Introduction to Design & Development of SDR

(Software Defined Radio)

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Founder of MATHSOUL SYSTEMS

August 01, 2020

Overview

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  Examples : Radio Broadcasting, Radio Communication, Radar etc..

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- Radio can also be said as a physical or electronic device which used for signaling & Communicating using radio waves.

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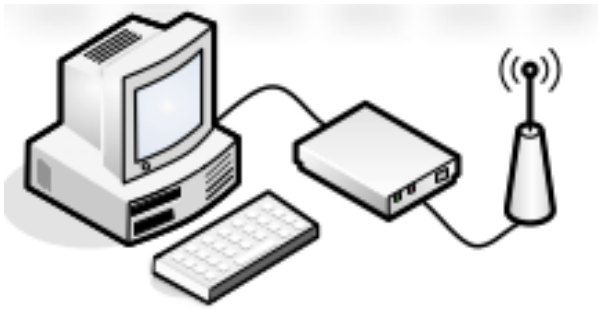
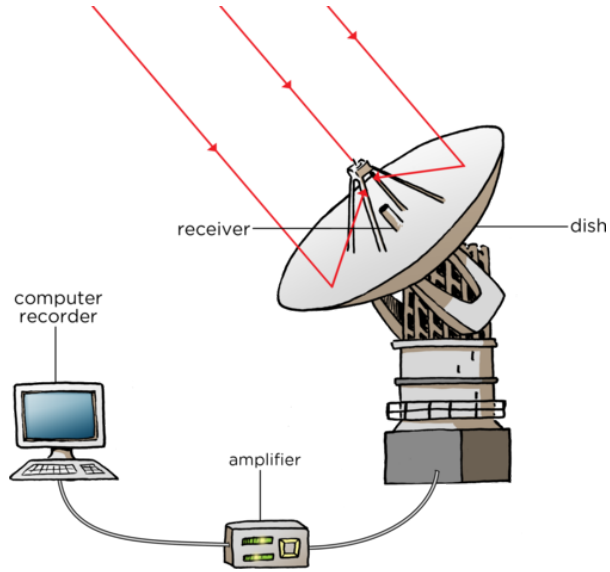
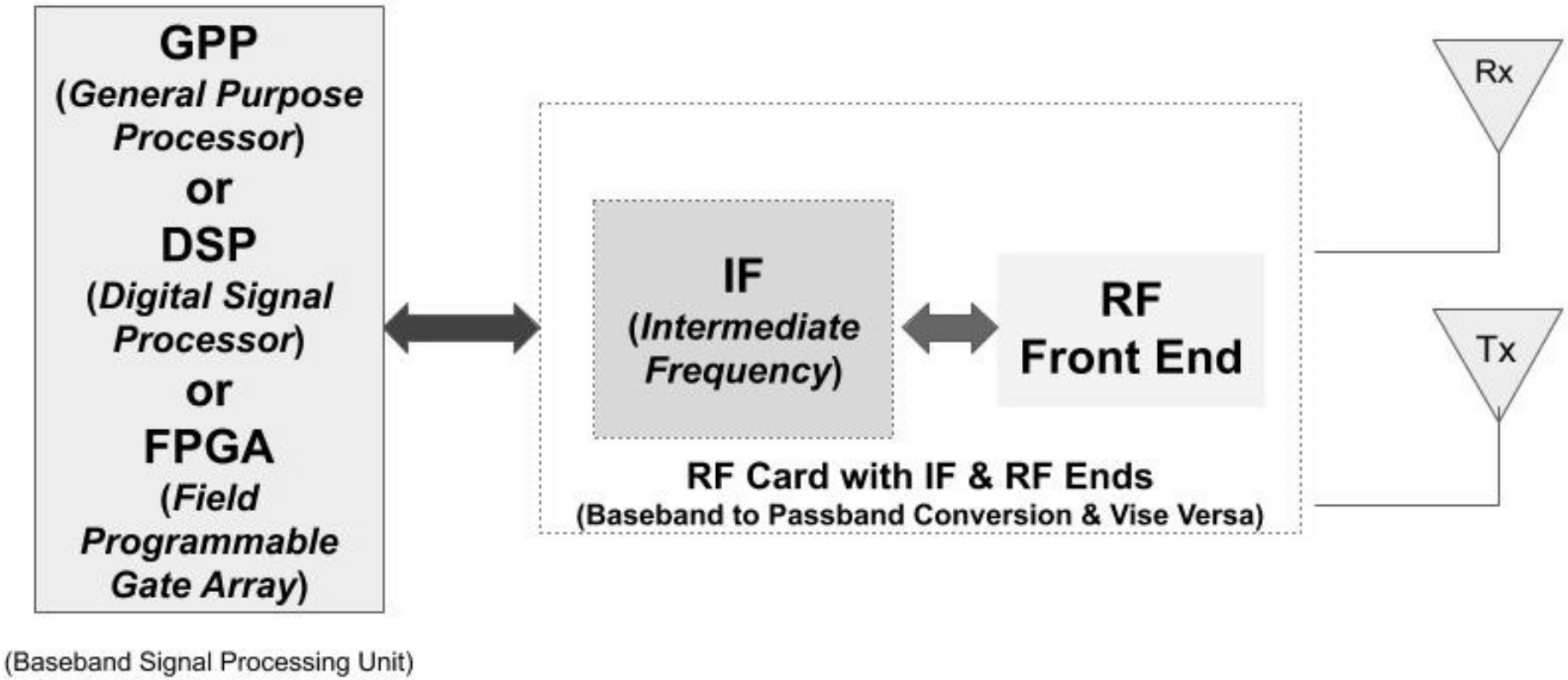
- **Software Defined Radio (SDR)** is a re-configurable radio, used in real time prototype design of various communication applications.
- Defiance Radio, RADAR, Cellular Network etc.. are some of the examples of SDR applications.





Generic Architecture of SDR



SDR is broadly divided into three segments **Baseband Processing Unit**, **Baseband-Passband Conversion Unit** & **RF Unit**

Classification of SDR

- SDR requires a peace of software for the **Baseband Signal Processing**.
- Based on the Baseband Signal Processing unit, SDR has been classified into three categorizes.
  1. **GPP based SDR**
     GPP based System + RF Card
  2. **DSP based SDR**
     Digital Signal Processor based Board + RF Card
  3. **Soc FPGA based SDR**
     FPGA based SoC + RF FMC Card

GPP Based SDR

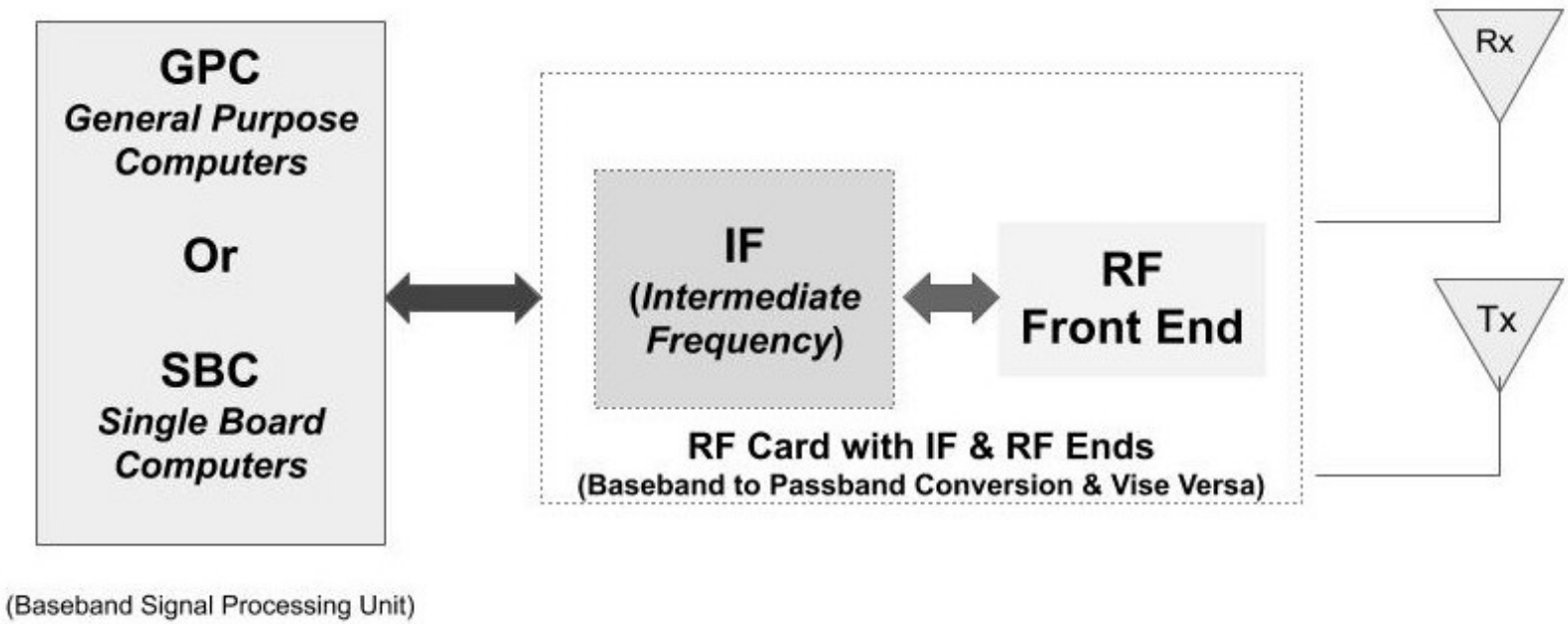


Figure: GPP Based SDR Block Diagram

Types of GPP based SDR

Based on **Baseband Signal Processing Unit** (GPP Unit), GPP based SDRs are classified into two types

1. General Purpose Computers (GPC with GPP of Intel architecture) based SDR.
2. Single Board Computers (SBC with GPP of ARM architecture) based SDR.

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Based on **Baseband-Passband Conversion Unit** (RF Cards), GPP based SDRs are classified into three types

1. GPP interfaced with RF Card
2. GPP interfaced with FPGA based RF Card
3. GPP interface with FPGA based SoC RF System

Outline

General Purpose Computer Based SDR

- Baseband Processing Unit is developed using General Purpose Computer.

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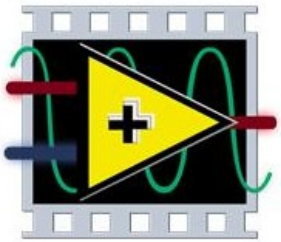
- Software's used for Baseband Signal Processing



LabVIEW

MATLAB® & SIMULINK®

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Universal Software Radio Peripheral(USRP)

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- Ettus Research USRP's are of four types
  1. Bus Series – Eg : USRP B210
  2. Network Series – Eg : USRP N210, USRP N310
  3. Embedded Series – Eg : E320
  4. X Series – Eg : X300, X310

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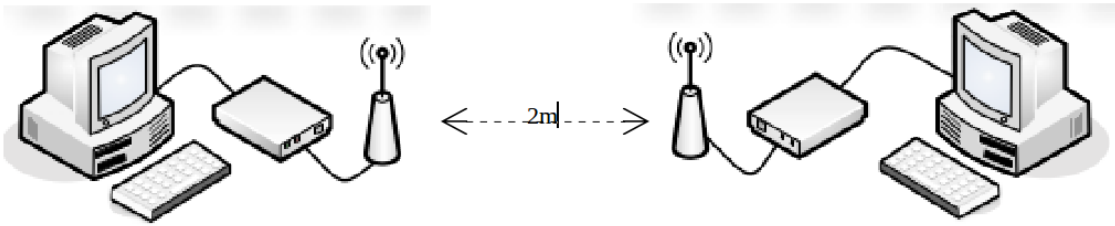
- NI-USRPs are also have the similar classification, but they are highly recommended to use with NI LabView.

MATLAB SDR Experimental Setup



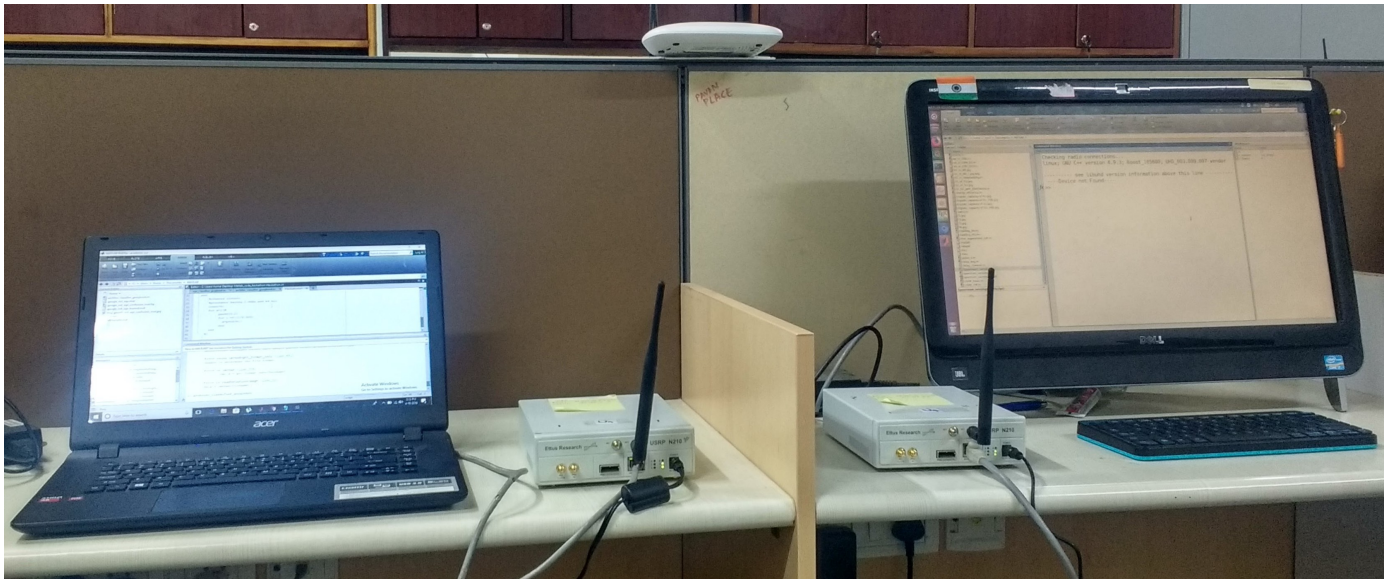


Figure: MATLAB SDR Experimental Setup

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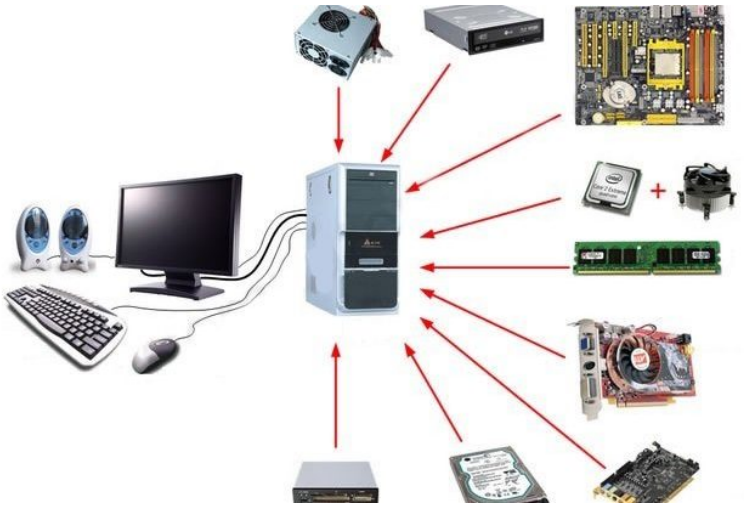

Figure: General Purpose Computer

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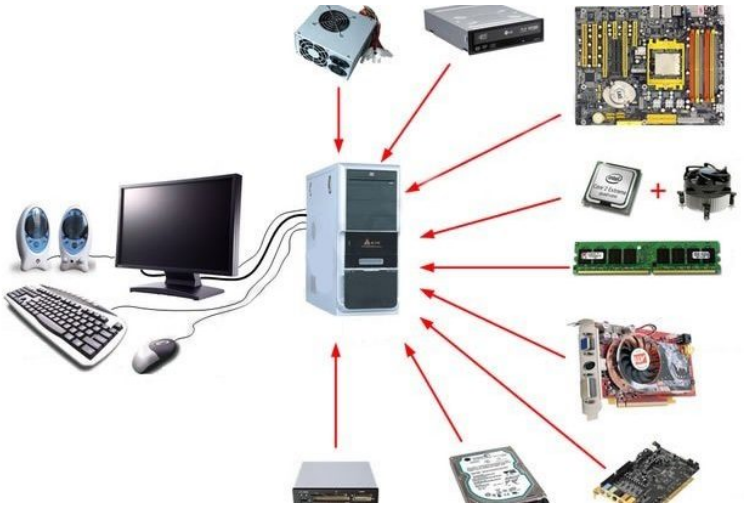

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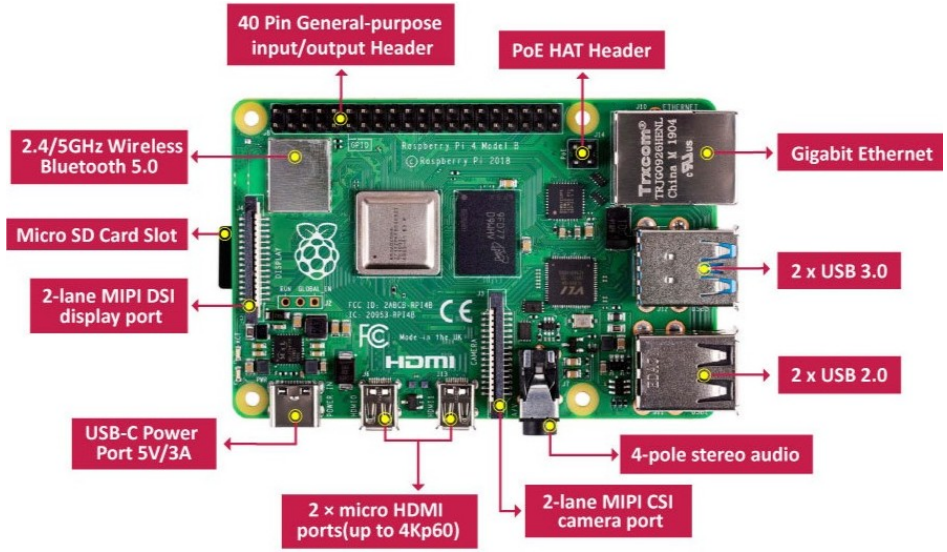

Figure: Raspberry Pi 4 SBC

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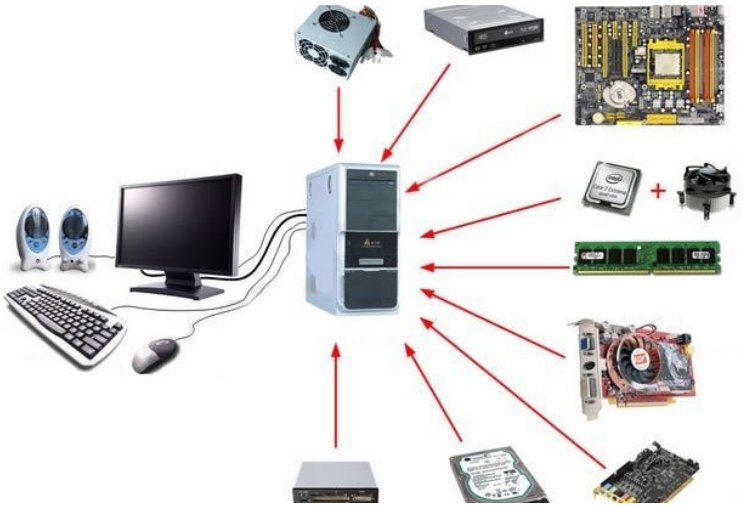

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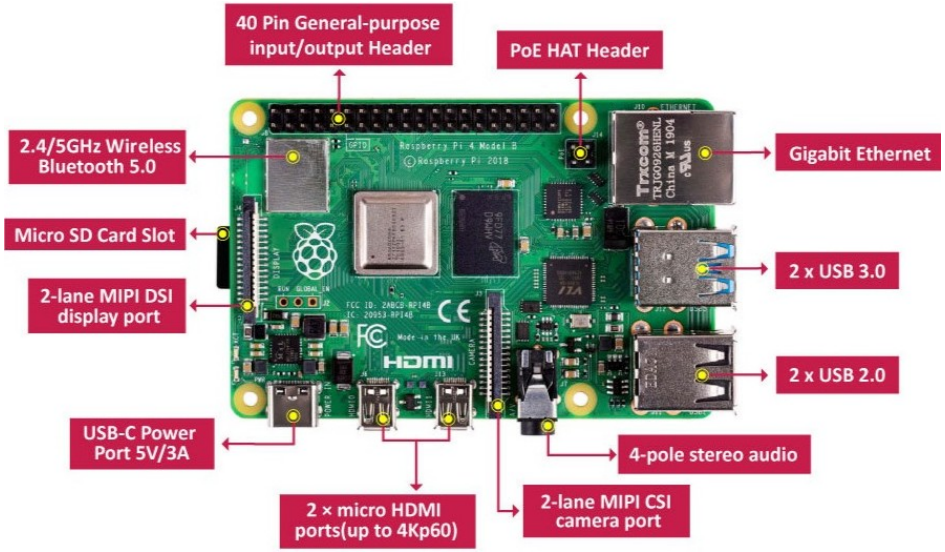

Figure: Raspberry Pi 4 SBC

Note : Form more details of SBC, go through the reference document *"SBCs & Raspberry Pi Basics"*

Single Board Computer Based SDR

- Single Board Computers like Raspberry Pi 4, Tinker Board, Odroid XU4, Jetson Nano are recommended for SBC based SDR development.
- Python and C++ UHD API, GNU Radio, OAI are used in SBC to change the parameter of RF Cards (Boards) & send processed baseband signal from SBC to RF Cards (Boards).
- SBC based SDRs are highly recommend for the development of real time prototype systems.

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- **USRPs without Baseband Processing Unit**
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  N-Series & X-Series operational configuration can be changed with the of doughtier cards.
  Examples of some Daughter cards are
  - SBX Daughter Card
  - WBX Daughter Card
  - UBX Daughter Card
  - TwinRx Daughter Card

GPP Based SDR with RF Card

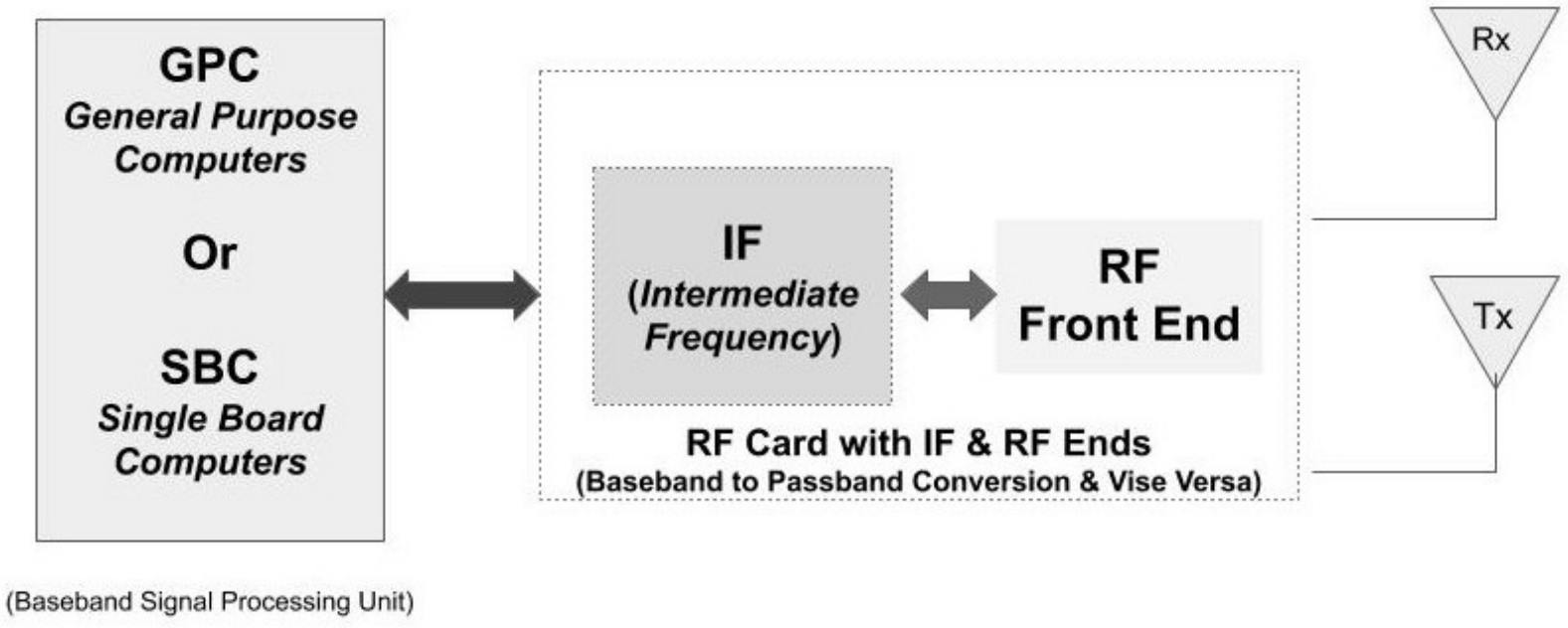
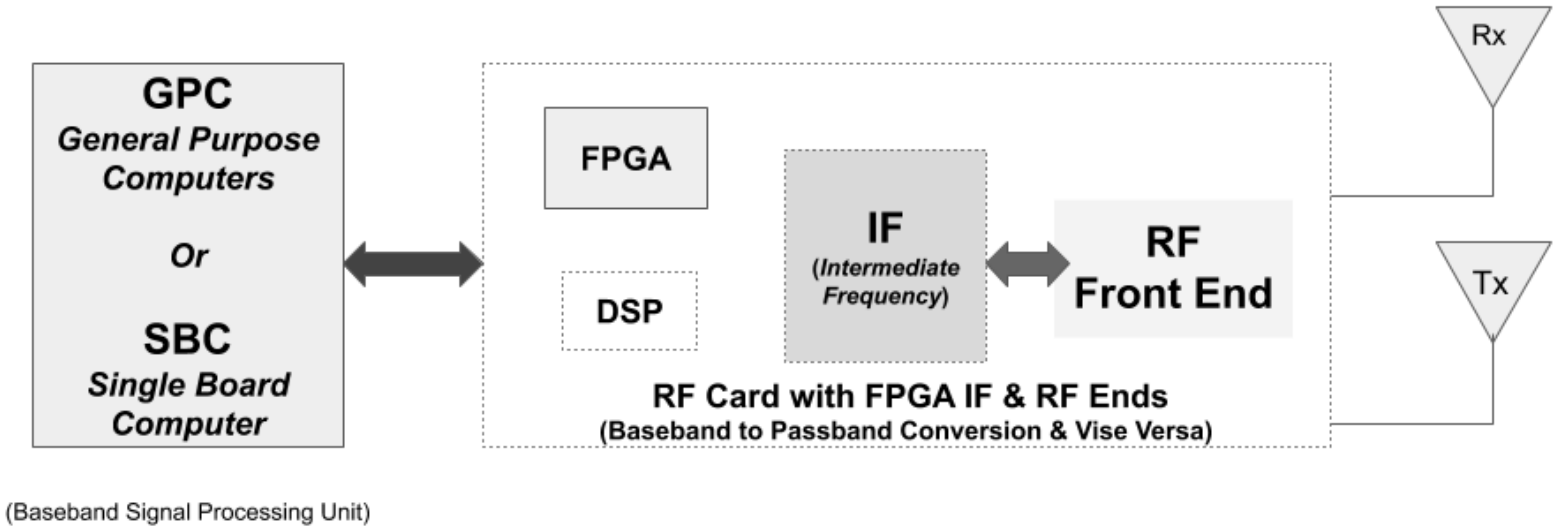


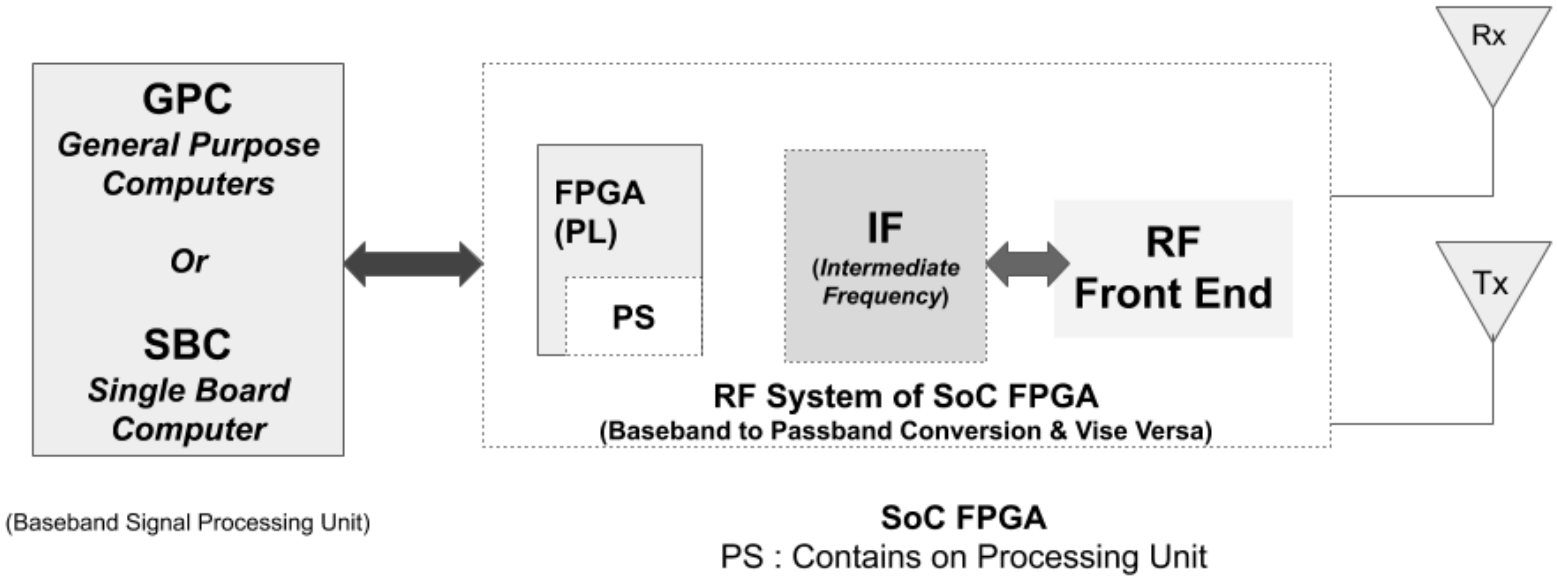
Figure: GPP connected to RF Card without Baseaband Processing Unit

- USRP B210
- BladeRF
- USRP N210
- Adlam Pluto SDR

GPP Based SDR with FPGA based RF Card



GPP Based SDR with SoC FPGA based RF Card



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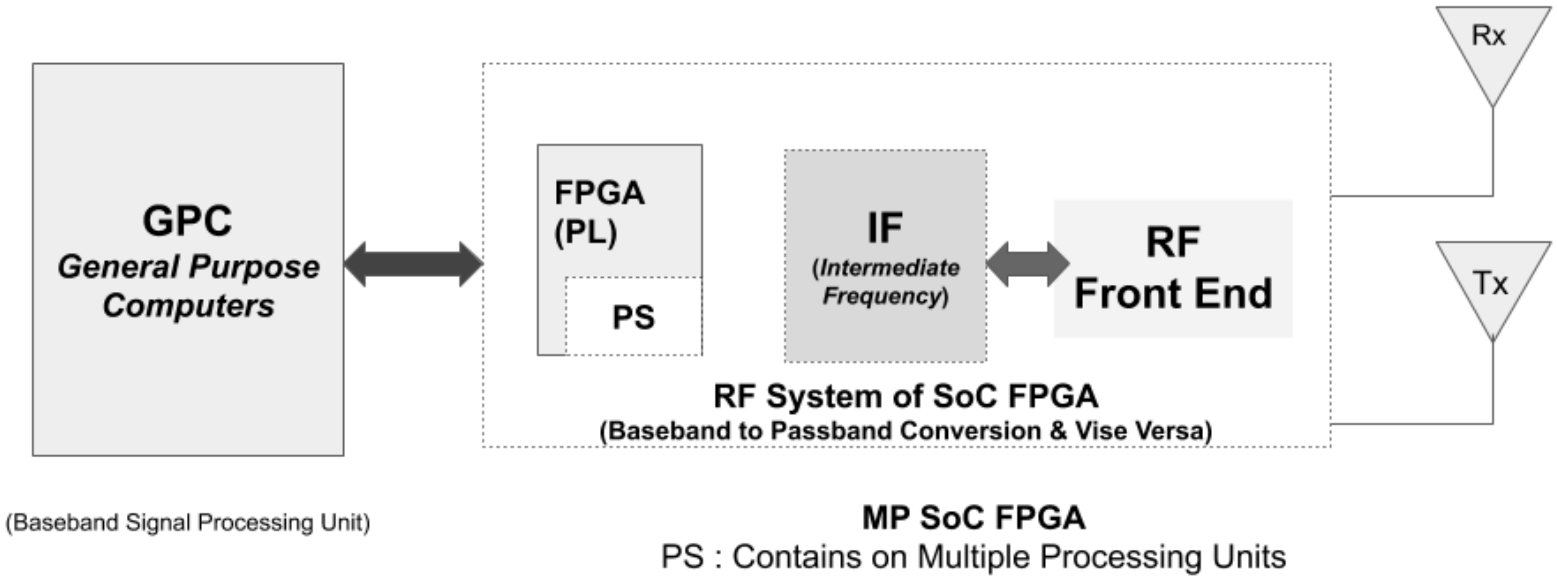
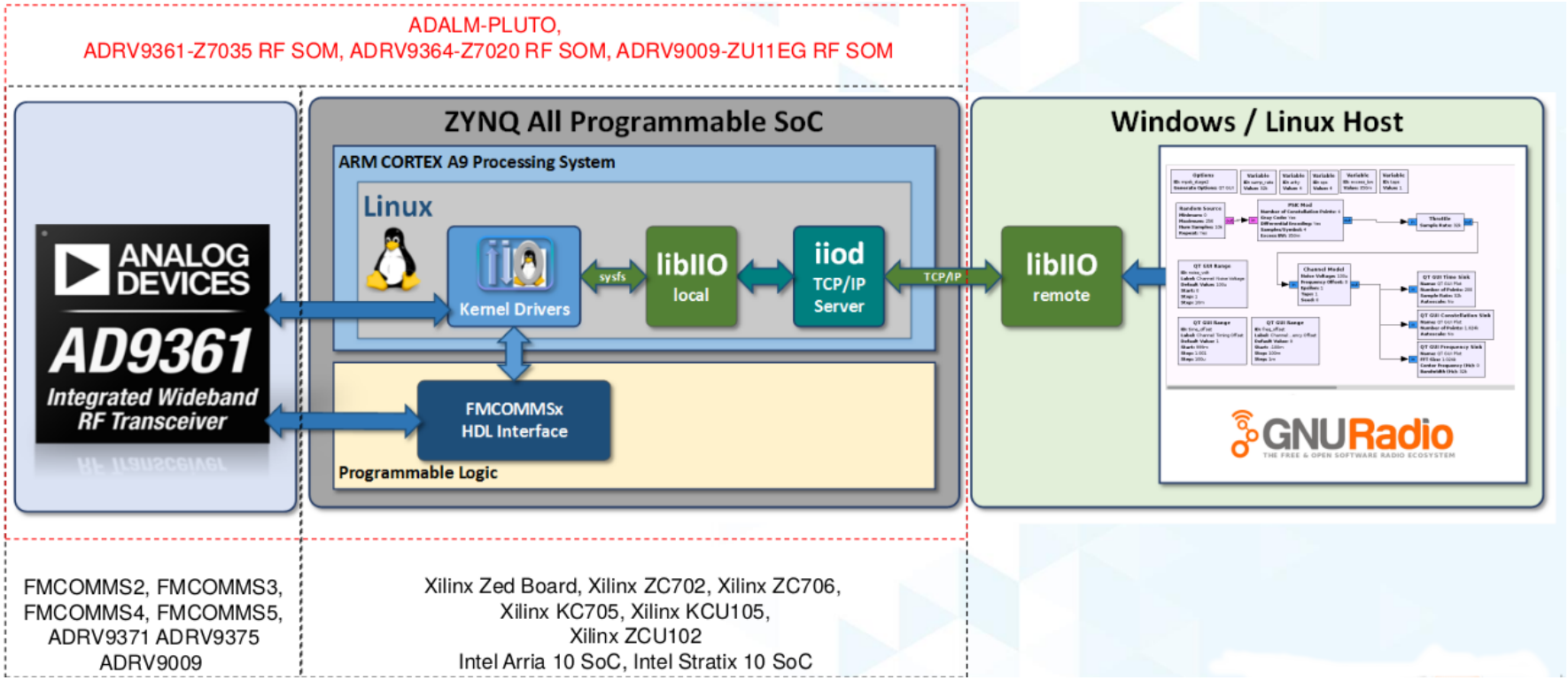


Block Diagram of GPP Based SDR with RF SoM



Note : RF SoM – RF System-on-Module.

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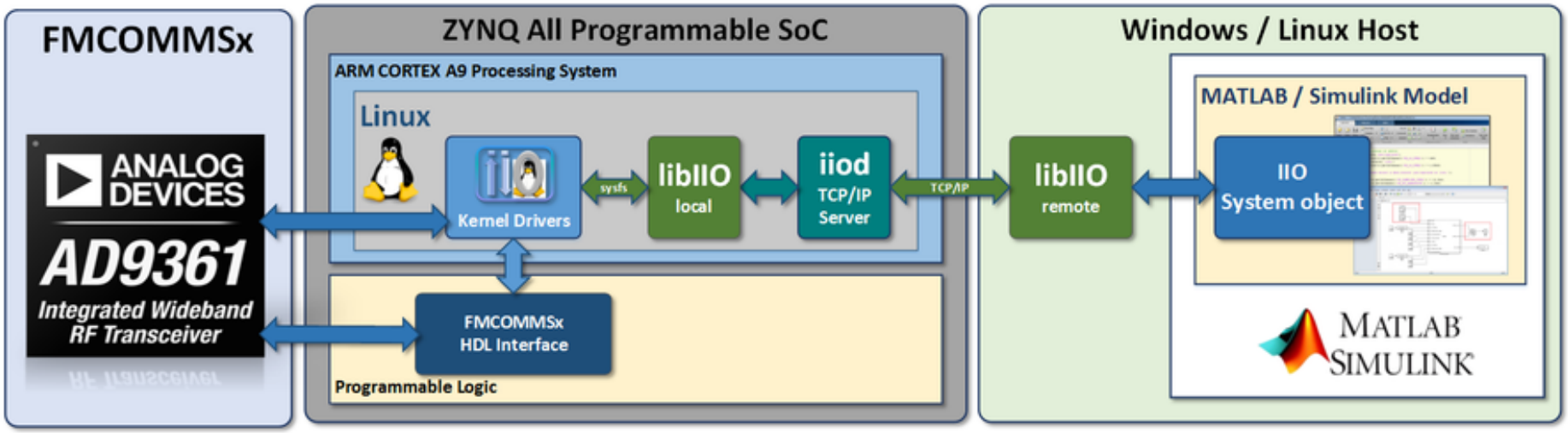

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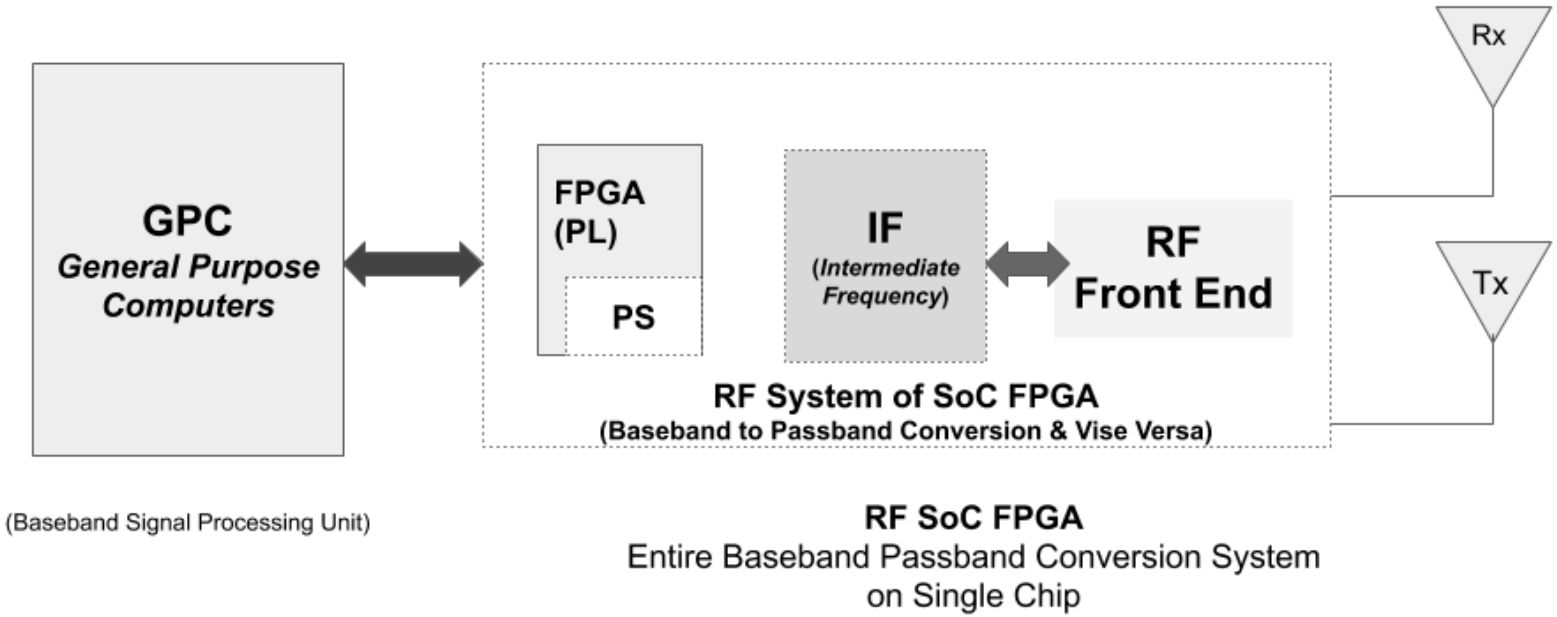
GPP Based SDR with RF SoC



DSP Based SDR

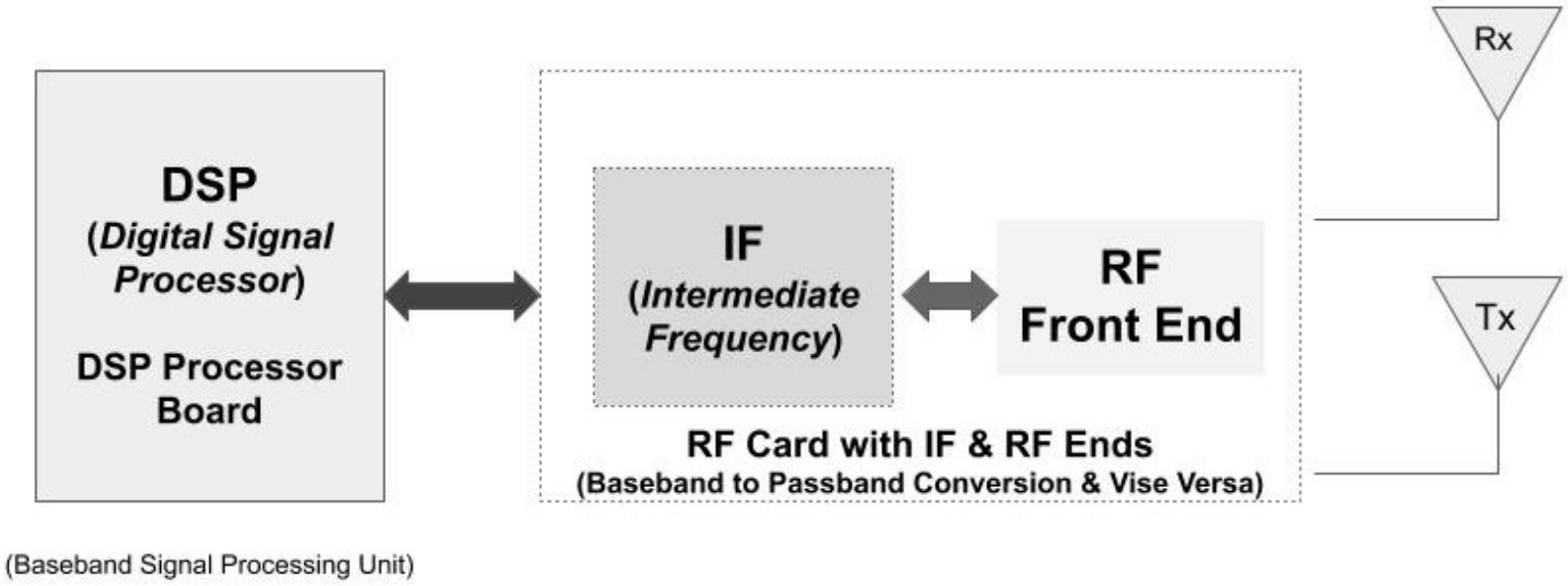


Figure: DSP Based SDR Block Diagram

DSP's like TMS320C6678 (Multi core Fixed and Floating Point Digital Signal Processor) are used to develop Baseband Signal Processing Unit.

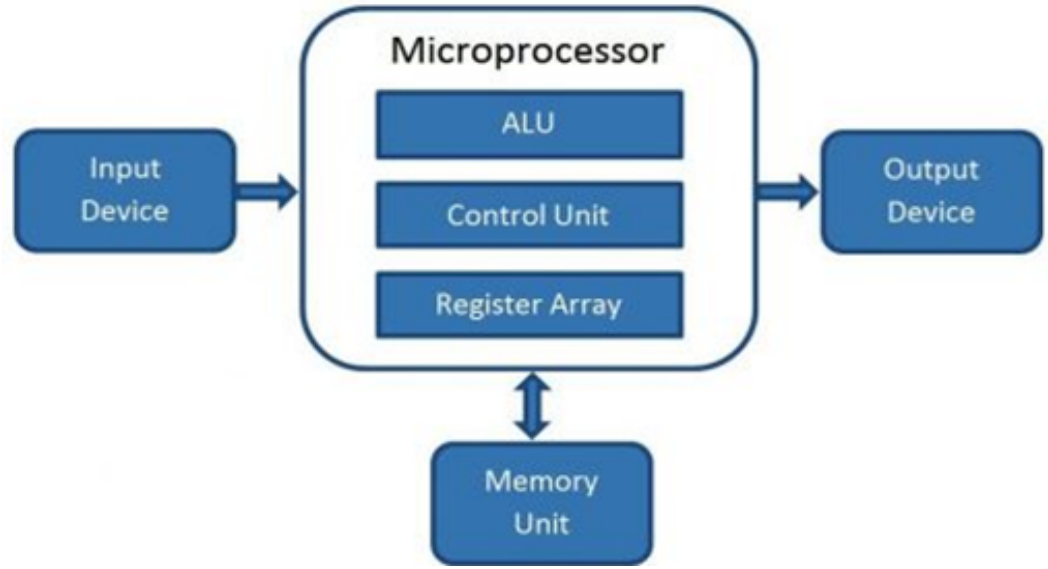
DSP Based SDR

DSP boards are interfaced with RF Cards (Boards) like USRP X310 or RRH to develop DSP base SDR.

- TMS32066xx are one of the best processors to develop SDR
- It can be used for real time prototype development, like Testbed development, DF System etc.
- It is expensive and high processing speed compared to GPP Based SDR.
- It has got its own IDE to develop and dump the C or C++ codes.

Outline

Operation of Processor



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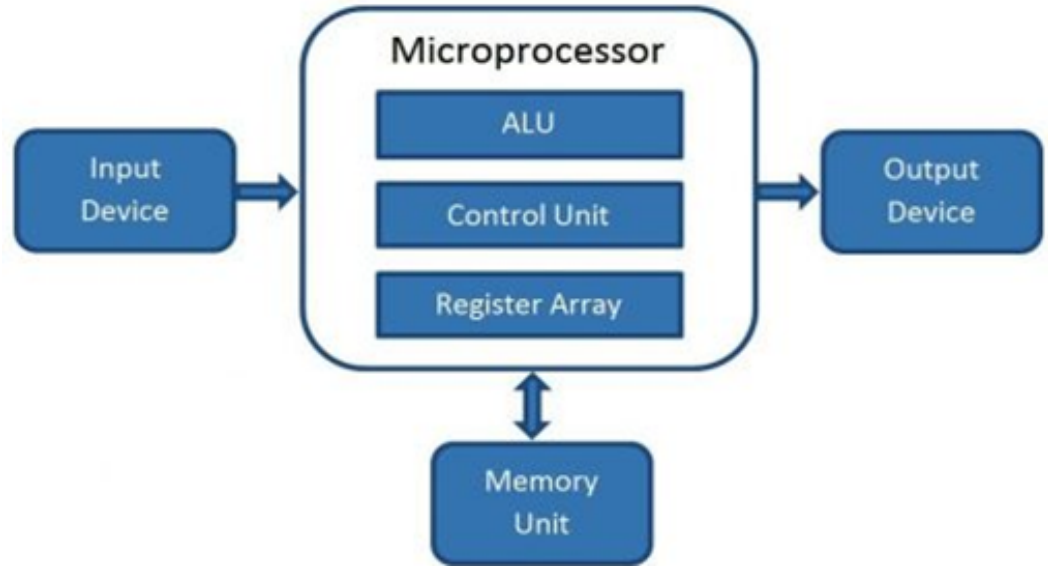

Note : Board & Generic Classification of processors based on architecture is

1. Intel
2. AMD
3. ARM

ARM Processor

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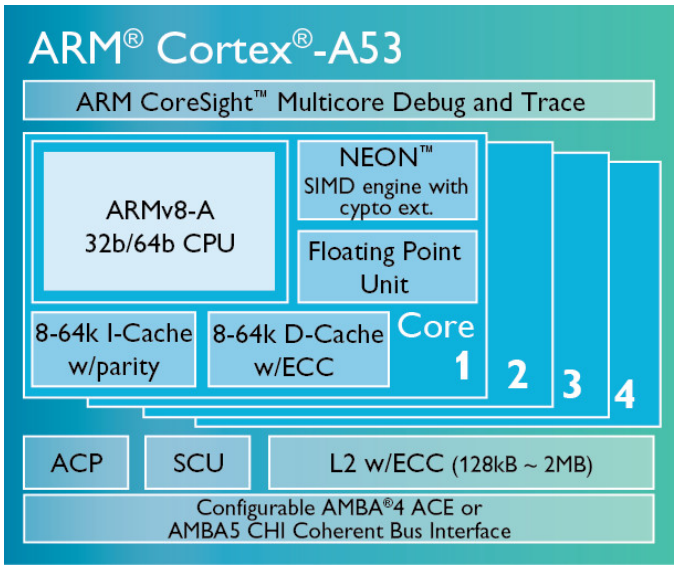
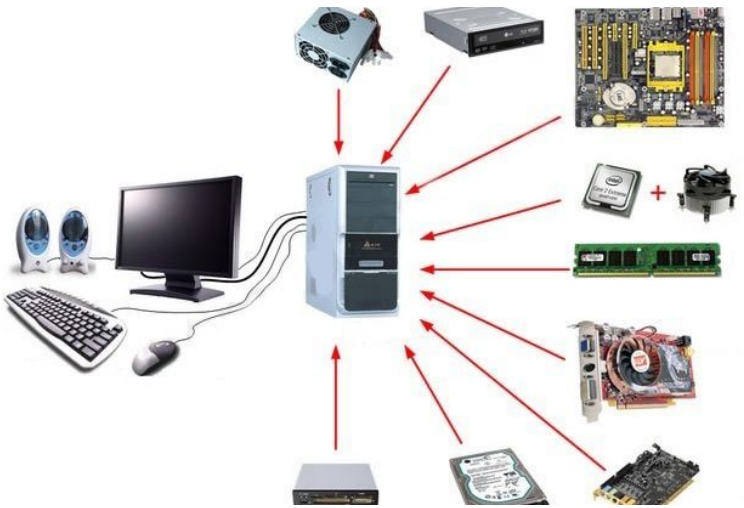
- Famous ARM Processor is Dual/Quad-core Arm Cortex-A53



Computer by ARM Processor



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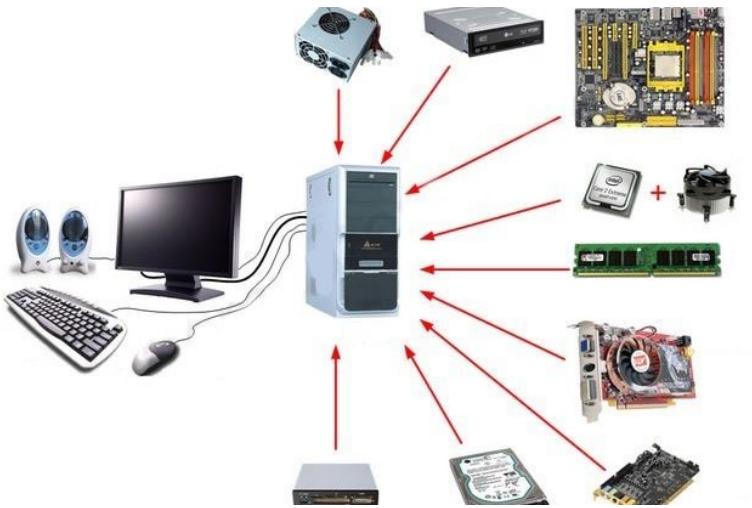

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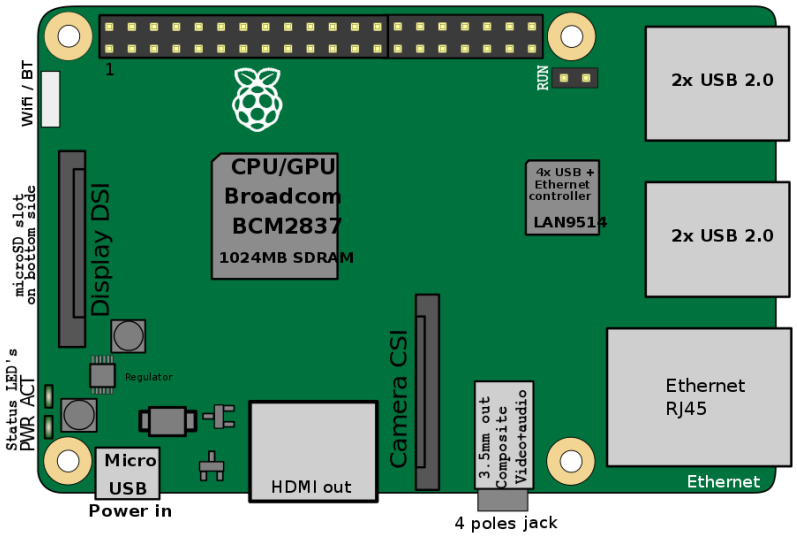

Figure: Raspberry Pi 3 B Plus

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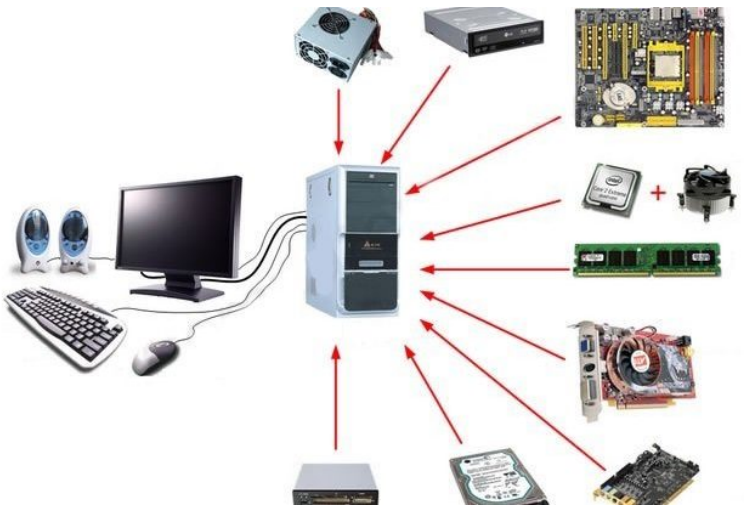

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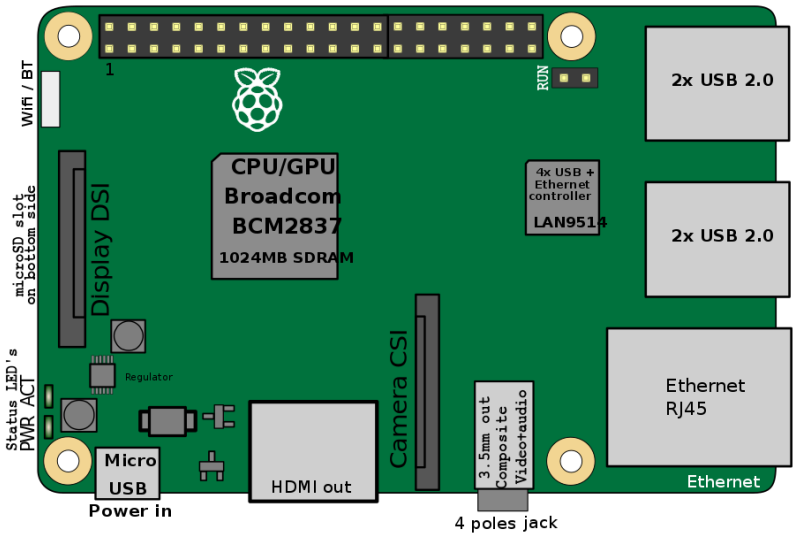

Figure: Raspberry Pi 3 B Plus

- ARM Processor helped to develop Single Board Computer (SBC).
- SBC made prototype development easy and better.

Processor Architecture & Programming

- Assembly, C, C++, Python, MATLAB are the familiar programming languages addressed in hierarchic.

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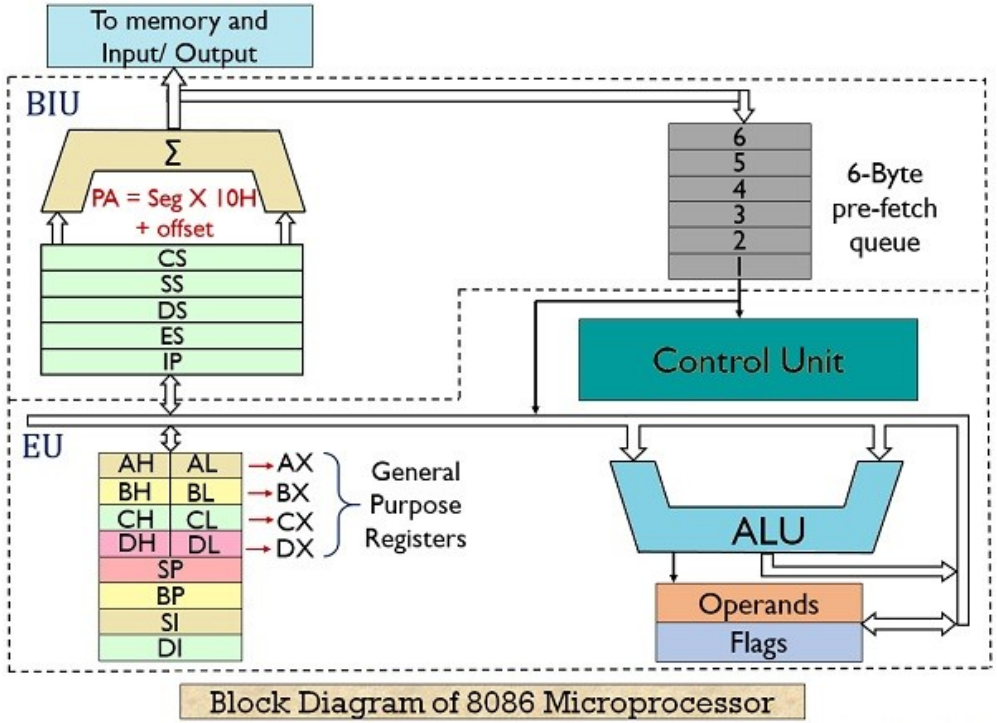

Block Diagram of 8086 Microprocessor

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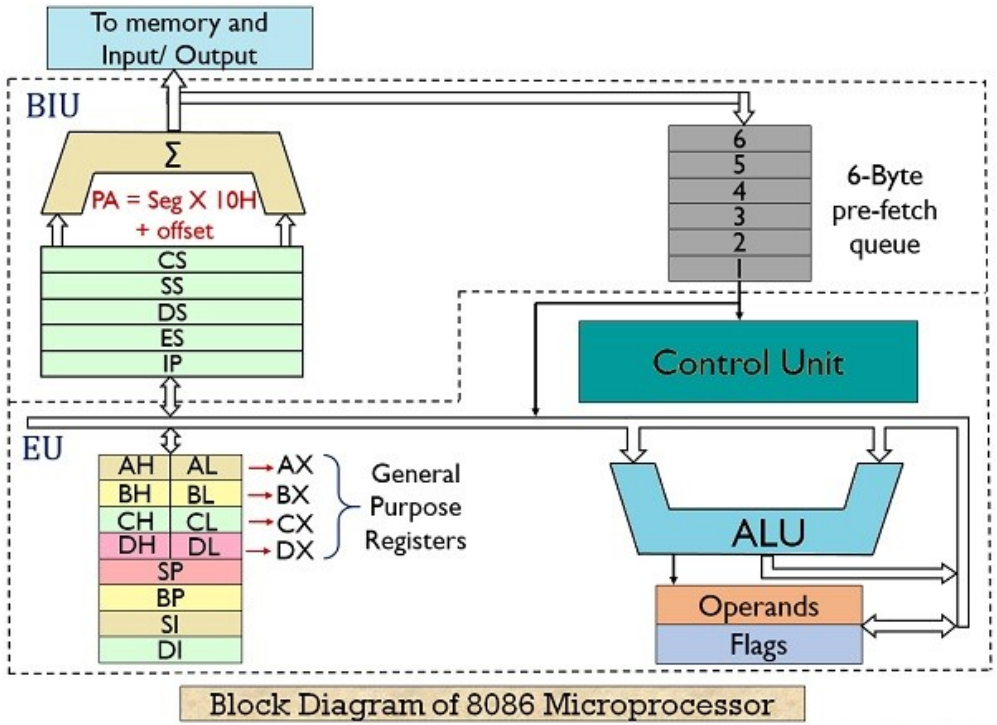

Block Diagram of 8086 Microprocessor

- C, C++ , Python (High level Programming Languages) are architecture Independent.

Program Flow Graph

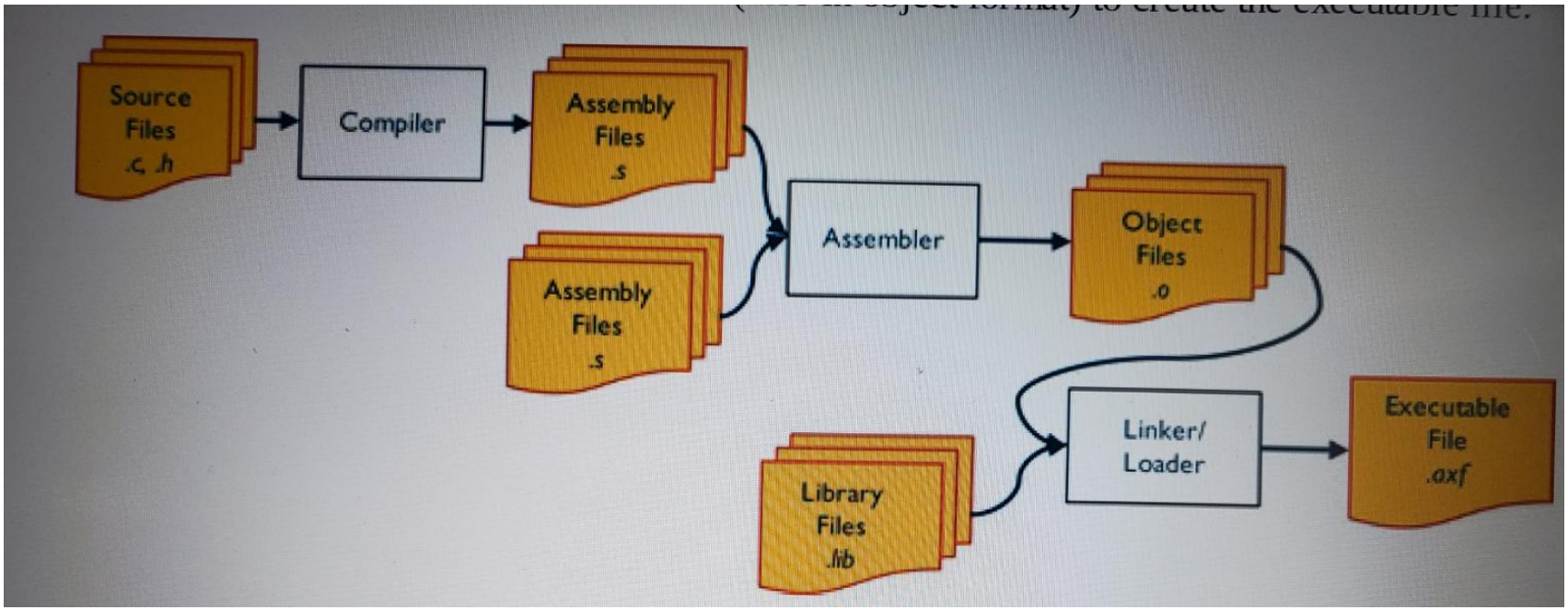

Figure: C Program Flow Graph

FPGA

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- FPGA are semiconductor devices that are based around a matrix of configurable logic blocks (CLBs) connected via programmable interconnects.

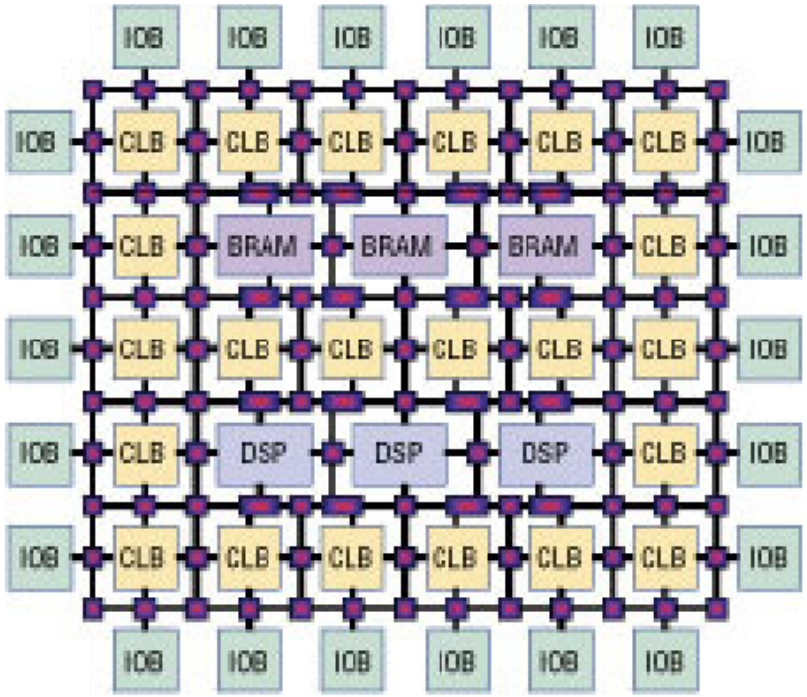

Figure: Internal Architecture of Xilinx FPGA

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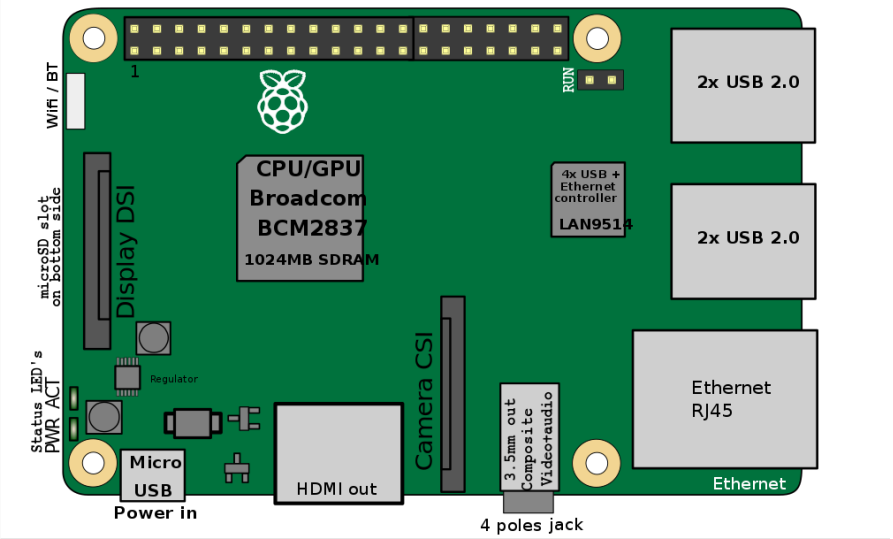
- One-time programmable (OTP) FPGAs are available

Note : Know more, click `https://www.xilinx.com/products/silicon-devices/fpga.html`

FPGA as System Module



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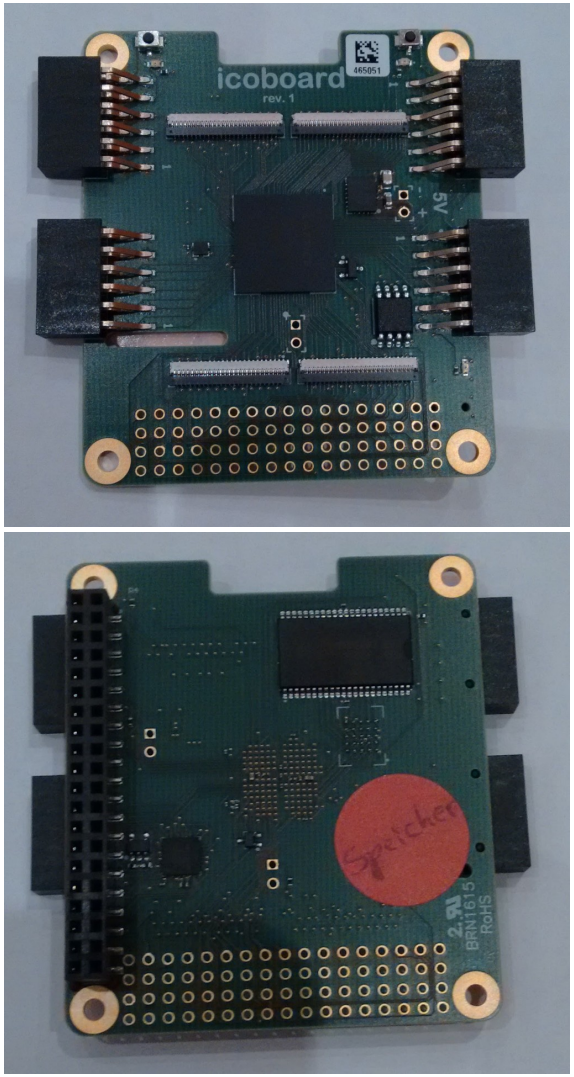


Figure: ICO Board

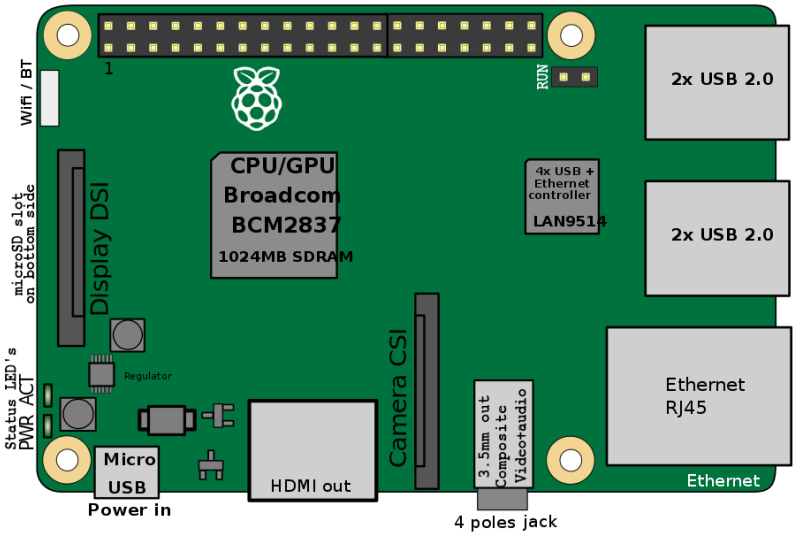


Figure: Raspberry Pi 3 B Plus

FPGA vs SoC FPGA

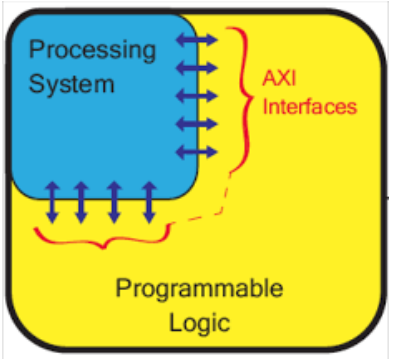


Figure: System-on-Chip FPGA

FPGA vs SoC FPGA

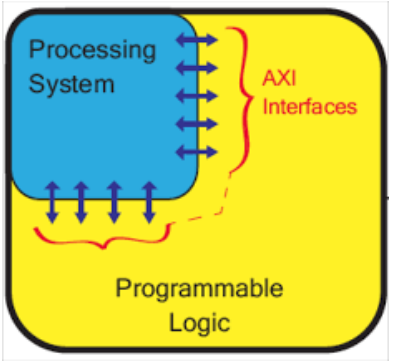


Figure: System-on-Chip FPGA

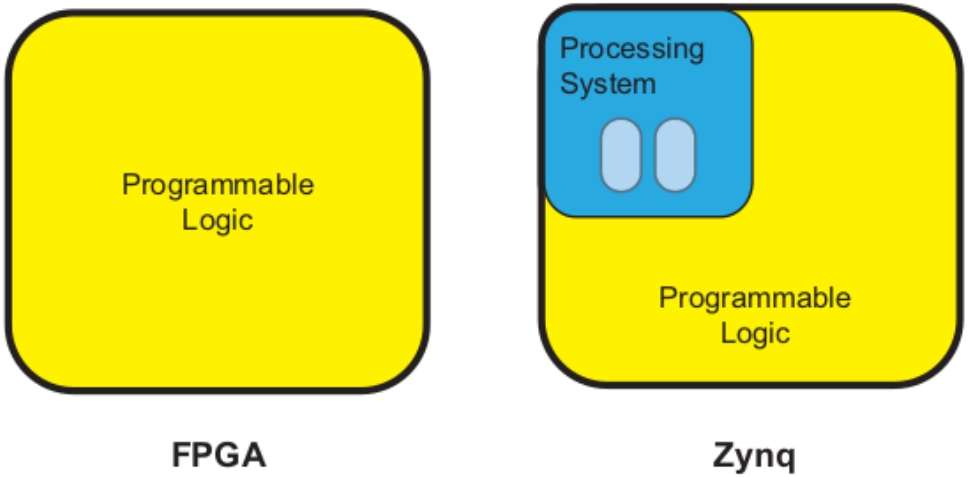


Figure: FPGA Vs SoC FPGA

FPGA as System Module with TPU

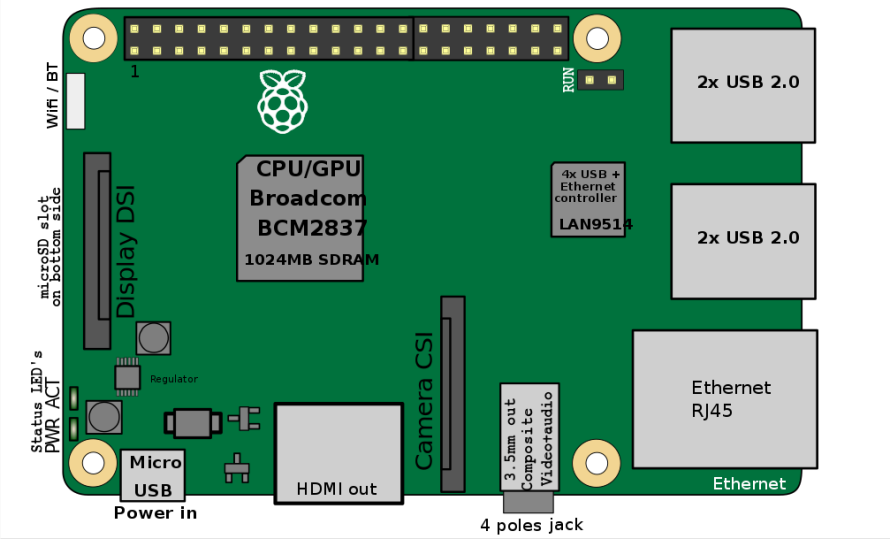


Figure: Raspberry Pi 3 B Plus

FPGA as System Module with TPU

Figure: ARM TPU

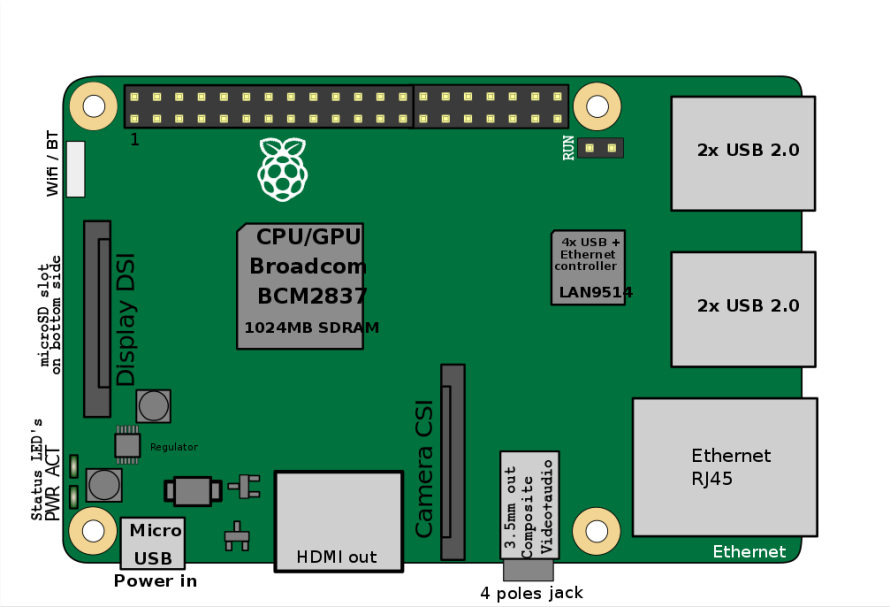


Figure: Raspberry Pi 3 B Plus

FPGA as System Module with TPU

Figure: ARM TPU

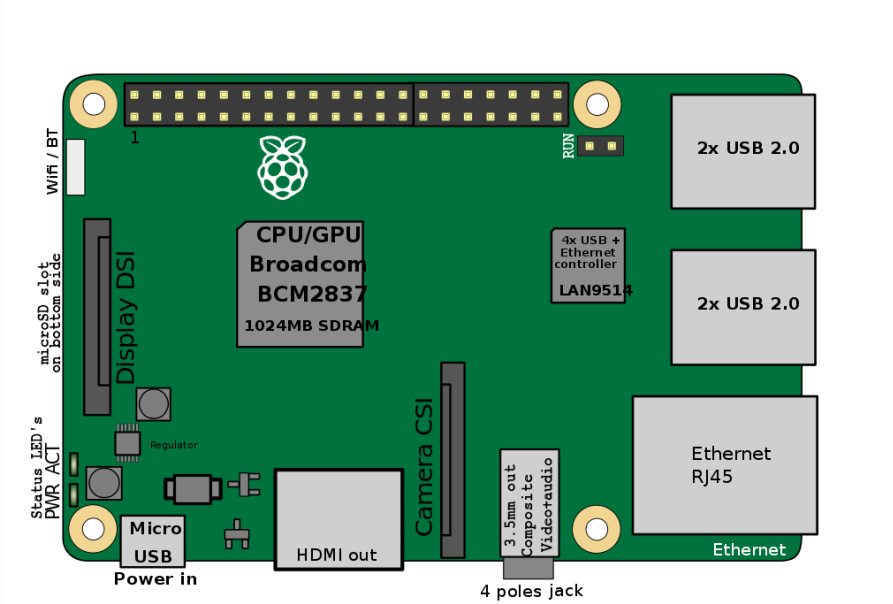
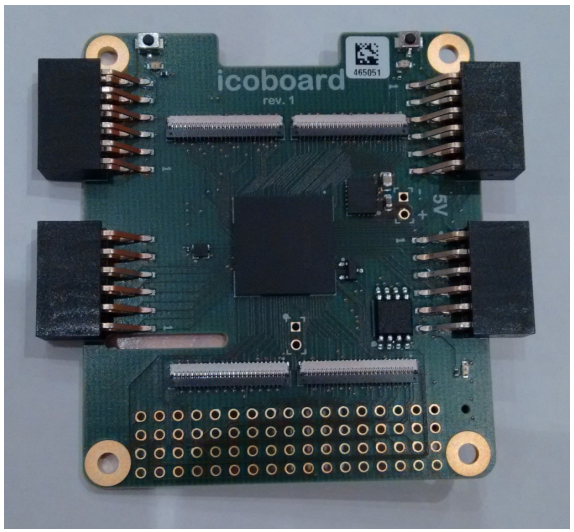


Figure: Raspberry Pi 3 B Plus



FPGA, SoC FPGA, MP SoC FPGA

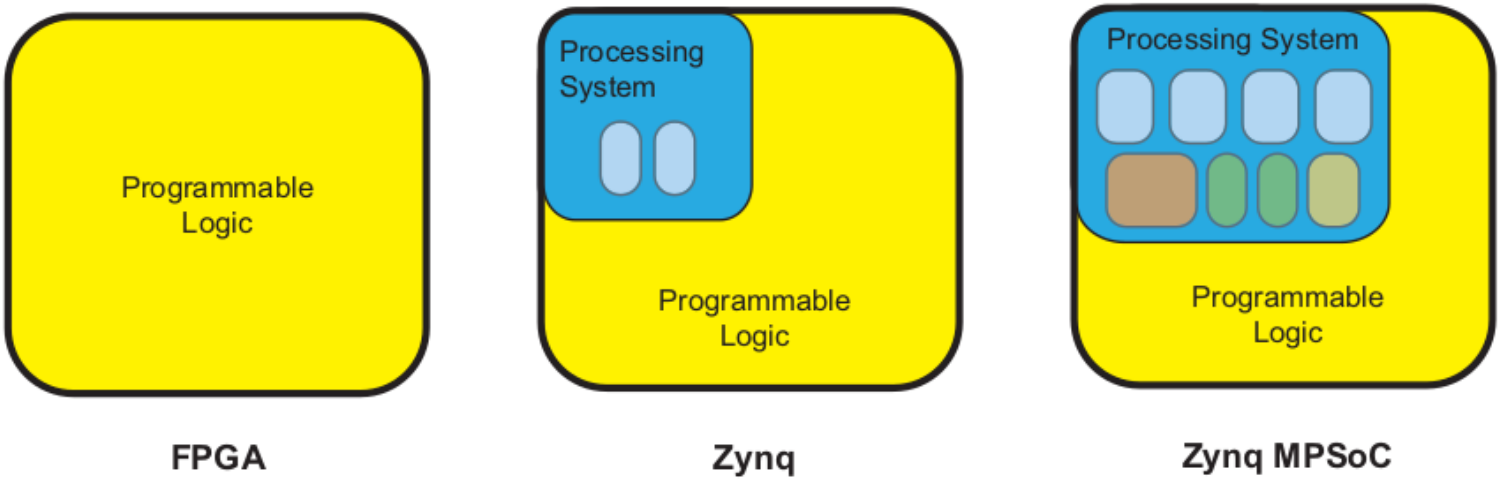


Figure: FPGA to MP SoC Hierarchic

Outline

Types of SoC FPGA

PROCESSING SYSTEM	Zynq-7000 SoC	Zynq UltraScale+ MPSoC	Zynq UltraScale+ RFSoC
Application Processing Unit	Single/Dual-core Arm Cortex-A9 MPCore™ up to 1GHz	Dual/Quad-core Arm Cortex-A53 MPCore up to 1.5GHz	Quad-core Arm Cortex-A53 MPCore up to 1.33GHz
Real-Time Processing Unit	-	Dual-core Arm Cortex-R5 MPCore up to 600MHz	Dual-core Arm Cortex-R5 MPCore up to 533MHz
Multimedia Processing	-	GPU Arm Mali™-400 MP2 up to 667MHz, Video Codec supporting H.264-H.265	-
Dynamic Memory Interface	DDR3, DDR3L, DDR2, LPDDR2	DDR4, LPDDR4, DDR3, DDR3L, LPDDR3	DDR4, LPDDR4, DDR3, DDR3L, LPDDR3
High-Speed Peripherals	USB 2.0, Gigabit Ethernet, SD/SDIO	PCIe® Gen2, USB3.0, SATA 3.1, DisplayPort, Gigabit Ethernet, SD/SDIO	PCIe® Gen2, USB3.0, SATA 3.1, DisplayPort, Gigabit Ethernet, SD/SDIO
Security	RSA, AES, and SHA, Arm TrustZone®	RSA, AES, and SHA, Arm TrustZone	RSA, AES, SHA, Arm TrustZone
Max I/O Pins	128	214	214

Figure: PS Comparison

Types of SoC FPGA

PROGRAMMABLE LOGIC	Zynq-7000 SoC	Zynq UltraScale+ MPSoC	Zynq UltraScale+ RFSoC
Max Logic Cells / System Logic Cells (K)	444	1,143	930
Max Memory (Mb)	26.5	70.6	60.5
Max DSP Slices	2,020	3,528	4,272
33G Transceivers	-	-	16
Max I/O Pins	250	668	408

Figure: PL Comparison

SoC FPGA Based SDR

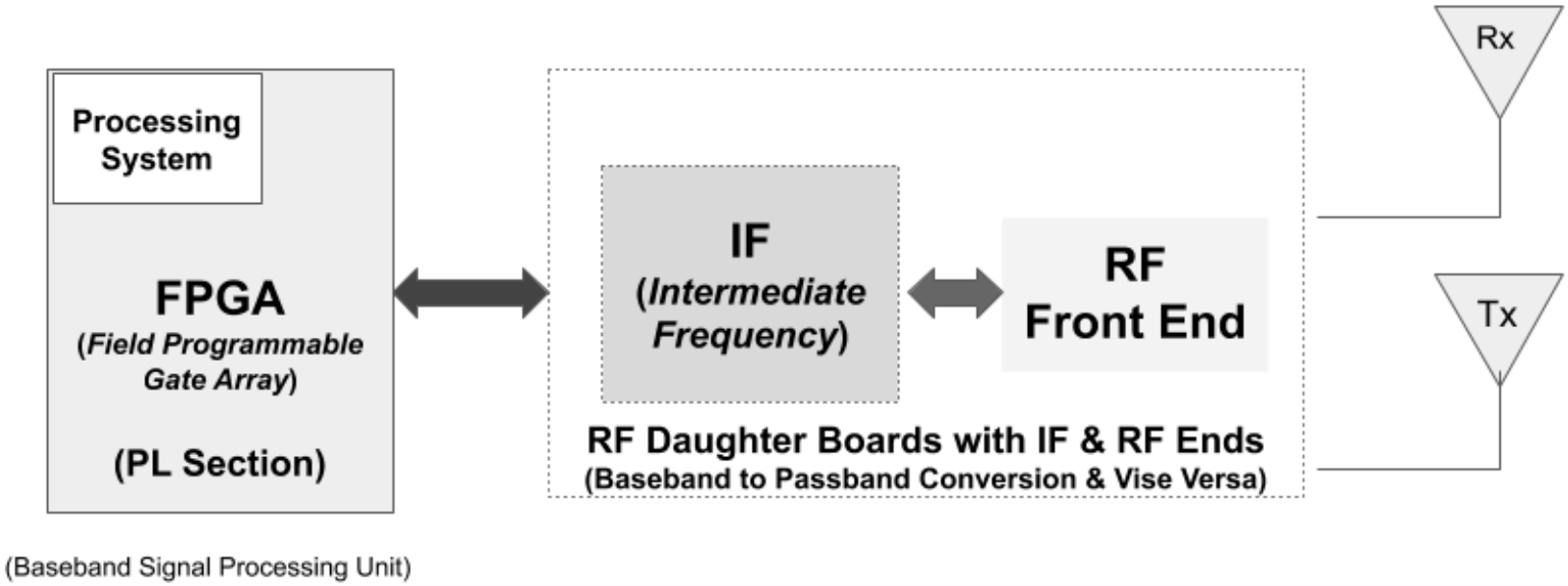


Figure: Soc FPGA Based SDR Block Diagram

- SoC FPGA based SDR are broadly Classified into two types, RF SoM & RF SoC
- RF SoM : RF System-on-Module
- RF SoC : RF System-on-Chip

Outline

RF System-on-Module (RF SoM)

- AD9364 is a Transceiver Chip
- Board with the chip is a Transceiver Card

Figure: RF Transceiver Card

RF System-on-Module (RF SoM)

- AD9364 is a Transceiver Chip
- Board with the chip is a Transceiver Card

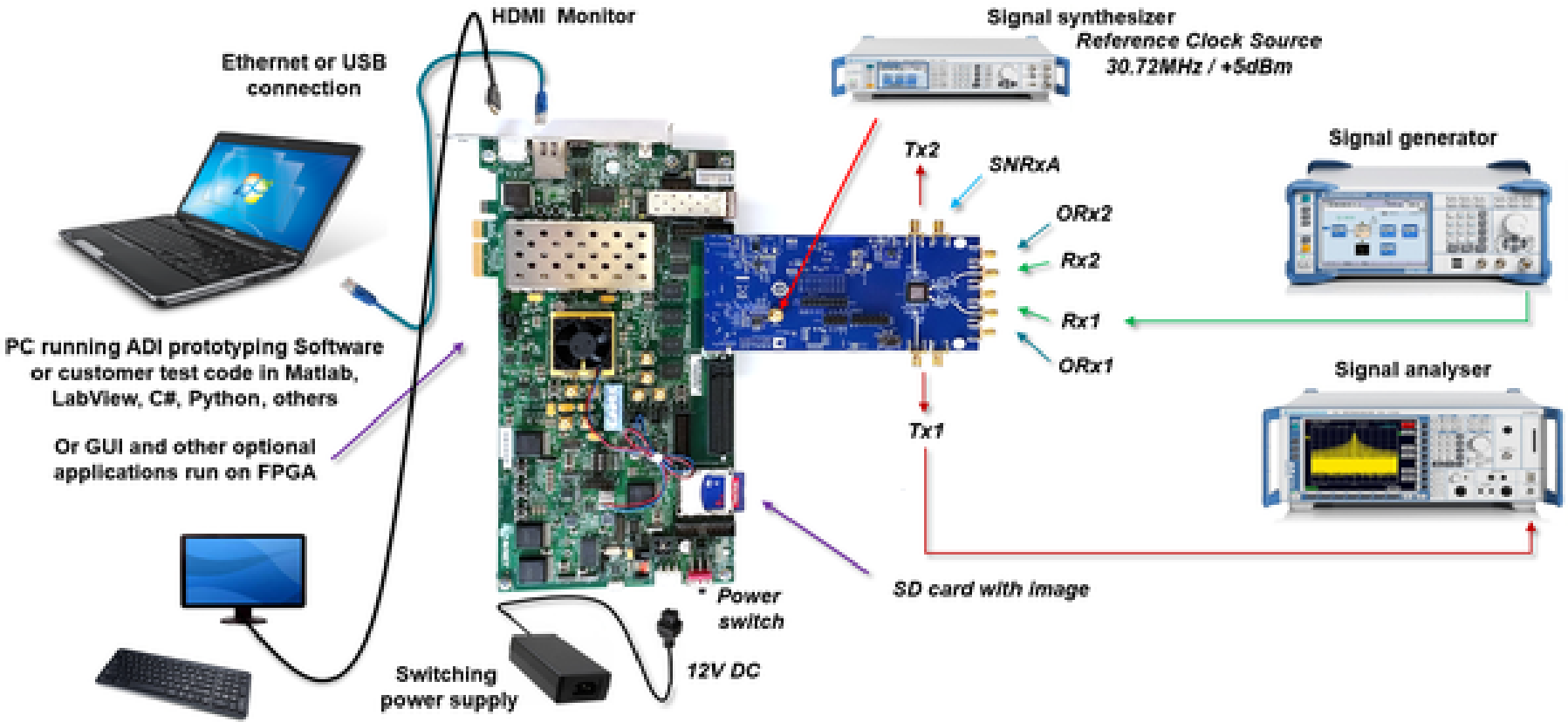
Figure: RF Transceiver Card

Figure: RF SoM using Zedboard

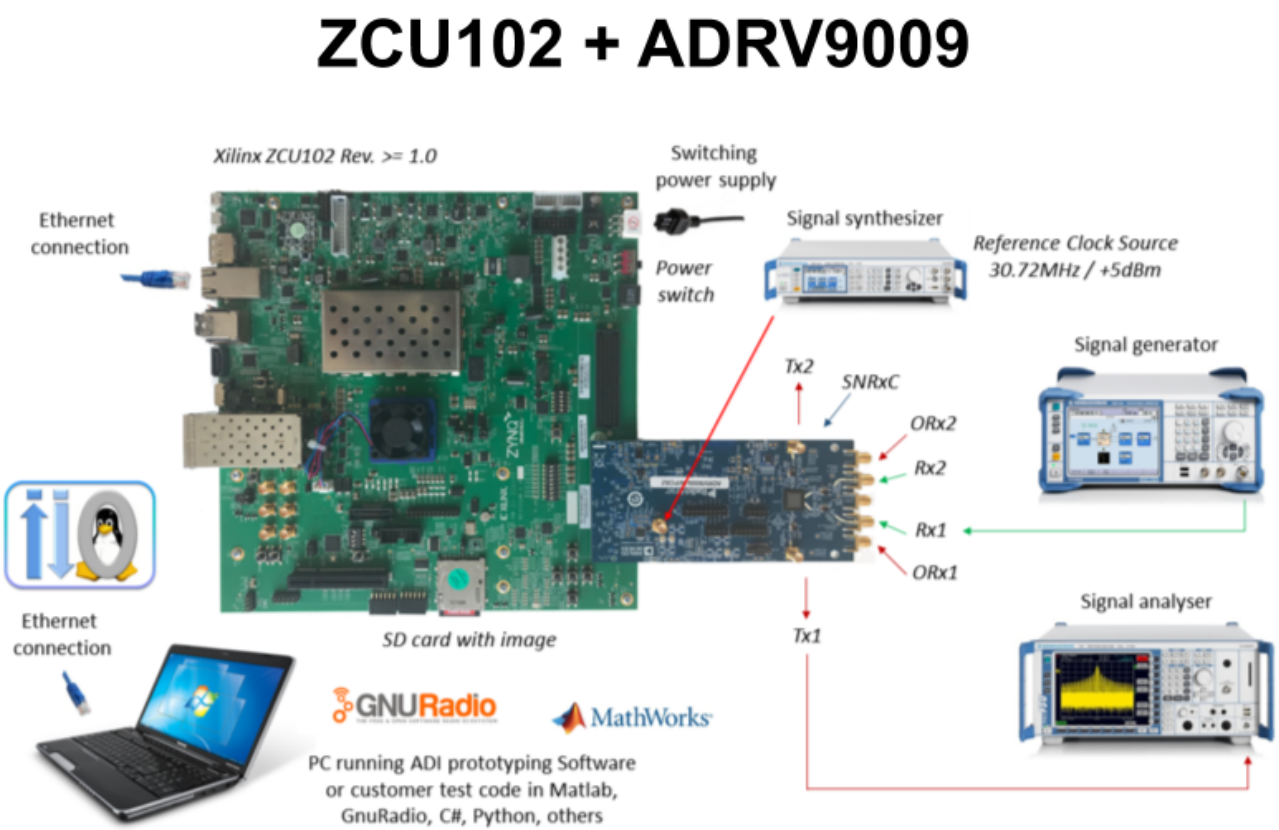
- RF Transceiver Card is place on ZedBoard to form an RF Module. (SoC gives farmware and control support)
- RF Module is used for the development of an RF System . So, it is known as RF System-on-Module

RF SoM with Zynq SoC

ZC706 - ADRV9371

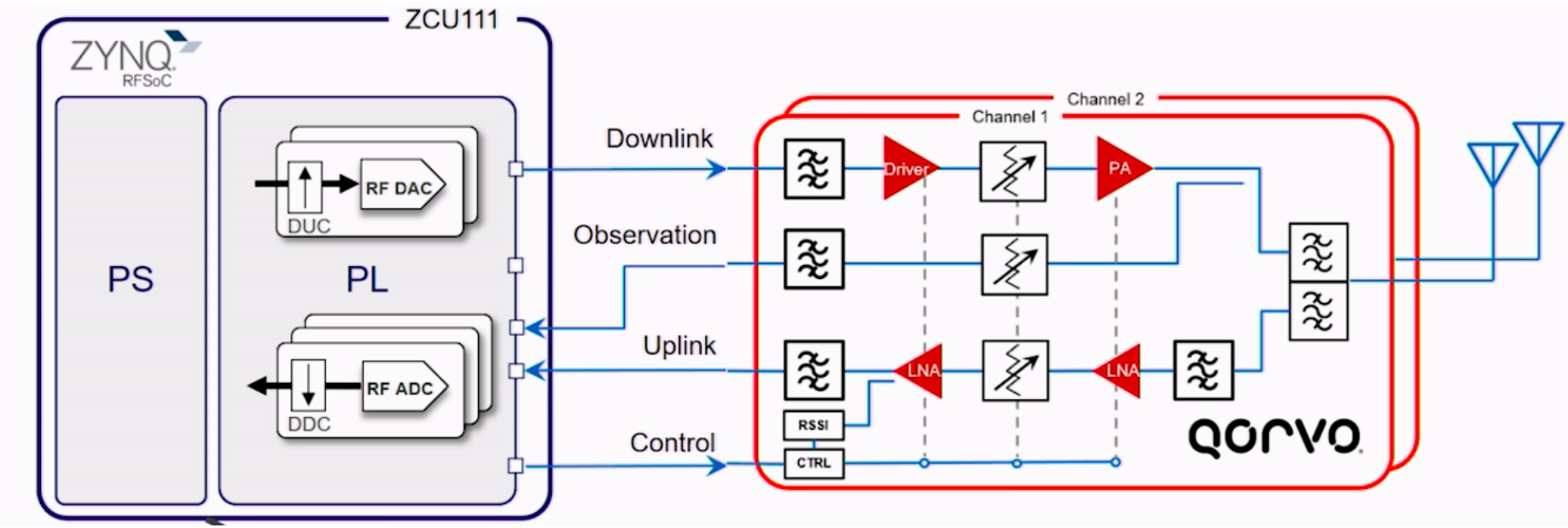


RF SoM with Zynq MP SoC

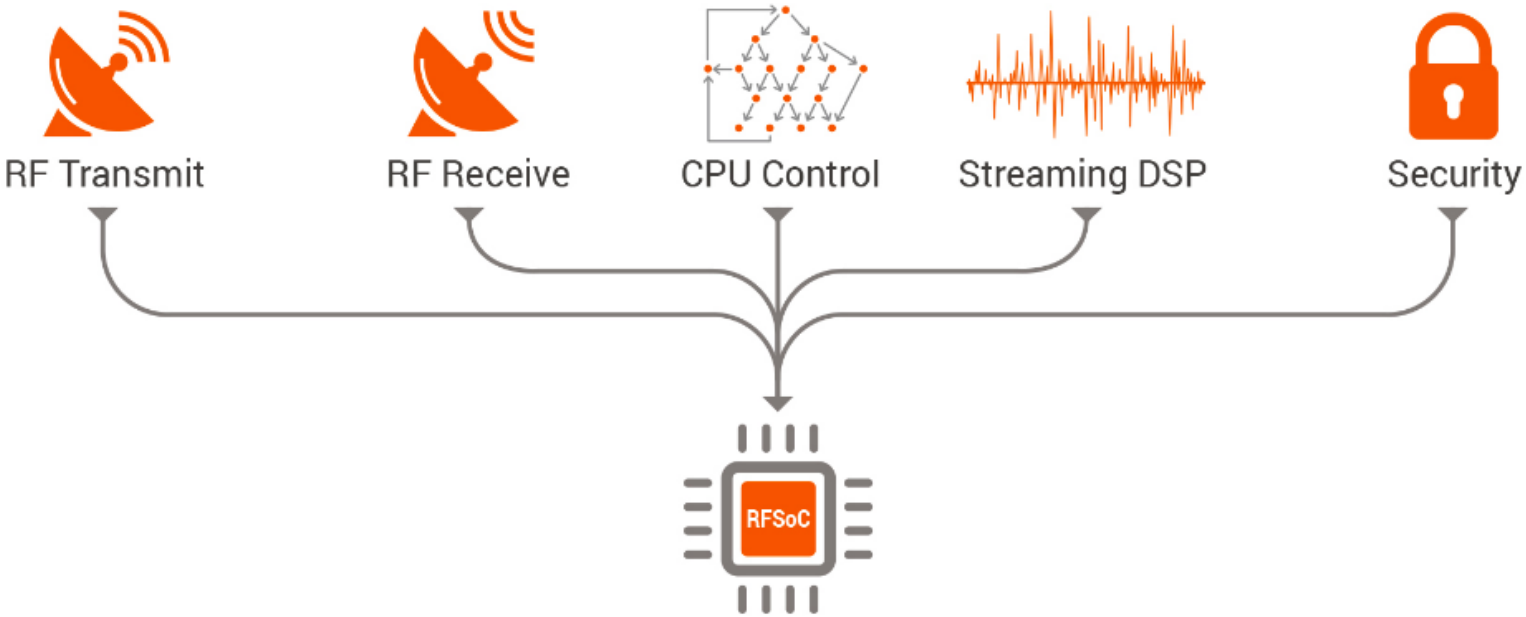


Outline

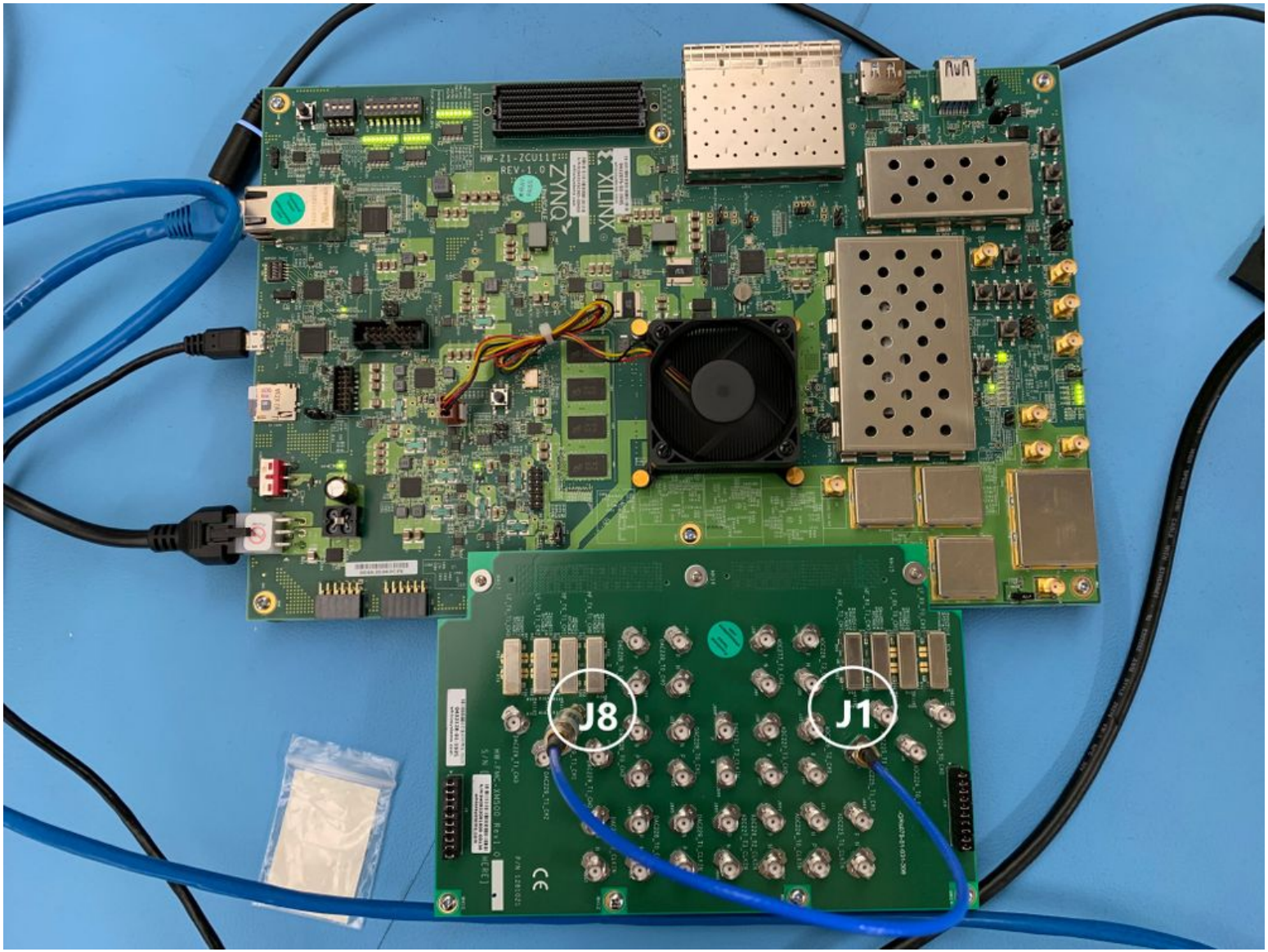
Radio Frequency System-on-Chip



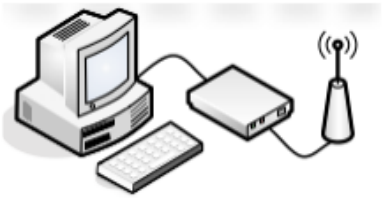
Radio Frequency System-on-Chip



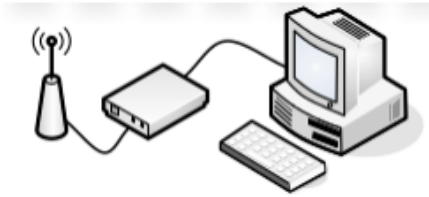
RF SoC ZCU111



SISO

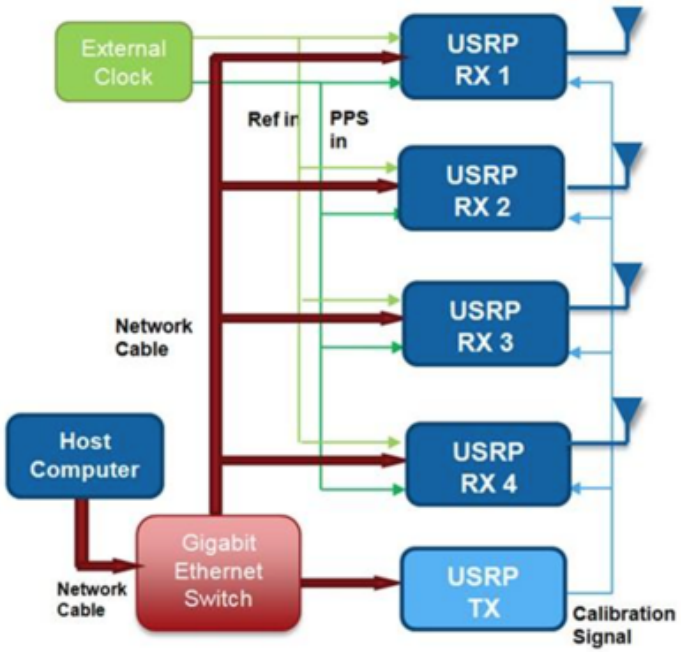


SDR Tx



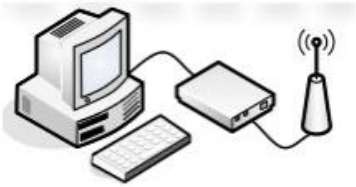
SDR Rx

MIMO & DoA

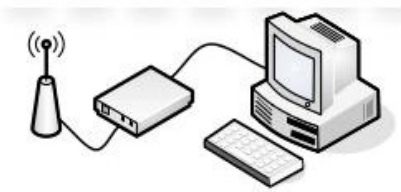

External Clock
Ref in
PPS in
USRP RX 1
USRP RX 2
USRP RX 3
USRP RX 4
USRP TX
Network Cable
Host Computer
Gigabit Ethernet Switch
Network Cable
Calibration Signal

4G LTE or 5G NR Prototype

Core Network



4G LTE : eNB
5G NR : gNB



4G LTE : UE
5G NR : NR UE

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