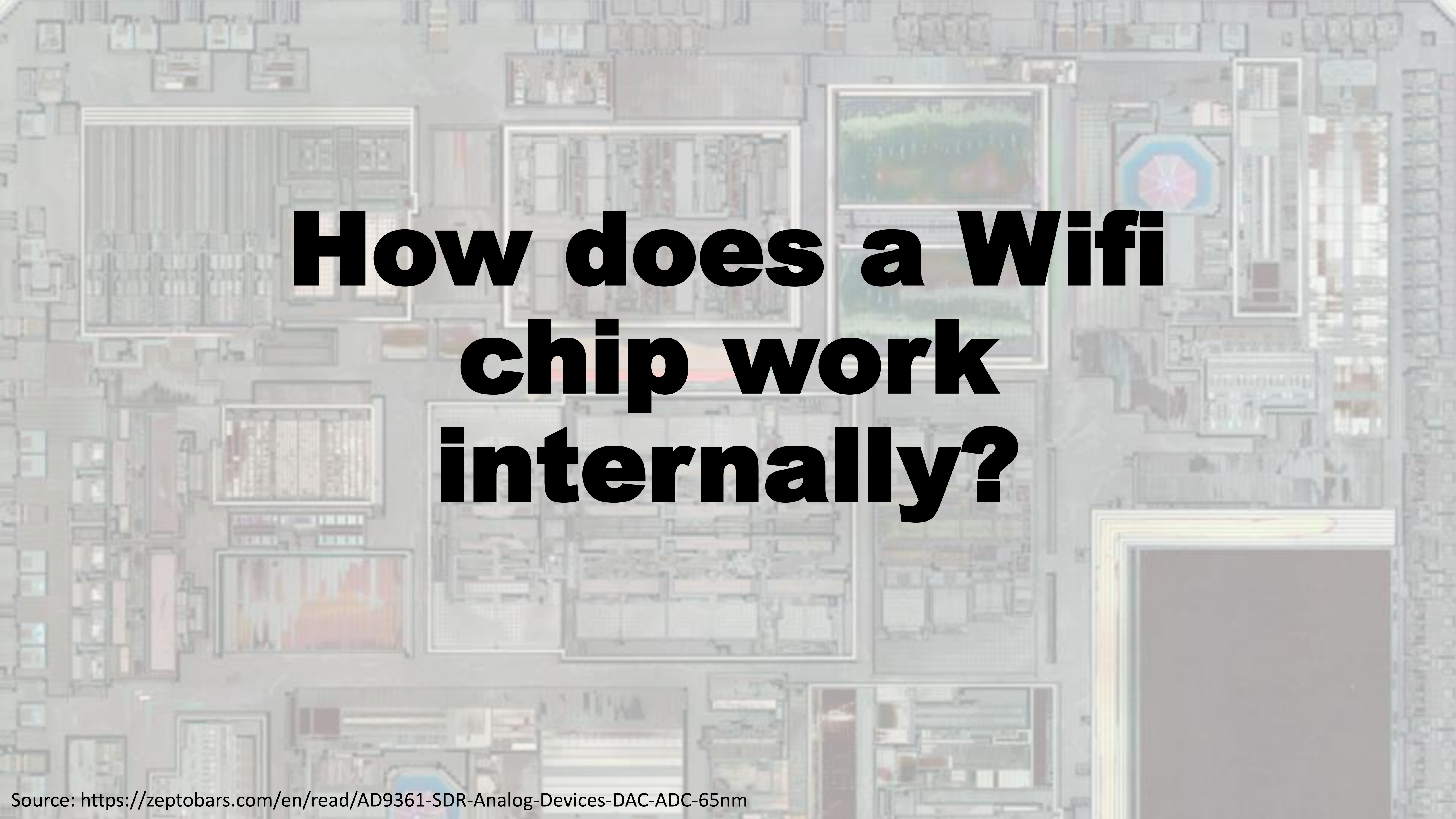
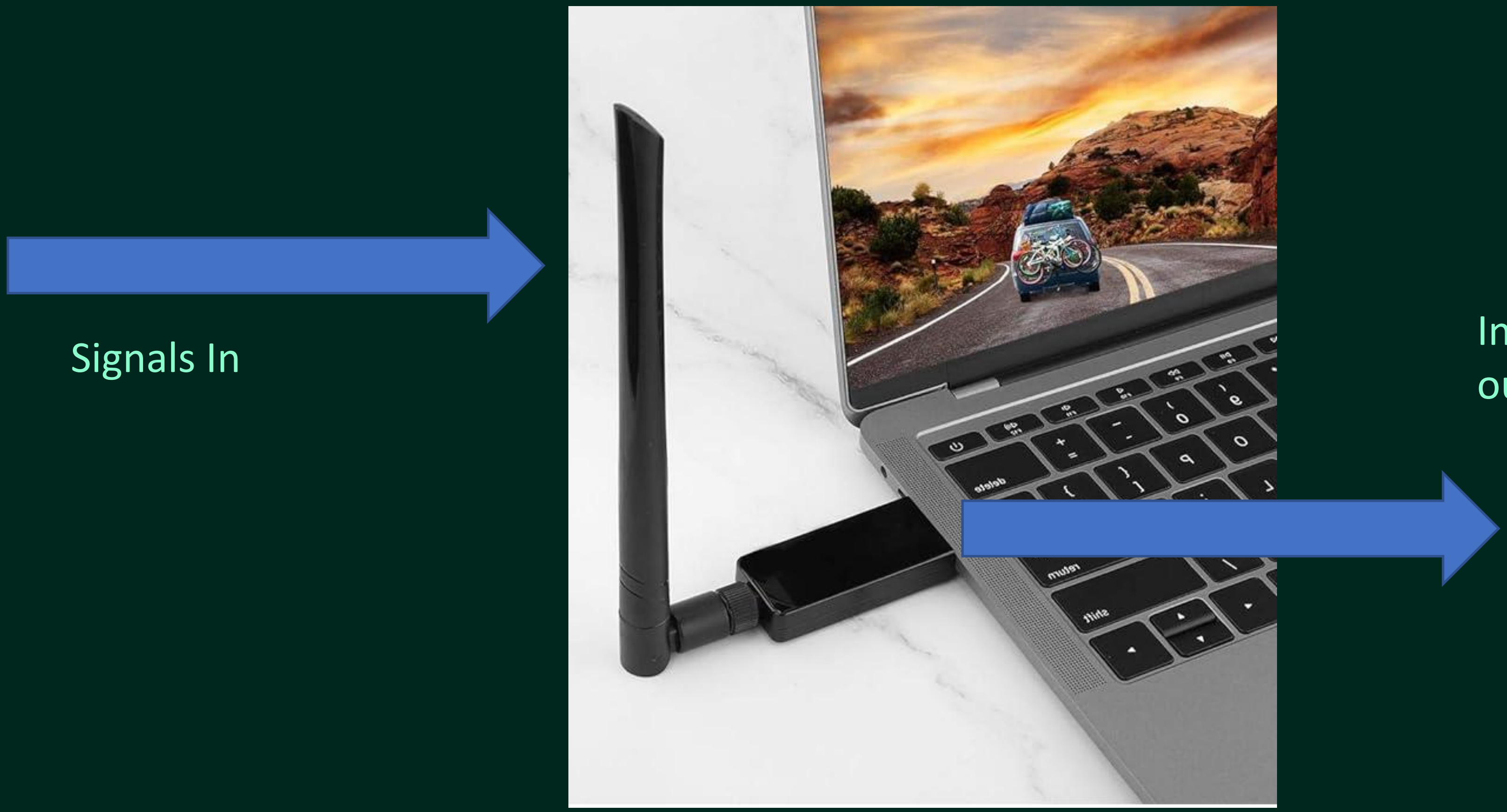


How does a Wifi chip work internally?

Source: https://zeptobars.com/en/read/AD9361-SDR-Analog-Devices-DAC-ADC-65nm

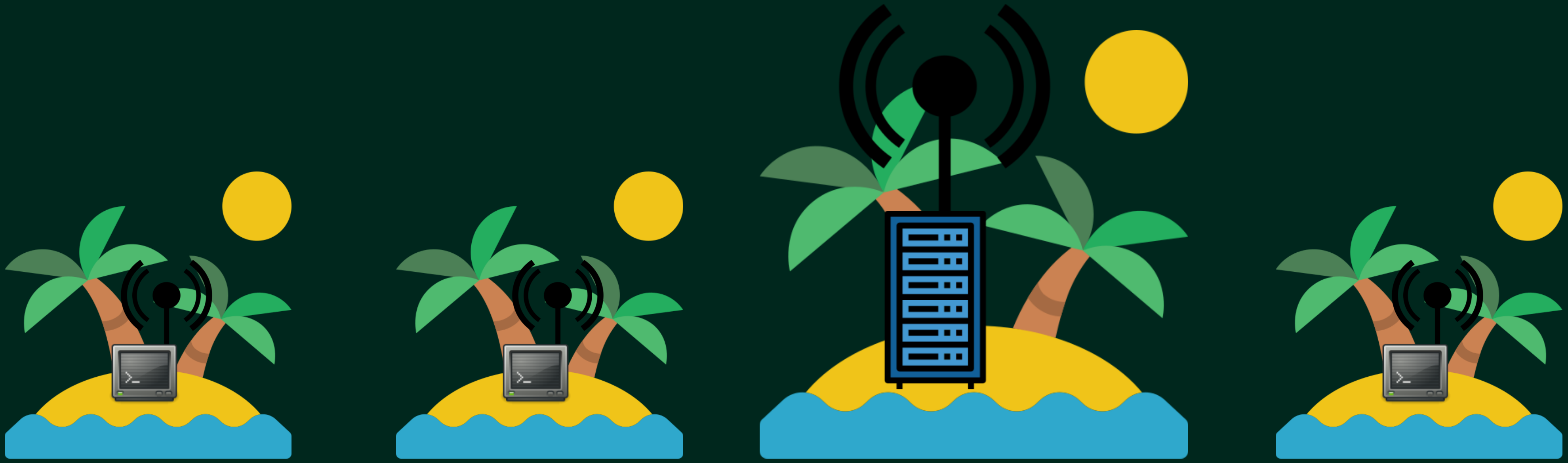
Wifi Chip as Blackbox



Signals In

Internet out?

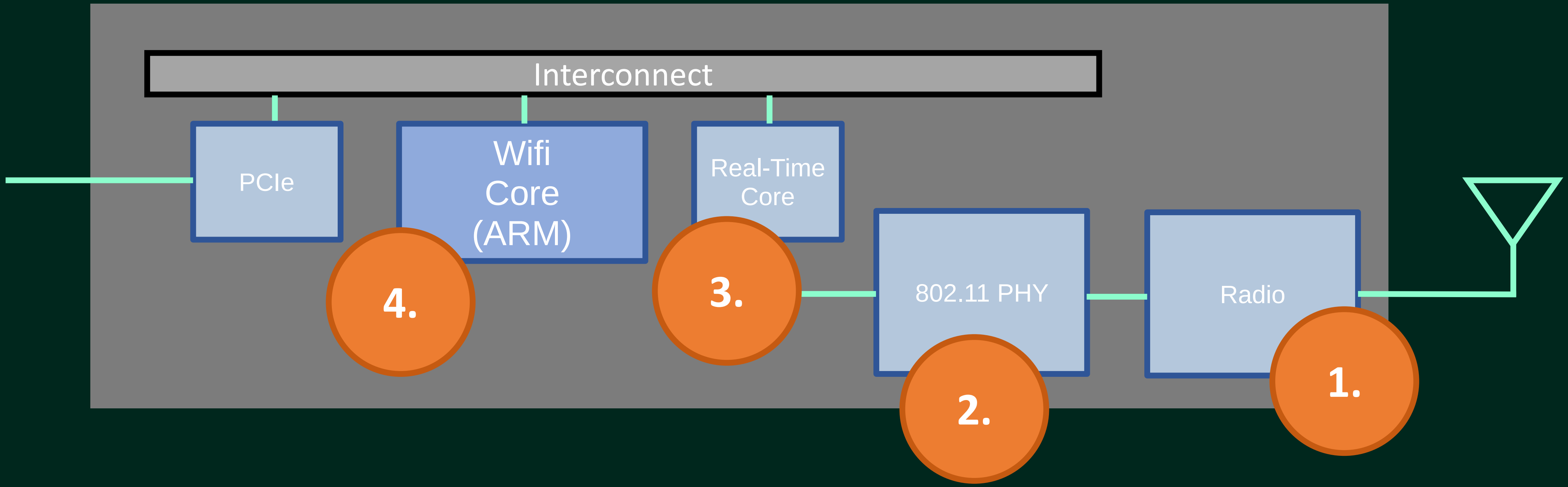
History: ALOHAnet



Wifi Standards

Year of Adoption	IEEE Standard	Generation Name
1999	802.11**a**	Wi-Fi 2
2003	802.11**g**	Wi-Fi 3
2008	802.11**n**	Wi-Fi 4
2014	802.11**ac**	Wi-Fi 5
2019	802.11**ax**	Wi-Fi 6
2020	802.11**ax + 6GHz**	Wi-Fi 6e
2024	802.11**be**	Wi-Fi 7

Building blocks of a Wifi Chip

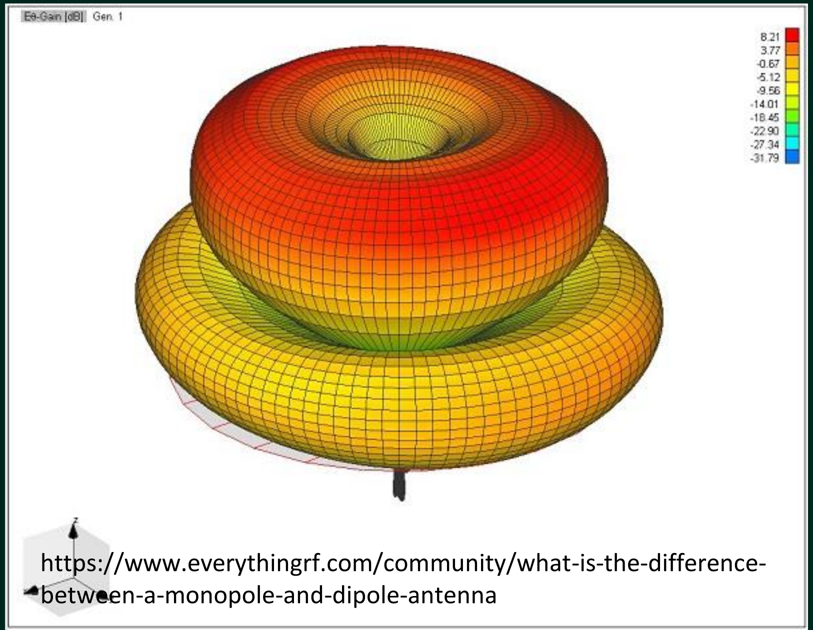


Wave length

- Antenna needs to resonate with the frequency we need
- 2.4 GHz for Wifi at channel 6:

$$\lambda = \frac{v}{f} \qquad \lambda = \frac{299.792.458\frac{m}{s}}{2.437.000.000\,\frac{1}{s}} = 0.12\ \mathrm{m}$$

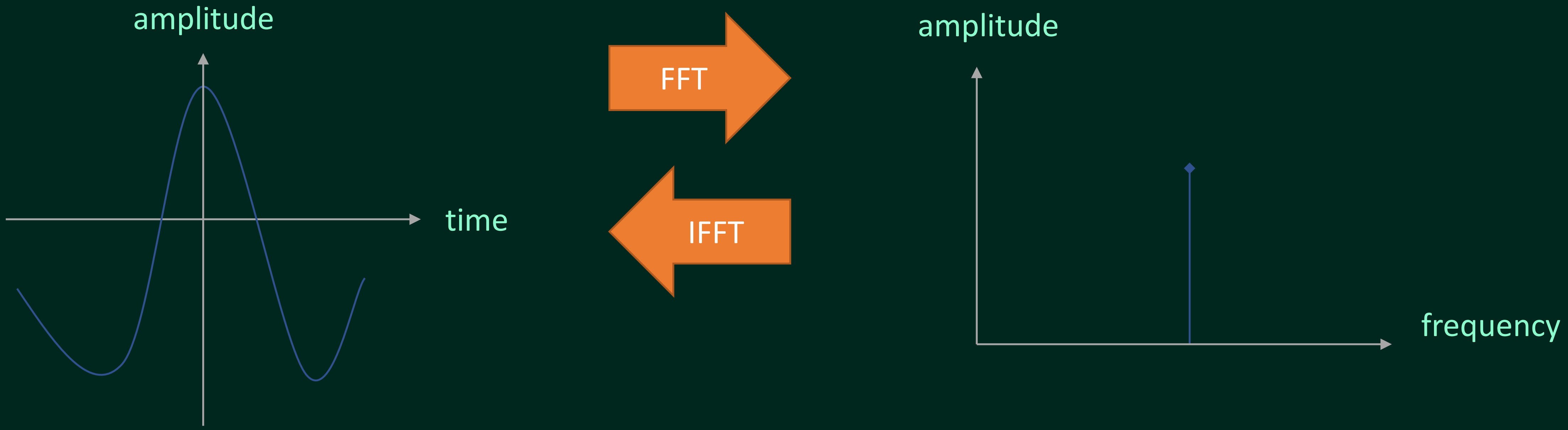
- Antenna length can also be **half** or **quarter** the wave length
- Antenna **orientation** is important! Keep Antennas of sender and receiver on the same polarization.



https://www.everythingrf.com/community/what-is-the-difference-between-a-monopole-and-dipole-antenna

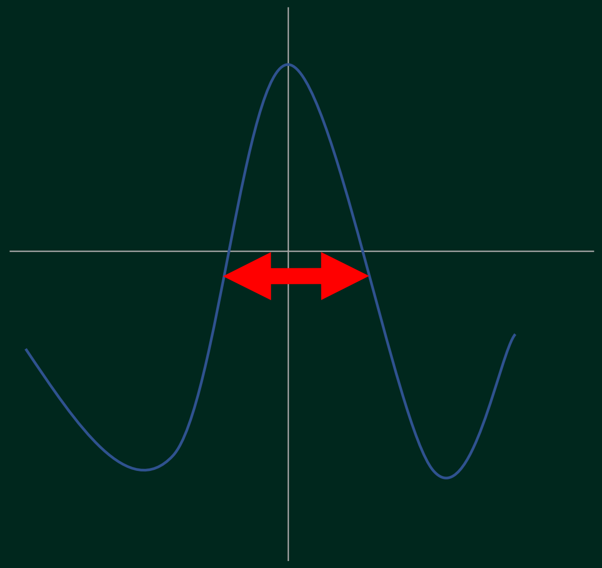
Signals

- Time Domain
- Frequency Domain

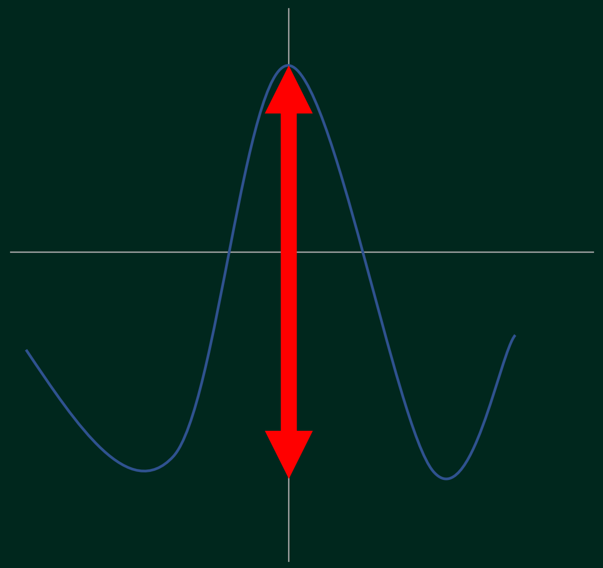


Ways to encode data in wireless signals

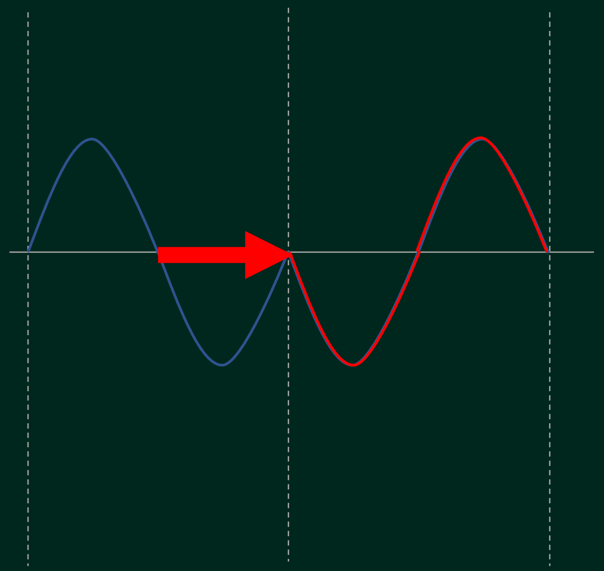
- Frequency



- Amplitude



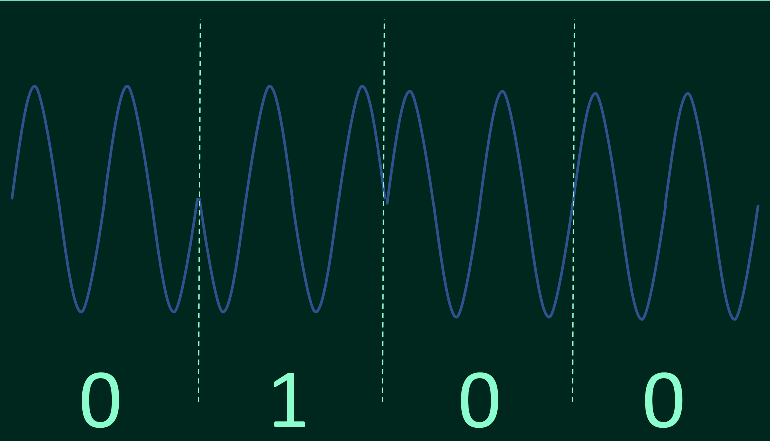
- Phase



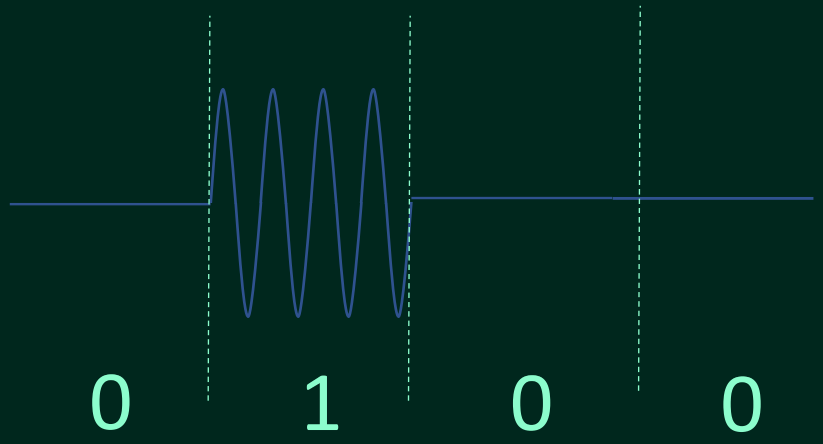
For WIFI

Modulation

- Phase Modulation



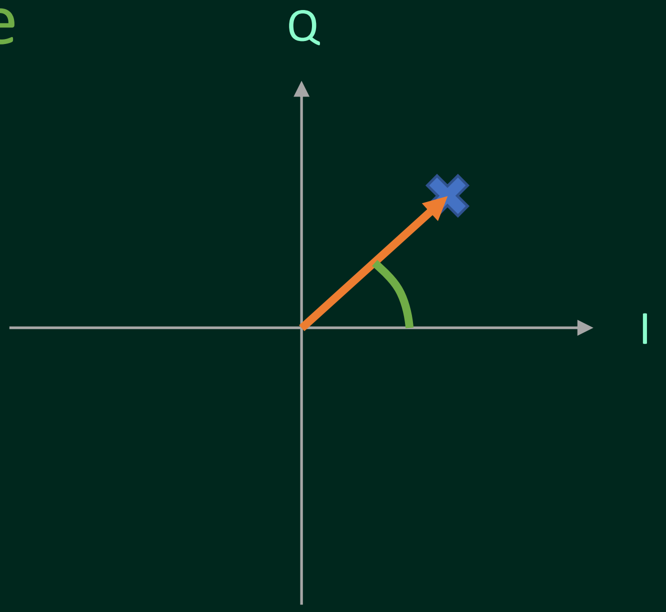
- Amplitude Modulation

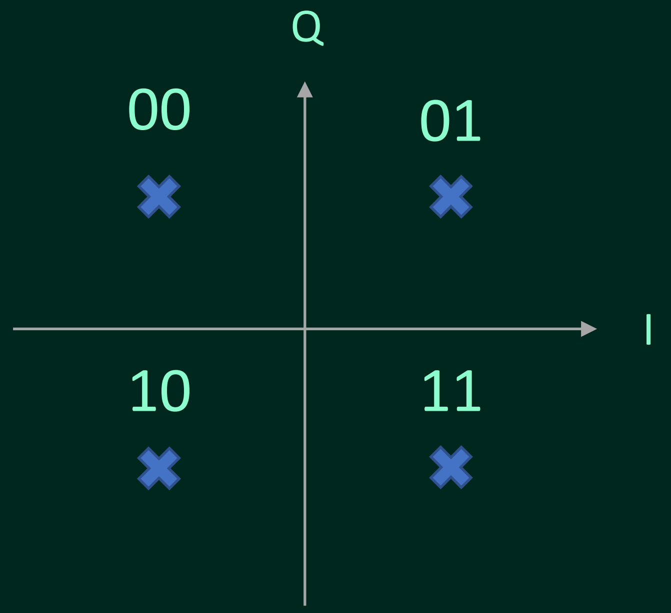


I and Q: Constellation Diagram

Vector:

- Length: Amplitude
- Angle: Phase

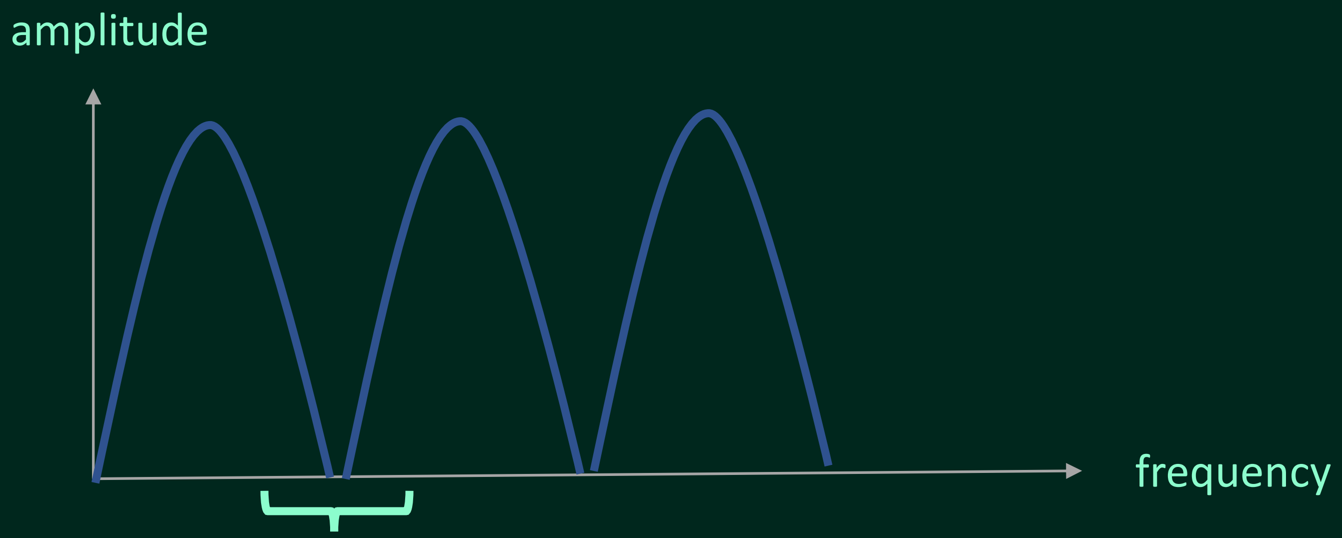




➡ QPSK

OFDM (Orthogonal Frequency Division Multiplexing)

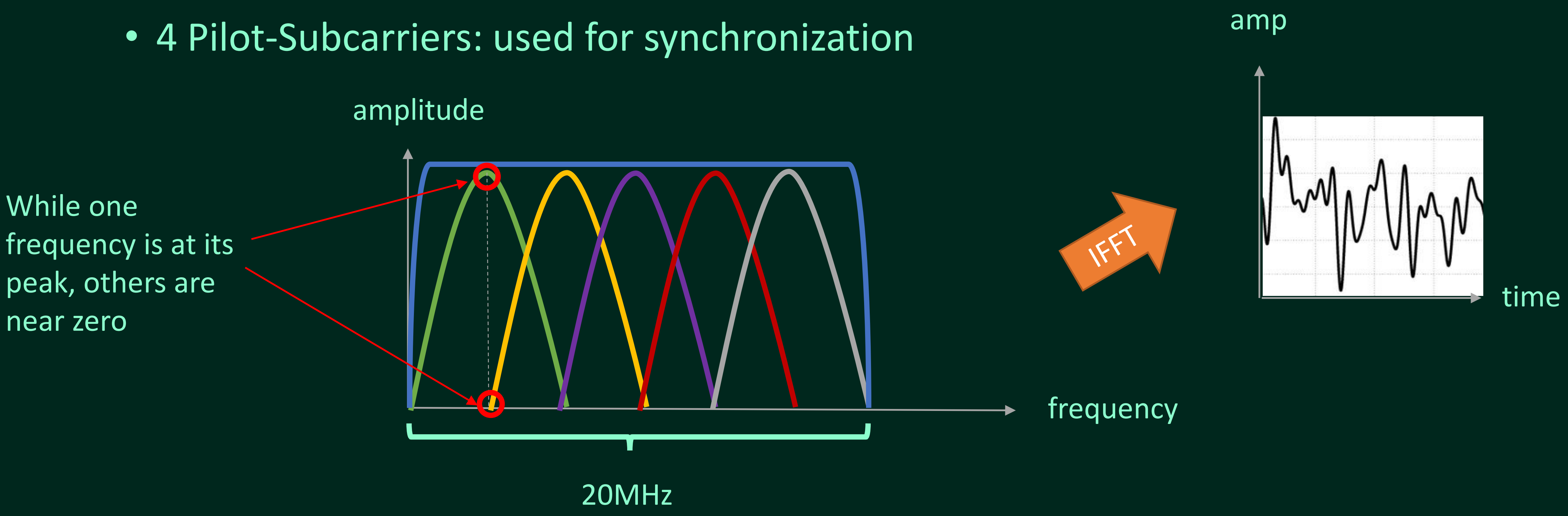
- Sending multiple carriers at once



Overlap not allowed
due to interference!

OFDM (Orthogonal Frequency Division Multiplexing)

- Subcarriers can be close together **without spacing**
- 52 Subcarriers in total for 802.11a
  - 48 Data-Subcarriers
  - 4 Pilot-Subcarriers: used for synchronization



While one frequency is at its peak, others are near zero

Why 54MBit?

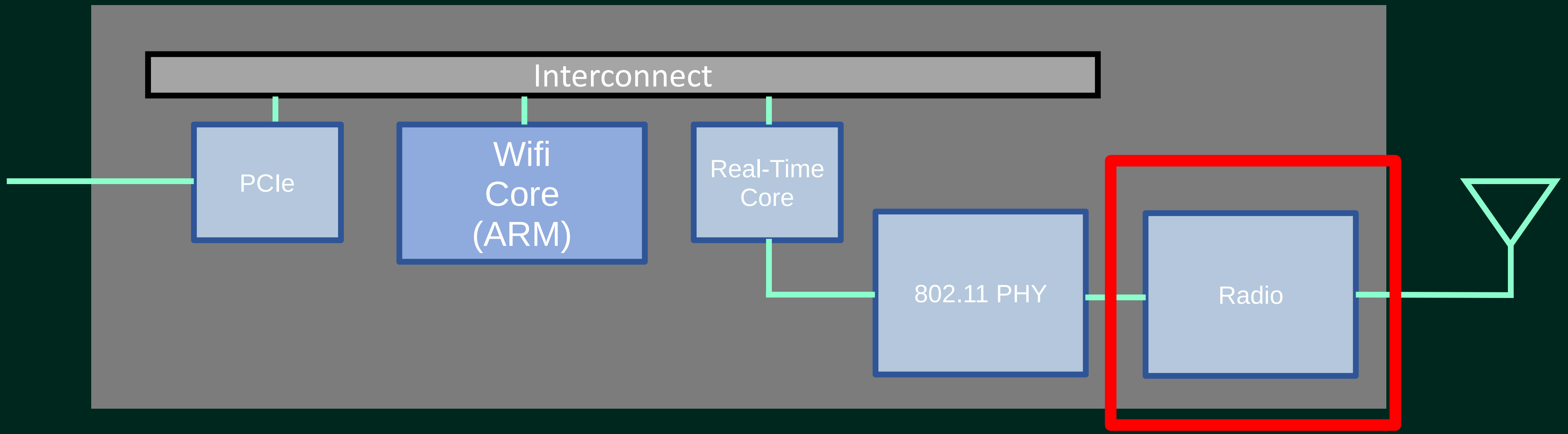
- Data Rate: $\frac{bits\ per\ symbol * Number\ of\ subcarriers}{OFDM\ symbol\ duration} * encoding$:

64-QAM:
6 bits per symbol

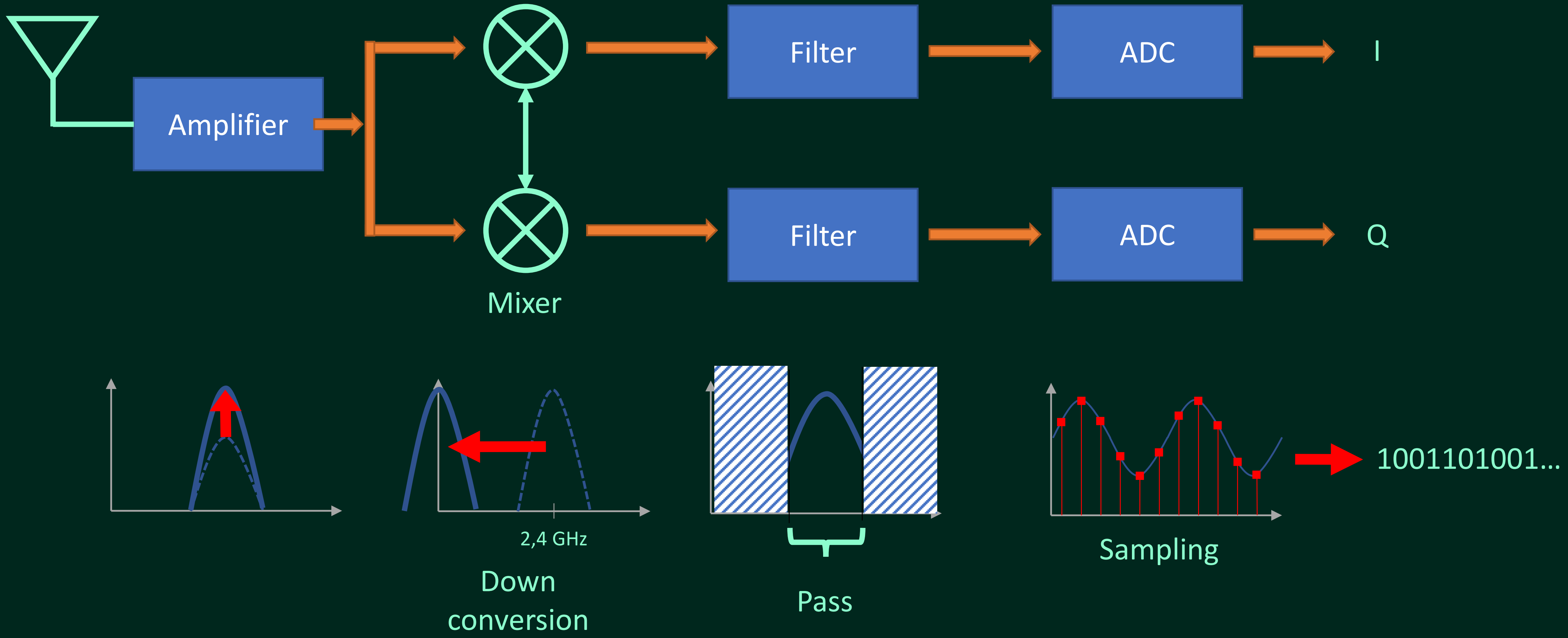
$$\frac{6 * 48}{4 * 10^{-6}} = 72Mbps * \frac{3}{4} = 54Mbps$$

4 µs includes 0.8 µs
guard interval

Building blocks of a Wifi Chip



Hardware to get I and Q



Amplifier

Mixer

Filter

ADC

I

Filter

ADC

Q

2,4 GHz

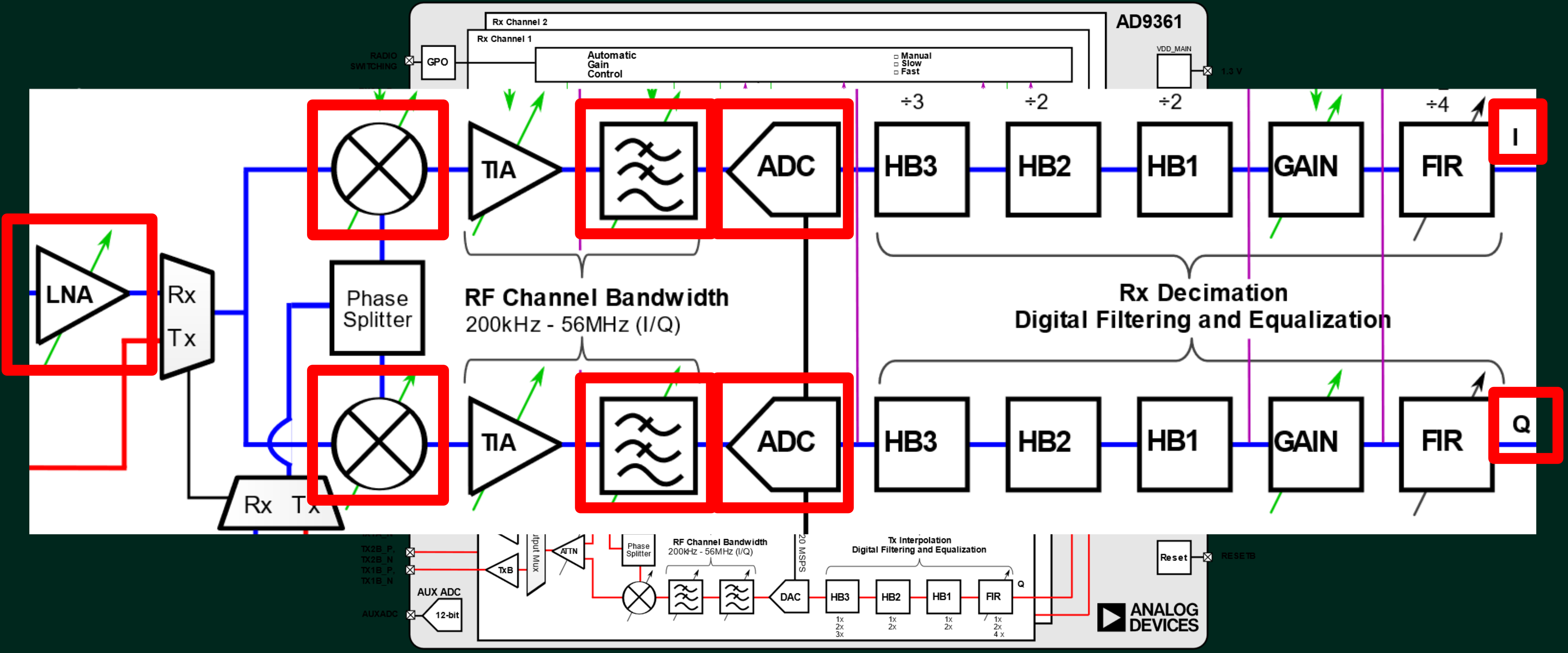
Down conversion

Pass

Sampling

1001101001…

I/Q using SDR: Analog Devices AD9361

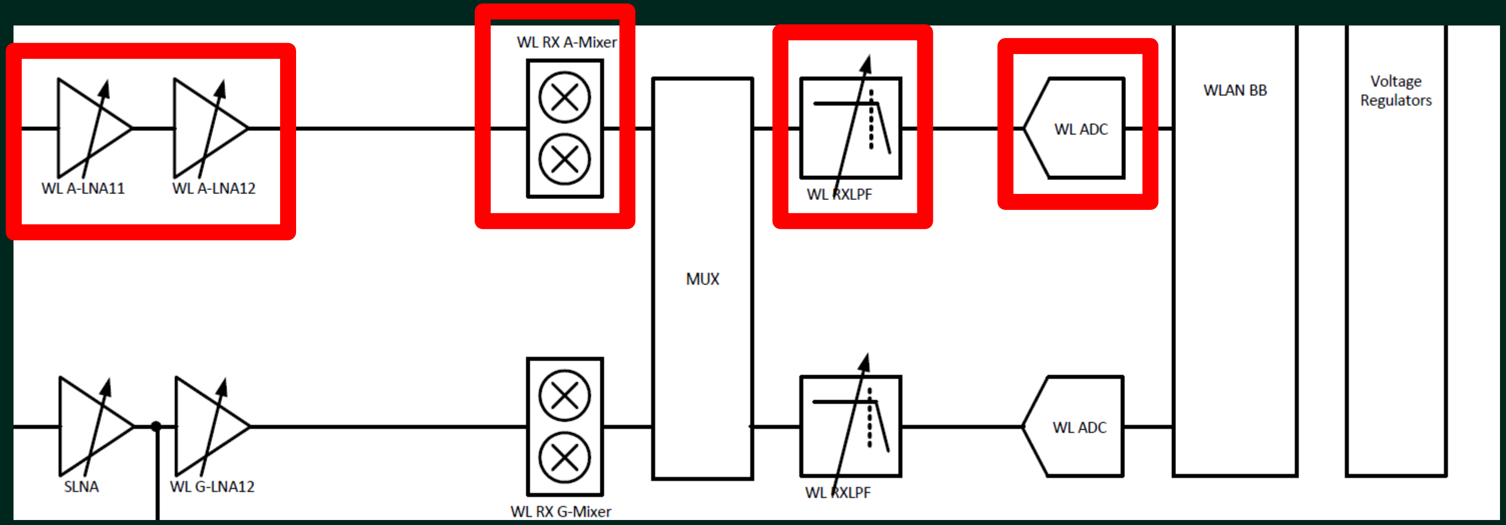


https://wiki.analog.com/resources/eval/user-guides/ad-fmcomms2-ebz/ad9361

I/Q in Broadcom Wifi chips

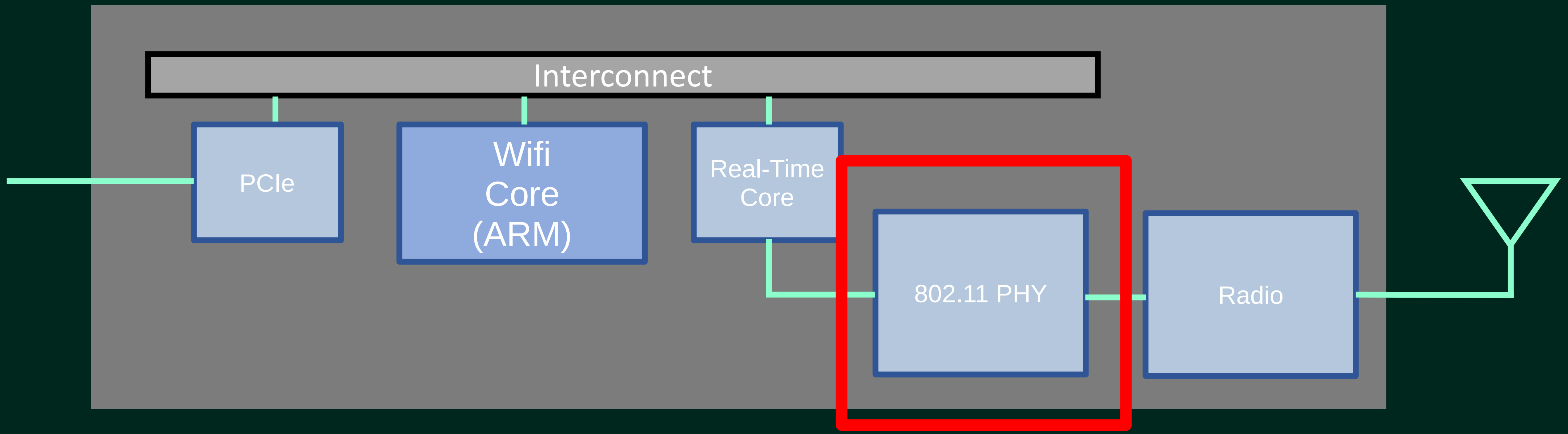
RX

- LNA: Low Noise Amplifier
  - 2.4 GHz shared between BT and WIFI
  - 5GHz dedicated
- LPF: Low Pass Filter



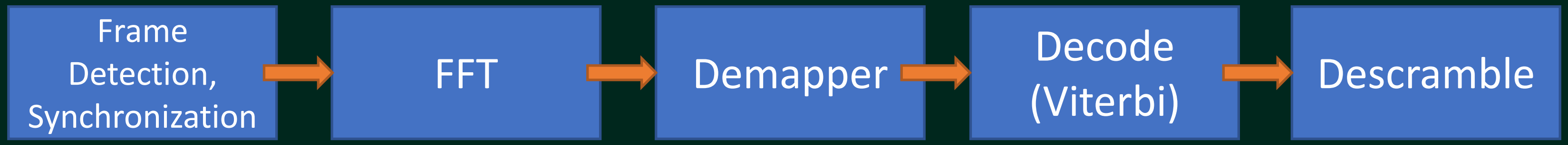
https://www.infineon.com/dgdl/Infineon-CYW4339_Single_Chip_5G_WiFi_IEEE_802.11ac_MAC_Baseband_Radio_with_Integrated_Bluetooth_4.1-DataSheet-v10_00-EN.pdf?fileId=8ac78c8c7d0d8da4017d0ee1e7d367fd

Building blocks of a Wifi Chip

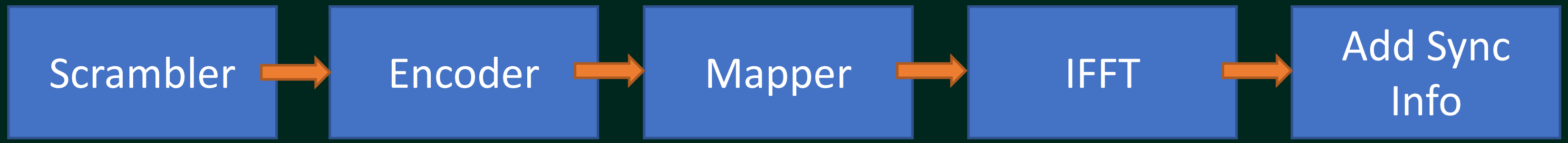


Pipeline IQ and Bit Processing

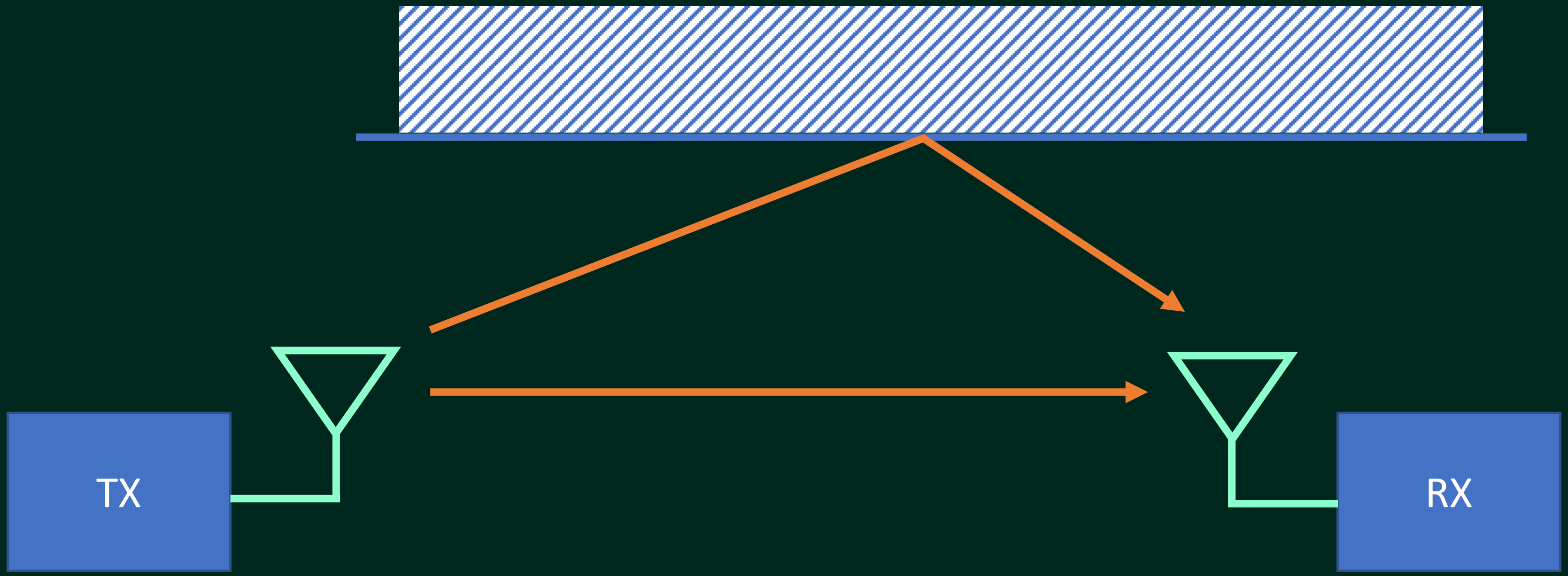
- RX

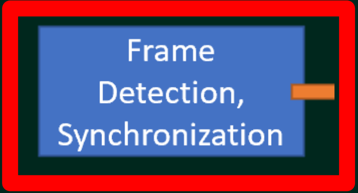


- TX



Multipath Effects

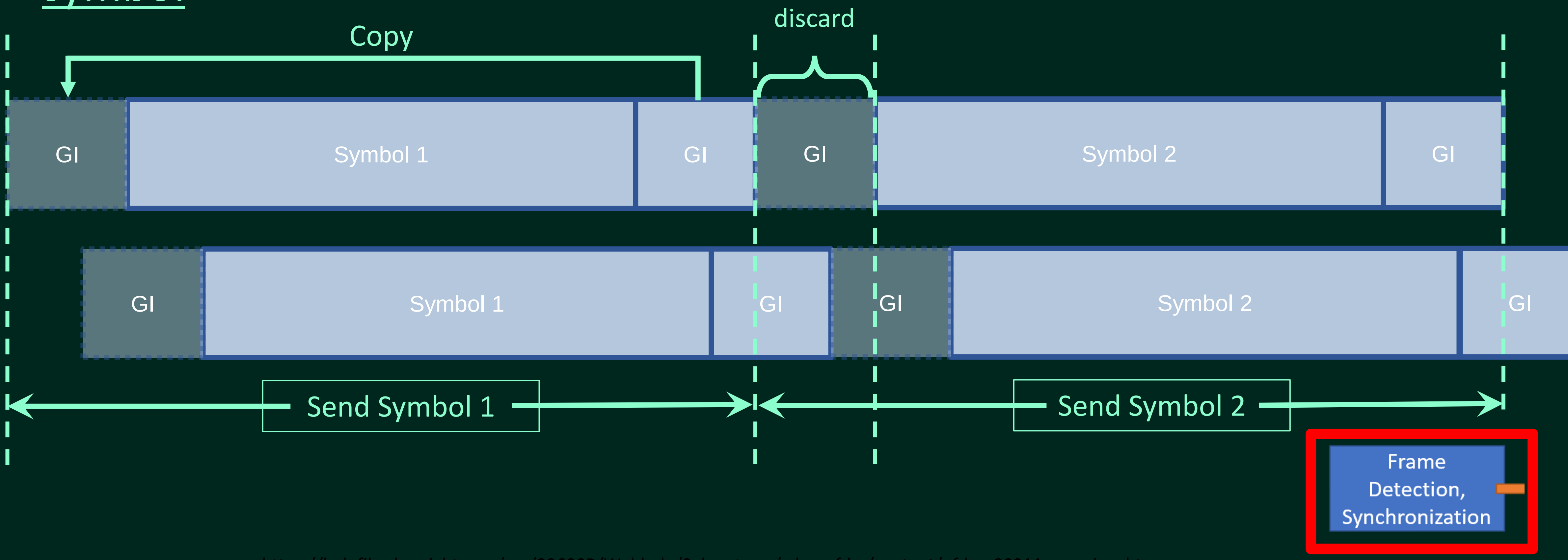




https://helpfiles.keysight.com/csg/89600B/Webhelp/Subsystems/wlan-ofdm/content/ofdm_80211-overview.htm

Multipath Effects – Guard Interval

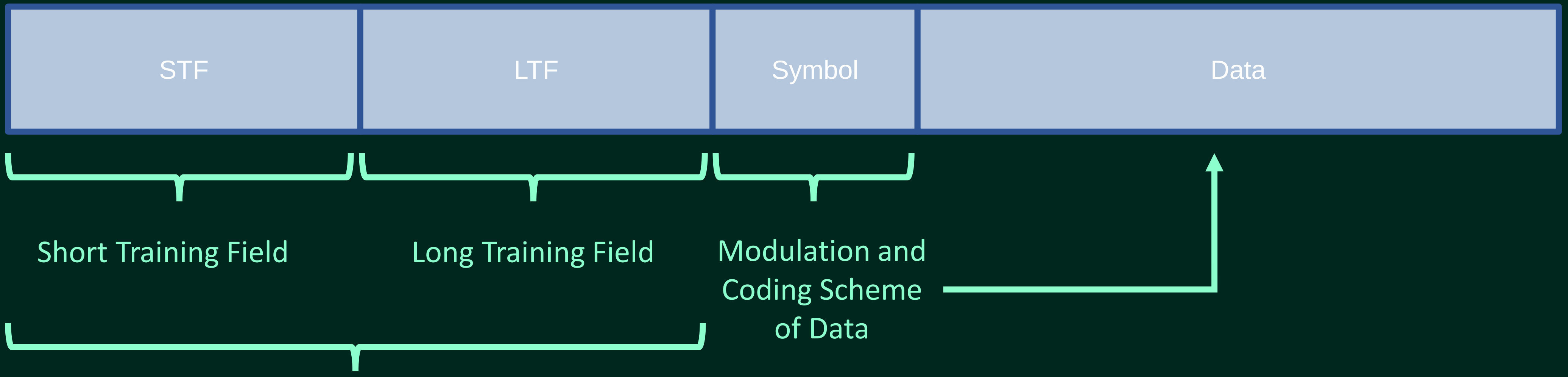
- Guard Interval or Cyclic Prefix protects against interference with next symbol



https://helpfiles.keysight.com/csg/89600B/Webhelp/Subsystems/wlan-ofdm/content/ofdm_80211-overview.htm

Frame Format with Preamble

- Frames begin with a Preamble (here shown for OFDM in 802.11a)



Short Training Field

Long Training Field

Modulation and Coding Scheme of Data

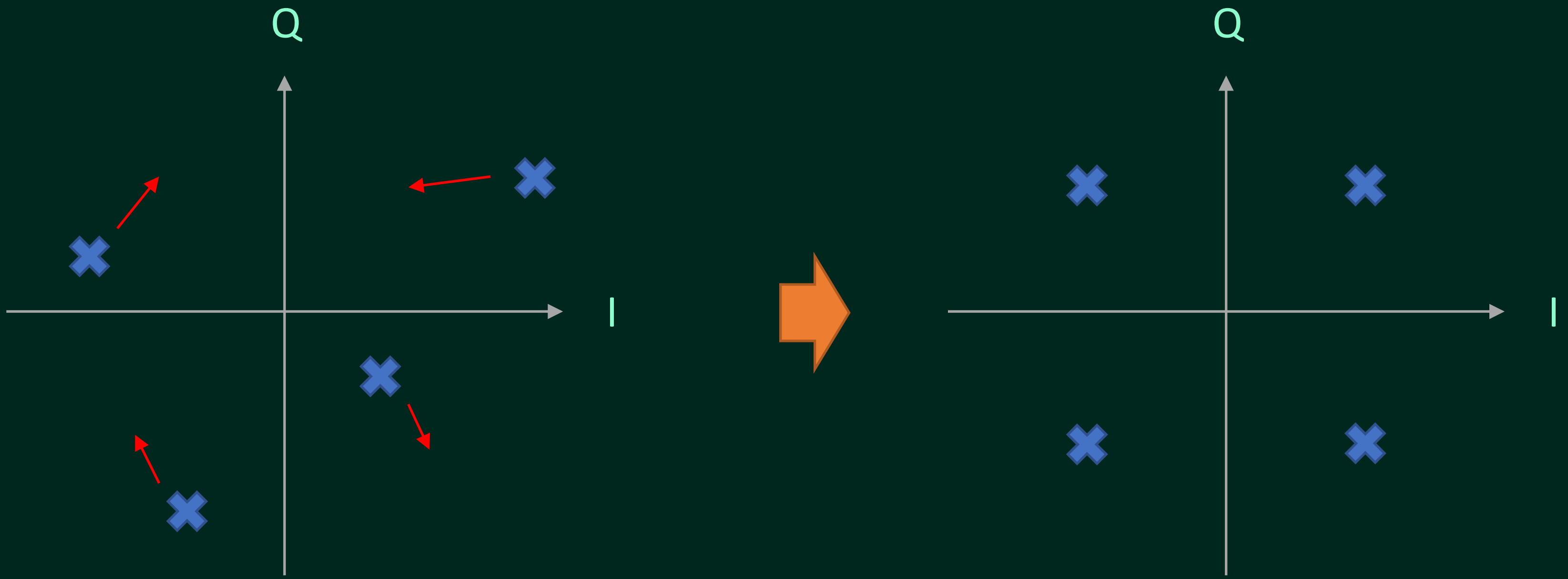
Well known magnitude and phase. Can be used to get start of the packet + **equalization**

Frame Detection, Synchronization

https://helpfiles.keysight.com/csg/89600B/Webhelp/Subsystems/wlan-ofdm/content/ofdm_80211-overview.htm

Preamble - Equalization

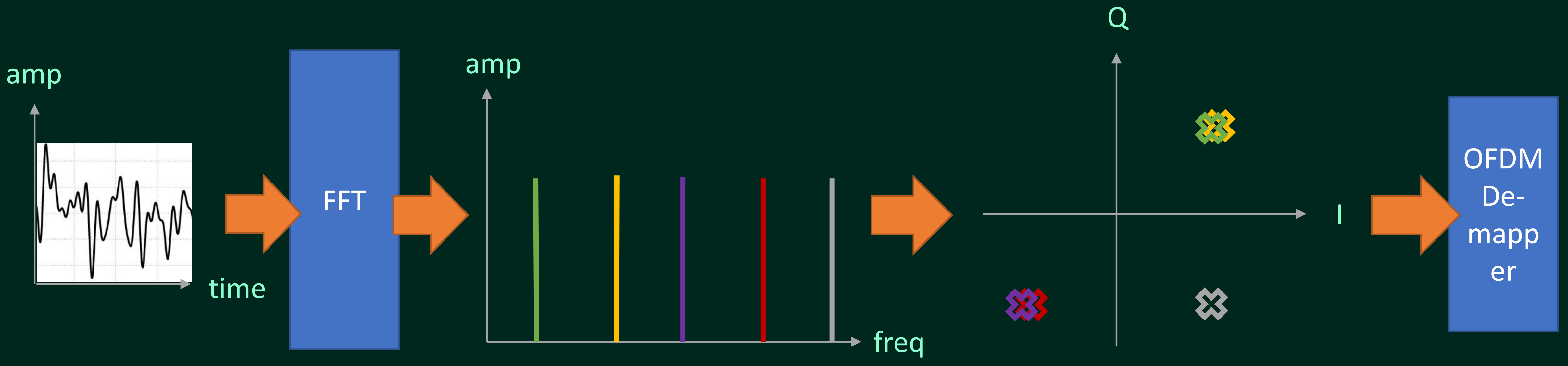
- Fix amplitude and phase offsets introduced by channel

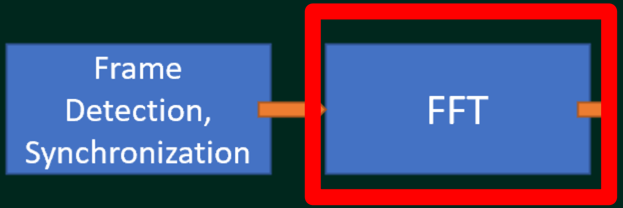


Frame Detection, Synchronization

FFT

- Use FFT to get phase and amplitude for each sub-carrier

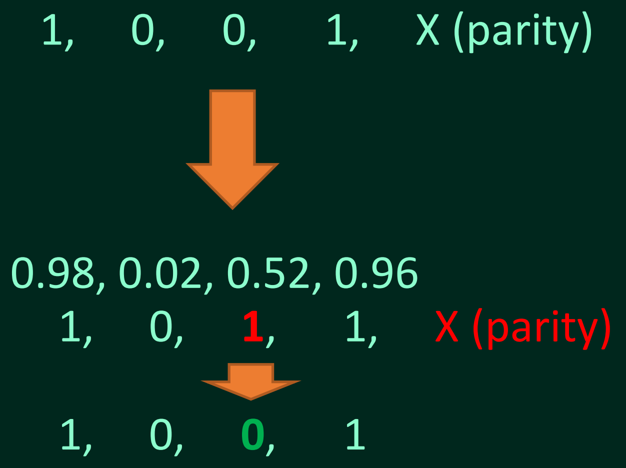


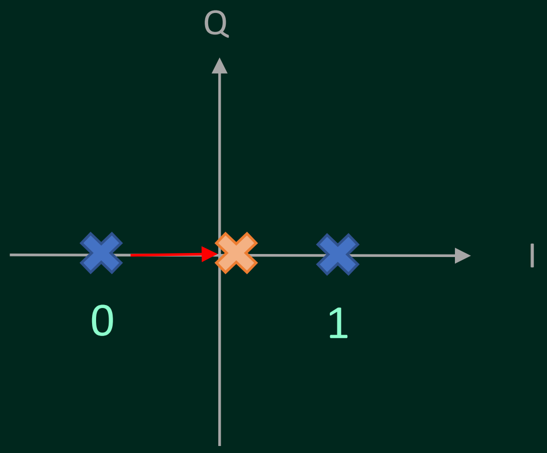


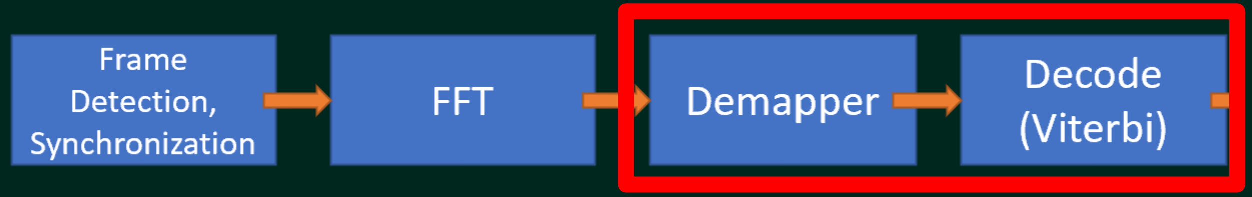
Demapper and Decoder

In case of errors, how can we know which bits are wrong?

1. Demap: Create probabilities (using Viterbi) of **how likely** it is that a **symbol is a certain value**
2. Decoder: Use probabilities to **figure out which bit is wrong** in case parity bit does not match

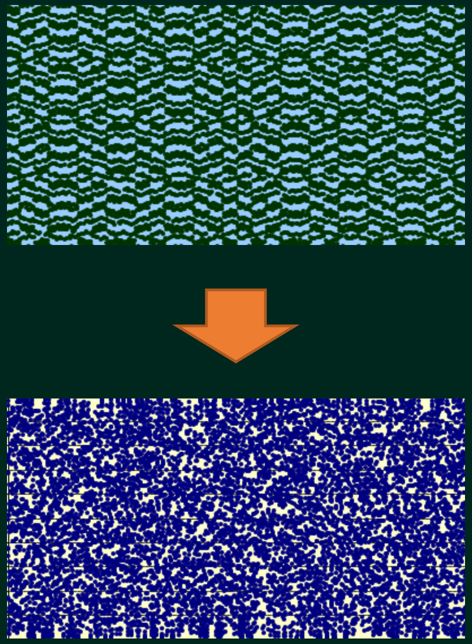




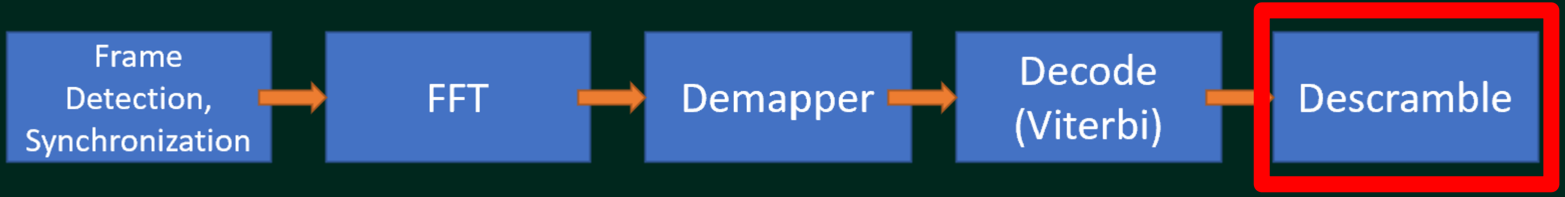


Descramble

- Reverse:
  - Create **even number** of **zeros and ones**
  - Avoid **long runs of zeros or ones**
    - spread power across spectrum
    - avoid interference with other channels
- Using LFSRs: **Linear Feedback Shift Registers**

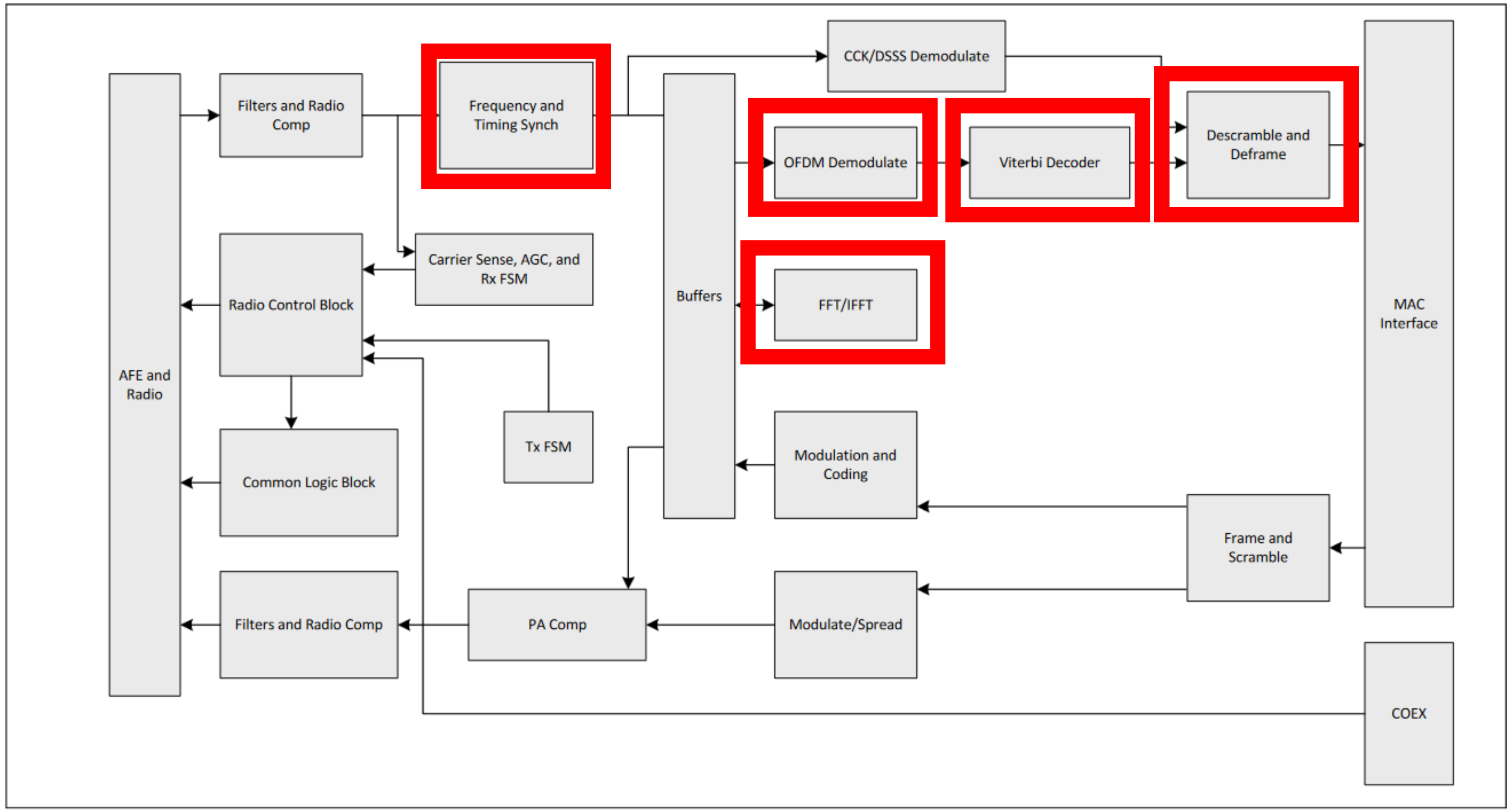


https://excelunusual.com/an-animated-linear-feedback-shift-register-lfsr-as-a-pseudo-random-pattern-generator-in-excel-2003-part4/



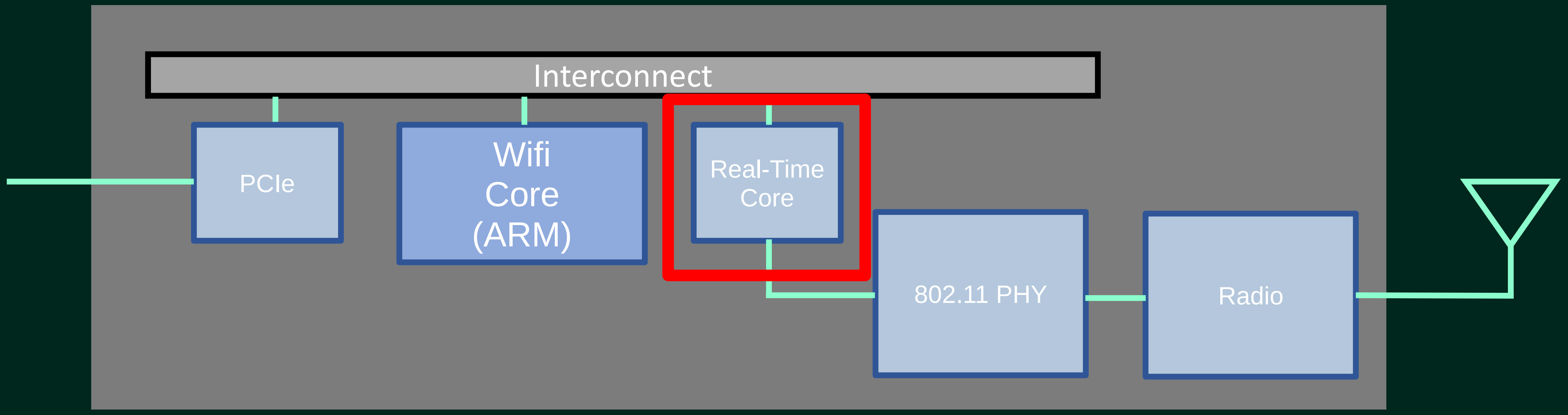
Pipeline IQ and Bit Processing

Figure 24. WLAN PHY Block Diagram



https://www.infineon.com/dgdl/Infineon-CYW4339_Single_Chip_5G_WiFi_IEEE_802.11ac_MAC_Baseband_Radio_with_Integrated_Bluetooth_4.1-DataSheet-v10_00-EN.pdf?fileId=8ac78c8c7d0d8da4017d0ee1e7d367fd

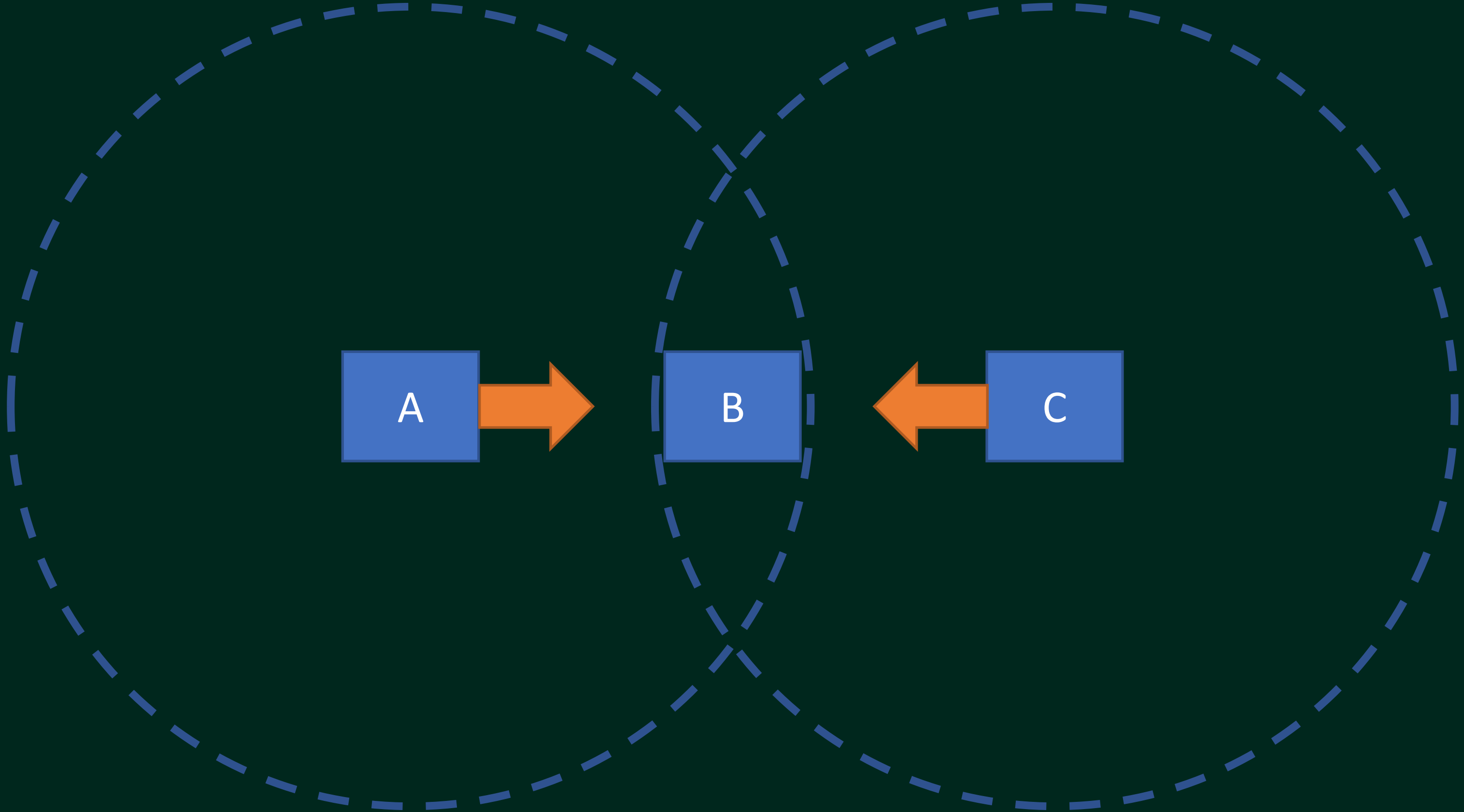
Building blocks of a Wifi Chip



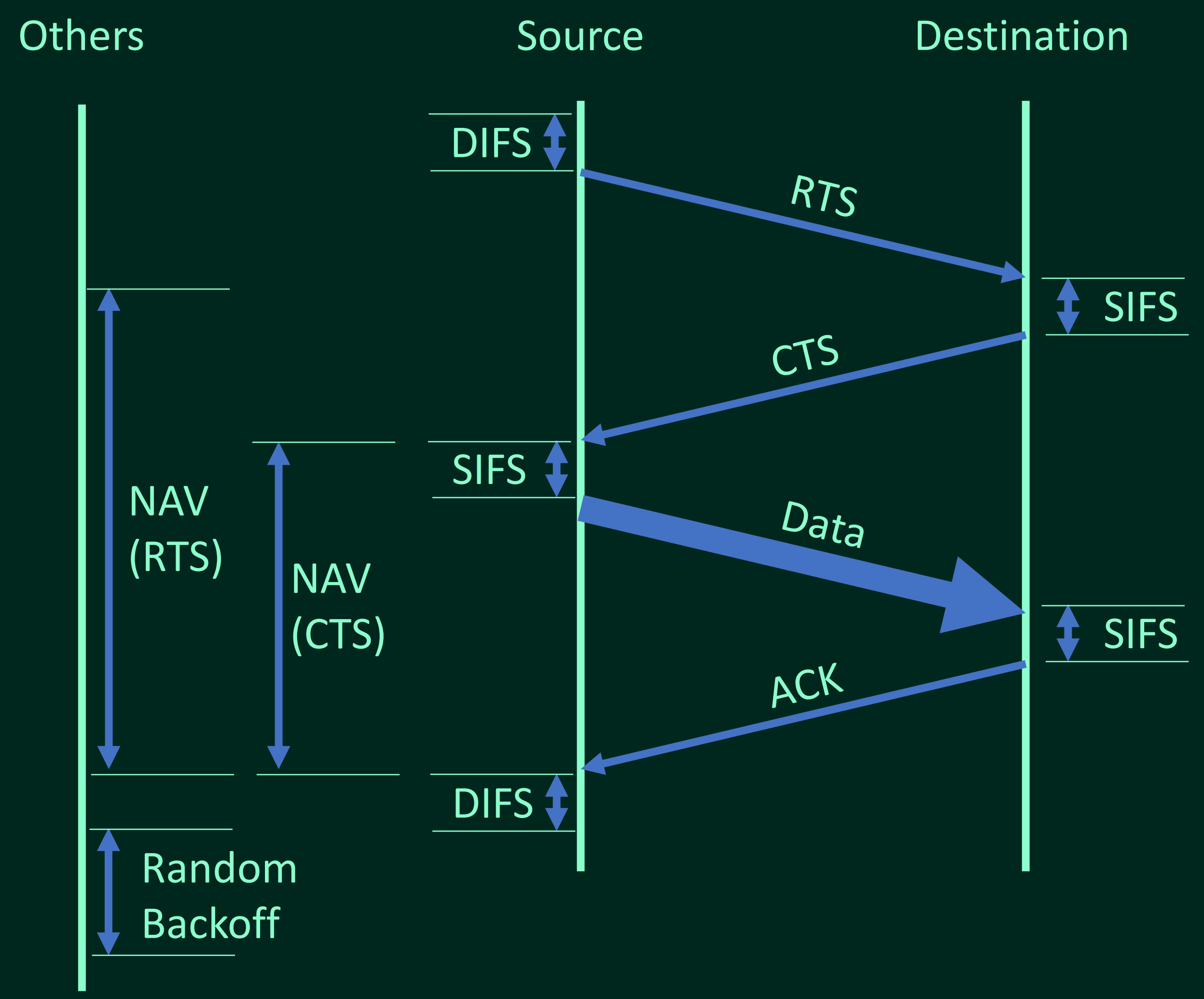
Can we send and Receive at the same time?

- No! Only sending or receiving possible at the same time with one transceiver → Shared medium
- Ethernet: **Carrier-sense multiple access with collision detection (CSMA/CD)**
- Wifi: **Carrier-sense multiple access with collision avoidance (CSMA/CA)**

Hidden Terminal Problem



DCF: Distributed Coordination Function



DCF: Distributed Coordination Function

DIFS: DCF Interframe Space

SIFS: Short Interframe Space

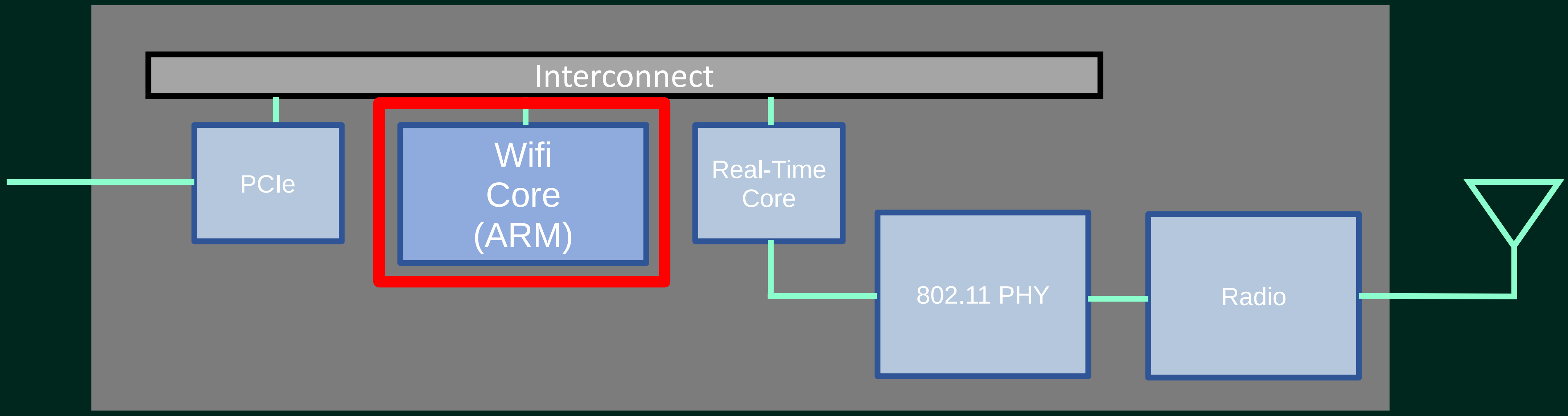
RTS: Request To Send

CTS: Clear To Send

ACK: Acknowledgement

NAV: Network Allocation Vector

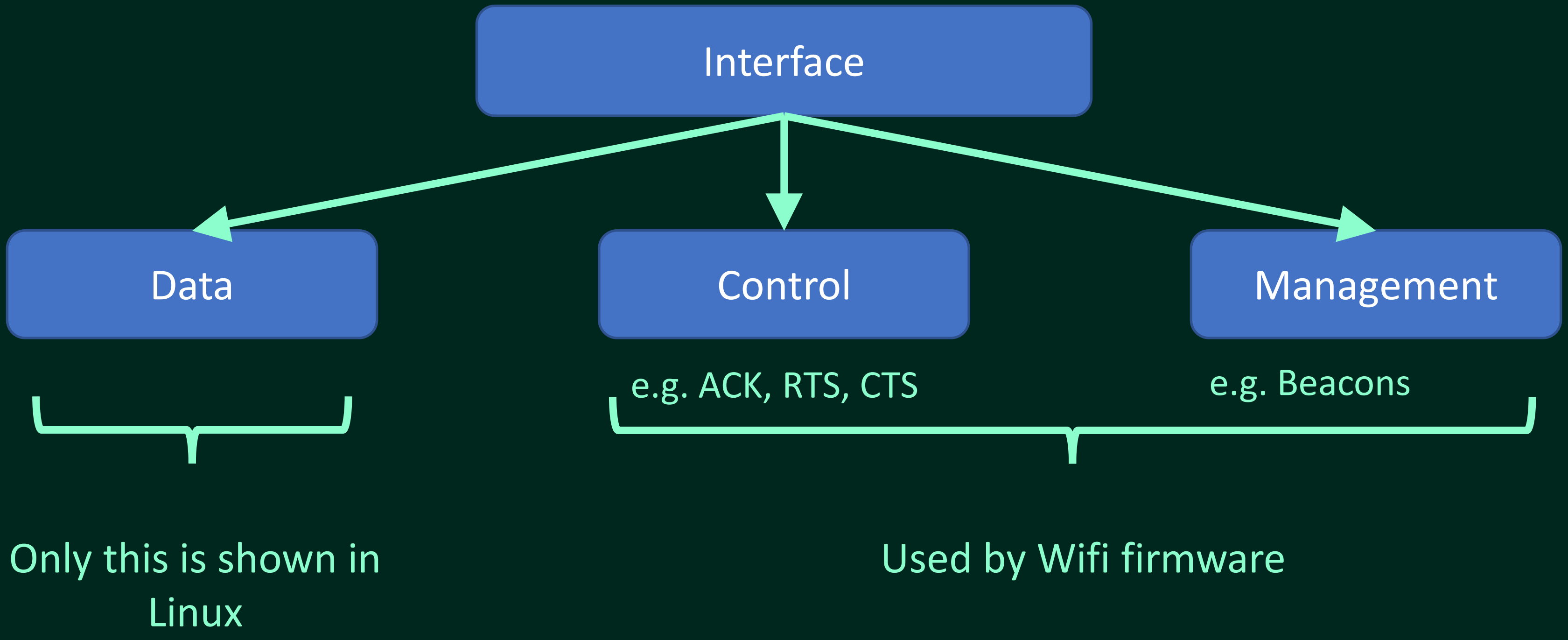
Building blocks of a Wifi Chip



What is the MAC layer responsible for?

- Frame aggregation and fragmentation
- Scanning
- Authentication + Association
- Power Saving
- Roaming
- Checksums

Frame Types



Interface

Data

Control

Management

e.g. ACK, RTS, CTS

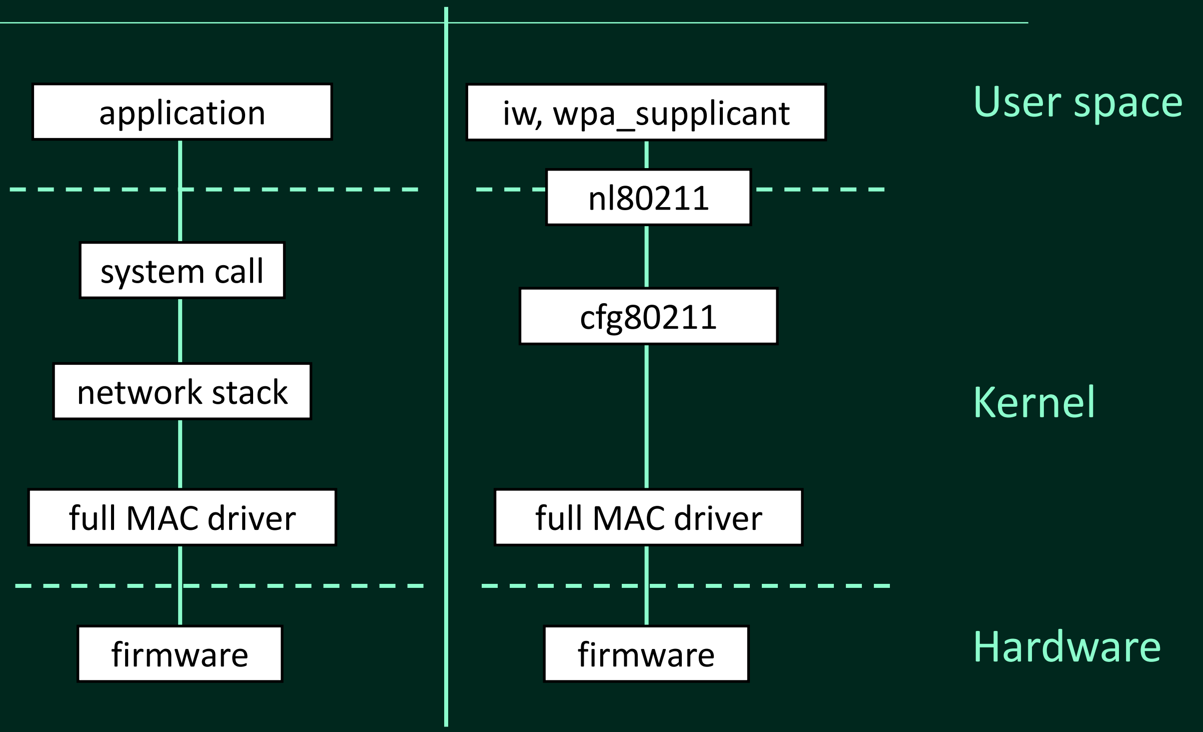
e.g. Beacons

Only this is shown in Linux

Used by Wifi firmware

Wireless Data in Linux

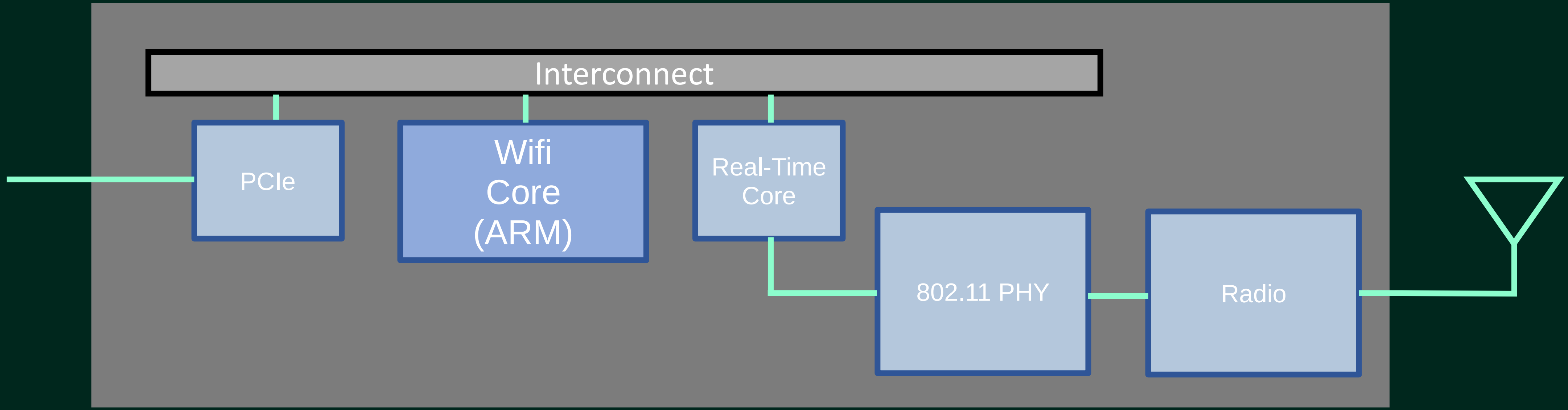
Data and management/configuration move differently thorugh the Linux kernel



Flow of data (left) and management/configuration (right) through the Linux kernel

Open Source Firmware?

open source ?



Open Source Firmware - Problems

❑HW initialization: HW Registers are not known

❑Primitives for Sending and Receiving packets

❑Tasks or processes need to be understood to run code independent of main loop

❑Control “real time” part of FW
→needed DCF: Sending ACKs (done by HW in ESP8266)

❑HW packet filtering

❑License: needs “clean room” documentation to develop FW which could be GPL licenced and be usable in Linux Kernel

Thank You!

Q&A

Contact: daniel@wegemer.com

Links

- Analog Devices Course
  - https://www.analog.com/en/resources/analog-dialogue/articles/rf-signal-chain-discourse.html
  - https://www.analog.com/en/resources/analog-dialogue/articles/rf-signal-chain-discourse-part-2-essential-building-blocks.html
- I/Q Data
  - http://whiteboard.ping.se/SDR/IQ
  - https://towardsdatascience.com/mind-your-is-and-q-s-the-basics-of-i-q-data-d1f2b0dd81f4
- https://wirelesspi.com/
- https://www.ni.com/en/support/documentation/supplemental/15/labview-communications-802-11-application-framework-1-1-white-pa.html
- https://www.tek.com/en/documents/primer/wi-fi-overview-80211-physical-layer-and-transmitter-measurements
- Explanation videos on various digital signal processing algorithms and methods: https://www.youtube.com/@iain_explains
- SDR
  - Youtube Introduction Series using HackRF One: https://www.youtube.com/playlist?list=PL75kaTo_bJqmw0wJYw3Jw5_4MWBd-32IG
  - https://ajoo-github-blog-old.pages.dev/
- AD9361 datasheet: https://www.farnell.com/datasheets/2007082.pdf
- Projects
  - https://github.com/open-sdr/openwifi
  - https://github.com/esp32-open-mac/esp32-open-mac
  - Modify Broadcom Wifi Chip firmware: https://nexmon.org
- https://mcsindex.com/
- Open Source MATLAB alternative: https://octave.org/