LOW-COST DEVELOPMENT FULL DUPLEX COMMUNICATION SYSTEM USING ADALM-PLUTO SDRs

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In the name of ALLAH, the Most benevolent, the Most Courteous

CERTIFICATE OF CORRECTNESS AND APPROVAL

This is to officially state that the thesis work contained in this report

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under my supervision and that in my judgement, it is fully ample, in scope and excellence, for the degree of Bachelor of Electrical Engineering in Military College of Signals, National University of Sciences and Technology (NUST), Islamabad.

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DECLARATION OF ORIGINALITY

We hereby declare that no portion of work presented in this thesis has been submitted in support of another award or qualification in either this institute or anywhere else.

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without their guidance the project would be incomplete.

The group members, who through all adversities worked steadfastly.

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ABSTRACT

Price cuts and expanded chances for student-owned equipment are already having an influence on the open lab paradigm and changing the curriculum of analogue and digital communications courses in electrical engineering at a range of schools. Student-owned portable equipment, for example, provides for more hands-on learning and allows the lab to be flipped to promote student involvement. This method had little influence on analogue and digital communications until recently since the most competent equipment, such as the ubiquitous RTL Software Defined Radio (RTL SDR), was prohibitively costly or inexpensive. The ADALM-PLUTO SDR dongle lacks the capabilities required to build and implement a full-duplex communication system. The analogue Active Learning Module-Pluto Software Defined Radio (or PlutoSDR) equipment, which is currently available for $250 (academic price), looks capable of bridging the gap between these two extremes, both of which are full-fledged transceivers. This section examines the benefits and drawbacks of using PlutoSDR into classroom and open lab situations. To begin, we'll examine PlutoSDR's hardware capabilities, restrictions, and installation requirements. Then, using PlutoSDR, GNU Radio, and MATLAB/Simulink, we'll walk through a communication lab example.

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Chapter 1: INTRODUCTION, MOTIVATION AND LECTURES

1.1 Background

Software Defined Radios technology is not new. It has already been used for years. The major benefit of SDRs was its compatibility with software is very much flexible and easy as compared to conventional radio in developing the technical components and installing on hardware. The only step back was all existing radios were half duplex and coup up with very limited software's which restricts its accessibility to learning and practical handling. ADLAM PLUTO SDR was developed to overcome these two major setbacks in very low price as compared to cost effect of previous SDRs.

The PlutoSDR Module is a tool that links the theoretical and real-world radio frequency operations of the user. When used in combination with a host, it provides a personal portable lab that may augment classroom education and practical application. For example, MATLAB and Simulink each have their own graphical user interface (GUI), allowing for easy use and reducing the learning curve, helping students to learn faster, work smarter, and explore more.

Keeping in view, the above discussion ADLAM PLUTO genuinely fulfill the requirements of a well-developed SDR in very low price making it more accessible and user friendly for students in understanding the working and developing further in engineering field at university level where price has always been a major concern for engineering institutions in developing countries like Pakistan.

1.2 Introduction of ADLAM PLUTO SDR

The Analogue Devices Active Learning Module-Pluto Software Defined Radio, often known as PlutoSDR, is built on the AD9363 RF agile transceiver technology. Analogue Devices' (a big semiconductor manufacturer) newest SDR, the Pluto SDR (aka ADALM-PLUTO), can broadcast and receive data. PlutoSDR works on OS X, Windows, and Linux and is powered by Libiio drivers, allowing students to experiment with a wide range of devices. With the capacity to increase the frequency range and bandwidth, this device provides up to 20 MHz of variable channel bandwidth between 325 MHz and 3.8 GHz. In full duplex mode, it can broadcast or receive 61.44 MSPS using independent receive and transmit channels.

The ease of usage the ADALM-PLUTO active learning module (PlutoSDR) helps electrical engineering students grasp the fundamentals of software-defined radio (SDR), radio frequency (RF), and wireless communications. In full duplex mode, the PlutoSDR has distinct reception and broadcast channels. This radio is available in a pocket-sized version. The kit includes two tiny 4cm whip antennas, a short 15cm SMA wire, and a USB cable. The Pluto SDR is packaged in a blue plastic box measuring 11.7 x 7.9 x 2.4 cm and weighing 114 g. SMA connections are offered in two types: RX and TX. There are two LEDs, a USB port, and a power-only USB port on the opposite end.

Figure 1: ADALM-PLUTO SDR (Analog Device)

(https://www.analog.com/en/design-center/adalm-pluto.html, n.d.)

PlutoSDR integrates with the MATLAB and Simulink software packages and features a simple graphical user interface (GUI) to help students learn quicker and work smarter.

1.3 ADALM-PLUTO SDR Setup and instructions

PlutoSDR requires the most recent drivers to be downloaded and installed on Windows, despite the fact that the necessary modules are available by default in most contemporary Linux versions. PlutoSDR should show as a detachable mass storage device when the Windows drivers are loaded. When you open the device, you'll be sent to the info.html page, which has further fast start instructions. Initially, the PlutoSDR is set up to operate with Windows software such as MATLAB, Simulink, and IIO Oscilloscope. However, by using the AD9364 configuration rather than the usual AD9363 configuration, it is feasible to make a serial connection to the PlutoSDR and perform instructions that increase the tuning range from 70 MHz to 6 GHz and the bandwidth to 56 MHz.. Installing the PlutoSDR with MATLAB/Simulink allows for this setup modification.

The PlutoSDR is a very new technology, with just a few software defined radio apps supporting it. SDR is straightforward, and its freeware software package is commonly used with low-cost RTL SDR dongles, however PlutoSDR may also be utilised. After updating the PlutoSDR firmware and installing the necessary drivers, the software may run the receiver and demodulate AM/FM/DSB/SSB/CW signals. Third-party developers have built plug-ins that perform a variety of useful operations that augment SDR's capabilities. The configuration, spectrum, and waterfall display that come from receiving FM broadcast band stations through SDR.

In addition to MATLAB functionalities, the MathWorks Support Package for the ADALM-PLUTO Radio contains Transmitter and Receiver Simulink blocks for the PlutoSDR in the Communication System Toolbox. The Simulink blocks Transmitter and Receiver have parameter windows for configuration. Simulink has been used to mimic digital communication networks in undergraduate education for over a decade. To ease a first course in digital communications, these Simulink models include correlated transmitters and receivers for carrier frequency, phase, and symbol timing. However, the PlutoSDR allows you to simulate and implement carrier frequency and phase synchronization, as well as symbol timing recovery.

1.4 Waveform and Block Codes

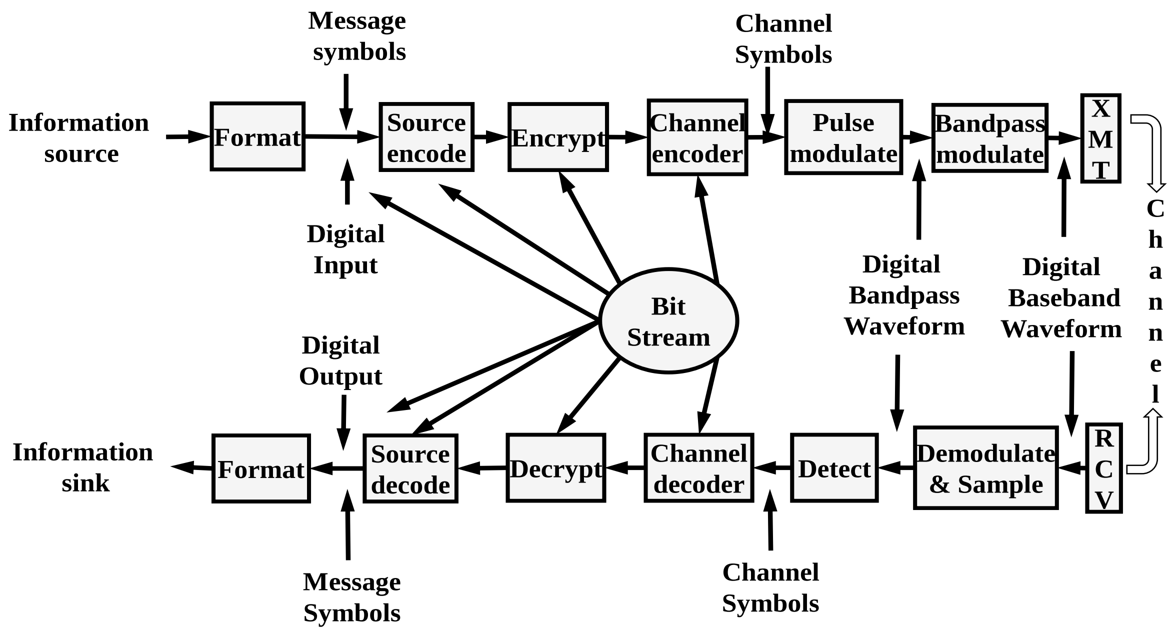

Figure 1.4: Waveform coding block diagram

Waveform coding is a technique for compressing audio signals by preserving the shape of the original waveform. A waveform coding block diagram consists of three main components: an analog-to-digital converter (ADC), a quantizer, and an encoder. The ADC samples the analog signal at a fixed rate and converts each sample into a binary number. The quantizer reduces the number of bits per sample by assigning each sample to one of a finite set of levels. The encoder assigns a code word to each quantized level and outputs a bit stream that represents the compressed signal. It seems like you are talking about a waveform coding technique that uses orthogonal codes to reduce detection errors and enhance transmission efficiency. The proposed method separates the high-speed data stream into many parallel streams and maps them into a predefined set of bi-orthogonal codes that are modulated by a bank of modulators that use the same carrier frequency. This method reduces the number of waveforms required and enhances transmission efficiency. It also contains an error control mechanism. The proposed method is low-cost and low bandwidth.

1.5 Cost Comparison with other SDRs

Name	Type	Frequency range	Max bandwidth	TX capable	Sampling rate	Host Interface	Windows	Linux	Mac	FPGA	Base pric
Aaronia SPECTRAN V6	Pre-built	10 MHz – 8 GHz (planned modules) 9 kHz – 20 GHz; 9 kHz – 40 GHz.	Up to 490 MHz (2 Rx with 245 MHz each)	Yes	2 GSPS	USB	Yes	Yes	Yes	1 x XC7A200T-2 (930 GMACs)	US$ 3,450
Aaronia SPECTRAN V6 Command Center	Pre-built	10 MHz – 8 GHz 9 kHz – 26 GHz; 9 kHz – 40 GHz.	Up to 980 MHz (4 Rx with 245 MHz each)	Yes	8 GSPS	Full IQ and/or Spectra data rate streaming.	Yes	Yes	Yes	4 x XC7A200T-2 (930 GMACs each)	US$ 24,650
AD-FMCOMMS5-EBZ	Pre-built	70 MHz – 6 GHz	54 MHz due to filter	Yes	61.44 MSPS	USB	Yes	Yes	Yes		US$ 1,286
ADALM-PLUTO	Pre-built	325 MHz – 3.8 GHz (70 MHz – 6 GHz with software modification	20 MHz (streaming may be less due to USB 2.0)	Yes	61.44 MSPS	USB & Ethernet.	Yes	Yes	Yes	Xilinx Zynq Z-7010	US$ 246
AirSpy R2	Pre-built	24 – 1700 MHz	10 MHz	No	10 MSPS MSps ADC sampling, up to 80 MSPS	USB	Yes	Yes	Yes		US$ 169
AirspyHF+	Pre-built	9 kHz - 31 MHz60 MHz - 260 MHz	660 kHz	No	36 MSPS	USB	Yes	Yes	Yes		US$ 169

Table 1: Cost Comparison of Adalm-Pluto SDR

The ADALM Pluto SDR is a low-cost transceiver that can operate from 325 MHz to 3.8 GHz with a bandwidth of up to 20 MHz. It has a USB 2.0 interface and can be programmed with GNU Radio, MATLAB, Simulink, and other software tools. The ADALM Pluto SDR costs around $250 and is suitable for beginners and hobbyists who want to learn about SDR and wireless communications.

How does the ADALM Pluto SDR compare with other SDRs on the market? Here are some examples of SDRs with different features and price ranges:

- The Hack RF One SDR is a half-duplex transceiver that can cover from 1 MHz to 6 GHz with a bandwidth of up to 20 MHz. It has a USB 2.0 interface and is compatible with many SDR software applications. It is fully open source and has a large community of users and developers. The Hack RF One SDR costs around $300 and is ideal for advanced users who want to experiment with a wide range of frequencies and modes.
- The RTL-SDR is a low-cost receiver that can tune from 24 MHz to 1.7 GHz with a bandwidth of up to 3.2 MHz. It has a USB 2.0 interface and works with popular SDR software such as SDR, HDSDR, GQRX and more. It can be used for various applications such as FM radio, ADS-B, trunked radio, weather satellites and more. The RTL-SDR costs around $255 and is perfect for beginners who want to explore the radio spectrum with minimal investment.
- The SDR Play RSP1A is a high-performance receiver that can cover from 1 kHz to 2 GHz with a bandwidth of up to 10 MHz. It has a USB 2.0 interface and supports various SDR software such as SDR uno, SDR Console, Cubic SDR and more. It has multiple filters, gain stages, noise reduction and notch filters to improve the signal quality and sensitivity. The SDR Play RSP1A costs around $220 and is suitable for intermediate users who want to enjoy a wide range of radio signals with high quality.

Chapter 2: Mobile Frequency Band Spectrum Sensing by ADALM PLUTO

2.1 Spectrum sensing

When used as a receiver, the ADALM-PLUTO SDR can recognize signals at numerous frequencies. This example explains how to use MATLAB, Communications Toolbox, and DSP System Toolbox to assess signal downstream spectrum. With the RTL-SDR Radio and ADALM-PLUTO Radio, you may use either recorded or real-time signals. Change the radio's central frequency to tune it to a signal-bearing band. The spectrum analyzer is then used to view and measure the received spectrum.

2.2 Required Software and Hardware.

To run this example utilizing gathered signals, you will need the following software:

1. The Toolbox for Communication.
2. DSP System Toolbox.

In this example below the ADALM-PLUTO SDR is used as RTL-SDR Radio in real time and captured the different broadband communication signals which are being used in Pakistan for communication purpose, by just changing the carrier frequency of each spectrum we get the different wave spectrum. Each broadband has its unique carrier frequency to operate and from that we can see the difference between them.

2.3 Zong 2100 MHz spectrum for 4G

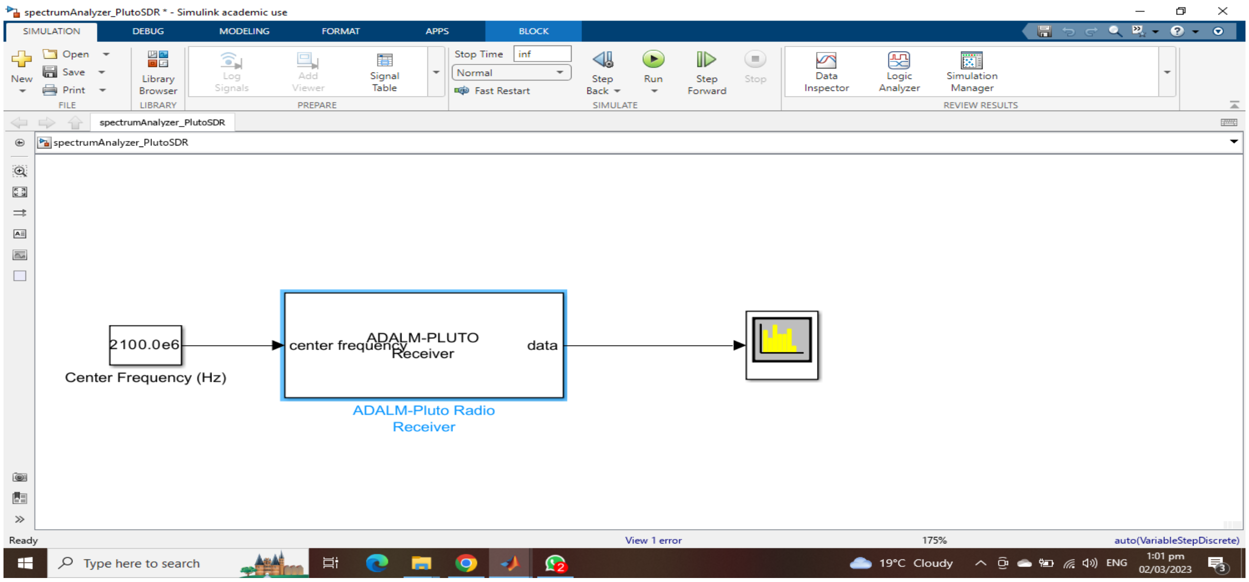

Figure 2.3(a): Carrier frequency of Zong (2100MHz)

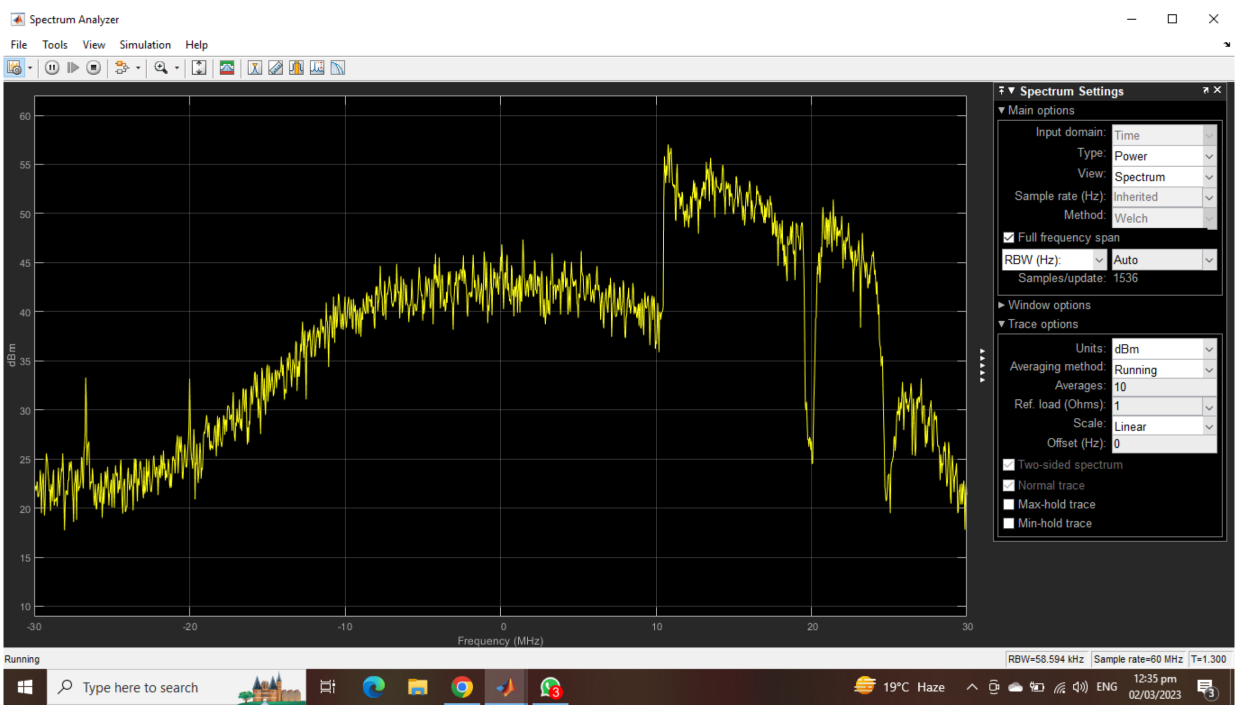

Figure 2.3(b): Spread Spectrum of Zong Signals

2.4 Mobilink jazz 1800MHz 4G frequency band

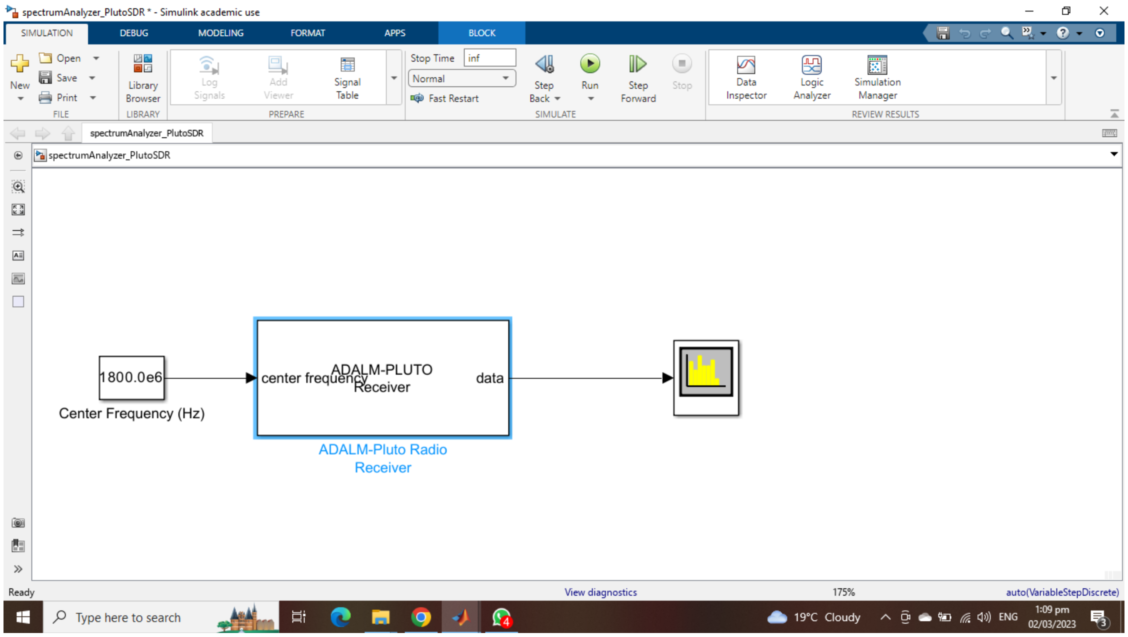

Figure 2.4 (a): Carrier Frequency of Mobilink (1800 MHz)

Figure 2.4 (b): Spread Spectrum of Mobilink Signals

2.5 Telenor 850 Mhz 4G frequency band

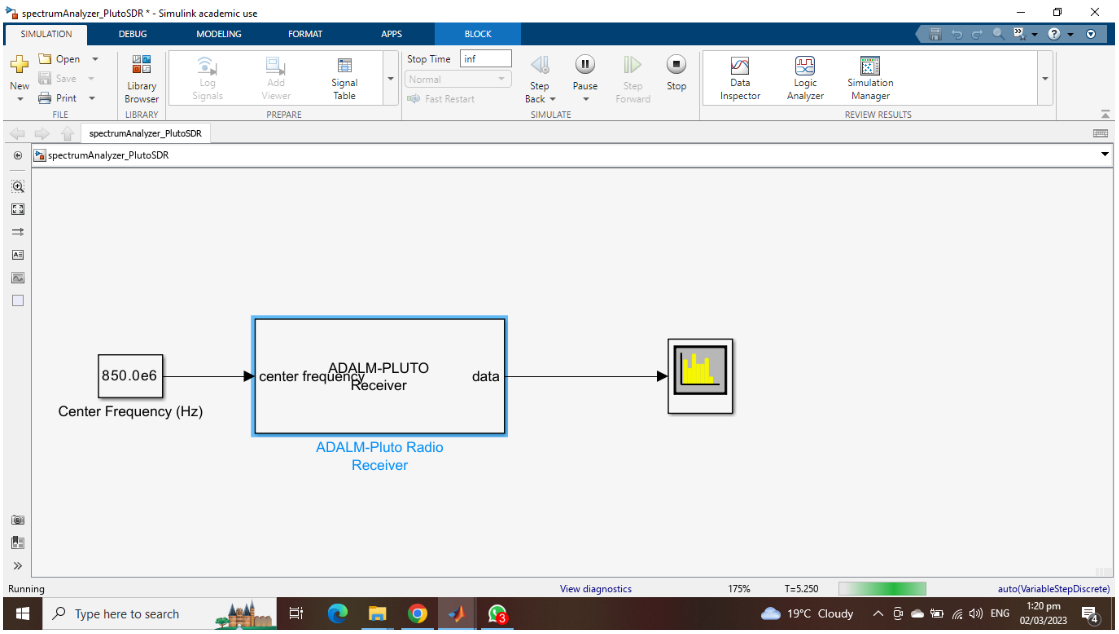

Figure 2.5 (a): Carrier Frequency of Telenor (850 MHz)

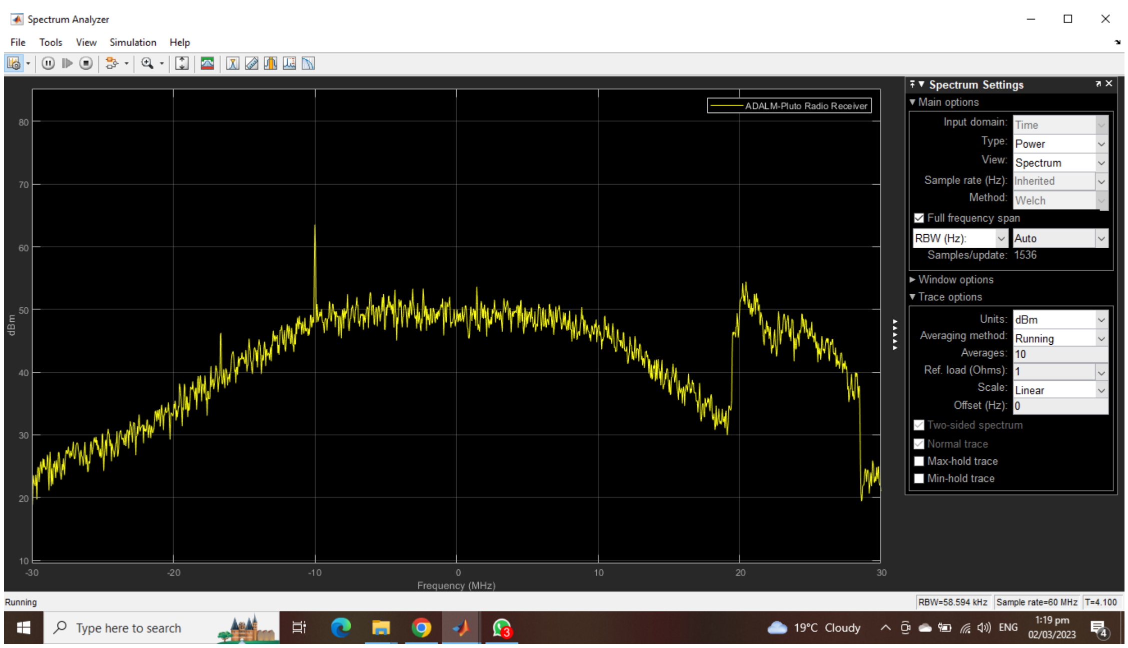

Figure 2.5(b): Spread Spectrum of Telenor Signals

Chapter 3: Implementation of Transceiver module for SDR system using ADALM PLUTO platform.

3.1 Application of Experiment

SDR is used in this exercise to introduce basic communication systems. Basic modulation methods like as BPSK, QPSK, and 8PSK are used to demonstrate SDR reception and transmission operations. We utilised an ADALM-PLUTO module with a core frequency of 915MHz for both transmitting and receiving. Because this module supports full-duplex transmission and reception, combining transmission and reception is suitable. In this experiment, we use the MATLAB SIMULINK programme to generate the sending and receiving blocks. Figures 3.1(a) and 3.1(b) depict the transmitting and receiving block schematics.

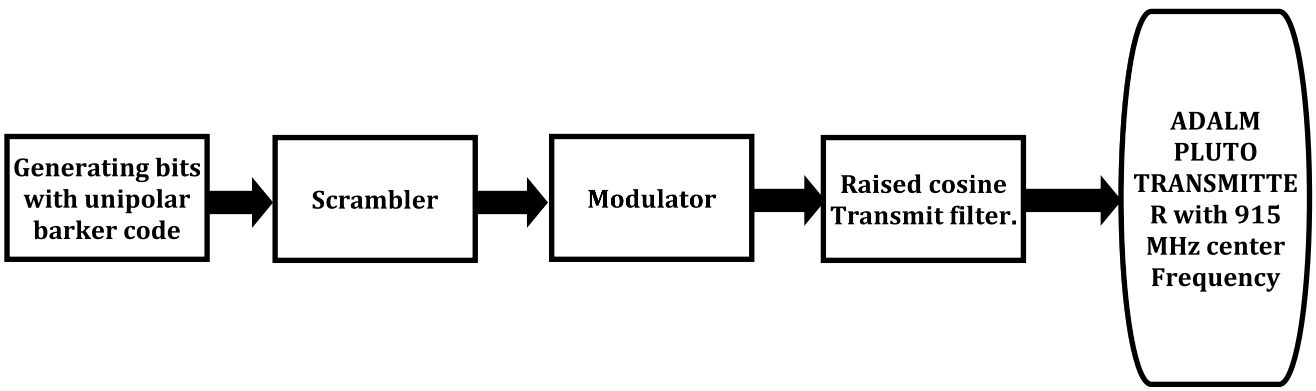

Figure 3.1(a): SDR Transmitter diagram

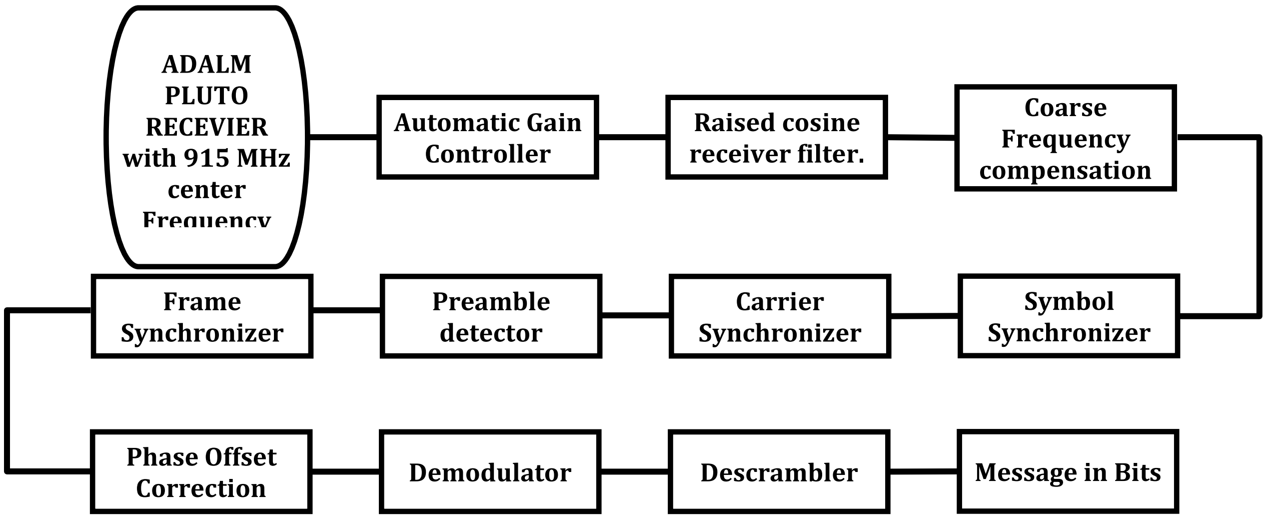

Figure 3.1(b): SDR Receiver block diagram

3.2 Creating the Simulink model.

Open a new Simulink model and create the model shown in figure below.

- **RTL-SDR Receiver configuration**:
  - Sampling rate: 240e3
  - Output data type: single
  - Samples per frame: 1000
  - "Lost samples output port" enabled. This signal will be non-zero when samples are lost, indicating that the model is not running in real-time.
  - Tuner gain controlled via Input port. Use a Constant block and Slider Gain, allowing you to adjust the RTL-SDR receiver gain while the model is running. Most RTL-SDR devices allow gain values between 0 and 60 db.
- Multiple Spectrum Analyzer and Time Scope blocks are included. You may need to comment these out to achieve good performance. Use them as needed to debug your model and/or view signals of interest.
- Use the Digital Filter Design (found in DSP System Toolbox → Filtering → Filter Implementations) block to create a bandpass filter that will pass the DSB-LC waveform. It is suggested to begin with a 60th order Bandpass FIR Equiripple filter.

- The Complex to Magnitude-Angle (found in Simulink → Math Operations) block will demodulate the DSB-LC signal at fi to 0Hz.
- The FIR Decimation (found in DSP System Toolbox → Filtering → Multirate Filters) block will change the sample rate of the signal. Specify a decimation factor of 5, which means the sample rate will be reduced by a factor of 5 at the output of the block. Therefore, the sample rate for the remainder of the model will be 240e3/5 = 48e3 which is a standard sample rate for audio signals.
- The DC Blocker (found in DSP System Toolbox → Signal Operations) block does exactly as its name implies.

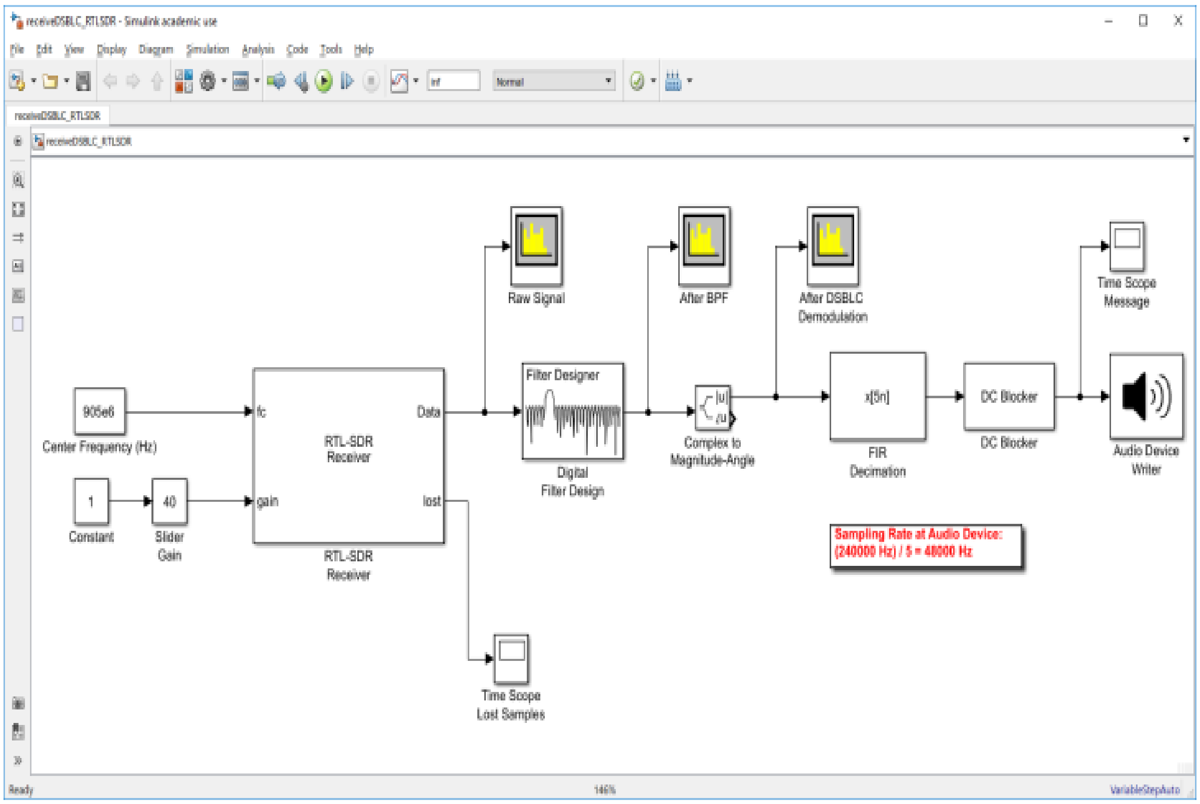

Figure 3.2: Simulink model for the DSB-LC receiver.

3.3 Results

We transformed the input message to bits after coding the scrambling method, added a barker code for phase offset correction, then modulated the message using three distinct modulation techniques: BPSK, QPSK, and 8PSK. A square root raised cosine transmitter filter with interpolation of 2 is used before transmitting the information. After being converted from digital to analogue at the module's transmitter block, the signal was sent using a transmitting antenna with a central frequency of 915MHz.

The signal will be received using the same central frequency as the transmitter at the receiving end. After the signals were received, an automated gain controller was utilised to handle them, and the signal was broadcast using a root raised cosine received filter for three modulations. After that, synchronisation was performed to correct the temporal offset, and these synchronisations are classified as symbol synchronizers, carrier synchronizers, and signal constellation diagrams.

Figure 3.3: Result for Simulink model for the DSB-LC receiver.

Chapter 4: CONCLUSION

The ADALM-PLUTO is a well-designed SDR with good specifications and a fair pricing. Flipped classroom in digital communication is now possible thanks to the ADALM PLUTO SDR and a range of software settings. A transceiver module for a software defined radio system was developed and built using the ADALM PLUTO platform. This module offers several appealing characteristics, including low cost, compact size, low power consumption, ease of movement, simplicity of configuration, and simplicity of deployment. This course has been raised to the level of digital logic, processor systems, circuits, and electronics, all of which employ comparable low-cost technologies in the flipped classroom and open laboratory.

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