GNU Radio ile Uygulamalı Haberleşme Sistemleri-IV

Linux Kış Kampı
Afyonkarahisar, 4-8 Şubat 2026

Outline

- Quick Recap
- Digital Comms
- ADS-B
- QPSK
- Survey

Recap - Analog Communications

- Amplitude/Frequency/Phase
- AM/SSB/NBFM/WBFM/CW
- Of the all above which one has the smallest bandwidth?

OpenWebRX

- Web-based SDR receiver
- default port: 8073
- Receiver book: https://www.receiverbook.de/
- Online map: https://www.receiverbook.de/map

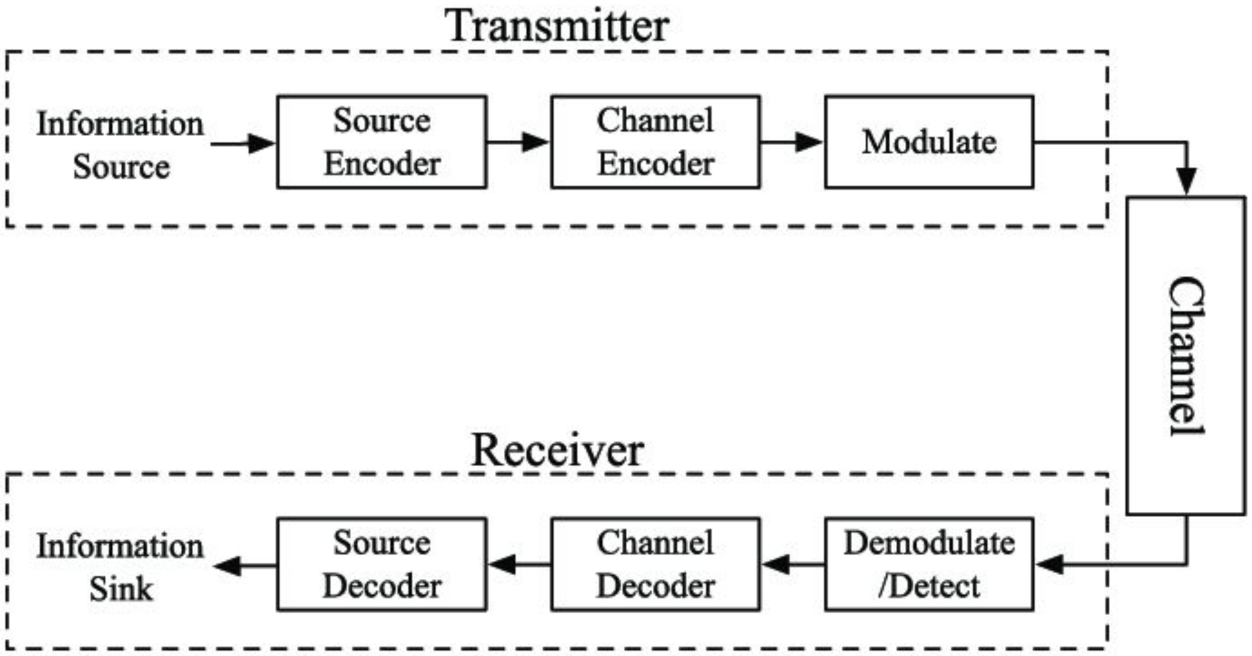
Schedule

- First Day: GNU Radio Introduction, DSP, GR Simulation Mode
- Second Day: SDR Introduction, RTL-SDR, GR Real-Time Mode
- Third Day: Analog Communications
- **Fourth Day: Digital Communications**

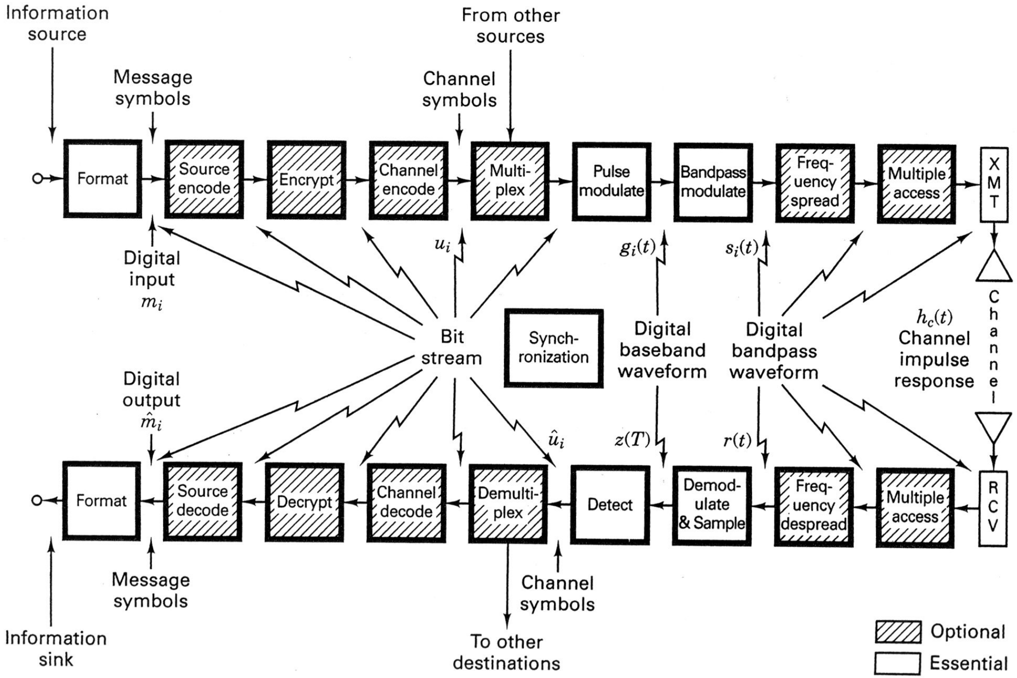
Digital vs Analog

- Source data
- Continuity
- Noise
- Error

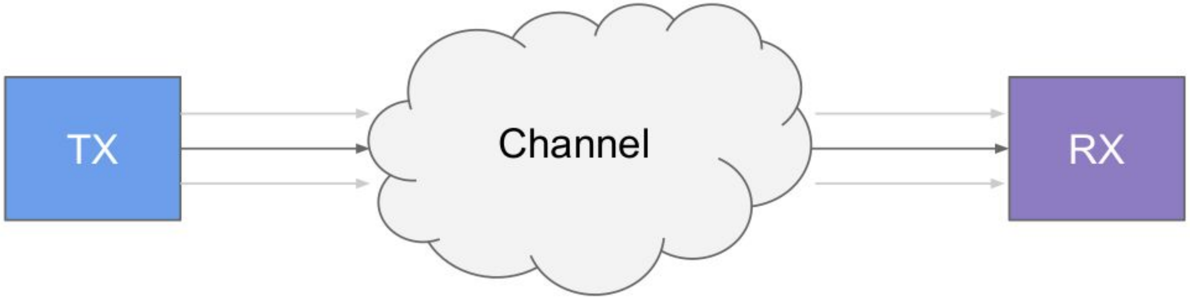
Communication Systems Block Diagram



Digital Communications - Detailed

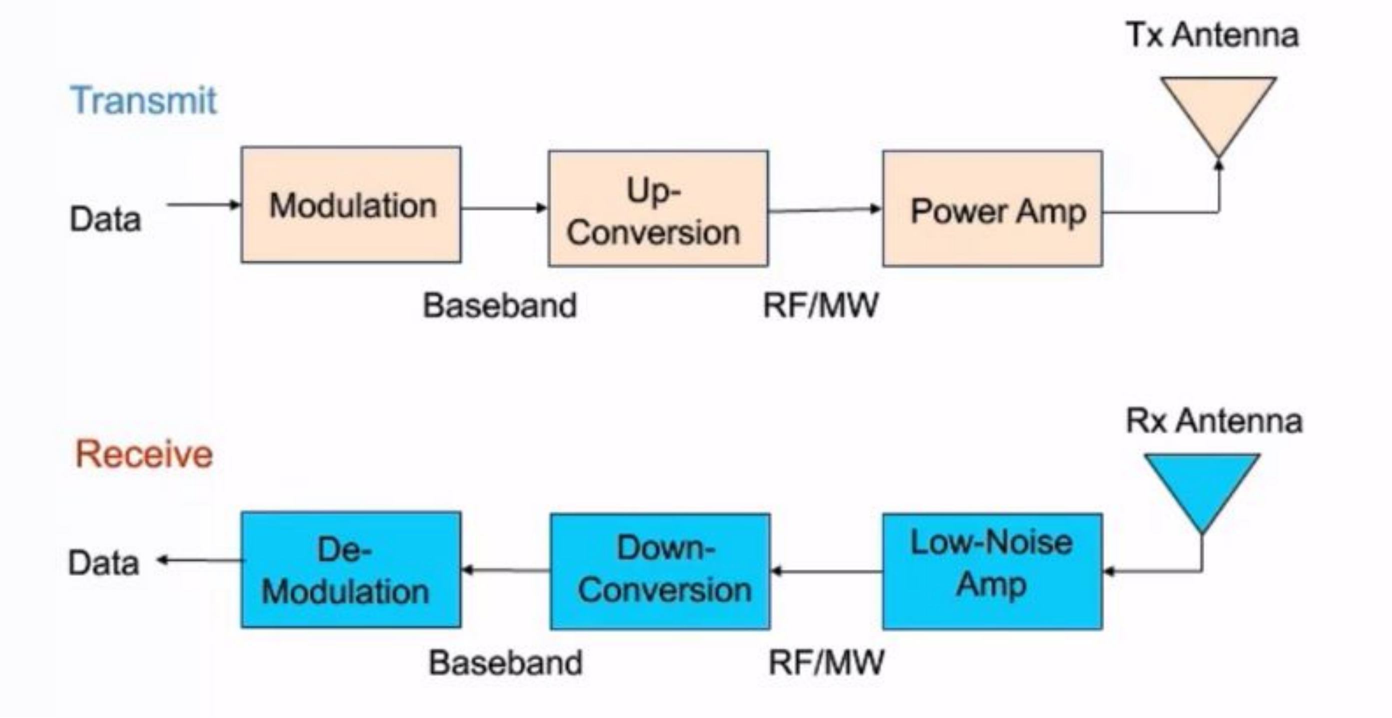


Wireless system: big picture



A transmitter, a receiver and a channel between them

Elements of Transmit/Receive



Transmitter

- Bits → Waveforms
  - Encoding
    - Add redundancy (intelligently) to help the receiver to recover the information despite errors.
- Modulation
  - Group/map bits into symbols.
  - “Mount” symbols on an analog waveform to be sent over the air.

Modulation Waveform

- Generate a basic analog signal and modify it according to the incoming bits and symbols:
    - Modify various aspects: amplitude, frequency or phase
        - AM, FM, Phase modulation

Modulation Order

- Defines the number of bits that are mapped to a symbol/signal.
  - With each Mod. order M, we can have up to M different symbols.
    - Mod. order M = 16: every log2(16) = 4 bits are mapped to a symbol.

      0000 → S1 0001 → S2 … 1111 → S16

Modulation Symbols

- Groups of bits:
    - Can be represented as an integer
        - E.g., 0010 → 2
    - Or, in a different plane as we will see next

IQ Representation

- A sinusoid signal can be represented by two other orthogonal sinusoids:
  - Inphase: $a \cos(2\pi ft)$
  - Quadrature: $b \sin(2\pi ft)$
    - Create an “orthonormal basis”.
      - A complex 2D plane where any point can be reached through a linear combination of I & Q:

$$v = aI + jbQ$$

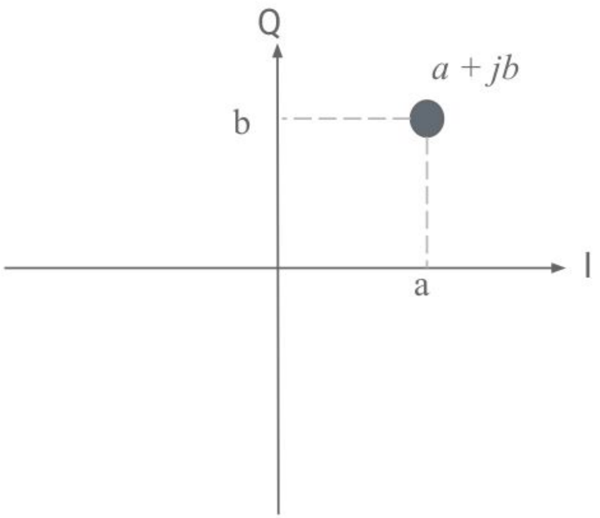
Web Resources for IQ Data

I/Q Data for Dummies

What’s Your IQ – About Quadrature Signals… | Tektronix

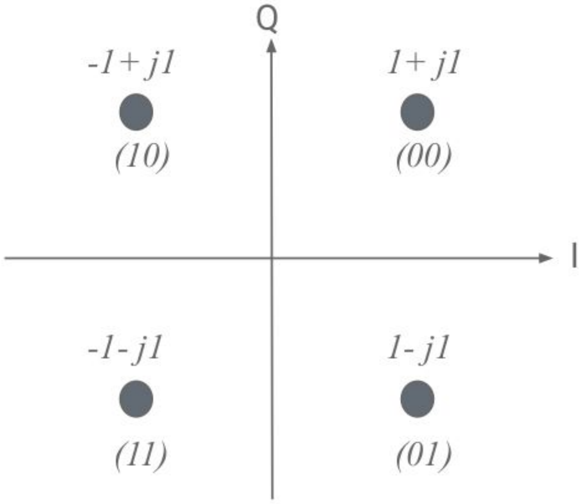
Constellation Diagram

- A 2D representation of symbols along I and Q:
  - Now, we define the symbols as complex numbers in the form of a+jb.
    - I and Q implied.
  - We don't normally choose any a & b.
    - Choose such that the points on the constellation have regular distances.
      - E.g., ±1, ±1j



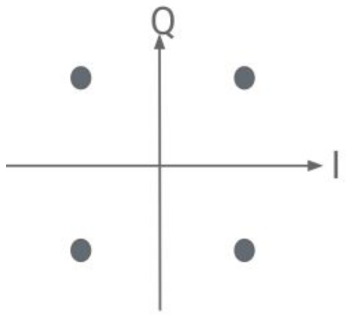
QAM

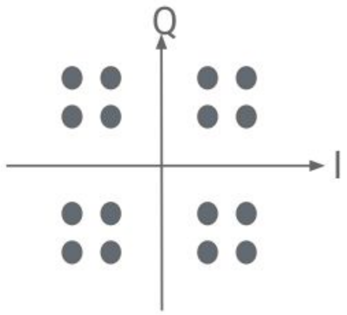
- What we saw was Quadrature Amplitude Modulation (QAM).
  - Generate signals through modifying the amplitude of two fundamental signals
  - Map each group of bits to these amplitudes.
  - Most used modulation scheme in modern wireless systems.
  - Bit values are assigned to QAM points in a particular order such that the hamming distance between neighboring points is always 1.
  - With this bit assignment, we probably see a 1-bit error even if we misdetect the symbol due to channel noise.



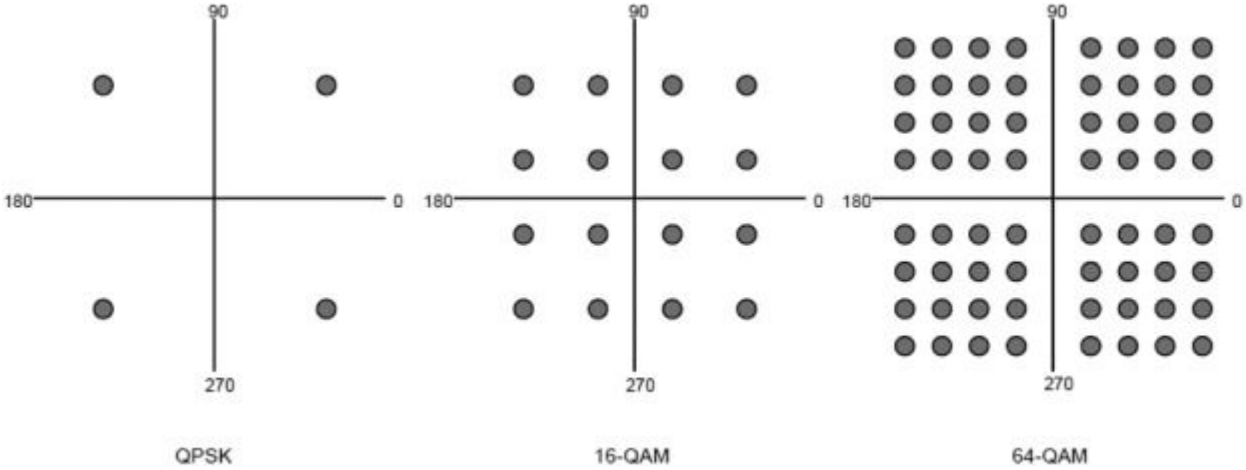
More QAM

- Can send more bits per symbol:
  - Higher modulation orders: 16-QAM, 64-QAM, 256-QAM
- Restricted by transmit power
  - For the same power budget, symbols get packed closer
    - Harder to sort out on the receiver side.





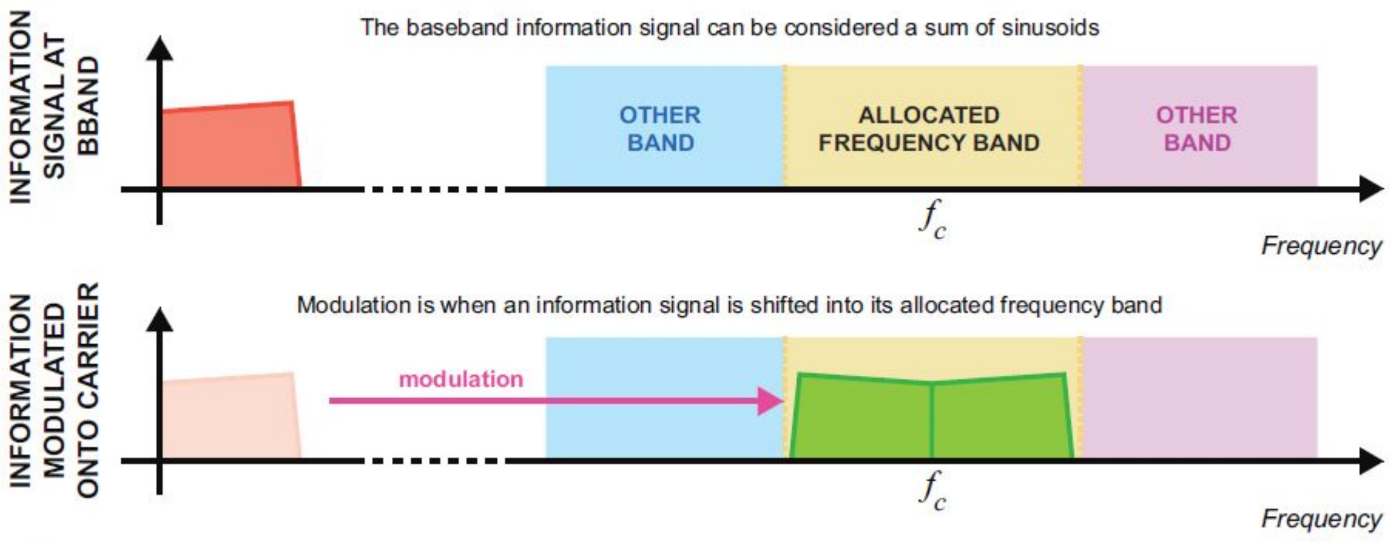
Higher modulations



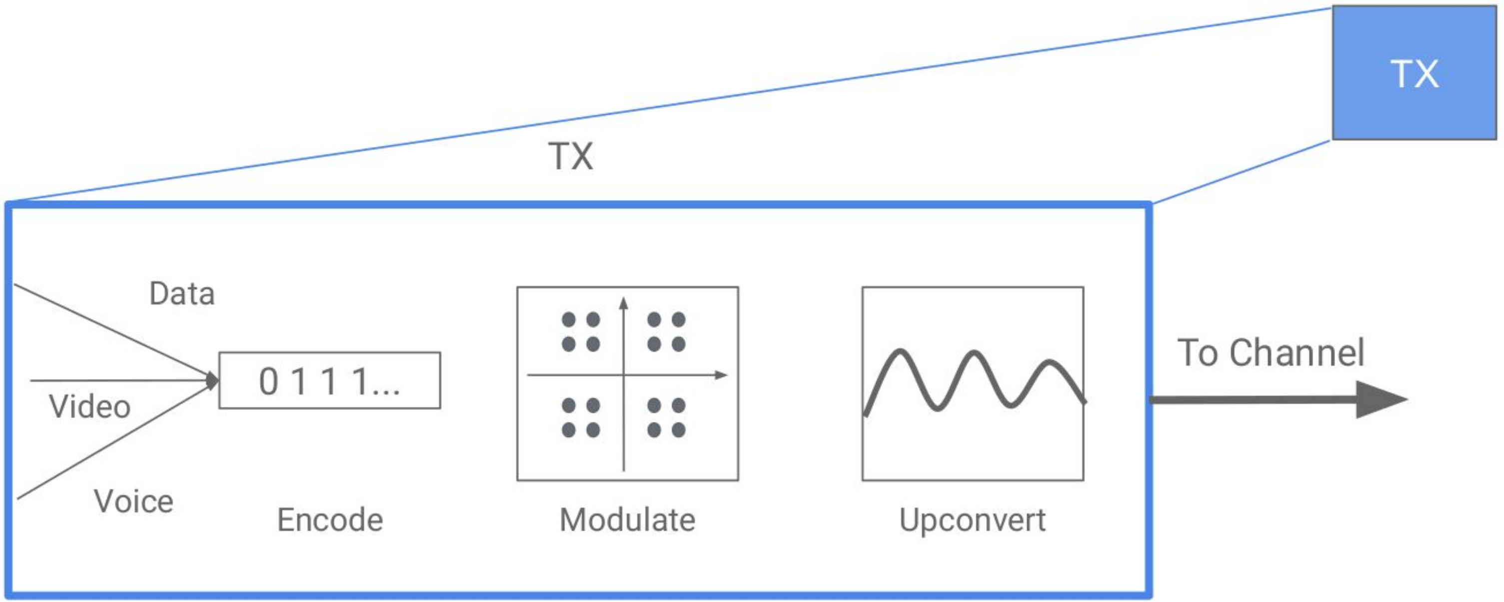
Upconversion (Carrier Modulation)

- Suppose we want to transmit a signal, s(t).
- We can’t just go ahead and transmit it!
  - Regulations on spectrum usage
- We need to move it to where we’re allowed to transmit.
  - Upconversion:
    - Multiply signal with a carrier sinusoid.
      - Sinusoid with carrier frequency fc

Shift the Signal

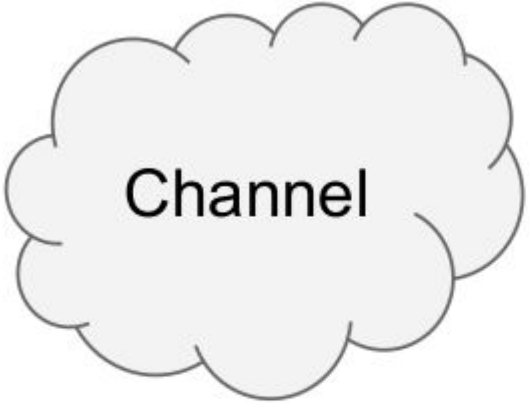


Transmitter: Putting all together



Channel

- Source of all difficulties in wireless.
    - Effect of the environment on the transmitted signal
        - Pathloss
        - Fading
            - Multipath
                - signal arriving through different paths
            - Doppler shift



Channel Modeling

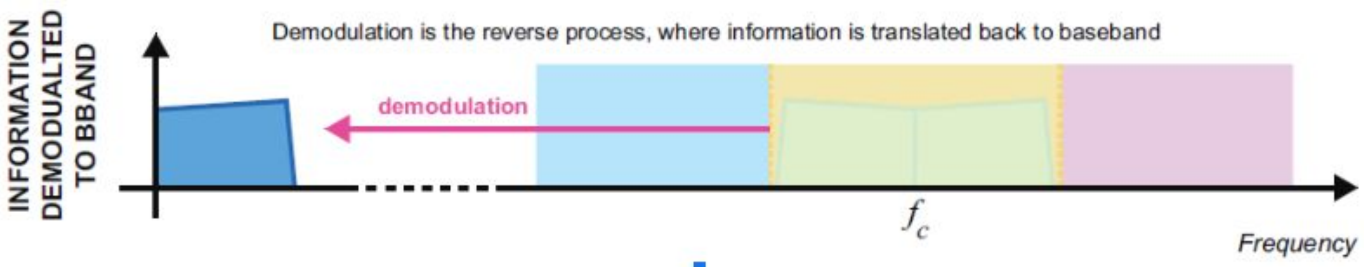
- It’s a random process.
- Modeled by random distributions. Most popular:
  - AWGN
  - Rayleigh
  - Rice

Receiver

- Waveforms → Bits
  - Downconversion
  - Synchronization
  - Equalization
  - Demodulation

Downconverison (Carrier Demodulation)

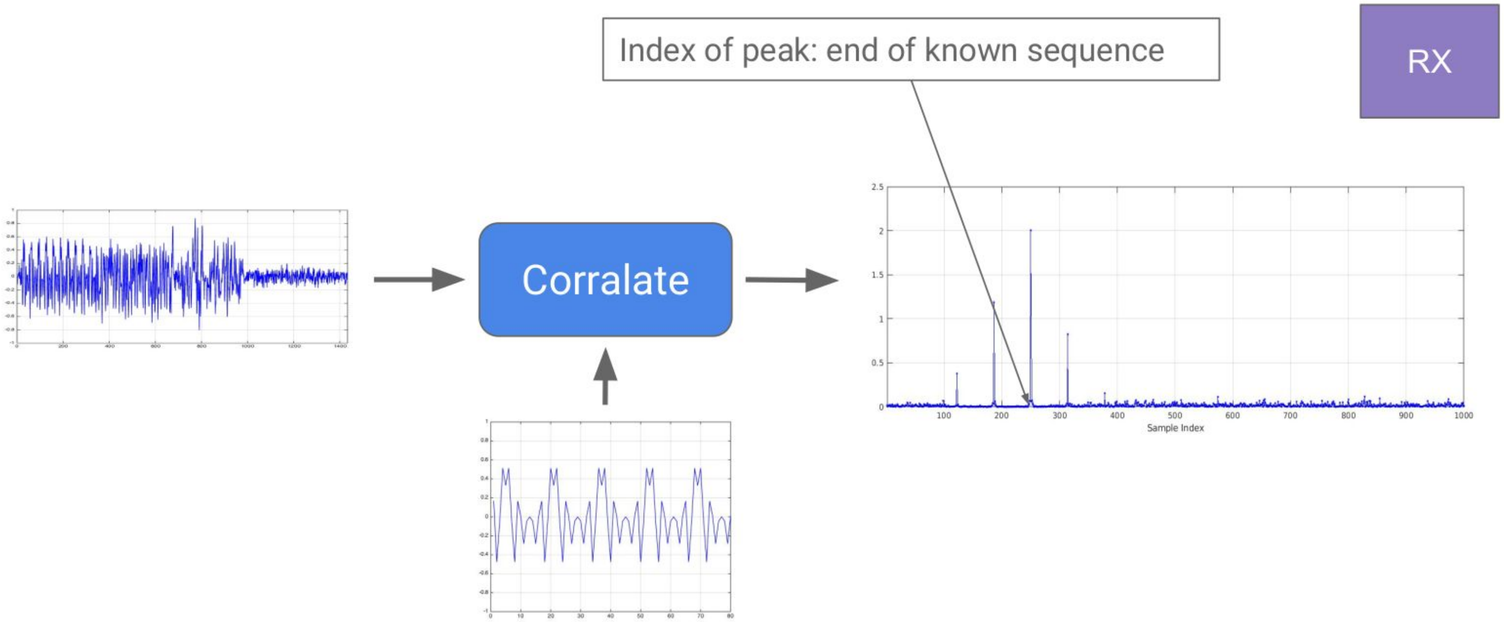
- Mirroring upconversion at the TX
  - Just multiply the received waveform with a sinusoid at the carrier frequency



Synchronization

- Before doing anything the receiver needs to first detect the start of a stream/packet/frame of incoming data.
- Correlate with a known sequence (sync. Signal)
  - Make out the start of the data stream relative to the correlation peak
  - Receiver knows where and how long the known sequence is

Synchronization



Equalization

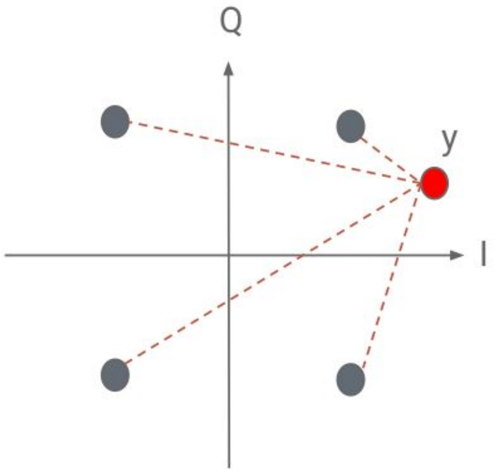
- Channel introduces errors.
- Need to offset these errors.
  - Reverse channel effect.
- Use the/a known sequence, called pilot, to estimate the channel
  - Remove the pilot. What’s left is channel + noise.
  - Get better estimates by averaging over more sequences.

Demodulation

- Decide which symbol, consecutively which bits, were sent.
- Need criteria to decide based on received signal
    - Maximum likelihood
        - Assume xi was sent (given), what is the probability of observing yj? → Choose xi with max. probability.
- Maximum a posteriori
    - Given observation yj what is the probability that xi was sent? → Choose xi with max. probability.

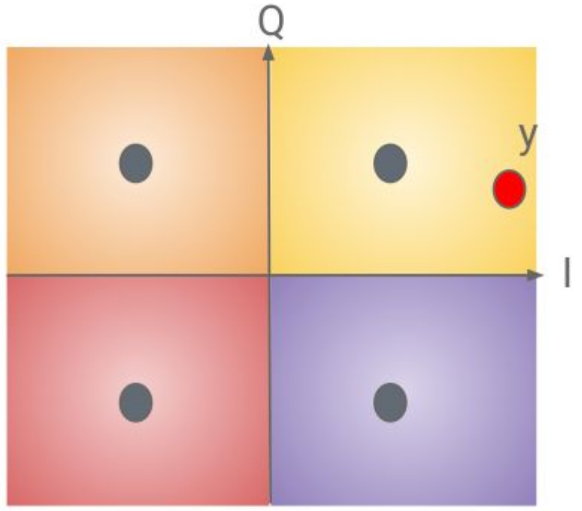
Smallest Distance

- If every symbol has the same probability of being sent, both criteria are the same.
- Smallest distance.
  - Choose the constellation point closer to where the received symbol has landed



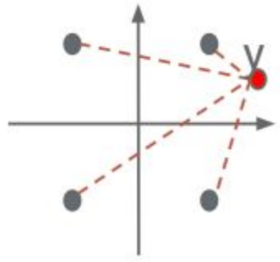
Decision Regions

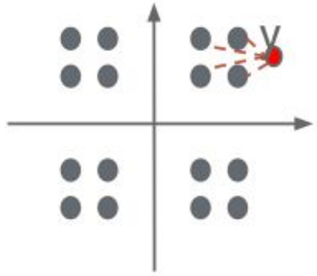
- These criteria define decision regions
  - Areas around each constellation point xi, where each point is closer to xi than any other constellation point xj.
  - Very regular for QAM
  - Decide based on which region y lands on



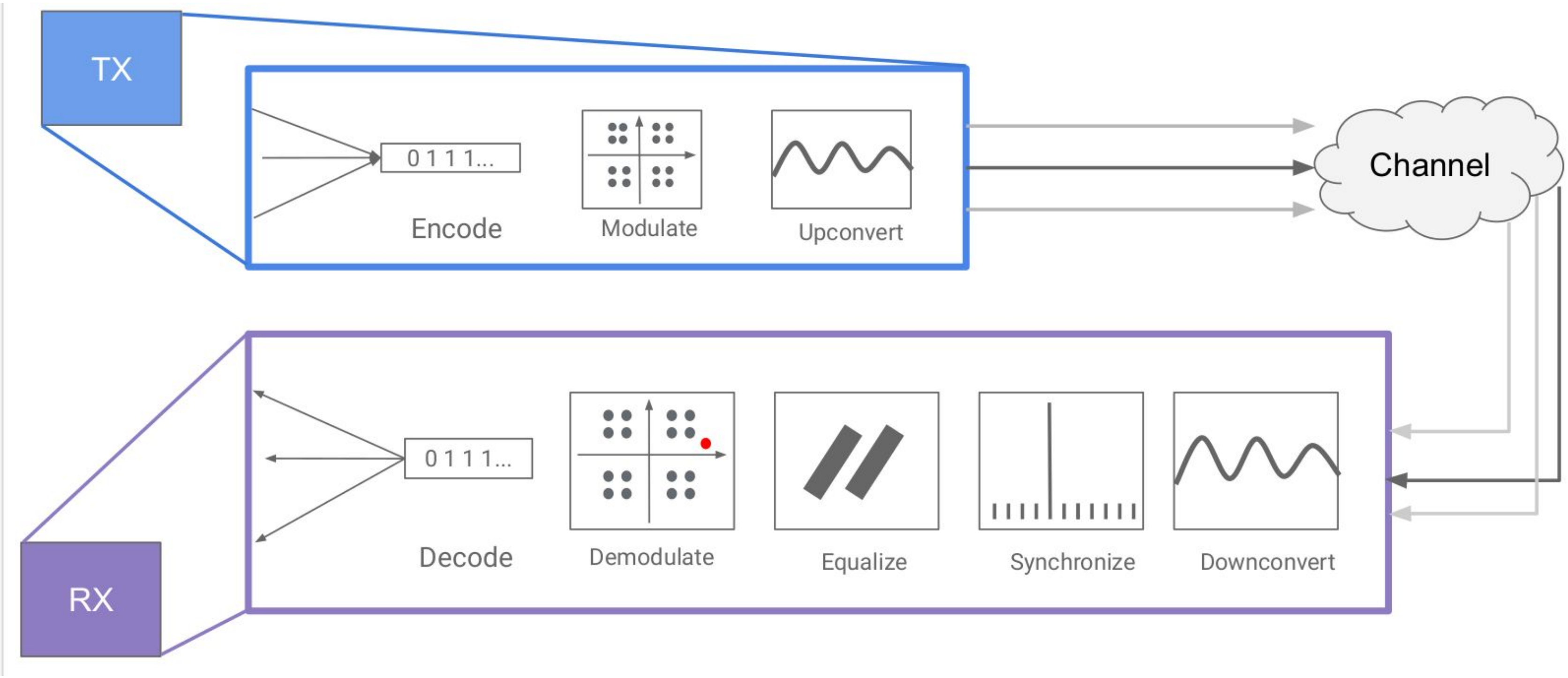
Errors

- Packing more symbols on the constellation increases rate.
  - More bits/channel use.
- Leads to more errors
  - Smaller distances/decision regions for same power
- Higher constellation orders need higher SNR
  - Makes the received symbol to land closer to the correct point.

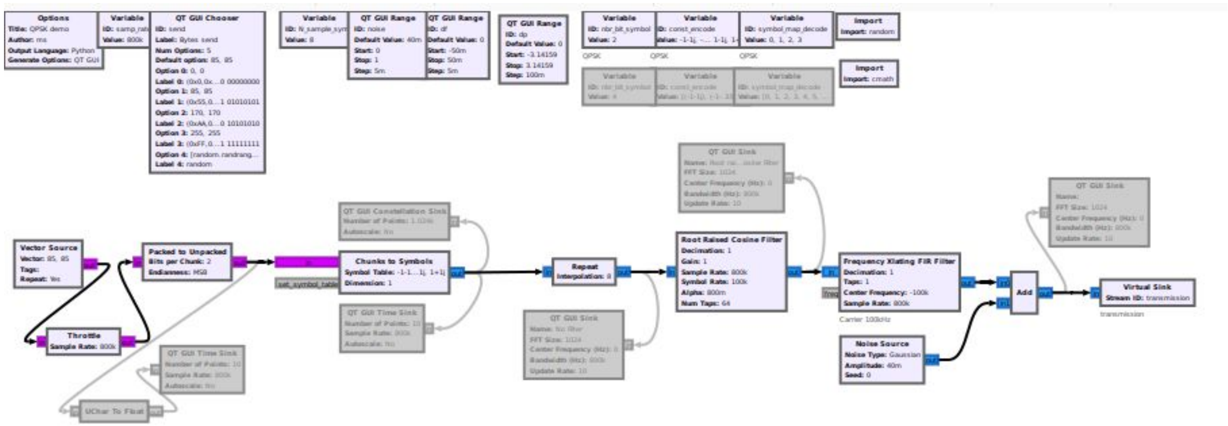


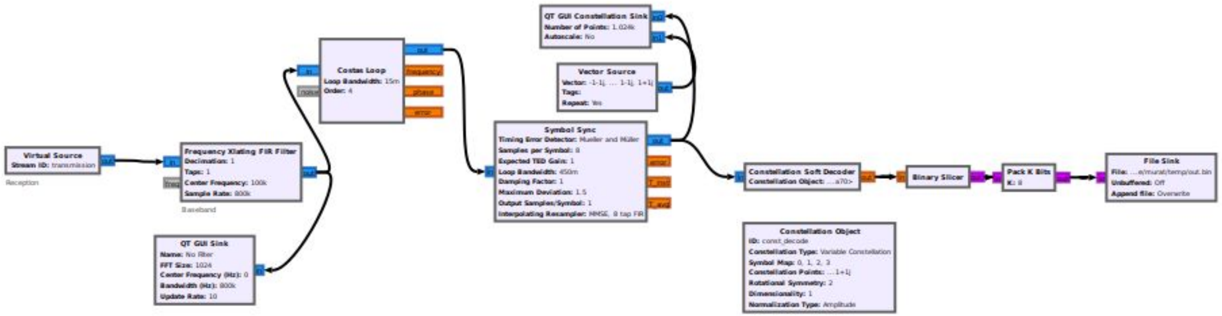


Wireless System: Putting all together



End-to-End Digital Communication System Simulation



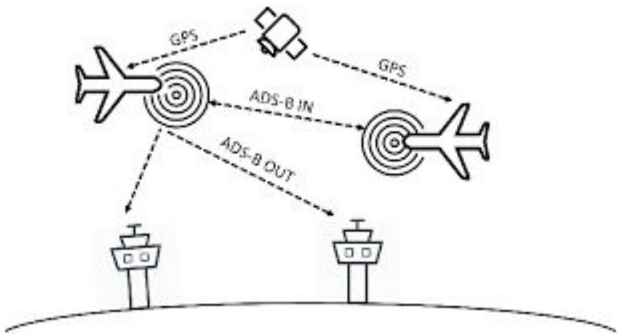


RADAR

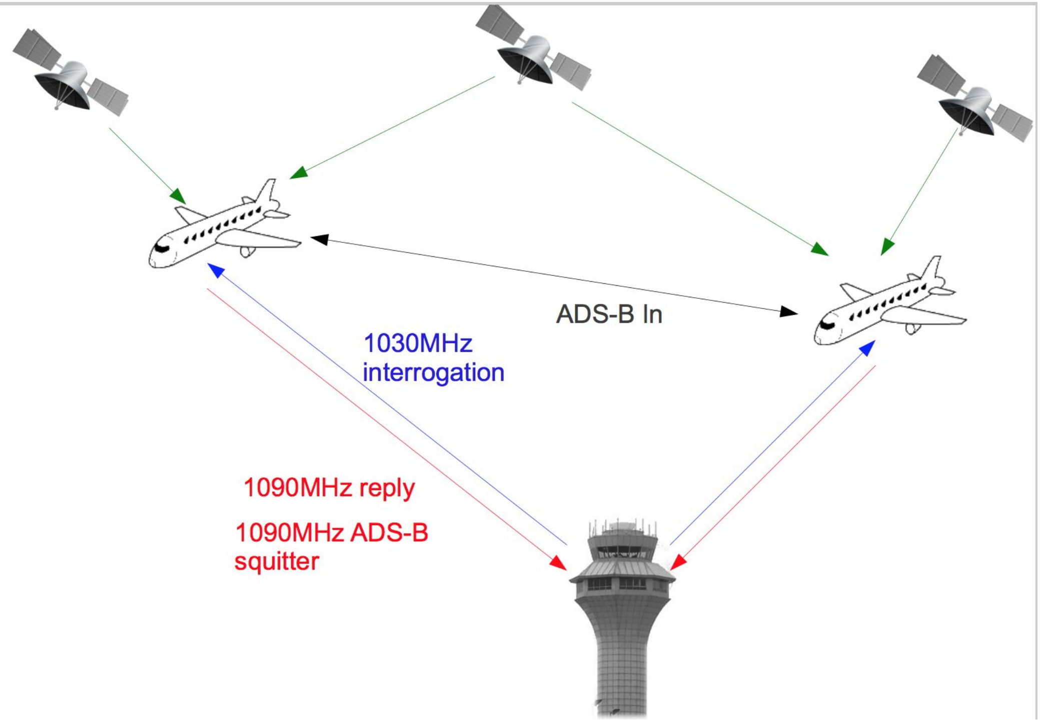
- Large areas of airspace are not covered by radar
- Radar installations are expensive!

Automatic Dependent Surveillance–Broadcast (ADS-B)

- Replacement for active RADAR
- Location, velocity, …
- 5-10 Messages/second
- You can receive
  - 1200 messages/second
  - from 133 different airplanes

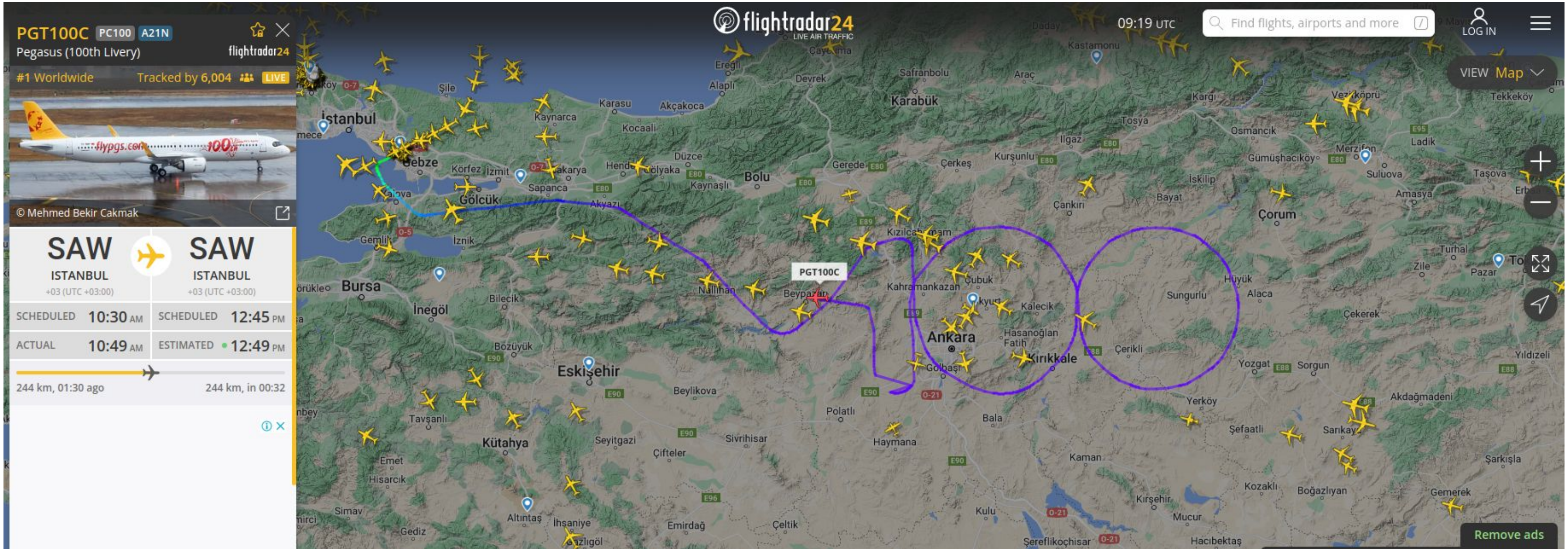


ADS-B


ADS-B In
1030MHz
interrogation
1090MHz reply
1090MHz ADS-B
squitter

ADS-B Aggregators

Pegasus 100


PGT100C PC100 A21N
Pegasus (100th Livery)
flightradar24
#1 Worldwide
Tracked by 6,004
LIVE
© Mehmed Bekir Cakmak
SAW
ISTANBUL
+03 (UTC +03:00)
SAW
ISTANBUL
+03 (UTC +03:00)
SCHEDULED 10:30 AM
SCHEDULED 12:45 PM
ACTUAL 10:49 AM
ESTIMATED 12:49 PM
244 km, 01:30 ago
244 km, in 00:32
flightradar24
LIVE AIR TRAFFIC
09:19 UTC
Find flights, airports and more
LOG IN
VIEW Map
PGT100C
İstanbul
Bursa
Eskişehir
Ankara
Bolu
Karabük
Çorum
Kırıkkale
Kütahya
Remove ads

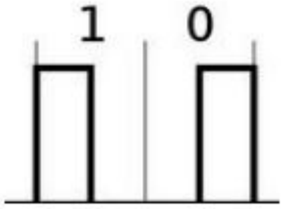
Cumhuriyet

Drawing Hearts

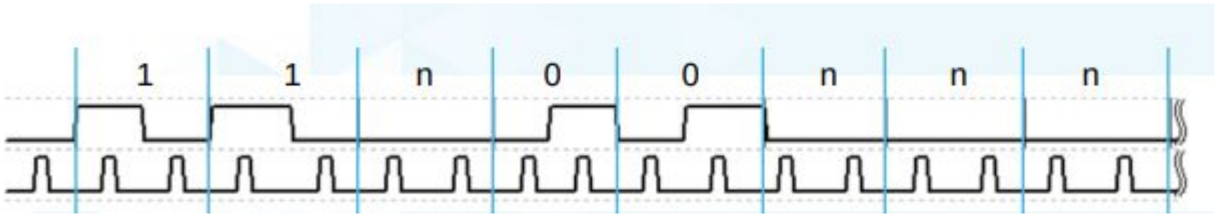
Check out for more on drawing hearts!

- https://www.flightradar24.com/blog/a-brief-history-of-drawing-hearts-with-an-airliner/

ADS-B Data Format

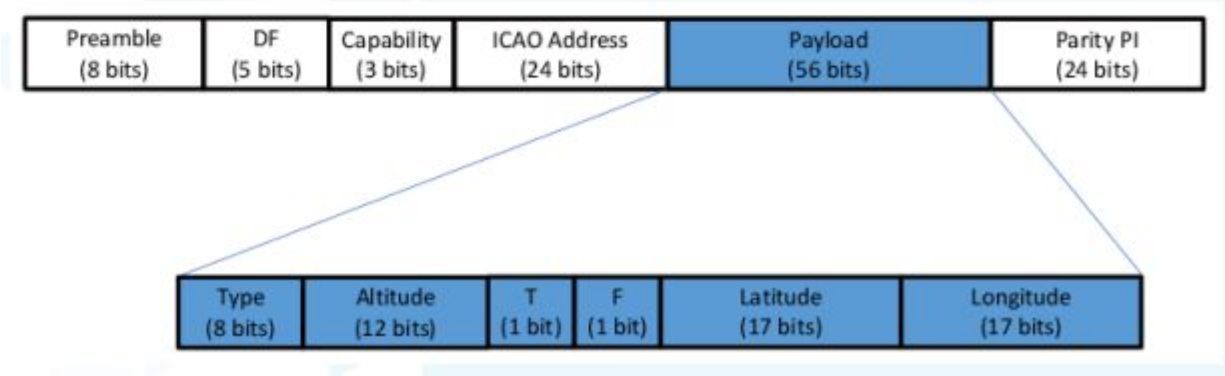


- Pulse Position Modulation (PPM)
- There are 2 bits, (1 and 0), and therefore two positions
- Manchester encoding used
- Each “bit” is 1μs long, the pulse is 0.5 μs.
- 8-bit preamble of “11n00nnn”
- Sample each bit twice (every 0.5 μs), or 2 MSPS



ADS-B Packets

- Short squitters are 56bits (8bits Control, 24bits address, 24bits parity check)
- Long squitters are 112bits (8 bits preamble + 8bits control, 24bits address, 56bits ADS-B message, 24bits parity)



ADS-B Hunting

- Use RTL-SDR to catch ADS-B signal

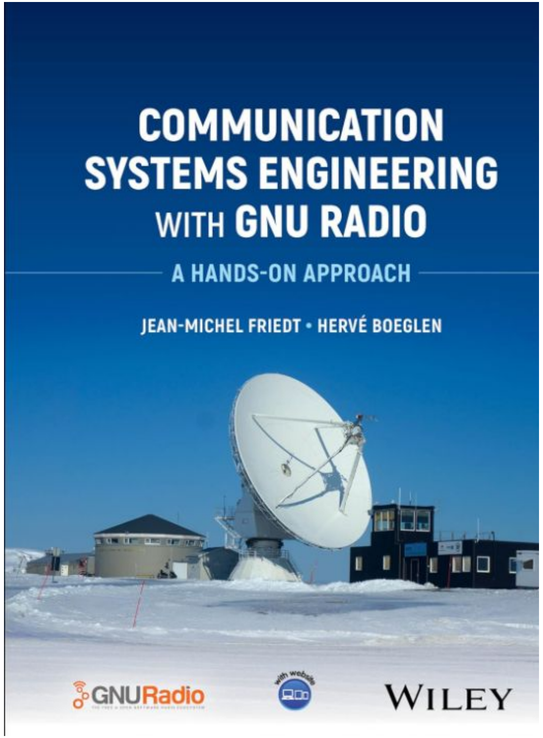
Schedule

- First Day: GNU Radio Introduction, DSP, GR Simulation Mode
- Second Day: SDR Introduction, RTL-SDR, GR Real-Time Mode
- Third Day: Analog Communications
- Fourth Day: Digital Communications

What we have seen so far

- SDR
    - RTL-SDR
    - HackRF
- Apps
    - GNU Radio
    - SDR++
    - SDR Angel
    - OpenWebRX
- Modulations
    - WBFM, AM, SSB, CW, NBFM, ADS-B

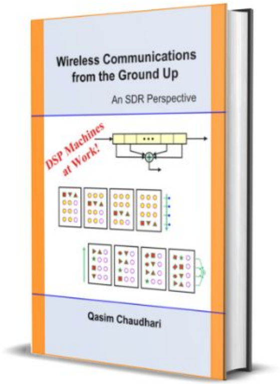
Resources - Book



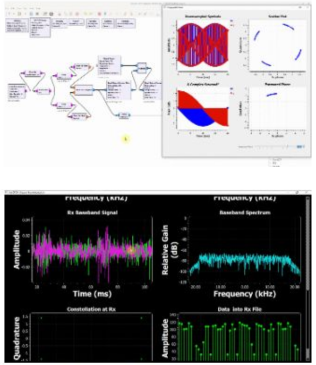
Resources - https://wirelesspi.com/

Wireless Pi

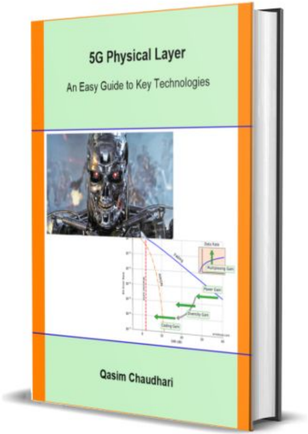
Discover the Joy of signal processing, SDRs and wireless communications



Wireless Communications from the Ground Up – An SDR Perspective



Software Defined Radio – From 0 to 1



5G Physical Layer – An Easy Guide to Key Technologies

Resources - https://pysdr.org/

PySDR: A Guide to SDR and DSP using Python

Your feedback

Your **feedback** is valuable!

ytregitim@gmail.com

Survey

- Have your say before leaving!

Nice to ***communicate*** with you all!

- Reach out to me at ytregitim@gmail.com
- Find me on LinkedIn
- Contact me for educational/academic deliveries