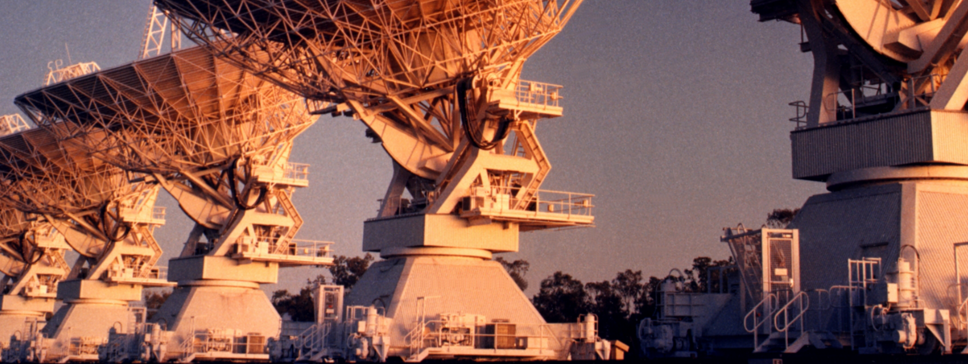


DSP Basics - Modulation

2021

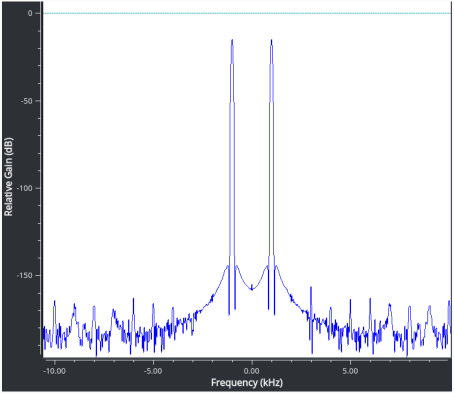
TAs Winter 2021 : Michalis Raptakis , Eleftheria Plevridi
csdp1250@csd.uoc.gr, plevridi@csd.uoc.gr
Computer Science Department, University of Crete

Recap!

Complex Numbers and IQ representation

Complex Numbers and IQ representation

Lets plot the frequency domain of a cos() signal using the iq_example.grc

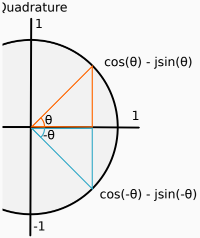


Even if the example used a single $\cos(x)$ signal at 1 kHz there is another one at -1 kHz!!!

The usual suspect!

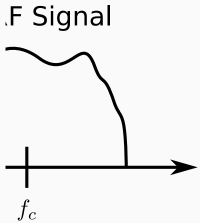
Trigonometric identities!

- $\sin(-\theta) = -\sin\theta$
- $\cos(-\theta) = +\cos\theta$



Recall the DFT and how it transforms a time domain signal into a summation of cosines. Due to the above identities, a real signal at frequency f should produce a mirrored signal at $-f$ at the frequency domain

- We showed that **real** signals will always have positive and negative spectral components
- In baseband applications (eg. audio), this is not a problem, as there is no notion of a negative frequency
- What about RF signals?



Complex Numbers and IQ representation

- Having mirroring on RF signals is not practical
- We do not want to occupy bandwidth to repeat the same information
- **The solution:** IQ representation
- The term “I/Q” is an abbreviation for “in-phase” and “quadrature.”

- “in-phase” and “quadrature” refer to two sinusoids that have the same frequency and are 90° out of phase.

More info here www.allaboutsircuits.com

Complex Numbers and IQ representation

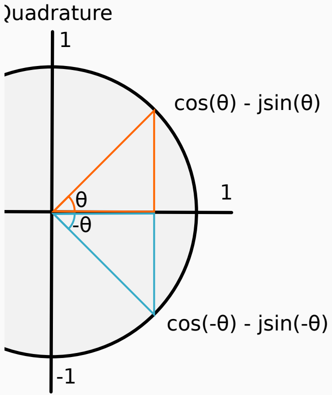
The solution!
Use the IQ representation

$$x(t) = e^{-j2\pi ft}$$

$$= \underbrace{\cos(2\pi ft)}_{\text{In-phase(I)}} - j \overbrace{\sin(2\pi ft)}^{\text{Quadrature (Q)}}$$

Complex Numbers and IQ Representation

Adding the quadrature component removes the ubiquity of the $\cos(\theta) = \cos(-\theta)$



Example!
Use the iq_representation.grc flowgraph to visually identify complex numbers and IQ representation

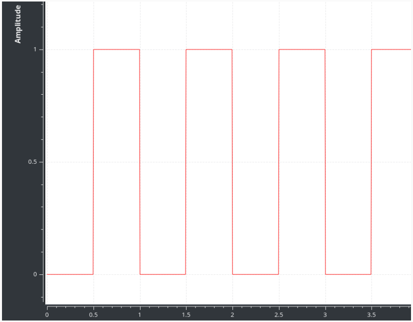
Pulse Shaping Filtering

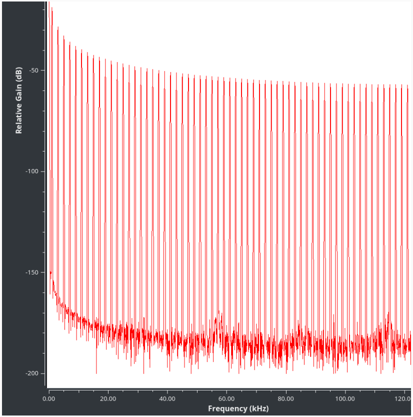
Pulse Shaping Filtering

- Filters can be used also for pulse shaping
- The goal is to minimize spurious signals and increase the spectral efficiency
- Spurious signals can be generated by extreme transitions of the source signal
- A simple square wave generated from a bit stream has an infinite bandwidth ➔non practical to transmit

Pulse Shaping Filtering

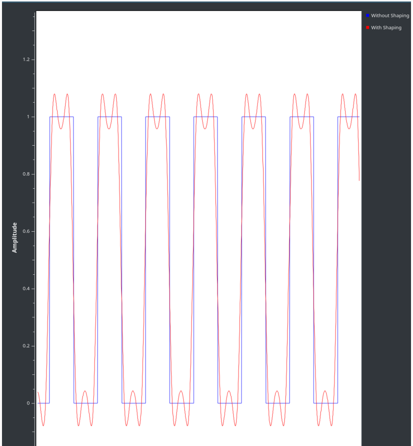
- A simple square wave generated from a bit stream has an infinite bandwidth ➔non practical to transmit
- A square wave is an infinite sum of sine waves

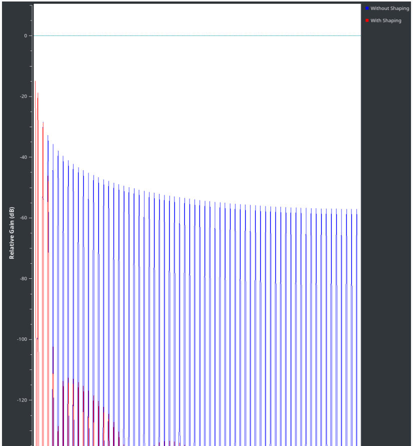




Pulse Shaping Filtering

- Commonly for shaping we use the Root Raised Cosine filter (RRC)
- Smooths the extreme transitions thus reducing the spurious



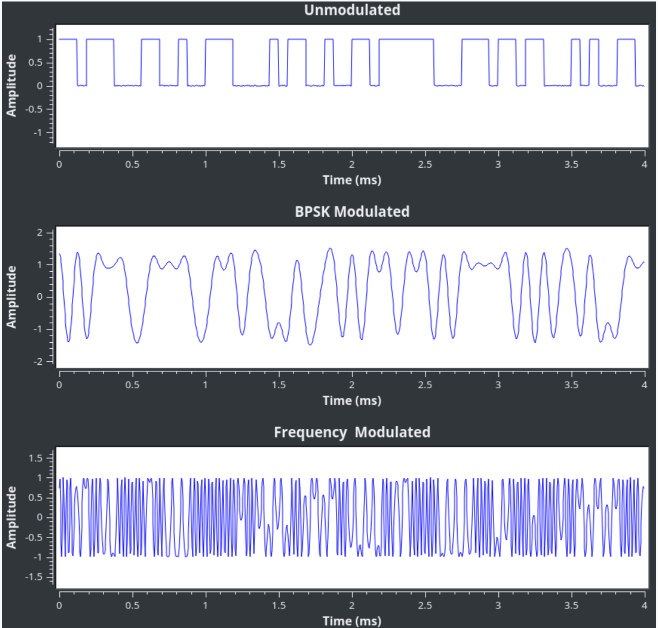


Modulation

Modulation

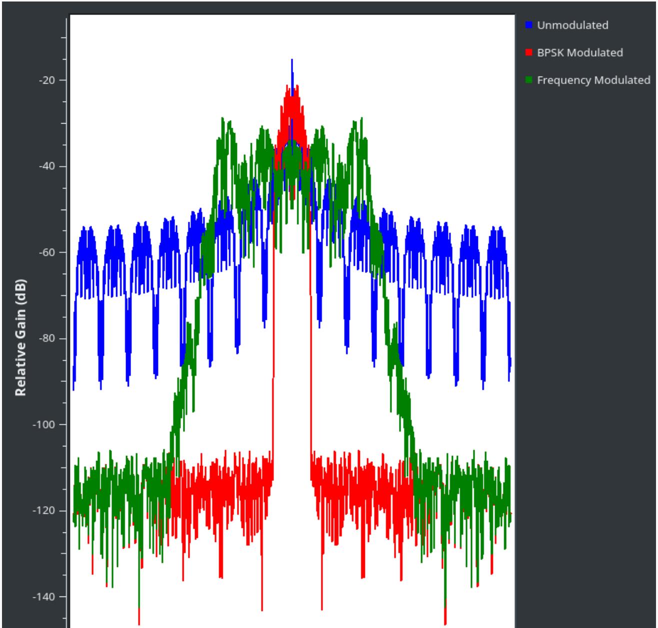
- As we saw before, it is impractical to transmit information in a binary form
- **Modulation** is the process of translating a bit stream into an analog waveform
- Modulation provides:
    - Spectral efficiency
    - Noise immunity
    - Avoids (or introduces :P) hardware impairments

Modulation



Unmodulated
Amplitude
Time (ms)
BPSK Modulated
Amplitude
Time (ms)
Frequency Modulated
Amplitude
Time (ms)

Modulation

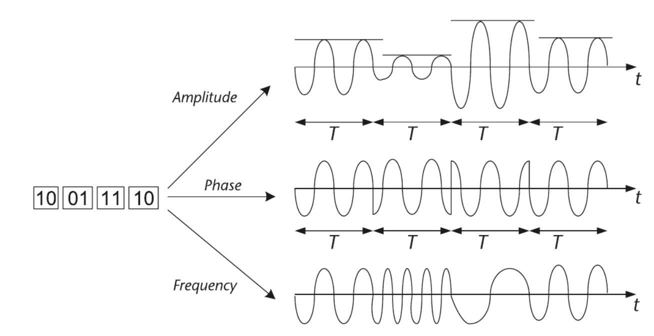


Unmodulated
BPSK Modulated
Frequency Modulated
Relative Gain (dB)
-20
-40
-60
-80
-100
-120
-140

Modulation

Well known modulation schemes are:

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Shift Keying Modulation (PSK)

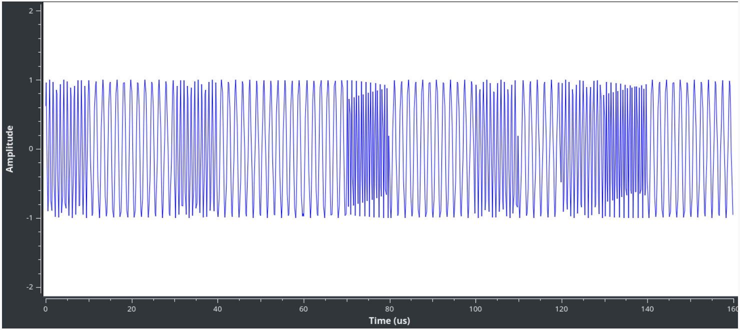


Modulation

- There is no ”perfect” modulation
- The choice of modulation depends always on the application
- Some modulations can deliver high data rates but require good signal quality
- Modulations like AM has very simple hardware circuits

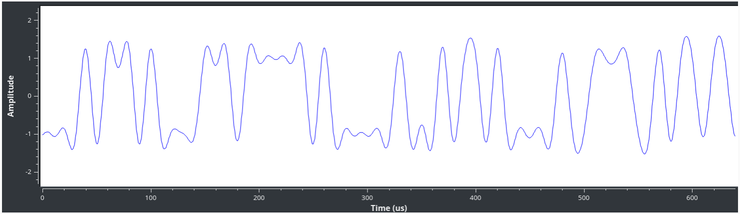
Frequency Shift Keying (FSK)

- Maps bits into separate frequencies
- If two frequencies are used, it is called 2-FSK
- If four distinct frequencies are used, it is a 4-FSK, etc

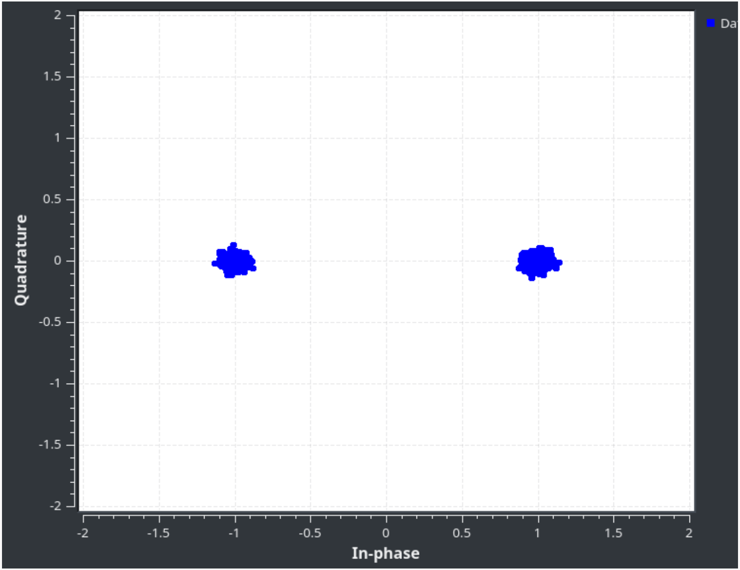


Phase Shift Keying (PSK)

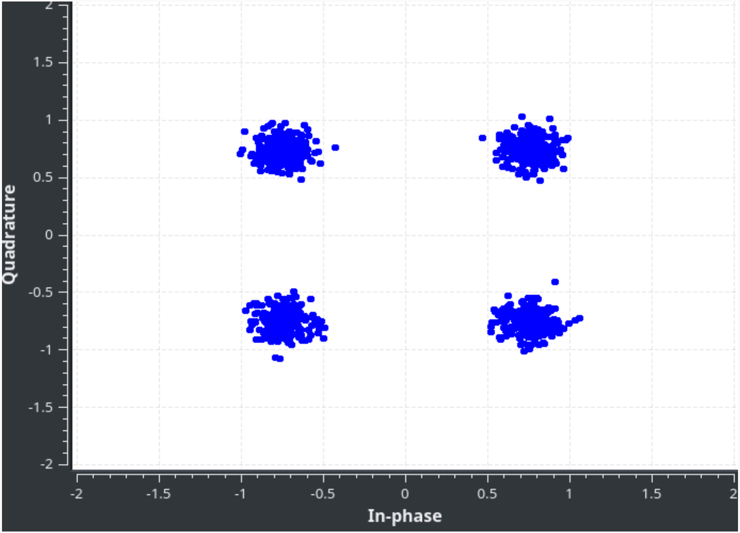
- Maps bits into phase transitions
- BPSK: Two phase transitions between 0 and π
- QPSK: For phase transitions $[\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}]$



Phase Shift Keying (PSK)



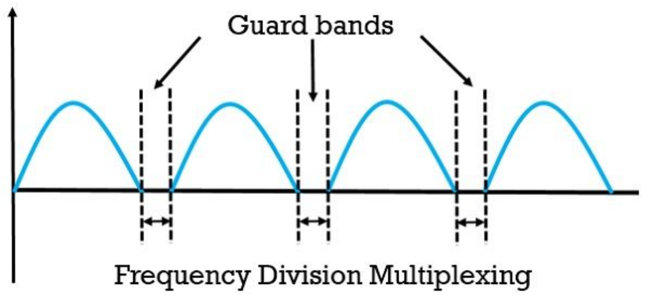
Phase Shift Keying (PSK)



FDM - OFDM - OFDMA

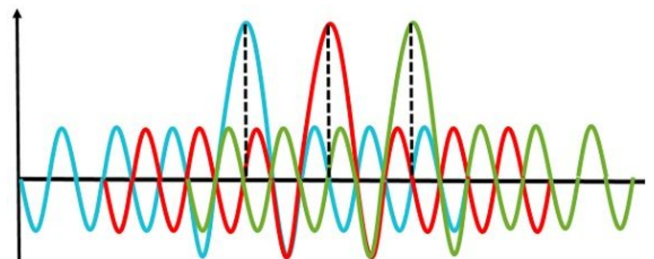
FDM - Frequency Division Multiplexing

- The entire bandwidth is divided by several sources
- FDM makes use of guard band.
- FDM is easily affected by other RF resources, causing it vulnerable to interference.

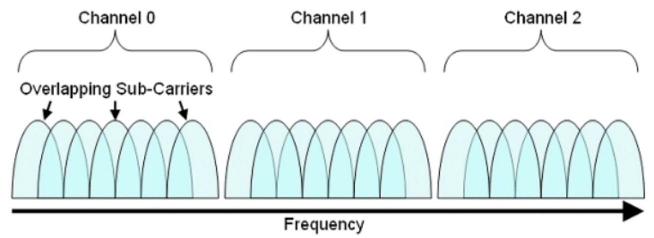


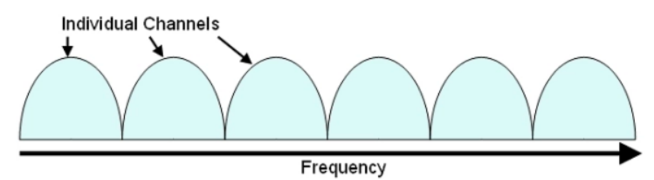
OFDM - Orthogonal Frequency Division Multiplexing

- In OFDM all the subchannels are dedicated to the single data source.
- Only a single user can transmit on all of the sub-carriers at any given time.
- OFDM eliminated the use of guard band.



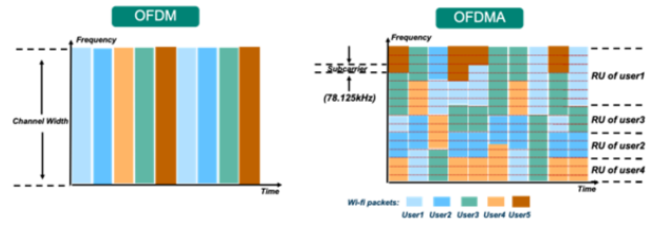
FDM - OFDM


Channel 0
Channel 1
Channel 2
Overlapping Sub-Carriers
Frequency


Individual Channels
Frequency

OFDMA - Orthogonal Frequency Division Multiple Access

- An extension of OFDM
- Allows multiple users to transmit simultaneously on the different sub-carriers per OFDM symbol.
- It has 3x higher throughput than single-user OFDM for short packets of data or multiple endpoints.

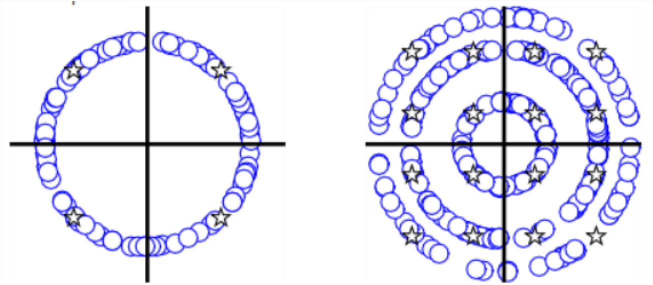


Carrier Frequency Offset (CFO)

CFO (1/4)

Carrier Frequency Offset usually arises due to:

- **Frequency mismatch between the Tx and Rx oscillators**: No two devices are the same and there is always some difference between the manufacturer's nominal specification and the real frequency of that device. Moreover, this actual frequency keeps changing (slightly) with temperature, pressure, age, and some other factors.

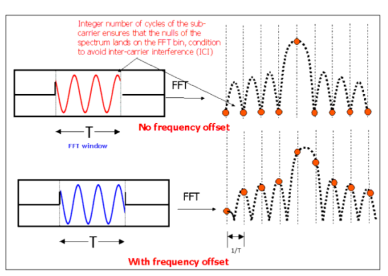


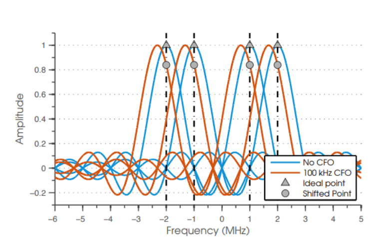
(a) 4-QAM constellation (b) 16-QAM constellation

This phenomenon is perceived as a ”shift” in frequency domain

CFO (3/4)

CFO in Frequency domain

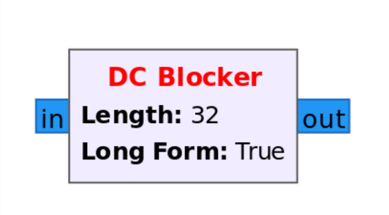


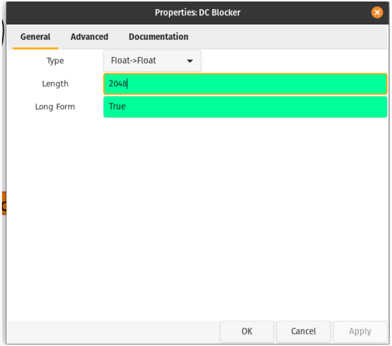


Can we recover from it ?

CFO (4/4)

To recover from the CFO effect in the GNU Radio you can use :





This recovery should take place when decoding the signal. So you need to place this block accordingly in the lab2-5 grc and observe what happens

More sources

Things happening around us!

- Paper from MobiCom '21: ”EarGate” Human Identification through signals
- LoRaWAN technology - IoT
- RF and Satellites
- SatNOGS - Open Source global network of satellite ground-stations