Labs in Information and Communication Technologies **Assignment 2**
Spring Semester
Telecommunications Circuits Laboratory
EPFL

Digital Radio Transmitter Using Quadrature Modulation

For this lab session, we will use a simple GNU Radio flowgraph that allows to adjust various parameters of a digital radio transmitter. It also shows you the signal at different points of the digital signal processing (signal generation and transmission) chain in both time- and frequency-domain.
Launch GNU Radio Companion, open the file *digital_modulation.grc* available on Moodle and run the flowgraph.

Complex Valued Modulation

Introduction

Quadrature modulation technique makes use of two carriers, one called I "in phase" (cos) and one called Q "quadrature" (sin). These carriers which correspond to the projections of the complex phasor on the real and imaginary axis, are modulated separately by the complex-valued baseband signals.
The two baseband signals also called complex waveform, sampled at the symbol rate M produce the constellation diagram. Each point of the constellation represents a symbol and is associated to a binary sequence (bits). The quadrature modulation technique is employed during digital phase shift keying (PSK) and quadrature amplitude modulation (QAM).
In the graphical interface, you find this step on the top-left, and you can select the modulation scheme. Different modulation schemes provide a different number of constellation points and can therefore represent a different number of data bits with one symbol.

Note On Bandwidth

There exist two different definitions of bandwidth:

- The **Baseband bandwidth** is equal to the maximal frequency of a signal. Often used for signals which are symmetrical around the frequency zero.
- The **Passband bandwidth** is equal to the difference between the maximal and minimal frequency of a signal. It is a more generic definition of bandwidth, which does not assume symmetry around the frequency zero.

Exploring Modulation Orders

We first explore different modulation schemes.

Task-1.1 Try different QAM constellations. Provide constellation plots of 16-QAM and 64-QAM?

Task-1.2 How many bits are encoded in one symbol of a 16-QAM and in a 64-QAM constellation?

Task-1.3 We want to know which mapping is used by the QPSK modulation. To this end, you can tick the *Use custom bits* option to transmitt the bit sequence you want. Press the Return key to apply the changes.
Provide a constellation plot with the constellation points annotated by the corresponding bit labels (00, 01, 10, 11).

Digital Baseband Signal Generation and Filtering

Introduction
In this second step, we study the generation of a band-limited digital baseband signal that can then be upconverted to the carrier frequency. The transmitter interface shows the steps after the constellation mapping, upsampling (zero insertion) and the pulse shaping (which defines the signal bandwidth). The graphs show the time domain waveform and the spectrum after each step.

Signal Before Upsampling

Set the constellation to QPSK and untick *Use custom bits* to use a random bit sequence.

Task-2.1 From the *Symbols* plot, can you recover what is the symbol frequency this transmitter uses?
What is the data rate in [bit/s]?

Task-2.2 What is the minimum passband bandwidth (in Hz) required to represent this signal?
Hint: The Nyquist-Shannon sampling theorem states that a signal sampled at a rate f_s can perfectly represent a band-limited signal with $f_{\text{max}} < f_s/2$

Upsampled Signal

Upsampling corresponds to zero insertion. The spectrum of the upsampled signal is a periodic repetition of the signal before upsampling.

Task-2.3 From the *Upsamples symbols* plot, can you identify the upsampling factor used by this transmitter? Can you recover the same information from the spectrum? Illustrate with plots. Hint: You can access the option menu for a plot by using a mouse wheel click, left click and drag to zoom, and right click to undo a zoom.

Task-2.4 After zero insertion, what is the minimum passband bandwidth required to represent this signal?

Filtered Signal

Since the spectrum of the upsampled signal is just a periodic repetition of the original spectrum, we can filter out those periodic repetitions (images) to limit the bandwidth without loosing any information on the signal of interest. The corresponding signal and spectrum is shown in the "Filtered Spectrum".
We will now observe the importance of the choice of low-pass filter, by comparing different configurations:

1. Rolloff factor = 0.00001 (corresponds to a sinc filter)
2. Rolloff factor = 0.35
3. Rolloff factor = 1

Task-2.5 Consider the filtered spectrum. What is the $20\,\mathrm{dB}$ passband bandwidth of the filtered spectrum (BW at $20\,\mathrm{dB}$ down from the average within the passband) for the three cases evaluated with a filter length of 20?
Provide plots of the filtered spectrum for the three configurations. (You can click on a signal label to hide its curve)

Task-2.6 Consider the eye-diagram (time-domain waveform with multiple symbol repetitions plotted on top of each others). The eye-opening is the distance between the symbol levels.
For the three configuration proposed measure the following openings and provide the corresponding plots:

- What is the eye-opening at the correct sampling instant (i.e., in the middle of the graph)?
- What is the eye-opening when sampling at an offset of 25% of the symbol period?

Can you explain the behaviour of the sinc filter at the correct sampling time? Which parameter is involved?

Task-2.7 Can you present the trade-offs to take into account in the choice of a rolloff factor?

Task-2.8 Based on the eye diagram, explain the advantages/disadvantages of using QPSK versus QAM64?

Task-2.9 To give some context on the relevance of the bandwidth used for RF transmissions, we will look at the actual cost of the cellular radio spectrum.
To get the right to use radio frequencies, telecommunication operators have to participate to an auction valid for a a given number of years, which results are public.
By simply looking at the result table available here and assuming that all frequency bands are as valuable. What is the price per MHz that Swisscom bought for the next 15 years?
As the spectrum is sold using an auction system, the price can vary greatly between countries. From the report FCC auction 110, what is the price per MHz for the 3.35-3.45 GHz band in the US?

Task-2.10 The plot ”Constellation Diagram” shows the both the in-phase and quadrature eye diagram on the 2D plane.
The time is not visible anymore, but the blue lines show the path, in time, that the signal takes to go from one constellation point to the next.
Can you find a configuration and transmitted bits that causes the constellation diagram to be a circle? Provide the configuration you propose and a screenshot of the constellation diagram.