Practice 4: MPSK

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May 3nd, 2025

Abstract

The implementation and analysis of M-PSK and QPSK modulations using GNU Radio was addressed. The power spectral density (PSD) and the constellations associated with each modulation technique were evaluated. Also, it was analyzed how increasing the value of M in M-PSK affects the distribution of symbols in the constellation, making the system more susceptible to noise. Finally, a comparison was made between M-PSK and QPSK, highlighting their differences in terms of bandwidth, bit rate and symbol rate.

Key words: GNU Radio, MPSK, QPSK

1 Introduction

M-PSK modulation (M-Level Phase Shift Keying) is a fundamental technique in digital communication systems, used to transmit information by varying the phase of a carrier signal. Its implementation has a wide variety of purposes, from satellite communications to mobile networks, including fiber optics. For this lab, an M-PSK transmitter was implemented using GNU Radio, in order to explore its theoretical principles, its practical implementation and the analysis of key parameters such as bandwidth, spectral efficiency and the relationship between symbol and bit rate. Also, the impact of noise on constellations was studied and different modulation schemes, such as QPSK, were compared to understand their advantages and limitations at the time of transmission.

Also, the objective of this report is to study the behavior of these modulation schemes in both the time and frequency domains, analyzing not only their radiofrequency (RF) versions but also their complex envelope (CE) representations.

2 Methods

Once the folder corresponding to practice 4 was opened in GitHub, we proceeded with the implementation of MPSK modulation (see Figure 1) following the procedures detailed in the reference video [1]. Next, it was requested to obtain and display the power spectral density (PSD) of the constellations, which is presented in Figure 2.

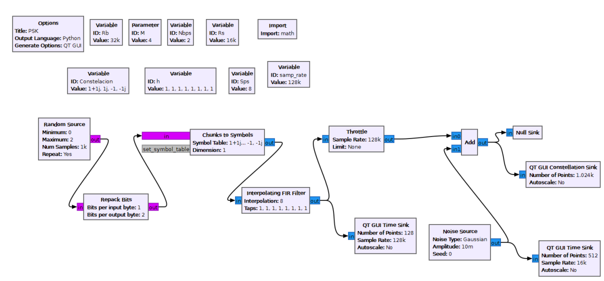

Fig. 1: MPSK Modulation.

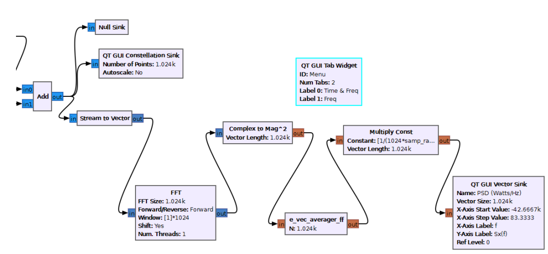

Fig. 2: Blocks used to obtain the power spectral density (PSD).

An exhaustive analysis was performed in which the bandwidth was obtained and the PSD ratio was evaluated. Subsequently, the truth table was reprogrammed, using the ‘vector source’ block (see Figure 3) to generate the bits present in the source . Next, the QPSK modulation was implemented (see Figure 4), following the indications of the video suggested in the practice [2], and a new analysis of the modulation was performed. Then, each member of the group designed a different constellation, from which they concluded respectively.

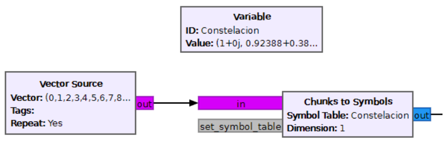

Fig. 3: Vector Source.

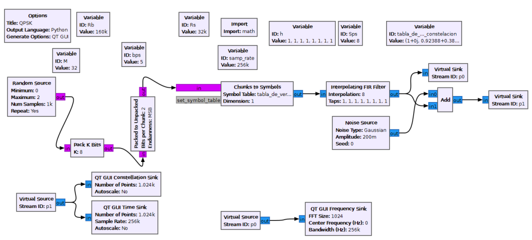

Fig. 4: QPSK Modulation.

3 Results

Constellation 1:[1+0j,0+1j,-1+0j,0-1j] was simulated and analyzed to verify that the complex envelope bandwidth is equal to the symbol rate in PSK modulations. Furthermore, the spectrum crosses zero at integer multiples of the symbol rate, as shown in Fig. 5.

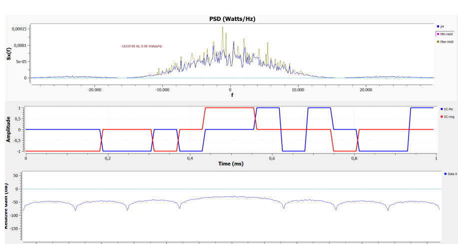

Fig. 5: MPSK signal with constelation:[1+0j,0+1j,-1+0j,0-1j] , its PSD and frequency spectrum

To verify that GNU Radio produces the same complex envelope signal, a vector source was used to generate predefined input bits along with Constellation 2:[-0.77-0.77j,-1+0j,-0.77+0.77j,0+1j,0.77+0.77j,1+0j,0.77-0.77j,0-1j] as shown in Fig. 6.

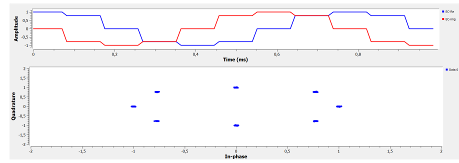

Fig. 6: 8PSK Complex Envelope and constellation with vector source

Constellation 3:[0.77+0.77j,-0.77+0.77j, -0.77-0.77j,0.77-0.77j], was used to analyze and compare the Complex Envelope Bandwidth, Power Spectral Density (PSD), frequency spectrum, bitrate, and symbol rate with the previous constellations, as shown in Figures 7 and 8. The results showed that the symbol rate was equal to the bandwidth as it was with the previous constellations. However, since the number of bits transmitted per symbol differed, the bitrate varied: for QPSK modulation(2 bits per symbol), the bitrate was twice the symbol rate, while for 8PSK modulation(3 bits per symbol), it was three times the symbol rate.

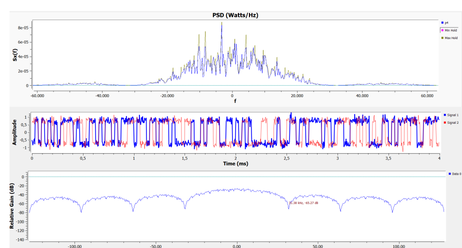

Fig. 7: QPSK signal with constellation:[0.77+0.77j,-0.77+0.77j, -0.77-0.77j,0.77-0.77j] , its PSD and frequency spectrum

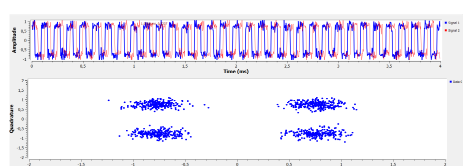

Fig. 8: QPSK signal complex envelope with vector source and constellation:[0.77+0.77j,-0.77+0.77j, -0.77-0.77j,0.77-0.77j]

Finally, the results of the simulation of the three additional MPSK modulation constellations made from each of the members of the group can be observed in 9, 10, 11 and 12.

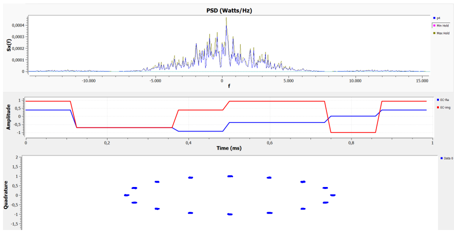

Fig. 9: 16PSK signal with random source, PSD and constellation:[1+0j, 0.92388+0.38268j, 0.70711+0.70711j, 0.38268+0.92388j,0+1j, -0.38268+0.92388j, -0.70711+0.70711j, -0.92388+0.38268j,-1+0j, -0.92388-0.38268j, -0.70711-0.70711j, -0.38268-0.92388j,-0-1j, 0.38268-0.92388j, 0.70711-0.70711j, 0.92388-0.38268j]

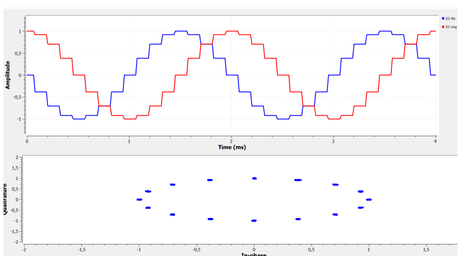

Fig. 10: 16PSK signal with predifined vector source and constellation:[1+0j, 0.92388+0.38268j, 0.70711+0.70711j, 0.38268+0.92388j,0+1j, -0.38268+0.92388j, -0.70711+0.70711j, -0.92388+0.38268j,-1+0j, -0.92388-0.38268j, -0.70711-0.70711j, -0.38268-0.92388j,-0-1j, 0.38268-0.92388j, 0.70711-0.70711j, 0.92388-0.38268j]

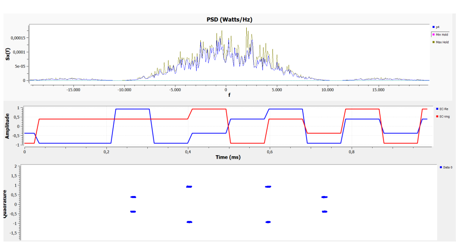

Fig. 11: 8PSK signal with random source, PSD, and Constellation:[0.9239+0.3827j, 0.3827+0.9239j, -0.3827+0.9239j, -0.9239+0.3827j, -0.9239-0.3827j, -0.3827-0.9239j, 0.3827-0.9239j, 0.9239-0.3827j]

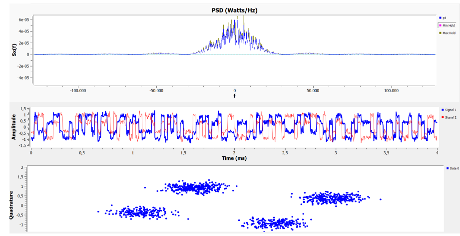

Fig. 12: 4PSK signal with random source, PSD, and -Constellation: [0.9239+0.3827j, -0.3827+0.9239j, -0.9239-0.3827j, 0.3827-0.9239j]

4 Conclusions

The bandwidth of the modulated signal was determined and its relationship to the symbol rate (R_s) was observed. These results showed that zero crossings in the spectrum are directly linked to this rate because, in modulations such as M-PSK, the position of zeros in the power spectral density (PSD) follows a $\text{sinc}^2(f)$ whose nulls occur at integer multiples of R_s. If R_s is 32 kbaud, zero crossings would appear at ± 32 kHz, ± 64 kHz, etc. This confirms the importance of designing systems with appropriate parameters to optimize spectrum usage.

In M-PSK modulations, the higher the value of M, the greater the sensitivity to noise. This occurs because as M increases, the symbols are located closer together in the constellation, reducing their margin of tolerance to disturbances. In QPSK ($M = 4$) the symbols are separated by $90°$, in 8-PSK ($M = 8$) there are only $45°$ between them, causing small interferences to move one symbol into the region of another and generate errors. Although high-M modulations allow more bits per symbol to be transmitted (higher spectral efficiency), they require channels with high signal-to-noise ratio (SNR) to remain stable.

In high-order modulations ($M \geq 32$), the proximity between symbols in the constellation makes them extremely sensitive to noise and distortions. To mitigate this, increasing the amplitude of the Complex Envelope (CE) is a key strategy, as it widens the distance between points, reducing the probability of errors. However, this alone is not sufficient. To optimize performance in these modulations, it was concluded that implementing raised cosine filters with a low roll-off helps minimize bandwidth, while ensuring that the filter has a steeper frequency response; this reduces intersymbol interference (ISI) without sacrificing spectral efficiency.

References

[1] comdiguis.older, "Modulación 8psk en gnu radio usando dos métodos: Vco y tabla de verdad," 2021, [Video en línea]. Disponible en: https://www.youtube.com/watch?v=47FUTpV7y4A.

[2] ——, "Implementación de un modulador m-psk en gnu radio. en particular qpsk," 2022, [Video en línea]. Disponible en: https://www.youtube.com/watch?v=2rsu-c26Tqo.