

2112087-ADSP

by Jacob Brown

Submission date: 12-Jan-2025 02:43PM (UTC+0000)

Submission ID: 248089212

File name: 32800_Jacob_Brown_2112087-ADSP_641246_48285716.docx (39.45M)

Word count: 3005

Character count: 16394

Advanced Digital Signals
Processing and
Communication

ACDA6018

Implementation of narrow
band jamming and hopping
techniques with RTL-SDR
Receiver design utilising GNU
radio

2112087

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Abstract

This paper investigates the ease of use and comparison between an unfiltered narrow band frequency modulated signal against its filtered counterpart, then considering the impact that jamming has on this signal. Further on, it also designs and demonstrates the GNU flow and python scripting required for a fully operational modulated and demodulated FHSS signal with interference. Finally, an RTLSDR system shall be designed to allow for a basic receive function.

Introduction

Jamming as a technique has existed in many forms for a long time now, typically characterised by two main approaches, broad and narrow band jamming[1] In an increasingly utilised frequency spectrum, the

ability to avoid high power is high amongst industrial interest, with telecommunications companies seeking to optimise even further upon existing models, there is no question as to how valuable band management techniques might well be to ensure a continued high level of functionality for the plethora of services dependant upon this infrastructure in the event of targeted disruption.

This report shall seek to outline the process around designing an SDR structure as appropriate for hopping with an accompanying jamming protocol to emulate a user that could otherwise interfere with the device if not for its avoidance mechanisms. Additionally, this report shall also outline the design of an RTLSDR system in such a way that it will be fully conducive to use with a FM radio.

Literature Review

Following a literature review, there are several key takeaways. Following studies conducted by Renato Ferriera[2], it seems that the application of jamming upon SDR systems is not universally adopted, but an increasingly popular and promising field, along with an increasing demand for jamming following additional usage of UAVs, leads to a high rate of adoption globally, though this paper mostly focuses on the implementation of barrage jamming, a method that is already ubiquitous globally and hosts an array of its own issues.

Possibly one of the most relevant papers was published by a R. S. Goswam[3], amongst others and seeks to outline and analyse NBFM and its use on an SDR. While this does little to investigate the jamming side particularly, it produces some useful insights into the function NBFM and particularly how this could be designed to function within GNU radio. This design methodology will likely prove critical to assessing and comparing function against an expected output.

Published in Radioelektronika, Czechia, therein the 2019 conference notes were published an introspective and design log for Civilian Unmanned aerial systems and implementation of frequency hopping within GNU radio for this purpose[4]. While it is one intended for drone use, it is a somewhat universal design, with the radio processing blocks being easily modular and adaptable, which will provide a great aide in design, with a useful basis for hop synchronization. However, due to this system using a preprogrammed vector, it would not be of as great a use in a responsive system, as it is a non-random sequence.

Finally for this analysis is the another with a focus on jamming, this time with a focus on WiFi published by Jorge Alberto Duarte Garcia[5]. This provides an incredibly useful source for analysing the effectiveness of jamming against a complex frequency environment, due to the fact that most variations of WiFi and indeed, some of those analysed within this report are ones that utilise QAM, it proves to have a great level of similarity to the proposed system for this project in particular. Due to this similarity, it can prove as both a verification, while also demonstrating how Gaussian noise might be a valid application for the jamming process itself.

Narrow Band Frequency Modulation (NBFM)

Assuming the most simple conclusion, it is possible to operate under the assumption that use of combined process blocks inside GNU is perfectly permitted, implementing NBFM within GNU is a simple process that only requires the use of a NBFM receive block. This can also be transmitted with a NBFM transmit block[6]. Considering this simplification, a somewhat simple scheme can be outlined and observed in figure 1.

Figure 2, Above, Frequency and time plots of gain and amplitude

Jamming

Introducing a jamming element necessitates the inclusion of new factors into the design, of course taking the form of a jamming signal. As appears to be an industry standard, Gaussian noise is applied to act as the signal source while passed through a filter to form the jamming signal when combined with a carrier. This is controlled by two new metrics, controllable by the operator. These are the amplitude of the jamming signal and the cutoff for the lowpass filter. The latter of which acts as a control on the width of the frequencies jammed, which will be needed for demonstrating frequency hopping as too wide of a barrage would render it null, while the amplitude acts to adjust interference within that selected band.

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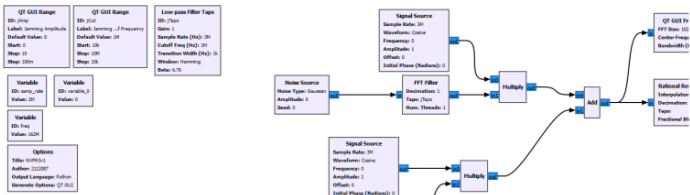


Figure 3, Above, first iteration jamming signal flow diagram

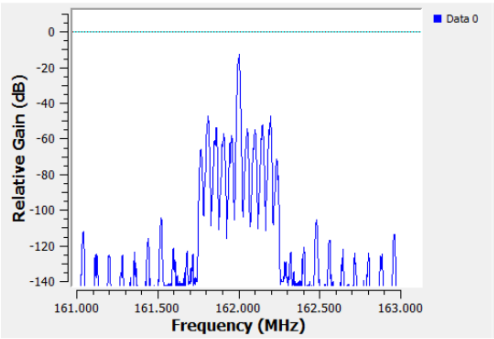


Figure 4, Above, Frequency plot of relative gain pre jamming

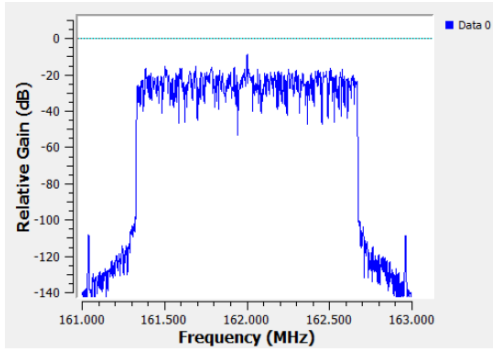


Figure 5 , Above, Frequency plot of relative gain post jamming

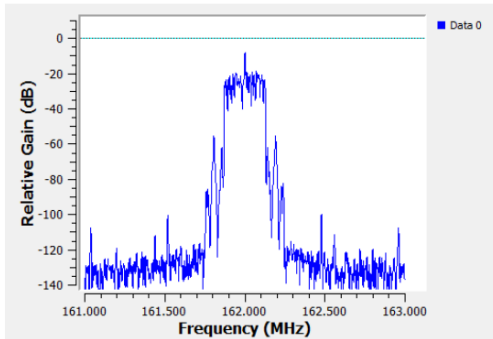


Figure 6, Above, Frequency plot of relative gain post jamming with a reduced jamming power

The above functions perfectly as a static jamming technique, through both optical and audial analysis, laying the groundwork for not only demonstrating the need for FHSS but also for testing the limits to which it may function effectively in the next phase of development.

5

Frequency Hopping

Frequency hopping poses a variety of issues with implementation, while it is fundamentally easy, it is an incredibly difficult task that would require an entire system redesign to operate seamlessly as it requires both a demodulation and modulation component to be synchronized. While it is easy to randomise one end, a seeded random is required to synchronize both. In a proposal for this problem as presented by Muhammed Mustaqim[7] a transmit is provided with no means of reliable demodulation or randomisation, making this a pseudo-representation and not an actually practicable one, as it even this would require an almost complete redesign of the transmit function to incorporate a seeded random outside of a synchronised secondary signal.

This resulted in an almost complete reformatting, following an implementation design principle from a Solomon[8] but requiring some heavy retrofitting to conform to the newer GNU and Python versions, a successful final implementation was created that demonstrated a Jamming signal and a successful frequency hopping spread spectrum broadcast without using additional imports or installs.

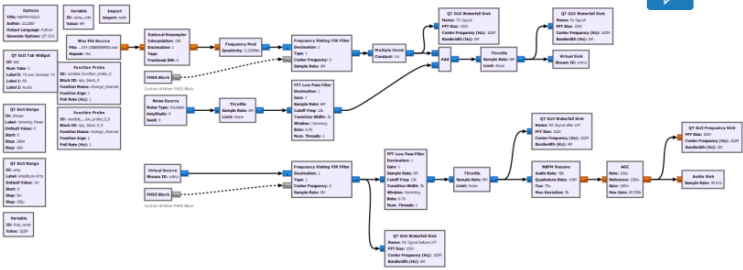


Figure 7, Above, Radio flow diagram of the FHSS receive and transmit system with jamming

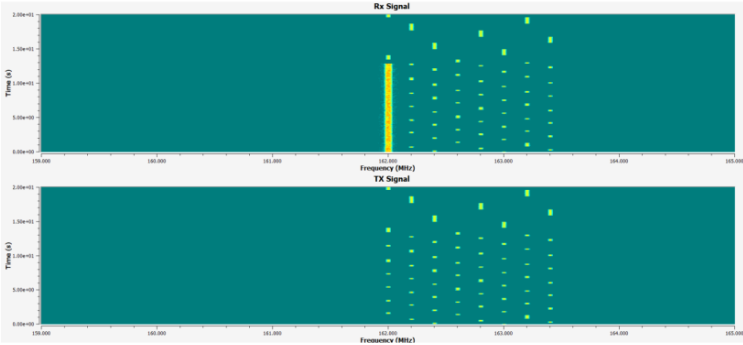


Figure 8, Above, waterfall plot of the post jamming signal and pre jamming signal

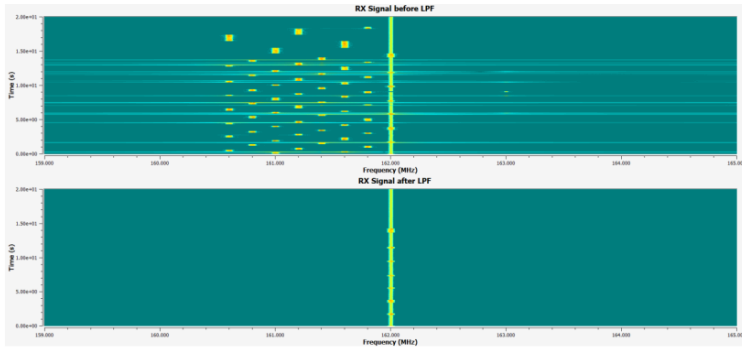


Figure 9, Above, waterfall plots of the pre-filter signal and post-filter signal

The above system, following its readjustments, now filters and resamples in a more transparent manner, displays data more conveniently and essentially surpasses the previous two iterations, performing each of their tasks better, though losing some customisability.



Analysis

The previous jamming and FHSS system is a demonstration of two different approaches to the jamming and NBFM techniques, as well as constructing a functional frequency hopping protocol, though it is regrettably not randomised in order to preserve synchronization. While this would be sub optimal in real function, the fact that this demodulates successfully means that it is an improvement over previously cited methods and would still function effectively against a static jamming pulse.

As can be observed through the graphs in the previous section (Notably in figure 9) The broadcast song, "Mae hen wlad fy nhadau"[9] can still be heard for a majority of the broadcast, only facing notable interference periodically when the frequency hop enters the jammed channel for a second every ~8 seconds. This creates a much clearer audio picture than the jammed signal, regardless of the power transmitted, while the quality of the audio has decreased due to throttling and filtering, it is still entirely recognisable. With the additional bonus of exemplifying two methods of jamming via block arrangement, one of which utilising an FFT while another only using signal sources mixed into a digital resampler on both ends.



RTL SDR Setup and Design

Calculation

The calculation that goes into the design of the RTL SDR receive setup are relatively simple, only comprising of a couple of equations that are best formatted as bellow, the values selected are values conforming to FM radio frequencies and standard resolutions, as such, the actual integers are fairly consistent across a lot of GNU resources.

Input sample rate of 2.048MHz

Rational resampler of decimation 32 to interpolation of 3. Resulting in a factor of 32/3

Using the above factor on the 2.048Mhz results in 192000Khz, the value to be used for the WBFM receiver quadrature.

In the event that a filter is to be applied, assuming the sample rate stays constant the decimation for the filter can be assumed to be 2, this would reduce the rate feeding into the WBFM by half, assuming the factor, 96Khz becomes the new quadrature.

Design

The design methodology is a largely simple one, featuring a relatively small amount of blocks. The system appears to perform both with and without the filter to a relatively high degree of accuracy, partially due to the decimation factor chosen but also partially due to the automatic gain control present inside the soapy source. In order to maintain readings throughout the duration of the system operation, three separate GUI blocks have been included with the capacity to produce waterfall, frequency, constellation and time domain graphs. Figure 10 demonstrates this system flow diagram While this system does lack a power slider, this was deemed unnecessary to include due to the requirements and the alarmingly high volume at which static already played in certain fringe cases, due to this not being listed as a requirement it is assumed to cause no problems in its exclusion.

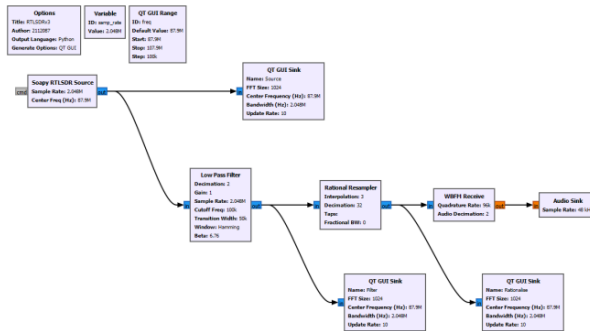


Figure 10, Above, GNU radio flow diagram of the RTL-SDR system

Validation

At first pass, the validation process seems successful, both running older versions without the filter and with the filter, a clearly audible signal can be detected. The primary benefit of choosing the FM frequency to demonstrate the efficacy against means that it is possible to use highly reliable radio station broadcasts to verify the receive capability, particularly classical FM (92MHz) was used as a constant, however this will inevitably change depending on the region this device is used within. This removes the requirement to jury-rig in an audio file and allows validation to be condensed to one step. Within figures 11, 12 and 13 it is possible to observe the expected alterations in waterfall plots, seeing the progression from a distributed and disorderly signal to a mostly coherent, concentrated signal following its processing.

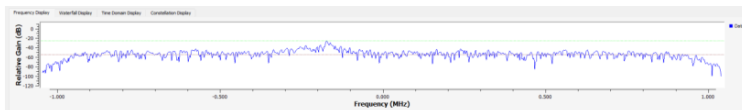


Figure 11, Above, Frequency chart of the post processing signal

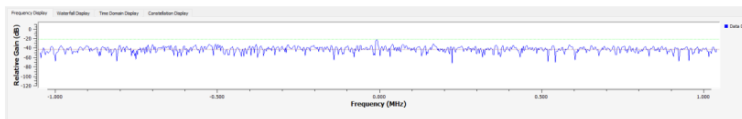


Figure 12, Above, Frequency chart of the unfiltered received signal

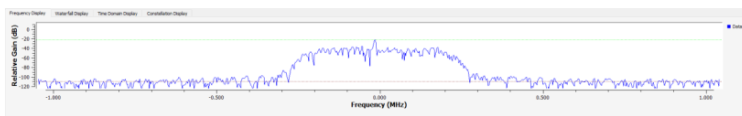


Figure 13, Above, Frequency chart of the post-filter but pre-rationalisation signal

Similar progression can be observed inside the frequency plot graphs, as noted in figures 14, 15 and 16, seeing a distorted signal increasingly split from the noise floor and coalescing into a centre point, creating an audible signal while also conforming to the expected transformations against their point in processing.

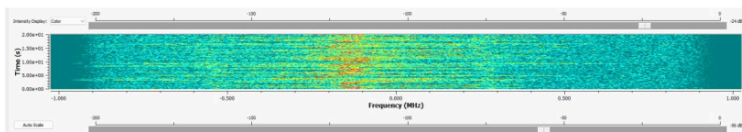


Figure 14, Above, Blackman-Harris waterfall diagram of the post processing signal

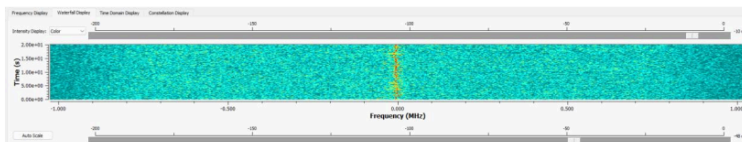


Figure 15, Above, Blackman-Harris waterfall diagram of the unfiltered received signal

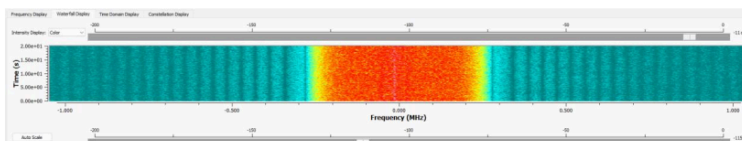


Figure 16, Above, Blackman-Harris waterfall diagram of the post-filter but pre-rationalisation signal

The final step of validation involves considering the signal to noise ratio (SNR). Here we can see a pattern much the same to the previous two plots however, it is also a particularly useful insight as it is possible to observe the coalescence around the centre signal, progressing substantially towards a reduced SNR as processing continues. It is here that one of the main maluses of using FM to validate appears, as the small size of the antenna doesn't allow for a flawless read. As such an exact read is difficult to produce, however, the scale of reduction is noticeable, by an order of a 60% reduction in disparity, between figure 18 and figure 17, as such a directly proportional level of SNR reduction can be observed. While this could be improved it is nonetheless a significant and concrete proof of the efficacy of the system. This efficacy could be further enhanced with the use of a smaller tuning step and larger antenna in a more conducive location.

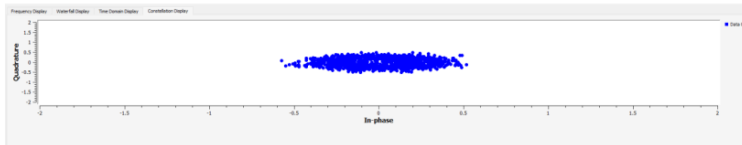


Figure 17, Above, Constellation diagram of the post processing signal

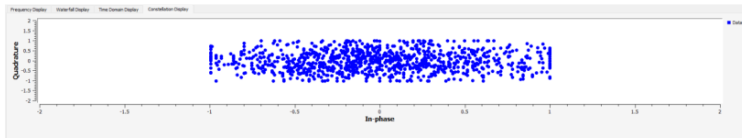


Figure 18, Above, Constellation diagram of the unfiltered received signal

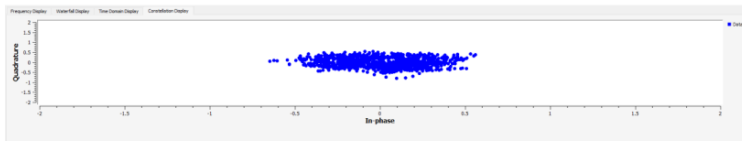


Figure 19, Above, Constellation of signal post filter and pre rationalization

Impact and Ethics

When considering the impact of jamming and frequency hopping, it is only logical to jump to examples within the medical sphere, such as pacemakers and dialysis machines, devices which, even as small interruption could have lethal effects[10]. Additionally, interruptions to the wrong parts of the frequency spectrum could cause equally catastrophic ¹² is, such as interfering with the maritime emergency band and fire and rescue band designations. However, it is also worth noting that, while jamming can have more visible consequences when utilised unethically, frequency hopping can do, too.

Of greatest issue is that of surveillance. If FHSS is utilised by bad actors, particularly in cases ¹³ re those bad actors pair it with other techniques for masking data, dramatic consequences can be recognised. The fact that it creates such a secure channel could render attempts to disrupt events such as smuggling or

trafficking null and void[11], as well as creating a more complex environment to jam similar events with, should the material be proliferated widely.

While these technologies are unlikely to be used by individual bad actors, they could pose a substantial threat if utilised by larger organisations or groups and applied against public interest. possessing a potential to drastically disrupt the deontological basis that underlines the operating ethos currently present in most applications and governmental and militarily operated systems[12]. Hypothetically speaking, this could create an environment where a shift to egotistical doctrine would be required, creating a dramatically more dangerous situation for personnel across all sides of a situation, civilian or combatant.

While these are not risks inherent with broader use of SDR technologies, they are risks of its implementation with a particular focus regarding jamming, it is only necessary to remember the contributions amateurs made to the Falklands war[13] to understand that dissemination of communications systems can prove a vital boon for society and security, provided it is regulated and controlled, allowing for greater civilian interoperability on a tactical level and permitting the freer dispersal of information independent of interference  14 as mentioned can be a double edged sword.

Conclusion

To finalize this report, it can be concluded that narrowband frequency modulation, which then follows the direction of jamming and frequency hopping therein, is a viable solution to both the jamming and jamming avoidance component of a broadcast. Were this system to be utilised anywhere in particular, there are several items that it would benefit from, not limited to an increased quality or at minimum better placement along with a more literal hardware component to test the FHSS system by.

Further research is likely best directed into a statistical modelling of this form of solution against alternatives, such as investigating more intense broadband jamming, which  15 st the limits and require a full seeded randomisation of the frequency hopping. Additionally, conducting an investigation into hardware improvements and ease of implementation, as particular use cases would likely need specified antennas and similar accompanying adjustments, thus comparing it against a particular real-world scenario could be beneficial.  16

Appendix



a8e6-dcca-4b00-afd
4-23686906f603.wav
.wav file for use with GNU

Bibliography

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- [11] Welch Henry, 'Ending encryption - potential implications on human trafficking', Nottingham, Apr. 2022.
- [12] Erwin Stephanie K. and Kirsch Leslie, 'Foundational Theories and Approaches to Ethics Education within the U.S. Military', *Journal of Military Learning - Army University Press*, Oct. 2018.
- [13] Moore Hannah King Ros, 'How two amateur radio enthusiasts secretly passed soldiers' "I am safe" messages during Falklands War', *BFBS Forces News*, Dec. 07, 2022.

FINAL GRADE

57 /100

GENERAL COMMENTS

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 literature review covers various topics, but it should place greater emphasis on discussing key findings related to NBFM, GNU Radio, SDR, and FHSS. Instead of merely summarising previous studies, the review should critically analyse their results, methodologies, and relevance to the research. A more focused discussion on how these technologies contribute to the study would improve depth and coherence.



Comment 2 | Knowledge & Understanding (20)

Regarding NBFM, while the NBFM blocks are shown, it is crucial to discuss frequency deviation, modulation index, and fundamental NBFM concepts, which are currently missing.

PAGE 4



Comment 3 | Practical Skills (25)

Waterfall representations for NBFM should be included for better visualisation and analysis.

PAGE 5



Comment 4 | Knowledge & Understanding (20)

Although the operation of the jammer is mentioned, the concept behind jamming is not well explained.

PAGE 6



Comment 5 | Cognitive Skills (20)

How frequency and amplitude of the signal are affected needs further elaboration. Moreover, the SNR levels and values of signal distortion are missing, which are essential for assessing the system's performance.



Comment 6 | Knowledge & Understanding (20)

For FHSS, while it is evident from the waterfall graph that FHSS has been implemented, the review should explain how the blocks operate by providing a brief explanation of their functionality.

PAGE 7



Comment 7 | Knowledge & Understanding (20)

It is also important to describe the fundamental concept of frequency hopping, including how distorted signals can be recovered using this technique, which is currently absent.

PAGE 8



Comment 8 | Practical Skills (25)

Some constellation graphs are missing, which are crucial for visualising signal integrity.



Comment 9 | Cognitive Skills (20)

The review should address SNR and performance metrics of FHSS with supporting values, which are currently lacking.

PAGE 9



Comment 10 | Cognitive Skills (20)

While some values for RTL-SDR blocks (such as sample rate and decimation) are provided, a more detailed explanation of the blocks would enhance understanding.

PAGE 10



Comment 11 | Practical Skills (25)

It is commendable that various graphs are presented, including post-processing, unfiltered, and pre-rationalised signals. However, a deeper analysis and discussion comparing these signals are necessary to draw meaningful conclusions.

PAGE 11



Comment 12 | Knowledge & Understanding (20)

The discussion on the lethal effects of jamming and the challenges of FHSS in the wrong hands is well articulated.



Comment 13 | Cognitive Skills (20)

The mention of 'interruptions to the wrong parts' is a strong point, but further explanation is required.

PAGE 12



Comment 14 | Transferable Skills (15)

The phrase 'double-edged sword' effectively conveys the risks, but a more detailed discussion on both the positive and negative consequences would add depth to the analysis.



Comment 15 | Transferable Skills (15)

The concepts should be discussed in greater detail, and the graphical representations should be analysed thoroughly, particularly regarding changes in values.



Comment 16

Although the experiment appears to be conducted successfully, the conclusions drawn are limited and could be strengthened

through a more comprehensive discussion of the findings.



Comment 17 | Transferable Skills (15)

While the literature review includes numerous references, the depth of writing remains shallow.

GRADING FORM: ADSP_GRADING_TEMPLATE

JACOB BROWN

56.90

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.



- Limited grasp of topics. Research and citations are vague, with noticeable gaps.
- Limited grasp of SDR principles. Research and evaluation are vague, with noticeable gaps.

8

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.



- Limited grasp of NBFM concepts. Explanations are vague with significant gaps.
- Satisfactory understanding with basic explanations, but limited detail.
- Satisfactory understanding. Basic explanations, but limited detail.
- Minimal knowledge. Little effort in signal explanation and SNR analysis.
- Satisfactory understanding. Basic descriptions, but lacking clarity.
- Basic understanding. Explanations are incomplete or unclear in several areas.
- Limited grasp of signal analysis. Descriptions are vague, with noticeable gaps in comparisons or SNR analysis.
- Basic understanding. Explanations of ethics and benefits are limited.

10.6

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.



- Limited setup, vague parameter descriptions.
- Basic analysis with unclear reasoning.
- Limited application, vague comparisons.
- Minimal effort, significant inaccuracies.
- Limited discussion, vague understanding.
- Limited understanding with vague or incorrect signal demodulation.
- Minimal effort in signal analysis, with significant

8.5

inaccuracies in interpretation.

- Basic discussion with unclear reasoning about societal benefits or interference management.

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: Displays satisfactory practical skills, but with limited accuracy in RTL-SDR receiver setup or signal representation. Block functionality and decimation factors are described, but with insufficient clarity. Visualisation tools are used, but the analysis lacks depth and detailed comparisons.

18.5

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.

11.3

Minor gaps in analysis depth or documentation.
Ethical considerations are discussed but need more detail.