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

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Introduction

The start of this project shows the use and design of a regular Wide Band Frequency Modulation (WBFM) technique used in multiple everyday applications. Following from this there were two main objectives which required the use of the simulation software GNU radio. The first task was to generate and simulate a form of Narrow Band Frequency Modulation (NBFM) and implement a form of gaussian jamming and use Frequency Hopping Spread Spectrum (FHSS) anti-jamming to clear the signal. The system could then be analysed using multiple channels to assess what will happen to the message signal throughout this process. To confirm the signal has been received in, the audio file set up, will be played through the computer's speakers.

The secondary task was to fully design an RTL-SDR receive diagram and observe the signal changes at multiple points. This would involve obtaining a signal capture of a randomised FM radio broadcast and explain the process in which this signal is being modulated, demodulated and then received by the Software Defined Radio.

Background Research

Frequency Modulation

Frequency Modulation is the combination of both the message and the carrier signal which is utilised by encoding the message required within the carrier and adjusting the frequency to give the output signal, in accordance with the varying amplitude of the message wave [1]. This allows the signal to have a greater chance of being transmitted and not being affected by the outside environment before reaching the receiver location.

In FM both the phase and the amplitude doesn't change allowing only the frequency to be altered to create the transmission signal. The main use of FM is communication audio links. This is because, FM is, unlike other modulations, very wide band. This wide band aspect can be tuned to a specified frequency which is known as NBFM. Another version of FM is Wide Band Frequency Modulation (WBFM), used for wider band frequency  mission over the air.

Anti-Jamming Backgrounds / Capabilities

At current there are several ways in which Frequency Modulation can be achieved as well as, ways that anti-jamming can be used to disrupt or block the required signal from reaching its receive location. The main use for jamming frequencies  is in broad military applications using Electro-Magnetic (EM) waves as a means to disrupt, deter or inevitably control the outcome within the battle environment [2]. Some of these applications include missile warning systems, radar detection, radio reconnaissance, anti-drone and cellular capabilities [2].

Current FM Communications

The current forms of FM communications consist of areas such as point to point radio transmit and receive, Radar communications, satcom communications. FM is currently used in these capabilities for the simple reason that it is far less susceptible to many types of interference and noise due to its multiplication with the carrier wave which is an off shoot of the main message signal [3].

Task 1

FM Equation and Calculations

To create an FM signal which can be modulated and demodulated, a series of calculations need to be undertaken. There are multiple aspects of FM that are required in order to allow the signal to be clear at the receiver module. The finalised transmission signal is a combination of the phase angle, required frequency, the carrier frequency and carrier amplitude, as well as the modulation index.

NBFM Transmission Index:

$\theta_i(t) \rightarrow$ Phase Angle

$f_c \rightarrow$ Frequency of the Carrier Signal

$A_c \rightarrow$ Amplitude of the Carrier Signal

$k_f \rightarrow$ Sensitivity of the Frequency Modulation

$m(t) \rightarrow$ Modulating Signal

$A_m \rightarrow$ Amplitude of the Modulating Signal

$f_m \rightarrow$ Frequency of the Modulating Signal

$\beta \rightarrow$ Frequency of the Modulating Signal

$\Delta f \rightarrow$ Frequency Deviation

NBFM Transmission Calculations:

$$\theta_i(t) = 2\pi \int [f_c + k_f m(t)] dt$$

Equation 1 - Phase Angle

$$m(t) = A_m \cos 2\pi f_m t$$

Equation 2 - Message Signal

$$\theta_i(t) = 2\pi \int [f_c + k_f (A_m \cos 2\pi f_m t)] dt$$

Equation 3 - Phase angle and Message Signal

$$s(t) = A_c \cos \theta_i(t)$$

Equation 4 - Modulated Signal

$$s(t) = A_c \cos [2\pi f_c t + 2\pi k_f \int A_m \cos 2\pi f_m t dt]$$

Equation 5 - Modulated Signal with the Phase and Message

$$\int \cos(2\pi f_m t) dt = \frac{1}{2\pi f_m} \sin 2\pi f_m t$$

Equation 6 - Integration of the Combined Signal

$$\beta = \frac{A_m k_f}{f_m} = \frac{\Delta f}{f_m}$$

Equation 7 - Frequency of the Modulated Signal

$$s(t) = A_c \cos[2\pi f_c t + 2\pi \frac{A_m k_f}{2\pi f_m} \sin 2\pi f_m t]$$

Equation 8 - Final Modulated Signal

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin 2\pi f_m t] \text{ (} 2\pi \text{ cancels)}$$

Equation 9 - Final Modulated Signal After Cancelling

The above calculation has been used in this report to build the FM transmitter. The FM system in figure 1 follows this calculation to create the modulated message signal.

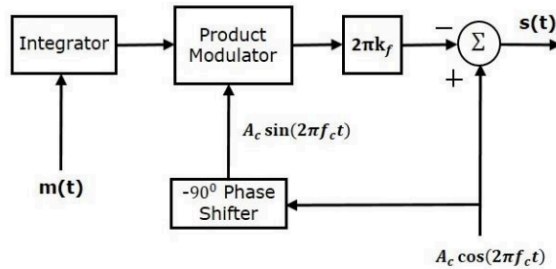


Figure 1 - NBFM Block Architecture [4]

NBFM Modulation and Demodulation

NBFM Modulation

Shown below is a simple system, set out in GNU radio to display and simulate the modulation of an FM message audio signal using the FM transmission calculations. The wav file at a sample rate of 48k and frequency of 2 KHz is multiplied by the modulation index of 0.5 and put through a phase modulation of 1. This signal is then multiplied with the carrier signal to produce the finalised FM transmission signal.

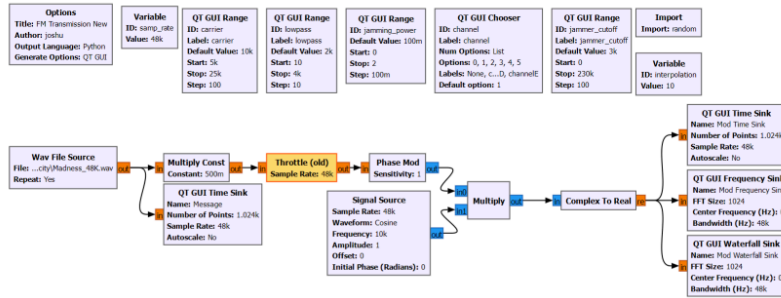


Figure 2 - NBFM Modulation Block Diagram

Shown below is the message signal input for the NBFM system. This signal is produced by using audacity to make an audio recording at a sample rate of 48k which is the desired sample rate of this specific FM system. It can be seen that the audio signal has a fluctuating amplitude between -1 and 1. Using this, boundaries can be set out for the carrier signal which it will be multiplied by.

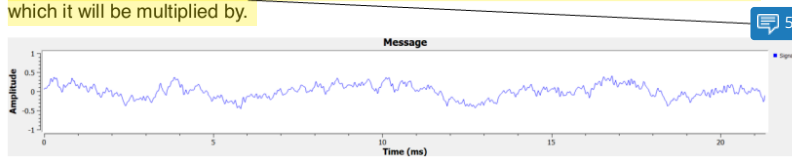


Figure 3 - NBFM Audio Signal in the Time Domain

After the signal is multiplied by the modulation index and the phase, the carrier signal is multiplied in. The carrier signal is used within FM to allocate the frequency required for the signal to be modulated in order for it to be transmitter over the air (OTA). Fm is used in this way as it is the least susceptible of the modulation schemes to outside noise making it perfect for point to point transmission. Shown below is the carrier signal which is a constant cosine wave with the frequency of 10 KHz.

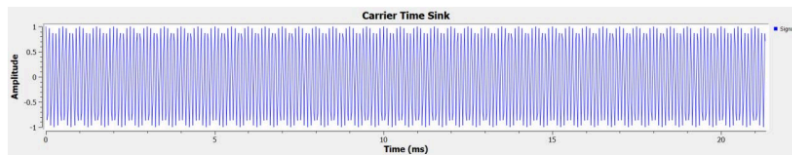


Figure 4 - NBFM Carrier Signal in the Time Domain

NBFM with a Gaussian Jammer

The gaussian jammer set up in this system is done so in such a way that the jamming can be increased or decreased to observe the differences in the signals transmission and receive capabilities. When the jammer is added the noise signal gets considerably distorted due to a change in the frequency outside of the carrier frequencies range. Although similar to the carrier frequency, it can be observed that without jamming, the signal is able to be modulated and can be received normally.

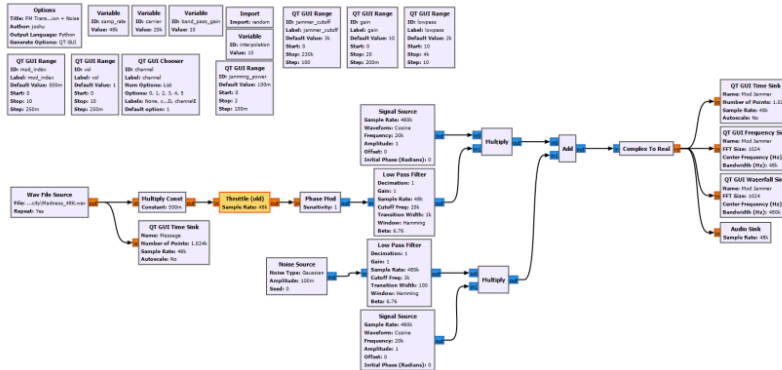


Figure 5 - NBFM Modulation Block Diagram with a Jammer

Figure 5 shows the regular Modulation scheme used before whilst also adding a jammer. This system can mimic a jammer which would be used to intercept over the air transmissions. The system uses a white gaussian input combined with the carrier frequency and added to the main signal. This gives the effect of randomised noise when transmitting that would require filtering before the receiver can obtain the original message signal.

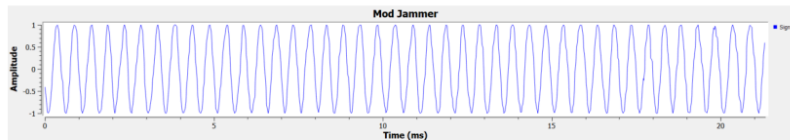


Figure 6 - NBFM Modulation without Noise

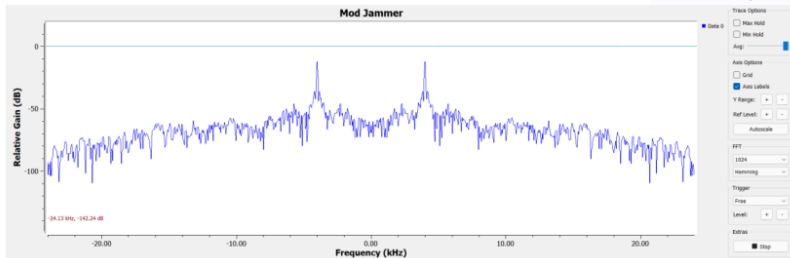


Figure 7 - NBFM Frequency Spectrum Modulation with No Noise

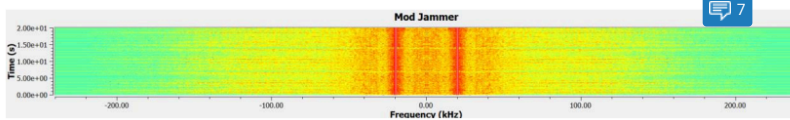


Figure 8 - NBFM Modulation without Noise (Waterfall Diagram)

The spectrum and waterfall here show the two carrier side lobes with the main frequency between the bands. This noise between the bands is just the modulated signal, however it could not yet be received in this format due to the frequency being muddled with that of the carrier frequency.

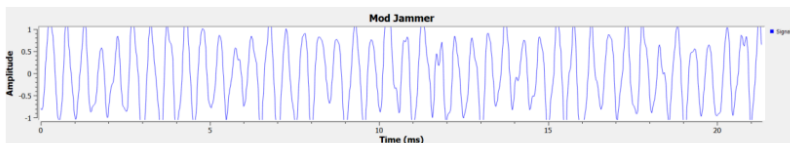


Figure 9 - NBFM Modulation with Noise

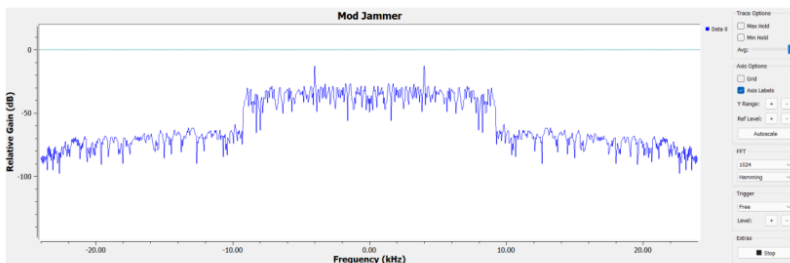


Figure 10 - NBFM Frequency Spectrum Modulation with Noise

As shown here, there message signal can clearly be shown half inside and half outside of the side bands of the carrier frequency. This means that the jammer power is high, and the signal cannot be transmitted without noise. This jamming is shown with the fluctuation in figure 9 when noise has been added.

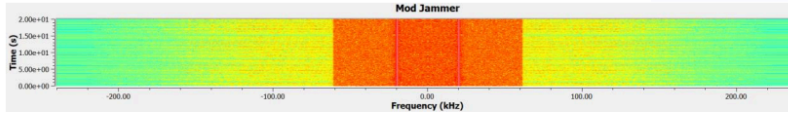


Figure 11 - NBFM Modulation with Noise (Waterfall Diagram)

The waterfall diagram in figure 11 shows the jammer when the power is increased, distorting the signal. This can be shown by the massive orange band proceeding outside of the carrier frequency set at 20 KHz.

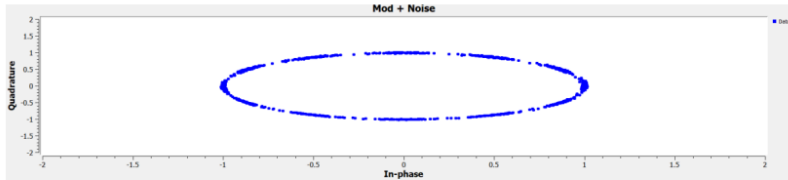


Figure 12 - NBFM Modulation + Noise Phase Constellation Diagram

Figure 12 shows the phase of the modulation and noise in the frequency modulation system. This image shows the phase between 1 and -1 depending on the phase of the sensitivity used.

NBFM with FHSS Anti-Jamming Capabilities

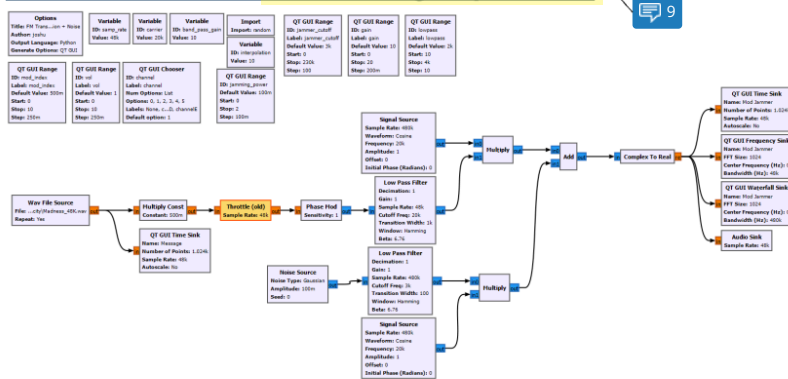


Figure 13 - NBFM Modulation Block Diagram with Jamming and FHSS Anti-Jamming

Frequency Hopping Spread Spectrum (FHSS) is utilised by multiplying the carrier signal by a randomised channel which can be user altered if required. FHSS in simple terms is the changing of the channel used, altering the frequency to avoid any noise or incoming jamming from another external source [5]. The signal source multiplied by the low pass filter carries this capability and allows the user to change the channel, thus changing the carrier frequency, which increases the spectrum range. This allows the required message to be

filtered from the jammer properly before it is received. This anti-jamming capability is widely used in encrypted end to end communications to allow the signal to hop onto other channels to still relay the required high level messages as seen below.

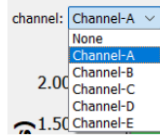


Figure 14 - FHSS Anti-Jamming Channel Select

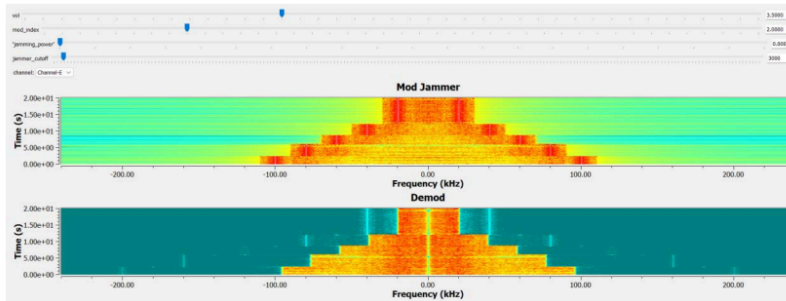


Figure 15 - FHSS Anti-Jamming Waterfall Diagram

The first waterfall diagram in figure 15 above shows the message signal when it is multiplied by the carrier frequency across all 5 channels. As displayed, the modulated signal is altered with each channel which has been chosen due to the signal source carrier frequency being multiplied with the channel number. Channel A is 1, channel B is 2 and so forth. This means that the frequency of the message can change to allow the message to still be passed over the air with the surrounding noise.

The second waterfall diagram shows how the message signal has been demodulated to give the clear audio signal. Like the modulated signal, the demodulated signal adapts the frequency in accordance with the channel selected to allow the signal to be received.

NBFM Demodulation with Tx and Rx Analysis

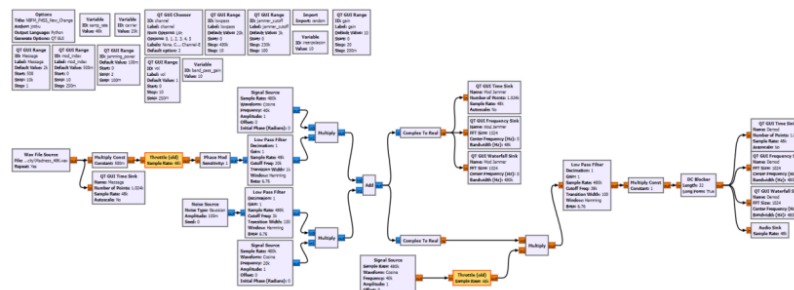


Figure 16 - NBFM Full System with Demodulation

Figure 16 shows the full FM GNU radio system which included FM modulation, gaussian jamming, FHSS anti-jamming and FM demodulation. The message signal is received by demodulating the over the air noisy signal, so the message can clearly be heard. Demodulation is done by multiplying the noisy signal again by the carrier signal multiplied by the user selected channel range. This method allows the carrier signal to be cancelled out from the previous multiplication during the modulation process. The result of this is the original message signal without any noise addition. When transmitting the lowpass filter cut off can be adjusted to help widen the range of the frequencies which the signal can be sent on. This allows multiple signal signals at many different frequencies to be transmitted and received with clarity.

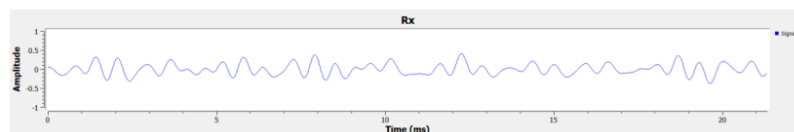


Figure 17 - Receiver FM Signal Demod

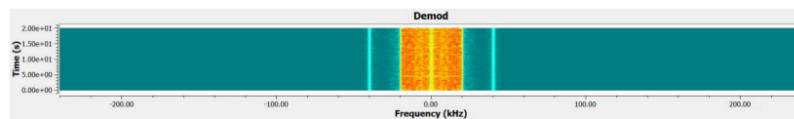


Figure 18 - NBFM Demodulation Waterfall Model

Figure 17 and 18 shows the fully demodulated signal of the FM wav file transmission. The signal can clearly be shown as centred around 0 KHz and well within the 40 MHz frequency carrier band. This means that the signal is being received properly and is able to be played and / or read.

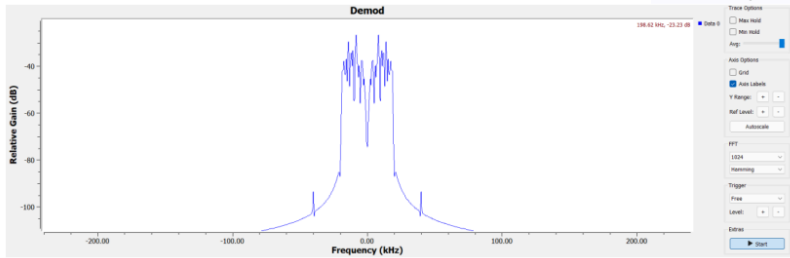


Figure 19 - NBFM Frequency Spectrum Demodulation

The frequency spectrum shown above displays all of the message signal within the carrier frequency bands, to receive a clear signal either side of the central frequency.

Task 2

RTL-SDR Setup and Design

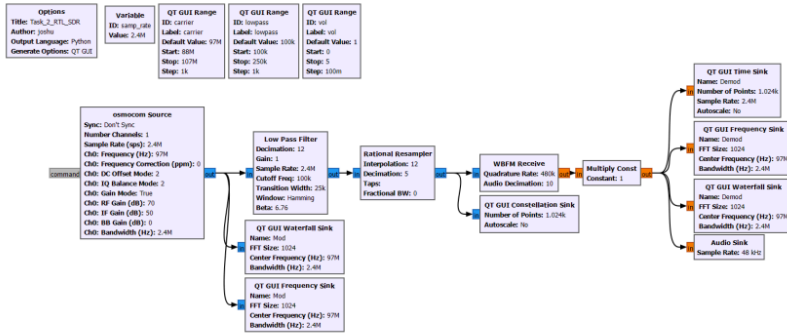


Figure 20 - RTL-SDR GNU Radio Set-Up

$$s(t) = I(t) + jQ(t)$$

Equation 10 - RTL-SDR Equation

The equation above represents the real and imaginary parts of the FM modulator and demodulator for IQ sampling. The real and imaginary parts are split and combined with the carrier frequency to then be passed through the low pass filter. The lowpass filter (LPF) on both the I and Q parts is used strictly for focusing on one particular channel which has been selected to transmit on. The LPF then filters off all of the other channels around this frequency to only allow the transmitted signal to be received.

The decimation factor within the LPF is used as a sample sizer for the incoming signal. The decimation allows the specific number of samples taken from the original signal to be whittled down to a manageable sample size. In this case the sample rate was set at 2.4M samples every second which is a huge file when captured. The decimation factor has been set to 12, meaning that the overall sample size per second is divided by 12 to 200K samples per second. This allows the low pass filter to work at a manageable rate. Every channel within FM operates with a bandwidth of 200 KHz making the samples now equal the bandwidth [6].

The frequency transition width also had to be adjusted to facilitate the sample rate and frequency change. The transition width correlates directly to the size of the frequency band. The bigger the width, the wider the frequency band. After the LPF a rational resampled is used to keep the samples at the same rate ready to be demodulated. These samples then go into the Wide Band Frequency Modulation (WBFM) Block. This WBFM block is used to alter the audio size to be in correct alignment with the 48 KHz needed to represent the inbound FM transmission. This is done by dividing the quadrature rate of 480 K by a decimation factor of 10. The multiply constant at the end of the system is used to increase the volume of the signal so it can be here when received.

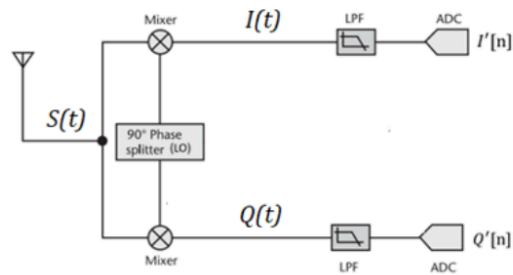


Figure 21 - RTL-SDR Block Diagram

Above is the block diagram which will be followed to create the FM capture.

Wide Band Frequency Modulation (SDR)

WBFM LPF Index:

$m \rightarrow$ Decimation Factor = 12

$f_{\max} \rightarrow$ Cutoff Frequency = 100 K Hz

$f_{\text{sample}} \rightarrow$ Sample Rate = 2.4 M

$f_{\text{sampleNew}} \rightarrow$ New Sample Rate = 200 K Hz

WBFM LPF:

$$f_{\text{sampleNew}} \geq 2 * f_{\max}$$

Equation 11 - New Sample Rate $> 2 * \text{Cutoff Frequency}$

$$f_{\text{sampleNew}} = \frac{f_{\text{sample}}}{m}$$

Equation 12 - New Sample Rate

$$f_{\text{sampleNew}} \geq \frac{2.4 \text{ M}}{12} = 200 \text{ K}$$

Equation 13 - New Sample Rate with Figures

$$200 \text{ K} \geq 2 * 100 \text{ K}$$

Equation 14 - New Sample Rate Calculation Confirmed

$$200 \text{ K} \geq 200 \text{ K}$$

Equation 15 - Final New Sample Rate

WBFM Re-Sampler Index:

$m \rightarrow$ Decimation Factor = 5

$\text{int} \rightarrow$ Interpolation = 12

$f_{sampleNew} \rightarrow \text{New Sample Rate} = 200\text{ K}$

$f_{sampleOutput} \rightarrow \text{Output Sample Rate} = 480\text{ K}$

WBFM Re-Sampler:

$$f_{sampleOutput} = f_{sampleNew} * \frac{int}{m}$$

Equation 16 - Sample Rate Output

$$f_{sampleOutput} = 200\text{ K} * \frac{12}{5}$$

Equation 17 - Sample Rate Output with Figures

$$f_{sampleOutput} = 480\text{ K}$$

Equation 18 - Final Sample Frequency Output

WBFM Receiver Index:

$m \rightarrow \text{Decimation Factor} = 10$

$f_{sampleOutput} \rightarrow \text{Output Sample Rate} = 480\text{ K}$

$f_{audioOutput} \rightarrow \text{Output Audio Sample Rate} = 48\text{ K}$

WBFM Receiver:

$$f_{audioOutput} = \frac{f_{sampleOutput}}{m}$$

Equation 19 - Audio Output Sample Rate Equation

$$f_{audioOutput} = \frac{480\text{ K}}{10}$$

Equation 20 - Audio Output Sample Rate with Figures

$$f_{audioOutput} = 48\text{ K}$$

Equation 21 - Final Audio Output Sample Rate

Signal Analysis and Visualisation

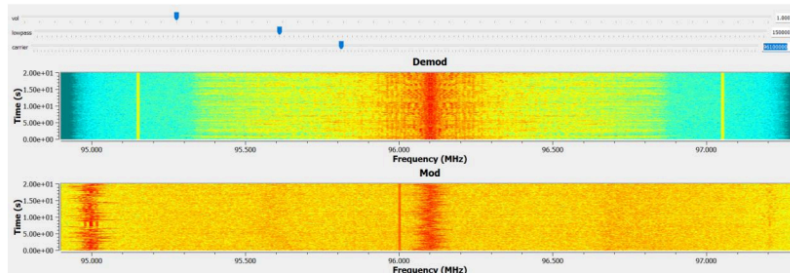


Figure 22 - Modulation and Demodulation of the FM Broadcast Signal

The frequency displayed here in figure 21 is of BBC radio Solent which operates on a frequency of 96.1 MHz. It can be seen that the modulation at 96.1 has a distinct red line where the radio station is transmitting. The modulation here is displayed with general noise from the atmosphere and other frequencies. This noise is effectively a natural jammer for communication systems.

The demodulated signal at the top of figure 21 shows the two side bands of the carrier frequency and the signal along the central frequency of 96.1 MHz. The clear indication that it is a clean signal is most of the transmitted demodulated signal is within this 1.9 MHz frequency band. It can also be seen that there is another frequency channel centring and operating around 95 MHz. Using the carrier frequency slider at the top of the page, the frequency can be adjusted to be able to receive this lower frequency radio station (Fiesta FM).

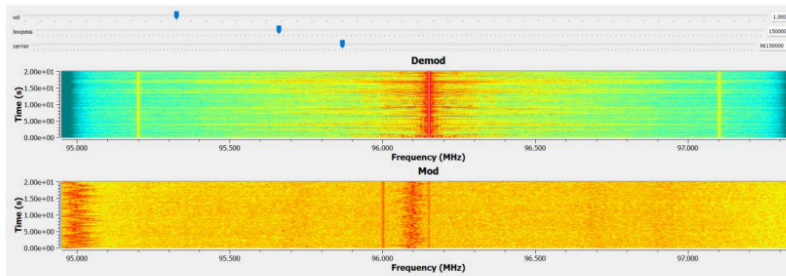


Figure 23 - Modulation and Demodulation of the FM Broadcast Signal (Out of the Carrier)

Figure 22 shows the same frequency section used but shifted 0.05 MHz higher. As shown in the demodulation before (figure 21) the frequency still centres around 96.1 MHz as expected however, now there is a shift the message signal now pushes outside of the carrier bands creating mass distortion of the radio broadcast. Most of the FM channel bandwidth around 0.2 MHz wide with the centre being half of this, meaning that the band can be 0.1 MHz higher or lower than the central frequency [7].

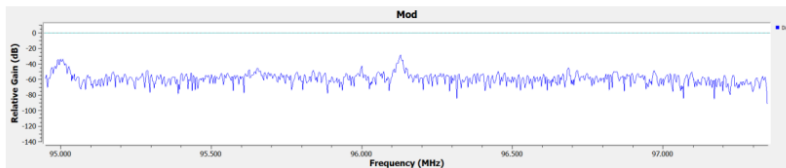


Figure 24 - Modulated BBC Solent FM Signal

The modulated signal above shows the signal after its has been through the lowpass filter. The centre is along 96.1. The noise along the other frequencies is the unfiltered over the air transmission noise. This is shown to be significantly lower than the higher signal spikes at both 95 and 96.1 MHz.

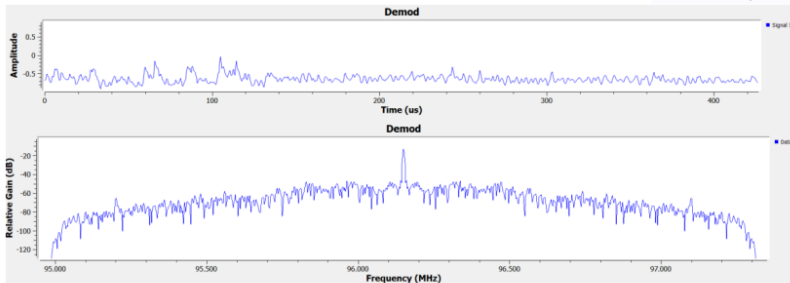


Figure 25 - RTL-SDR Time and Frequency Demodulation Graphs

Figure 24 shows the fully demodulated signal of the FM radio broadcast BBC Solent at 96.1 MHz. The signal is clearly identified in the frequency domain with the spike being centred on the required transmission and receiver frequency.

Ethical Considerations and Impacts

The use of radio frequency within the United Kingdoms domain is controlled, operated and authorised by the Office for Communications (Ofcom). If a required frequency is to be used, Ofcom must be notified to either deny or allow access of the frequency band used as well as, if you're planning to block any channels. This is due to the possibility of accidentally or purposefully jamming a widely used channel such as radio or television. Jamming or restricting these types of channels is highly illegal.

Although jamming is highly restricted and usually illegal, however there are applications where it is necessary to carry out blocking of channels. One main area is for military point to point encrypted radio communication. The jamming is important as military comms, both friendly and enemy, are incredibly classified. This means with the right jamming and filters; the enemies communications could be blocked whilst friendly signals can pass through. Secure communications are generally highly encrypted to isolate and contain highly classified information and it is against the law to use these practices to listen into encrypted or secure radio and satellite communications.

If communications in and around the UK are not regulated, there could be mass panic or dangerous incidences like attacks or no telephone usage due to unrestricted jamming or secure comms leaks.

Conclusion

After reviewing NFBM and FHSS, it can be found that the introduction of a filter and frequency hopping can be used to avoid jamming capabilities. By using FHSS the user can hop between multiple channels in order to avoid the singular channel which is being blocked to disrupt data communications between two parties. This anti jamming, in this capacity, is extremely effective however, in real world applications this method may not be the best way to avoid signal blocking. This is due to the simulation within this report having a refined amount of noise as opposed to real world noise or jamming. Although the concept may be the same, when transmitting over the air, there are many more complications with an amassed amount of noise to filter off. This is shown by the volume of noise within the WBFM SDR testing in figure 22.

Considering the factors stated above, an improvement for the next iteration of this work would be to add more lowpass or band pass filters could help with restricting wider band frequencies when radiating. This would help to filter away more unwanted noise surrounding it attempting to block the signal from reaching the receiver.

Overall, the project shows that there is a capability for anti-jamming techniques such as FHSS and WBFM. Factors such as the frequencies being used can be adapted to solidify the data within this report and establish advances which can be made to the systems to increase their adaptability to different levels of jamming techniques.

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JJP-ACDA6018-ADSP-Final_Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

77 /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 understanding of Frequency Modulation (FM) is presented. However, it would be beneficial to briefly mention the classification of FM and its block diagram for a more structured understanding.



Comment 2 | Engagement with Lit (20)

The application of anti-jamming techniques is discussed, but it would be more effective if the effects of jamming or its consequences were explained before introducing anti-jamming strategies.



Comment 3 | Knowledge & Understanding (20)

The conceptual architecture of FM is well explained, including mathematical expressions.



Comment 4 | Knowledge & Understanding (20)

It is commendable that the derivation of these expressions and how they apply to each traditional block is noticeable.



Comment 5 | Knowledge & Understanding (20)

A brief outline of how the signal is processed in the designed Narrowband FM (NBFM) GNU Radio blocks is provided.



Comment 6 | Cognitive Skills (20)

It would be better to specify the values of the modulation index, bandwidth, and frequency deviation, along with an explanation of how these values are chosen.

**Comment 7** | **Practical Skills (25)**

Observations from the sink outputs are well made, allowing for a comparison of the signal's performance with and without noise.

**Comment 8** | **Cognitive Skills (20)**

The analysis of the waterfall sink is insightful, particularly in explaining how noise dominates the actual signal.

**Comment 9** | **Cognitive Skills (20)**

The advantages of FHSS should be discussed. The role of frequency hopping as an anti-jamming technique should be clearly stated.

**Comment 10** | **Knowledge & Understanding (20)**

A clearer explanation of the conventional blocks of FHSS is needed to provide a more comprehensive understanding of its implementation.

**Comment 11** | **Knowledge & Understanding (20)**

The concept of using Frequency Hopping Spread Spectrum (FHSS) is introduced, with frequency hopping mentioned.

**Comment 12** | **Practical Skills (25)**

The effects of anti-jamming are evident in the waterfall diagram, demonstrating its effectiveness.

**Comment 13** | **Practical Skills (25)**

A strong understanding of the GNU Radio procedure is reflected in the explanation, particularly in describing how channels function.

**Comment 14** | **Cognitive Skills (20)**

Observations should also focus on what exactly happens during this process and how the jammed signals are recovered at each stage, ensuring that all critical points are captured.

**Comment 15** | **Cognitive Skills (20)**

The use of the decimation factor is well explained, and a brief mention of how it is set in this design is provided, which adds clarity.

**Comment 16** | **Cognitive Skills (20)**

The real and imaginary components of the SDR receiver are well represented, with appropriate mathematical expressions, which is commendable.

**Comment 17** | **Cognitive Skills (20)**

Mathematical calculations are included, providing clarity on the experiment, which is commendable.

**Comment 18** | **Knowledge & Understanding (20)**

Each block of the design is thoroughly explained, and the signal processing steps are well documented.

**Comment 19** | **Cognitive Skills (20)**

The output audio signal, the frequency at which it operates, and supporting screenshots are clearly presented.

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

The effects of jamming are discussed under ethical considerations, there is a lack of discussion regarding secure communication, interference, and privacy concerns. More points addressing these aspects should be included.

**Comment 21** | **Transferable Skills (15)**

Good observations are made in the conclusion. However, it would be beneficial to

extract and highlight key values from sink observations to strengthen the analysis.

PAGE 21



Comment 22 | Engagement with Lit (20)

The references and citations are limited. Expanding the background study with more research would improve the depth of the discussion.



Comment 23 | Transferable Skills (15)

The report is well-organized and follows a clear structure, which enhances readability and comprehension.

GRADING FORM: ADSP_GRADING_TEMPLATE

JOSHUA PORT

77

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.



- Comprehensive understanding of topics with appropriate citations and research, though some areas could be enhanced.
- "• Good understanding of SDR principles with relevant research, though certain aspects in citations or depth could be improved."

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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.
- Basic understanding. Explanations of ethics and benefits are limited.
- Comprehensive knowledge of GNU Radio flow and block functions, though some areas could be elaborated further.
- Basic understanding. Explanations of signal analysis could need more depth.
- Basic understanding. Explanations of ethics and benefits are limited.

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.



- Good setup and understanding of modulation and demodulation, with mostly accurate configuration and interpretation of parameters.
- Excellent analysis of jammer effects with clear and insightful use of visual tools.
- Satisfactory application, limited clarity.
- Satisfactory comparison, limited clarity.
- Limited discussion, vague understanding.
- Demonstrates sound cognitive skills in configuring the receiver, ensuring proper signal demodulation, and managing bandwidth, though with minor inconsistencies.
- Satisfactory analysis with limited clarity or depth in interpreting signal parameters.
- Basic discussion with reasoning about societal benefits and interference management.

13.1

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: Demonstrates excellent practical skills in setting up NBFM modulation and demodulation, introducing a jammer, and implementing FHSS for anti-jamming. Provides detailed and accurate

23.1

analysis using Frequency, Time, Waterfall, and Constellation sinks. Strong comparisons of original, jammed, and anti-jammed signals, clarity, and system performance.

Task 2: Demonstrates excellent practical skills with precise setup and effective configuration of the RTL-SDR receiver. Accurately represents signals using $s(t)=i(t)+jq(t)$, with clear explanations of block functionality and decimation factors. Utilises Waterfall, Time, and Frequency sinks effectively for analysis.

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.



Demonstrates exceptional transferable skills by effectively applying GNU Radio tools to simulate NBFM and RTL-SDR systems, integrating mathematics and communication principles. Provides detailed analysis and clear documentation. Strong ethical reasoning and societal understanding displayed.

13.2