Real-Time Video Transmission using Gaussian Minimum Shift Keying (GMSK) on GNU Radio and USRP for Radiation Monitoring Applications in Nuclear Reactors

Nabiha Ben Abid
Department of Microelectronics and Instrumentation
University of Monastir
Monastir, Tunisia

Abdalla M. Khattab
Department of Computer Science, AlBaha University, Saudi Arabia.
Egyptian Atomic Energy Authority (EAEA), Egypt

Hani A.M. Harb
Department of Software Engineering
AlBaha University, Saudi Arabia

Chokri Souani
Department of Microelectronics and Instrumentation
University of Monastir,
Monastir, Tunisia;

ABSTRACT
Wireless communication has undergone a significant transformation with the explosive expansion of Software-Defined Radio (SDR) systems. By enabling software flexibility and reducing hardware dependency, SDR systems facilitate the rapid development of efficient and adaptable communication protocols. This study introduces a real-time video transmission system built upon Gaussian Minimum Shift Keying (GMSK) modulation, specifically tailored for radiation monitoring applications in nuclear reactors. The system is implemented using GNU Radio and Universal Software Radio Peripheral (USRP) devices, leveraging their robust capabilities for flexible signal processing.

The research meticulously examines the system's performance under various conditions, analyzing key metrics such as Bit Error Rate (BER), latency, and signal quality. While the primary focus is on GMSK, comparative analyses with other modulation schemes, such as BPSK and QPSK, are conducted to highlight the advantages of GMSK in this demanding environment. The results demonstrate the feasibility and reliability of GMSK-based real-time video streaming for critical nuclear facility surveillance, achieving respectable performance metrics crucial for safety and operational awareness. Further enhancements, including improved latency and signal clarity, can be realized through optimizing sample rates and filtering parameters, underscoring the system's potential for robust deployment in high-stakes radiation monitoring scenarios.

General Terms
Wireless Communication, Software-Defined Radio (SDR), Digital Signal Processing (DSP), Modulation Techniques, Real-Time Systems, Data Transmission, System Performance , Nuclear Safety, Environmental Monitoring, Critical Infrastructure.

Keywords
GMSK, SDR, BER, USRP, Nuclear Reactors, Radiation Monitoring, Video Transmission, GNU Radio, GStreamer

1. INTRODUCTION
The escalating global demand for energy, coupled with the critical need for safe and sustainable power sources, has positioned nuclear energy as a vital component in meeting future demands. However, the operation of nuclear reactors necessitates stringent safety protocols, paramount among which is continuous and reliable radiation monitoring. Ensuring the safety of personnel and the surrounding environment requires robust systems capable of accurately assessing radiation levels and transmitting critical data in real time, especially from hazardous or inaccessible areas within nuclear facilities. Traditional monitoring methods often face limitations in terms of human exposure, data latency, and deployment flexibility in complex or high-radiation environments[1].

In parallel, the dramatic advancements in wireless communication and the explosive expansion of Software-Defined Radio (SDR) systems offer transformative solutions to these challenges. By enabling software flexibility and reducing hardware dependency, SDR systems make it easier to build effective communication protocols. SDR technology fundamentally shifts hardware-centric communication problems into flexible, software-driven solutions, significantly reducing hardware dependency and accelerating the development of sophisticated communication protocols. This flexibility is particularly advantageous for specialized applications where custom communication links are required, such as in nuclear safety. Items such as filters, modulators, and converters, traditionally implemented as expensive, fixed-function hardware, are now represented as software blocks in SDR systems . This allows for a wide variety of communication applications to be developed using the same underlying blocks. Wireless communication performance has been improved by using simulation environments that require less time, effort, and expense compared to the real world.

For these reasons and because of the ease of installation of the various components, SDR systems are used [2]. The purpose of these systems is to turn hardware problems into software problems. Since communication hardware is represented by software blocks in SDR systems, a wide variety of communication applications can be developed using the same blocks. SDR systems can be implemented using the GNU Radio environment. The GNU Radio software is free and open-source software that contains signal processing blocks. Communication applications using GNU Radio are designed with the blocks included in this software. These signal processing blocks are created using the C++ programming language. The Python language, on the other hand, connects these blocks to create flowcharts [3]. Some hardware uses SDR to perform communication experiments. USRP (Universal

Software Radio Peripheral) devices that allow sending and receiving radio frequency signals within a certain frequency range are among such equipment. USRP devices allowed personal computers to become high-bandwidth SDR systems [4]. Researchers using these devices can easily design advanced communication systems relevant to various fields, including critical infrastructure monitoring.

Previous research has explored the capabilities of SDR for various real-time video transmission applications. Nimmi et al. [5] aimed to stream real-time video using GStreamer and GNU Radio, using USRP and RTL-SDR devices for capturing, compressing, and encoding camera footage. Dhruv and Vishal [6] transmitted real-time high-resolution video using USRP B210 devices, with video encoded in H.264 format using GStreamer. Rupali et al. [7] used GMSK (Gaussian Minimum Shift Keying) modulation in GNU Radio software after obtaining real-time video. The authors tested the system they created using SDR-LAB kits and examined the effect of modulation techniques on video transmission. Ghani et al. [8] transmitted video obtained via a high-frequency video capture device indoors using OFDM, GNU Radio, and USRP B200 modulation, using bandwidths of 0.5 MHz, 1 MHz, and 2 MHz and obtaining the best results at a frequency of 1 MHz.

It has been demonstrated that secure video transmission can be performed. Debachri et al. [9] aimed to design a dynamic spectrum access network to provide high-definition, 360-degree video streaming. Video coding and adaptation of channel selection were studied, with coding parameters determined based on the characteristics of the received signal. Channel-related parameters such as center frequency and channel bandwidth were adjusted by radio transmitters based on the transmission activities of users. In this study, the best encoding rates were found by a mechanism based on several thresholds. Another mechanism based on the threshold value was used to find the most suitable channel between the receiver and the transmitter. During the testing process, 360-degree real-time video compressed with the H.264 standard was used in a closed environment using USRP and GNU Radio. As a result of the tests, it was concluded that even if the RF (Radio Frequency) conditions change, the video encoder and the USRP devices adapt to the new conditions and the video quality increases with the adaptation studies. Shavanthi et al. [10] performed transmission tests and simulations of a previously recorded video using different transmission modes, modulations, and code rates. Video transmission was done using USRP B210 and GNU Radio. They proposed DVB-T/T2/S/S2 (Digital Video Broadcasting - Terrestrial/Satellite) designs for video transmission. Different sampling rates, transmission types, FFT (Fast Fourier Transform) lengths, modulation types, and code rates were used in the test phase. In this study, it was found that different standards were applied successfully, although there was a delay in the video transmission process. Our study was designed as part of a project to provide high-resolution video transmission between vehicles, to provide transfer of useful information and to get rid of distortions that occur during transmission of analog video signal by transmission between two neighboring vehicles. To this end, high-resolution, real-time video was transmitted wirelessly via the GStreamer library, the GMSK modulation technique, GNU Radio software, and USRP B210 devices. In this system, a laptop computer is used on the receiver side and an NI-USRP device is used on the transmitter side. The NI USRP-2920 has a transmit and receive frequency range of 50 MHz to 2.2 GHz with GNU Radio software.

However, interference, noise, and multiple fades wreak havoc on a reliable communication system. The bit error rate has its own importance in the quality of service (QoS). It is not very convenient to run the performance of the system, so to make it easier there is a platform where we can perform multiple modulation schemes. The SDR platform is much more convenient to use. The output of various modulation techniques such as BPSK, QPSK, QAM, PAM, GMSK, and OFDM has been studied and analyzed in this field using various parameters such as constellation diagram, spectral density, channel capacity, power efficiency, and bit error rate on various platforms, like Matlab/Simulink and GNU Radio [11]. We have looked at the fundamentals of modulation schemes, as well as their performance analysis and requirements. BPSK and QPSK were the modulation schemes we studied to analyze and examine bit error rate (BER) [12].

The objective of this study is to implement and evaluate a GMSK-based system for real-time video transmission specifically tailored for radiation monitoring applications within nuclear reactors. The system is tested under both simulation and hardware conditions, and its performance is benchmarked against BPSK and QPSK modulation schemes to highlight its suitability for such critical environments.

This work is divided into three parts: at the beginning, we describe the methods and materials of our system, then we discussed two basic techniques BPSK and QPSK and evaluated their performance parameter like Bit Error Rate (BER) using GNU Radio over USRP; The simulations, results and interpretation of the development of a GMSK transmitter and receiver are explained in Section 2, while the conclusion is presented in Section 3.

2. METHODOLOGY

2.1 System Overview

The transmission hardware, modulation strategy, encoding module, and video source make up the system. GStreamer handles video input, compresses the stream, and formats it into MPEG2. Following processing in GNU Radio, the stream is modulated before being sent via a USRP device. The block diagram of our study is given in Figure 1.

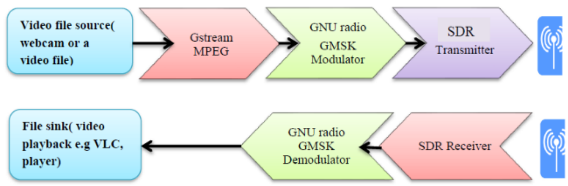

Fig.1. Block Diagram

2.2 Modulation Technique

The dependability and resilience of most communication systems are generally impacted by common problems like noise and interference. Bit error rate (BER) analysis was employed in this work to evaluate the performance of a GMSK system developed using GNU Radio under various modulation methods, particularly BPSK and QPSK.

System performance, especially bit error rate, can be studied and analyzed using a variety of digital modulation techniques. Only two methods—Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK)—were used in the simulated environment in this work.

One of the most basic digital modulation methods is BPSK. Binary symbols "1" and "0," each occupying a given period T, modulate one of two possible phases that are transmitted [13]. Despite its resilience, BPSK is more susceptible to high noise levels, which raises the possibility of demodulation mistakes.

For *BPSK:*

$$s(t) = A_c \cos\left(2\pi f_c t + \pi m(t)\right) \quad (1)$$

For QPSK:

$$\emptyset_1 = \sqrt{T}\cos(2\pi f_c t), \quad 0 < t < T \quad (2)$$

$$\emptyset_2 = \sqrt{T}\, sin(2\pi f_c t), \quad 0 < t < T \quad (3)$$

Let m(t) be the binary data that needs to be sent; it can have values of '0' or '1'. The method QPSK uses one of four possible carrier phase shifts—0°, 90°, 180°, and 270°—to transmit data, with each symbol representing two bits of information. The binary symbol pairs "00", "01", "10", and "11" are used to modulate the carrier phase [11]. The primary benefit of QPSK over BPSK is that it doubles the data rate for the same bandwidth and binary rate.

Bit Error Rate BER (Bit Error Rate) is a key parameter for evaluating the performance of a wireless data channel in a digital communication system. It is defined as the average number of bits received in error divided by the total number of bits received during the system's operating period [14].

In this work, we investigated two modulation schemes, as previously discussed, to analyze and measure the BER performance using Software Defined Radio (SDR) on a platform such as GNU Radio.headings.

GMSK Modulation Technique (Gaussian Minimum Shift Keying) Gaussian Minimum Shift Keying (GMSK) is a popular digital modulation method for wireless communication applications. The findings in this study show that real-time video data may be reliably transmitted using GMSK [14].

A Gaussian filter is applied to a regular Minimum Shift Keying (MSK) signal to create GMSK. By smoothing the modulated signal's phase transitions, a Gaussian-shaped impulse response filter produces a wider main lobe and low side lobes, which lessens interference from nearby channels.

GMSK provides higher spectral efficiency and better noise immunity than other phase shift keying (PSK) algorithms, which makes it especially appropriate for noisy and bandwidth-constrained settings.

An I/Q modulator and a quadrature baseband processor are the two primary parts of a quadrature modulator structure, which is one of the most effective ways to design a GMSK modulator. The modulation index, which is normally set to m = 0.5 for best results, may be precisely controlled thanks to this architecture [15] . The following is a mathematical representation of the generated GMSK signal:

$$s(t) = I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t) \quad (4)$$

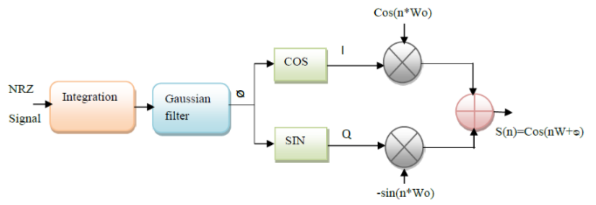

Fig.2. GMSK Modulator

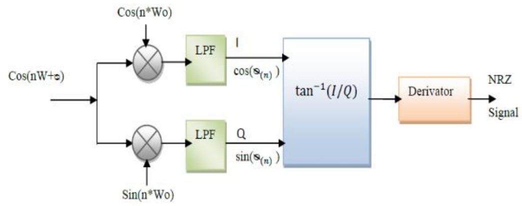

Fig.3. GMSK Demodulator

MPEG-2 In applications involving wireless communication, digital video compression is essential. It is extensively utilized in many different domains, including the transfer of 3D medical imaging over low-bandwidth networks and the transmission of medical videos [16]. When sending high-quality video content over communication channels with limited bandwidth, video compression efficiency becomes even more important.

In this investigation, raw video streams recorded using the GStreamer library were compressed using the MPEG-2 standard. The MPEG audio codec was set up for this implementation with a bitrate of 48 kbps, two audio channels, and a sampling rate of 14 MHz. With a bitrate of 120 kbps and a frame rate of 25 frames per second (fps), the video codec was configured as MPEG-2 + MPGA (TS).

These compression parameters were selected to provide a balance between transmission efficiency and video quality, making them especially appropriate for real-time streaming over wireless networks with limited capacity. GStreamer is a multimedia framework written in the C programming language that enables the processing of acquired video data. It supports a wide range of multimedia formats, including MP3, Ogg/Vorbis, AVI, MPEG-1/2, QuickTime, H.264, and many others. This framework is widely used for signal processing applications involving audio and video streams in various formats. GStreamer is built around core components called elements, which can be combined to form pipelines. Each element performs a specific task such as capturing, playing, encoding, decoding, scaling, or compressing media. When elements are connected in sequence, they pass data from one to another. However, if the output format of one element is incompatible with the input format of the next, the pipeline fails to execute, and GStreamer raises an error. In this study, a GStreamer pipeline was constructed to capture, scale, and compress real-time video before sending it to GNU Radio on the transmitter side. This preprocessing step enabled seamless integration between multimedia data handling and signal transmission (Ben Abid and Souani, 2022[17]).

Table 1. H.264 or mpeg2 video compression performance [17]

Video Information

	Resolution	Frame Rates	Binary Bits
Raw Video	1280x720 pixels. 25 Frames/s	928 Kbits	Raw Video
MPEG2 Or H.264	1280x720 pixels. 25 Frames/s	128 Kbits/s	MPEG2 Or H.264

With this Pipeline, a real-time image was taken from the source file on the transmitter side, scaled to 1280 × 720 resolution and 25 frames/s, converted to MPEG2+MPGA (TS) format and broadcast. Once the pipeline is created, proceed to the step of generating the GNU Radio flowchart.

USRP (Universal Software Radio Peripheral) A device in the Software Defined Radio (SDR) family, the Universal Software Radio Peripheral (USRP) is intended for the creation and deployment of SDR-based applications [18]. The USRP product line was created by Ettus Research, a National Instruments subsidiary led by Eric Blossom and Matt Ettus, and was named the Wireless Innovation Forum's Technology of the Year 2010. Across a broad frequency range, this SDR hardware module provides both transmission and reception capabilities. Because of their flexibility and low cost, USRPs are frequently utilized in academic institutions and research labs. The gadget incorporates necessary hardware components for signal processing and can operate as a transmitter or receiver. The USRP's modular architecture, which has swappable daughterboards that enable the system to function across many radio frequency (RF) bands, is one of its primary characteristics. A general-purpose CPU, an FPGA, digital-to-analog converters (DACs), and analog-to-digital converters (ADCs) are all part of the device architecture. Efficient up conversion of signals for high-frequency transmission and down conversion of received high-frequency signals to baseband are made possible by the Field-Programmable Gate Array, or FPGA. The USRP uses Ethernet or USB ports to connect to a host computer. It also has two transmit and two receive antenna connections, giving you more options when it comes to multi-antenna setups. There are several USRP models available, each with unique features and functionalities. The USRP B2920 model was employed in this investigation. This type offers up to 1 GHz of real-time bandwidth and facilitates transmission over a frequency range of 50 MHz to 2.2 GHz.

Two antennas were included with the device: the VERT400 (Tri-Band Vertical Antenna), which covered 144 MHz, 400 MHz, and 1200 MHz, and the VERT2450 (Dual-Band Vertical Antenna), which operated in the 2.4 GHz and 5 GHz bands. With one antenna supporting the transmitter and the other the receiver, these antennas were linked to the USRP. In the experimental system, this configuration allowed for real-time video transmission [17]. GNU Radio, first, we used a saved video clip as the source for our experiment. Playing the video that was sent by the transmitter module and confirming that the receiver module could successfully replicate it were the objectives. By merely establishing a loopback connection between the transmitter and the receiver within the software environment, this test was carried out in simulation mode without the need for the USRP hardware.

Using the same system characteristics, we conducted a similar test in a second phase, but this time we added the NI-USRP 2920 device to the transmission chain and eliminated the loopback. Real over-the-air video transmission was made possible by the implementation of the transmitter and receiver on several USRP devices.

A VLC Media Player can be used as a real-time video source for live video input. The video signal is processed, compressed, and sent to the GNU Radio platform for broadcast using the GStreamer framework. Flexible testing of hardware-based and simulated real-time video communication systems is made possible by this design.

3. SIMULATION, RESULTS AND DISCUSSION

To improve the radiation efficiency of an antenna and extend the operating range of a communication system, the use of modulation is essential. Modulation involves altering certain characteristics of a carrier waveform—such as amplitude, frequency, or phase—in relation to another signal, typically the input information signal. In this study, we examined the basic modulation techniques and evaluated their performance using the Bit Error Rate (BER) as a key metric. The system was tested with a video source transmitted and received through the GNU Radio platform to assess the impact of modulation on real-time multimedia transmission. When using digital transmission, the percentage of bits containing errors divided by the total amount of bits transmitted, received, or processed over a specific period of time is called BER. Typically, the rate is stated as 10 to the negative power. The digital equivalent of signal-to-noise ratio in an analog system is BER. We started with the error bit binary phase modulation graph in Figure 4 which contains a file source block of type .ts at a sample rate value of 14 MHz and then move on to the error rate block of type .ts. With the aid of GNU Radio, the BER performances of the BPSK and QPSK approaches are examined. With an Eb/N0 ratio of 10 dB, the BPSK has a BER of 0.4419 percent, whereas the QPSK has a BER of 0.2181 percent. Under similar circumstances, GMSK displays comparable performances. The constellation diagrams for each modulation scheme are shown in Figures 5 and 6.

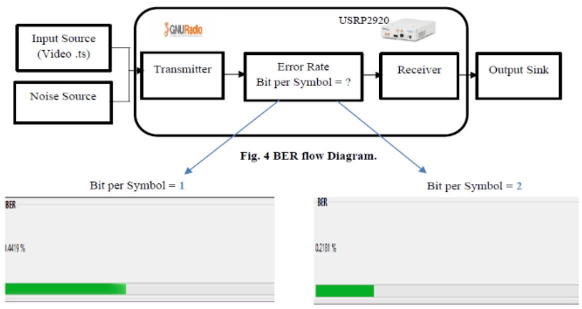

Fig. 4 BER flow Diagram.

Fig.5 BER BPSK output **Fig. 6 QPSK output**

From the simulations of Figure 5 and 6 we can say that the BPSK system is double that of the QPSK system, the selection of digital modulation system is mainly affected by the variable Bits per Symbol in the Error Rate block. Three key criteria influence the choosing of a digital modulation system: Efficiency of bandwidth at the receiver, Error performance is defined as the likelihood of making a bit error as a function of signal-to-noise ratio. We now proceed to the second section of our study, which focuses on utilizing GNU Radio to implement

GMSK modulation. As seen in Figure 7, a test bench was created and is made up of multiple modules, from the data source to the data sink. The architecture and parts needed for the test bench's design and simulation are also specified in this model. The GMSK transmission chain allows for a clear depiction of the end-to-end communication process because each block has a distinct function.

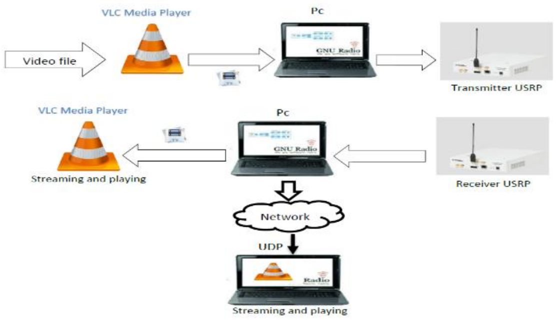

Fig.7. DVB test bench design description.

In the present work, the test bed was designed to be versatile and suitable for real-world communication demonstrations. The experiment was conducted in two main stages:

In the first stage, we performed a simulation of video stream transmission using GMSK modulation implemented under GNU Radio. The configuration used for this simulation is illustrated in Figure 7, and the video stream was transmitted successfully in this setup. In the second stage, we introduced the NI-USRP 2920 device into the transmission chain to send and receive I/Q baseband data. Although the video transmission was successful, the quality was slightly lower compared to the simulation, and a noticeable transmission delay was observed. The GNU Radio flowgraphs corresponding to the two experimental setups are presented in Figures 11 and 12.

3.1 Simulator Mode without USRP

In the first step, we use a stored video file as the source. We try to play this video sent by the transmitter and check if we are able to reproduce the same video on the receiver. This has to be done in simulation mode, without using the USRP, and simply by looping back the transmitter and receiver. This implemented configuration is shown in Figure 8. The system input is a pre-recorded video file processed by the GNU Radio software. The video sent by the transmitter was played on the receiver to verify whether the latter recovered the original signal. This was done in simulation mode without using the USRP. This test was conducted to ensure a reliable implementation and proper debugging before integrating the USRP. During media transcoding, we reduced both the audio and video bitrate. The role of the GRC session is to modulate and demodulate the incoming signal and to send the baseband audiovisual data, which is then recovered by VLC at the output through the UDP protocol, using the specified IP address and port. The video was streamed to the local host PC over an IP-based network, and the main data transfer protocol used was UDP.

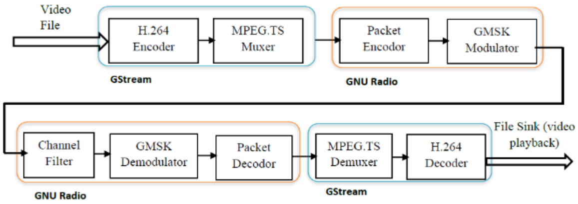

Fig. 8. Flow graph of a GMSK Modulation Simulator Mode

The first test was successful. A spectrum result of the transmitted video along with the received video is shown in Figures 9 and 10. The video file was transmitted via GNU Radio, saved to a file, and successfully streamed to the VLC receiver. This GNU Radio flowchart provides routing from one network port to another. Encoding, muxing, and transcoding were performed by the VLC player.

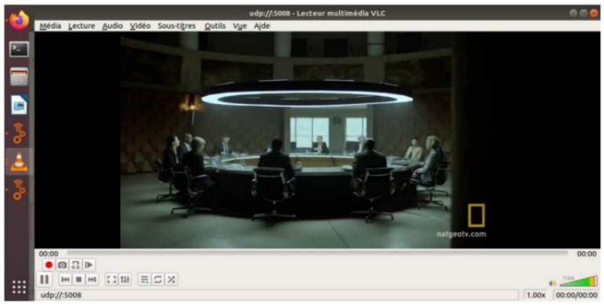

Fig. 9. Successful Video Reception

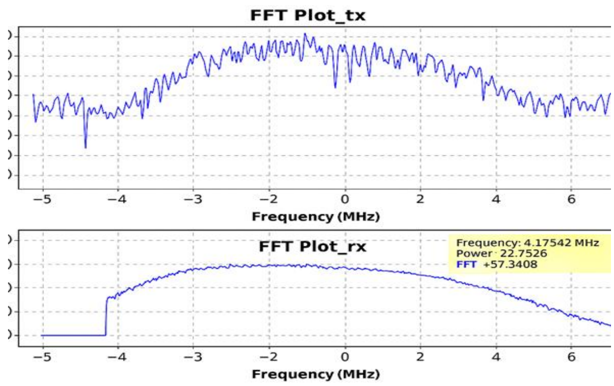

Fig. 10. GMSK Modulation Spectrum

The frequency spectrum of the GMSK-modulated signal is depicted in Figure 10; the transmitted signal is shown in the upper panel (FFT_Plot_tx), and the received signal is shown in the lower panel (FFT_Plot_rx). Gaussian filtering is characterized by a bell-shaped curve in the transmission spectrum, with the major lobe roughly spanning from –1.5 MHz to +1.5 MHz. The efficient spectral shaping is confirmed by the smooth roll-off, which reaches approximately -20 dB at ±3 MHz. Prior to interpolation and upconversion in the USRP chain, the signal is baseband-centered, as indicated by the symmetry about 0 MHz. Instantaneous symbol power variations and non-averaged FFT noise cause slight spectrum fluctuations of ±5 dB.

The same occupied bandwidth is seen on the receiver side, albeit the noise floor is somewhat higher at about -57 dB. Out-of-band noise was probably assessed using a marker at 4.17 MHz, which yielded an estimated spectral peak-to-noise ratio of roughly 85 dB, a value that is more indicative of the FFT dynamic range than actual SNR. A shorter FFT window or the analog front-end filtering of the USRP may be the cause of a slight attenuation on the high-frequency side of the received spectrum. The GMSK signal is confirmed to be spectrally restricted by the alignment of the Tx and Rx spectra and the conserved bandwidth, which show very no frequency drift. Although more FFT averaging or post-filtering could improve the visibility of the primary lobe for more accurate analysis like EVM or ACPR, the observed noise floor shows enough dynamic range for real-time video transmission

3.2 Simulator Mode with USRP

In this study, two different GNU Radio flowchart designs were created for the transmitter and receiver components. The transmitting flowchart is shown in Figure 11, and the receiving flowchart is shown in Figure 12. The NI-USRP 2920 hardware is integrated into the implementation diagram (Figure 6). The source file is modulated and transmitted using a USRP transmitter. The transmitted signal is then received by the USRP receiver, demodulated using GNU Radio, and played using VLC Player. In this testbed, the entire signal processing chain is carried out using the USRP devices connected to the computer.

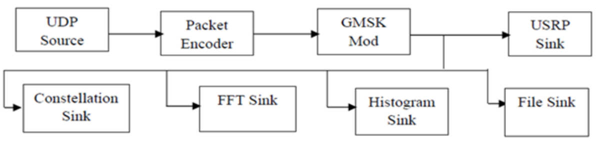

Fig.11. Flow graph of video Transmitter using GMSK Modulator

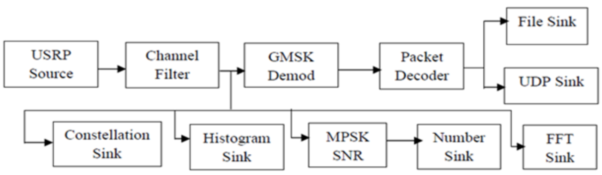

Fig.12. Flow graph of video receiver using GMSK Demodulator

When the GNU Radio transmitter flow diagram given in Figure 11 is examined, the Tx.ts file obtained by using GStreamer with the block named UDP Source is read. In order to control this data received by GNU Radio, the File Sink block was used, the data was saved in the tx2.ts file and a healthy image was obtained. Packet coding was done with Packet Encoder block. The GMSK Mod block is used to modulate the encoded data GMSK. WX GUI FFT SINK was used to get the FFT output of this data, and the WX GUI Constellation Sink block was used to display the constellation output. In addition to this, another property of data to be transferred with the WX GUI Histo Sink block is examined. Finally, the UHD:USRP Sink block was used to transmit the obtained complex data to the USRP device. Thanks to this block, the center frequency of the transmitting USRP device is 88 MHz, the sampling frequency is 14 MHz, the gain value is 50 dB and the antenna input used is TX/RX.

When the flowchart of the GNU Radio receiver given in Figure 12 is examined, it is seen that the inverse operations are applied on the transmitter side. The data obtained as a result of the transactions carried out by the receiver are saved in the Rx.ts file. Finally, the video data will be read by the "UDP sink" block using the file player allowing permanent broadcasting "VLC Media Player". GNU Radio and VLC Media Player are interconnected using the UDP protocol. Therefore this configuration uses video in MPEG-TS format. In addition to the outputs obtained on the transmitter side, the SNR (Signal to Noise Ratio) value is obtained.

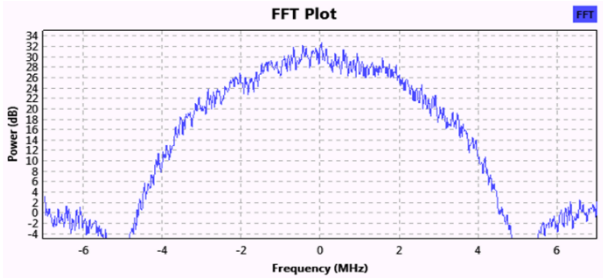

Fig.13. Transmitter FFT Signal Output

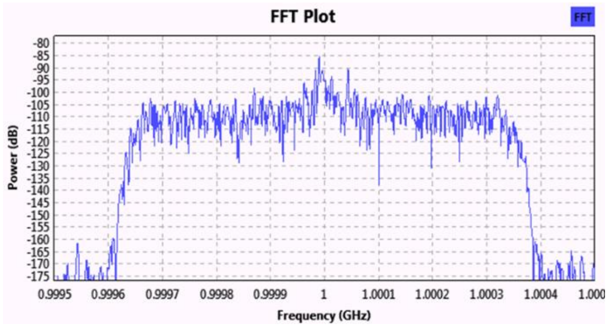

Fig.14. Receiver FFT Signal Output

The FFT spectrum of the transmitted signal produced by the GNU Radio transmitter is shown in Figure 13. The baseband transmission is indicated by the frequency axis's center at 0 MHz. A filtered modulation system like GMSK is characterized by a spectral form that resembles a smooth bell curve with a power peak at about 32 dB. As can be seen from the occupied bandwidth, which roughly ranges from –4 MHz to +4 MHz, the signal is symmetric and well restricted. This demonstrates that the transmission chain is operating properly with suitable signal filtering and clean modulation.

The FFT spectrum of the received signal obtained with the NI-USRP 2920 hardware is displayed in Figure 14. This spectrum is focused around 1 GHz, which is the carrier frequency used for over-the-air transmission, in contrast to the baseband signal seen in Figure 13. With peaks at about -90 dB and a noise floor at about -130 to -150 dB, the received signal's power level is much lower, suggesting an excellent signal-to-noise ratio. Because to channel limitations or RF filtering, the seen bandwidth is smaller than the sent signal. A tiny spike at 1 GHz could be a local oscillator leak or a residual carrier. Overall, both figures show that the signal was successfully transmitted from beginning to end, confirming the system's functionality in both simulated and actual radio frequency environments. The broadcast signal is successfully received and demodulated within the anticipated frequency range, as confirmed by the spectral alignment. Each point's distance from the origin in the constellation diagrams shown in both figures represents the strength of the signal. Every point is represented as a complex value and correlates to a transmission symbol. The modulation method that is employed determines the distribution and form of these points. The existence of noise and other channel impairments is the main cause of the simulated findings' obvious distortion. Furthermore, synchronization problems—

specifically, the imprecise alignment of the transmitter and reception frequencies—are a major cause of degradation, as they result in symbol misplacement and possible packet loss.

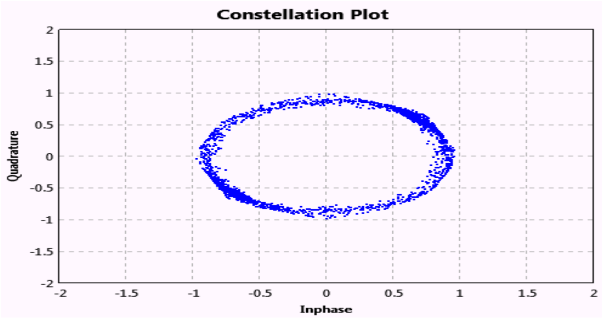

Fig. 15. Transmitter Constellation Output

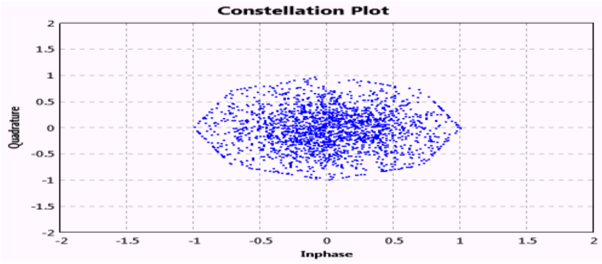

Fig. 16. Receiver Constellation Diagram

Histogram plots, which shed light on noise effects and amplitude distribution, can also be used to examine signal properties during video transmission and reception. These histograms, which show differences in signal levels and any distortions produced across the communication chain, are depicted in Figures 15 and 16.

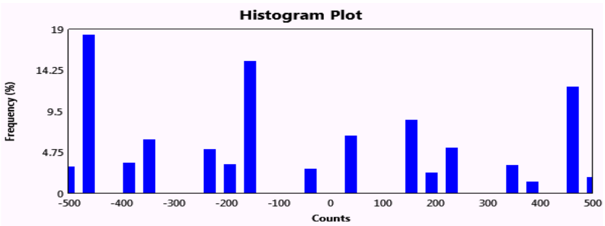

Fig. 17. Transmitter Histogram Output

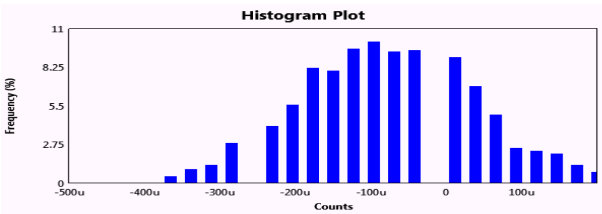

Fig.18. Receiver Histogram Output

The vertical axis in the histogram outputs shown in Figures 17 and 18 shows the frequency (or number of occurrences) of each value in the dataset, while the horizontal axis shows the range of observed values, organized into frequency bins. Both the transmitter and receiver sides' signal amplitudes or sample values are visually distributed via these histograms. There is a noticeable variation between the transmitted and received signals, despite the histogram plots appearing to be static. In particular, the transmitter's value distribution exhibits a more ordered and repeating pattern that mirrors the properties of the original modulated signal. The receiver histogram, on the other hand, shows a less consistent and more scattered distribution, which could be caused by transmission-related signal degradation, hardware flaws, or channel noise. The impact of actual transmission conditions on the received signal is further highlighted by the fact that the transmitter's value repetition sequence differs from the receiver's. This comparison can assist in locating causes of distortion or loss in the transmission chain and is crucial for evaluating the fidelity and integrity of the communication system. Figure 19 displays the Signal-to-Noise Ratio (SNR) comparison between the sent and received video signals. The performance of a GMSK-based real-time video transmission system, which can broadcast live video and save the received video for later analysis, is depicted in this image.

The received signal's instantaneous SNR is measured at about 0.000216 units, as the figure illustrates. This incredibly low number indicates a high degree of transmission-related noise or signal deterioration. Channel impairments, low transmission power, hardware constraints, or incorrect gain settings in the USRP device could all be the cause of this outcome. The system effectively completes the end-to-end transmission despite the low SNR, proving that GMSK modulation is resilient in noisy situations. on enhance signal quality and overall video fidelity at the receiver, optimization in the form of system calibration, filtering, or antenna alignment is possible, according on the measured SNR value.

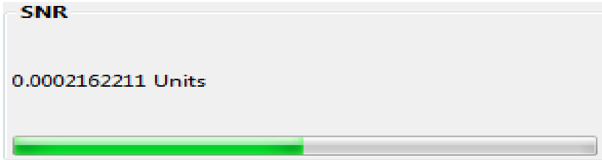

Fig.19. Receiver SNR Output

Fig.20. Image output of the receiver

Figure 20 shows the screen output obtained on the receiver side, using open source software GNU radio Real-time video encoding and decoding can be performed significantly with minimal data loss by using H.264 encoder and H.264 decoder. The video quality in this mode is degraded was not high enough, This is caused, when the network was unstable or poor quality, there will be a considerable amount of erroneous packets received or packet loss which caused the video cannot be read correctly. Setting up a network is a reliable way to exchange information, share resources and improve communication in two different ways, but this exchange usually takes a considerable amount of time. This time means the exact time it takes for a packet to reach the point of reception after being sent from the sending terminal. This time is called delay or latency. Delay time is not fixed as it represents the sum of other delays such as serialization delay, propagation delay, processing delay and queuing delay.

In our study, in addition to the GNU Radio outputs, the video delay times obtained with the sample rate value are examined in Table 2. According to the given results, as the sample rate value increases, the delay time decreases.

Table 2. The relationship between sample rate and response delay time

Samples rates /Time latency			
200 MHZ	400 MHz	700 MHZ	1 GHz
12 Seconds	9 Seconds	4 Seconds	3 Seconds

After performing this implementation, it can be concluded that the behavior of the signal is transmitted successfully, but with more errors and interference, this was expected. The video quality in this mode is degraded which is obvious and can be attributed to several factors. This is due to the larger sources of error that the signal can experience during its transmission, which can come from many different elements such as noise, introduced by the USRP card, and it can come from the Ethernet connection port. Some packet loss due to inability of spontaneous synchronization between transmitter and receiver frequency. Although there was some packet loss, the quality degradation was not high enough. Secondly, when the network was unstable or poor quality, there will be a considerable amount of erroneous packets received or packet loss, which caused the video, cannot be played or played slowly. Packet loss can be a comparative measure of the number of packets sent and received versus the total number sent, expressed as a percentage. The router drops packets for many reasons: When the link is in a congested state, when there is a switching problem, and when there is a packet transmission error due to external factors. It can also be said that the data has been successfully transmitted to the receiver. There was a delay in the observation of 4-20 seconds during the transmission of the real-time video signal. To have a good quality of service, it is preferable that the delay becomes short and negligible, in particular for real-time applications. But in reality, this delay will not be an easy task because there is all parallel traffic waiting to be sent and consuming sample rate. This can confuse users because the waiting time is one of the most requested criteria by the general public. Nobody likes to wait, which puts delay among the biggest problems for a network.

4. CONCLUSION

Today, designers of wireless transmission systems are faced with certain challenges. Classical methods often rely on bulky and expensive components with a non-modifiable architecture, leading to high manufacturing costs and limited adaptability to new standards and norms. These challenges, however, have driven researchers to propose new, fully digital wireless transmission architectures, notably the Software-Defined Radio (SDR) concept. The fundamental technology chosen for this project is Software-Defined Radio, a powerful paradigm for data transmission. SDR is expected to bring about a technological revolution in current wireless communication systems. The excellent GNU Radio software, combined with efficient hardware from the USRP family, offers a powerful software-defined radio platform characterized by ease of use, time savings, and low cost. Through this work, SDR has been introduced as a novel concept combined with a popular modulation and demodulation technique in wireless communication systems. A tangible project was successfully implemented based on GNU Radio and USRP, realizing real-time digital video broadcast on a more versatile and less expensive SDR platform. The project focused on a digital video broadcast implementation using a flexible, reconfigurable, more generic, and "universal" all-digital architecture. The testbed was designed to utilize software-defined radio devices, allowing for a flexible implementation with high parameterization capabilities for communication links. SDR devices also enable the use of open-source software, facilitating a cost-effective implementation. While the chosen implementation platform proved to be a good choice, it required substantial man-hours for software installation and proper operational learning. In conclusion, this research represents a significant step towards enhancing monitoring systems in critical nuclear reactor environments. Real-time video transmission was successfully achieved on the test bench, with system performance primarily limited by its sampling frequency. The principles of wireless communications have been elucidated in this work, and new ideas for improved receiver transmission are proposed. Software-Defined Radio has demonstrated its potential to be the future of communication systems, particularly in applications demanding high reliability and flexibility in harsh environments, such as radiation monitoring in nuclear reactors. Future work may focus on integrating adaptive modulation, advanced error correction algorithms, and exploring mobile scenarios to further enhance robustness and deployability in complex radiation monitoring scenarios, such as those in remote or inaccessible areas within nuclear facilities or broader radiation monitoring networks.

Data Availability

The GMSK Mod dataset used to support the findings of this study is available in the GitHub repository (https://github.com/pintuiitbhi/wireless_communications/blob/master/GMSK).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

5. ACKNOWLEDGMENTS

Each author has made significant contributions to the research and preparation of the manuscript and all authors has reviewed and approved the final version of the manuscript submitted for publication/presentation. We confirm that no other individuals who have made substantial contributions to the work have been omitted as author.

6. REFERENCES

[1] IAEA, "Nuclear Safety Review 2024," International Atomic Energy Agency, Vienna.

[2] Bowman, M., Debray, S. K., and Peterson, L. L. 1993. Reasoning about naming systems.

[3] Ding, W. and Marchionini, G. 1997 A Study on Video Browsing Strategies. Technical Report. University of Maryland at College Park.

[4] Fröhlich, B. and Plate, J. 2000. The cubic mouse: a new device for three-dimensional input. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems .

[5] Tavel, P. 2007 Modeling and Simulation Design. AK Peters Ltd.

[6] Sannella, M. J. 1994 Constraint Satisfaction and Debugging for Interactive User Interfaces. Doctoral Thesis. UMI Order Number: UMI Order No. GAX95-09398., University of Washington.

[7] Forman, G. 2003. An extensive empirical study of feature selection metrics for text classification. J. Mach. Learn. Res. 3 (Mar. 2003), 1289-1305.

[8] Brown, L. D., Hua, H., and Gao, C. 2003. A widget framework for augmented interaction in SCAPE.

[9] Y.T. Yu, M.F. Lau, 2005. "A comparison of MC/DC, MUMCUT and several other coverage criteria for logical decisions", Journal of Systems and Software, in press.

[10] Spector, A. Z. 1989. Achieving application requirements. In Distributed Systems, S. Mullender.