

JHeeks Advanced DSP Assignement

by Jack Heeks

Submission date: 13-Jan-2025 08:39PM (UTC+0000)

Submission ID: 248327828

File name: 32726_Jack_Heeks_JHeeks_Advanced_DSP_Assignement_641246_1238936789.docx (6.65M)

Word count: 3609

Character count: 20519

Advanced Digital Signal Processing

Implementation and Analysis of NBFM Jamming Techniques and RTL-SDR Receiver Design Using GNU Radio

Embedded Electronic Systems

Contents

Introduction	1
Background Research.....	2
Frequency Modulation Communication	2
Anti-Jamming Techniques.....	2
Jammer Techniques Using GNU Radio	3
NBFM Modulation and Demodulation:	3
Adding a Jammer	5
Implement FHSS for Anti-Jamming	7
Analysis and Comparison	10
Message	10
FM Modulation	11
FM Demodulation	11
Jamming	11
FHSS Anti-Jamming	12
Ethics and Impact.....	13
RTL-SDR Receiver	14
Setup and Design	14
Signal Analysis and Visualization.....	15
SDR Source	15
Low Pass filter	16
WBFM Receive	17
Rational Resampling.....	18
Ethics and Impact.....	18
References	19

Introduction

In this assignment two FM communication systems will be designed and analysed using GNU Radio, a WBFM receiver using an RTL-SDR and a NBFM jammer. This includes implementing FHSS as an anti-jamming technique, assessing system performance through signal quality evaluation, and exploring the ethical implications of secure communication methods and SDRs.

Background Research

Frequency Modulation Communication

Introduced in the late 1930s FM Radio revolutionized broadcasting resulting in clearer and more robust audio, less susceptible to interference. Despite the advantages, FM faced resistance due to the dominance of AM Radio and the required infrastructure changes. FM finally gained popularity in the 1960s, offering a broader range of programming and superior audio quality.^[1]



Anti-Jamming Techniques

The evolution of adaptive anti-jamming integrates techniques like AFH and adaptive DSSS, combining frequency, power, modulation, and filtering strategies. Although effective in practical systems, traditional methods lack learning and perception capabilities. Recent research applies AI, using algorithms like genetic and particle swarm optimization, to enhance anti-jamming by optimizing communication parameters.^[2]



Jammer Techniques Using GNU Radio

Simulate a Narrowband Frequency Modulation (NBFM) communication system using GNU Radio.

Introduce a jammer at the FM transmitter, and then implement the Frequency Hopping Spread Spectrum (FHSS) anti-jamming technique to protect the message. Finally, analyse the performance of the system under different conditions.

NBFM Modulation and Demodulation:

Frequency modulation is made up of a modulating signal and the carrier wave used to transmit the message. The signal is encoded onto the carrier wave by altering the message frequency.

$$s(t) = A_c \cos(\omega_c t + \phi_c)$$

$(\omega_c t + \phi_c)$ represents the angle of the carrier wave

Equation 1 – Expression for Frequency Modulation Carrier^[3]

$$s(t) = A_c \cos(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau)$$

Equation 2 – Expression for Frequency Modulated Wave^[4]

- A_c – Amplitude of the Carrier Signal
- f_c – Frequency of the Carrier Signal
- k_f – Frequency Deviation Sensitivity
- $m(t)$ – Modulating Signal

Frequency Deviation determines the amount that the Frequency Modulated signal can vary from the nominal carrier frequency^[5], the sensitivity of deviation is determined by the modulation index.^[6]

$$\beta = \frac{\Delta_f}{f_m}$$

Equation 3 – Expression for Modulation Index^[7]

Bandwidth is the range of frequencies used to transmit and receive the message signal; typically the a large range of frequencies is required to carry the information.^[8]

$$FM(BW) = 2(\Delta_f + f_m)$$

In the case for NBFM it is accepted that $\Delta_f \ll f_m$

$$\Rightarrow m_f \ll 1$$

$$BW = 2(m_f f_m + f_m) = 2f_m(m_f + 1)$$

$$\therefore \text{for } m_f \ll 1$$

$$BW = 2f_m$$

Whereas the case for WBFM accepts that $\Delta_f \gg f_m$

$$\Rightarrow m_f \gg 1$$

$$BW = 2(m_f f_m + f_m) = 2f_m(m_f + 1)$$

$$\therefore \text{for } m_f \gg 1$$

$$BW = 2f_m m_f = 2\Delta_f$$

Equation 4 – Expressions for FM Bandwidth^[9]

β – Modulation Index
 Δ_f – Frequency Deviation
 f_m – Modulating Frequency
 BW – Bandwidth

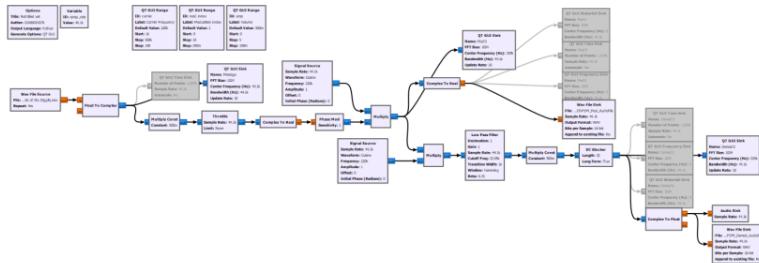


Figure 1 – Frequency Modulation and Demodulation GNU Radio Flowgraph

Figure 1 shows FM modulation and demodulation, starting with giving the audio WAV file a modulation index of 0.5 with the multiply constant block. The audio signal is then throttled to a sample rate of 44.1k to match the audio sink rate, and the signal is then converted from complex to real and assigned a phase modulation sensitivity of 1. This signal is then multiplied with a signal source (carrier wave) to provide a frequency modulated signal. Then the signal is converted back to real so it can produce a WAV audio file, and the time, frequency and waterfall sinks are added to show the modulated signal waveform.

Next the modulated signal is then multiplied with the carrier wave to demodulate it, and then passed through a low pass filter to remove any high frequency noise gained through transmission. The multiplication constant provides a volume control for the received signal and finally the DC blocker removes any DC bias from the received signal so that the audio is centred around 0V and the block set a default length of 32 – and the long form of the filter.

Figure 2 shows the modulated signal in waterfall, time and frequency sinks, the time sink shows the signal in the time domain. Whereas the frequency and waterfall sinks display the signal in the frequency domain, showing the range of frequencies being used to transmit the audio signal and the power of those frequencies.

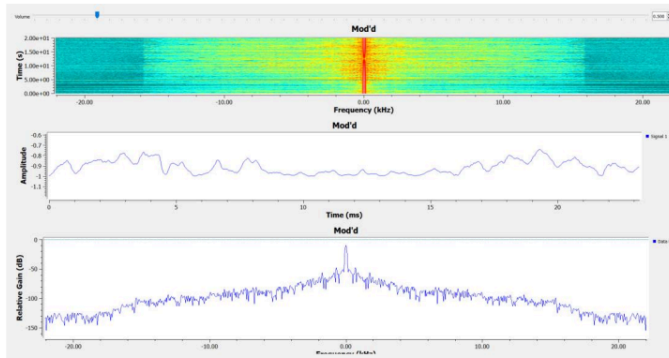


Figure 2 – Frequency Modulated Signal

The waterfall graph displays clearly the frequencies used to transmit the audio file as they appear red and yellow in the bandwidth shown with the extremities of the signal shown in a green colour showing a clear definition between the signal and the background noise. This waterfall graph can be mapped onto the frequency spectrum graph below.

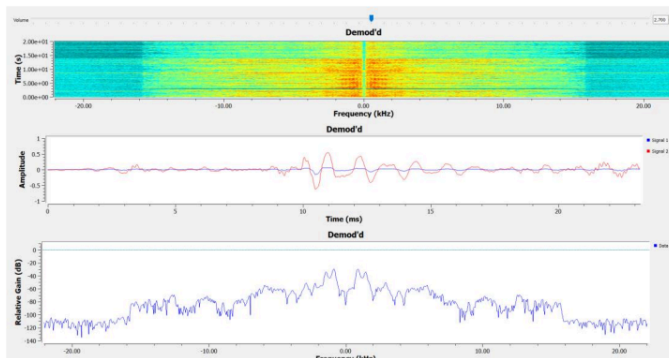


Figure 3 – Demodulated Signal

Figure 3 shows the demodulated signal in the form of the three sink graphs showing the spectrum separated around the centre frequency to show the two sides of the spectrum.

Adding a Jammer

Figure 4 below shows the flowgraph of FM modulation and demodulation with added noise jamming. The jamming source is provided by adding filtered gaussian noise to the modulated message signal using a noise source block to generate the selected noise (throughout the spectrum) to be added to the system, the noise generated in this function block is gaussian as this noise type is

selected within the block. Equation 5 shows the expression for the transmission produced within the flowgraph, the FM signal equation with added filtered noise given as h (filter constant) and $n(t)$.

$$J(t) = \left[A_c \cos(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau) \right] + [h * n(t)]$$

Equation 5 – Expression of Frequency Modulated wave with Added Filtered Gaussian Noise

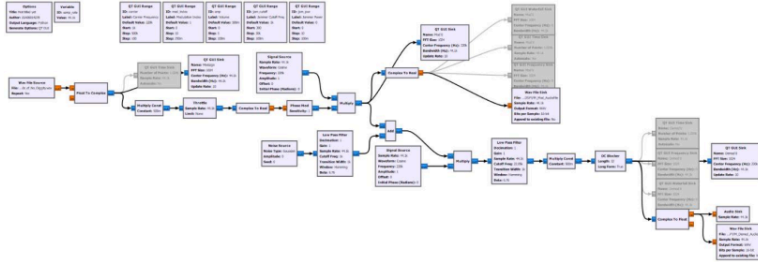


Figure 4 – FM Transmission with Gaussian Noise Jammer

The jamming is shown below in figure 5 as the red and orange signal within the transmitted signal, the noise can be seen at the centre shown as the dark red on the waterfall or largest peak on the frequency graph. The filter for the can be seen acting to increase the span of the noise across the transmission spectrum providing a larger bandwidth for the noise to occupy.

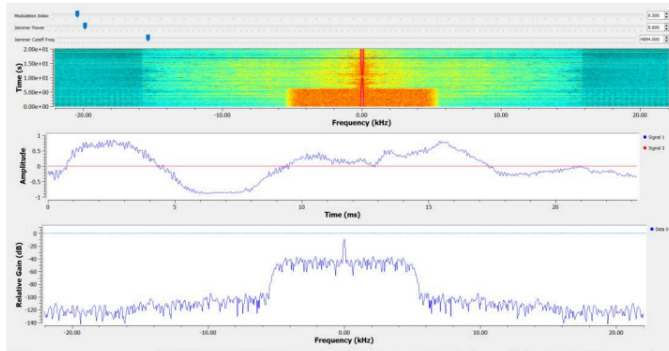


Figure 5 – Additive Gaussian Noise Jamming

Figure 6 shows the constellation graph produced by the jammed signal. The points are all sporadically spaced and loosely grouped into an oval shape showing the effects of the jamming. The jammer power increases the distance between the points on the constellation in all directions whereas the jammer filter cut-off frequency alters the point distances along the in-phase axis.

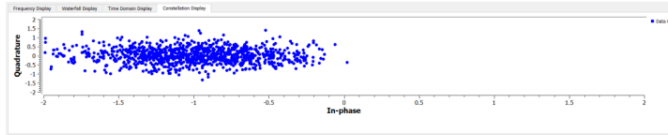


Figure 6 – Constellation Graph of Additive Gaussian Noise Jamming

11

Implement FHSS for Anti-Jamming

Figure 7 shows the implementation of FHSS as the anti-jamming method. This methodology uses channels to allow the signal to hop across the spectrum, protecting the signal and evading the jamming. The signal channel is randomised at the first carrier signal by multiplying the carrier with a random channel. The modulated signal is then filtered to 20kHz using a low pass filter and multiplied with the negative carrier, next the jamming signal is implemented.

The jamming signal is made up of a modulated noise source. The noise is filtered to provide bounds and then is multiplied by a carrier wave of 25kHz and the random number function selecting a channel value from -5 to 5 to distribute the noise throughout the full bandwidth available.

$$F(t) = \left[A_c \cos(2\pi(Cf_c)t + 2\pi k_f) \int_0^t m(\tau) d\tau \right] \cdot [h(t) * (-f_c)] + [h(t) * (n(t) \cdot 25 \times 10^3 \cdot C)]$$

Equation 6 – FHSS Expression

Equation 6 shows the expression that makes up the FM transmission, jamming source and anti-jamming implementation.

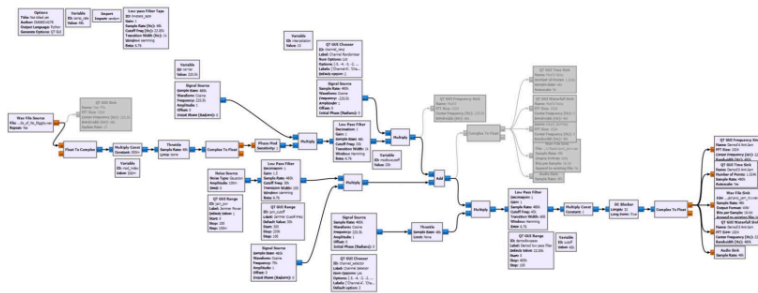


Figure 7 – FM Transmission with FHSS Anti-Jamming

Figure 8 below shows the channel seeking upon receiving the transmitted signal the waterfall plot shows the different bandwidths of each channel during searching, with the extremities having larger bandwidths and the channels near the centre having smaller bandwidths. The time domain graph shows that the received signal is mostly intact with only a slight amount of additive noise from the jamming.

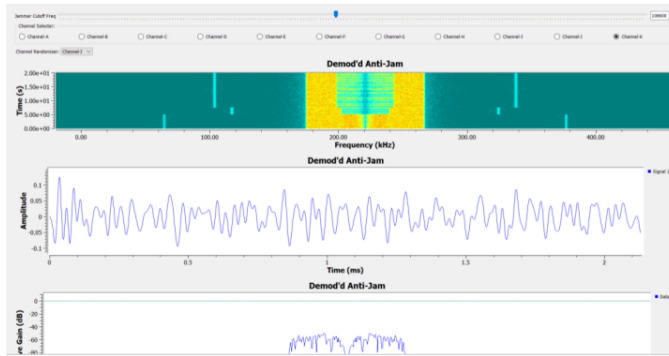


Figure 8 - Channel Seeking

Figure 9 shows the constant tone jamming generated by the added jamming; the tone appears in this channel based on the random number selected during the equation to make up the carrier wave for the modulated noise source. This is where the majority of the jammer power is as shown by the time domain graph, you cannot see any of the original signal amongst the noise in the channel.

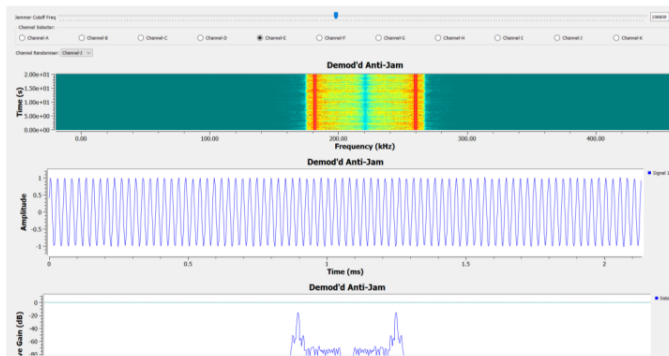


Figure 9 - Constant Tone Jamming

This is the same for the constellation graph – shown in figure 10 – which is very spread out along the width of the band in use and centred along the middle of the Quadrature axis unable to produce the usual elliptical shape.

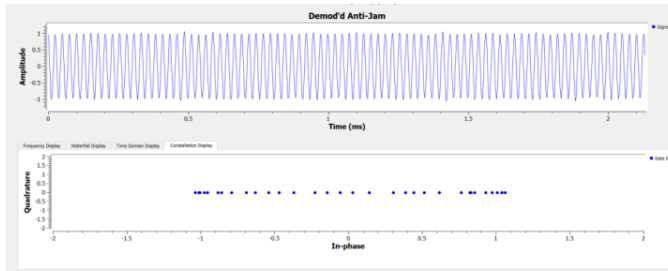


Figure 10 – Constellation Graph

The anti-jammed message can be seen shown below in figure 11, the signal is clearly seen in red in the channel centred around the carrier frequency, the time domain graph shows the demodulated audio signal without additive noise influence. The frequency graph at the bottom shows message in the low pass envelope above all other noise throughout the spectrum. Figure 12 shows the constellation graph as a tight set of points not interfered with by any external noise.

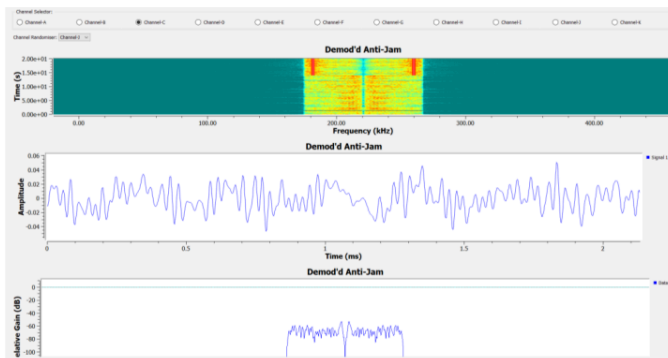


Figure 11 - Anti-Jammed Message Signal

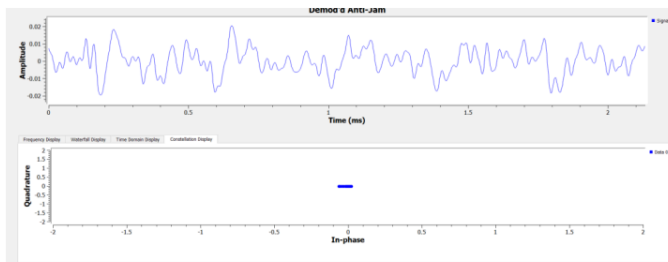


Figure 12 – Constellation Graph

Using the jammer cut-off frequency variable the low pass filter can be changed to allow more or less noise through into the system as shown in figure 13 by the yellow/red bands of noise in the channel bands, this can also be seen in the constellation graph in figure 14 with the points starting to become more spread out as the noise passed into the system by the filter affects the received signal providing interference, making the signal noisy. The overall impact on the system is that the jammer cut-off frequency variable changes the width of the band that the jamming noise can occupy.

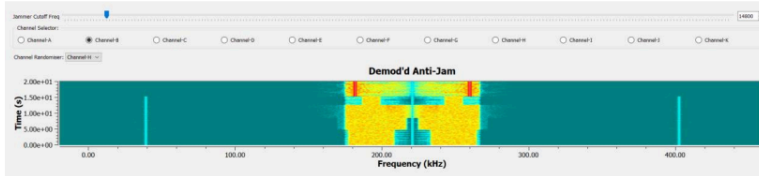


Figure 13 - Altering Jammer Cutoff Frequency

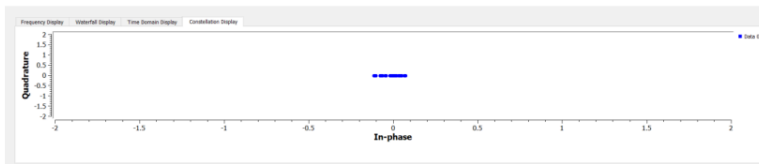


Figure 14 – Constellation Graph

Analysis and Comparison

Message

The message is shown in figure 15 identified with a signal to noise ratio between 30 – 70dB and a bright red peak at the centre of the graph surrounded by the yellow signal sitting approximately 50dB above the noise.

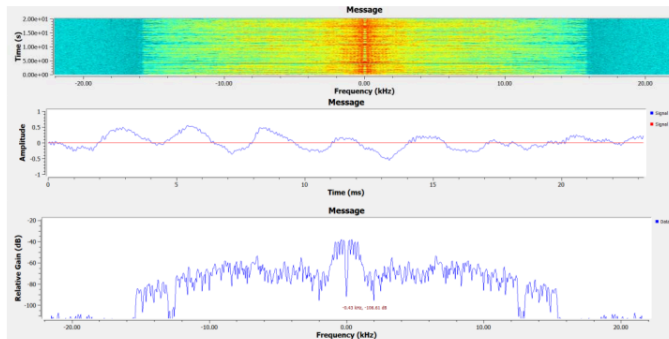


Figure 15 – Message Time and Frequency Domain Graphs

FM Modulation

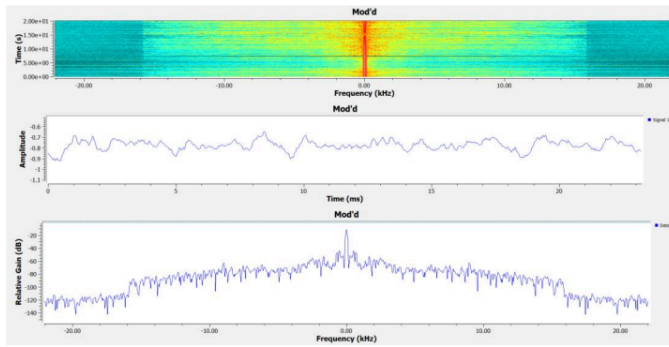


Figure 16 – Frequency Modulated Signal

FM Demodulation

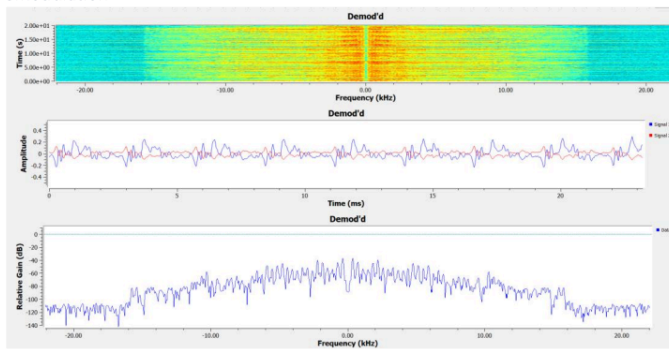


Figure 17 – Demodulated Signal

Jamming

The additive noise jamming signal is clearly shown below in figure 18 affecting the message signal in the time domain graph, the waterfall graph shows red at the carrier frequency and for the high-power jamming surrounding carrier frequency as well as yellow regions of the waterfall graph where the noise has increased the overall power of that frequency point.

The SNR is still similar to the unjammed signal; however, the deviation of the signal is greatly increased. This is due to the addition of the noise used to Jam the modulated message which reduces the clarity of the received message

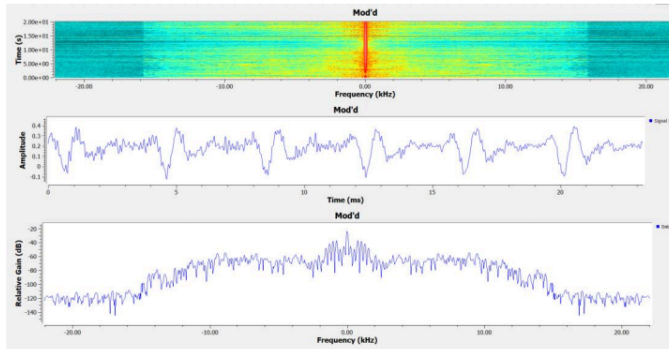


Figure 18 – FM Message with Additive Noise Jamming

FHSS Anti-Jamming

The anti-jamming technique used is FHSS utilising channels to alter the transmission bandwidth to evade the noise randomly added to the channels. The carrier frequency can be seen as the red signal or peak on the waterfall and spectrum graphs while the orange portion of the waterfall graph maps to the filtered noise that can be seen in the spectrum at the bottom.

The modulated signal is shown to be approximately 25dB with the carrier frequency 70dB above the noise. The noise can then be given a larger bandwidth using the filter cutoff to increase the influence over the channel selected, the channel selected is where the carrier frequency sits within the spectrum.

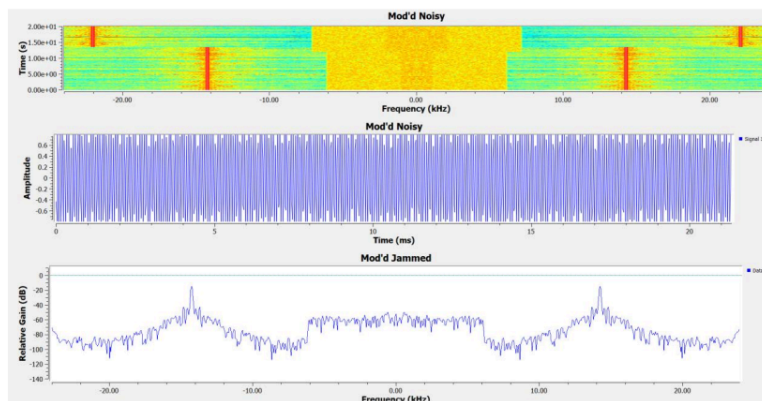


Figure 19 – FHSS Transmitted Signal

Ethics and Impact

Jamming RF broadcasts is an illegal act, also making it immoral. The RF spectrum is divided into many bands of allocated spectrum usage, any disruption to the spectrum usage is an illegal act and can lead to consequences like fines and jail time. The ethical implications of jamming signals consist of national security, public safety, and personal privacy.^[10]

An example of unethical jamming of RF signals is the soviet union jamming of western broadcasts in east Berlin and East Germany as a whole. This was done to protect the sovereignty being upheld by the Soviet Union against the western ideals of free flowing information.^[11]

Another ethical concern is the modern use of cell phone jammers for large public events. Phones could be jammed due to interference with licenced bands, such as emergency communications. And some case allow for entities such as law enforcement and government agencies to jam phones because are authorised in some circumstances.^[12]

Secure communication offers protection from cyberattacks and ensure that transmitted data is harder to obtain by individuals outside of the intended receiver ensuring confidentiality of the information.^[13] FHSS allows users to quickly change the carrier frequency of the transmitted signal with little interference as the transmission band divided into sub-band. The transmitted signal is difficult to jam or intercept if the frequency hopping algorithm is not known and the transmitted signal can share bands with conventional transmission with minimal interference.^[14]

RTL-SDR Receiver

Using an RTL-SDR receiver design a GNU Radio flowgraph to tune into a chosen frequency, then analyse the signal quality at different stages.

Setup and Design

The variables used for this flowgraph are the device sample rate, cut-off frequency, transition, quadrature value and RF gain control and volume sliders. As well as either a set frequency or frequency range slider.

The RTL-SDR Source block is given variables to determine the number of receive channels the SDR has, the sample rate is given a large value to capture more points along any received signals. The channel 0 frequency is given the variable `fc` to allow for frequency seeking along the full spectrum available to the SDR.

The frequency correction, DC offset, and IQ balance are all set to 0 as these are not needed or known for this system. And the Gain mode is set to manual control (False) as this allows the user to control the gain options, the gain options are RF, IF, and Baseband which are the three distinct stages of the RF circuit within the SDR.

A low pass filter is required to remove high frequency noise that can be picked up during transmission. The decimation of the filter is calculated by dividing the sample rate by the quadrature to reduce sampling rate and computational resources^[15]; $2M$ rate is divided by 500k quadrature to give a decimation of 4. The gain is left as 1, and the cut-off frequency is set at 100kHz to allow the audio through, and the trans^[16] is 1MHz to set the speed of sweeping between the start and stopband frequencies^[16]. A Hamming window is selected as this window concentrates the energy of a spectrum frame and reducing the disparity of the signal edge by multiplying each frame with this specific function.^[17]

The signal is then passed into a wideband FM receive block where a quadrature rate is given to the block the quadrature rate is the input sample rate of complex baseband input.^[18] and the audio decimation is given a value of 1 as this means that the signal is not decimated. Next the rational resampler block is used as a polyphase FIR filter to upsample and downsample the audio signal based on an interpolation and decimation value. This is done based on the formula output signal rate = interpolation $\cdot$ fs / decimation.^[19]

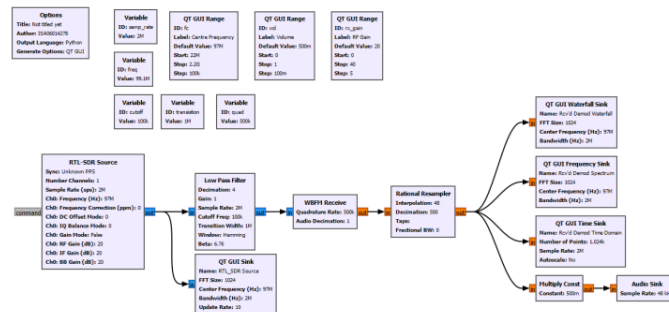


Figure 20 – Wideband FM Receiver

Signal Analysis and Visualization

SDR Source

The signal received at the source can be seen across a narrow bandwidth of the range that the SDR is capable of receiving. This is shown in figure 21 as the signal at the centre of the graph with an alternative signal shown 750MHz below the intended signal, these frequencies shown are the local oscillator values used by the SDR to down-convert the RF at the antenna to the IF utilised within the SDR.

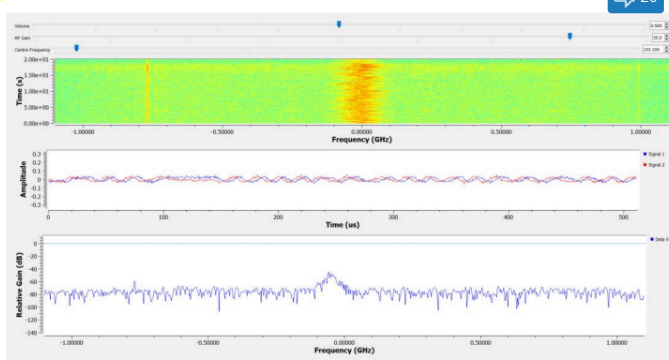


Figure 21 – Received Signal Frequency and Time Domain Graphs

Figure 22 shows the constellation plot of the received signal indicating the spread and position of the IF signal produced within the SDR. It is along the centreline of the Quadrature axis with a small variation along the centre of the In-Phase axis, this shows the signal is strong and unaffected by noise.

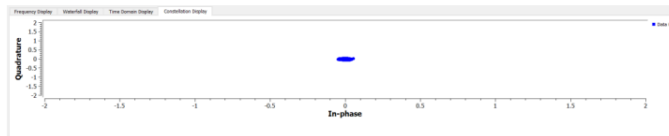


Figure 22 – Received Signal Constellation Graph

Low Pass filter

Figure 23 shows the signal post filtering. This acts to remove high frequency noise and the signal multiplied by the LO frequency, leaving only the signal divided by the LO. The total bandwidth of the signal post filtering is now 100kHz, therefore expanding the fractional bandwidths of all signals. Thus, the signal shown in figure 23 appears larger.

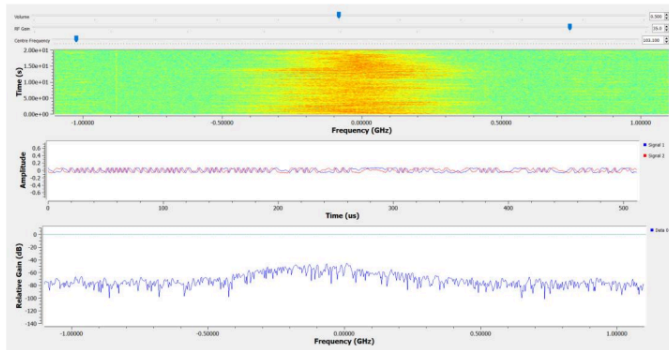


Figure 23 – Low Pass Filtered Frequency and Time Domain Graphs

Figure 24 is a post filtering constellation graph the main difference visible is longer width in the In-Phase axis. The increased bandwidth is represented in this graph.

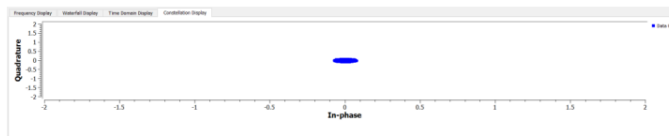


Figure 24 – Low Pass Filtered Constellation Graph

WBFM Receive

Having passed the signal to the WBFM demodulation block it can be seen at the centre of the graphs with an image of the modulating signal either side. This appears as a narrowband signal of a demodulated received FM signal; the filtering effects can be seen as the signal tapers off 1GHz either side of the message signal.

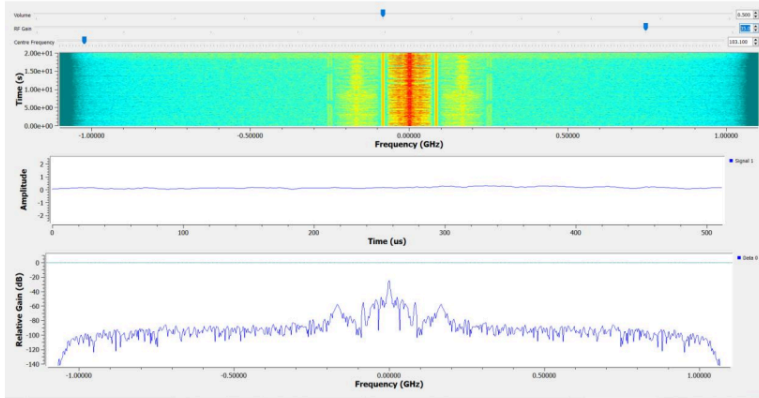


Figure 25 – Demodulated Signal Frequency and Time Domain Graphs

The constellation plot shows the points in-line along the Quadrature axis but is spread out along the In-Phase axis clearly seen to be favouring the negative side showing an imbalance in the system.

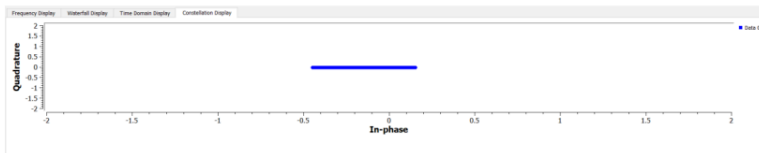


Figure 26 – Demodulated Signal Constellation Graph

Rational Resampling

This function resampled the signal by up and down sampling the frequency of the carrier allowing for the signal to be better matched to the 44.1kHz audio sink sample rate versus the 2MHz sample rate used at the SDR source block. As shown below in figure 27 the signal has been resampled to expand the bandwidth occupied by the demodulated message signal.

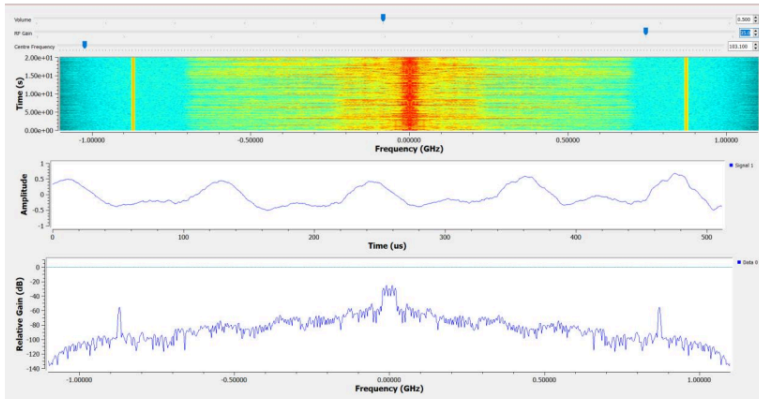


Figure 27 – Rational Resampling Frequency and Time Domain Graphs

This resampling has been used to rebalance the signal in the system as shown below in figure 28, the plot points are centred along the In-Phase axis. This graph indicates a more balanced demodulated signal.

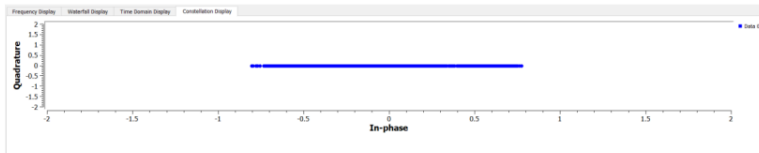


Figure 28 – Rational Resampling Constellation Graph

Ethics and Impact

Software Defined Radios offer an affordable entry to RF work utilising software to perform the RF capabilities usually carried out by expensive RF components, this allows them to be bought and used by hobbyists and in education providing access to all to develop RF skills without risk of damaging the components.^[20] This however raises concerns of privacy and security as these devices can be vulnerable to attacks which change the RF behaviour^[21] due to the flexibility and reconfigurability^[22] of SDR devices. SDR technology can be used to expand broadcast frequency ranges raising privacy concerns, for example, an SDR could be used to access transportation or logistics information.^[23]

References

- [1] 'Radio History: The Evolution of FM Radio - Mini-Circuits Blog'. Accessed: Jan. 13, 2025. [Online]. Available: <https://blog.minicircuits.com/radio-history-the-evolution-of-fm-radio-through-time/>
- [2] Q. Zhou and Y. Niu, 'From Adaptive Communication Anti-Jamming to Intelligent Communication Anti-Jamming: 50 Years of Evolution', *Advanced Intelligent Systems*, vol. 6, no. 8, p. 2300853, 2024, doi: 10.1002/aisy.202300853.
- [3] 'Frequency modulation', SlideShare. Accessed: Dec. 24, 2024. [Online]. Available: <https://www.slideshare.net/slideshow/frequency-modulation-12759213/12759213>
- [4] 'Frequency Modulation(FM): Definition, Equation, and Applications', GeeksforGeeks. Accessed: Dec. 24, 2024. [Online]. Available: <https://www.geeksforgeeks.org/frequency-modulation/>
- [5] 'What Is Frequency Deviation', Talkpod. Accessed: Dec. 24, 2024. [Online]. Available: <https://talkpod.com/blogs/two-way-radio-wiki/what-is-frequency-deviation>
- [6] 'Frequency Modulation: Theory, Time Domain, Frequency Domain | Radio Frequency Modulation | Electronics Textbook'. Accessed: Dec. 24, 2024. [Online]. Available: <https://www.allaboutcircuits.com/textbook/radio-frequency-analysis-design/radio-frequency-modulation/frequency-modulation-theory-time-domain-frequency-domain/>
- [7] 'FM_Frequency_Modulation_EngineersTutor.pdf'. Accessed: Dec. 24, 2024. [Online]. Available: https://engineerstutor.com/wp-content/uploads/2020/10/FM_Frequency_Modulation_EngineersTutor.pdf
- [8] S. WØSTU, 'FM Bandwidth', hamradioschool. Accessed: Dec. 24, 2024. [Online]. Available: <https://www.hamradioschool.com/post/fm-bandwidth>
- [9] 'Carson's Rule for Bandwidth Calculation - Working Principle, Derivation', GeeksforGeeks. Accessed: Dec. 24, 2024. [Online]. Available: <https://www.geeksforgeeks.org/carsons-rule/>
- [10] T. Turgeon, 'The Legal, Ethical, and Regulatory Aspects of GPS Jamming', GNSS Jamming. Accessed: Dec. 29, 2024. [Online]. Available: <https://www.gnssjamming.com/post/legal-aspects-of-gps-jamming>
- [11] R. B. Price, 'Jamming and the Law of International Communications'.
- [12] 'Cell phone jammers: answering questions about privacy and public safety', IT News. Accessed: Dec. 29, 2024. [Online]. Available: <https://rumpkernel.org/cell-phone-jammers-balancing-privacy-and-public-safety/>
- [13] Microsys, 'Importance of Communication Security and Industry Best Practices', Microsys Inc. Accessed: Dec. 29, 2024. [Online]. Available: <https://microsysinc.ca/importance-of-communication-security/>
- [14] 'What is frequency-hopping spread spectrum (FHSS)?', Search Networking. Accessed: Dec. 29, 2024. [Online]. Available: <https://www.techtarget.com/searchnetworking/definition/frequency-hopping-spread-spectrum>
- [15] 'Decimation (Digital Filter Design Toolkit) - NI'. Accessed: Dec. 31, 2024. [Online]. Available: https://www.ni.com/docs/en-US/bundle/labview-digital-filter-design-toolkit-api-ref/page/lvdfdtconcepts/dfd_decimation.html
- [16] 'Filters | PySDR: A Guide to SDR and DSP using Python'. Accessed: Dec. 31, 2024. [Online]. Available: <https://pysdr.org/content/filters.html>
- [17] 'Hamming Window - an overview | ScienceDirect Topics'. Accessed: Dec. 31, 2024. [Online]. Available: <https://www.sciencedirect.com/topics/computer-science/hamming-window>
- [18] 'WBFM Receive PLL - GNU Radio'. Accessed: Dec. 31, 2024. [Online]. Available: https://wiki.gnuradio.org/index.php?title=WBFM_Receive_PLL
- [19] 'Rational Resampler - GNU Radio'. Accessed: Dec. 31, 2024. [Online]. Available: https://wiki.gnuradio.org/index.php/Rational_Resampler

- [20] M. A. Ramos, R. Camacho, P. A. Buitrago, R. D. Urda, and J. P. Restrepo, 'Software Defined Radio, a perspective from education', *Front. Educ.*, vol. 8, Jan. 2024, doi: 10.3389/feduc.2023.1228610.
- [21] J. de J. Rugeles Uribe, E. P. Guillen, and L. S. Cardoso, 'A technical review of wireless security for the internet of things: Software defined radio perspective', *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 7, pp. 4122–4134, Jul. 2022, doi: 10.1016/j.jksuci.2021.04.003.
- [22] J. Fitton, 'Security Considerations for Software Defined Radios', 2002.
- [23] 'Software Defined Radio', Knight Lab Studio. Accessed: Dec. 31, 2024. [Online]. Available: <https://studio.knightlab.com/projects/software-defined-radio/>

JHeeks Advanced DSP Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

74/100

Feedback on A4HEP Learning Objectives

B1: Demonstrates a good application of knowledge in problem-solving. You have successfully met the requirements for this learning outcome.

B2: Effectively analyses problems and reaches logical conclusions. You have successfully met the requirements for this learning outcome.

B3: Proper selection and application of computational and analytical techniques. You have successfully met the requirements for this learning outcome.

B6: Successfully applies a systems approach to problem-solving. You have successfully met the requirements for this learning outcome.

B8: Demonstrates strong ethical analysis and informed decision-making. You have successfully met the requirements for this learning outcome.

B12: Effectively applies laboratory and workshop skills in investigations. You have successfully met the requirements for this learning outcome.



Comment 1 | **Engagement with Lit (20)**

A basic history and the advantages of Frequency Modulation (FM) are presented.



Comment 2 | **Engagement with Lit (20)**

The discussion could be more engaging by addressing the need for anti-jamming techniques. Additionally, the effects of jamming should be explained to highlight its impact on communication systems.



Comment 3 | **Knowledge & Understanding (20)**

More details on Narrowband FM (NBFM) modulation and demodulation are needed, including traditional block diagrams, applications, and advantages.



Comment 4 | **Knowledge & Understanding (20)**

A comparison between NBFM and Wideband FM (WBFM) should also be included to clarify their differences.



Comment 5 | **Knowledge & Understanding (20)**

Relevant expressions related to FM, along with the formulas for frequency deviation and modulation index, are well captured.



Comment 6 | **Cognitive Skills (20)**

The explanation of NBFM implementation in GNU Radio blocks is well done.



Comment 7 | **Knowledge & Understanding (20)**

It is commendable that the signal processing in each block, for both modulation and demodulation, is clearly explained.



Comment 8 | **Practical Skills (25)**

The time-domain, frequency-domain, and waterfall sink outputs are well presented.



Comment 9 | Cognitive Skills (20)

Bandwidth and frequency deviation values should be explicitly shown, and a brief explanation of how these values are derived from the formula would enhance clarity.



Comment 10 | Knowledge & Understanding (20)

The process of adding noise to the signal is described effectively, with appropriate expressions provided.

PAGE 8

PAGE 9



Comment 11 | Cognitive Skills (20)

The constellation graph accurately depicts the impact of noise. However, additional explanations comparing the signal with and without noise would strengthen the analysis.



Comment 12 | Cognitive Skills (20)

A strong understanding of Frequency Hopping Spread Spectrum (FHSS) as an anti-jamming technique is evident, which is commendable. Including a more detailed explanation of the basic FHSS blocks would add value.



Comment 13 | Knowledge & Understanding (20)

The concept of FHSS is well-applied by introducing random channel selection in the blocks.

PAGE 10

PAGE 11



Comment 14 | Knowledge & Understanding (20)

The effects of filtering in mitigating jamming signals are also well explained.

PAGE 12



Comment 15 | Cognitive Skills (20)

A useful comparison is made between the original signal, NBFM signal, jammed signal, and FHSS signal. However, incorporating Signal-to-Noise Ratio (SNR) calculations and a tabular comparison of these cases would make the analysis more comprehensive.

PAGE 13

PAGE 14

PAGE 15



Comment 16 | Knowledge & Understanding (20)

The ethical implications of jamming are clearly discussed, with legal aspects mentioned.



Comment 17 | Cognitive Skills (20)

Expanding the discussion to include the ethical impact on interference, social benefits, and communication efficacy is providing more complete preceptive which is commendable.

PAGE 16



Comment 18 | Knowledge & Understanding (20)

The setup of the Software-Defined Radio (SDR) receiver is explained well, with clear descriptions of the signal flow through each block.



Comment 19 | Cognitive Skills (20)

The explanation of decimation values is included, but further clarification on the necessity of decimation and its role in signal processing would be beneficial.

PAGE 17



Comment 20 | Practical Skills (25)

Observations of signals in GNU Radio sink blocks are well made. However, a deeper analysis is needed, including observations on SNR and signal strength.

PAGE 18

PAGE 19

PAGE 20



Comment 21 | Transferable Skills (15)

Overall, More emphasis should be placed on traditional SDR blocks and the missing mathematical expressions of complex functions. Additionally, the FHSS technique should be explained in greater detail, covering its fundamental principles.



Comment 22 | Cognitive Skills (20)

The ethical Impacts on considering SDR is limited. More detailed work which says about interference management, social benefits should also be included.

PAGE 21



Comment 23 | Engagement with Lit (20)

Citing multiple journal papers is commendable, as it strengthens the discussion with relevant references.



Demonstrates exceptional transferable skills by effectively applying GNU Radio tools to simulate NBFM and RTL-SDR systems, integrating mathematics and communication principles.

GRADING FORM: ADSP_GRADING_TEMPLATE

JACK HEEKS

73.50

ENGAGEMENT WITH LIT (20)

Task 1: Demonstrate understanding of NBFM, jamming effects, and FHSS. Citations and research on related topics. Task 2: Show understanding of SDR receiver principles and signal representation. Evaluate research on SDR technology and related topics.



- Excellent understanding of NBFM, jamming, and FHSS. Citations and research are thorough and relevant.
- Good understanding of SDR principles with relevant research, though certain aspects in citations or depth could be improved.

17

KNOWLEDGE & UNDERSTANDING (20)

Task 1 (i) Understanding NBFM, modulation, and demodulation. Exploring bandwidth, frequency deviation, and impact on signal quality. Task 1 (ii) Analysing jamming effects by studying noise sources and interference. Observing impact via frequency, time domain, and constellation diagrams. Task 1 (iii) Investigating FHSS to reduce interference and evaluating its effectiveness. Task 1 (iv) Comparing original, jammed, and FHSS signals. Studying Signal-to-Noise Ratio (SNR), clarity, and system efficiency. Task 1 (v) Understanding ethical issues in jamming. Discussing legal aspects and FHSS benefits for security. Task 2 (i) Designing a WBFM receiver using RTL-SDR and GNU Radio. Studying block functions and sampling. Task 2 (ii) Visualising signals via waterfall plots, frequency sinks, and time-domain analysis. Studying SNR, stability, and filtering. Task 2 (iii) Evaluating privacy and interference issues. Analysing societal benefits like improved efficiency and technology.



- Strong knowledge of NBFM, with well-explained concepts, though additional depth could further enhance understanding.
 - Good understanding of jammer effects, with scope for added depth.
 - Sound knowledge of FHSS application, though certain areas in explanation could be refined.
 - Satisfactory understanding. Basic descriptions, but limited detail in SNR or performance.
 - Good understanding of ethics and societal benefits, with scope for more detailed insights.
 - Satisfactory understanding. Basic explanations of block functions and sampling principles, but lacking depth.
 - Well-developed understanding of signal analysis, with clear explanations, but stage comparisons and SNR details could be refined.
 - Ethical considerations of SDR are limited.
- Considering societal benefits, impacts and secure communication could enhance the work

13.6

COGNITIVE SKILLS (20)

Task 1 (i) NBFM Modulation and Demodulation: Understands modulation, demodulation, bandwidth, and clarity. Task 1 (ii) Add a Jammer: Evaluates noise, interference, and signal impact in frequency, time, and constellation domains. Task 1 (iii) Implement FHSS for Anti-Jamming: Applies FHSS to reduce interference and compare signal stability. Task 1 (iv) Analysis and Comparison: Compares original, jammed, and FHSS signals using frequency and time-domain tools. Task 1 (v) Ethics and Impact: Assesses legal and societal effects of interference in secure communication. Task 2 (i) Setup and Design of WBFM Receiver: Designs WBFM receiver, focusing on setup, bandwidth, and stability. Task 2 (ii) Analysis and Visualisation: Examines signal analysis, error detection, and filtering techniques. Task 2 (iii) Ethics and Impact: Reviews interference impact and decision-making in WBFM technology.



- Satisfactory setup, limited interpretation of parameters.
- Good analysis of jammer effects, with clear use of visual tools, though some aspects could be refined.
- Basic implementation with limited clarity.
- Basic comparison with limited reasoning.

10.8

- Satisfactory discussion, limited depth.
- Basic understanding with missing the complex signals.
- Basic analysis with limited reasoning.
- Minimal effort in discussing ethics and societal impact.

PRACTICAL SKILLS (25)

Task 1: Hands-on experience in transmitter and receiver setup, understanding signal bandwidth and frequency deviation. Implementing noise sources and analysing interference effects using frequency, time, waterfall, and constellation sinks. Applying FHSS techniques for anti-jamming and evaluating signal clarity through SNR analysis and stage comparisons. Developing an awareness of secure communication and legal implications. Task 2: Practical implementation of RTL-SDR receiver setup, signal representation, and processing. Understanding block functionality, decimation factors, and performing signal analysis using waterfall and frequency sinks. Visualising constellation diagrams and evaluating signal stability through SNR measurements. Comparing different demodulation stages for performance optimisation.



Task 1: Shows good practical skills in simulating NBFM and using FHSS for anti-jamming. Jammer introduction and signal analysis are effective, but minor gaps exist in explaining parameters like bandwidth and frequency deviation. Comparisons of signal stages are clear but need more depth. Task 2: Shows good practical skills with a well-configured RTL-SDR receiver and accurate signal representation. Minor gaps in explaining block functionality or decimation factors. Signal analysis and visualisation are effective but lack some detail. Comparisons across stages are clear but need more depth.

19.5

TRANSFERABLE SKILLS (15)

Enhancing mathematical integration and simulation skills using GNU Radio and RTL-SDR. Developing ethical reasoning and effective communication for teamwork and professional interactions. Practising systematic reporting, structured problem-solving, and clear presentation skills.



Shows strong transferable skills with good application of GNU Radio tools and solid understanding of signal processing concepts. Minor gaps in analysis depth or documentation. Ethical considerations are discussed but need more detail.

12.6