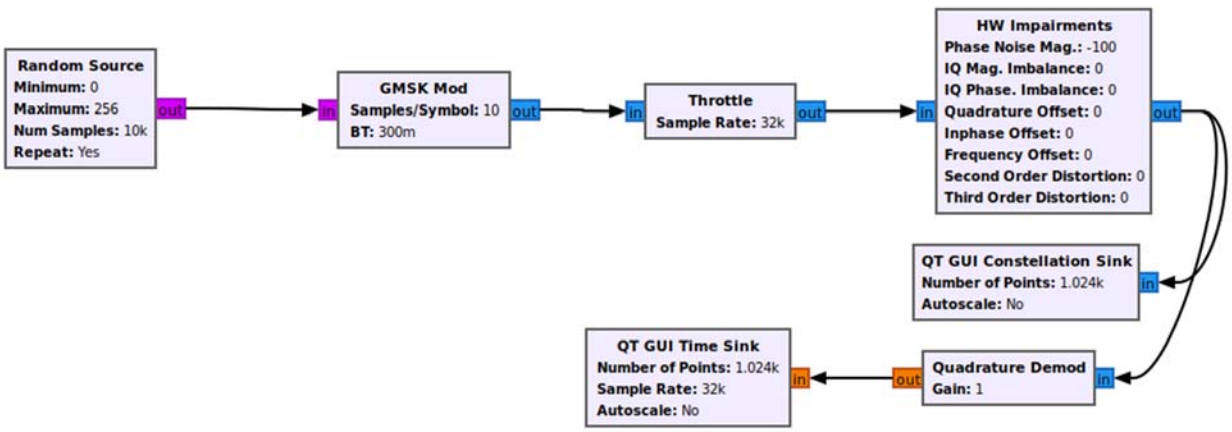
Work Flow

Block Selector

To deal with digital signals, the individual processing stages for example filtering, correction, analysis, detection etcetera as processing blocks, which can be connected using simple flow-indicating arrows:



When building a signal processing application, we must make a complete graph of blocks and is called as flowgraph in GNU Radio.



GNU Radio comes with a large set of existing blocks. An index to all of them can be found in GNU Radio documentation. Few are most used blocks in flowgraphs.

1.3.1 Waveform Generators

1.3.1.1 Constant Source

A constant source of signal (DC)

1.3.1.2 Noise Source

Can produce Active White Gaussian Noise or random noise.

1.3.1.3 Signal Source (e.g. Sine, Square, Saw Tooth)

These generate signals of our choice (cosine, square, Saw Tooth etc.) and desired frequency.

1.3.2 Modulators

1.3.2.1 AM Mod/Demod

This block can perform Amplitude Modulation and demodulation with provided sample rate.

1.3.2.2 Continuous Phase Modulation

This block will take data in complex form and modulate this data with a sine wave of provided frequency and mentioned sample rate

1.3.2.3 PSK Mod / Demodulation

This block will perform phase shift keying modulation and demodulation on provided digital data.

1.3.2.4 GFSK Mod / Demodulation

Gaussian Frequency Shift Keying is a type of Frequency Shift Keying modulation where signal is passed through a gaussian filter to shape the pulses before modulating which greatly reduces spectral bandwidth and out-of-band spectrum. This is helpful when adjacent channel has high power and there is a chance of interference between channels. This block modulates data into GFSK and demodulates GFSK signal into data.

1.3.2.5 GMSK Mod / Demodulation

Gaussian Mean Shift Keying Modulation/ Demodulation.

1.3.2.6 QAM Mod / Demodulation

Quadrature Amplitude Modulation/ Demodulation.

1.3.2.7 WBFM Receive

Wide Band Frequency Modulation / Demodulation.

1.3.2.8 NBFM Receive

Narrow Band Frequency Modulation / Demodulation.

1.3.3 Instrumentation (i.e., GUIs)

Instrumentation are very useful blocks for analyzing received or transmitted signals visually.

1.3.3.1 Constellation Sink

This visualizes constellation of a modulated signals; it shows amplitude and phase of a digital modulation.

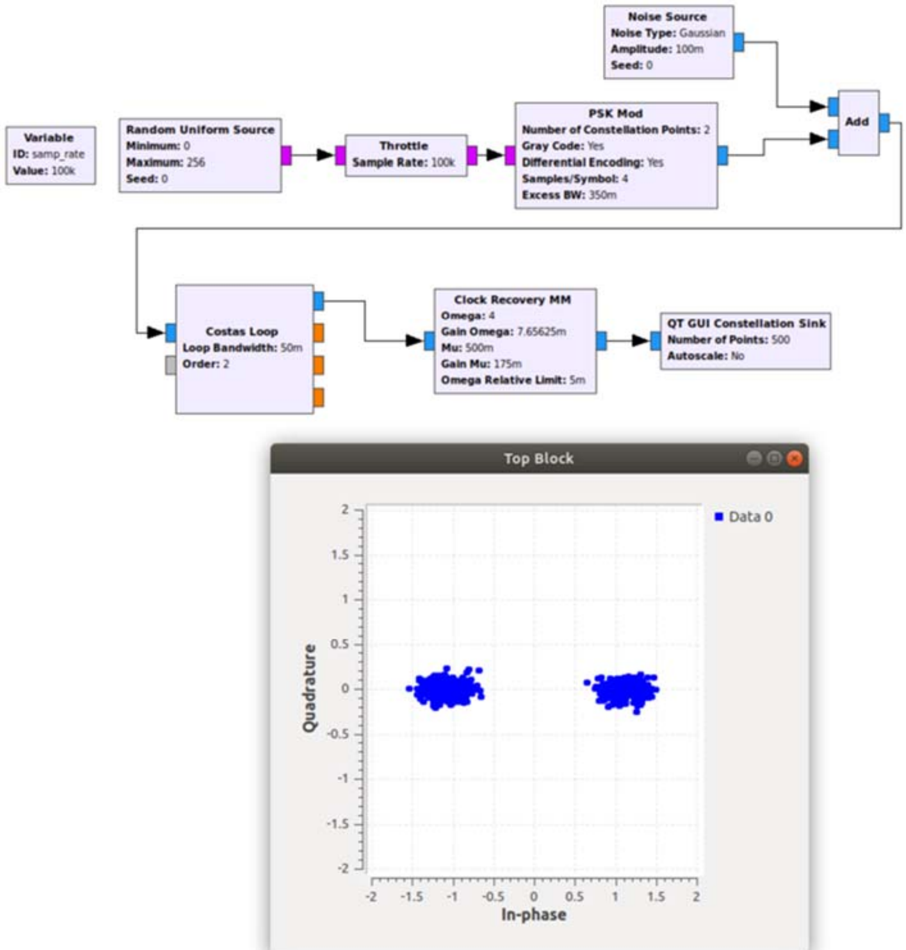


Figure 1.1.3.2 Example of constellation sink

1.3.3.2 Frequency Sink

This is a graphical sink which displays signals of interest frequency domain. It is a graphical version of FFT.

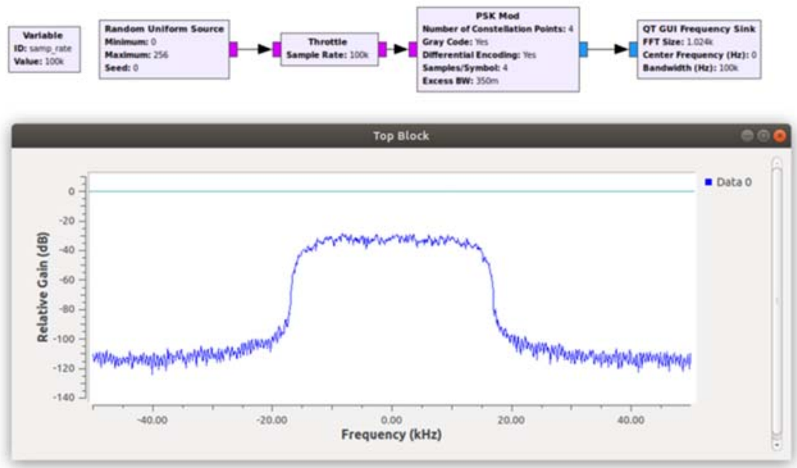


Figure 1.1.3.3 Example of frequency sink

1.3.3.3 Time Sink

It is a graphical interface which displays signal of interest in time domain.

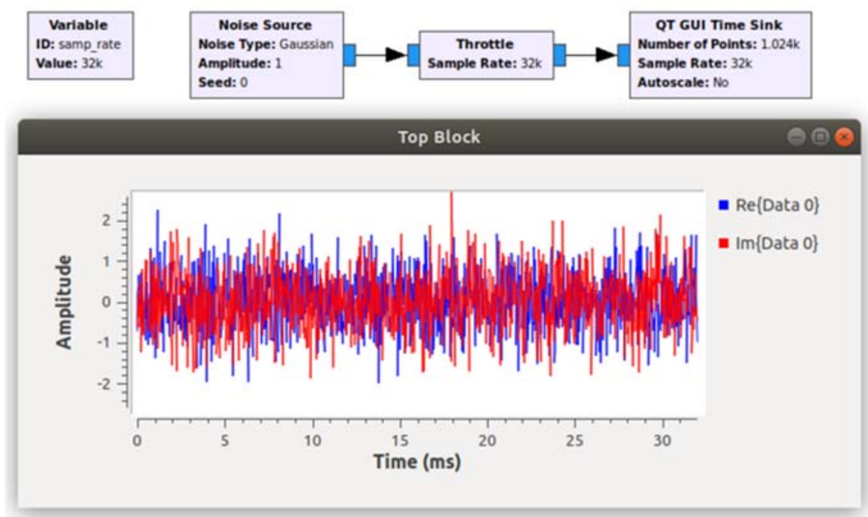


Figure 1.3.4 Example of time sink

1.3.3.4 Waterfall Sink

This shows spectral density of signals in the form of color map, we have extensively utilized this feature in our project.

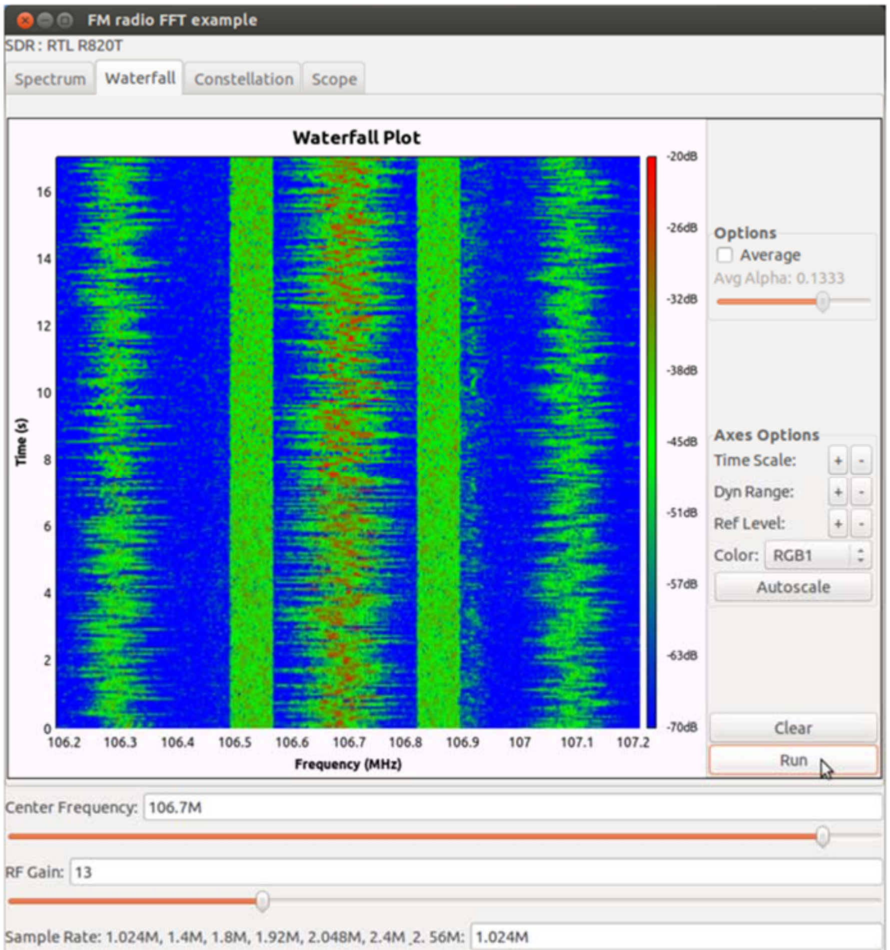


Figure 1.1.3.5 Example of waterfall plot

1.3.4 Math Operators

These do basic math operations on the signals. They are self-explanatory.

- **Abs**
- **Add**
- **Complex Conjugate**
- **Divide**
- **Integrate**
- **Log10**
- **Multiply**
- **RMS**

- **Subtract**

1.3.5 Filters

Filters are basic components of DSP, and their use is almost compulsory in every signal flowgraph. Few filter blocks provided by GNU Radio are.

- Band Pass / Reject Filter
- Low / High Pass Filter
- IIR Filter
- Generic Filter bank
- Hilbert

Tasks as signal normalization, sync and visualization can be done by making a suitable signal processing flow graph. Just by connecting appropriate block one after other a complete system is made. There is also option of writing own block in python if some logic is not already present is available blocks.

It is important to consider GNU Radio is primarily a structure for the development of signal processing blocks and their interaction. It has inbuilt extensive library of blocks. But it should be borne in mind that GNU Radio itself is not a software that is ready to do something specific. it is the operator's task to make something useful out of it.

1.4 Workflow of project

Having given brief explanation of basic elements composing our project, it is now pertinent to explain working methodology of our project before diving in detailed explanation of each part.

As explained earlier, in aid of already present equipment relate to EW with Pakistan Army, we have made a small detachment that can monitor, intercept, detect and classify wireless spectrum and device. For this we assumed that our detachment will be based on one USRP, Laptop and an operator. For all the tasks mentioned above, we made an appropriate sequence, following that, will make all tasks easily possible to accomplish.

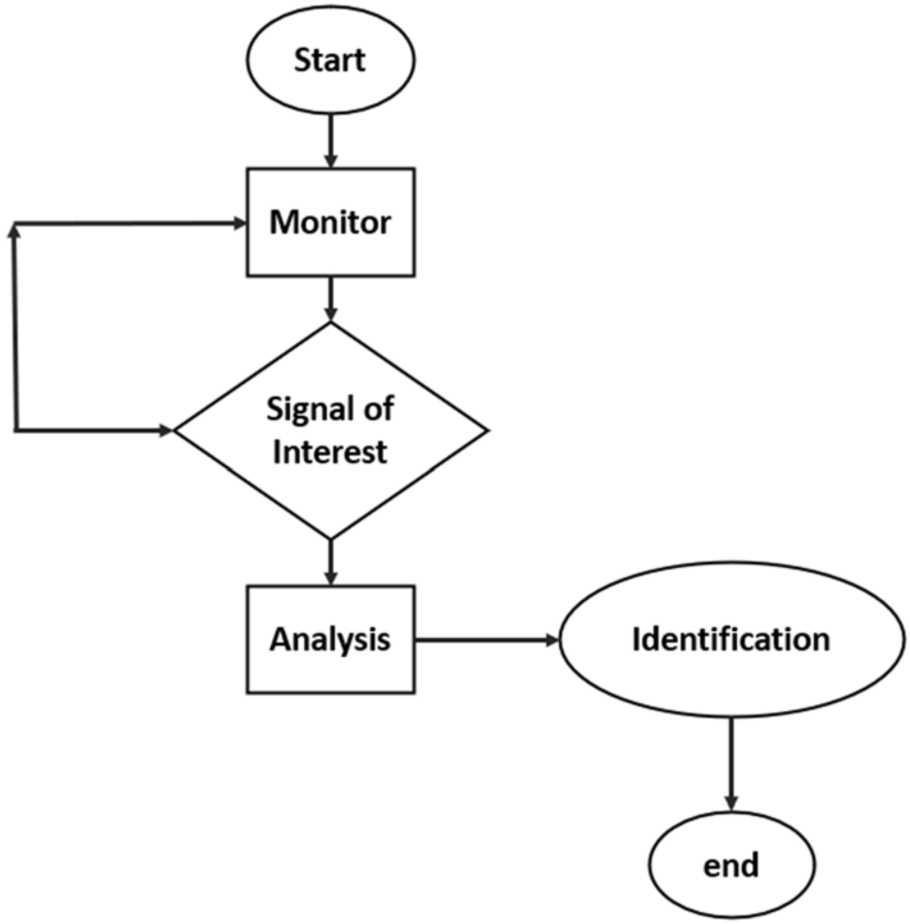


Figure 11.4.1 Workflow of project

First the operator will continuously monitor for any new unknown signal being transmitted in area of operation, based on signal characteristics it will be decided by operator that either this is signal of interest or not. If it is signal of interest, operator will try its interception provided the signal is transmitted in plaintext. If signal is encrypted, then it will be saved in database and will be analyzed further in detail. We will explain all steps with detail in coming parts.

CHAPTER 2 : LITERATURE REVIEW

2.1 Overview of RF Signal: Radio frequency (RF) is a unit of measurement used to describe how quickly electromagnetic radio waves oscillate between frequencies as high as 300 gigahertz (GHz) and as low as 9 kilohertz (kHz). An RF field can be used for many forms of wireless broadcasting and communications with the use of antennas and transmitters. [4]

The utilization of RF fields is widespread among wireless devices. The RF spectrum is used by a variety of devices, including cordless and smartphones, radio and television broadcasting stations, Wi-Fi and Bluetooth, satellite communications systems, and two-way radios. In addition, radio frequencies are used by devices other than communication devices, such as microwave ovens and garage door openers. Some wireless devices use infrared (IR) frequencies, which have shorter electromagnetic wavelengths, such as TV remote controls, computer keyboards, and computer mouse.

2.2 Traditional App approaches to RF signal detection and classification: Traditional approaches to RF signal detection and classification have been widely used before the emergence of AI and ML techniques. These methods primarily rely on signal processing algorithms and expert knowledge in signal interpretation. Here are some commonly employed traditional approaches:

Matched Filtering: Matched filtering is a widely used technique for detecting signals in the presence of noise. It involves correlating the received signal with a template signal, known as the matched filter. If the received signal matches the template, a high correlation value indicates the presence of the desired signal. Matched filtering is effective for detecting signals with known waveforms, such as continuous wave (CW) signals.

Power Spectral Density Estimation: Power spectral density (PSD) estimation is a technique used to analyze the frequency content of a signal. It calculates the power distribution across different frequency components in the signal. By estimating the PSD of an RF signal, it becomes possible to identify the presence of specific frequency components, which can aid in signal detection and classification.

Correlation Techniques: Correlation techniques involve comparing the received signal with known signal patterns or templates. Cross-correlation and autocorrelation are commonly used methods. Cross-correlation compares the received signal with a reference signal, while autocorrelation measures the similarity of a signal with a delayed version of itself. By performing correlation analysis, it becomes possible to detect signals based on their similarity to known patterns.

Statistical Methods: Statistical methods, such as hypothesis testing and statistical pattern recognition, have been used for RF signal detection and classification. These approaches involve defining statistical models for different types of signals and comparing statistical analysis of the received signal characteristics to models. If received signal's statistical properties match a specific model, it can be classified accordingly.

Although traditional approaches have been successful in certain applications, they have limitations. They often require prior knowledge of signal characteristics and are less adaptive to complex and dynamic signal environments. Additionally, these methods may struggle with distinguishing between similar signals or detecting unknown or novel signals.

By examining the existing literature, this chapter provides a comprehensive overview of the historical context, conventional methods, and recent advancements in RF signal analysis. It establishes a foundation for the subsequent chapters, focusing on the development and evaluation of an automated system for RF signal detection and classification.

2.3 Refrances

1. Shupeng Zhangy, Yibin Zhangy, Xixi Zhangy, Jinlong Suny, Yun LinHaris Gacaninz,Fumiyuki Adachiyy, and Guan Guiy A Real-World Radio Frequency Signal Dataset Based on LTE System and Variable Channels

This paper utilizes software radio peripheral as a dataset generating platform. Therefore, the user can customize the parameters of the dataset, such as frequencyband, modulation mode, antenna the proposed dataset is generated through various and complex channel environments, which aims to better characterize the radio frequency signals in the real world. We collect the dataset at transmitters and receivers to simulate a real-world RFF dataset based on the long-term evolution (LTE)

2. Chen, Y., Lin, J., & Liang, Y. (2016). A review of automatic modulation classification techniques: classical approaches and new trends. IEEE Access, 4, 3589-3602.

This paper provides a comprehensive review of automatic modulation classification (AMC) techniques, which is a crucial step in RF signal classification. It discusses traditional approaches based on statistical features, as well as more recent methods utilizing machine learning and deep learning algorithms. The paper compares the performance of various techniques and provides insights into their strengths and limitations.

3. Farquharson, M. J., & Stirling, D. (2016). A survey of automatic modulation classification techniques: classical approaches and emerging trends. IET Communications, 10(17), 2272-2283.

This survey paper provides a comprehensive analysis of classical and emerging automatic modulation classification techniques. It covers statistical, feature-based, and machine learning approaches. The authors discuss the challenges associated with various modulation schemes and highlight recent trends in modulation classification research.

CHAPTER 3: SIGNAL DETECTION AND PROCESSING

3.1 Signal processing in GNU Radio

GNU Radio is a software-defined radio (SDR) platform that provides a wide range of signal processing blocks for developing radio communication systems. Signal processing in GNU Radio involves the manipulation of digital signals to achieve specific objectives, such as filtering, modulation, demodulation, and decoding.

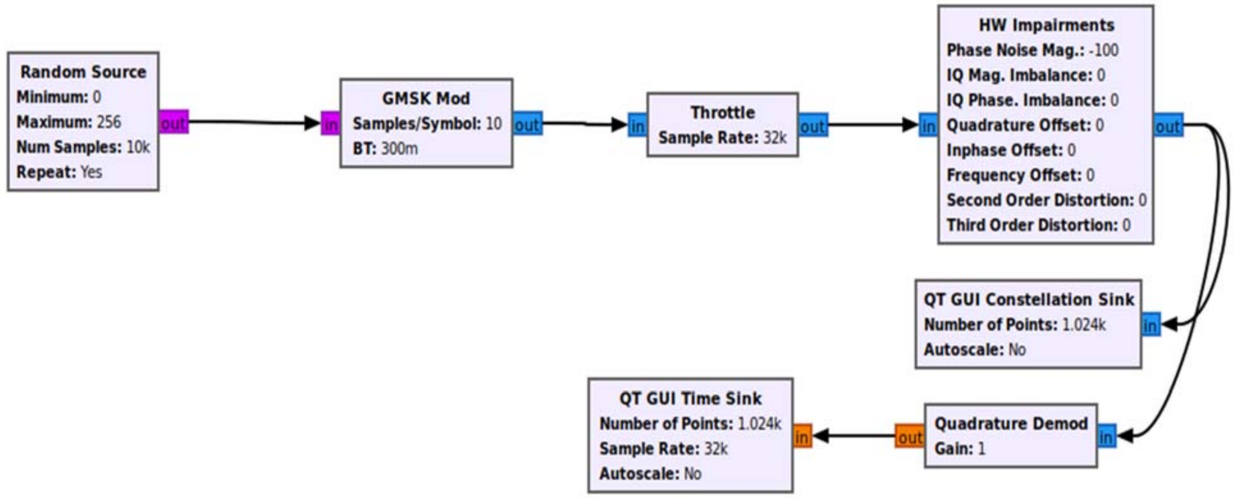
The basic building block of GNU Radio is the signal processing block. There are several types of blocks available in GNU Radio, including source blocks, sink blocks, and processing blocks. Source blocks generate signals, sink blocks consume signals, and processing blocks manipulate signals in various ways.

Filtering is an important signal processing technique used in GNU Radio. It is used to remove unwanted noise and interference from a signal. GNU Radio provides several filter blocks, including low-pass filters, high-pass filters, and band-pass filters.

Modulation and demodulation are other important signal processing techniques used in GNU Radio. Modulation involves the conversion of a baseband signal into a higher frequency signal that can be transmitted over the airwaves. Demodulation is the process of converting a modulated signal back to its original baseband signal. GNU Radio provides several modulation and demodulation blocks, including amplitude modulation (AM), frequency modulation (FM), and quadrature amplitude modulation (QAM).

In addition to these basic signal processing techniques, GNU Radio provides a range of other signal processing blocks for more advanced applications, including signal decoding, error correction, and synchronization.

Overall, signal processing in GNU Radio is a flexible and powerful tool for developing radio communication systems. It allows users to manipulate and process signals in a variety of ways, enabling them to achieve specific objectives and develop customized solutions for their applications.



3.1.1 Signal processing in GNU Radio

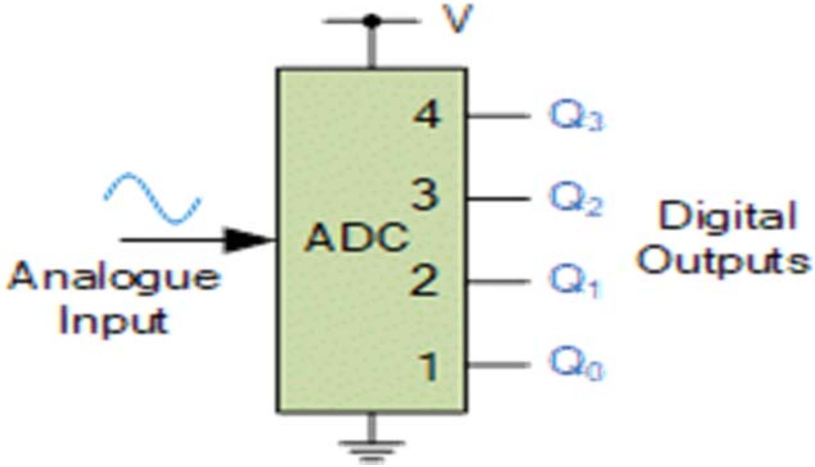
3.2 Analog to Digital Conversion through USRP Hardware

When a Universal Software Radio Peripheral (USRP) is connected to GNU Radio, the analog-to-digital conversion is performed by the USRP hardware. The USRP is a hardware platform that is used to implement SDRs, and it contains one or more analog-to-digital converters (ADCs) that convert analog signals into digital signals.

In GNU Radio, the USRP is typically controlled using the "UHD" (USRP Hardware Driver) module, which provides an interface between GNU Radio and the USRP hardware. The UHD module allows GNU Radio to set the sampling rate, center frequency, and other parameters of the USRP, as well as receive data from the USRP.

When data is received from the USRP, it is in the form of digital samples, which can be processed by GNU Radio using various signal processing blocks. These blocks can be used to filter, modulate, demodulate, and otherwise manipulate the digital signal.

In summary, the analog-to-digital conversion is performed by the USRP hardware, and the resulting digital samples are then processed by GNU Radio using signal processing blocks.



3.2.1 Analog to digital converrsion

3.3 Signal Processing Blocks

GNU Radio is an open-source software that provides a wide range of signal processing blocks to enable the design and implementation of various digital signal processing (DSP) algorithms. These signal processing blocks are used to perform various signal processing tasks such as filtering, modulation/demodulation, encoding/decoding, and so on. Here are some commonly used signal processing blocks in GNU Radio:

Signal Source Blocks: Signal Source blocks are used to generate input signals for the flowgraph. Examples of signal sources include Constant, Noise, Random Source, and Signal Generator.

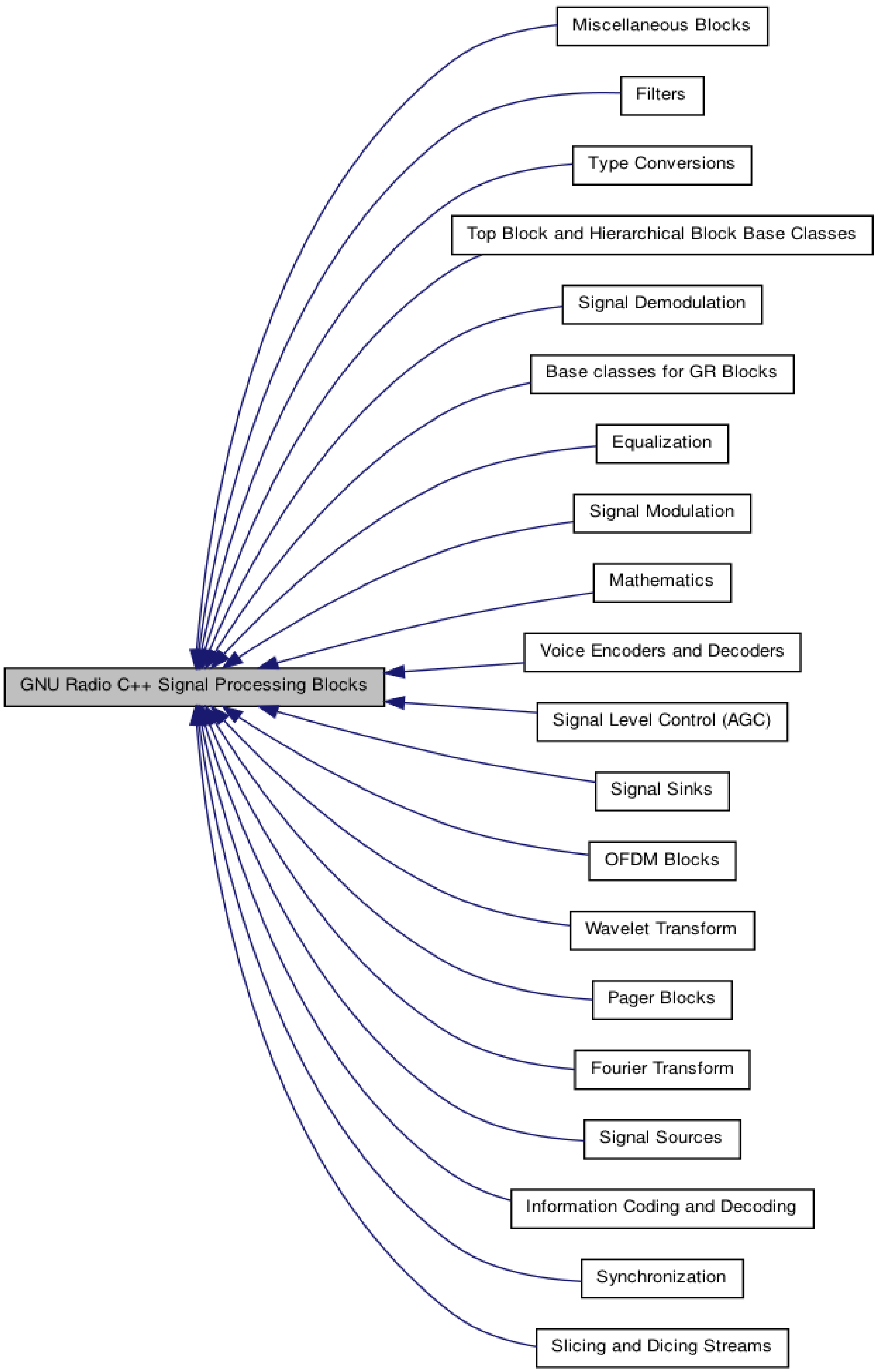
Filter Blocks: Filter blocks are used to filter input signals to remove unwanted noise or interference. Examples of filter blocks include Low Pass Filter, High Pass Filter, Band Pass Filter, and Band Stop Filter.

Modulation Blocks: Modulation blocks are used to modulate input signals to carry information over a carrier frequency. Examples of modulation blocks include Amplitude Modulation (AM), Frequency Modulation (FM), Phase Modulation (PM), and Quadrature Amplitude Modulation (QAM).

Demodulation Blocks: Demodulation blocks are used to recover the modulated signal from the carrier signal. Examples of demodulation blocks include Envelope Detector, Frequency Discriminator, and Phase Locked Loop (PLL).

Decoding Blocks: Decoding blocks are used to decode the encoded signal. Examples of decoding blocks include Convolutional Decoder, Reed-Solomon Decoder, and Turbo Decoder.

Sinks Blocks: Sink blocks are used to display, store or save the output signal from the flowgraph. Examples of sink blocks include File Sink, GUI Sink, Null Sink, and WX GUI Sink.



3.3.1 Signal Processing Blocks

3.4 Identification of signal of interest

Identification, as explained earlier will come from experience and time. When an operator will be sure about occupation of spectrum by friendly forces, any new suspicious signal will be regarded as signal of interest. This means all the subsequent work as explained in workflow diagram (Figure 1.8) will be applied to any suspicious signal that was not already occupied by friendly forces. Type of modulation and encoding can be identified by careful observation of time spectrum and power spectrum density of signal. For example, in amplitude modulation, frequency is same whereas power changes as per data. So, its power spectral density will be same across frequency by will fade completely when data is 0 and appear completely when data is 1. [6]

Figure 3.4.1 Amplitude modulation PSD

Chapter 4: SIGNAL IDENTIFICATION AND CLASSIFICATION

The last part of the project comprises the most important part of our project. Fingerprinting signals is a process to distinguish two or more radios or any wireless device, based on signal characteristics i.e., frequency, bandwidth, burst period, hop count etc. Basic programming on GNU radio software has been done to identify the received signals. First it is performed using one signal generator and then using multiple signal generators.

Currently, Pakistan Army lacks this technology and we proudly state that our efforts has contributed a huge step towards this technology.

4.1 Parameters I

Signal identification can be done through multiple parameters i.e., frequency sink, time sink and waterfall etc. Determine the frequency range of the signal you want to identify. Set up a receiver in GNU Radio using a compatible SDR device or radio. Configure the receiver's center frequency, sampling rate, and other parameters according to the signal's characteristics.
Use a demodulation block in GNU Radio to demodulate the signal if it is a modulated signal.

Analyze the signal's properties using GNU Radio's built-in signal analysis tools or by exporting the signal data to an external analysis tool.

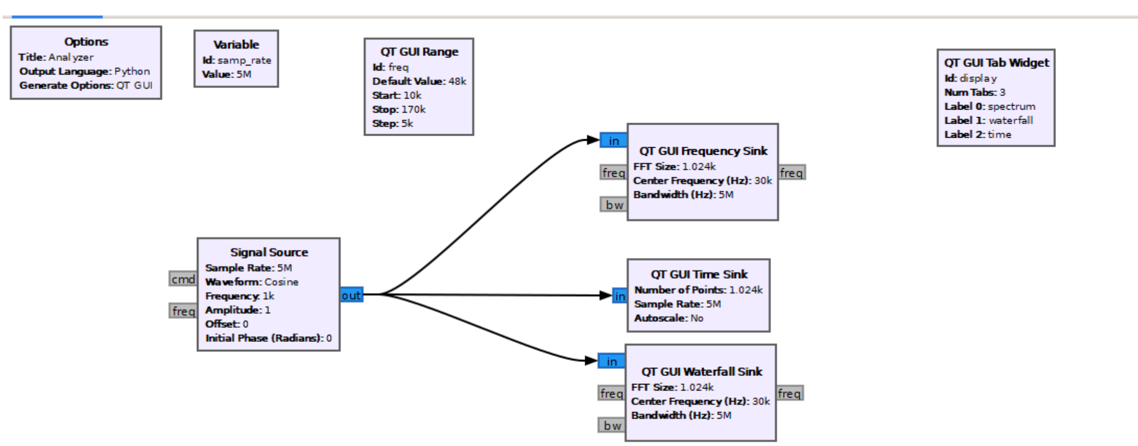


Figure 4.1.1 Simplified classification of wireless devices.

4.1.1 Intended transmission characteristics.

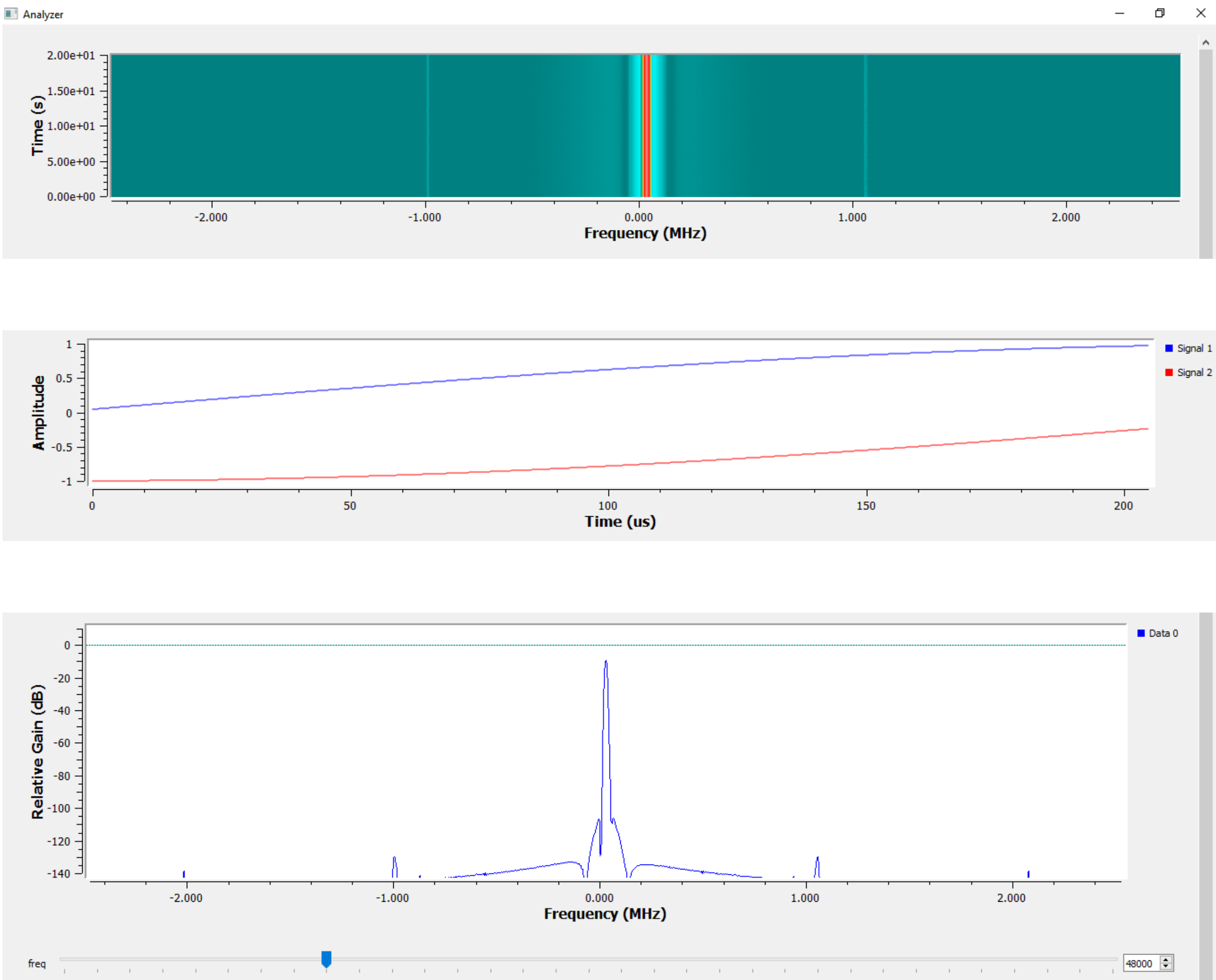


Figure 0.1 Intended transmission characteristics.

4.1.2 Test conditions

We created a single signal generator in GNU radio and extracted different characteristics of the received signal through frequency sink, time sink and waterfall sink. The results obtained are shown in figure 3.1.2.

4.1.3 Results

Once their signal was recorded, we were able to easily distinguish between their transient response. As you can see in Figure 3.1.1 the signal of signal generator is characterized through frequency sink, time sink and waterfall sink. The waterfall sink graph shows the signal intensity being received. When we apply more than one signal generator, a denser waterfall graph will be shown. Time sink graph shows the results in relation to time and amplitude. The Frequency sink graph shows the results in relation to frequency and gain of the signal.

4.2 Parameters II

Now we will take two signal generators and distinguish the signal according to its characteristics using the same sink graphs.

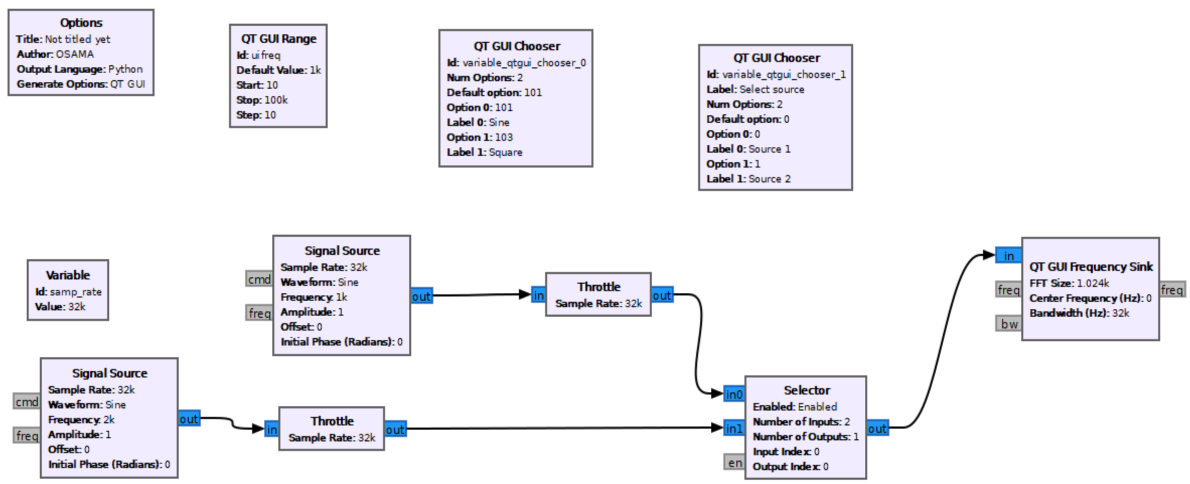


Figure 4.2.1 Unintended transmission irregularities in LMR

4.1.1 Test conditions

We created two-signal generators in GNU radio and extracted different characteristics of the received signal through frequency sink, time sink and waterfall sink. The results obtained are shown in figure 3.2.2.

4.1.2 Results

Once their signal was recorded, we were able to easily distinguish between their transient response. As you can see in Figure 3.2.2 the signal of signal generator is characterized through frequency sink graph. The Frequency sink graph shows the results in relation to frequency and gain of the signal. The results graph shows the frequencies of both the signals in sine wave form as well as square wave form.

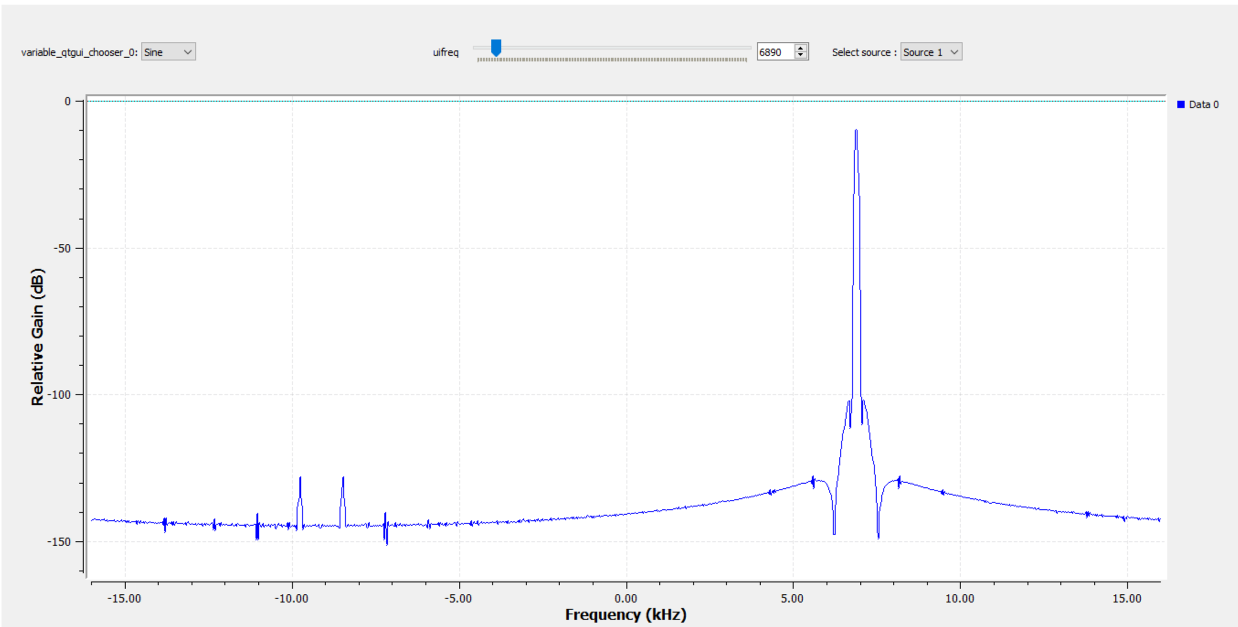


Figure 4.2.2

Figure 4.2.2 shows the sine graph of source 1 which is the first signal generator.

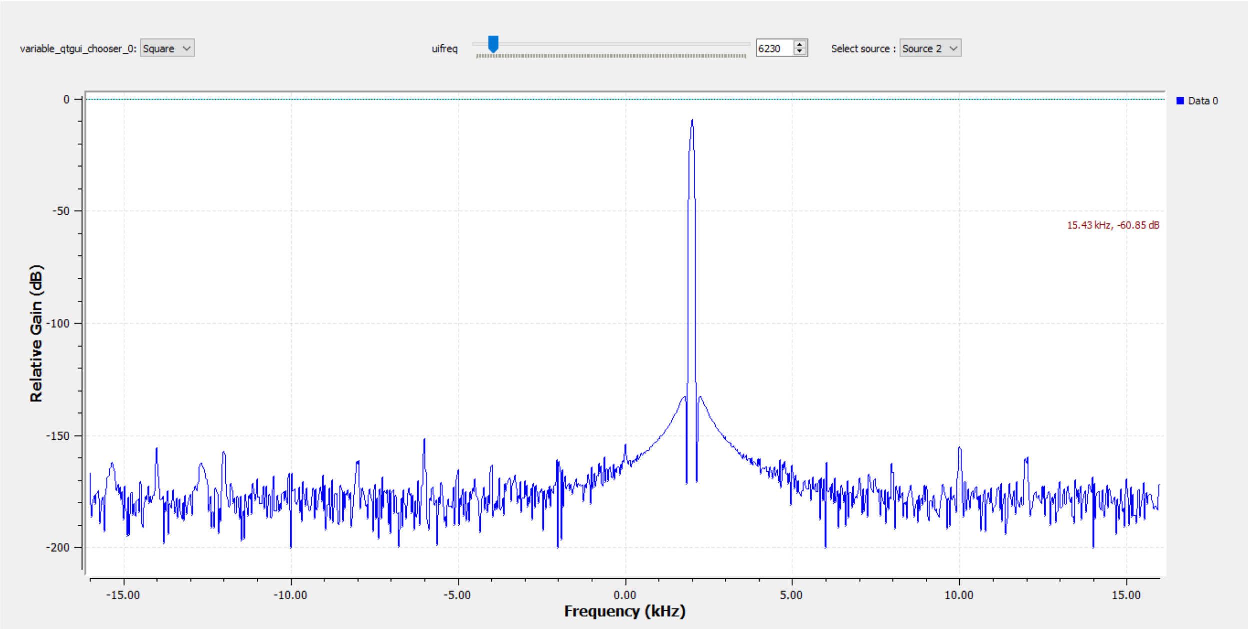


Figure 3.2.3 shows the sine graph of source 2 which is the second signal generator.

4.3 Parameters III

In next phase we used three signal i.e Bluetooth(2.4-2.8 GHz) ,WIFI(2.4 GHz) and GSM Cellular band(900 – 1800 MHz). USRP detect the signals and feed to the GNU radio software. The output of UHD:USRP Source is input to QT GUI Waterfall graph & QT GUI Frequency graph as displayed in diagram 3.1.2.1. Flowgraph of the GNU radio is designed suth that it uses the center frequency to get the maximum signal strength. The output is shown in figure 3.1.2.2. The waterfall graph of the intended signals matched with SIDIGWIKI Figure 3.1.2.3 This wiki's goal is to aid in radio signal identification using example sounds and waterfall pictures.

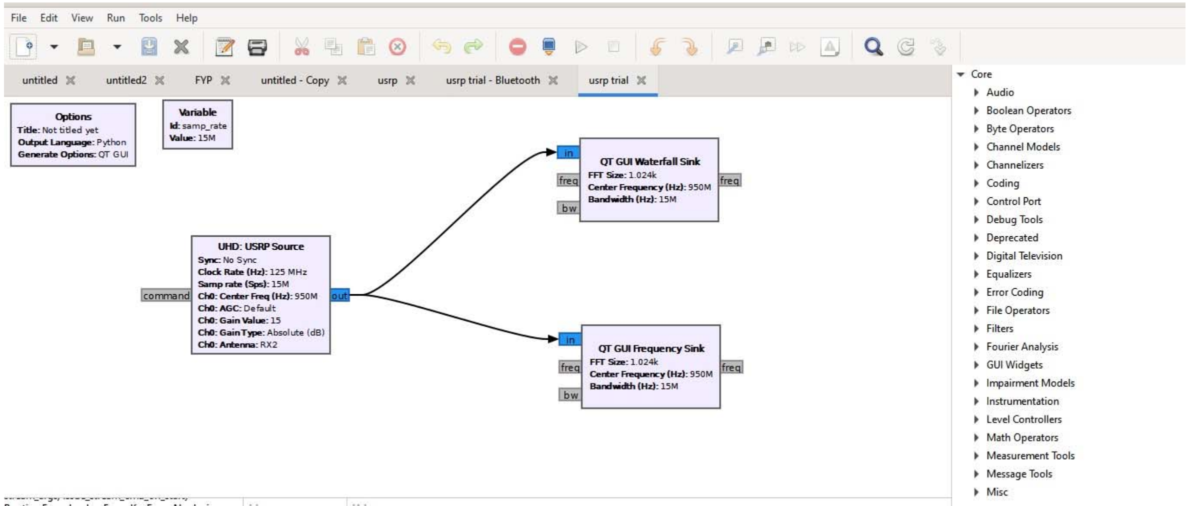


Figure 4.3.1

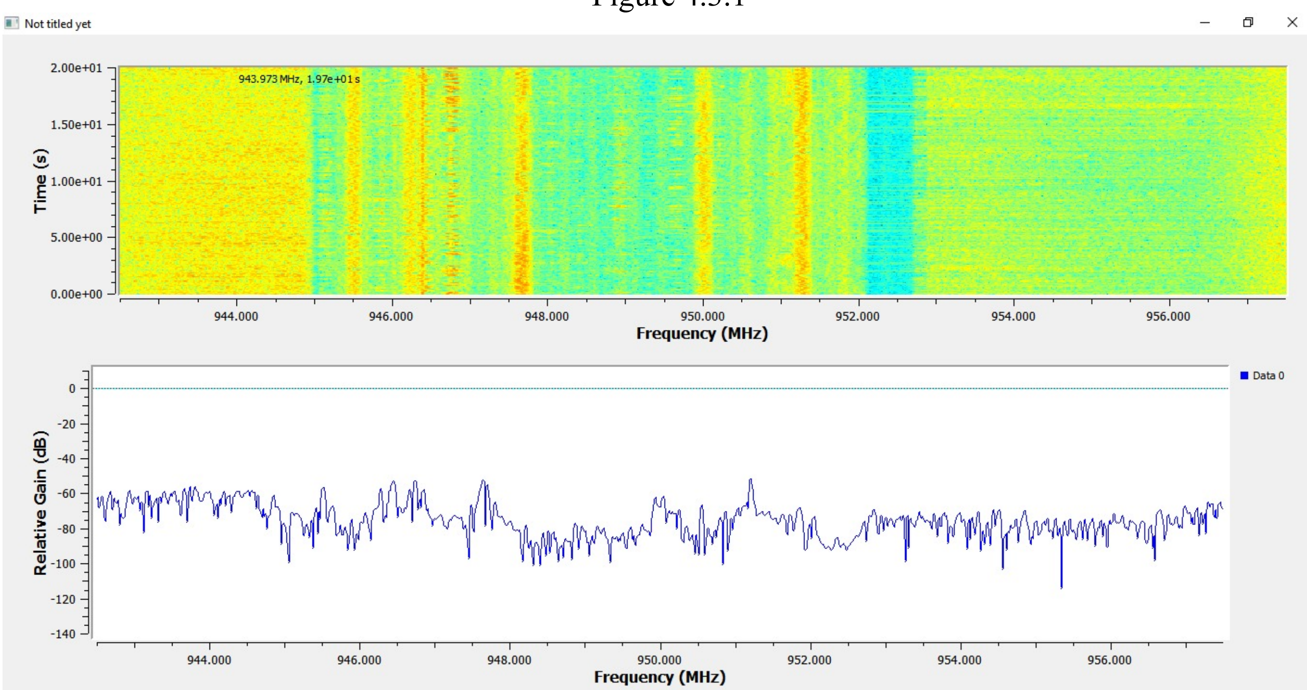
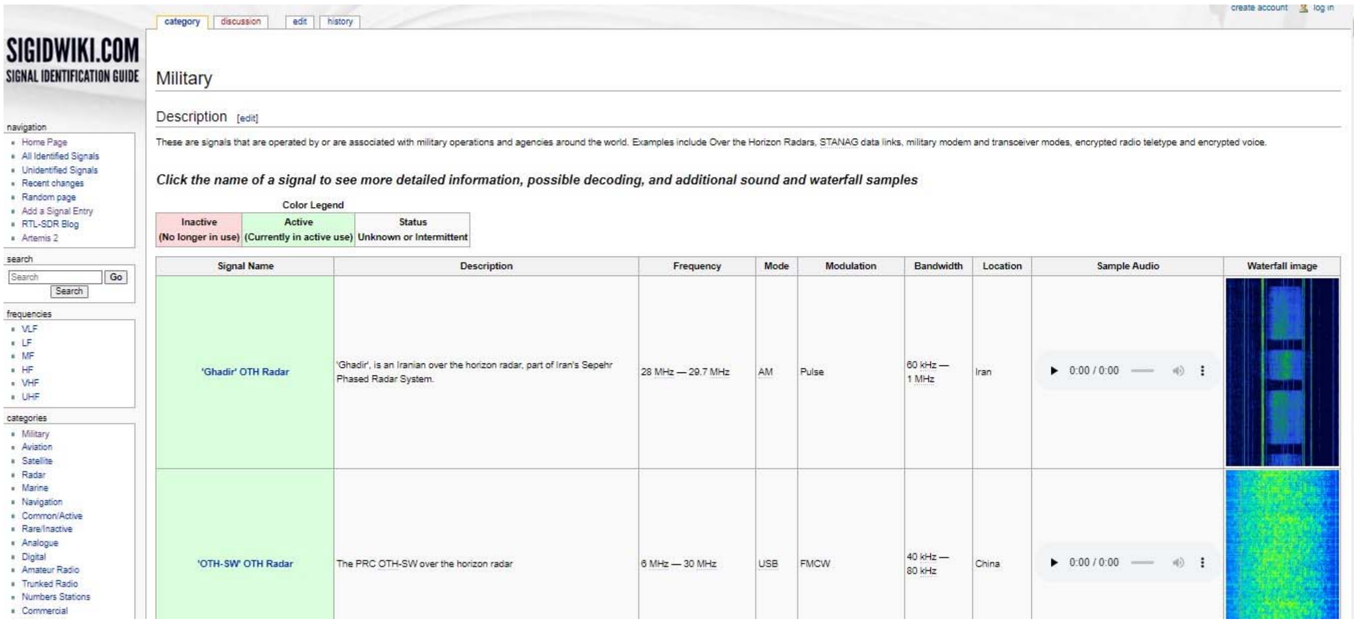


Figure 4.3.2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SIGNAL IDENTIFICATION GUIDE
Military
Description [edit]
These are signals that are operated by or are associated with military operations and agencies around the world. Examples include Over the Horizon Radars, STANAG data links, military modem and transceiver modes, encrypted radio teletype and encrypted voice.
Click the name of a signal to see more detailed information, possible decoding, and additional sound and waterfall samples
Color Legend
Inactive (No longer in use)
Active (Currently in active use)
Status Unknown or Intermittent
navigation
Home Page
All Identified Signals
Unidentified Signals
Recent changes
Random page
Add a Signal Entry
RTL-SDR Blog
Artemis 2
search
Go
Search
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VLF
LF
MF
HF
VHF
UHF
categories
Military
Aviation
Satellite
Radar
Marine
Navigation
Common/Active
Rare/Inactive
Analogue
Digital
Amateur Radio
Trunked Radio
Numbers Stations
Commercial
Signal Name
Description
Frequency
Mode
Modulation
Bandwidth
Location
Sample Audio
Waterfall image
'Ghadir' OTH Radar
'Ghadir', is an Iranian over the horizon radar, part of Iran's Sepehr Phased Radar System.
28 MHz — 29.7 MHz
AM
Pulse
60 kHz — 1 MHz
Iran
0:00 / 0:00
'OTH-SW' OTH Radar
The PRC OTH-SW over the horizon radar
6 MHz — 30 MHz
USB
FMCW
40 kHz — 80 kHz
China
0:00 / 0:00

Figure 4.3.3

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