M-PSK Modulation

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Github: https://github.com/leo09p/COMMII_A1_G8/tree/Practica_4

Abstract
Using GNU Radio, it is possible to visualize constellation diagrams that illustrate the symbols or points employed for transmitting digital data. Each position within the constellation corresponds to a unique bit combination, functioning in a way similar to a truth table. The modulation techniques studied in class can be implemented through block flow graphs, enabling the observation of constellation patterns, power spectral density (PSD), signal characteristics, and the specific type of modulation applied.

I. Introduction

In this laboratory exercise, several modulation schemes previously studied in class were explored, focusing particularly on the analysis of constellation diagrams. By configuring different processing blocks, various modulation types were generated and examined to evaluate how they are affected by factors such as interference (e.g., white noise), modulation format, and the nature of the input data. Additionally, key performance parameters such as bandwidth, spectral efficiency, and symbol rate were assessed. Some of the blocks provided by the instructor were modified to obtain broader and more representative results.

II. METHODOLOGY

A. Proposed block architecture

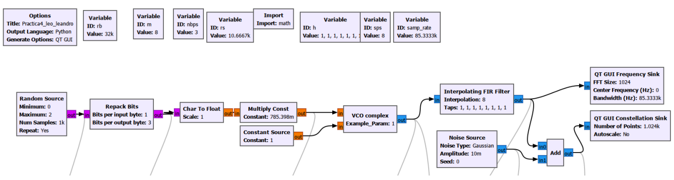

Fig. 1. System's Flowchart.

Figure 1 represents the flowchart designed for the implementation of various proposed modulations. Specifically, in the figure 1, it can be seen the labeling of each respective set of blocks where, based on their meaning. To analyze the variants of this modulation, we first tested modifying the variable M.

B. Main block architecture

Besides the code developed during class sessions, an additional block configuration provided by Professor Homero Ortega was employed. This setup was designed to generate M-PSK modulation using both a random data source connected to a VCO and a lookup table linked to the constellation diagram. This behavior can be observed in Figures 2 and 3.

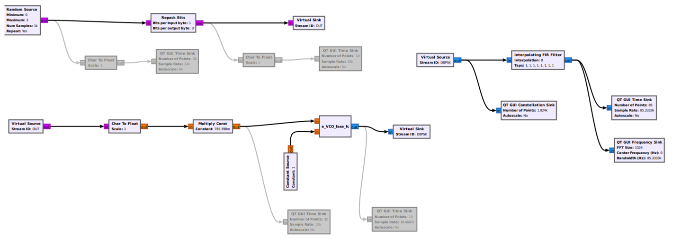

Fig. 2. MPSK Modulation block diagram with VCO.

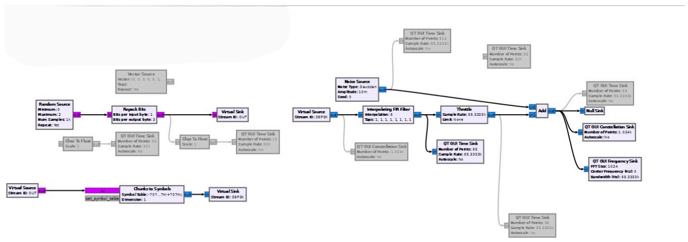

Fig. 3. QMPSK Modulation block diagram with Truth table.

III. ANALYSIS OF RESULTS

The analysis of results was carried out following the structure defined in the methodology. Based on the data obtained during the experiment, a detailed interpretation of the signal's behavior in different scenarios was made. The main findings and their relevance within the context of the study are presented in this section.

A. VCO module analysis

According to the help documentation:
"The VCO block consists of two inputs and a single output. The inputs correspond to an amplitude array and a phase array. Using these inputs, the block generates an output signal based on a complex exponential function. When expressed in its trigonometric form, this function can be decomposed into real and imaginary components, allowing the separation of the in-phase and quadrature elements of the system, which are then returned as output values."

B. QPSK Modulation

The implementation of the QPSK modulation or also known as 4-PSK had variations with respect to the previously used flowchart, because in this case a block was used as a truth table to define the phases of each source code.

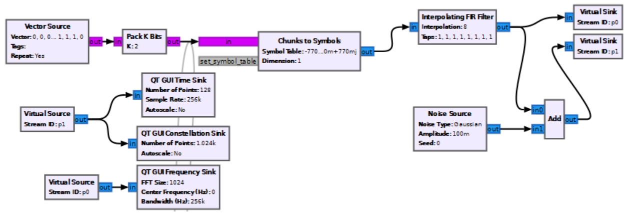

Fig. 4. QPSK's Flowchart.

Subsequently, Figure 5 displays the time-domain signal, power spectral density (PSD), and constellation diagram. It was confirmed that the four expected phase states are present and correctly positioned in quadrature. Additionally, the configuration includes the use of a truth table mapped according to Gray coding.

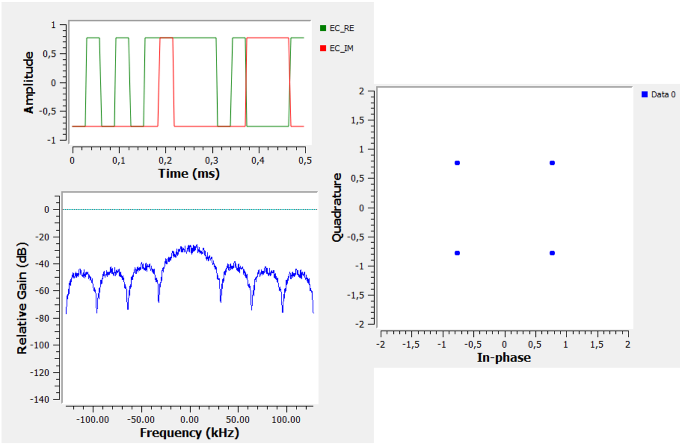

Fig. 5. QPSK's PSD, Time, and Constellation plots.

The bandwidth of the modulation was defined by the symbol rate parameter Rs, which was set to 32 kHz. Furthermore, the PSD exhibited a certain number of lobes, determined by the configuration of the FIR interpolation filter and the samples per symbol (SPS). In this case, a value of 16 SPS was selected to emulate the behavior of a real signal passing through the intended SDR system.

C. MPSK Modulation

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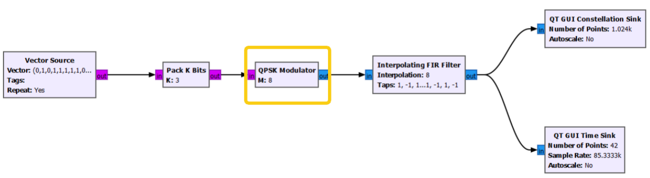

Fig. 6. MPSK Flowchart.

The output of this configuration is shown in Figure 7. In the case of M=8 modulation, the constellation diagram appears incomplete because two of the possible symbols were never generated and the corresponding input values were simply not received.

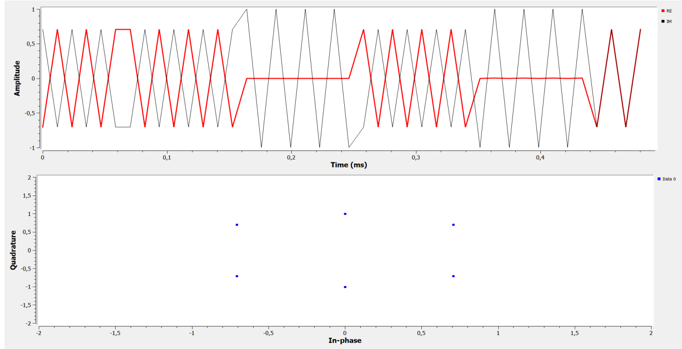

Fig. 7. Modulator results.

D. 8PSK Modulation

The 8-PSK modulation in this case was carried out using Professor Homero Ortega's block scheme, located in Figure 3. In this modulation, an example of it was observed in Figure 8 in terms of phase and quadrature graphs.

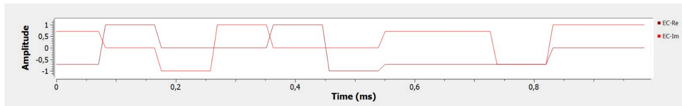

Fig. 8. Output IQ code from 8PSK.

From this, eight types of states were observed, some with amplitudes of 0.77, others with an amplitude of 1, and others taking this amplitude but in a negative form. With this, the states that ended up identifying the symbol of every 3 bits sent could be confirmed. From these, then the respective constellation diagram for the encoding was observed in Figure 9, where the symbols were spaced a total of 45° to obtain an 8PSK modulation.

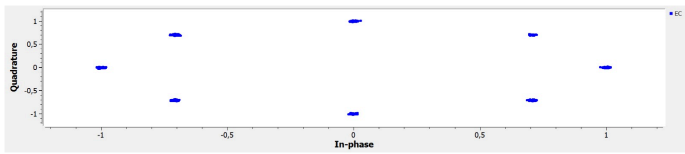

Fig. 9. Constellation diagram for 8PSK.

The constellation diagram was compared when it was susceptible to noise. For this purpose, white Gaussian additive noise (AWGN) was added in Figure 3. The following results were obtained in Figures 10 and 11.

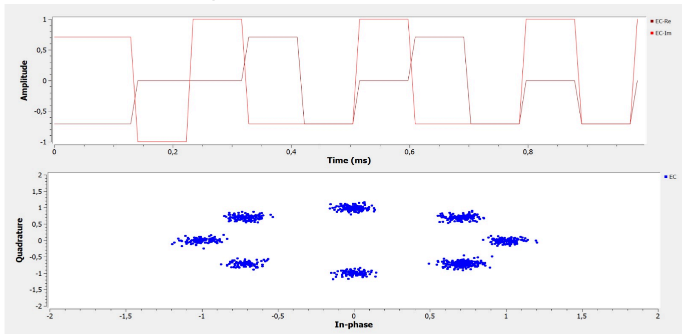

Fig. 10. 10 Percent AWGN added to 8PSK.

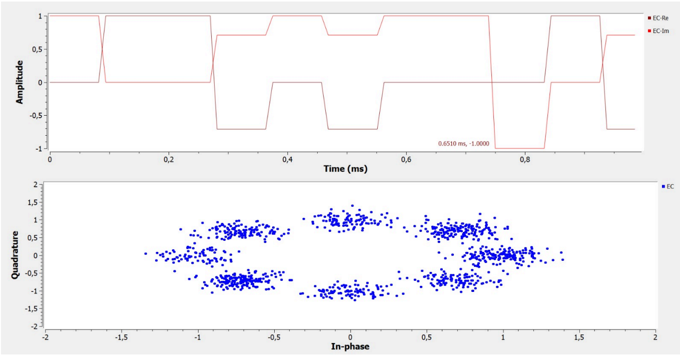

Fig. 11. 20 Percent AWGN added to 8PSK.

It was noted that with 10% noise relative to the input signal, the system still produced a recognizable output. However, as the noise level increased, interference became more evident, as shown in the case of 20% noise in Figure 11.

In terms of frequency response, it was confirmed that the bandwidth was determined by the symbol rate. This occurred because each symbol now represented three bits of information, effectively concentrating more data into a single transmission interval. As a result, the bit rate increased, which is advantageous from a data throughput perspective. This behavior was verified in Figure 12.

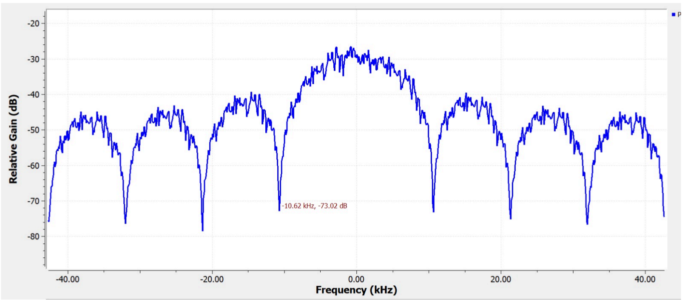

Fig. 12. Bandwidth of the 8PSK signal.

Based on the use of a vector source block, a rather unique behavior was observed in Figures 13 and 14.

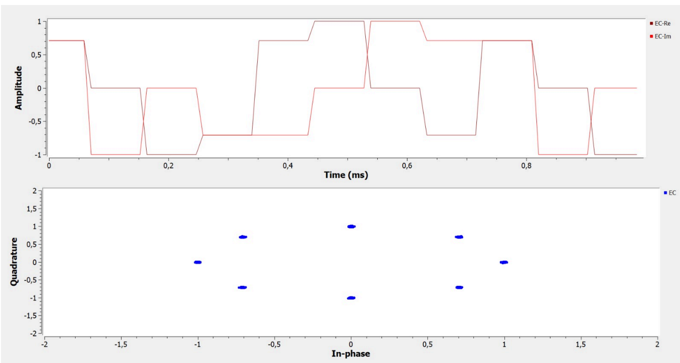

Fig. 13. Full vector source constellation diagram.

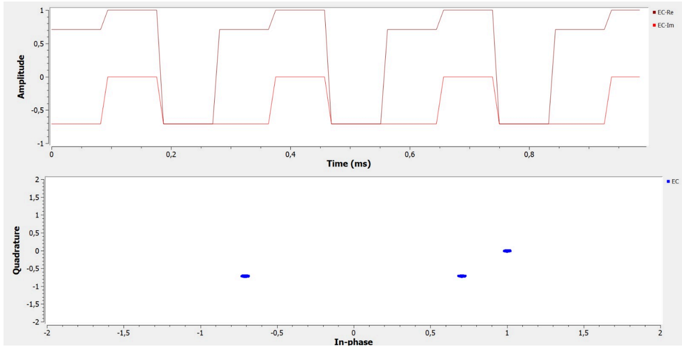

Fig. 14. 3 symbol constellation diagram.

E. Proposed Modulation: M modulation

A new modulation was proposed, with some range X, this in order to visualize that depending on the truth table the constellation diagram will change, this type of modulation I call it M, because it has the shape of M, here is the truth table:[(0-0.1j,-0.25+0.25j,0.25+0.25j,0+0j,1+0j, 1+1j, -1+1j, -1-1j,1-1j,-1+0j,-0.5+0.5j,0.5+0.5j,0.75+0.75j,-0.75+0.75j,-1-0.5j,1-0.5j,-1+0.5j,1+0.5j)]. The result can be seen in the figure 15 below.

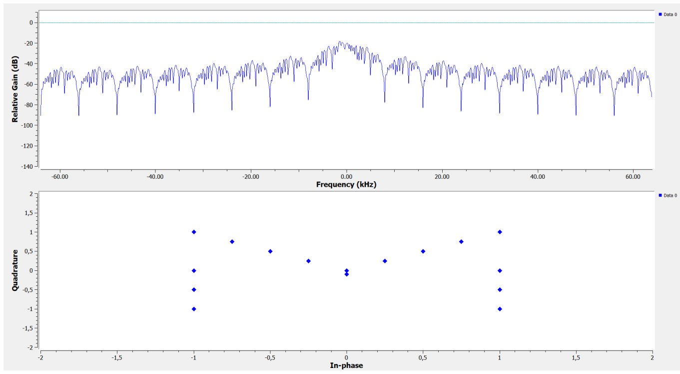

Fig. 15. Constellation plots M.

The PSD analysis indicates a bandwidth of approximately 8 kHz. Although this is relatively narrow, it aligns with the principles of spectral efficiency (SE). In M-PSK modulation, increasing the value of M typically results in reduced bandwidth usage, which in turn improves SE. The inclusion of the label "M" in the constellation diagram is intentional it visually emphasizes the specific modulation order being employed.

F. Proposed Modulation: Diamond modulation

The diamond modulation was proposed for its assimilation to a prism in the constellation diagram, this had its variation from the 8-PSK modulation, since it was decided to have 8 points to have a SPAN of equivalent phases, and that the number of points in the constellation diagram was a power of 2. The modulation truth table is as follows: (1+0j, 0.5+0.5j, 0+1j,-0.5+0.5j, -1-0j, -0.5-0.5j,0-1j, 0.5-0.5j)

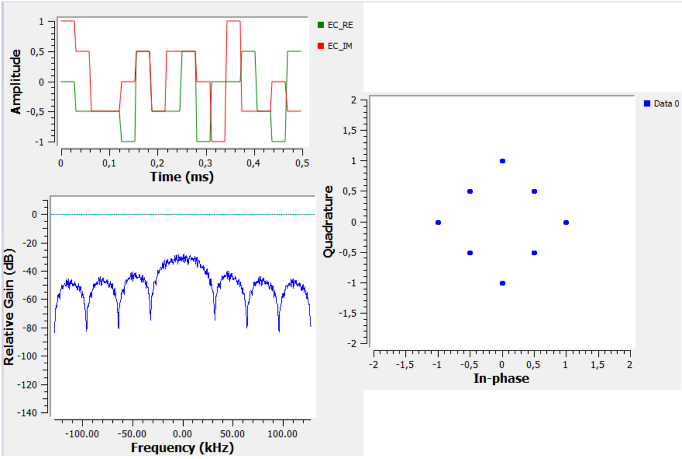

Fig. 16. Diamond Modulation Proposed.

When compared to the original modulation, it was found that the diamond modulation preserves similar characteristics, such as bandwidth. However, it differs by incorporating amplitude modulation, resembling a 5-PAM scheme, where each component of the complex envelope can take five possible levels, both positive and negative.

The main drawback of this modulation is its increased vulnerability to noise, since several constellation points are positioned very close to each other. Although the configuration is not critically sensitive, this factor must still be considered. The effect of noise on this modulation is illustrated below.

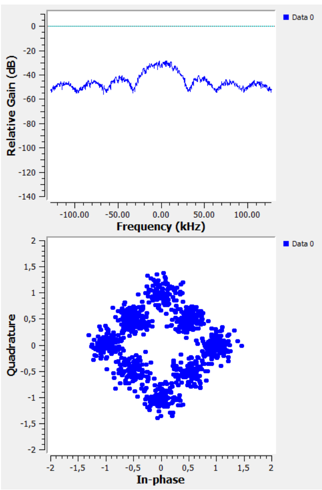

Fig. 17. Diamond Modulation with Gaussian Noise.

G. Proposed Modulation: PQPSK

The PQPSK modulation basically consisted of the QPSK modulation but shifted towards an axis where it behaved as unipolar. Thus, in this modulation, it could be observed particularly that it was affected by the DC component of the signal, as seen in Figure X.

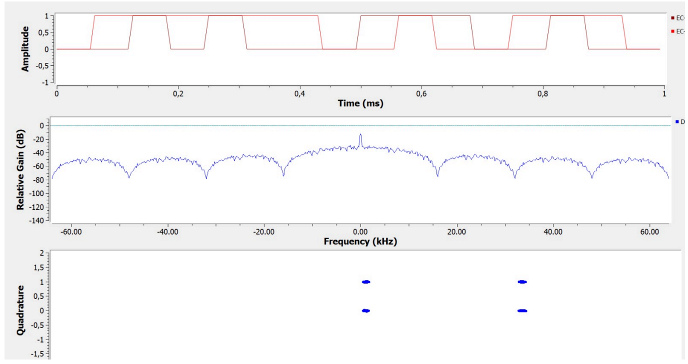

Fig. 18. PQPSK modulation proposed.

It was also noted that this scheme preserved the key characteristics of QPSK, such as its bandwidth and its level of noise susceptibility, which is largely determined by the spacing between constellation points. One of the main advantages retained by this modulation was the orthogonality between each of the symbols in the constellation.

IV. *CONCLUSIONS*

- In M-PSK modulation, spectral efficiency improves as the number of symbols (M) increases. This implies that higher-order MPSK schemes can transmit the same amount of information while occupying less bandwidth, resulting in a more efficient use of the radio spectrum.
- When designing new modulation schemes for specific applications, it is essential to carefully evaluate their implementation. The proposed diamond modulation, for instance, combines both amplitude and phase variations, which increases its complexity. However, this comes at the cost of higher noise susceptibility, as its constellation points are positioned closer together than in 8-PSK. Moreover, it does not provide improvements in bandwidth, symbol rate (Rs), or bit rate (Rb).
- It was essential to consider real-world conditions, such as the presence of additive white Gaussian noise (AWGN), since communication channels inherently introduce reflections and interference. Therefore, it was necessary to evaluate the tolerance of each modulation scheme to noise, typically through the use of filtering techniques to mitigate its effects.

V. *REFERENCIAS*

[1] H. Ortega y O. Reyes, «Comunicaciones Digitales basadas en radio definidas por sofware», Google Docs. Accedido: 29 de agosto de 2025. [En línea]. Disponible en: https://drive.google.com/file/d/1fd9M4_bIjwLOajQdkdN9ex2plYRoXomz/view?usp=drive_link&usp=embed_facebook