ADI and MATLAB Ambassador UPV: ADALM-PLUTO Hands On

By Arturo Fernández Gámez

_ TELECOM UPV VLC

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

Objetivos de la Jornada:

1. Entender que es una Radio Definida por Software (SDR)

2. Utilidad y Aplicaciones de una SDR en la industria

3. Programación de una SDR con MATLAB & Simulink

Agenda:

- 12:25
  - Presentación e Introducción a SDR
- 12:35
  - Analog Devices Software Defined Radio Solutions
- 12:45
  - **Ejercicio 1:** Transmisión de un tono en MATLAB
- 13:05
  - Descanso
- 13:10
  - **Ejercicio 2:** TX y RX FM Broadcast
- 13:20
  - **Ejercicio 3:**
- 13:40
  - Conclusión y Cierre

Contacto

- Arturo Fernández Gámez
  - Estudiante de 4º de Ing. de Telecomunicaciones
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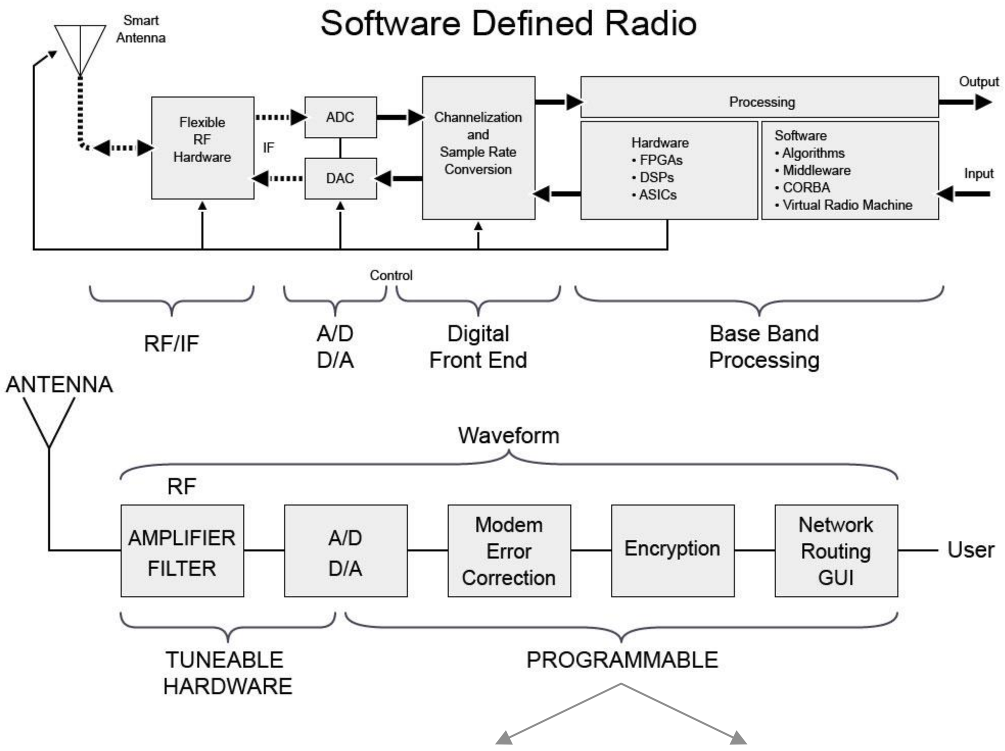
[MATLAB & Simulink - UPV]

[@matlab_upv]

¿Qué es una Software-Defined Radio (SDR)?

- Según el estándar P1900.1 del IEE [1]:
  - “Radio in which some or all of the physical layer functions are software defined”
- **¿Cuándo?**
  - En los 80s concepto y primeros pasos
- **¿Por Qué?**
  - Fines Militares
  - Programa *SpeakEasy* fase I & II
  - La USAF quería implementar diez formas de onda de radio diferentes en software en una sola plataforma.



Lógica Programable
(e.g. VHDL, Verilog)

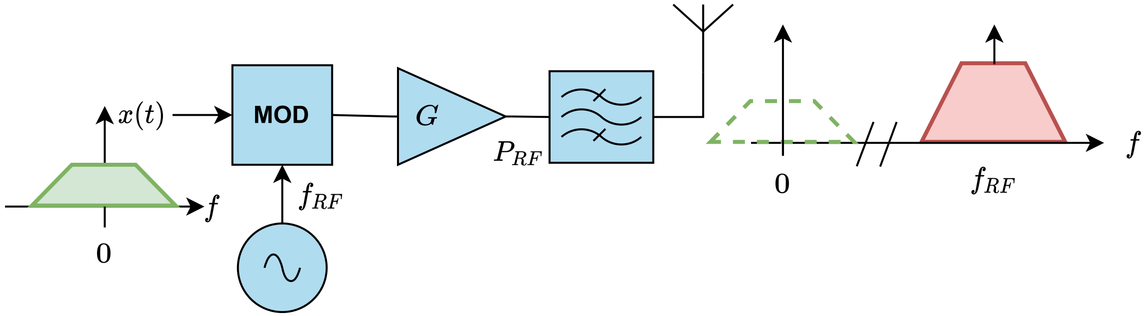
Software
(DSP, µC)

[1] "IEEE Standard for Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management," in IEEE Std 1900.1-2019 (Revision of IEEE Std 1900.1-2008) , vol., no., pp.1-78, 23 April 2019, doi: 10.1109/IEEESTD.2019.8694195.

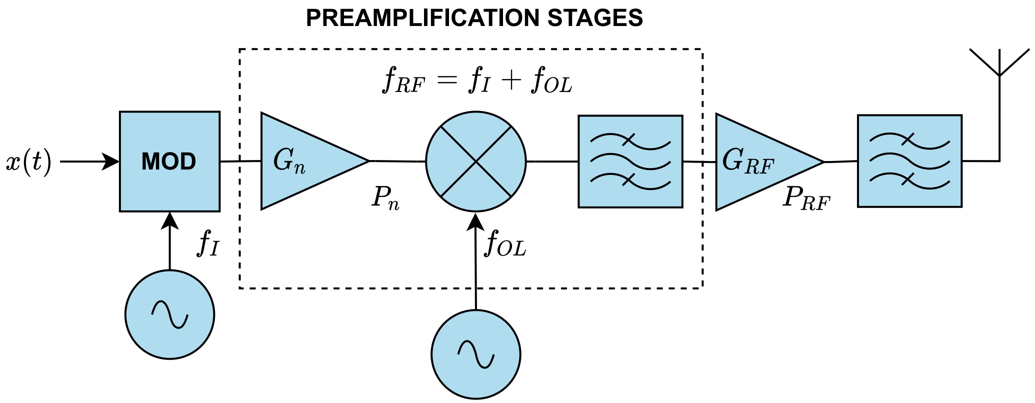
Image Source: SDR_et_WF.JPG: Topituukderivative work: McSush, Copyrighted free use, via Wikimedia Commons

¿Cómo funciona Software-Defined Radio (SDR)?

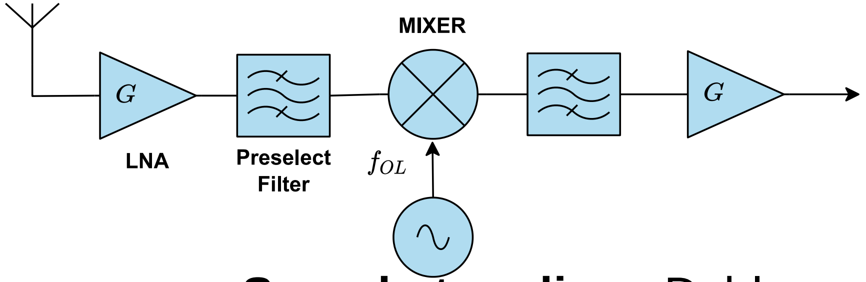
- Arquitecturas TX:
  - **Homodinos:** $f_{MOD} = f_{RF}$



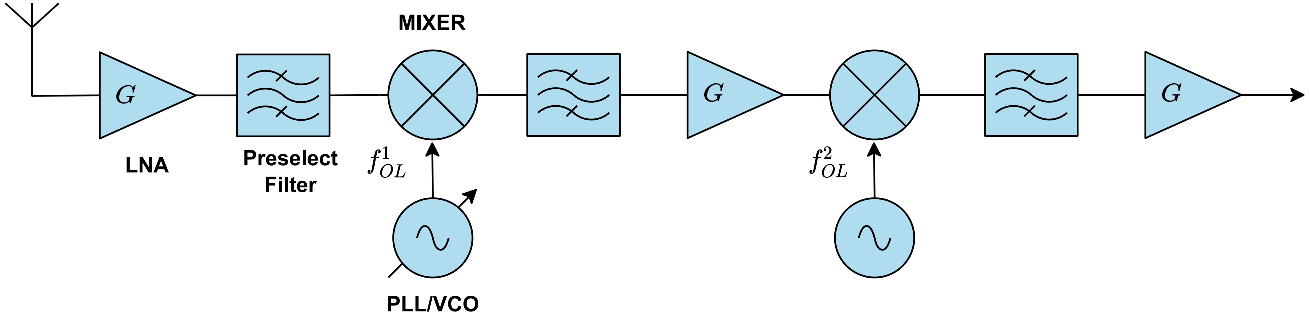
  - **Heterodinos:** $f_{MOD} \neq f_{RF}$



- Arquitecturas RX:
  - **Superheterodinas** Simples (E.H Amstrong 1918)

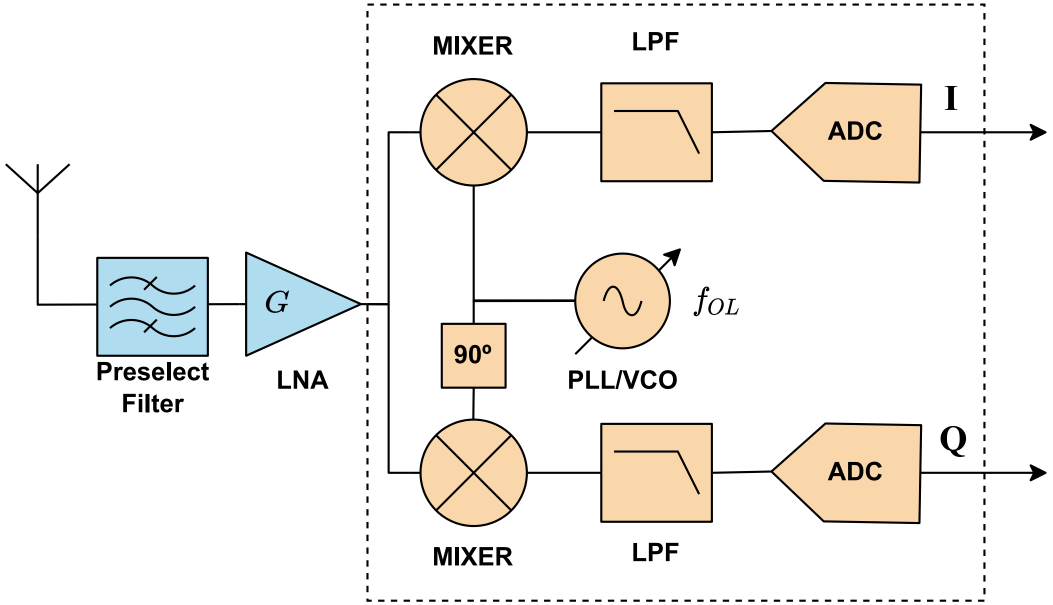


  - **Superheterodinas** Dobles



¿Cómo funciona Software-Defined Radio (SDR)?

- Arquitectura Zero IF (Intermedium Frequency)



  – Ventajas:
    - Todo el filtrado se realiza digitalmente en banda base
      - ➢ Más fáciles de diseñar y baratos.
      - ➢ Reducción de la frecuencia de muestreo de los ADC/DAC.
    - La reducción de los sistemas analógicos → Reducción del SWaP (Size Weight and Power).
  – Desventajas:
    - Difícil mantener los 90º de desfase entre las componentes I/Q → Degradación del rechazo a la imagen.
    - Imperfecciones en el aislamiento del OL durante el mezclado → *Carrier leakage*.

Analog Devices Software Defined Radio Solutions

Javier Calpe

ANALOG DEVICES
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DELIVERING INNOVATION THAT KEEPS OUR CUSTOMERS AHEAD OF WHAT'S POSSIBLE

- Aerospace and Defense
- Automotive
- Communications
- Consumer
- Energy
- Healthcare
- Industrial Automation
- Industrial Sensing
- Instrumentation
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- Power

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$9.1B*

125K+ Customers

10K+ Engineers

$1.5B+* R&D Investment

~70 Design Centers

~6.5K Patents

75K+ Products

*Unaudited, pro forma data based on ADI's and Maxim's SEC filings as of
July 31, 2021 and June 26, 2021 respectively.

Made Possible through our Market-Leading Technologies

Analog & Mixed Signal
Converter, Amplifier, Interface

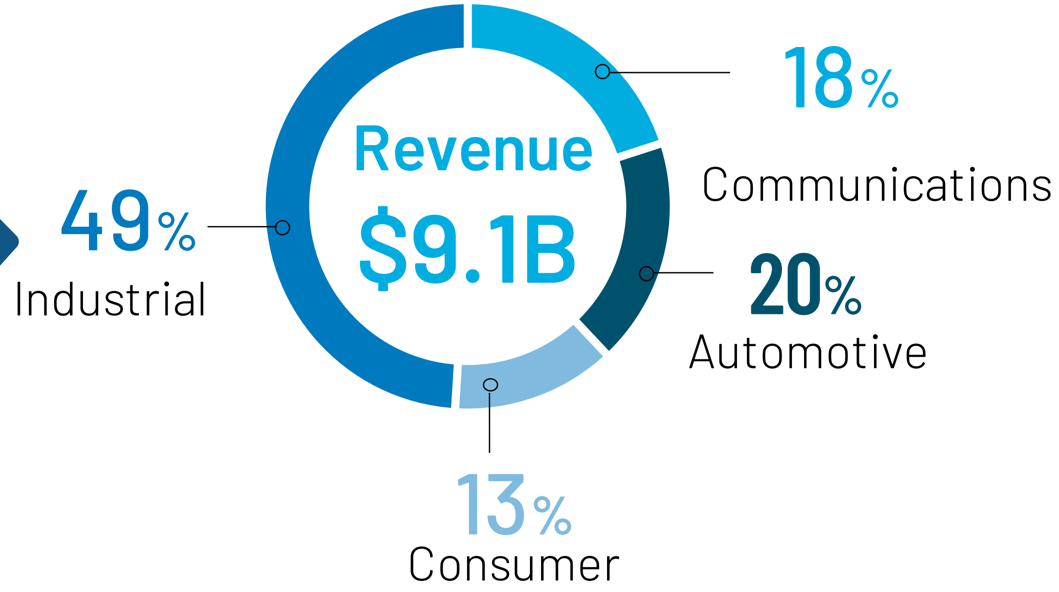
Power Management
Voltage Regulator, PMIC, Supervisory

Radio Frequency (RF)
DC to 100GHz, Microwave, mmWave

Edge Processors & Sensors
DSP, MCU, Inertial, Optical

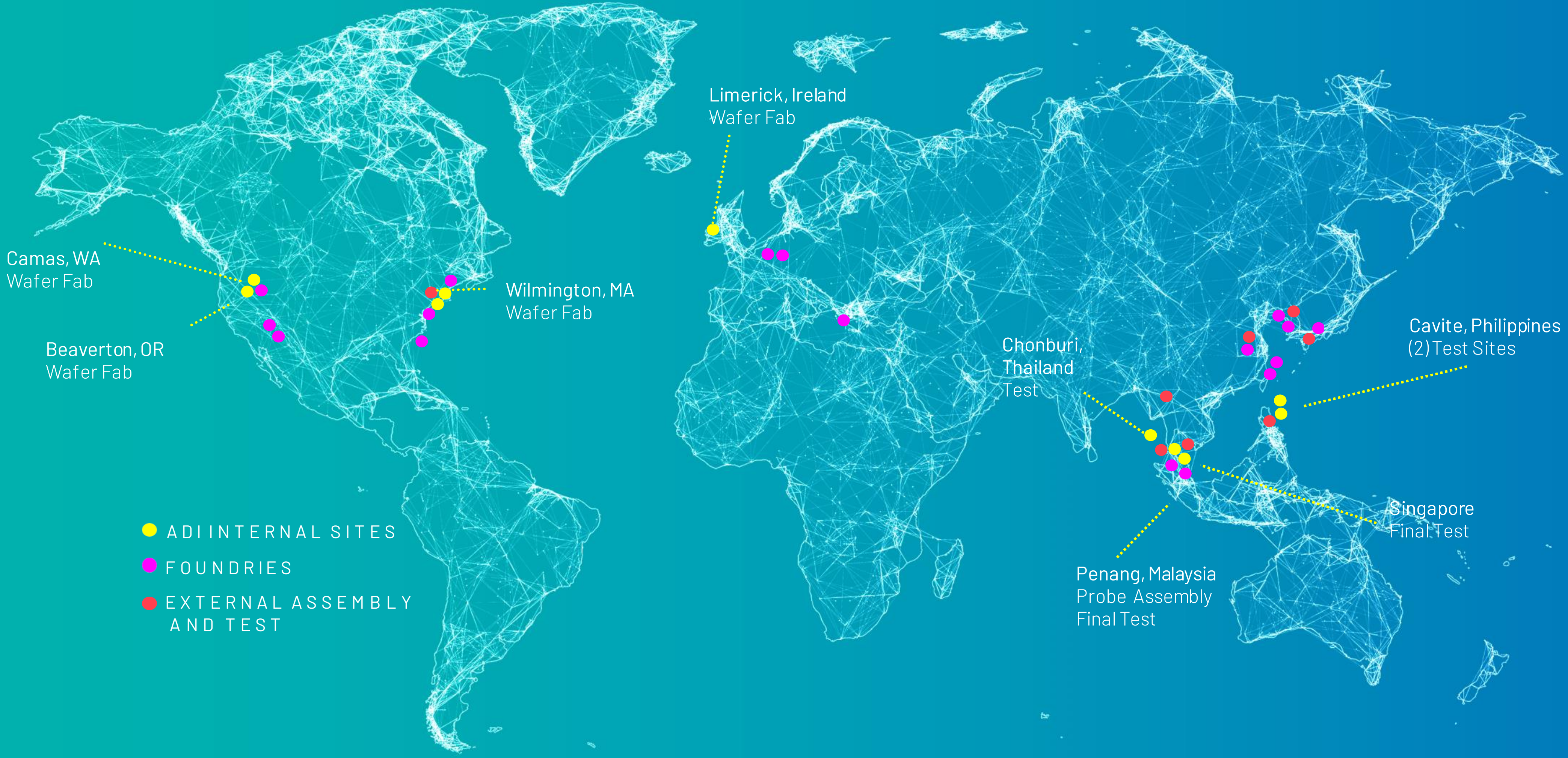
Solving complex design challenges from DC to 100GHz, nanowatts to kilowatts, sensor to cloud across diverse markets

End Market Revenue[1]



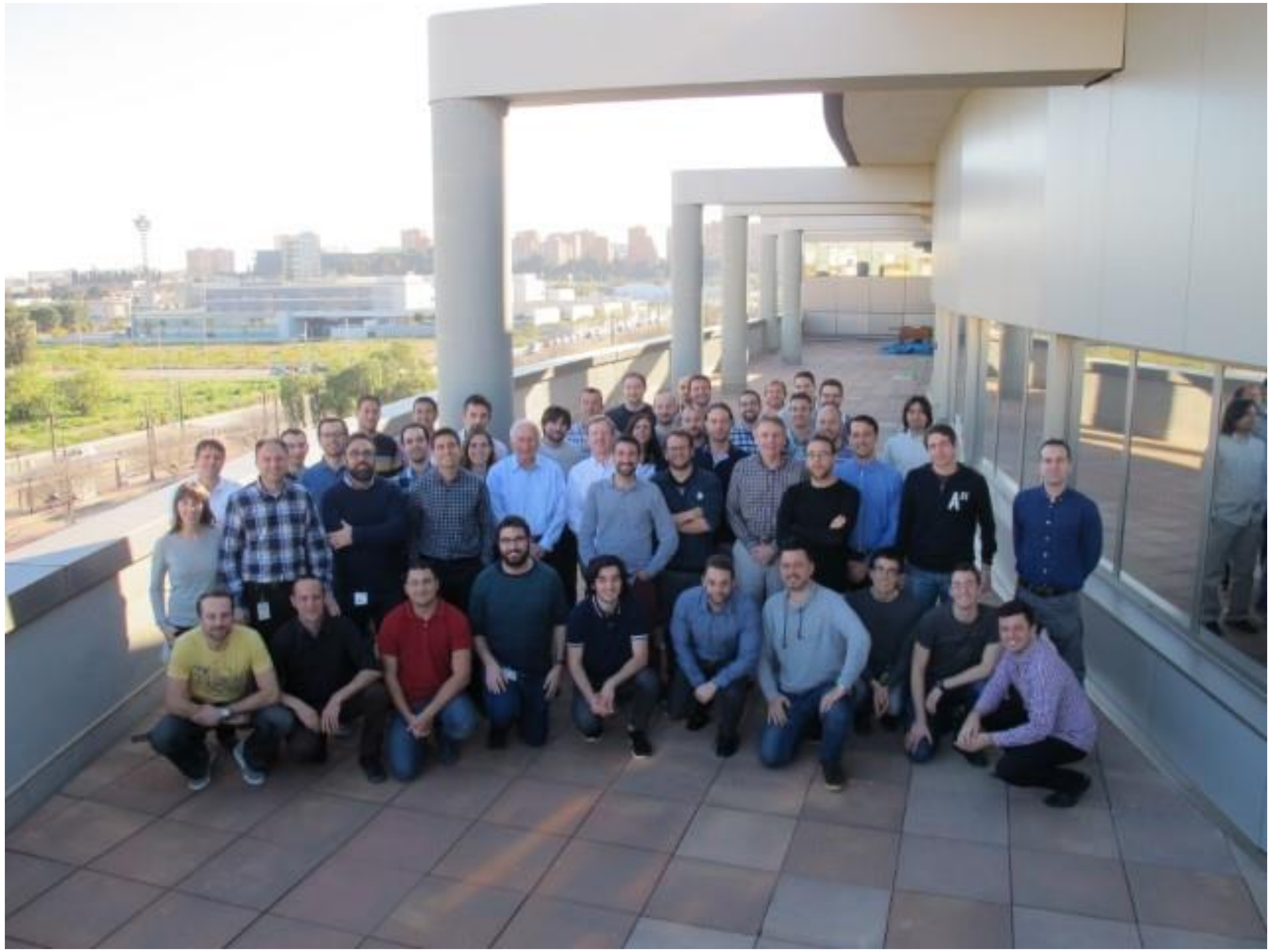
1. Unaudited, pro forma data based on ADI's and Maxim's SEC filings as of July 31, 2021 and June 26, 2021 respectively.

SUPPORTED BY ADI'S EXTENSIVE HYBRID MANUFACTURING & SUPPLY CHAIN NETWORK



9 INTERNAL FACTORIES | >50 SUPPLY CHAIN FACTORIES ACROSS 8 COUNTRIES | >15K OPERATIONS EMPLOYEES

Analog Devices S.L.

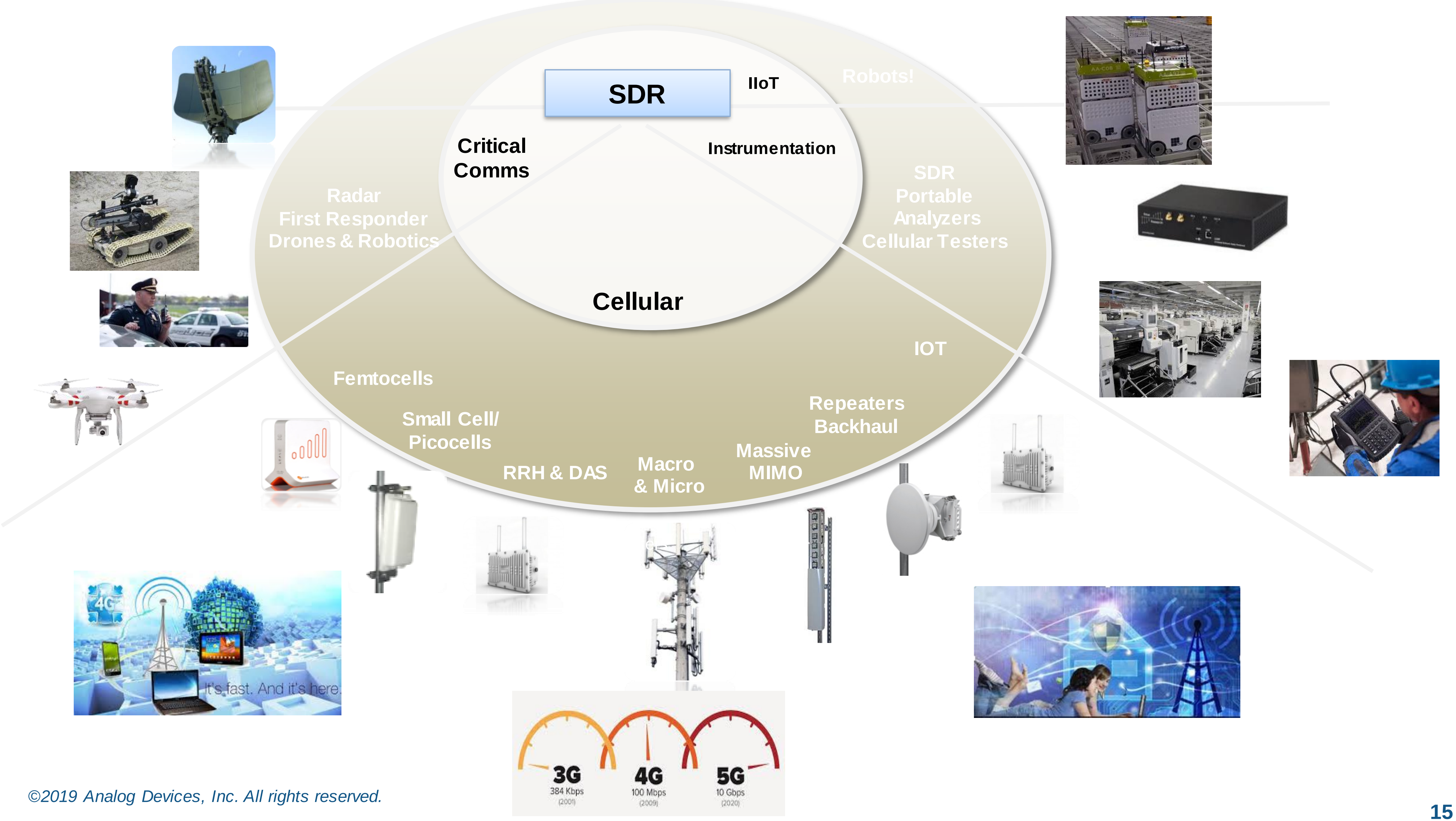


Spain
Development Centre

Valencia

Send your CV to **ADISPAIN@ANALOG.COM**

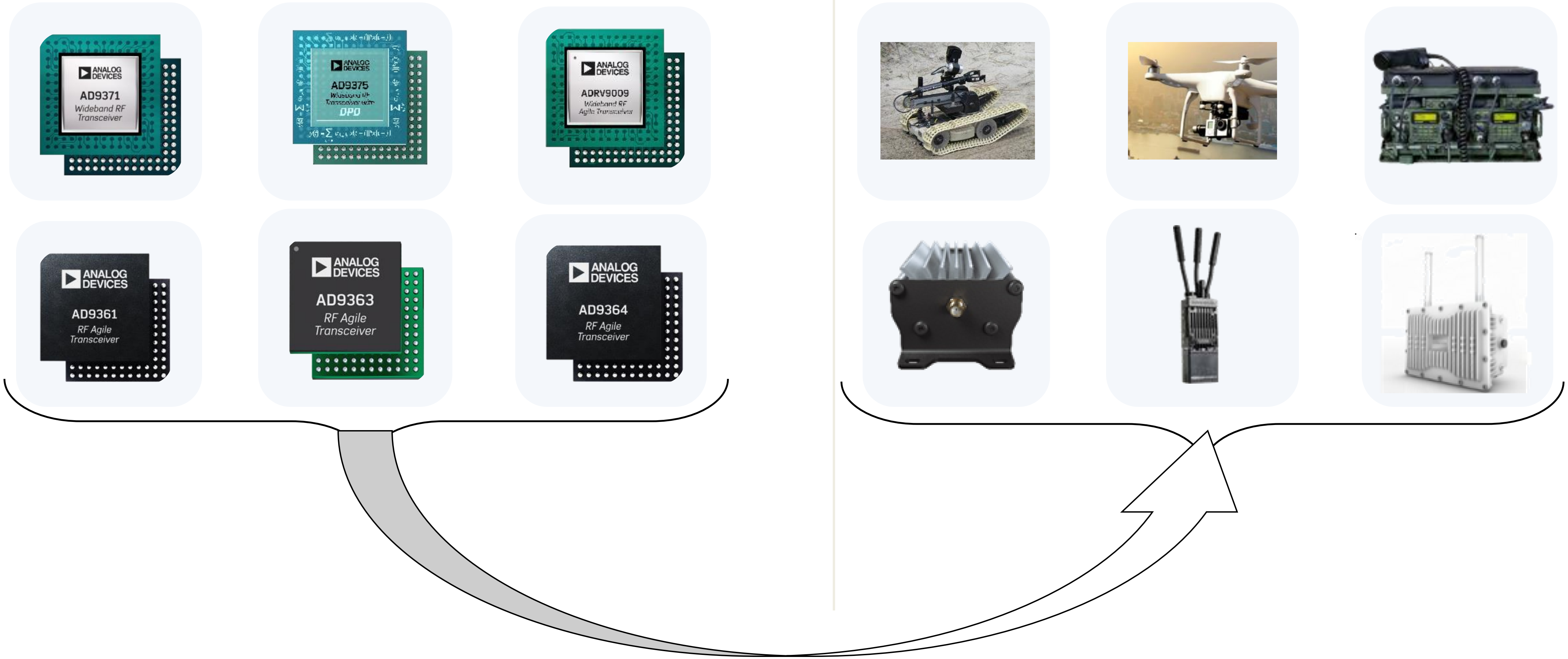
Software Defined Radio is expanding into new applications



Challenge

From devices/chips:

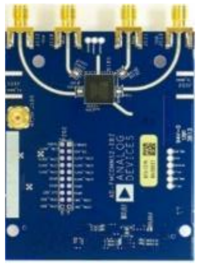
To Products:



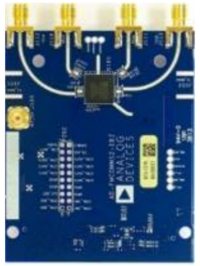
RadioVerse Evaluation and Prototyping Hardware

ADALM-PLUTO
- AD9363
- 1 x Rx, 1 x Tx
- *325 MHz – 3.8GHz*
- 200kHz – 20 MHz channel bandwidth

AD-FMCOMMS2
AD-FMCOMMS3
- AD9361
- 2 x Rx, 2 x Tx
- *tuning range*
  - *2.2 GHz – 2.6GHz*
  - *70 MHz – 6GHz*
- 200kHz - 56 MHz channel bandwidth



AD-FMCOMMS4
- *AD9364*
- *1 x Rx, 1 x Tx*
- 70 MHz – 6GHz tuning range
- 200kHz - 56 MHz channel bandwidth
- Shipping Now



ARRADIO
- AD9361
- HSMC, not FMC
- 2 x Rx, 2 x Tx
- *2.2 GHz – 2.6GHz tuning range*
- 200kHz - 56 MHz channel bandwidth
- Shipping Now!

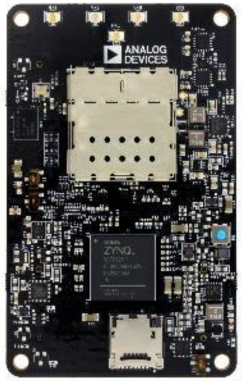
AD-FMCOMMS5
- *2 x AD9361*
- *4 x Rx, 4 x Tx*
- *Synchronized RF*
- 70 MHz – 6GHz tuning range
- 200kHz - 56 MHz channel bandwidth
- Shipping Now!

ADRV9371-N/PCBZ
ADRV9371-W/PCBZ
- *AD9371*
- *2 x Rx, 2 x Tx, 2 x Obs, 1x Sniffer*
- tuning range
  - 1.8GHz – 2.6GHz
  - 300MHz – 6GHz
- Tx synthesis bandwidth 250 MHz
- Rx BW: 8 MHz to 100 MHz

ADRV9375-N/PCBZ
ADRV9375-W/PCBZ
- *AD9375*
- *2 x Rx, 2 x Tx, 2 x Obs, 1x Sniffer*
- tuning range
  - 1.8GHz – 2.6GHz
  - 300MHz – 6GHz
- DPD actuator and adaptation engine for PA linearization

ADRV9008-1W/PCBZ (Rx)
ADRV9008-2W/PCBZ (Tx/Obs)
ADRV9009-W/PCBZ (TDD)
- *ADRV9008-1, ADRV9008-2, ADRV9009*
- *2 x Rx, 2 x Tx, 2 x Obs, 1x Sniffer*
- 75MHz - 6GHz tuning range
- Tx synthesis bandwidth 450 MHz
- Rx BW to 200 MHz

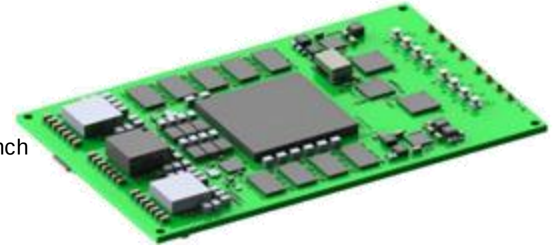
ADRV9364-Z7020
ADRV9361-Z7035
- *AD9364 + Zynq 7020*
- *AD9361 + Zynq 7035*
- 70 MHz – 6GHz tuning range
- 200kHz - 56 MHz channel bandwidth
- 1GB DDR + 32MB FLASH
- Ethernet + USB Phy



PACKRF
- *ADRV9361 reference design*
- Battery, PoE, Screen, Audio, GPS, IMU

ADRV-DPD1
- *AD9375 + 250 mW PA*
- 2 Rx, 2 Rx
- LTE Band 7
  - 2500 to 2570 Uplink
  - 2620 to 2690 MHz Downlink
- 2 PAs, 2 LNAs, duplex filters

ADRV9009-ZU11EG
- *2 x ADRV9009 + Zynq Ultrascale*
- 75MHz to 6GHz tuning range
- Rx BW 200MHz
- Tx synthesis bandwidth 450 MHz
- Integrated LO and Phase synch between all channels and Modules
- 4G x64 w/ECC PS; 4G (2Gb x32 x2Banks) PL
- USB3, USB2, PCIe 3.0 x8, QSFP+, SFP+, 1Gb Ethernet x2, and CPRI



SW Defined Radio Journey

Research

- Education and selection tools for matching ideas to solutions
- Behavioral models to test concepts quickly
- Make vs buy
  - SOM
  - Partner Hardware
  - Custom Hardware

Evaluate

- Common evaluation hardware and software
- Evaluation platforms
- Development systems
- Prototyping systems
- Integration with industry tools
- Automation with standard test equipment

C/C++

Design

- Online customer support
- Communities
- Forums
- Wikis
- Advanced tool flows for automatic HDL generation
- HDL reference designs
- Schematics, gerbers

Production

- Test procedures for ADI platforms
- Connectivity to test equipment
- Videos, and descriptions of board tests
- Modular, pre-tested hardware (SOM)

As developers move, their hardware/software requirements change

Research
- AD9361 Behavioral Simulation
- PlutoSDR Streaming to GNU Radio or IIO Scope

Algorithm Development
- GNU Radio / Python reference implementation
- Hardware streaming

Design Elaboration
- GNU Radio C++ modeling
- Simulink modeling
- Hardware streaming
- Data type conversion

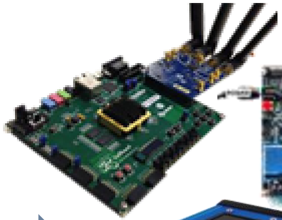
Prototype
- Deployment to development board
- Design optimization
- HDL Integration
- Driver Integration

Production
- Deployment to custom hardware
- Validation with complete hardware solution

PlutoSDR

Streams over USB
Includes : Host Libraries (libiio, libad9361-iio), GUI Software, GNU Radio and MATLAB application interfaces

RFSoM+FMC Carrier or Eval FMC + FPGA Carrier


Streams over USB/Ethernet, allows access to FPGA and local CPU (standalone operation), blue wire to HW
Includes above plus : Device Drivers, HDL interfaces, HDL libraries, Schematics, Gerber

PackRF or RFSoM + Custom Carrier

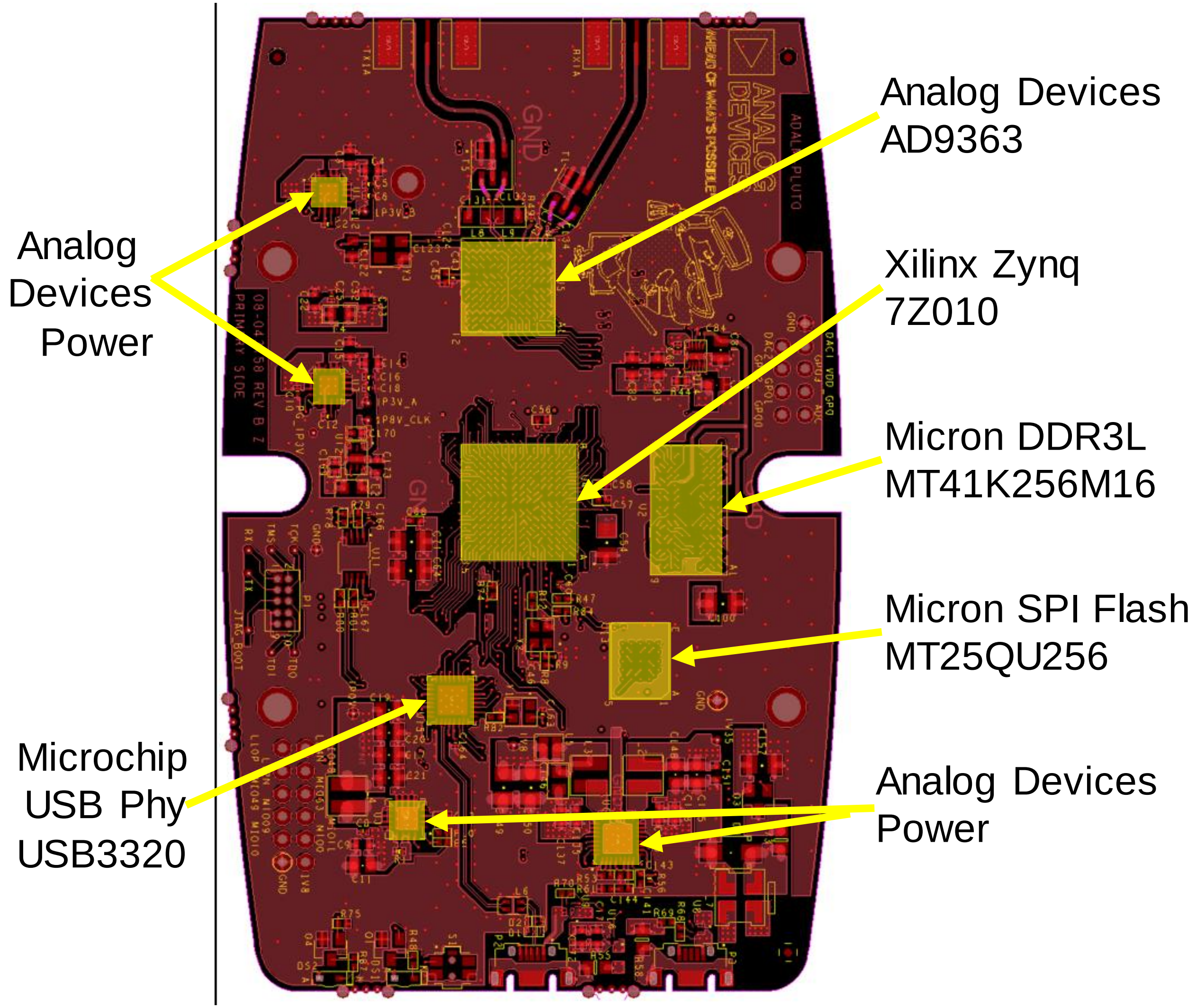
Prototype field testing, trials or bake off
Includes above plus standard peripheral access (screen, battery, GPS, PoE, Audio, etc)

Custom

Does whatever you want
Could include one or more or none of ADI: Host Libraries, GUI Software, Device Libraries, Device Drivers, HDL, Schematics, Gerber

ADALM-PLUTO Design

- Design is open, just like all other ADI designs
  - Shows a minimal full system design
    - From antenna to USB
    - RF to bits
  - Only 72 parts on the BOM
    - All IC, R, C, L, connectors, etc
  - Schematics, Gerbers, BOM, Allegro Files posted
    - https://wiki.analog.com/university/tools/pluto/hacking/hardware
  - Passes FCC and CE tests
  - Achieves better RF than AD9363 datasheet specs



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Resources

Support:

http://ez.analog.com

EngineerZone™
ANALOG DEVICES SUPPORT COMMUNITY

- ADALM-PLUTO
  https://ez.analog.com/university-program
- FPGA questions
  https://ez.analog.com/fpga
- Linux drivers & IIO & MATLAB
  https://ez.analog.com/linux-device-drivers/linux-software-drivers
- NO-OS Drivers:
  https://ez.analog.com/linux-device-drivers/microcontroller-no-os-drivers

Documentation:

ANALOG DEVICES AHEAD OF WHAT'S POSSIBLE™ | Wiki

http://wiki.analog.com/plutosdr

http://www.analog.com/plutosdr

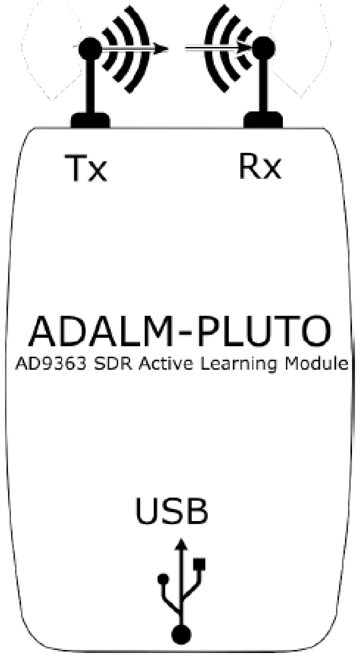
www.analog.com/RadioVerse

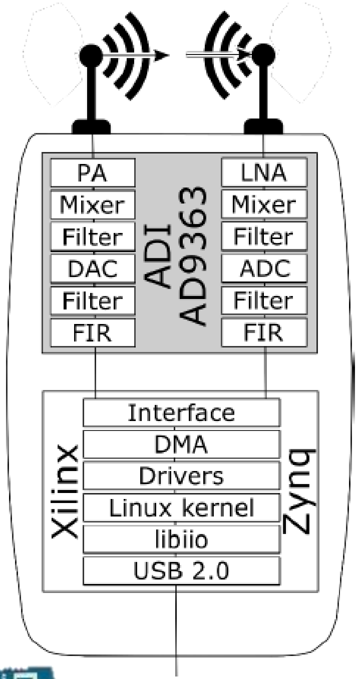
Introducción a ADALM-PLUTO

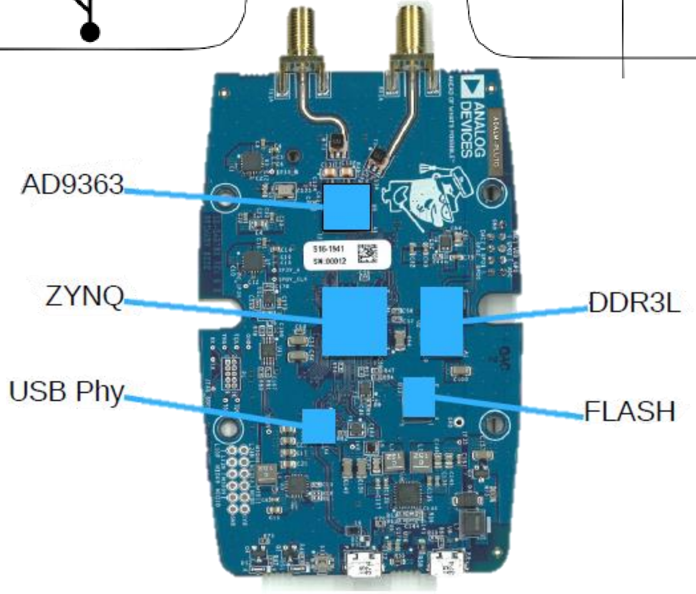
Specifications	Typical
Power	
DC Input (USB)	4.5 V to 5.5 V
Conversion Performance and Clocks	
ADC and DAC Sample Rate	65.2 kSPS to 61.44 MSPS
ADC and DAC Resolution	12 bits
Frequency Accuracy	±25 ppm
RF Performance	
Tuning Range	325 MHz to 3800 MHz
Tx Power Output	7 dBm
Rx Noise Figure	<3.5 dB
Rx and Tx Modulation Accuracy (EVM)	−34 dB (2%)
RF Shielding	None
Digital	
USB	2.0 On-the-Go
Core	Single ARM Cortex®-A9 @ 667 MHz
FPGA Logic Cells	28k
DSP Slices	80
DDR3L	4 Gb (512 MB)
QSPI Flash	256 Mb (32 MB)
Physical	
Dimensions	117 mm × 79 mm × 24 mm 4.62" × 3.11" × 0.95"
Weight	114 g
Temperature	10°C to 40°C

BW = 3450 MHz

5,012 mW

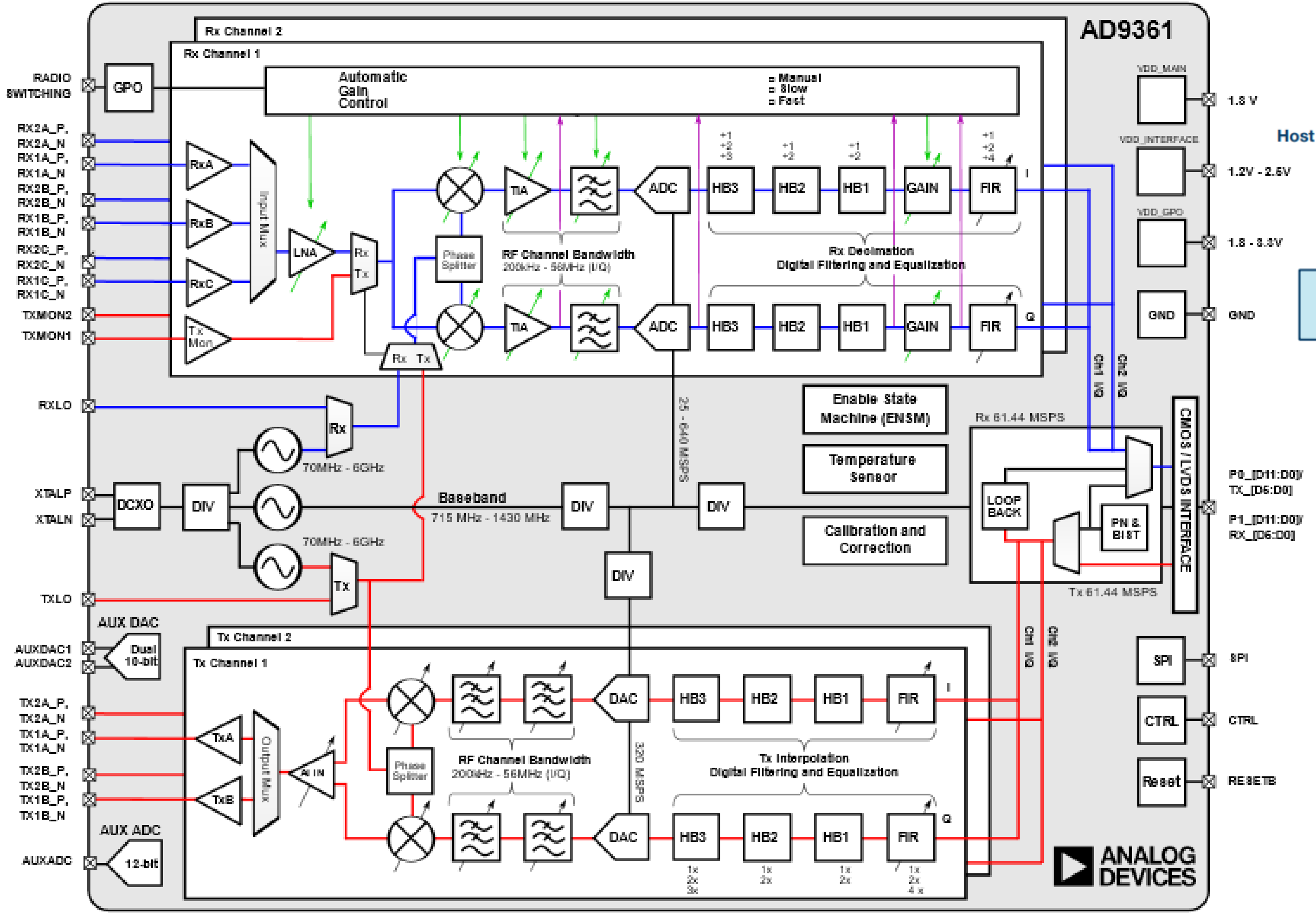






Analog Devices Inc. (2017, February 2). ADALM-PLUTO SDR Active Learning Module. Retrieved February 11, 2022, from https://www.analog.com/media/en/news-marketing-collateral/product-highlight/ADALM-PLUTO-Product-Highlight.pdf

Introducción a ADALM-Pluto



Simplified Block Diagram

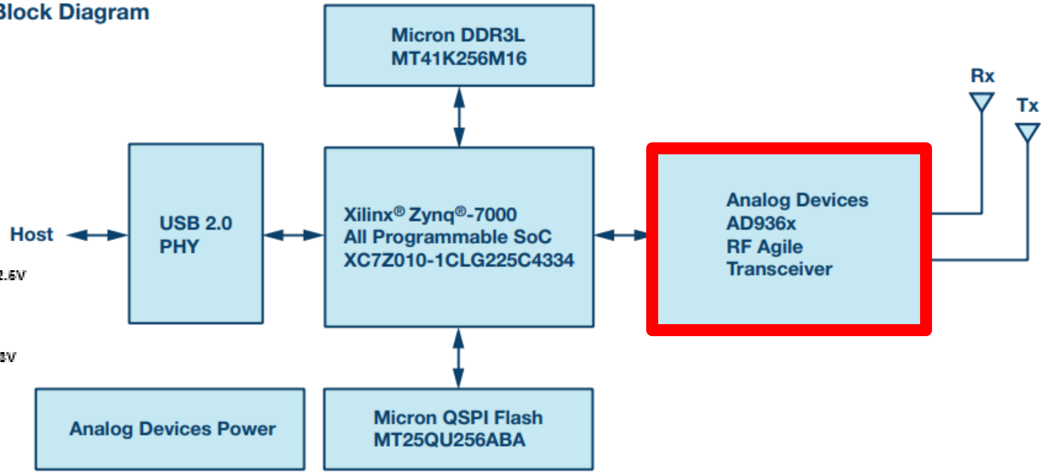
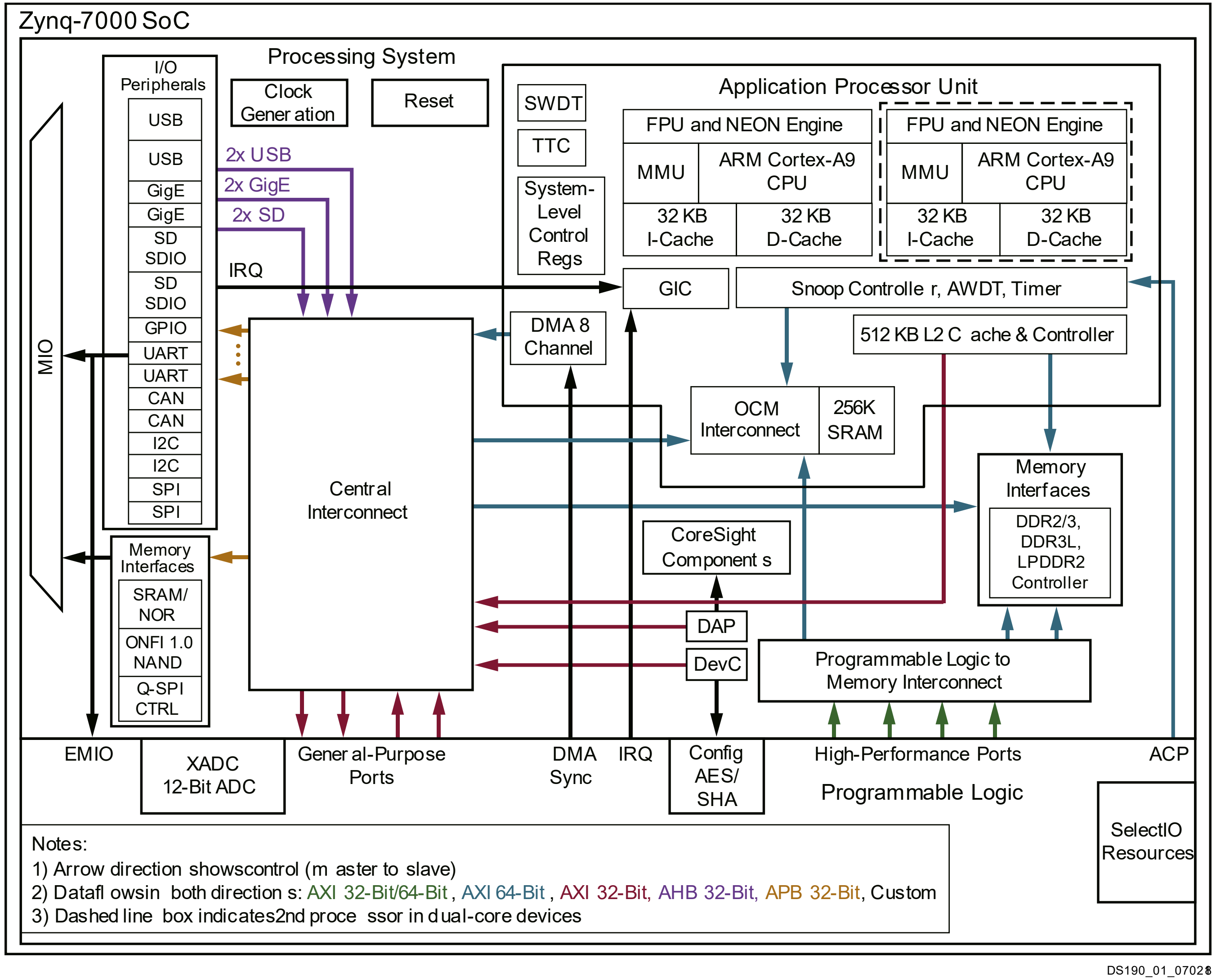


Figure Extracted From: https://wiki.analog.com/resources/eval/user-guides/ad-fmcomms2-ebz/ad9361

Introducción a ADALM-Pluto



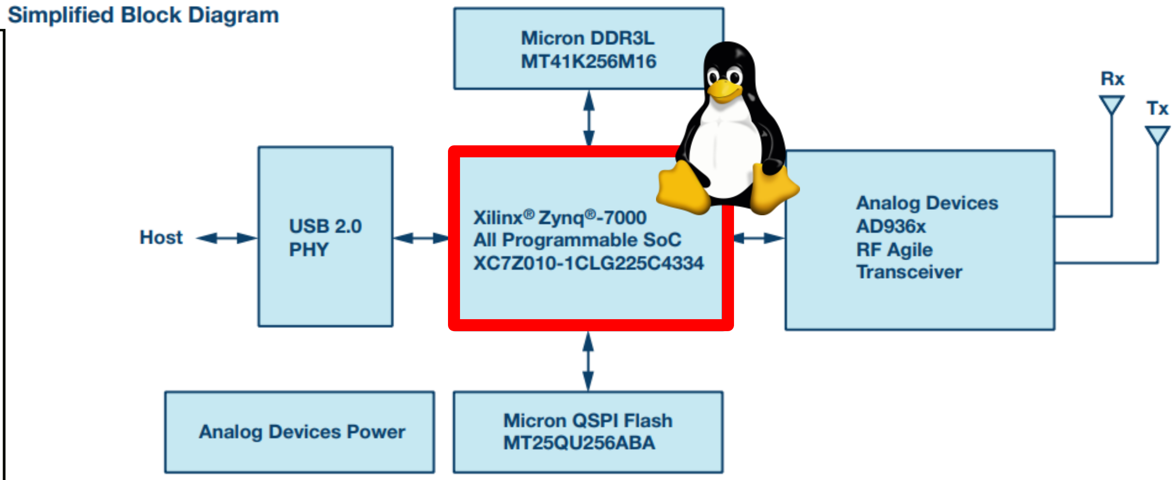


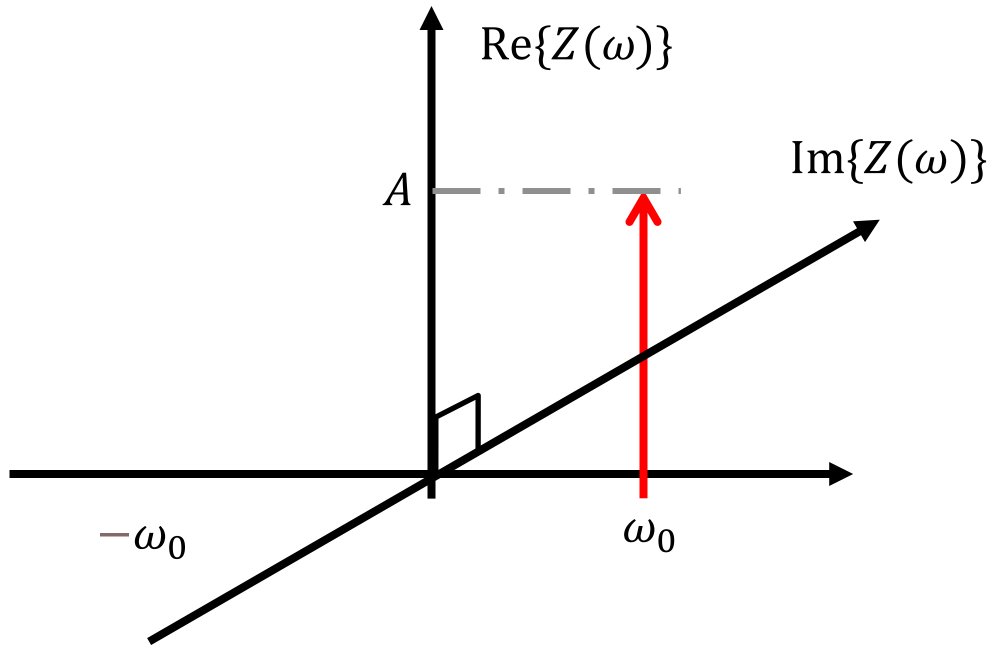
Figure Extracted From: Xilinx. (2018, July 2). Zynq-7000 SoC Data Sheet: Overview.

Ejercicio 1: Transmisión y recepción de un tono

- **Objetivo:** Transmitir y recibir un tono
  1. Abrir el fichero *PlutoSDRToneExample.mlx*
  2. *Leer los pasos.*
  3. *Completar los huecos y analizar el resultado.*
- *Requisitos:*
  - *Communications Toolbox Support Package for Analog Devices ADALM-Pluto Radio™*
  - *DSP System Toolbox™*

helperFindPlutoSDR()

$$z(t) = e^{j\omega_0 t} = x(t) + jy(t) = A\,(\cos(\omega_0 t) + j\,\sin(\omega_0 t))$$

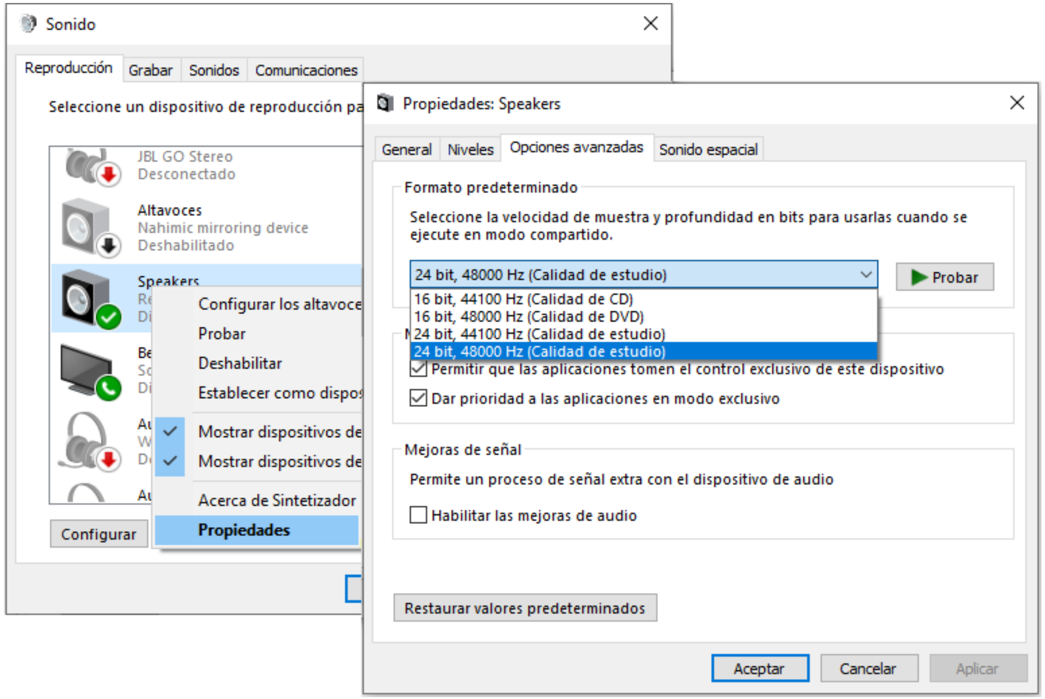


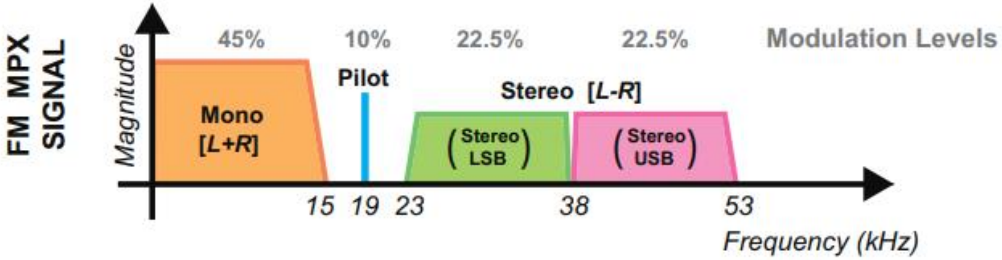
$$r(t) = I(t)\cos(\omega_c t) - Q(t)\sin(\omega_c t)$$

Ejercicio 2: FM Broadcast Receiver con Simulink

Construiremos un receptor FM monofónico o estéreo utilizando Simulink® y Communications Toolbox™.

- Aspectos a recordar:
  - Banda FM en España → CNAF Banda 87.5-108 MHz (UN-17)
    - “Radiodifusión sonora en ondas métricas”
    - Frecuencia COPE Valencia: 92 MHz
    - Frecuencia UPV Radio: 102.5 MHz
    - Frecuencia Europa FM: 103.2 MHz
  - Algunos parámetros
    - Frecuencia de Muestreo Audio: 45.6 KHz
    - Desviación en Frecuencia: 75 kHz (USA) y 50 kHz (UE)
    - Constante de Tiempo De-Énfasis LPF: 75 µs (USA) y 50 µs (UE)
    - Frecuencia de Muestreo FM: $f_s > 2f_{RF} = 2 \cdot 53\ KHz = 106\ KHz$





» `FMReceiverSimulinkExample`

Ejercicio 2: FM Broadcast Receiver con MATLAB

Construiremos un receptor FM monofónico o estéreo utilizando MATLAB® y Communications Toolbox™.

- Aspectos a recordar:
  - Banda FM en España → CNAF Banda 87.5-108 MHz (UN-17)
    - "Radiodifusión sonora en ondas métricas"
    - Frecuencia COPE Valencia: 92 MHz
    - Frecuencia UPV Radio: 102.5 MHz
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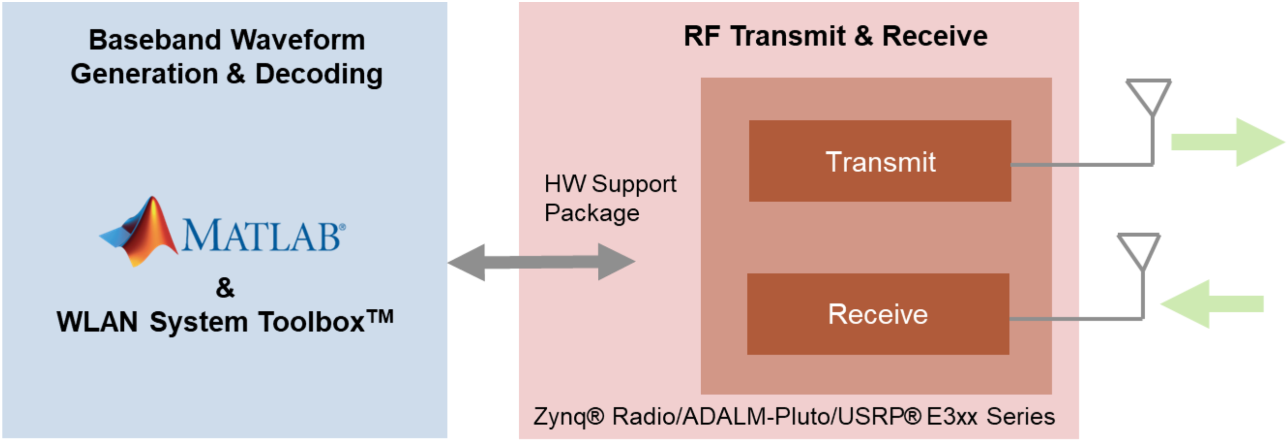
    - Frecuencia de Muestreo Audio: 45.6 KHz
    - Desviación en Frecuencia: 75 kHz (USA) y 50 kHz (UE)
    - Constante de Tiempo De-Énfasis LPF: 75 μs (USA) y 50 μs (UE)
    - Frecuencia de Muestreo FM: $f_s > 2f_{RF} = 2 \cdot 53\ KHz = 106\ KHz$

```
» edit FMReceiverExample
```

Ejercicio 3: Transmitir una imagen por WLAN

Transmitiremos una imagen por WLAN y mediremos el BER (Bit Error Rate)

- *Requisitos:*
  - *Communications Toolbox Support Package for Analog Devices ADALM-Pluto Radio™*
  - *DSP System Toolbox™*
  - *WLAN Toolbox ™*




```
» edit plutoradioWLANTransmitReceiveExample
```

Recursos adicionales

MATLAB Central

www.mathworks.com/matlabcentral

Mathworks Academia

www.mathworks.com/academia.html?s_tid=gn_acad

Cody Problems

www.mathworks.com/matlabcentral/cody

MATLAB Academy

https://matlabacademy.mathworks.com/

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