COLLABORATING WITH CLIENTS TO DEVELOP INNOVATIVE NEW TECHNOLOGY

VANTEON
WIRELESS SOLUTIONS

Software Defined Radio

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Vanteon 101

The Business

- Advanced Custom Embedded Electronics and Software Solutions
  - Architecture, Design, Development
  - Prototype & Test Services
- Rochester, NY Location, Founded in 1985
- Awarded Best Companies to Work for in NYS 10+ years
- > 90% Repeat Engagements

Strategic Focus

- Wired & Wireless Connectivity, Networking
- Software Defined Radio
- Energy, Power, Digital Signal Processing

Market Focus

- Military, Aerospace
- Healthcare, Industrial

Our Typical Client Profile

- Work with start-ups to the Fortune 50

Best Companies to work for NEW YORK

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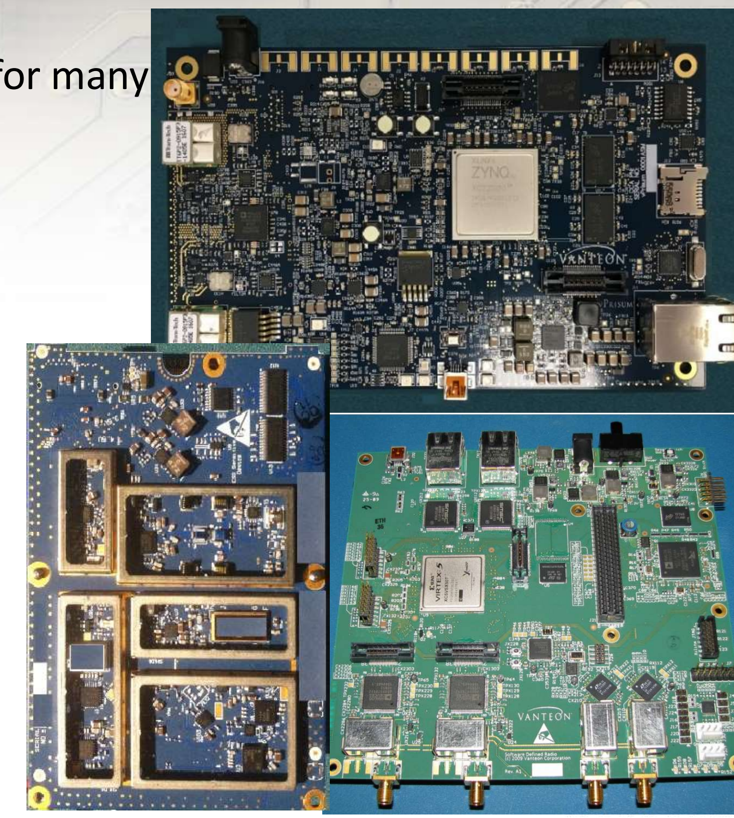
Software Defined Radio

SDR Experience

Vanteon has developed SDR technologies for many clients, with wide-ranging applications.

Client SDR Applications:

- RADAR
- Avionics Positioning Systems
- Automated Metering Infrastructure
- Military Communications
- Signals Intelligence and Classification
- Cellular Infrastructure
- RFID Systems
- Wayside Communications
- Signal Analysis / Test Equipment

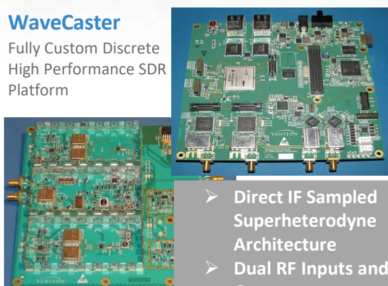


Vanteon Reference Designs at a Glance

vChameleon
Low-Cost Software Defined Radio Platform for Industrial applications

- Optimized for lowest cost SDR
- RF FE Freq range = 902 to 928 MHz
- Transceiver capable of 70MHz to 2.3GHz
- IBW = narrowband to 20 MHz
- 1 TX, 1 RX

WaveCaster
Fully Custom Discrete High Performance SDR Platform



- Direct IF Sampled Superheterodyne Architecture
- Dual RF Inputs and Outputs
- 900MHz, 2.4GHz, 5.8GHz RF

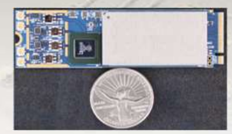
vNassa
Software Defined Radio Platform for Industrial Applications

- Optimized for 900 MHz ISM Band and low power
- Fast lock for frequency hopping
- Transceiver capable of 30MHz to 6GHz
- RF FE Freq range = 902 to 928 MHz
- IBW = 12 kHz to 26 MHz
- 1 TX, 1 RX

vProtean/vProtean+
Software Defined Radio Platform Optimized balance of performance and cost for the industrial market

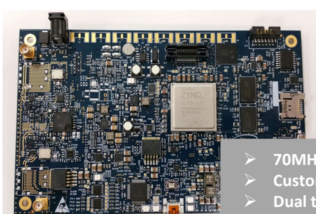
- Optimized balance of performance and cost
- Built for low power
- Fast lock for frequency hopping
- Freq range = 30 MHz to 6 GHz
- IBW = 12 kHz – 40 MHz
- 2 TX, 2 RX

vProtean | M.2
Software Defined Radio Platform Optimized higher throughput , increased processing and small formfactor.



- Optimized for small form factor and performance
- UltraScale+ MPSoC
- Supports IQ streaming on PCIe
- Freq range = 30 MHz to 6 GHz
- IBW = 12 kHz – 40 MHz
- 2 TX, 2 RX

vPrisum
High Performance TX/RX MIMO SDR Platform Based on ADI AD9361

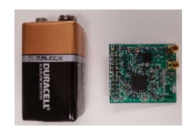


- 70MHz-6GHz Transceiver
- Custom discrete RF FE tuned 915 ISM band
- Dual transmit and receive RF ports
- Instantaneous bandwidths up to 56MHz

vGateway
IoT Gateway for bridging between Low Power Wireless Sensor Networks and the Cloud

- Bridges Cellular, Wi-Fi, Bluetooth, ZigBee, Dust, USB, Ethernet, LoRa & Custom RF protocols

vImpulse2
Dual Band, software configurable radio at 900MHz and 2.4GHz



- Multi-year battery life
- Less than 1µA sleep current
- Frequency Hopping Spread Spectrum Support
- Analog and Digital inputs for low power sensors
- Small form factor (~1" by 1")
- Custom Radio protocols

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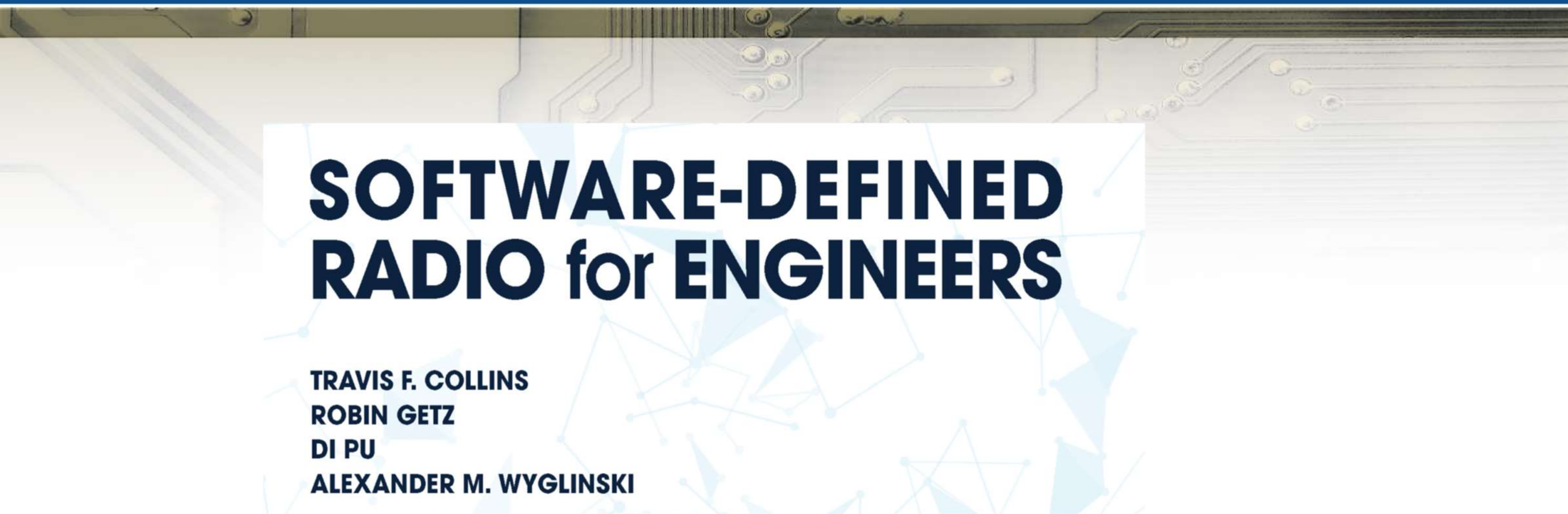
SDR Workshop and picked out some of intriguing conversation/lecture topics:

- Introduction of Radio Frequency
- Discuss how SDR differs from traditional radio methods
- Overview of the hardware associated with RF (antennas, analog radio circuitry, etc)
- Discuss the theory of the analog radio circuitry (amplification, filters, mixers, etc)
- Showcase the evolution of SDR (show how with each generation, SDR moves away from hardware and goes primarily towards software)
- Real-life applications of SDR
- How to get started with SDR (for hobbyists)
- Showcase an SDR kit in action (show the reception of RF signals through an SDR kit)

Reference eBook available from Analog Devices



From: [Software Defined Radios for Engineers]

Evolution Of Radio

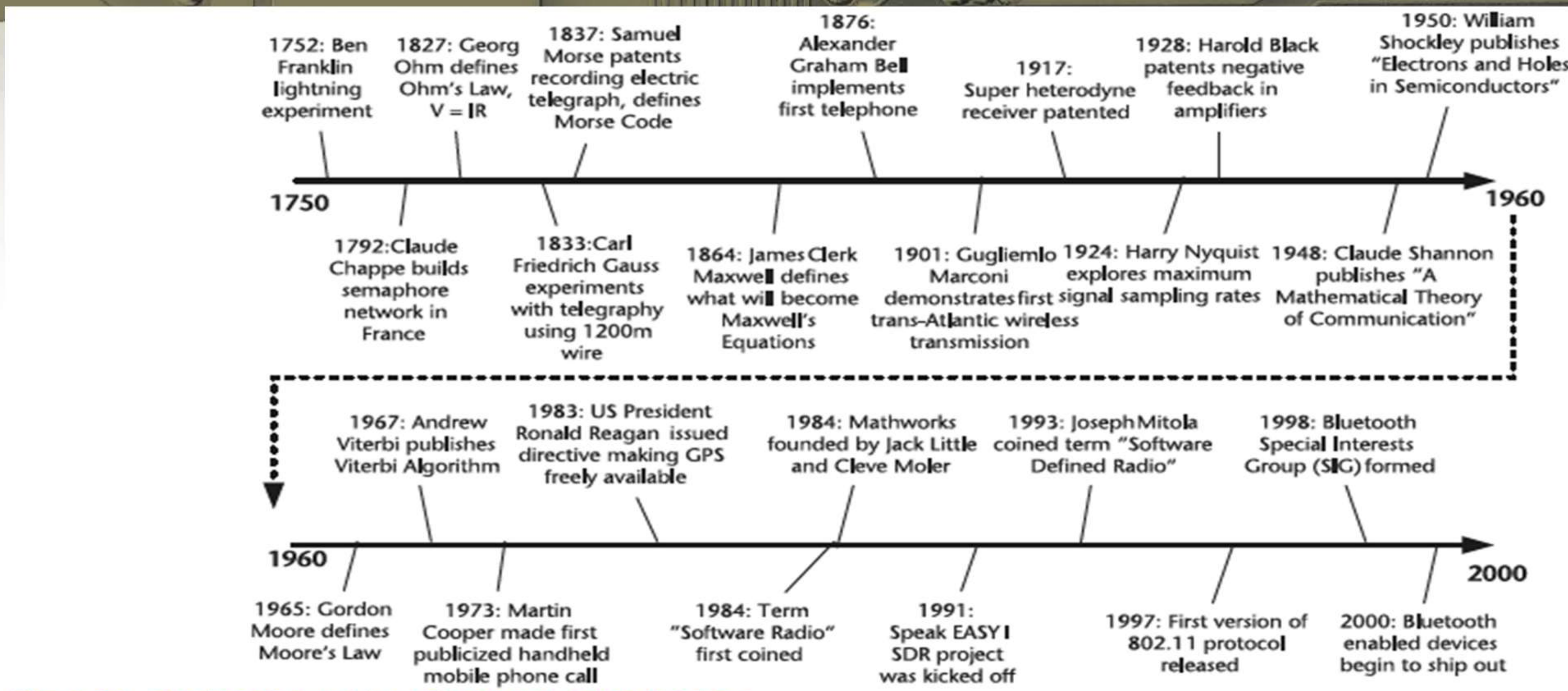


Figure 1.1 Timeline of several key milestones in communications.

From: Software Defined Radios for Engineers

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Introduction to Radio Frequency (RF)

- Radio waves are defined by the ITU as: "electromagnetic waves of frequencies arbitrarily lower than 3000 GHz, propagated in space without artificial guide (Radio Regulations, 2020 Edition)

- Radio Frequencies (RF) refers to the range of electromagnetic waves used in communication.

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Introduction to Radio Frequency (RF)

- A radio Band is a range of contiguous frequencies in which channels are usually set aside for some purpose
  - LF & MF (< 3 MHz) : AM radio, maritime
  - HF (3 – 30 MHz): Shortwave, amateur radio
  - VHF (30 – 300 MHz): FM, Television, Aviation
  - UHF (300 – 3,000 MHz): Television, Satellite, Emergency, G4
  - SHF (3 – 30 GHz): Radio Astronomy, Microwave, wifi
  - EHF (30 – 300 GHz): Satellites, radar, 5G
  - THF (300 – 3,000 GHz): Experimental Medical,

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IEEE Standard RF Bands (VHF)

Below is a table outlining key sub-bands within the 30–300 MHz range along with their typical applications, adapted in spirit from classifications like those in IEEE Standard 521-2019:

Frequency Range (MHz)	Sub-Band / Designation	Typical Applications and Uses
30 – 50	Lower VHF	Experimental and niche government/military applications
50 – 54	Amateur Radio (6 m)	Amateur radio operations (edge of the 6-meter band)
54 – 88	Lower VHF	Early TV channels (in some regions), specialized communications
88 – 108	FM Broadcast	Commercial FM radio broadcasting
108 – 137	Aeronautical Band	Airband communications, navigation aids (e.g., ILS, VOR)
137 – 174	Mid VHF	Weather data (NOAA weather radio), amateur radio (e.g., 2 m band), public safety, marine communications
174 – 216	High VHF	Television broadcasting (VHF TV channels in many regions)
216 – 300	Upper VHF	Military communications, land mobile radio, other public safety uses

Note: The exact boundaries and uses may vary by region and specific standards, but this table provides a general overview of the VHF spectrum's subdivisions.

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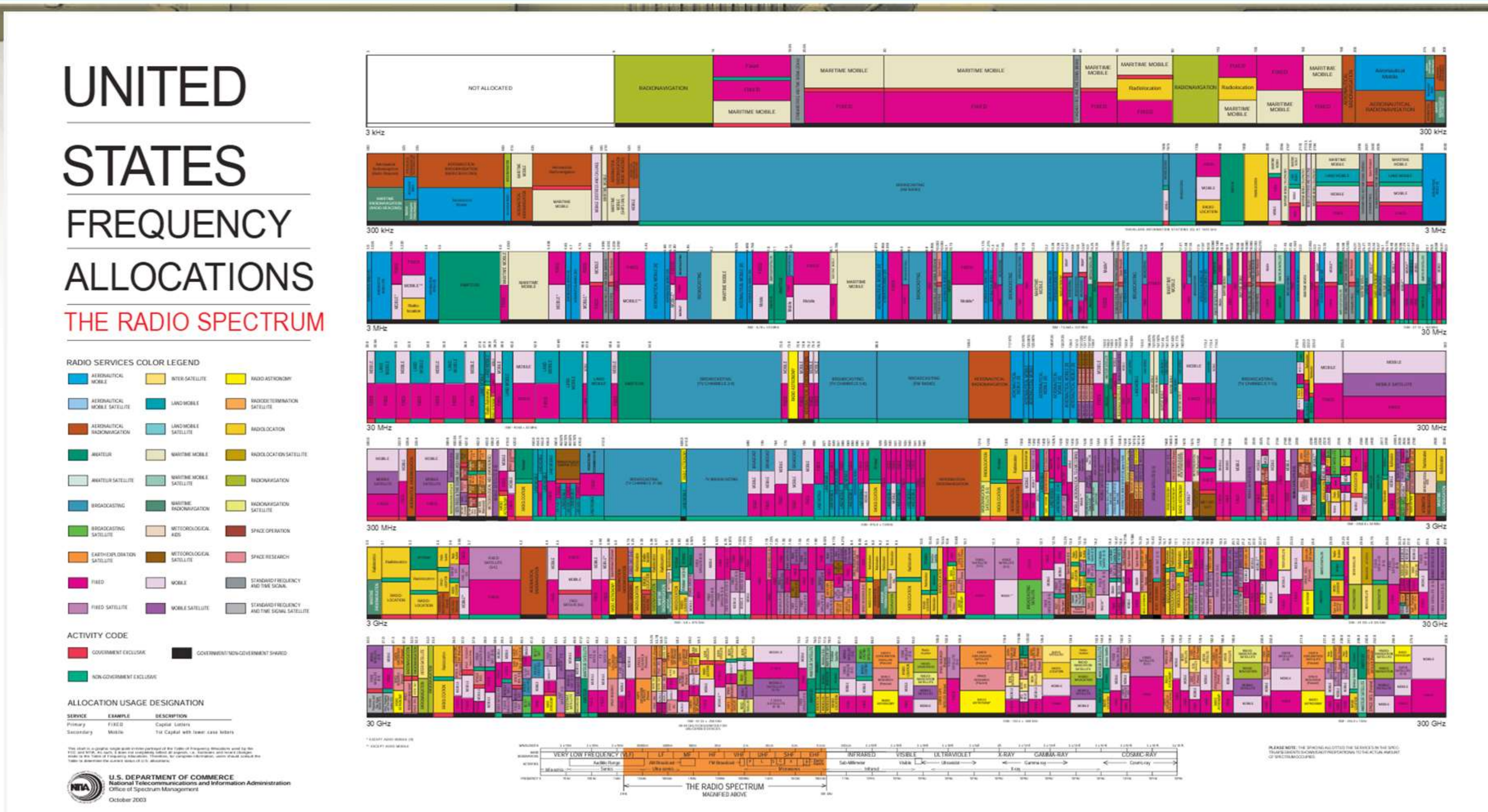
United States Frequency Allocation Chart



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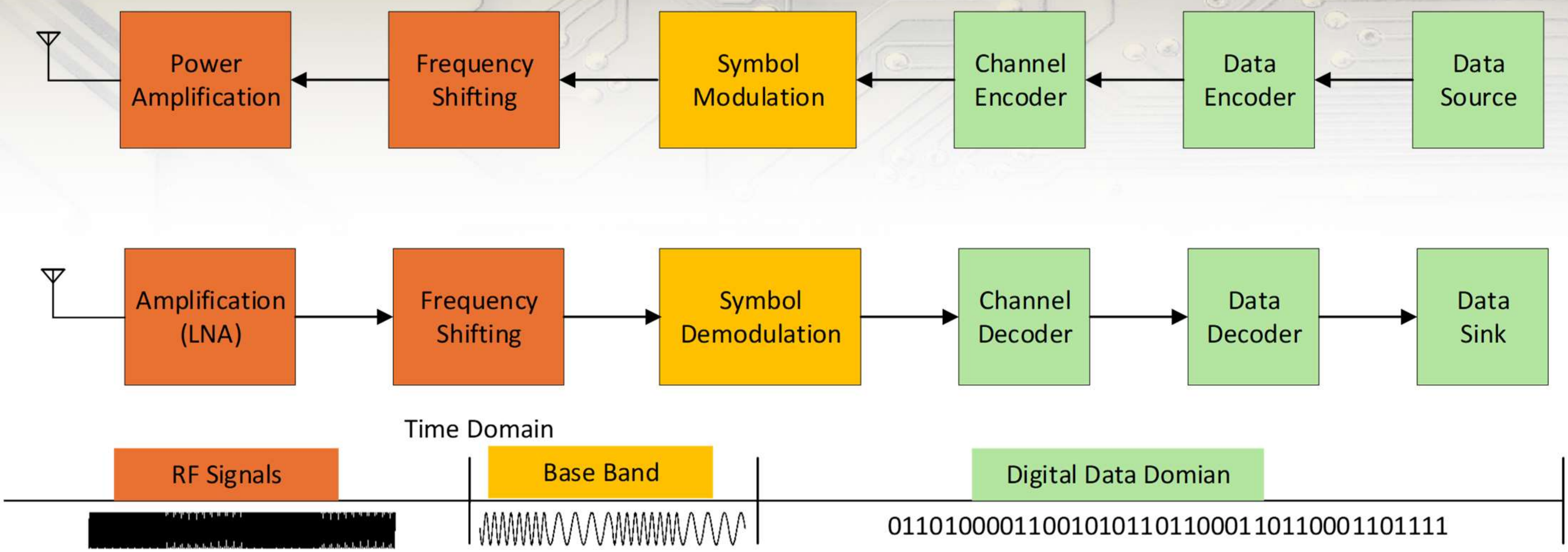
Digital Communication Radio



Hardware Associated with RF

- Antennas
  - Capture/Transmit RF signals
- Frequency Generation
  - Oscillators: Generate Stable Frequencies (typically fixed frequency)
  - Phased Lock Loop (PLL) can be used to derive other frequencies
- Analog Radio Circuitry
  - Amplifiers, Attenuation, Mixers, Filters
- ADCs & DACs
  - Convert Signals between Analog and Digital

Analog Radio Circuitry

- Amplifiers: Boosts RF signals
  - On Receive boosts weak RF signals for conversion by ADCs
  - On Transmit boosts RF signal for transmit strength
- Filters: Remove unwanted frequencies.
  - On transmit remove out of band frequencies for channel selection
  - On receive remove out of band frequencies for channel selection, anti-aliasing
- Mixers: Shift frequencies.
  - On Receive translate from RF to baseband
  - On Transmit translate from baseband to RF
    - Baseband is the frequency band centered around 0 Hz

Software Defined Radio (SDR)

What is SDR

SDR is defined by the IEEE working group 1900.1 and SDR Forum (now called Wireless Innovations Forum) simply as:

> *"Radio in which some or all of the physical layer functions are software defined"*.

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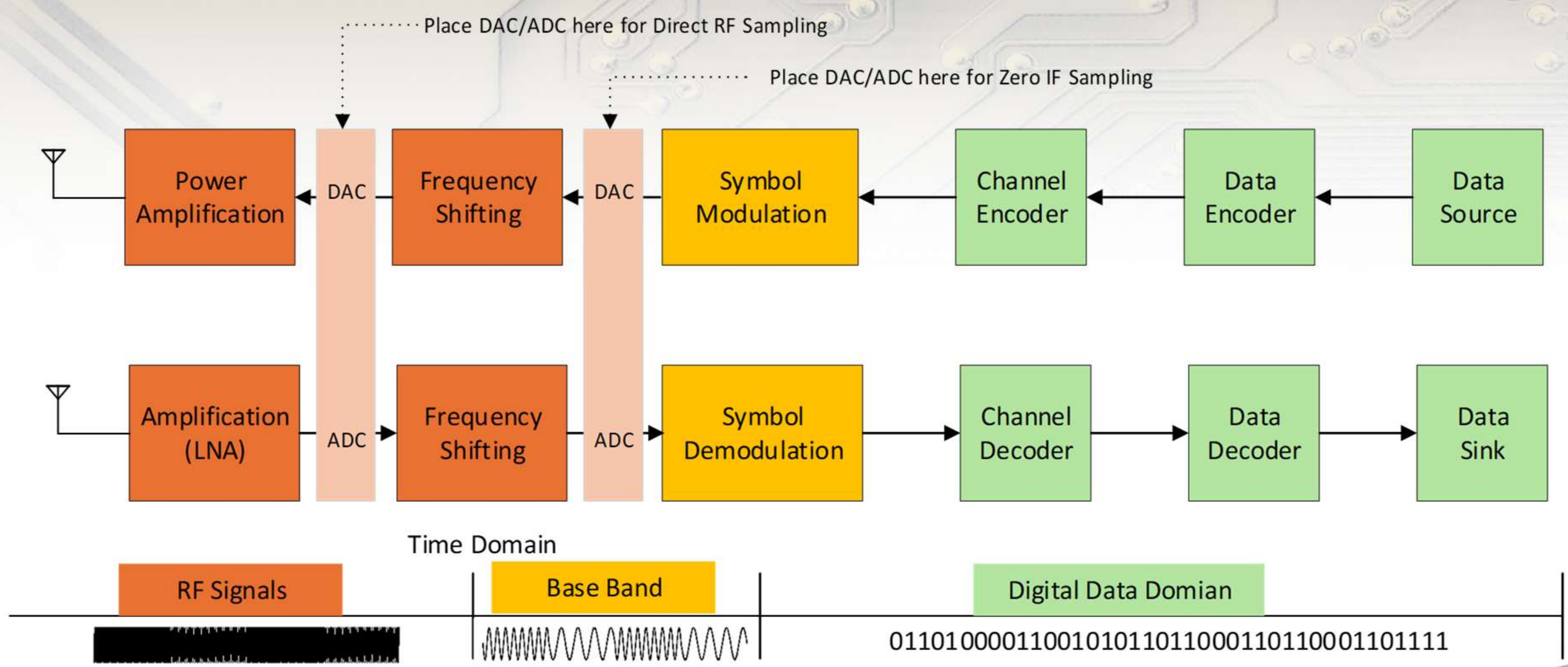
SDR vs Fixed Hardware Radio

- Fixed Hardware Radio
  - Fixed hardware components for specific bands, modulations, etc.
  - Hardware is fixed, no new features can be added
- Software Configured Radio
  - Software can control some configurations
    - Bit Rate, Preambles, sync word
    - May be able to select between limited modulations
    - Cannot add new modulations
- Software Defined Radio
  - Usually operates directly on sampled baseband data
  - Uses software/firmware for signal processing.
  - Radio functions can be completely changed by downloading new software/firmware
  - Radio bands may be fixed due to RF hardware

Digital Communication System



For a SW Defined Radio the decision is where to put the ADC/DAC

Zero IF Sampling Scheme

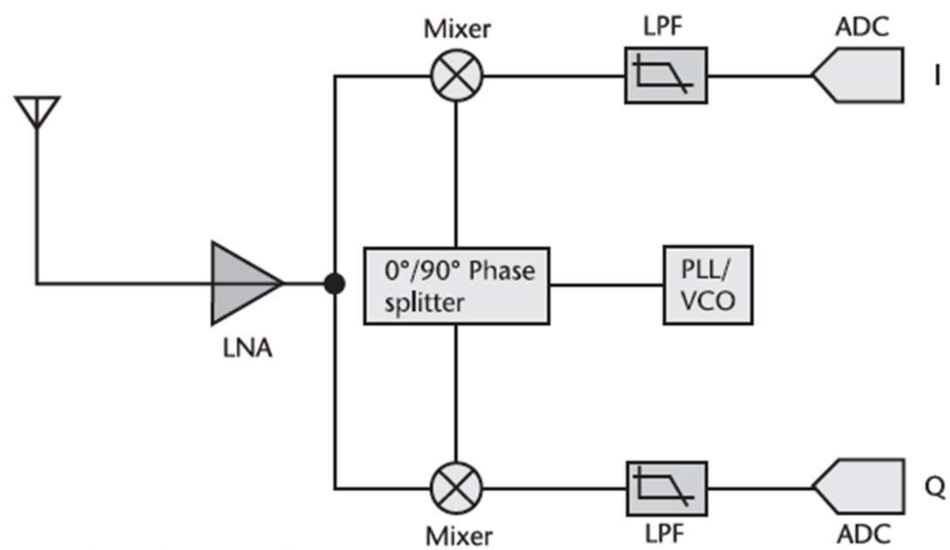


Figure 1.7 Zero IF architecture [4].

From: [Software Defined Radios for Engineers]

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Zero IF Architecture Overview

- Direct Conversion Receiver:
  - Converts the RF signal directly to baseband without an intermediate frequency stage.
- Phase Locked Loop (PLL), or Voltage Controlled Oscillator (VCO):
  - Generates the transmitted frequency, programmable.
- Simplified RF Front-End:
  - Low Noise Amplifier (LNA), Mixer, Low pass Filter (LPF)
  - Reduces the number of components compared to traditional superheterodyne receivers.
- Considerations:
  - Can be sensitive to DC offsets and LO leakage, which require careful design.
  - Analog signal Paths must be matched
  - Highly integrate ICs allow for more control of signal paths. With the PLL, mixers and analog paths in the same device, phase differences are better controlled.

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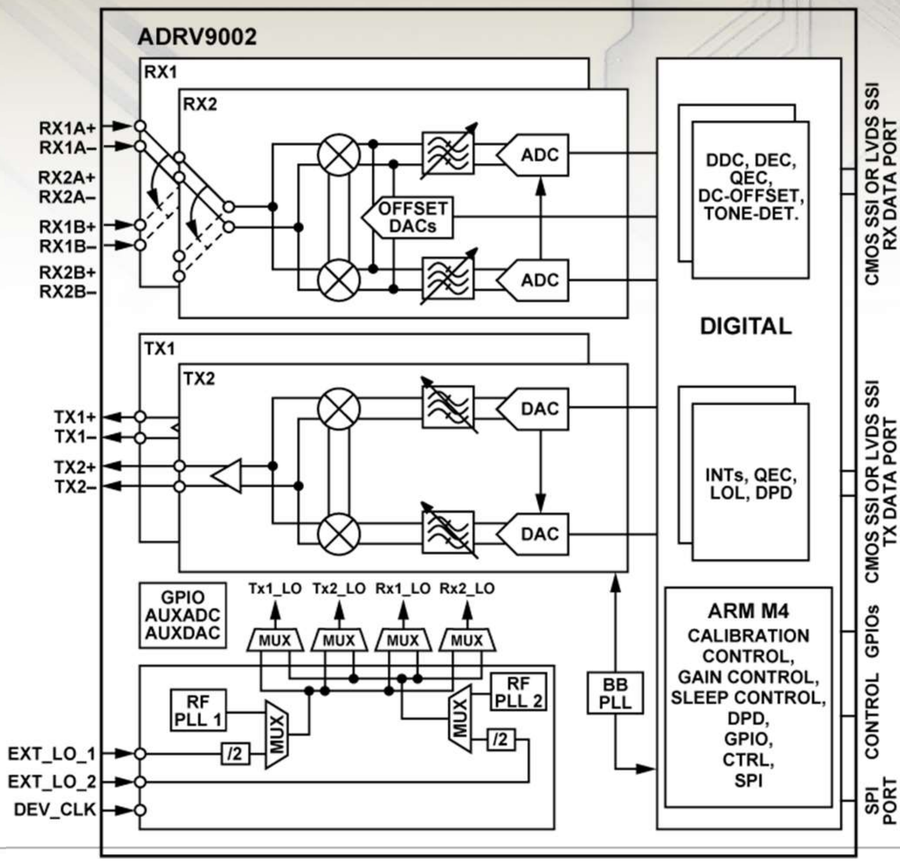
ADRV9002 From Analog Devices



ADRV9002 Features

- 2T×2R highly integrated transceiver
- Frequency range of 30 MHz to 6000 MHz
- Two fully integrated, fractional-N, RF synthesizers (PLLs)
- Transmitter and receiver bandwidth from 12 kHz to 40 MHz
- IQ data rates up to 61.44 MSps
- Fast frequency hopping

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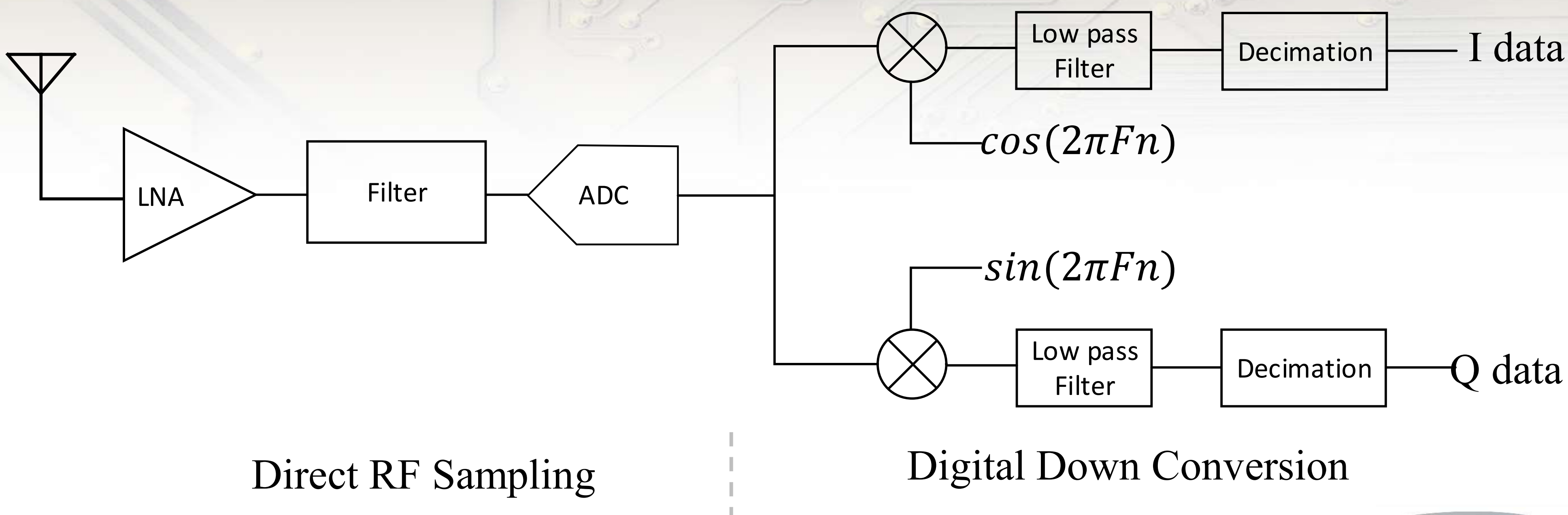
Direct RF Conversion



Direct RF Sampling Architecture Overview

- Direct Sampling of RF frequency
  - No Analog Mixing Stage
- Simplified RF Front-End:
  - Only signal conditioning, Amplification, filtering
  - Less analog components, less distortion
- Digital Down Conversion
  - Since mixing to base band is digital no channel mismatch
- Considerations:
  - Higher ADC Sample rates require more power
  - DSP processing at high data rates
  - Addition Digital processing required to mix to and from desired RF frequency

Ultra Scale plus RFSoC RF data converter from Xilinx

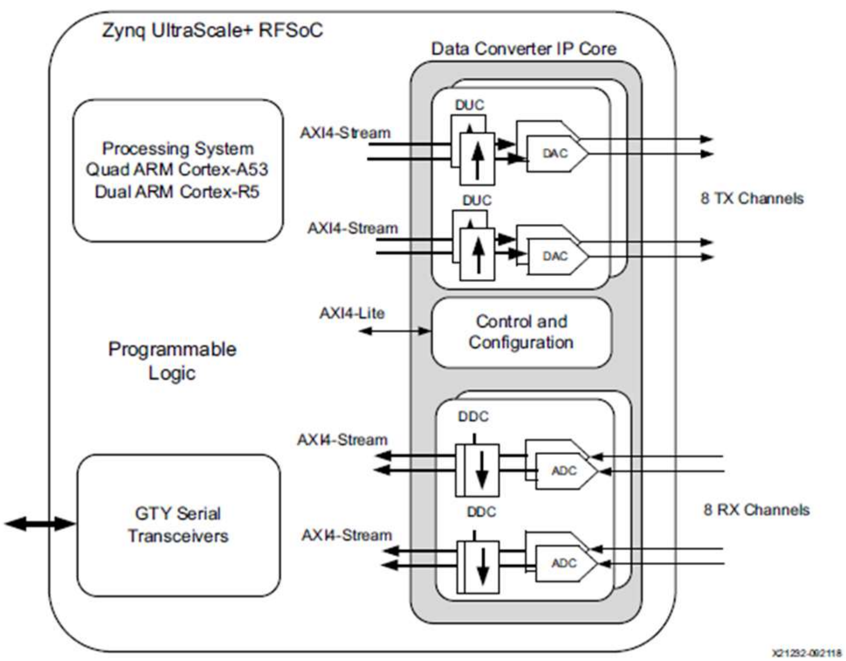


Figure 1-1: **Zynq UltraScale+ RFSoC RF Data Converter in RFSoC**

UltraScale+ RFSoC

- Direct RF sampling
- Highly programmable SoC
- RF-ADC up to 4 GSPS
- RX Bandwidth of 4 GHz
- RF-DAC up to 6.554 GSPS
- TX bandwidth > 6 Ghz
- Digital down converters (DDCs)
- Digital up converters (DUCs)
- Integrated PS with 6 Cores

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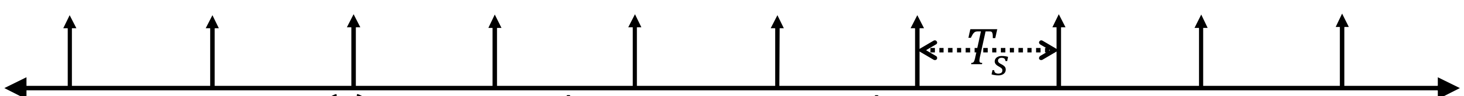
Signals - Sampling

- A time domain signal $x(t)$ can be converted to a discrete-time digital signal $x[n]$ using sampling.
- The signal $x(t)$ is sampled in time and amplitude (Quantization) to generate $x[n]$.
- Sampling is usually done at a constant time interval T_s to provide uniform sampling: $x[n] = x(nT_s)$
- Where $\frac{1}{T_s} = F_s$ the sampling frequency
- Can also think of uniform sampling as the time domain signal multiplied by a sampling function $p(t)$ where $p(t) = 1\ when\ t = nT_s$
  - $x_s(t) = x(t)\, p(t),\ and\ x[n] = \ x_s(nT_s)$



$p(t)$ = Dirac Pulse train in Time domain

Review Fourier Transforms

Fourier Transform

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt$$

Inverse Fourier Transform

$$x(t) = \int_{-\infty}^{\infty} X(w)e^{j2\pi\omega t}dt$$

Discrete Fourier Transform

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i2\pi\frac{k}{N}n}$$

Convolution

$$(f * g) := \int_{-\infty}^{\infty} f(\tau)g(t-\tau)d\tau$$

- Fourier Transforms convert between the time and frequency Domain
- One important relationship is multiplication in one domain results in convolution in the other.
- The Discrete Fourier Transform (DFT) operates on discrete or sampled data
- The Fast Fourier Transform (FFT) is an implementation of the DFT
- The DFT views the both the time domain and frequency domain as periodic, in that they repeat forever.

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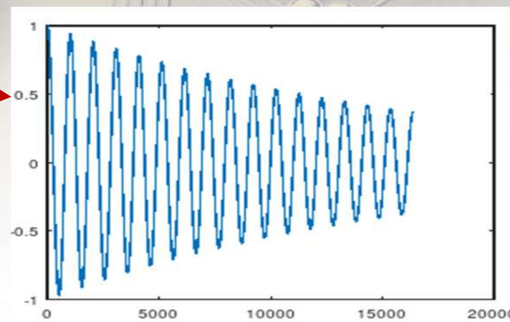
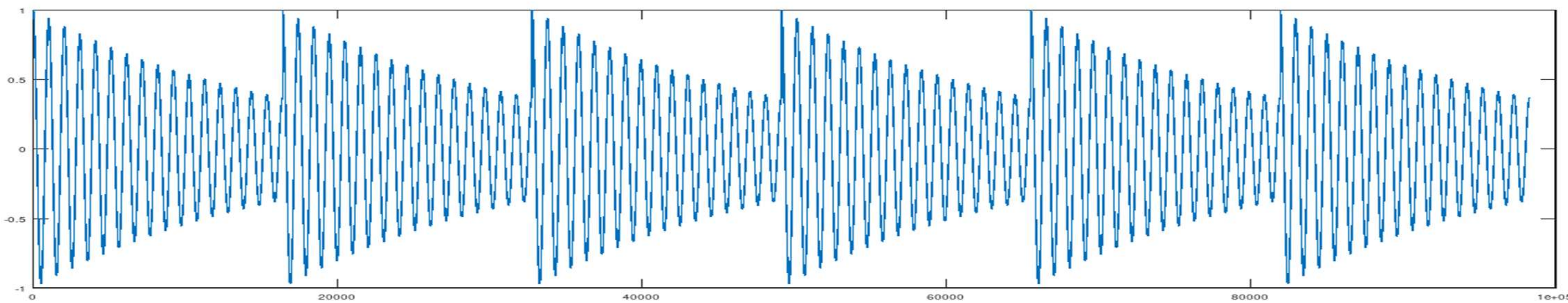
DFT View of the Time Domain

Your sampled signal



How the DFT sees it



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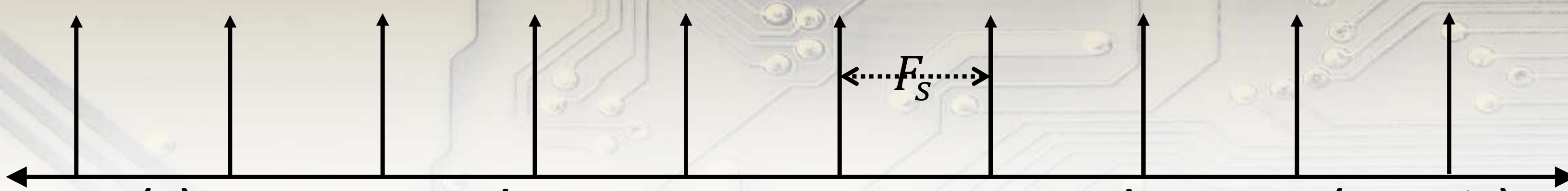
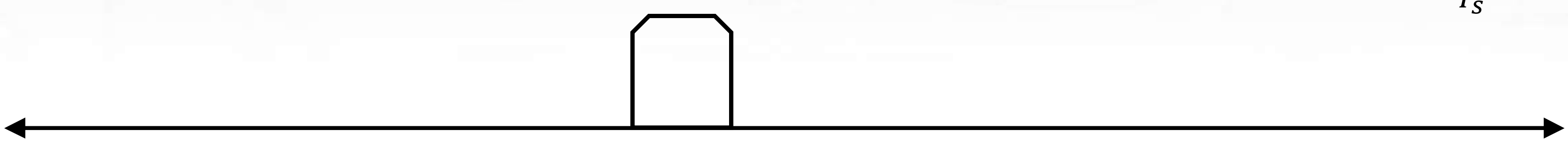
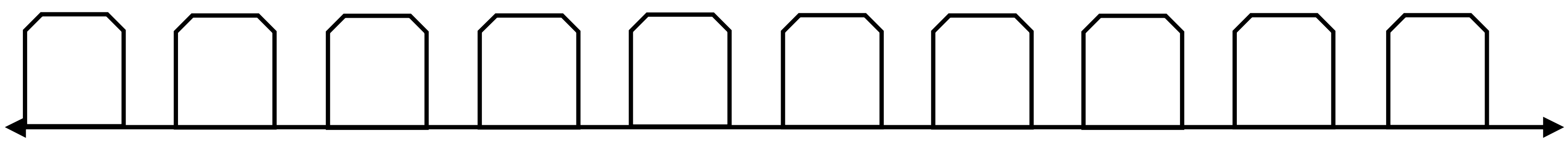
Digital Sampling Frequency Domain



p(t) is Dirac Pulse train in Frequency domain ($F_s = \frac{1}{T_s}$)

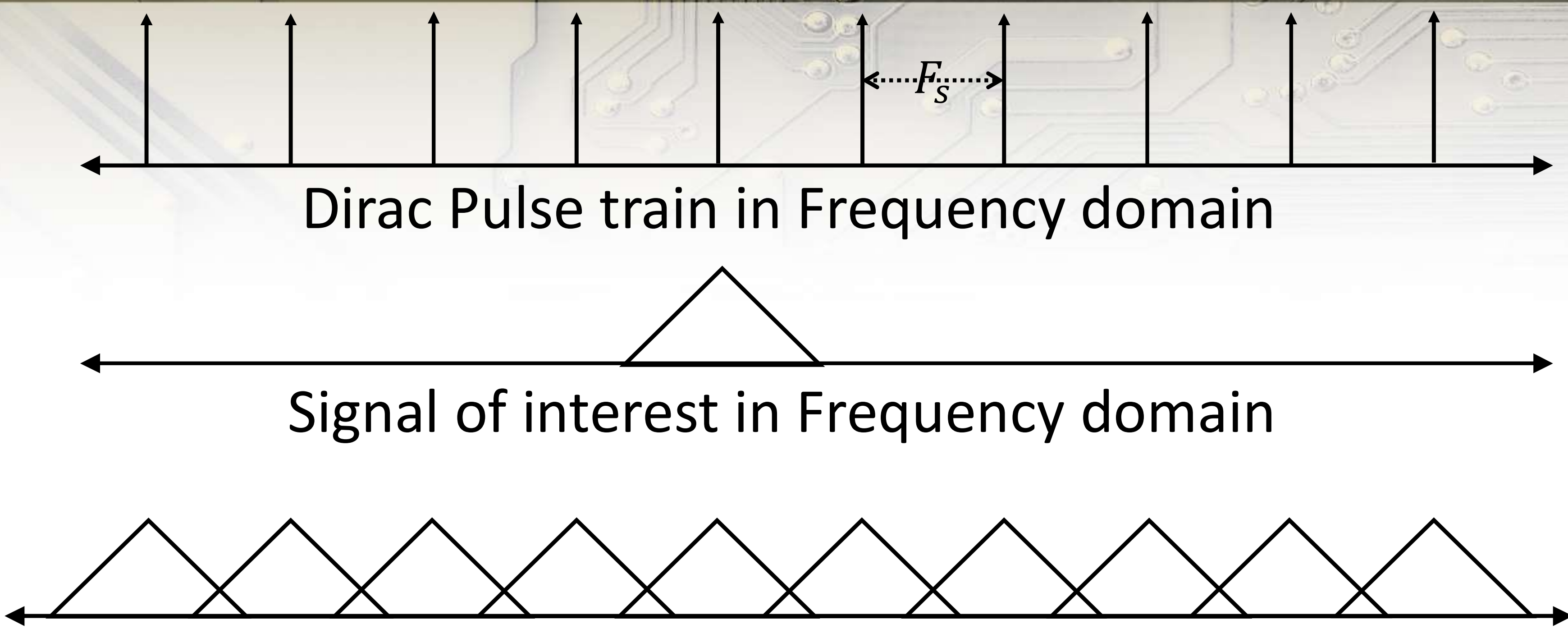


Signal of interest s(t) in Frequency domain



Convolution in Frequency domain

Digital Sampling Frequency Domain with Aliasing



Dirac Pulse train in Frequency domain

Signal of interest in Frequency domain

Convolution in Frequency domain

With Aliasing

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Nyquist Theorem

- For REAL band limited Signals
- $X(f) = 0\,, \quad |f| > B$
- The signal can be reconstructed if Fs > 2B
- $\left|X\left(\frac{F_S}{2} - f\right)\right| = \left|X\left(\frac{F_S}{2} + f\right)\right|$

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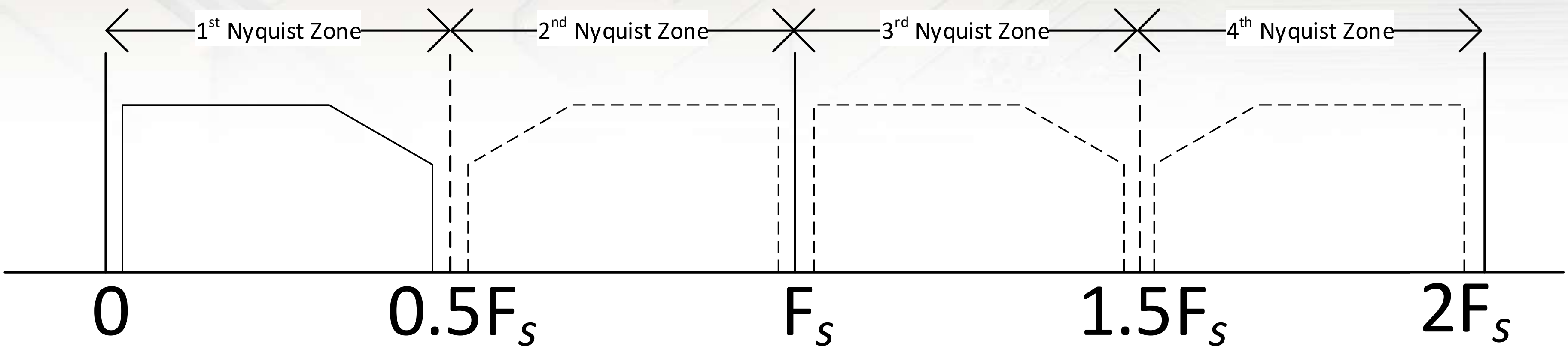
Nyquist Theorem

Nyquist zones – real signals



FFT generates data for Frequencies 0 to Sample Rate F_s

Usually only plot first half

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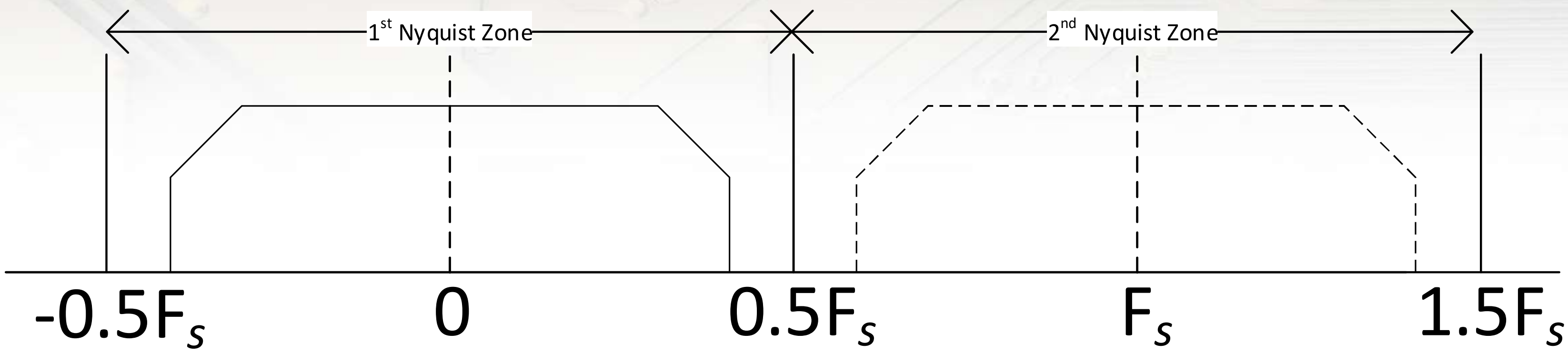
Nyquist Theorem

- For Complex band limited Signals
- Complex sampling allows for negative frequencies to be represented, The signal can be reconstructed if Fs > B
- $X(f) = 0\,, \quad \dfrac{f > \frac{B}{2}}{f < \frac{-B}{2}}$
- $X(f) \;=\; X(f \,+\, F_s)$

Nyquist Theorem

Nyquist zones – complex signals



FFT generates data for Frequencies 0 to Sample Rate F_s

Usually shift upper half to negative frequencies

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Aliasing versus Spurious

- Aliased Signals
  - Signals whose frequencies are outside the Nyquist zone
  - Usually removed with filtering.
- Spurious Signals
  - Due to non linearities in components
  - Harmonics distortions and such
  - Usually dealt with in HW, but digital processing may help

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Signal Metrics

- Spurious Free Dynamic Range (SFDR)
  - Ratio of RMS value of Signal to RMS value of largest spur.
- Total Harmonic Distortion (THD)
  - Ratio of the RMS value of the signal to the mean value of the root-sum-square of its harmonics.
    - Typically, only the first five harmonics are significant.
- Signal to Noise Ratio (SNR)
  - Ratio of the RMS signal amplitude to the RMS power of the noise without the harmonics.
- Effective Number of Bits (ENOB)
  - For a full-scale sine wave the SNR a prefect ADC will have $SNR = 6.02\ N + 1.76\ dB$
  - ENOB is defined as $\boldsymbol{ENOB} = \frac{\boldsymbol{SNR - 1.76\ dB}}{\boldsymbol{6.02\ dB}}$
  - ENOB is a function of SNR, improve SNR improve ENOB

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ENOB and Quantization Noise Reduction

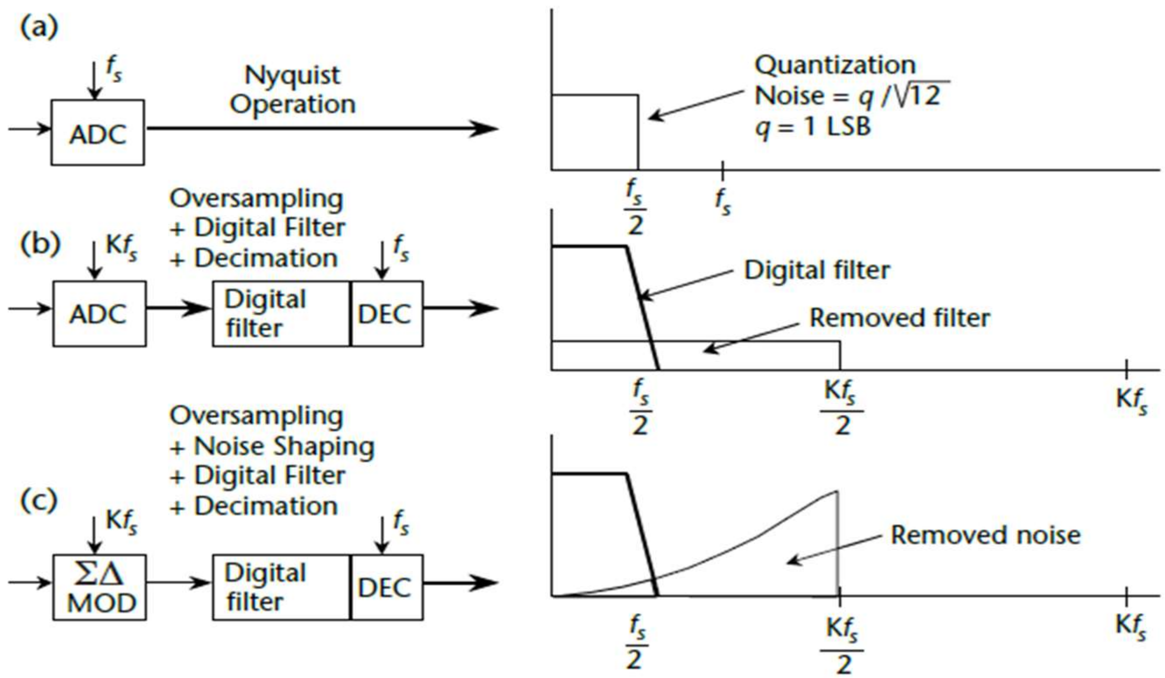

Figure 2.33 Oversampling, digital filtering, noise shaping, and decimation in a Σ-ΔADC.

From: [Software Defined Radios for Engineers]

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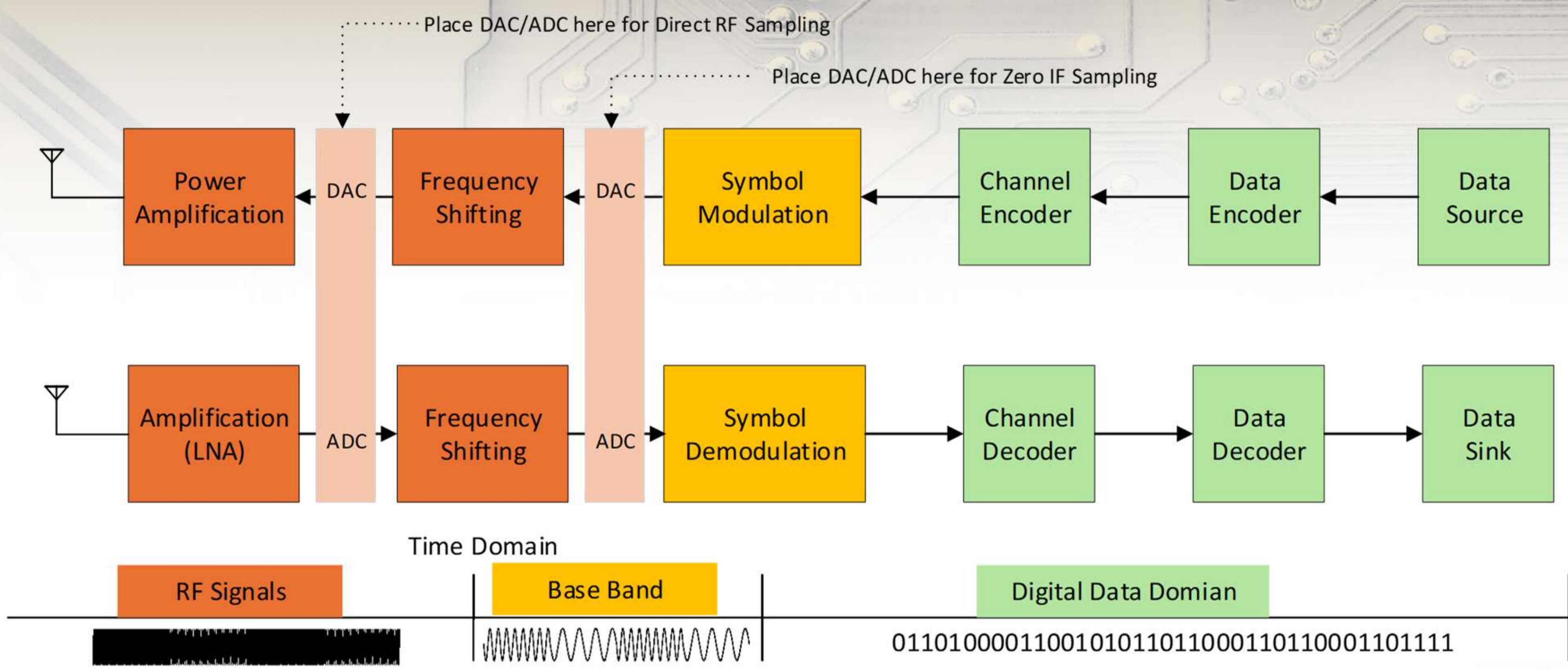
Improving ENOB

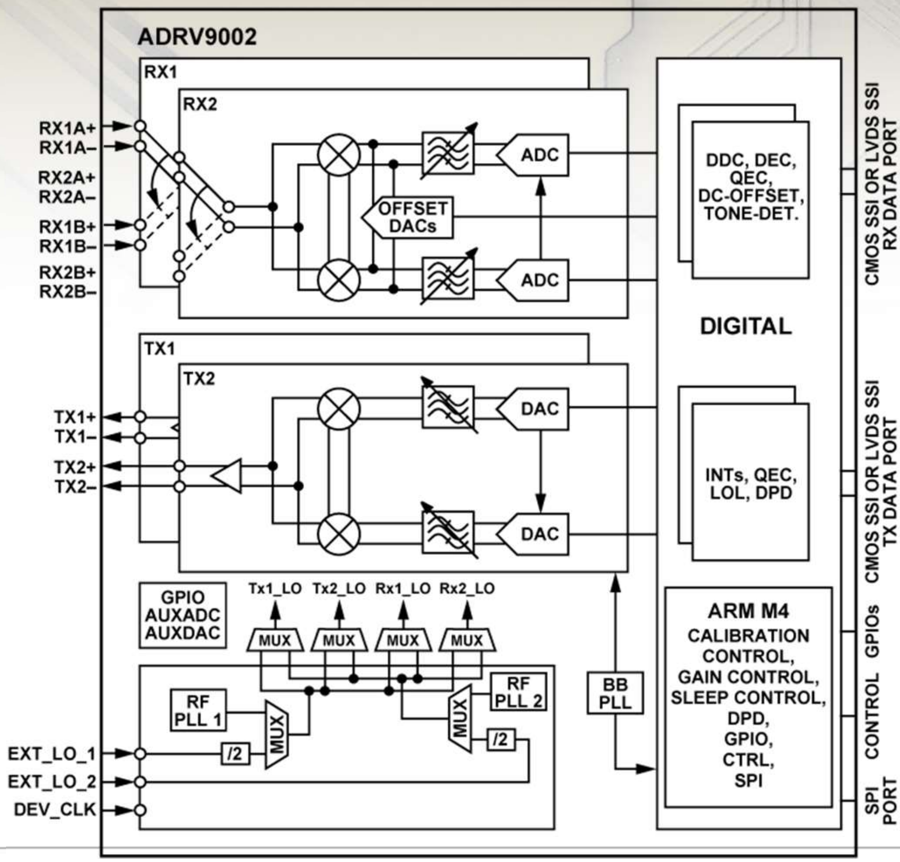
$$\boldsymbol{ENOB = \frac{SNR\ - 1.76\ dB}{6.02\ dB}}$$

- ENOB is related to the SNR
- By digitally processing the sample data to improve the SNR, the ENOB also increases
- For every 6dB increase in SNR there is a 1 Bit increase in ENOB
- ADC quantization noise can be reduced by oversampling the signal, then low pass filtering
- Using Delta Sigma Converters can shape the quantization noise
  - Noise is in the upper frequencies so more quantization noise is removed by low pass filtering

Digital Communication System



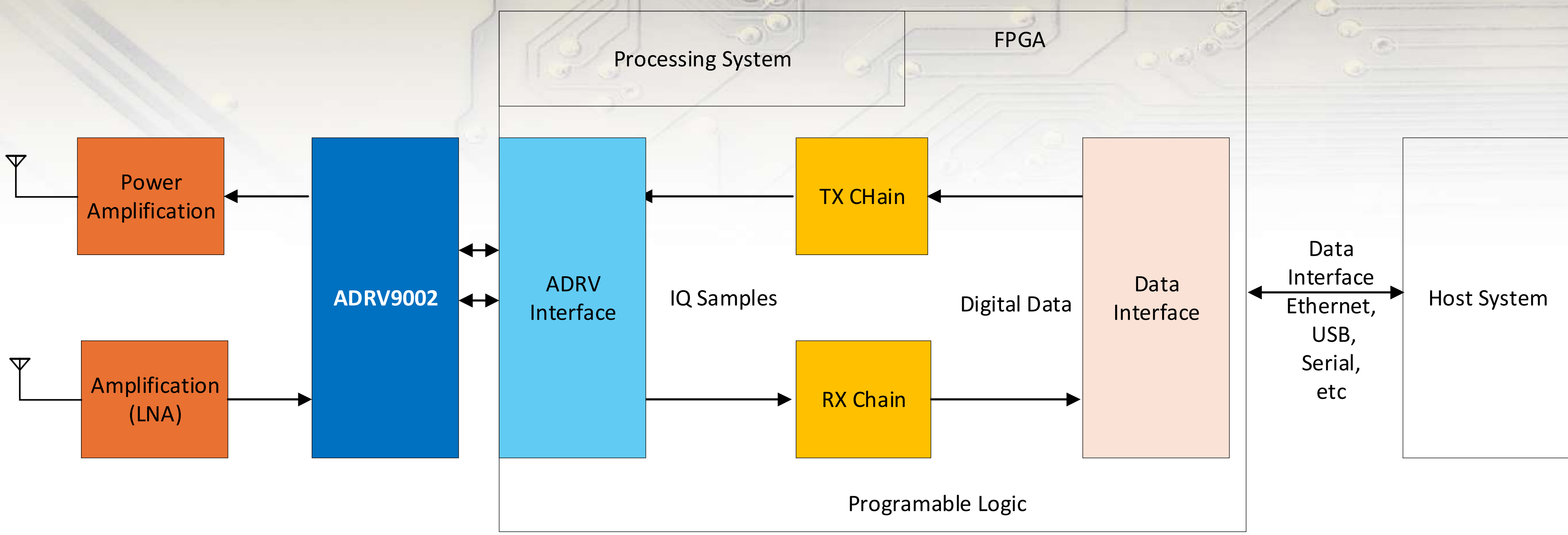
ADRV9002 From Analog Devices



ADRV9002 Features

- 2 × 2 highly integrated transceiver
- Frequency range of 30 MHz to 6000 MHz
- Transmitter and receiver bandwidth from 12 kHz to 40 MHz
- Two fully integrated, fractional-N, RF synthesizers
- Multichip synchronization capabilities
- Fast frequency hopping

Typical SDR Architecture for ADRV9002



All the Signal processing happens in the TX and RX chains

I and Q Samples

- The RF signal is split into two paths.
  - In-Phase (I) Component: Obtained by mixing the RF signal with a cosine (0° phase) reference from the Local Oscillator (LO).
  - Quadrature (Q) Component: Obtained by mixing the RF signal with a sine (90° phase-shifted) reference from the LO.
- Filtering:
  - Low-pass filters remove high-frequency mixing products, leaving the baseband signals.
- Digitization:
  - ADCs convert the filtered I and Q signals into digital form for further processing.
  - ADC on the I and Q path operate with the same sample clock.

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I/Q Samples as a Complex Signal

- The in-phase (I) and quadrature (Q) components can be combined to form a complex signal, expressed as:
  - $X[n] = I[n] + j\, Q[n]$
  - Based on Euler relation $e^{jx} = cos(x) + j\, sin(x)$

- Interpretation of the complex data:
  - Magnitude: Represents the signal's amplitude.
  - Phase: Captures the instantaneous phase information.

I/Q Samples as a Complex Signal

- Benefits:
  - Simplifies digital signal processing tasks such as modulation, demodulation, filtering, and frequency translation.
  - Provides a complete description of the signal's envelope and phase variations.

- Visualization:
  - Think of the complex signal as a vector in the complex plane, where the horizontal axis is the I component and the vertical axis is the Q component.

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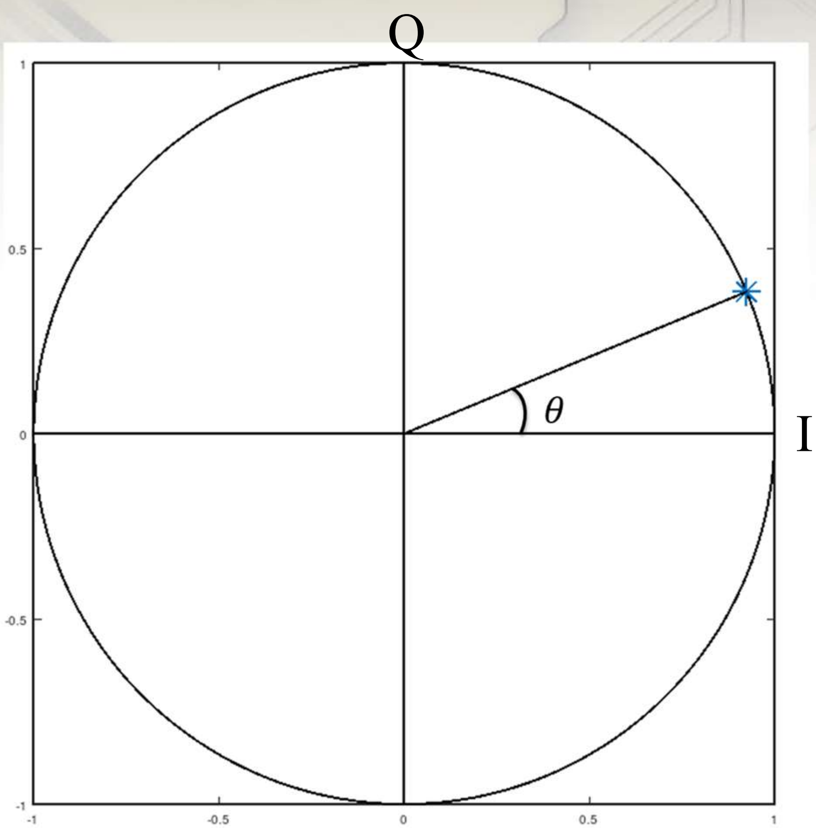
I/Q Samples as a Complex Signal



Sampled I and Q data represented as Complex data. From Euler's relationship

$$e^{j\theta} = cos(\theta) + j\, sin(\theta)$$

Sampled I and Q can be represented as complex

$$r(n) = I(n) + jQ(n)$$

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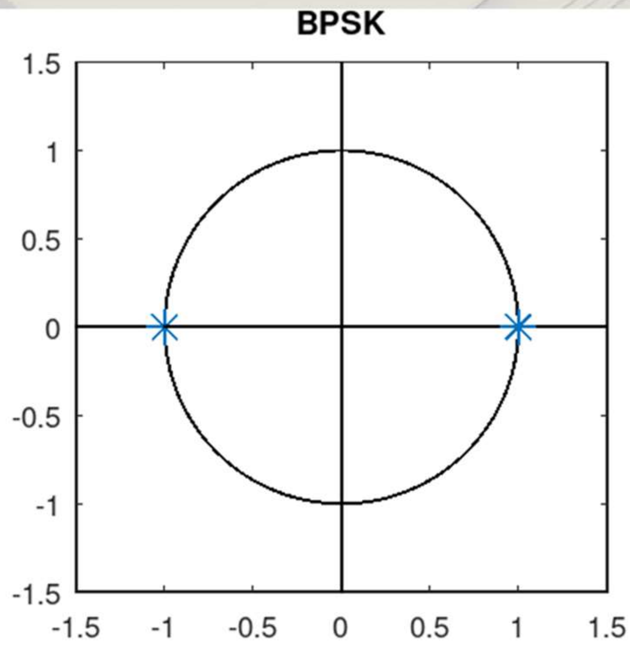
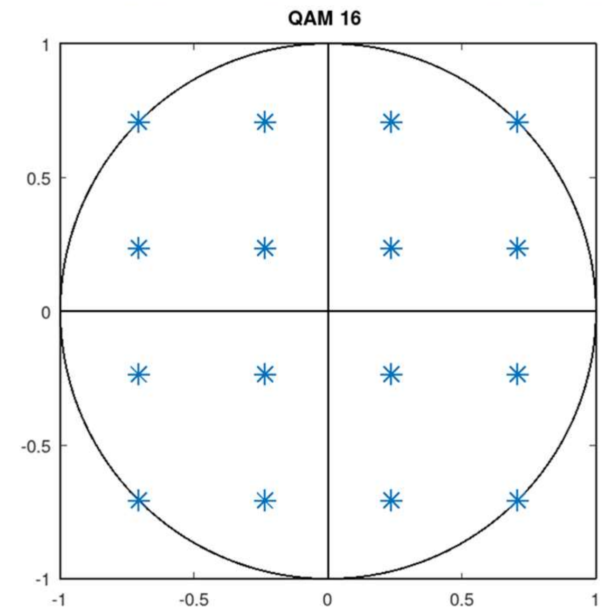
Complex Representations of Modulations





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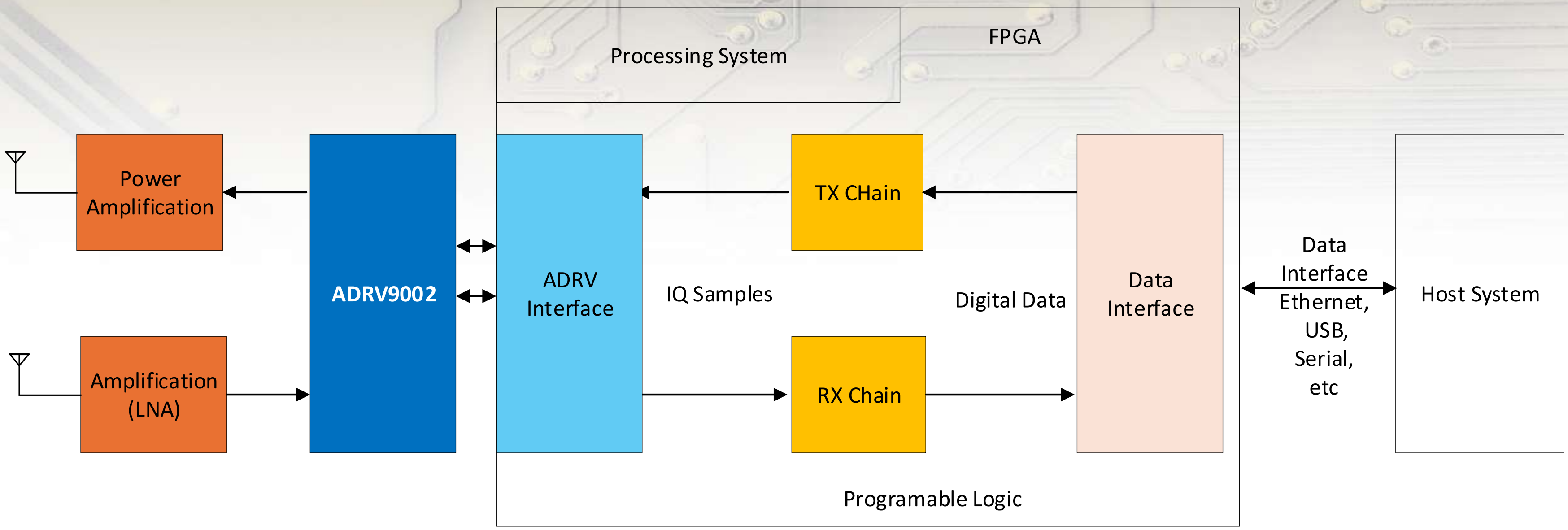
Typical SDR Architecture for ADRV9002



RX and TX processing can be done on complex data

Vanteon IP – vProtean™

IP Goal

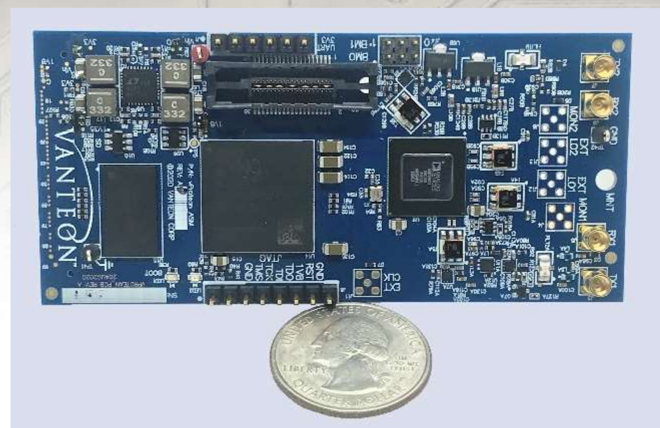
- Develop a wideband SDR for industrial and military RF/wireless applications

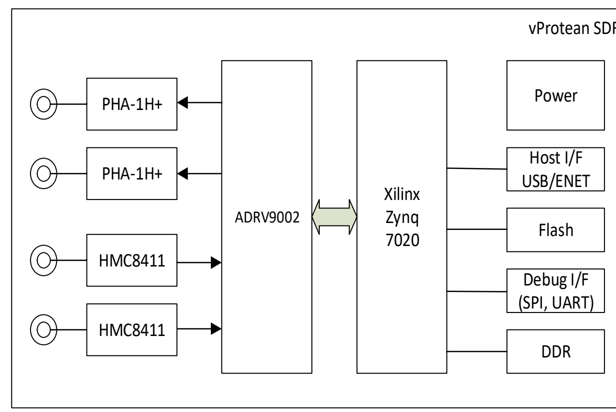
Design Applications

- Optimized balance of performance and cost for the industrial market
- Multi-channel narrowband receiver or endpoint
- WiSUN compliant 802.15.4g OFDM physical layer

Performance Specifications

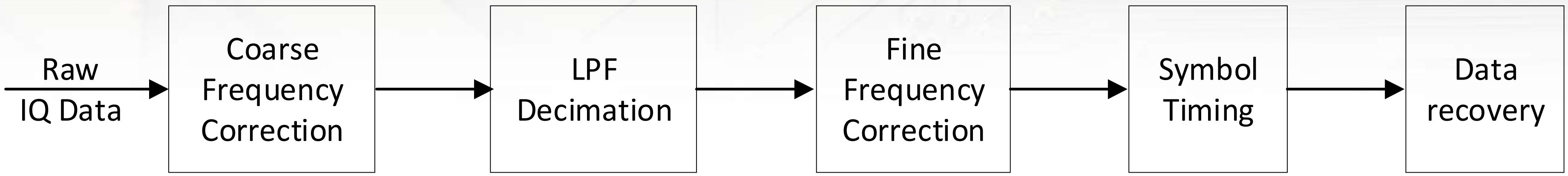
- ADI ADRV9002 and Xilinx Zynq Z-7020
- 30 – 6000 MHz RF front end
- 19 dBm transmit power
- 2 TX and 2 RX
- Low power consumption





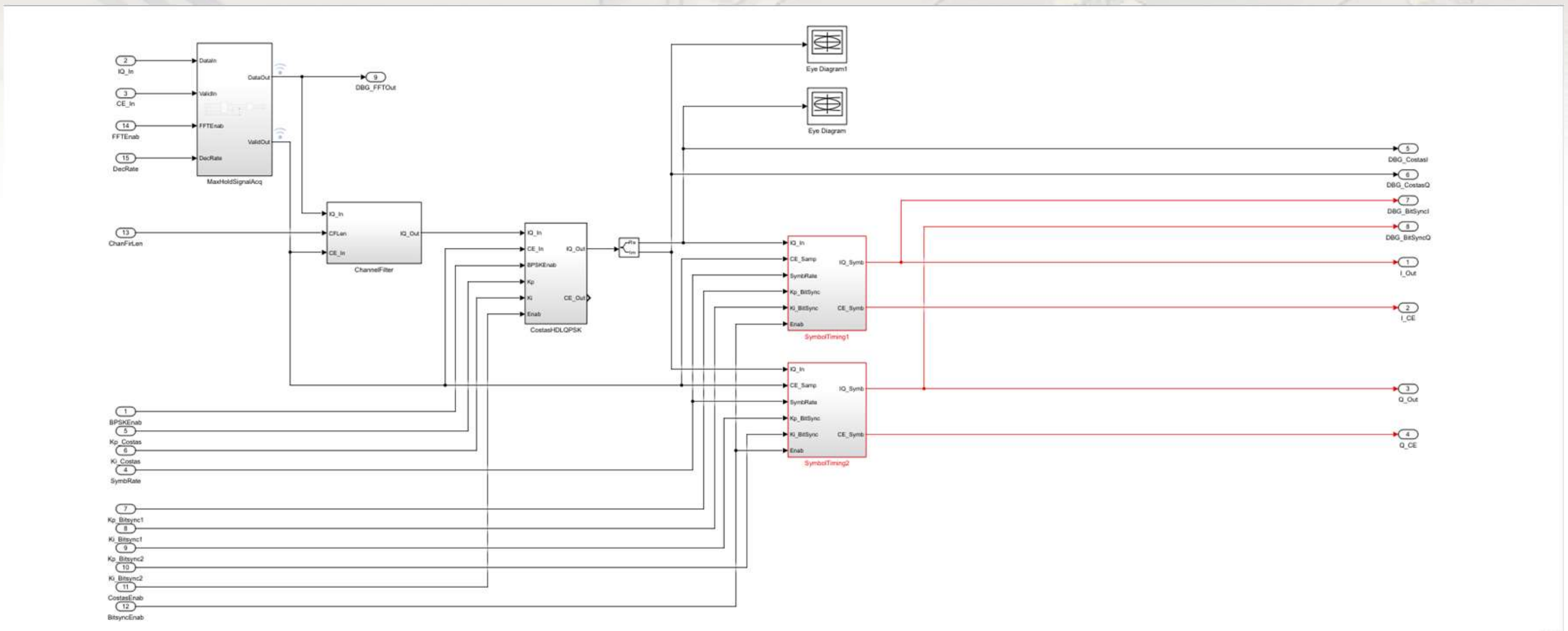
TEON SOLUTIONS

RX Chain for BPSK Demodulation



SDR Development Flow – BPSK Receive

Start with MATLAB/Simulink to generate a BPSK Receive chain



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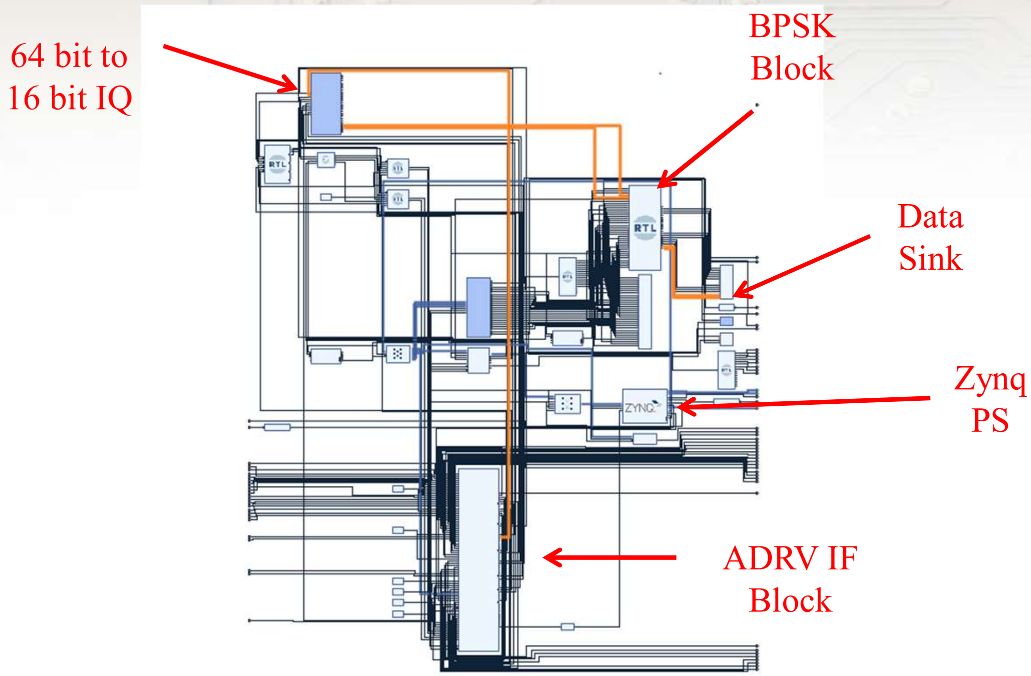
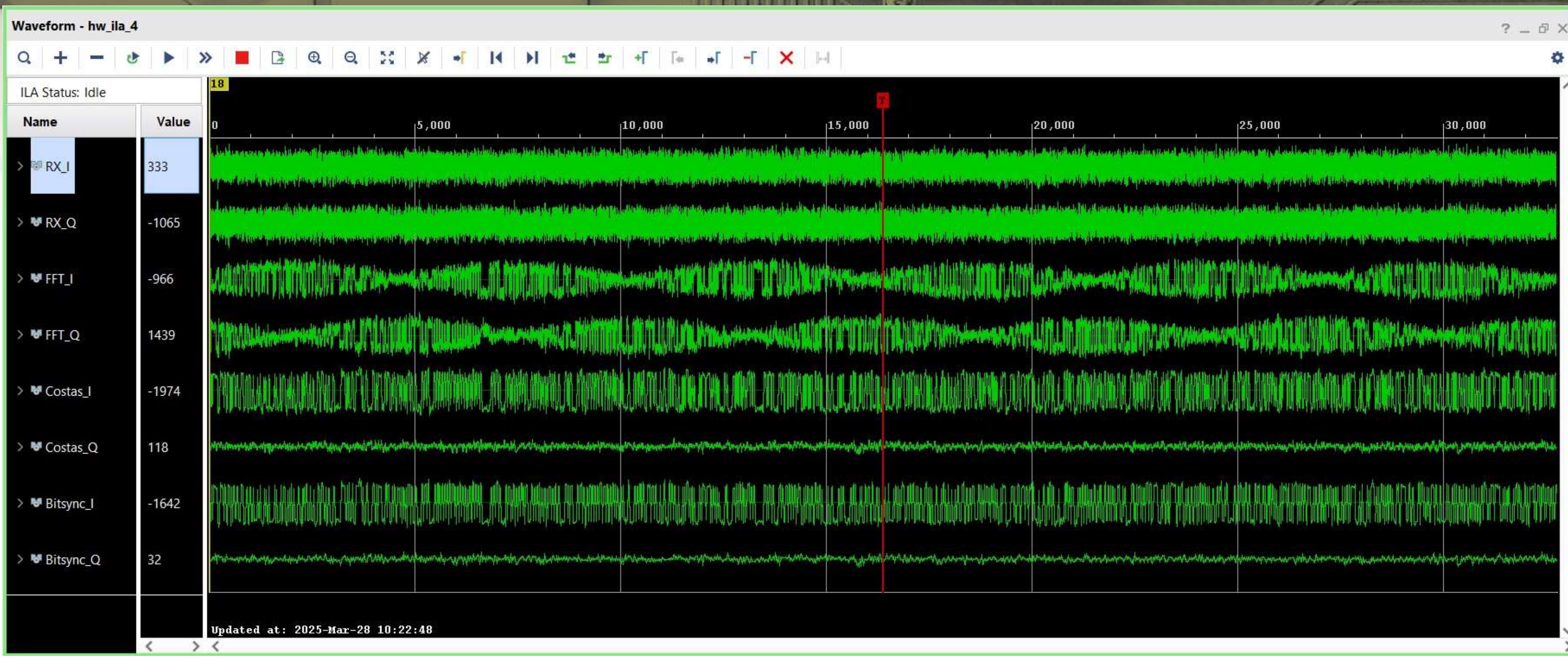
SDR Development Flow – BPSK Receive

Use VHDL code in FPGA Project



SDR Development Flow – Working with Live Data

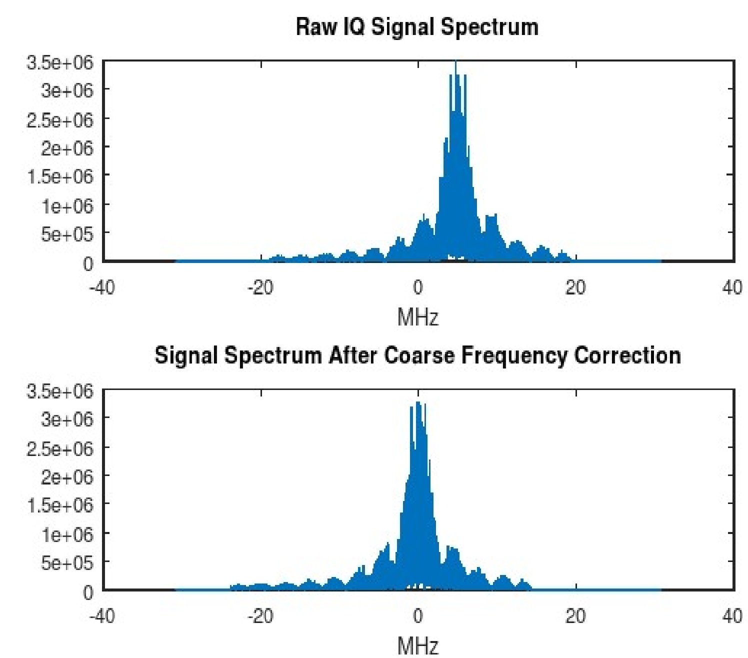


Can use ILAs in FPGA to capture, inspect, and export data

VANTEON WIRELESS SOLUTIONS

BPSK Demodulation – Coarse Frequency Correction

- Use FFT to find largest bin
- Use Bin Frequency to shift data to baseband
    - $r'(n) = e^{-j\omega_n} * r(n)$
- Followed by a LPF and Decimation
    - Reduces data computation



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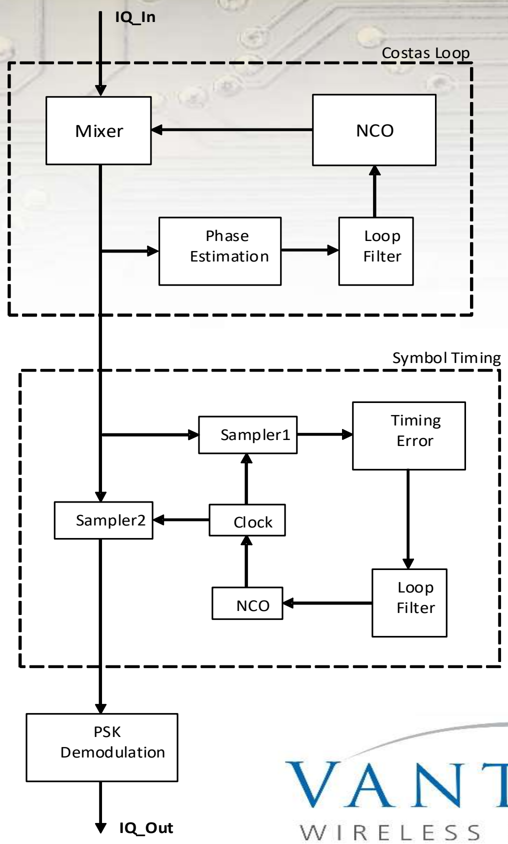
Fine Frequency Correction and Symbol Timing

- A Costas Loop is used for Fine Frequency Correction
  - A phase-locked loop (PLL) designed for carrier phase and frequency synchronization.
  - The received signal is mixed with a carrier.
  - A phase detector extracts the phase difference between the received signal and the local oscillator.
  - A loop filter and Numerical-Controlled Oscillator (NCO) adjust the frequency to track the signal
- Symbol Timing
  - Adjust the sampler to sample in the middle of a symbol
  - Sample Clock driven by an NCO
  - Sampler1 samples twice a symbol period, Middle and Zero Crossing.
  - Timing Error uses 3 samples to estimate the timing error
  - Timing Error is used to adjust NCO
  - Samper2 samples at middle of symbol period



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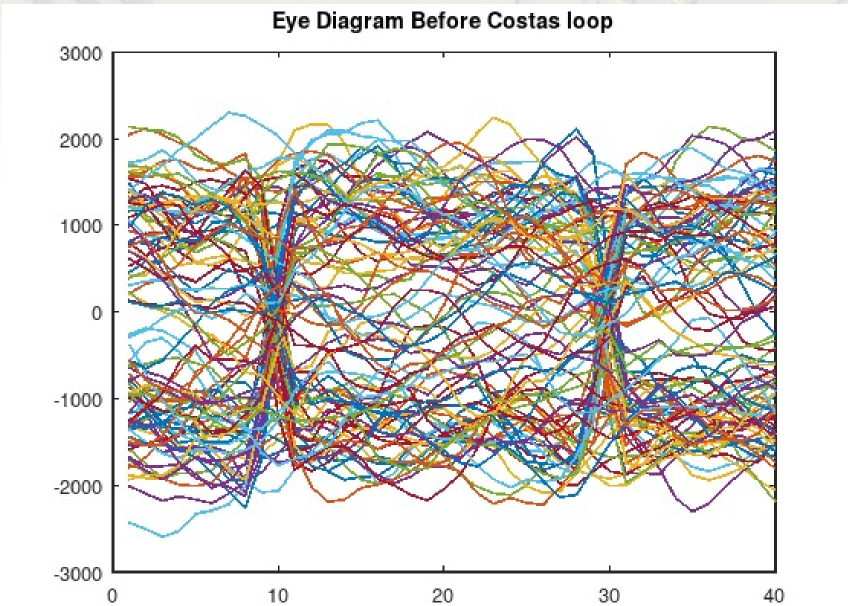
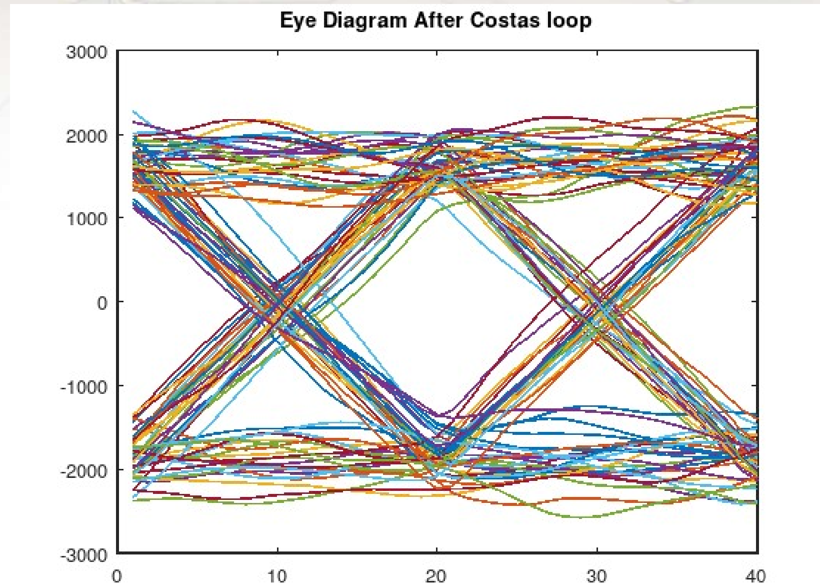
BPSK Demodulation – Eye Diagrams

- Use a Costa loop to determine and correct for frequency offset





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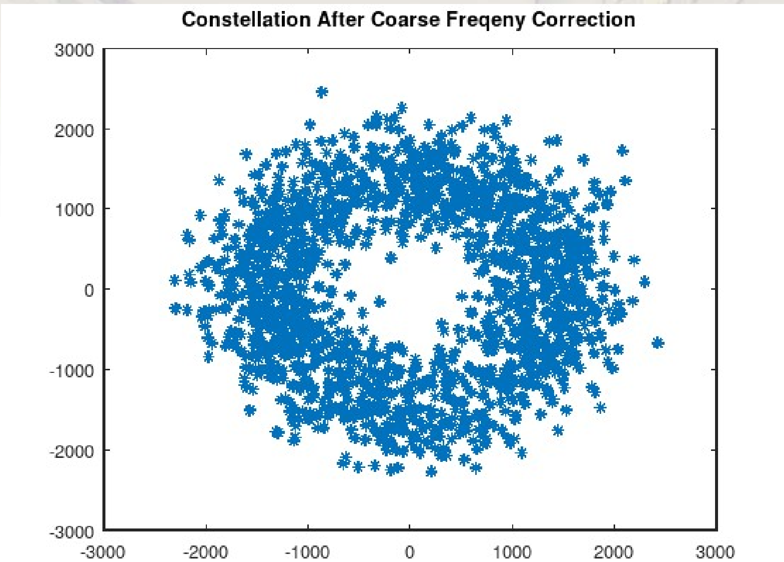
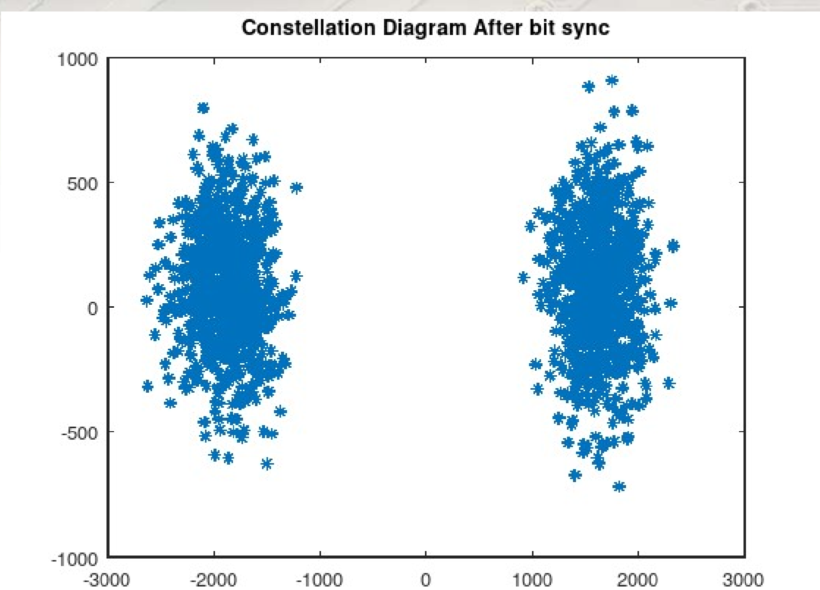
BPSK Demodulation – Symbol Timing

Recover the symbol timing and Sample





SNR is about 11 dB, the constellation spread shows the noise

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COLLABORATING WITH CLIENTS TO DEVELOP INNOVATIVE NEW TECHNOLOGY

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The Case for SDR in Industrial IoT

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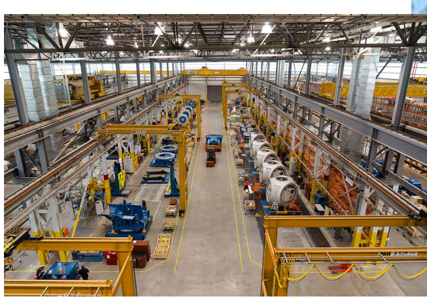
Introduction to IIoT

- IIoT is not new, just the name is new
- It has really evolved from SCADA systems (Supervisory Control and Data Acquisition) and wireless sensor networks to include cloud monitoring, control, and analytics
- Traditionally M2M communications have utilized proprietary protocols for all different applications
- Evolution of IIoT seeks to converge connections to standard protocols at the upper layers of the stack
- Industrial applications tend to have much longer life cycles than consumer IoT (decades rather than years)

Broad Market IIoT Examples

- **Electric utilities, Smart Grid**
- Manufacturing Plant Monitoring and Control
- Automatic Meter reading
- Oil and Gas Fields and Refineries
- Machine Health Monitoring
- Transportation of materials



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Challenges of IIoT

- **IIoT devices have decades of history in SCADA and proprietary wireless sensor networks**
- **Industries have made enormous investments in communication systems and are unlikely to just throw away that investment**
- **IIoT tend be long range wireless applications (mile+)**
- **Need to lower the cost and power over traditional SCADA**

Wireless M2M for industrial

Industrial wireless applications tend to use the 900 MHz ISM band

- **ISM = Industrial, Scientific, and Medical**
- **900 MHz has lower path loss and better penetration (it's just physics)**
- **IIoT typically has lower data requirements and needs less bandwidth (2.4 GHz ISM has 3X bandwidth over 900 MHz)**
- **900 MHz is less crowded than 2.4 GHz band (WiFi, Bluetooth)**
- **FCC rules for the 900 MHz band allow for strict control to avoid direct interference between products (FCC part 15.247)**

FCC Rules for 900 MHz ISM use

- **The maximum peak conducted output power is 1 watt for systems employing at least 50 hopping channels; 0.25 W for 25 to 49 channels.**
- **If the 20 dB bandwidth < 250 kHz, use at least 50 hopping frequencies, ≥ 250 kHz, use at least 25 .**
- **Hop on a pseudo-randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter.**
- **Channel separation minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater.**

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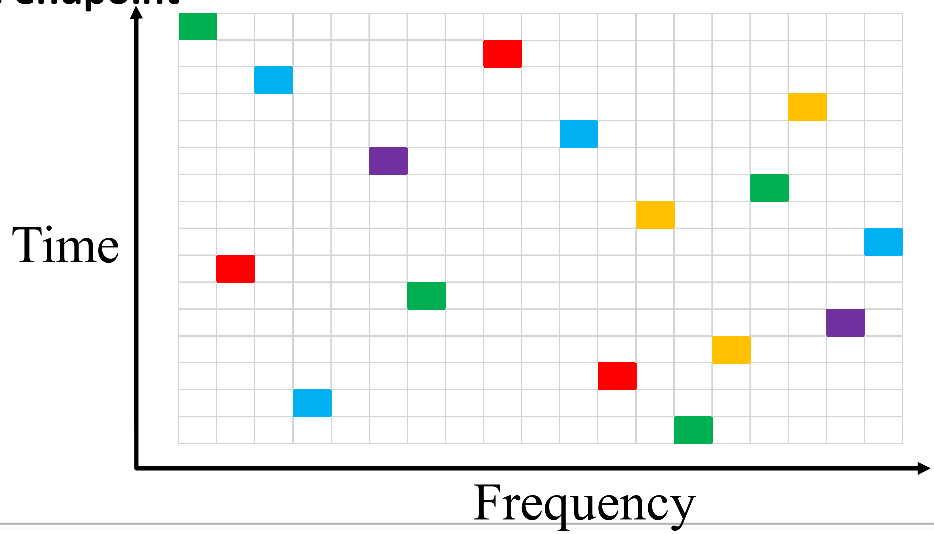
Traditional Solutions

- Most traditional (e.g. SCADA-like) solutions utilize a mostly symmetric radio solution where the network coordinator employs a physical layer that is very similar to the endpoint radio
- The network coordinator radio talks to it's children one at time, across different channels, never needing more physical layer horsepower than that of a single endpoint



Each Color represents a different endpoint node (sensor)

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Traditional Solutions

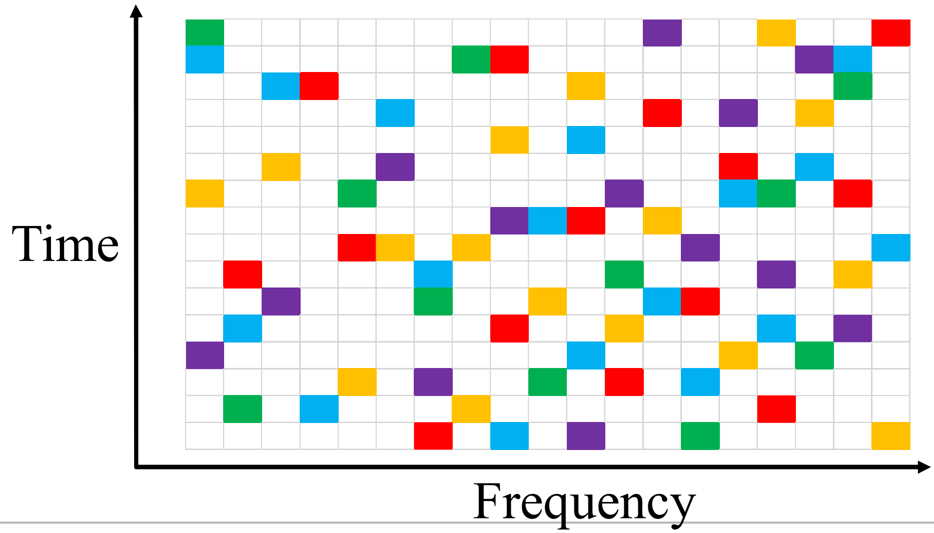
- **Allows a simple, low cost, physical layer to be implemented in the network coordinator**
- **Requires synchronization across the network so that the coordinator and endpoint of interest are on the same channel at the same time to transfer information**

SDR in IIoT

- **A primary advantage for SDR in IIoT is the flexibility of supporting decades of deployed hardware, while also having the capability to support current and future M2M physical layers**
- **New physical layer “waveforms” (i.e. modulation, symbol rates, channel coding, etc.) can be added as imagined as long as the SDR hardware supports the worst case physical constraints**
- **SDR not only allows “future proofing” through software upgrades, but can also support simultaneous processing of old and new waveforms in the same radio**

SDR in IIoT

SDR also allows increased capacity and availability through wide band processing and digital channelization.



Each Color represents a different endpoint node (sensor)

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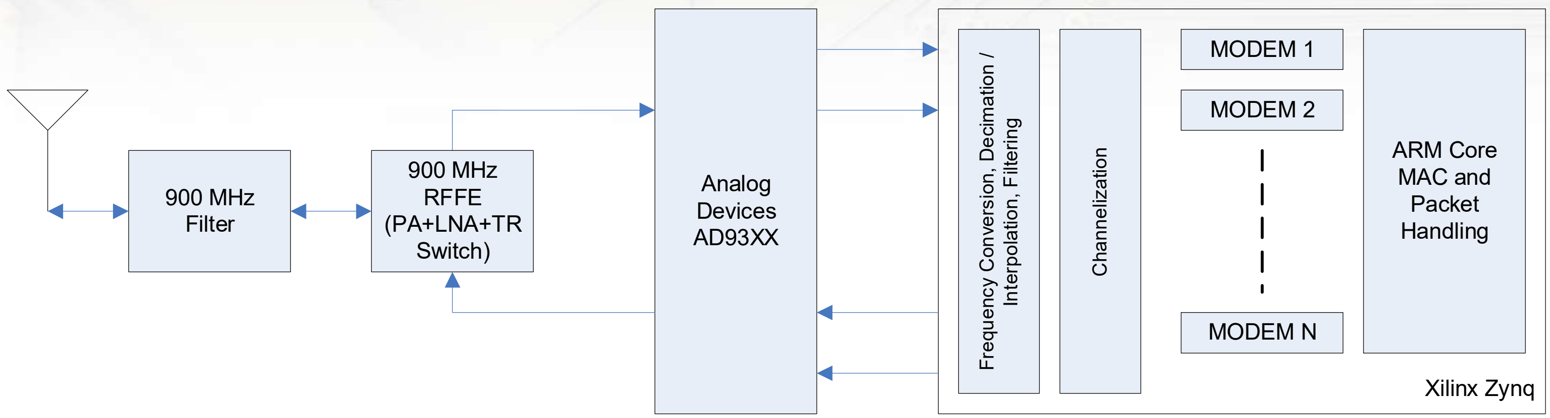
SDR in IIoT

SDR Collector Block Diagram (Tuned to 900 MHz band)



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SDR to increase endpoint battery life

- **Many IIoT applications have low sensor update rates, but require years of battery life on small batteries**
- **This is best achieved by maintaining a low duty cycle (i.e. being essentially off most of the time)**
- **A traditional network needs to maintain synchronization, so either wake up often enough to maintain frequency hopping synchronization through clock drift, or resync every time it wakes up**

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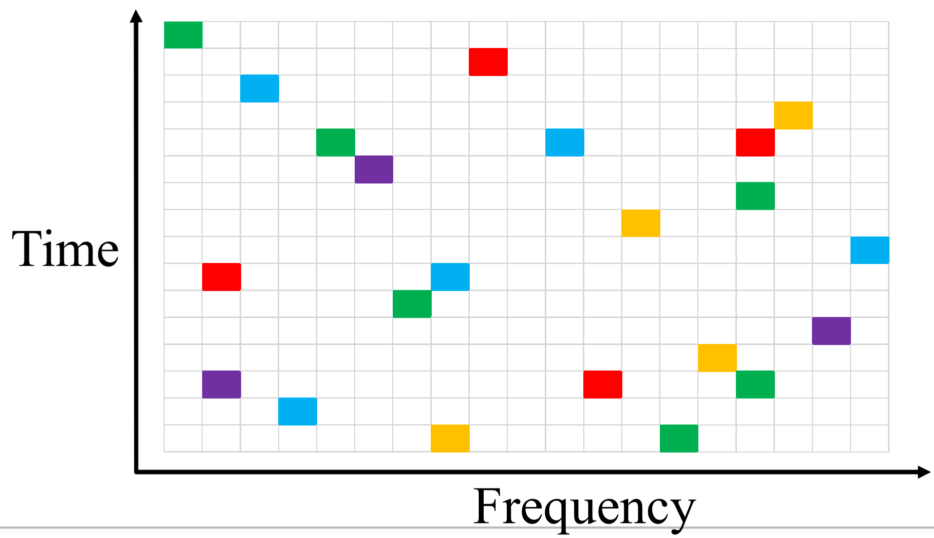
SDR to increase endpoint battery life

Since SDR can process all channels all the time, the endpoint can be allowed to wake up, transmit on a random channel, then go back to sleep for a very long period of time without wasting energy synchronizing.



Each Color represents a different endpoint node (sensor)

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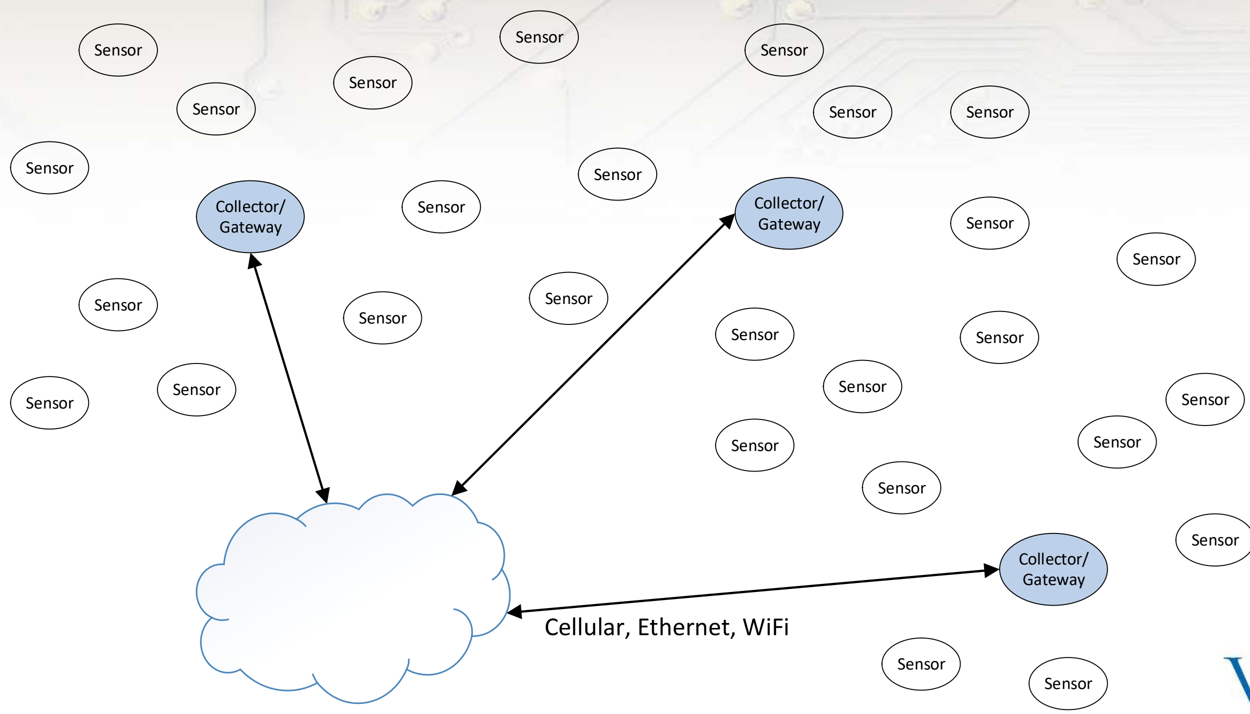
Vanteon IIoT Solutions

SDR collectors



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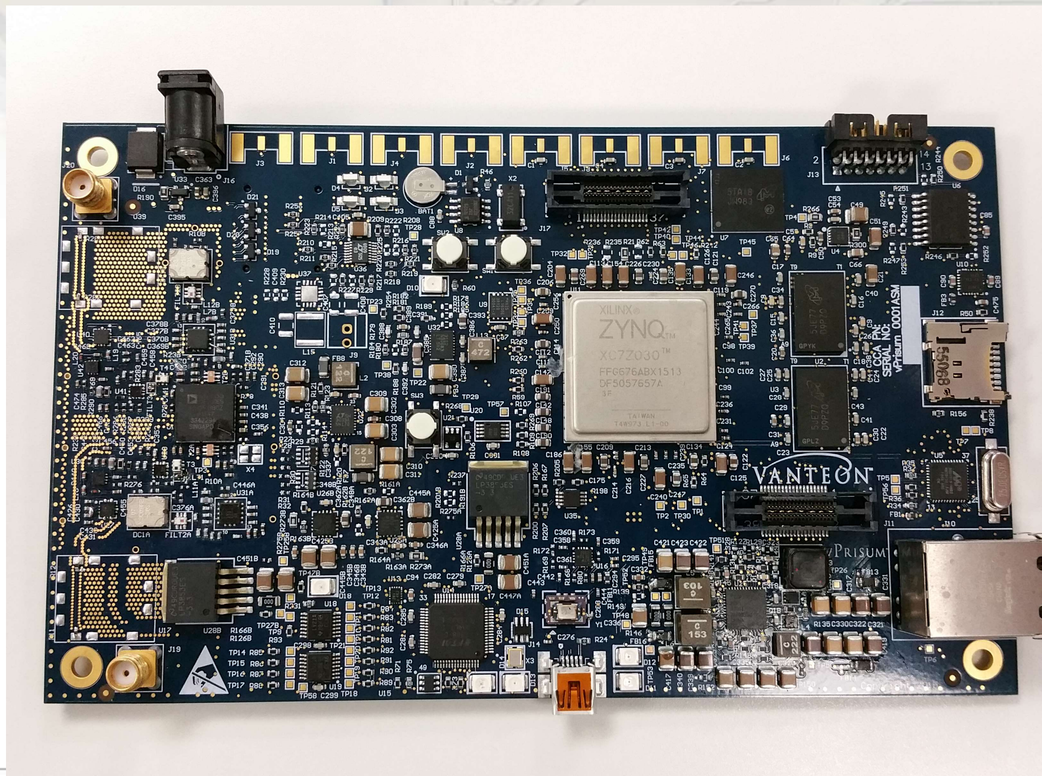
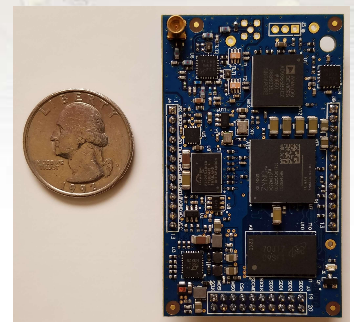
Vanteon IIoT Solutions

SDR collectors



vPrisum



vChameleon

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Future of Software Defines Radios with AI

Dynamic Spectrum Access

- AI can analyze the spectrum in real time enabling Cognitive Radio to adapt to avoid interference and maximize efficiency

Interference Migration

- Learn, detect, classify, and mitigate types of environment and deliberate interference
- Adjust SDR parameters to minimize noise.

AI based Signal Processing

- Automatically detect and classify modulation in real time
- Enhanced Demodulation and Decoding
  - Learn pattern and noise characteristics to making them more robust in noisy environments
  - Optimize error correction algorithms based on noise in environment

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Future of Software Defines Radios with AI

Adaptive Beam Forming

- Smart antenna dynamically control to focus transmission in optimal direction

Multiple Input Multiple Output (MIMO) systems

- Optimize for better spatial multiplexing and interference
- Enables higher data rates and improved reliability

Security and Resilience

- Intrusion detection such as spectrum attacks, spoofing, jamming
- Use AI driven frequency hopping to avoid jamming

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SW to use

If you search for SDR SW you will see lots of hits

- Most seem to be specific functionality, i.e. the SW uses a SDR to collect data, but the processing of the data is fixed.
- The same SDR HW can be used for many different types of radios.

Others like GNU Radio allow you to customize the signal Processing

- Can be used stand alone or with a SDR platform to collect the RF data.
- Signal processing done on host PC

Algorithm Development for HW deployment

- Need a platform such as MATLAB/Simulink where Algorithms can be modeled/simulated
- Need to be able to generate VHDL to program the logic
- Need a platform that can handle the signal processing and data flow

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What SDR Platforms are Available? Ask ChatGP

🧪 Entry-Level / Hobbyist SDRs

Device	Frequency Range	Bandwidth	Notes
RTL-SDR (RTL2832U)	~500 kHz – 1.75 GHz	~2.4 MHz	Super affordable, receive-only, USB dongle; ideal for learning and scanning
HackRF One	1 MHz – 6 GHz	20 MHz	Half-duplex; transmit & receive; open-source and widely supported
PlutoSDR (ADI ADALM-PLUTO)	325 MHz – 3.8 GHz (moddable to ~70 MHz – 6 GHz)	20 MHz	Full-duplex; great for learning and prototyping; very popular in academia
AirSpy Mini / R2	24 MHz – 1.8 GHz	6–10 MHz	Receive-only; better dynamic range than RTL-SDR
SDRplay RSP1A	1 kHz – 2 GHz	10 MHz	Receive-only; wide frequency coverage and better performance

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What SDR Platforms are Available? Ask ChatGP

⚙ Mid-Range / Advanced SDRs

Device	Frequency Range	Bandwidth	Notes
USRP B200/B210 (Ettus/National Instruments)	70 MHz – 6 GHz	56 MHz (B200), 61.44 MHz (B210)	USB 3.0; full-duplex; supported by GNU Radio
LimeSDR / LimeSDR Mini	10 MHz – 3.8 GHz	30.72 MHz	USB 3.0; open-source; full-duplex; strong community
BladeRF 2.0 Micro	47 MHz – 6 GHz	61.44 MHz	Full-duplex; FPGA support; good for development and testing
Vanteon SDR platforms	Varies	Varies	Customizable SDR platforms for industrial and defense applications

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What SDR Platforms are Available? Ask ChatGP

🛰 High-End / Professional SDRs

Device	Frequency Range	Bandwidth	Notes
USRP X310/X410 (Ettus)	DC – 6 GHz	Up to 400 MHz	Modular daughterboards, PCIe or 10G Ethernet, large FPGA
Per Vices Cyan	100 kHz – 18 GHz	Up to 1 GHz+	Very high-end; used in radar, defense, and satcom
FlexRadio (Amateur / Commercial)	HF / VHF	100+ kHz	SDR-based ham radios with high-end DSP and GUI support

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Resources

SDR for Engineers: https://www.analog.com/en/resources/technical-books/software-defined-radio-for-engineers.html

ADRV9001: https://www.analog.com/en/products/ADRV9002.html

Fourier Series: https://www.falstad.com/fourier/

Convolution: https://www.youtube.com/watch?v=C1N55M1VD2o

Sigma Delta ADC: https://www.analog.com/en/resources/technical-articles/sigmadelta-adcs-tutorial.html

Free Ebooks: https://www.dsprelated.com/freebooks.php

A good resource: https://www.dspguide.com/

VANTEON WIRELESS SOLUTIONS

Understanding OFDM and Higher-Order Modulations

What is Modulation?

- Process of encoding information onto a carrier wave.
- Increases transmission efficiency and reliability.

Types of Modulation:

- Analog: AM, FM
- Digital: PSK, QAM, OFDM

Why Use Higher-Order Modulations?

- Increased data rates
- Better spectrum efficiency

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Introduction to OFDM

Orthogonal Frequency Division Multiplexing (OFDM)
- A multi-carrier modulation technique.

Key Concept:
- Divides bandwidth into multiple subcarriers.
- Subcarriers are orthogonal to prevent interference.

Benefits:
- High spectral efficiency
- Resilient to multipath fading
- Used in 4G, 5G, Wi-Fi, DVB-T, and more

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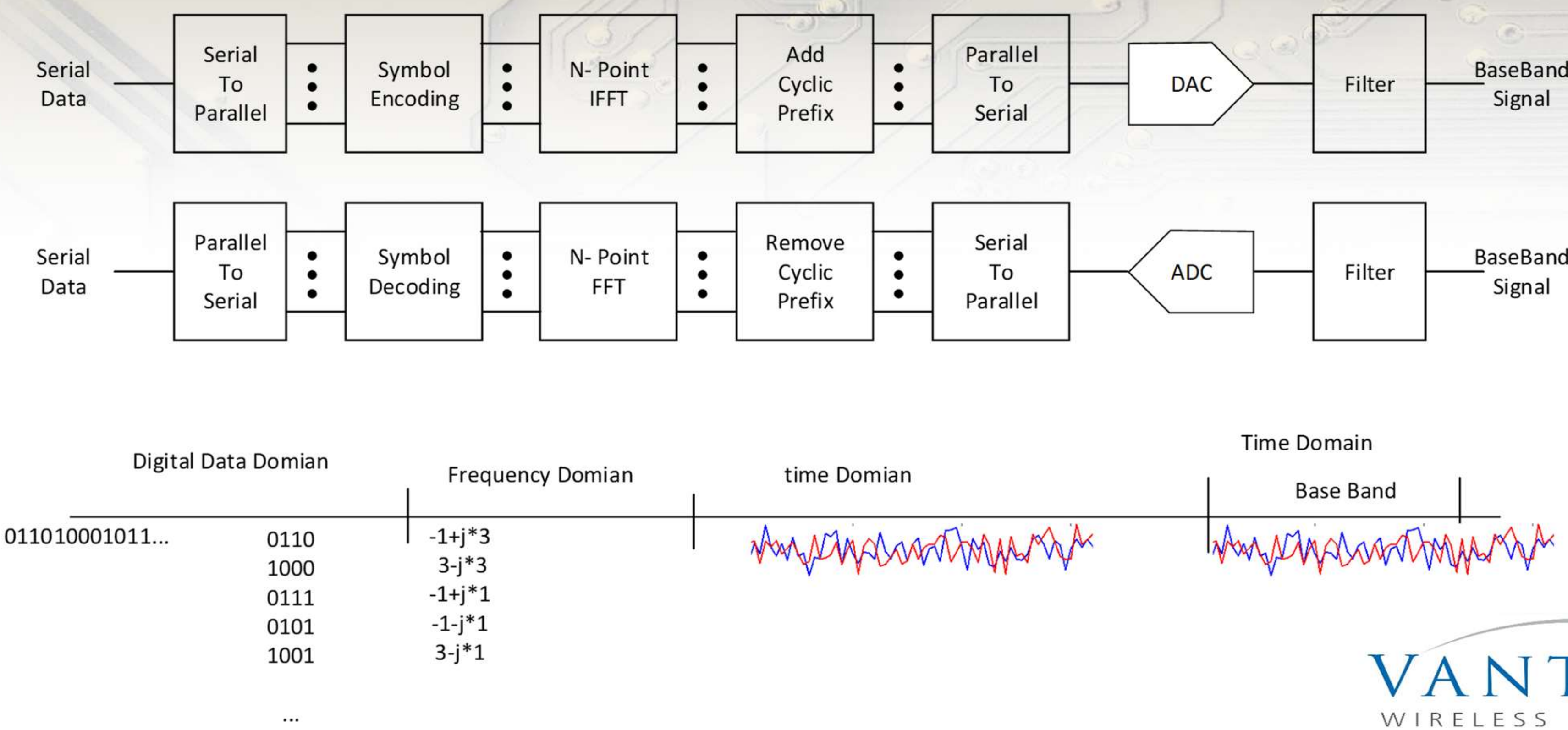
OFDM



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OFDM

- 1. Serial-to-Parallel Conversion: The input data stream is divided into multiple lower-rate parallel data streams to be transmitted on different subcarriers.
- 2. IFFT (Inverse Fast Fourier Transform): Converts frequency-domain data into time-domain signals, enabling orthogonality among subcarriers.
- 3. Cyclic Prefix Insertion: A guard interval is added by copying the end of the OFDM symbol to its beginning to combat inter-symbol interference (ISI) caused by multipath propagation.
- 4. Parallel-to-Serial Conversion: The parallel data streams are recombined into a single time-domain signal for transmission.

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OFDM

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OFDM

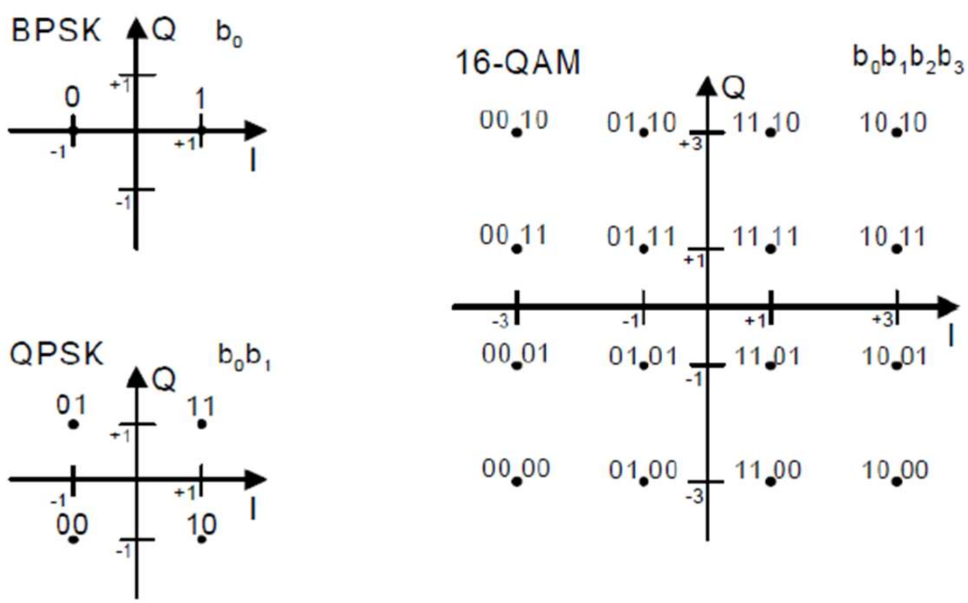

Figure 21-7—Bit-to-symbol mapping for SUN OFDM

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OFDM

Step 1 Serial to Parallel

0000	1001	0001	1001
1111	0110	0010	1111
0010	1001	1111	0011
0011	1110	1011	1010
1001	1110	1000	1111
1101	0001	1101	0001
0111	0100	1100	0000
1000	1110	1101	1111
1001	1010	1001	1101
1000	0000	0111	1100
0100	0101	0011	0000
0110	0001	1001	0011
1001	1011	1110	1001
0001	0000	0001	1011
1001	1101	1000	1011
0101	0111	1100	1011

Step 1 Digital Data to Frequency

-0.9487 - 0.9487i	0.9487 - 0.3162i	-0.9487 - 0.3162i	0.9487 - 0.3162i
0.3162 + 0.3162i	-0.3162 + 0.9487i	-0.9487 + 0.9487i	0.3162 + 0.3162i
-0.9487 + 0.9487i	0.9487 - 0.3162i	0.3162 + 0.3162i	-0.9487 + 0.3162i
-0.9487 + 0.3162i	0.3162 + 0.9487i	0.9487 + 0.3162i	0.9487 + 0.9487i
0.9487 - 0.3162i	0.3162 + 0.9487i	0.9487 - 0.9487i	0.3162 + 0.3162i
0.3162 - 0.3162i	-0.9487 - 0.3162i	0.3162 - 0.3162i	-0.9487 - 0.3162i
-0.3162 + 0.3162i	-0.3162 - 0.9487i	0.3162 - 0.9487i	-0.9487 - 0.9487i
0.9487 - 0.9487i	0.3162 + 0.9487i	0.3162 - 0.3162i	0.3162 + 0.3162i
0.9487 - 0.3162i	0.9487 + 0.9487i	0.9487 - 0.3162i	0.3162 - 0.3162i
0.9487 - 0.9487i	-0.9487 - 0.9487i	-0.3162 + 0.3162i	0.3162 - 0.9487i
-0.3162 - 0.9487i	-0.3162 - 0.3162i	-0.9487 + 0.3162i	-0.9487 - 0.9487i
-0.3162 + 0.9487i	-0.9487 - 0.3162i	0.9487 - 0.3162i	-0.9487 + 0.3162i
0.9487 - 0.3162i	0.9487 + 0.3162i	0.3162 + 0.9487i	0.9487 - 0.3162i
-0.9487 - 0.3162i	-0.9487 - 0.9487i	-0.9487 - 0.3162i	0.9487 + 0.3162i
0.9487 - 0.3162i	0.3162 - 0.3162i	0.9487 - 0.9487i	0.9487 + 0.3162i
-0.3162 - 0.3162i	-0.3162 + 0.3162i	0.3162 - 0.9487i	0.9487 + 0.3162i

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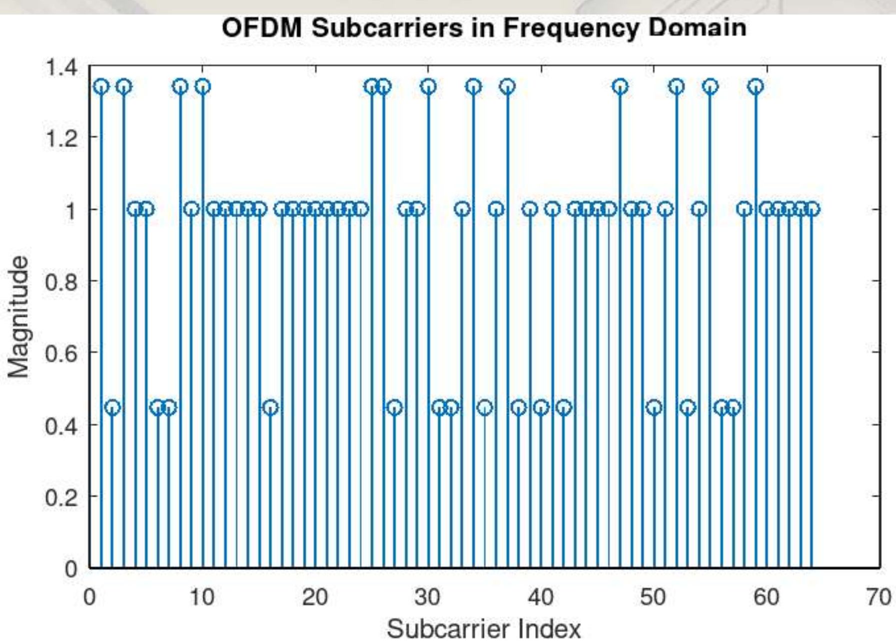
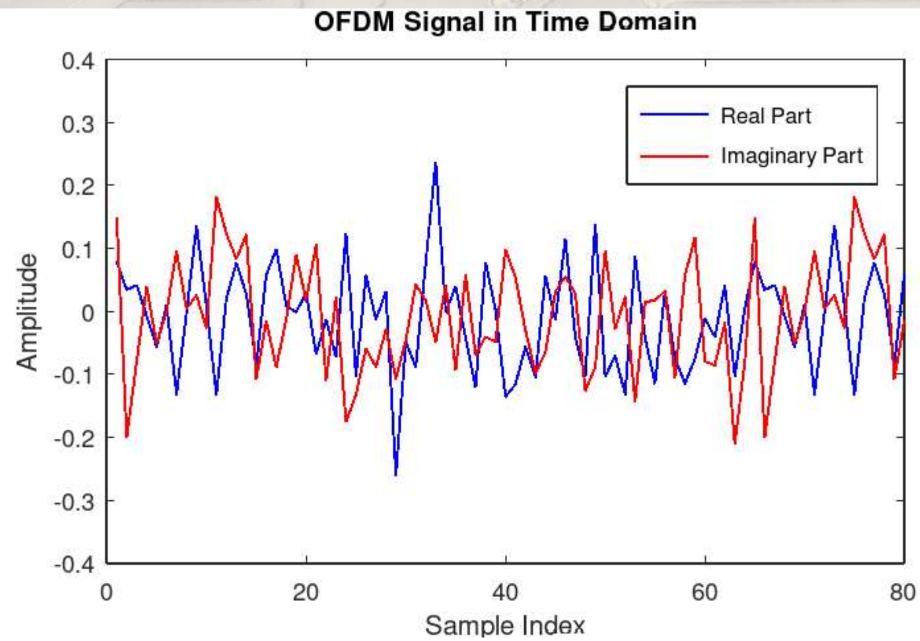
OFDM


OFDM Subcarriers in Frequency Domain
Magnitude
Subcarrier Index
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70


OFDM Signal in Time Domain
Amplitude
Sample Index
Real Part
Imaginary Part
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
20
40
60
80