Practice 3: From Radio Frequency to Complex Envelope (GNURADIO)

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Abstract

This report analyzes several types of modulation: OOK, BPSK and FSK, evaluating their behavior in the time and frequency domains. The constellations associated with each modulation technique and their variation when adjusting the carrier frequency and frequency deviation are studied. Through this analysis, the impact of these parameters on the performance of the modulations is evaluated, both in terms of RF signals and their representations in the time, spectral and complex envelope domains.

Key words: GNU Radio, OOK, BPSK, FSK

1 Introduction

In modern communication systems, modulation plays a fundamental role in adapting signals for efficient transmission and reception. This practice focuses on the implementation and analysis of three widely used digital modulation techniques: On-Off Keying (OOK), Binary Phase Shift Keying (BPSK), and Frequency Shift Keying (FSK). Each of these techniques presents unique characteristics in how information is encoded and transmitted, affecting aspects such as bandwidth usage and signal representation.

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. GNU Radio was used to simulate and visualize each modulation process, evaluate the effects of parameter variations(such as carrier frequency and frequency deviation), and examine the resulting signal constellations.

2 Process

Initially, a flowchart of OOK modulation was used with the purpose of analyzing its radiofrequency-modulated(RF) version and its complex envelope-modulated(CE) version in both time and frequency domains, as well as the effect of different carrier frequency values on them. Furthermore, the pyhton codes of the RF VCO and EC VCO blocks were analyzed and commented on as shown in 1 and 2.

```
import numpy as np
from gnuradio import gr
import math

class blk(gr.sync_block):
    #"""This block is a RF VCO and works as following: Este bloque modulada la señal, tiene dos entrada que son Amplitud y fase, el bloque work modula con la portadora"""

    def _init_(self, fc=128000, samp_rate=320000):
        gr.sync_block._init_(
            self,
            name='e_RF_VCO_ff',
            in_sig=[np.float32, np.float32],
            out_sig=[np.float32]
        )
        self.fc = fc
        self.samp_rate = samp_rate
        self.n_m=0

    def work(self, input_items, output_items):
        A=input_items[0]
        Q=input_items[1]
        y=output_items[0]
        N=len(A)
        n=np.linspace(self.n_m,self.n_m+N-1,N) #"Crea un vectoer 'n' que va desde n_m que en principio es 0 hasta n_m+N-1, donde N es el tamaño del vector de entrada que representa la amplitud, con una cantidad de valores igual a N"
        self.n_m += N
        y[:]=A*np.cos(2*math.pi*self.fc*n/self.samp_rate+Q)#"Señal modulada, RF, pasa banda"
        return len(output_items[0])
```

Fig. 1: RF VCO block commented code.

```
import numpy as np
from gnuradio import gr
import math

class blk(gr.sync_block):
    #"""This block is a CE VCO or baseband VCO and works as following: Este bloque produce la envolvente compleja de la señal de entrada que es la q se compone de A y Q"""

    def _init_(self,):
        gr.sync_block._init_(
            self,
            name='e_CE_VCO_fc',
            in_sig=[np.float32, np.float32],#"señals de entrada"
            out_sig=[np.complex64]"señal de salida"
        )

    def work(self, input_items, output_items):
        A=input_items[0]#"Señal que representa la amplitud de la salida"
        Q=input_items[1]#"Señal que representa la fase de la ssalida"
        y=output_items[0]#"Se crea la Señal de salida"
        N=len(A)#"Longitud del vector que representa la amlitud"
        y[:]=A*np.exp(1j*Q) #"Envolvente compleja"
        return len(output_items[0])
```

Fig. 2: CE VCO block commented code.

Afterwards, the flowgraph was modified for BPSK modulation with the objective of analyzing its radiofrequency and complex envelope modulations in both the time and frequency domains.

The flowgraph was then modified once more to analyze the FSK modulation in both its radiofrequency and complex envelope forms, within the time and frequency domains, as well as to observe its constellation diagram.

Finally, control questions were answered by analyzing the codes, modifying some variables and repositioning certain blocks in the flowgraph.

3 Results

In order to verify the correct operation of the OOK modulation, the carrier frequency and frequency deviation were varied. These modifications made it possible to analyze the behavior of the RF modulated signal and the complex envelope (CE) in the time and frequency domains, as well as to examine their respective constellations.

It was observed that the carrier frequency directly influences the frequency of the RF signal, affecting its representation in the time domain, as shown in Figures 3 and 4, as well as its frequency spectrum. In contrast, the frequency deviation does not present a significant impact on this form of modulation. Finally, it is concluded that none of these variations alters the constellation structure corresponding to the OOK modulation.

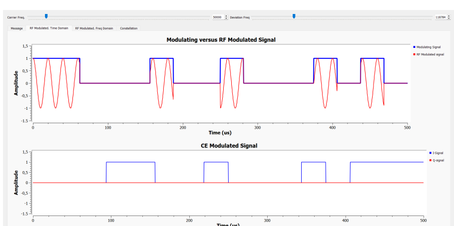

Fig. 3: RF Time Domain. Carrier = 50 kHz.

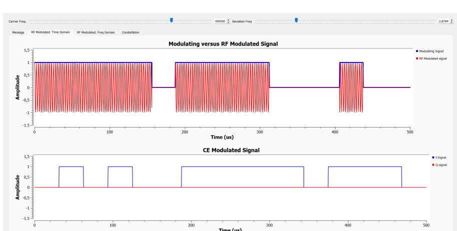

Fig. 4: RF Time Domain. Carrier = 400 kHz.

In BPSK modulation, as shown in Figure 5, by changing both the carrier frequency and the frequency offset, effects on the RF modulated signal can be observed, particularly during bit transitions. By increasing the carrier frequency, the signal spectrum shifts towards higher frequencies, and in the time domain a greater number of oscillations are evident. In turn, the frequency deviation affects the speed with which the phase change between symbols occurs: the greater the deviation, the more abrupt the phase transitions become, which may give the impression of a momentary increase in frequency at those moments. In addition, when observing the complex envelope, it can be seen that its real part is bipolar and that there is no imaginary component in this modulation, which is characteristic of a purely in-phase modulation.

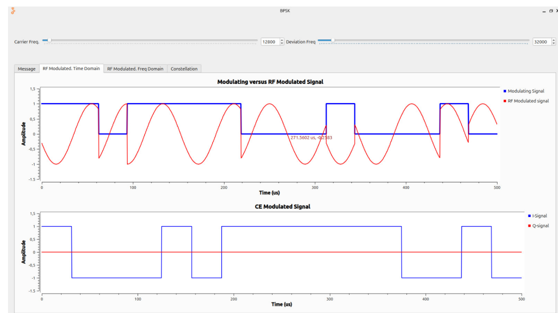

Fig. 5: BPSK modulation in the frequency domain.

However, in the frequency domain no changes were observed when varying the frequency deviation as shown in Figure 6. It is important to note that this variation does not alter the spectral content of the signal nor does it modify the characteristic constellation of the BPSK modulation, which remains invariant with two phase states: 0° and 180°, as shown in Figure 7, regardless of the frequency used.

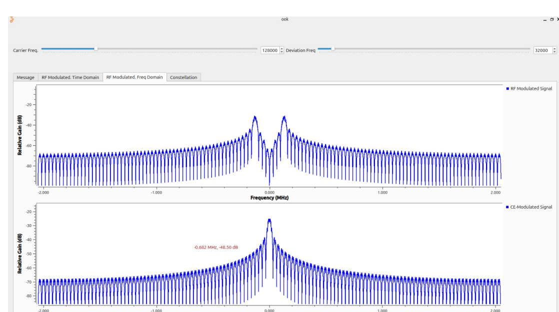

Fig. 6: Frequency domain BPSK modulation.

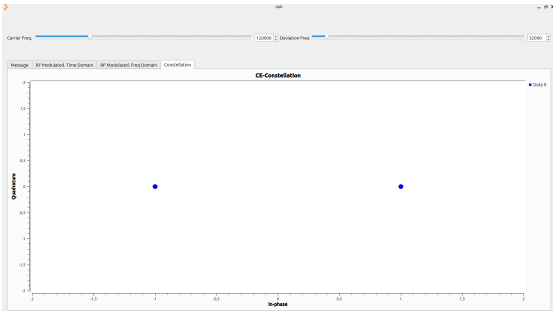

Fig. 7: Complex envelope constellation in BPSK modulation.

Furthermore, by modifying the constant by a value of -1, as shown in Figure 8, it was noticed that when the transmitted bit is a 0, the signal ends in the negative part; and when it is a 1, it ends in the positive part. This behavior makes it easier to identify the transmitted value by observing the end of each symbol.

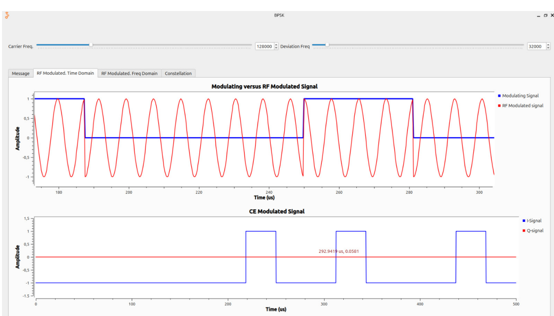

Fig. 8: BPSK modulation in the frequency domain using a scaling constant of -1.

FSK modulation is affected by both carrier frequency and frequency deviation, as can be seen in Figure 9. These parameters directly influence the RF modulated signal and its representation by the complex envelope (CE). Unlike BPSK, in FSK the EC has an imaginary component, and its constellation varies depending on the values of the carrier and frequency deviation used.

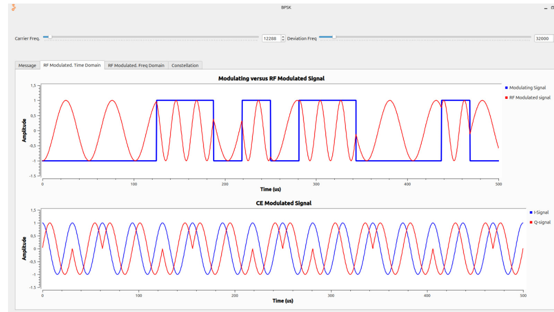

Fig. 9: Modulacion FSK en el dominio del tiempo.

In the frequency domain, when the frequency deviation is greater than the carrier frequency, a situation occurs as shown in Figure 10: the spectral components corresponding to the different symbols approach each other, causing the signals to overlap. This results in a loss of resolution in the RF signal.

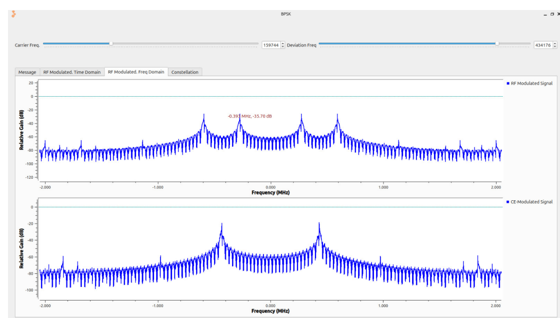

Fig. 10: Modulacion FSK en el dominio de la frecuencia con una desviacion de frecuencia mayor a la portadora

It is also observed that, when in an FSK modulation the frequency deviation is equal to the carrier frequency, a particular situation arises in which the frequency assigned to bit 0 is reduced to 0 Hz, as shown in Figure 11. In addition, by eliminating the characteristic oscillation of a carrier wave, the receiver loses the ability to correctly identify that bit, which can generate ambiguity and errors in the demodulation process. This condition also breaks the usual symmetry of FSK, affecting the receiver design and reducing the spectral separation between symbols, which can lead to frequency overlaps, as shown in Figure 12.

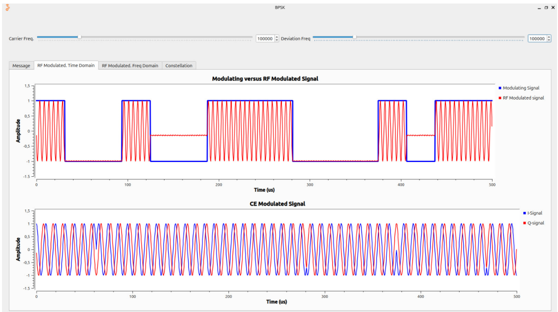

Fig. 11: FSK modulation in the time domain when the frequency deviation is equal to the carrier frequency.

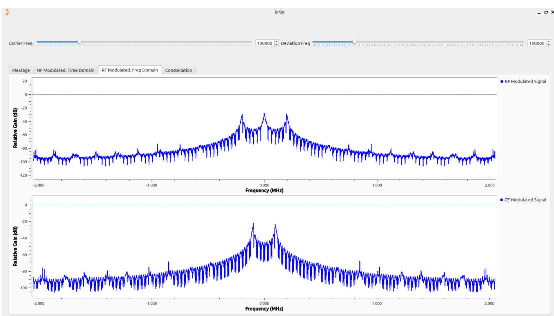

Fig. 12: FSK modulation in the frequency domain when the frequency deviation is equal to the carrier frequency.

On the other hand, when the frequency deviation is a multiple of the carrier, as shown in Figure 13, certain drawbacks may also arise. In these cases, harmonic interference or overlapping between spectral components may occur, making it difficult to differentiate symbols correctly.

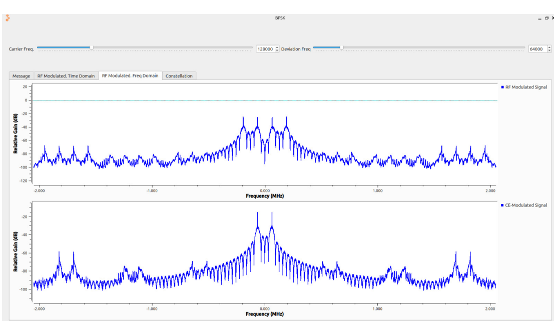

Fig. 13: FSK modulation in the frequency domain when the frequency deviation is a multiple of the carrier frequency.

In figure 14, it can be seen that, with a carrier frequency of 170 kHz and a frequency deviation of 45 kHz, there is almost no overlap.

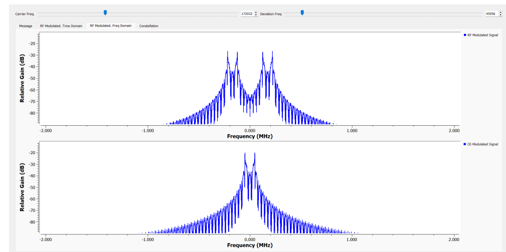

Fig. 14: FSK modulation in the frequency domain exhibits minimal overlap.

The frequency deviation fd is what determines the separation between the frequencies associated with the modulated symbols. In the FSK constellation, only the effect of fd is observed, since each symbol is represented by a different frequency, and the distance between the points in the constellation is directly related to the frequency deviation as shown in Figure 15.

To determine the number of points in the constellation, the frequency deviation fd is divided by the carrier frequency fc, and then multiplied by two. This calculation gives the number of points present in the constellation.

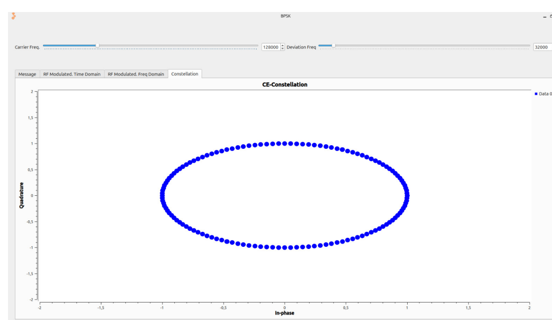

Fig. 15: FSK Modulation Constellation

4 Results of control questions

1.1. There are several ways to determine if this sps value is correct; however, the 2 clearest with current knowledge are: Nyquist's theorem is respected, the sampling frequency (derived from SPS) is at least twice the carrier frequency fc, this guarantees that there is no aliasing and that the signal can be reconstructed correctly. And with the power spectral density of the signal, which clearly shows the carrier and its sidebands, without spectral folding or excessive noise due to insufficient sampling.

1.3. The formula comes from how the complex envelope is formulated in the case of fsm modulation in analog communications in which there is a kf that depends on the frequency of the message to be transmitted, which in this specific case is Rb*SPS, and the frequency deviation to be transmitted in the modulated signal, which is multiplied by 2* pi so that it can be transmitted.

1.5. The upper input of the VCO controls the amplitude of the generated signal, and the lower input controls the instantaneous frequency of the signal (the frequency modulation). And this is directly related to how the blocks are declared in code, where the first input is the amplitude (A) and the second input is the phase (Q).

1.7. This relocation cannot be done, since it is not the same to integrate the message before and after the interpolation process. Because the interpolation adds more samples to the message, and for costs it is much better to adapt the signal before implementing the VCO because it would be more expensive if it is done as discussed.

5 Conclusions

The main difference between an OOK modulator in RF version and one in EC version is the presence of a carrier signal. The RF modulator raises the frequency of the message to move it to band-pass frequencies, which are more suitable for wireless transmission. In contrast, the EC modulator operates mainly on baseband frequencies, where it's more suitable for wireless transmission. In contrast, the EC modulator operates mainly at baseband frequencies, where no carrier is used, making it ideal for local or wired applications.

It was observed that when the frequency deviation exceeds the carrier frequency, the signals begin to resemble one another, leading to overlap and a loss of resolution in the RF signal. Since the sampling frequency fs is the inverse of the sampling period, it determines how many complete cycles of the signal can be displayed. However, if fs is not a multiple of the carrier frequency fc, the resulting signal lacks complete periods. This causes the system to attempt a reconstruction of an incomplete waveform, introducing phase discrepancies that ultimately affect the signal amplitude. Therefore, it is concluded that the carrier frequency fc should be significantly greater than the sampling frequency fs to ensure accurate signal representation.

The importance of the correct location of blocks such as interpolation filters, VCO and constant multipliers was evidenced, since their positions can affect for or against the modulated signal. In addition, it would be too expensive for the transmission of the information, if for example it's interpolated after passing through the multiplier and this reaches the VCO. Optimal use of resources must be made.