

RPH_Adv_DSP_Assignment

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Submission date: 15-Jan-2025 02:01PM (UTC+0000)

Submission ID: 248549403

File name: 32751_Rhys_Higgins_RPH_Adv_DSP_Assignment_641246_2006408778.docx (6.36M)

Word count: 5108

Character count: 30136



JANUARY 13, 2025

IMPLEMENTATION AND ANALYSIS
OF NBFM JAMMING TECHNIQUES
AND RTL-SDR RECEIVER DESIGN
USING GNU RADIO
ACDA6018

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WORD COUNT: 2748



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Introduction

This report will discuss the implementation of NBFM (Narrowband Frequency Modulation) and WBFM (Wideband Frequency Modulation) and critically evaluate system performance when NBFM jamming techniques are intentionally used to degrade system performance. The use of FHSS (Frequency-Hopping Spread Spectrum) as an anti-jamming technique will also be evaluated to assess its effectiveness against NBFM jamming in the frequency domain. All of the above will be simulated and implemented in GNU Radio.

Also considered in this report is the implementation of an SDR, Software Defined Radio, receiver in GNU Radio for the tuning to and subsequent analysis of a real broadcast WBFM radio signal.

Background Research

FM (Frequency Modulation) Methodology

FM communication refers to the encoding of information onto a carrier waveform through altering the instantaneous frequency of the carrier waveform, shown by Equation 2.

FM is one of the two forms of angle modulation, and it has largely superseded the older AM (Amplitude Modulation) encoding technique for wireless audio communications due to its better noise rejection, through a higher/better SNR (Signal to Noise Ratio) [1].

FM is widely used for radio broadcasting, two-way radio, and digital communications. A common form of FM used in digital communications being FSK (Frequency Shift Keying), where the carrier frequency is shifted to represent binary '0' and '1' [2].

In the context of wireless communication, both WBFM and NBFM may be implemented. The difference between the two being WBFM possessing modulation index of greater than 1, see Equation 3, NBFM being less than 1. WBFM is advantageous as it offers a better signal quality, at the expense of greater spectrum usage (wider bandwidth requirement) compared to NBFM [3].



Jamming Methodology

Jamming may be considered as an intentional denial of service to a means of wireless communication. The fundamental principle of jamming is to decrease the SNR of the targeted wireless system until only noise may be heard in the channel [4]. Jamming may be conducted in two forms, subtle and overt.

The overt method of jamming makes it obvious to the users of the affected wireless system that the communications system has been jammed. Examples of this include this would be Chinese Firedrake Jammer, which utilises a commercial AM Broadcast signal which to jam specific radio stations across South Asia which are unfavourable to the Chinese government, playing a sequence of folk songs at the same frequencies at which the target stations broadcast [5].



The subtle method is intended for the users of the affected system to not realise that their system is being actively jammed. These techniques are far more complex than overt jamming techniques. A somewhat well-known subtle jamming technique would be the use of the FM capture effect. Here, only the strongest carrier of two or more signals at a given frequency will be demodulated, meaning that a simple unmodulated carrier may be used to deny the reception of the modulated FM signal – without any auditory indication that jamming is taking place [6].

FHSS Methodology

FHSS, Frequency Hopping Spread Spectrum, is a technique which attempts to avoid jamming/interception (or even interference) in wireless communications applications. It does this through the rapid pseudo-random changing of the carrier wave frequency across a wide spectral band, defined by the lowest and highest frequency bands used [7] [8]. FHSS is commonly used in the unregulated 2.4GHz (802.11) Wi-Fi bands to avoid interference and is also used for military and law-enforcement applications as a mitigation for multipath fading [9].



Methodologies

NBFM, Jamming, & FHSS

The NBFM implementations discussed within this report will require a low modulation index of $\beta < 1$ and utilise a real audio file, encoded at 44kHz, to evaluate the performance of the modulator and demodulator. A number of 'sinks' will be added, the purpose of these being to capture the source, modulated, and demodulated waveforms in real time [10]. As the modulation index is less than 1 (NBFM), it is expected that the bandwidth and frequency deviation will be lower than that of an WBFM setup ($\beta > 1$) at the expense of an inferior SNR, Signal to noise ratio.

$$m(t) = \frac{3}{10} \cos[2\pi(44,000)t]$$

Figure 1: NBFM audio message signal

The NBFM implementations will have NBFM jamming added to the channel (between the modulator and demodulator) to observe the impact of the jamming on the system performance. Following system failure, FHSS will be added to the model to evaluate whether FHSS is capable of restoring system performance even when jammed.

RTL-SDR WBFM Receiver

An SDR is a radio device where physical layer functions are defined in software which able to transmit and/or receive at radio frequency (3kHz – 300GHz) [11] [12]. The SDR utilised for this will be the Nooelec NESDR Mini, which is based on the RTL-SDR (RTL2832 + R820T) platform [13].

The design will be tuned to receive from a local radio station to ensure best signal quality and will have a quadrature rate of ~100kHz to allow the receiver to capture the majority of the 100kHz channel spacing used in WBFM radio broadcasting in the UK [14] over the 88.0 to 108.0MHz UK FM Radio Frequency Allotment.

Design Flowgraphs

NBFM Modulation and Demodulation

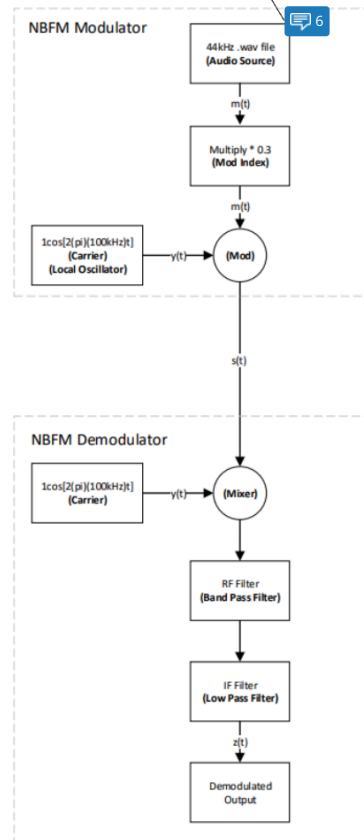


Figure 2: NBFM Modulator and Demodulator Flowgraph

NBFM with jamming

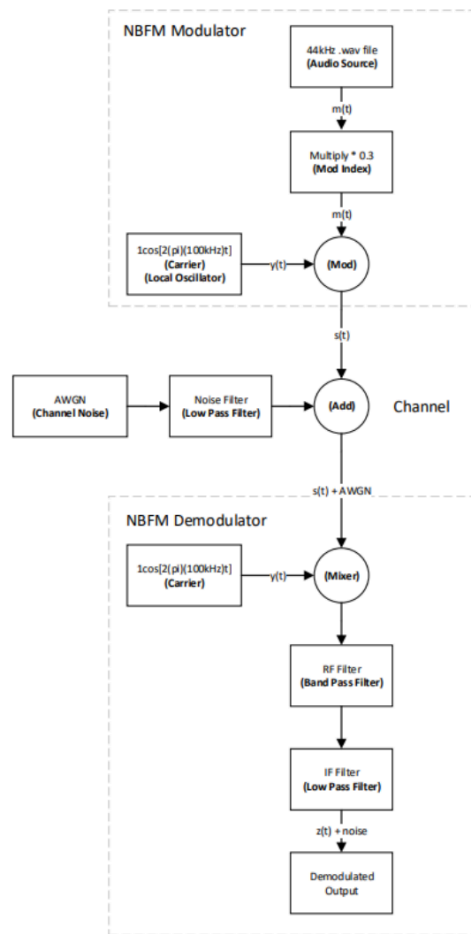


Figure 3: NBFM Flowgraph with channel AWGN (Jamming)

NBFM with FHSS

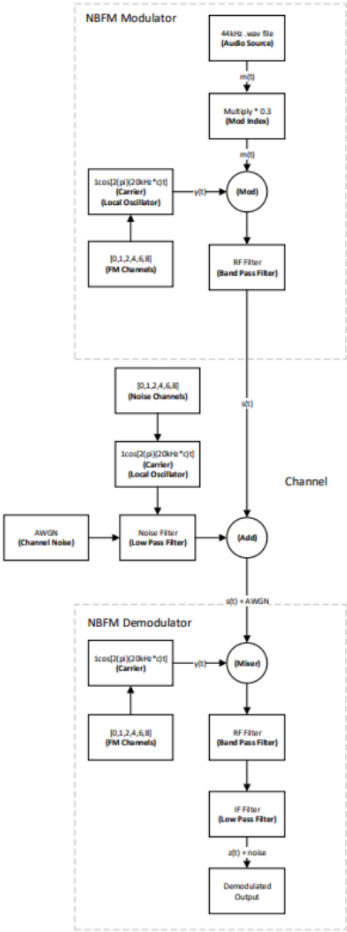


Figure 4: NBFM Flowgraph with channel FHSS

SDR WBFM Receiver

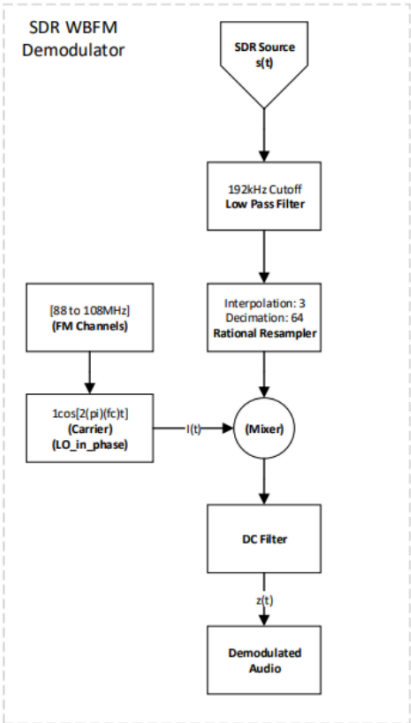


Figure 5: WBFM SDR Receiver (real component only)

Implementation

This section covers the design of both the NBFM Transmitter Receiver (with NBFM jamming and NBFM FHSS anti-jamming) and the design of the RTL-SDR receiver in GNU Radio.

NBFM Modulation & Demodulation

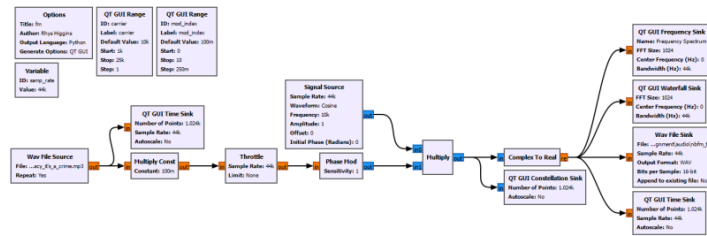


Figure 6: NBFM Transmit

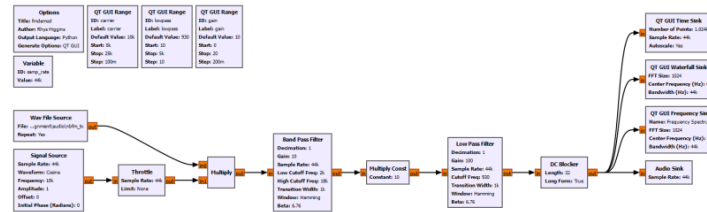


Figure 7: NBFM Receive

Figure 6 and Figure 7 shows an implementation of a NBFM modulator and demodulator, designed to playback a 44kHz single channel (mono) encoded audio file (.wav).

The modulated wave is transmitted along the channel until it reaches the receiver, where it is demodulated, removing the carrier from the signal through multiplication, and then filtered (using a Band Pass Filter first, then Low Pass Filter, and then a DC Block Filter), the demodulated waveform being saved as an audio file (.wav).

A sample rate of 44kHz was used to playback the audio file.

Figure 6 and Figure 7 have the following characteristics:

Modulation Index: 0.3 (0.1 – 0.9, NBFM), Message Frequency: 44kHz, Carrier Frequency: 10kHz, Frequency Deviation: 13,230kHz*, Band Pass Filter Low Cut-off: 2kHz, Band Pass Filter High Cut-off: 18kHz, Low Pass Filter Cut-off: 1kHz, Amplitude: 1, 0.3 (Carrier, Message).

*A modulation index of 0.1 should give a frequency deviation of 13.23kHz when rearranging Equation 5 ($h \cdot f_m = \Delta f$).

NBFM with Jamming

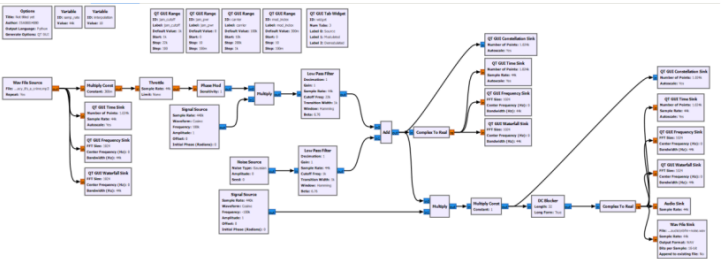


Figure 8: NBFM Transmit and Receive with Jamming

Figure 8 shows an implementation of an NBFM modulator and demodulator with an AWGN (Additive White Gaussian Noise) jammer added within the signal channel. Otherwise, all characteristics of the FM Modulator and Demodulator are identical to that of Figure 6, meaning that the receiver output and system performance will be the identical when the AWGN noise power is off and only differ when the AWGN is added.

The jamming component within the channel is controlled by two variables, Jamming Power (amplitude of jamming signal) and Jamming Cutoff (Frequency cutoff of LPF, Low Pass Filter). These variables allow the Jammer to be tuned in both Frequency and Amplitude.

The range of the Jamming Power variable is from 0 (no AWGN) to 10, controllable in .100 increments, allowing for performance to be evaluated from an SNR of 10:1 through to 1:10.

For the Jamming Frequency, this is tuneable from 1kHz to 22kHz in steps of 100Hz.

NBFM with Jamming & FHSS

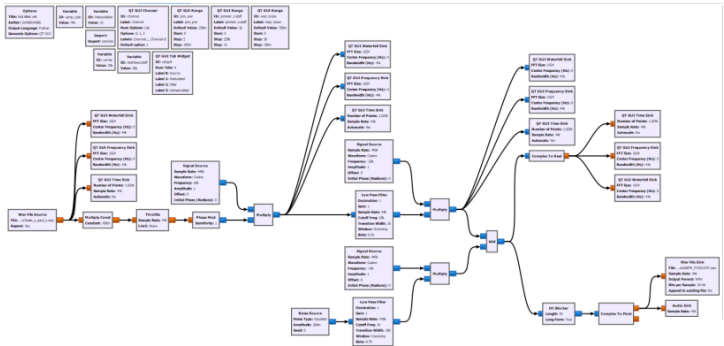


Figure 9: NBFM Transmit and Receive with Jamming & Frequency Hopping Anti-Jamming

Figure 9 is a development of the FM modulation and demodulation implementation shown in Figure 6 and Figure 8.

Where this implementation differs is that an FHSS component has been integrated into the modulator and demodulator design to allow the system to frequency hop across 5-channels in order to try and prevent the received audio from being jammed in the channel.

The frequency hopping component achieved through the multiplication of the channel selection (1,2,4,6,8) with the base carrier frequency (40kHz) in the modulator and demodulator.

RTL-SDR WBFM Demodulation

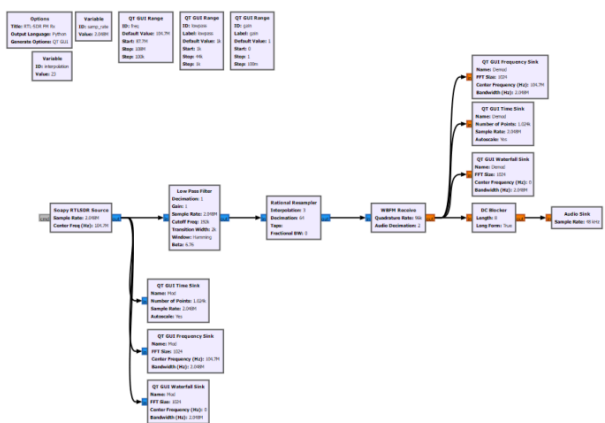


Figure 10: RTL SDR WBFM Demodulation Implementation

Figure 10 is an implementation of an WBFM receiver designed in GNU Radio to receive audio from commercial radio broadcasting stations in the UK, transmitting in the 88MHz to 108MHz band.

The first component is the 'Soapy RTLSDR Source', which is an SDR library intended to interface with a wide range of commercially available SDRs [15]. This block is tied to the QT GUI RANGE 'freq' variable, assigned to the 88-108MHz band, with 100kHz channel width, and a 2048MHz sampling rate. AGC, Automatic Gain Control, has been enabled so that the playback audio volume is at a constant level and not directly proportional to the received signal strength [16].

An LPF is then placed immediately after the SDR source to remove/attenuated unwanted noise/signals above the 100kHz channel [17].

The rational resampler converts the sampling rate of a signal to another sampling rate [18]. This block has been assigned an interpolation value of 3 and a decimation value of 64, given by Equation 12, giving 96kHz of bandwidth, sufficiently close to the allocated channel width of 100kHz used by FM radio stations.

This is followed by the WBFM receive block, used to demodulate the message signal. This block has been given a quadrature rate of 96kHz, 48kHz *2, matching the output sample rate from the rational resampler, the quadrature rate given using Equation 6.

Finally, a DC blocker is used to reference the signal to 0V [19]; the audio sink is then used to output the demodulated signal at 48kHz through audio speakers to validate system operation.

12

13

Sink Screen Captures

NBFM

Source Sink Captures

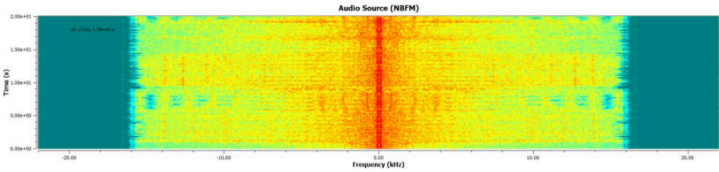


Figure 11: NBFM Source Audio Waterfall Sink

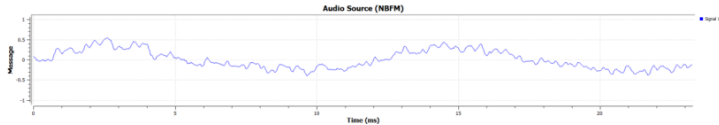


Figure 12: NBFM Source Audio Time Sink

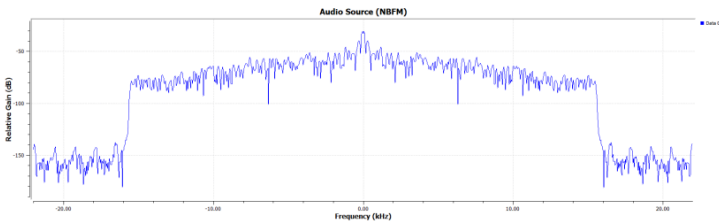


Figure 13: NBFM Source Frequency Spectrum

Modulated Sink Captures

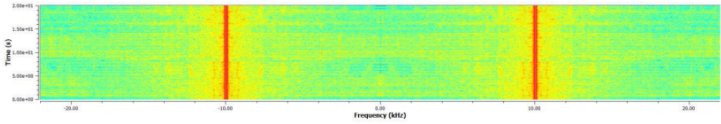


Figure 14: NBFM Modulated Audio Waterfall Sink

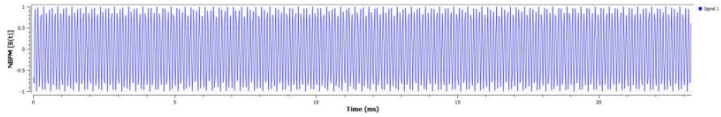


Figure 15: NBFM Modulated Audio Time Sink

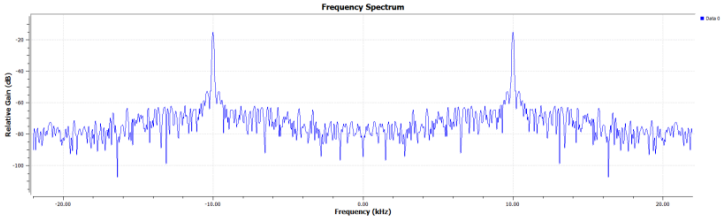


Figure 16: NBFM Modulated Audio RF Spectrum

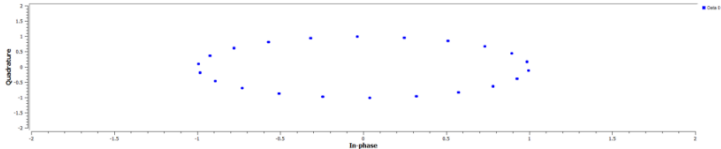


Figure 17: NBFM Modulated Audio Constellation Sink

Demodulated Sink Captures

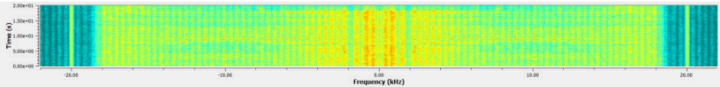


Figure 18: NBFM Demodulated Audio Sink

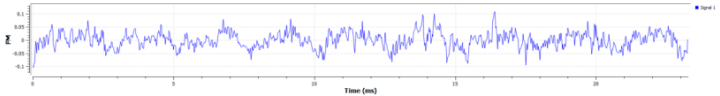


Figure 19: NBFM Demodulated Audio Time Sink

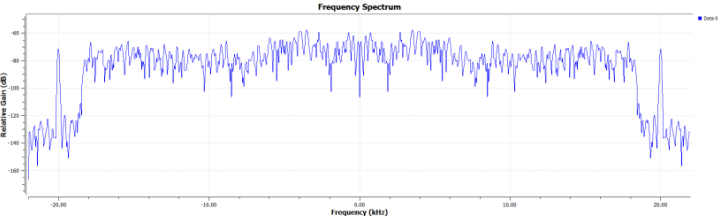


Figure 20: NBFM Demodulated Audio Frequency Spectrum

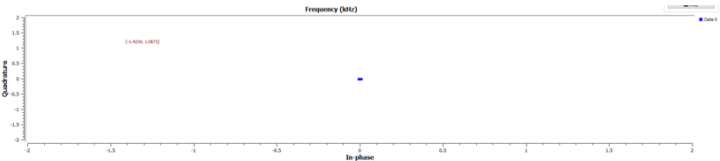


Figure 21: NBFM Demodulated Audio Constellation Sink

NBFM with Jamming

Source Sink Captures

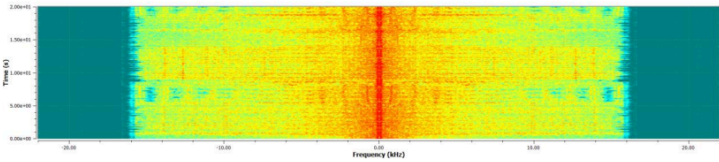


Figure 22: NBFM Source Audio Waterfall Sink

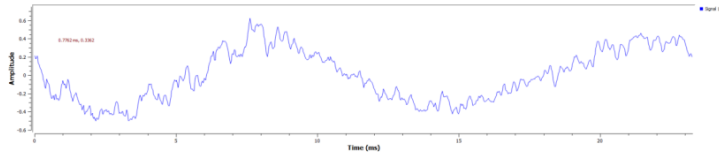


Figure 23: NBFM Source Audio Time Sink

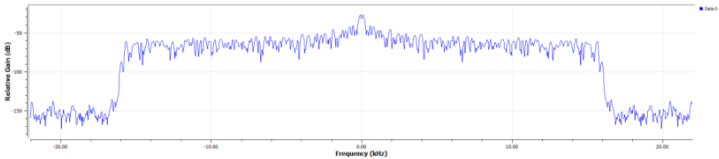


Figure 24: NBFM Source Audio Frequency Sink

Modulated Sink Captures

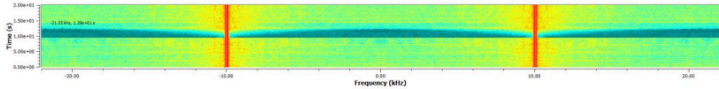


Figure 25: NBFM Modulated Audio Waterfall Sink

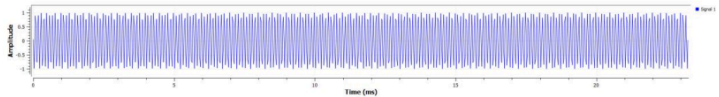


Figure 26: NBFM Modulated Audio Time Sink

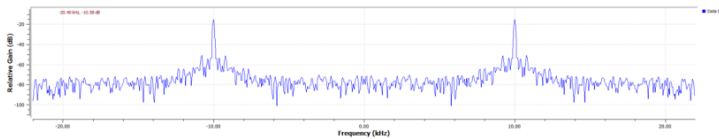


Figure 27: NBFM Modulated Audio Frequency Sink

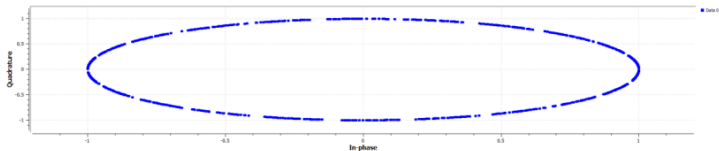


Figure 28: NBFM Modulated Audio Constellation Sink

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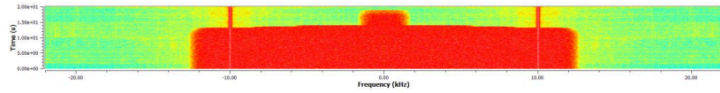


Figure 29: NBFM Modulated Audio Waterfall Sink with AWGN jamming

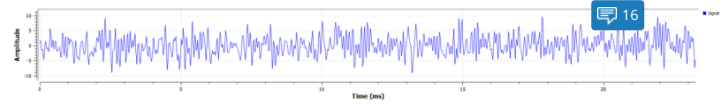


Figure 30: NBFM Modulated Audio Time Sink with AWGN jamming

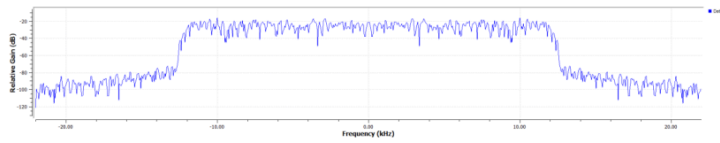


Figure 31: NBFM Modulated Audio Frequency Sink with AWGN jamming

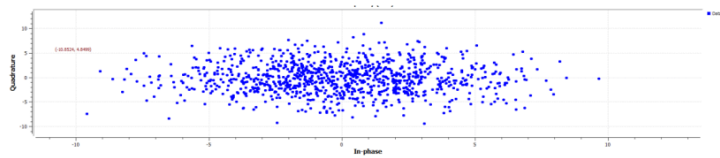


Figure 32: NBFM Modulated Audio Constellation Sink with AWGN jamming

Demodulated Sink Captures

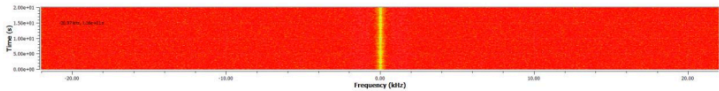


Figure 33: NBFM Demodulated Audio Waterfall Sink with AWGN jamming

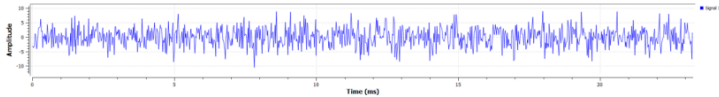


Figure 34: NBFM Demodulated Audio Time Sink with AWGN jamming

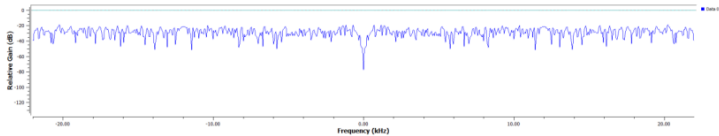


Figure 35: NBFM Demodulated Audio Frequency Sink with AWGN jamming

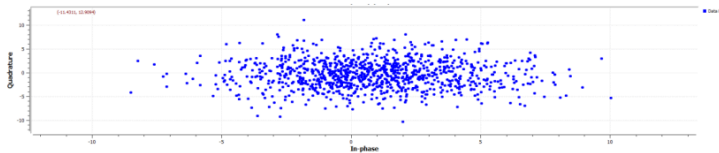


Figure 36: NBFM Demodulated Audio Constellation Sink with AWGN jamming

NBFM with FHSS

Source Sink Captures

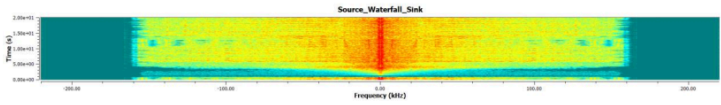


Figure 37: NBFM FHSS Source Audio Waterfall Sink [Channel B]

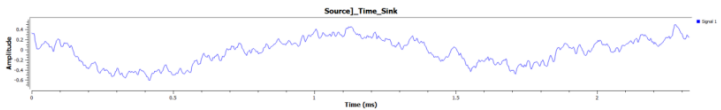


Figure 38: NBFM FHSS Source Audio Time Sink [Channel B]

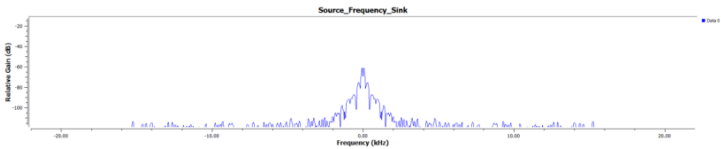


Figure 39: NBFM FHSS Source Audio Frequency Sink [Channel B]

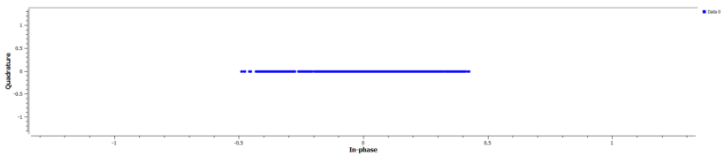


Figure 40: NBFM FHSS Source Audio Constellation Sink [Channel B]

Modulated Sink Captures

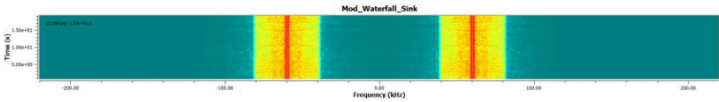


Figure 41: NBFM FHSS Modulated Signal Waterfall Sink [Channel B]

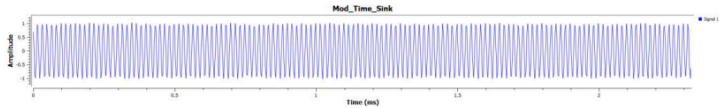


Figure 42: NBFM FHSS Modulated Signal Waterfall Sink [Channel B]

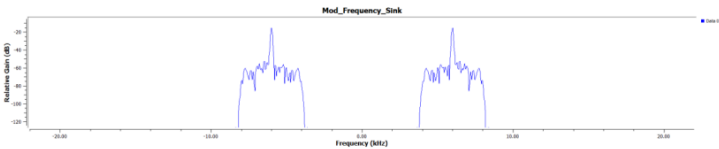


Figure 43: NBFM FHSS Modulated Signal Waterfall Sink [Channel B]

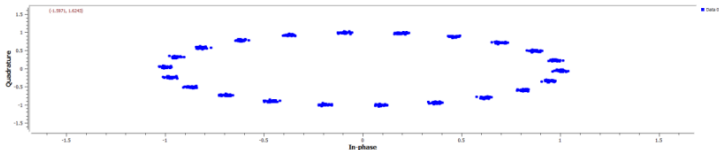


Figure 44: NBFM FHSS Modulated Signal Constellation Sink [Channel B]

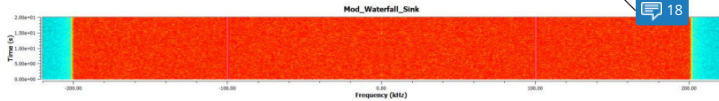


Figure 45: NBFM FHSS Modulated Signal Waterfall Sink with noise [Channel D]

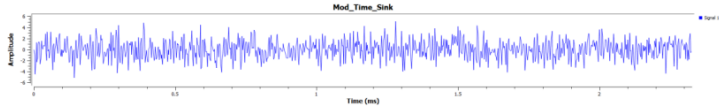


Figure 46: NBFM FHSS Modulated Signal Waterfall Sink with noise [Channel D]

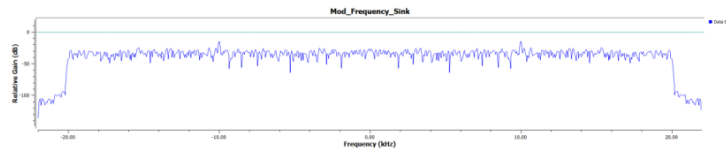


Figure 47: NBFM FHSS Modulated Signal Waterfall Sink with noise [Channel D]

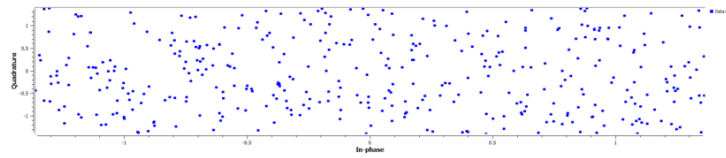


Figure 48: NBFM FHSS Modulated Signal Constellation Sink with noise [Channel D]

Demodulated Sink Captures

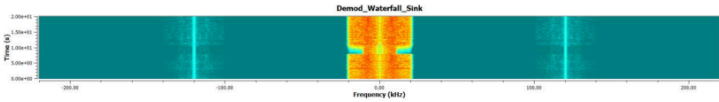


Figure 49: NBFM FHSS Demodulated Audio Waterfall Sink [Channel B]

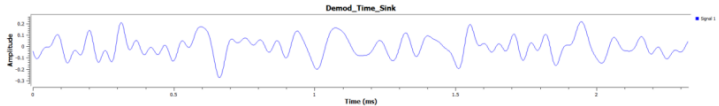


Figure 50: NBFM FHSS Demodulated Audio Time Sink [Channel B]

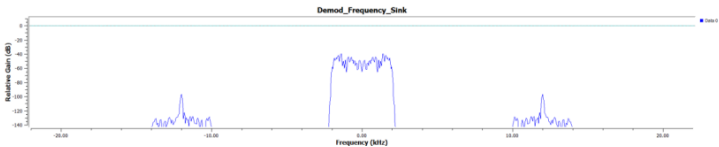


Figure 51: NBFM FHSS Demodulated Audio Frequency Sink [Channel B]

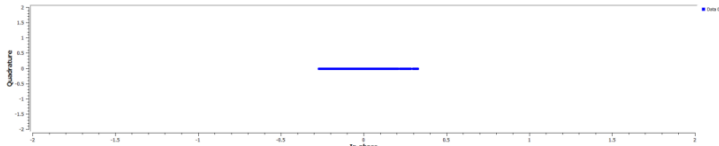


Figure 52: NBFM FHSS Demodulated Audio Constellation Sink [Channel B]

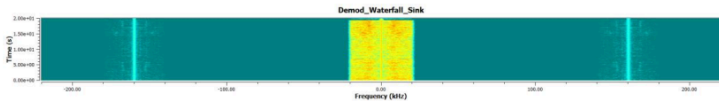


Figure 53: NBFM FHSS Demodulated Audio Waterfall Sink [Channel E]

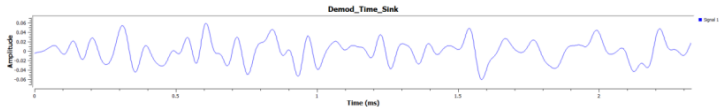


Figure 54: NBFM FHSS Demodulated Audio Time Sink [Channel E]

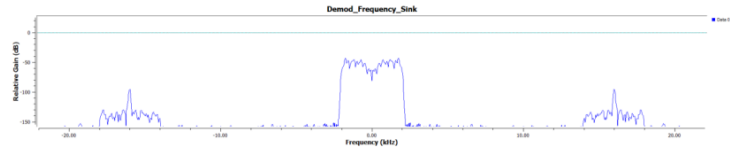


Figure 55: NBFM FHSS Demodulated Audio Frequency Sink [Channel E]

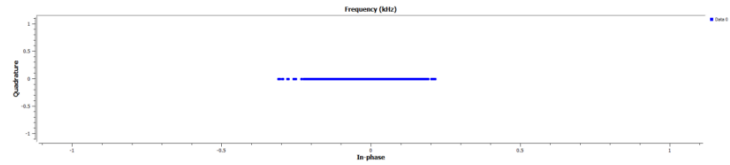


Figure 56: NBFM FHSS Demodulated Audio Constellation Sink [Channel E]

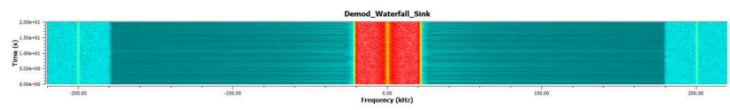


Figure 57: NBFM FHSS Demodulated Audio Waterfall Sink with noise [Channel D]

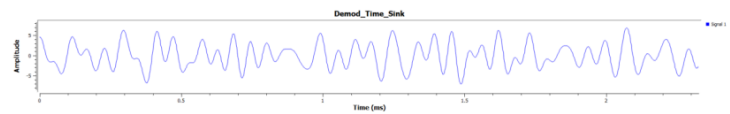


Figure 58: NBFM FHSS Demodulated Audio Time Sink with noise [Channel D]

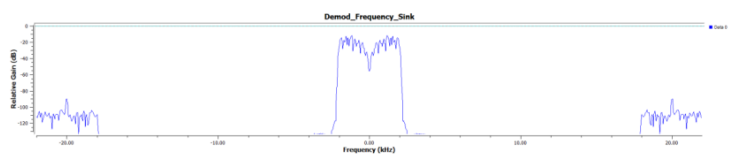


Figure 59: NBFM FHSS Demodulated Audio Frequency Sink with noise [Channel D]

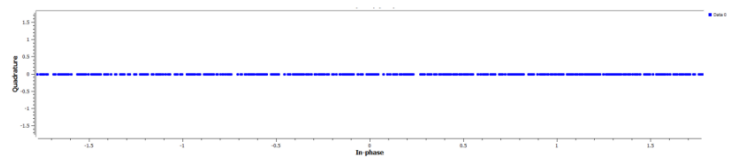


Figure 60: NBFM FHSS Demodulated Audio Constellation Sink with noise [Channel D]

RTL-SDR WBFM Receiver

Modulated Sink Captures

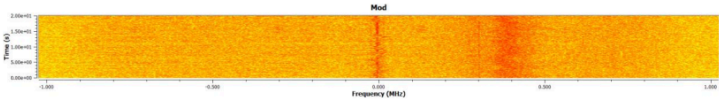


Figure 61: RTL-SDR WBFM Modulated Audio Waterfall Sink

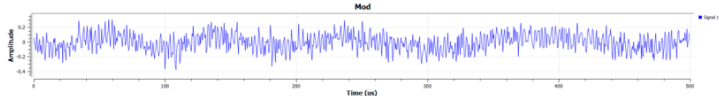


Figure 62: RTL-SDR WBFM Modulated Audio Time Sink

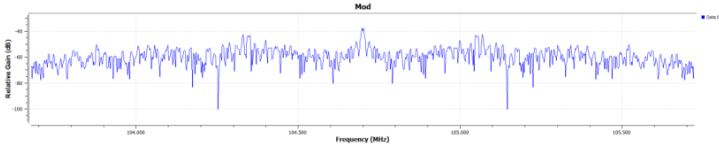


Figure 63: RTL-SDR WBFM Modulated Audio Frequency Sink

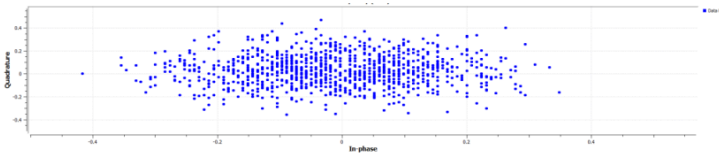


Figure 64: RTL-SDR WBFM Modulated Audio Constellation Sink

Demodulated Sink Captures

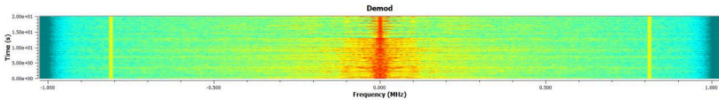


Figure 65: RTL-SDR WBFM Demodulated Audio Waterfall Sink

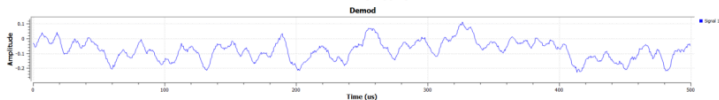


Figure 66: RTL-SDR WBFM Demodulated Audio Time Sink



Figure 67: RTL-SDR WBFM Demodulated Audio Frequency Sink

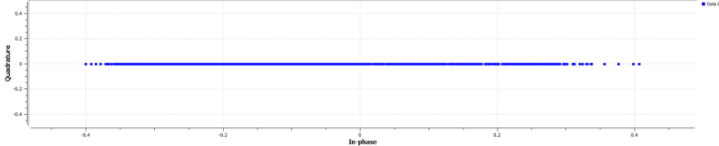


Figure 68: RTL-SDR WBFM Demodulated Audio Constellation Sink

Formulae and Expressions

$$m(t) = A_m \cos[2\pi f_c t]$$

Equation 1: Message Signal (for modulation) [20]

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

Equation 2: FM Modulated Signal [20]

$$\left| 2\pi k_f \int m(t) dt \right| < 1$$

Equation 3: NBFM Modulating Signal Equation [21]

$$s(t) = A_c \cos(2\pi f_c t) - A_c \sin(2\pi f_c t) 2\pi k_f \int m(t) dt$$

Equation 4: NBFM Modulated Signal [21]

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

Equation 5: FM Modulation Index [22]

$$\text{Quadrature rate} = \text{sample rate} \left(\frac{\text{interpolation}}{\text{decimation}} \right)$$

Equation 6: Quadrature Rate [23]

$$s(t) = A \cos[2\pi f_m t + \varphi]$$

Equation 7: SDR S(t) Signal [24]

$$LO_{IN-PHASE} = \cos[2\pi f_o t], LO_{Q-PHASE} = -\sin[2\pi f_o t]$$

Equation 8: Local Oscillator IN-PHASE and Q-PHASE Signals [24]

$$I(t) = S(t) \cdot LO_{IN-PHASE}$$

$$Q(t) = S(t) \cdot LO_{Q-PHASE}$$

Equation 9: Mixer Generated Output I/Q Baseband Components [24]

$$I'(t) = \frac{A}{2} [\cos 2\pi(f_m - f_o)t + \varphi]$$

$$Q'(t) = -\frac{A}{2} [-\sin 2\pi(f_m - f_o)t + \varphi]$$

Equation 10: I/Q Baseband Components Post Filtering (LPF) [24]

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

$$Z(t) = e^{Aj2\pi(f_m - f_o)t + \varphi}$$

Equation 11: Complex Baseband Output Signal [24]

$$\text{Sample rate} = \text{Current sample rate} * \left(\frac{\text{Interpolation}}{\text{Decimation}} \right)$$

Equation 12: Rational Resampler Equation [25]

Results and Analysis

NBFM

The NBFM transmit and receive implementation performed well, as expected considering that the simulation was conducted using a channel without any noise additive.

When comparing the frequency spectrum sink captures of the source and demodulated audio, see Figure 13 (source) and Figure 20 (demodulated), the overall profile and spectral use of the waveforms are similar, with a noise floor of around -140dB present and a signal of -50dB in strength for the demodulated signal and -40dB for the source, meaning that the output audio is 10x quieter than the source audio, as can be seen in the waterfall sinks Figure 11 (source) and Figure 18 (demodulated). However, this can be rectified by amplification of the signal, by a gain factor of 10, after demodulation and filtering (LPF).

22

NBFM Jamming

The NBFM jamming model was able to effectively jam the NBFM audio signal when jamming was applied to the communications channel between the transmitter and receiver.

Indeed, configuring an amplitude of 6 and a span of 12kHz for the jamming signal was effective in raising the noise floor of the system to -20dB, see Figure 31, which ultimately meant that the original message signal, $m(t)$, was unable to be recovered by the demodulator – see Figure 35. Using a higher frequency of noise with less amplitude, was still effective in significantly diminishing the quality of the demodulated audio. Furthermore, using the constellation diagrams given by Figure 28 and Figure 32, the effect of the added AWGN can clearly be seen on $s(t)$, where the quadrature (Q) and in-phase (I) constellation points of the diagram have been significantly altered, affecting the quality of the received signal.

NBFM FHSS

23

The FHSS implementation was able to successfully move to adjacent channels when gaussian noise interference was applied to the current channel. Using the FHSS technique, jamming applied to other channels did not impact the audio demodulation on adjacent channels.

The effectiveness of the hopping sequence can be seen comparing the NBFM waterfall sinks of channel B (60kHz carrier), see Figure 41, to Channel D (100kHz carrier), see Figure 45, and the demodulated audio frequency sinks of channel B, see Figure 51, to channel D, see Figure 59. From these results a single channel change, increasing/decrease the carrier frequency by 20kHz, was effective in avoiding the selected jammed channel, irrespective of noise amplitude. This can further be seen by the constellation diagrams in Figure 44 (Channel B) and Figure 48 (Channel D), where the constellation points (I and Q) of Channel B are similar to that of Figure 17 (NBFM without noise), whereas Channel D has a random correlation of constellation points due to the additive noise in the channel, showing channel B is unaffected by the jamming on channel D.

24

SDR

The SDR implementation was able to successfully demodulate the broadcast WBFM signal from a local radio station, Castledown FM 104.7MHz.

As can be seen in the waterfall sink, Figure 61, the adjacent channels +/-1MHz to the 100kHz channel used by the radio station also had a number of signals present. When compared to

the NBFM models, the SNR of the signal is significantly worse, with a noise floor of -55dB compared to -140dB within the simulations. However, the demodulated audio remained clear and audible at all times.

Discussion

Without additive noise being added to the NBFM signal, it was expected that the demodulated audio would largely be reflective of the original source audio both in terms of amplitude and frequency. From comparing the demodulated audio, $z(t)$, to that of that of source audio, $m(t)$, this hypothesis proved accurate.

When AWGN noise was added to the channel, a significant reduction in demodulated audio quality was observed. This effect was then compounded by raising the cutoff frequency for the low pass filter (used to control the AWGN frequency) or increasing the amplitude of the noise, eventually leading to system failure.

The FHSS technique adopted to recover from the AWGN noise was effective overall. FHSS was able to provide alternative communications channels to avoid the jamming on any given channel of the system. However, the limitations of the FHSS technique, as applied in this report, were that the implementation was unable to detect when the channel is being jammed and relied on the user to manually change the communication channel over.

Within the SDR component of this report, it was observed that with a real signal the noise floor was higher, resulting in a lower SNR. This was not unexpected as the SDR was receiving a WBFM broadcast using an antenna, with the test location (the authors house) being within a slight depression. It was also observed that the antenna supplied with the SDR was susceptible to noise from the charger used with the test system (laptop), the impact being a lower (worse) SNR whilst the test system was charging.

Ethical and Societal Impact



Jamming

In the UK, the use of signal jamming is illegal under the provisions of the Wireless Telegraphy Act of 2006. The maximum fine for this offense is a two-year custodial sentence, a fine, or both [26] [27]. The use of signal jammer apparatus in the UK is governed by Ofcom (Office of Communications), with authorisation delegated to DEMA (Defence Electromagnetic Authority), Ofcom possessing enforcement responsibilities [28].

Jamming is legislated to this extent in the UK as it may be regarded as unethical, having the capability to have a wide-scale societal impact. Indeed, as a consequence of the War in the Ukraine, a large number of GPS (Global Positioning System) navigation systems in commercial aircraft were affected by jamming during April 2024, posing a safety risk to passengers and crew aboard - a state actor being suspected of accountability due to the scale of the jamming [29].

Secure Communication

The ability to communicate securely is paramount to the operational integrity of a plethora of organisations and agencies. The principles of secure communication being the protection of data in transit against eavesdropping/interception [30].

In the context of radio communication, FHSS, alongside reserved (non-public) frequency allocation bands, as previously discussed in this report an oft-used method of ensuring that the communication channel remains secure [31]. FHSS when used for secure communication ensures that emergency services are able to communicate wirelessly and interoperate with minimal interference and are able to maintain public safety and public order [32].

SDR

SDR, Software Defined Radio, by its very nature is a highly configurable method of developing radio modulation and demodulation capability without expensive fixed-function hardware, through the use of software processing on an attached computer platform [33].

Platforms based around RTL-SDR hardware and GNU radio, as used in this report, are highly flexible and configurable (based on a Digital TV tuner) and offer a low barrier to entry to hobbyists and students [34]. Unfortunately, this also means that hostile actors can misappropriate this technology, and may use it to listen to reserved unencrypted private/governmental frequency allocations and also to commit other crime. An example would be capturing the unencrypted signals of keyless car key button presses, via a low-cost SDR, and then utilising these in a re-broadcast attack to unlock a target vehicle for theft/unauthorised access [35].

Conclusion

This report has shown FHSS to be an effective means of allowing for secure communication when narrowband frequency (NBFM) jamming is being used as a means of preventing communication. As well as this, it has shown the low-cost SDR is an effective tool in signal analysis and intelligence.

The limitations of the FHSS technique evaluated in this report, namely it requires manual user intervention, could be overcome through automating the frequency hops and using a more complex algorithm, rather than 5 channels derived from multiples of the carrier frequency. For the SDR, the noise even from local WBFM broadcast was significant and was heavily reliant on antenna placement. A better shielded antenna along with a more opportune location (i.e., outdoors) would have likely yielded a better SNR and therefore a clearer demodulated signal.

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FINAL GRADE

GENERAL COMMENTS

85/100

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)

The advantages and applications of FM are well covered, with a brief introduction to its fundamentals.



Comment 2 | Engagement with Lit (20)

The understanding of jamming is clearly explained, accompanied by a real-time example of jamming a targeted station, which is commendable.



Comment 3 | Engagement with Lit (20)

The concept of FHSS is clearly mentioned; however, it would be more effective with diagrammatic representations to enhance understanding.



Comment 4 | Knowledge & Understanding (20)

The statement regarding the selection of the modulation index is accurate.



Comment 5 | Knowledge & Understanding (20)

The definition and necessity of SDR are well explained.



Comment 6 | Knowledge & Understanding (20)

The flow diagram for all tasks is neatly presented.



Comment 7 | Cognitive Skills (20)

The values used in designing NBFM are clearly stated.



Comment 8 | Cognitive Skills (20)

The necessary formulas for calculating frequency deviation are appropriately

applied.

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Comment 9 | Practical Skills (25)

All tasks are effectively demonstrated using GNU Radio blocks, as evident from the screenshots.



Comment 10 | Cognitive Skills (20)

The impact of noise on frequency and amplitude to analyse jamming effects is well documented.

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Comment 11 | Knowledge & Understanding (20)

Further explanation is needed regarding the working of FHSS techniques in GNU Radio blocks.

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Comment 12 | Cognitive Skills (20)

The design of SDR blocks in GNU Radio is well captured, with each block's usage.



Comment 13 | Cognitive Skills (20)

The functionality of the blocks and how the values are given to the blocks are properly explained.

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Comment 14 | Practical Skills (25)

A good signal without Signal is well captured.



Comment 15 | Practical Skills (25)

The time, frequency, and waterfall representations, constellations of NBFM are clearly visible in the screenshots.

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Comment 16 | Practical Skills (25)

Applying the Jammer is evidently seen. The Sink represents clear understanding of the concept which is appreciable.

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Comment 17 | Practical Skills (25)

Well capture, this explains how the signal is distorted.

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Comment 18 | Practical Skills (25)

The different sink representation shows a clear idea on the distortion of signals and still responding to the audio signal with less noise. Keep the work!

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Comment 19 | Practical Skills (25)

The working of the FHSS are checked and it is working effectively satisfying the Task 1.

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Comment 20 | Cognitive Skills (20)

Formulas
such as the decimation factor and complex function capturing are included.

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Comment 21 | Knowledge & Understanding (20)

The
comparison of SNR values for NBFM and WBFM is well done and appreciable.



Comment 22 | Cognitive Skills (20)

The
analysis of NBFM is well conducted, with good observations made regarding the noise floor when signals are jammed.



Comment 23 | Transferable Skills (15)

The
conclusions drawn from the analyses are strong, though they could be enhanced by incorporating additional parameters such as signal distortion levels, SNR values, and power values.



Comment 24 | Practical Skills (25)

The
FHSS analysis is well presented, though it could be improved by including noise floor values.

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**Comment 25** | Transferable Skills (15)

Ethical considerations regarding signal jamming and the inclusion of emergency services in secured communication are well discussed. The example of unencrypted signals highlights the depth of ethical considerations in using RTL SDR.

**Comment 26** | Engagement with Lit (20)

The report maintains a good flow and The extensive use of reference materials adds depth to the writing, making it more credible and well-researched.

**Comment 27** | Engagement with Lit (20)

The inclusion of multiple references is commendable, with proper citation usage.

**Comment 28** | Transferable Skills (15)

The report maintains a good flow and structure throughout. However, further explanation is required on FHSS concepts and how the GNU Radio blocks operate based on FHSS principles. The sinks are well captured, with the impact and performance of noise clearly evident in the constellation diagrams. The extensive use of reference materials adds depth to the writing, making it more credible and well-researched.

GRADING FORM: ADSP_GRADING_TEMPLATE

RHYS HIGGINS

84.80

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.
- Excellent understanding of SDR receiver principles and signal representation. Research on SDR technology is thorough and well-cited.

17.5

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.
- Excellent understanding of jammer and its effects on frequency, time, waterfall, and constellation.
- Satisfactory understanding. Basic explanations, but limited detail or accuracy.
- Strong grasp of signals, with clear explanations, but some aspects in SNR or performance analysis require improvement.
- Good understanding of ethics and societal benefits, with scope for more detailed insights.
- Comprehensive knowledge of GNU Radio flow and block functions, though some areas could be

14.7

elaborated further.

- Well-developed understanding of signal analysis, with clear explanations, but stage comparisons or SNR details could be refined.
- Good understanding of ethical considerations and societal benefits, with minor gaps in detail.

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.
- Effective application of FHSS for jammer mitigation and signal comparison, though with some scope for improvement.
- Well-reasoned comparison of signals, with a fairly detailed analysis of SNR and performance.
- Logical reasoning in discussing ethics and societal benefits of secure communication, though with some areas needing further elaboration.
- Demonstrates sound cognitive skills in configuring the receiver, ensuring proper signal demodulation, and managing bandwidth.
- Displays good analytical skills in interpreting signal parameters like SNR and modulation index, with appropriate use of visualisation tools.
- Provides well-structured reasoning in evaluating ethical considerations, societal benefits, and managing interference.

16.1

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

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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. Constellation diagrams are used to verify SNR and signal stability, with detailed comparisons across stages.

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

13.5

documentation. Strong ethical reasoning and societal understanding displayed.