Practice 5: Modulation M-QAM

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May 10th, 2025

Abstract

In this practice we worked with M-QAM modulation using the GNURadio platform, with the objective of analyzing its behavior in different modulation orders. Schemes such as BPSK, QPSK, 8PSK and 16QAM were implemented by configuring constellation tables. Subsequently, the conversion to bandpass signals was performed by means of an up-converter, and their respective constellations, bit rates and frequency spectra were analyzed.

Key words: GNU Radio, M-QAM

1 Introduction

In modern digital communications, achieving high spectral efficiency and robustness against noise is essential for reliable and high-capacity data transmission. Quadrature Amplitude Modulation (QAM) is a widely used technique that combines both amplitude and phase modulation to transmit multiple bits per symbol. This is achieved by modulating two orthogonal carrier signals—commonly referred to as the in-phase (I) and quadrature (Q) components—enabling the representation of symbols as points in the complex plane, known as a constellation diagram. The density of these constellations increases with the modulation order (e.g., BPSK, QPSK, 8PSK, 16QAM), allowing higher data rates within a fixed bandwidth.

In this practice, digital modulation schemes including BPSK, QPSK, 8PSK, and 16QAM were implemented and analyzed using the GNU Radio platform. Custom constellation tables were configured for each modulation scheme, and their characteristics were evaluated through constellation diagrams, frequency spectra, and bit rate analysis. Additionally, an upconverter block was integrated into the system to simulate the transmission of these modulated signals in a bandpass format, enabling the observation of their behavior under noise and more realistic transmission conditions.

The primary objective of this practice was to understand and compare the performance of various digital modulation schemes in terms of spectral efficiency and resilience to noise.

2 Methods

The flowchart proposed in the practice was implemented [1], incorporating BPSK, QPSK, 8PSK and 16QAM modulations. For this purpose, the constellation table was adjusted by placing the corresponding points on the I and Q axes, as shown in Figure 1, where the respective constellations, frequency spectra and bit rates associated with each modulation were also analyzed.

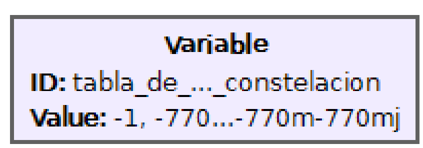

Fig. 1: Tabla de constelaciones

Subsequently, the previous steps were replicated using the simulated bandpass version. For this purpose, an upconverter block was integrated at the end of the system, in order to move the signal to the desired band, as shown in Figure 2.

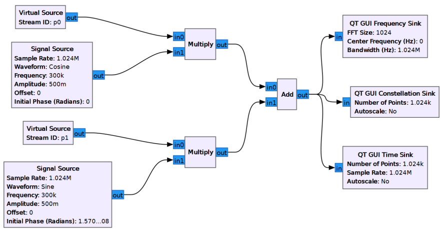

Fig. 2: Up converter

3 Results

The results for BPSK, QPSK, 8PSK, and 16QAM modulations, with a noise amplitude of 100 mV, a bandwidth equal to the symbol rate, a symbol rate of 32 kbaud, and a bitrate defined as the product of the bit-per-symbol quantity and the symbol rate, are shown in figures3,4,5 and 6.

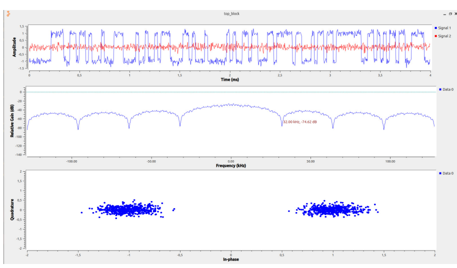

Fig. 3: BPSK signal with constellation=[1,-1] and bitrate=32kbps(1 bit*Rs), its frequency spectrum and constellation

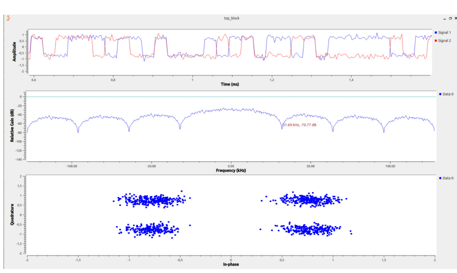

Fig. 4: QPSK signal with constellation=[-0.77+0.77j,0.77+0.77j,0.77-0.77j,-0.77-0.77j] and bitrate=64kbps(2 bit*Rs), its frequency spectrum and constellation

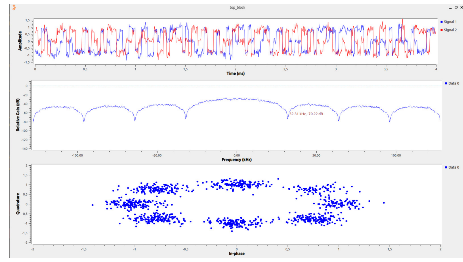

Fig. 5: 8PSK signal with constellation=[-1,-0.77+0.77j,1j,0.77+0.77j,1,0.77-0.77j,-1j,-0.77-0.77j] and bitrate=96kbps(3 bit*Rs), its frequency spectrum and constellation

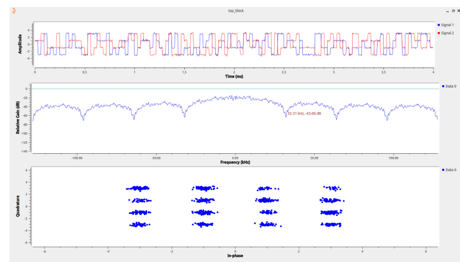

Fig. 6: 16QAM signal with constellation=[-3-3j,-3-1j,-3+1j,-3+3j,-1-3j,-1-1j,-1+1j,-1+3j,1-3j,1-1j,1+1j,1+3j,3-3j,3-1j,3+1j,3+3j] and bitrate=128kbps(4 bit*Rs), its frequency spectrum and constellation

Results from the bandpass versions of the same signals, with a noise amplitude of 50mV,cosine and sine amplitudes of the upconverter set to 500mV(Amplitude of the carrier signal=$\sqrt{Asen^2 + Acos^2}$=707.1 mV), and a carrier frequency of 300 kHz can be observed in 7,8,9 and 10.

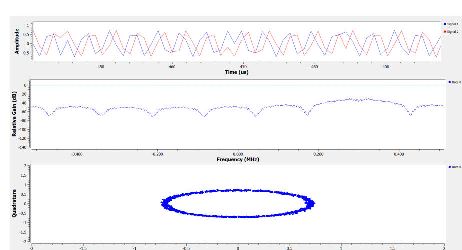

Fig. 7: BPSK Bandpass signal with constellation=[1,-1] and bitrate=32kbps, its frequency spectrum and constellation

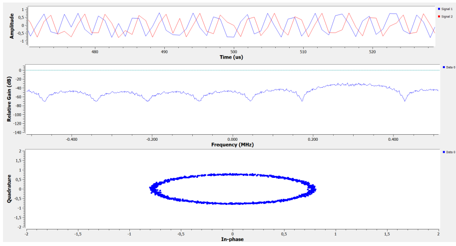

Fig. 8: QPSK bandpass signal with constellation=[-0.77+0.77j,0.77+0.77j,0.77-0.77j,-0.77-0.77j] and bitrate=64kbps, its frequency spectrum and constellation

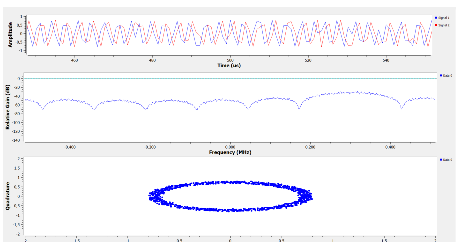

Fig. 9: 8PSK bandpass signal with constellation=[-1,-0.77+0.77j,1j,0.77+0.77j,1,0.77-0.77j,-1j,-0.77-0.77j] and bitrate=96kbps, its frequency spectrum and constellation

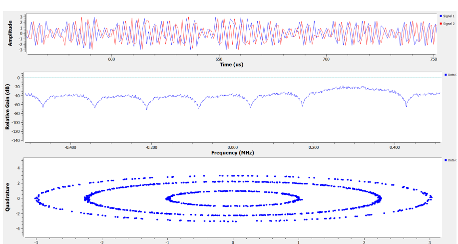

Fig. 10: 16QAM bandpass signal with constellation=[-3-3j,-3-1j,-3+1j,-3+3j,-1-3j,-1-1j,-1+1j,-1+3j,1-3j,1-1j,1+1j,1+3j,3-3j,3-1j,3+1j,3+3j] and bitrate=128kbps, its frequency spectrum and constellation

4 Conclusions

The up-converter in modulations such as 16-QAM introduces critical changes by shifting the signal to a carrier frequency, generating sidebands and concentrating noise around it. This especially affects dense constellations, where nearby symbols are more vulnerable to amplitude and phase distortions. Unlike baseband, where the noise is evenly distributed and the bandwidth is directly dependent on the symbol rate, in bandpass the spectrum is doubled and can have unwanted components if the filtering is not optimal.

Analysis of PSD in QPSK, 8-PSK and 16-QAM reveals a fundamental trade-off between spectral efficiency and robustness in real-world conditions. 16-QAM, with its more compact spectrum, maximizes data rate but is fragile to noise and nonlinear distortions, especially after the up-converter, where its sidelobes can interfere with adjacent channels. QPSK, although less efficient, offers a stable and resilient spectrum, ideal for less-than-ideal environments. 8-PSK, intermediate in efficiency, has a higher sensitivity to phase errors, visible in the widening of its PSD under oscillator noise.

By increasing Rs in QPSK, the constellation shows more specific things. If the symbol rate exceeds the available bandwidth, the dots are distorted by inter-symbol interference (ISI), as if the constellation dots stop being still and perfect to expand, blur, or even overlap. Therefore, by increasing Sps, more samples per symbol reveal details hidden from noise and filtering, but also consume much more resources, so an optimal ratio must be found by looking at the constellation and the spectrum.

References

[1] H. Ortega, "Modulation based on constellations - grc," http://github.com/hortegab/ComdigPractices2021sii/blob/main/Fase%20II/pract2/modulacion_basada_en_constelaciones.grc, 2021, accessed: May 9, 2025.