Digital Communication Systems Engineering with Software-Defined Radio

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Lecture 02

Microelectronics Evolution is Key!

- Rapid evolution of microelectronics over the past several decades
  - **Moore's Law** defines the long-term trend of the number of transistors accommodated on an integrated circuit
  - Doubling number of transistors per integrated circuit approximately every two years
  - Affects processing speed and memory
- Microelectronics industry has significantly influenced digital communication systems sector
  - Digital communication transceivers are becoming more *versatile*, *powerful*, and *portable*
- Microelectronics advancements have given rise to **software-defined radio** (SDR) technology
  - Baseband radio functions can be *entirely* implemented in digital logic and software

Types of Microelectronics for SDR Implementation

- General Purpose Microprocessor
  - Very flexible in terms of reconfigurability
  - Easy to implement new digital communication modules
  - Not specialized for mathematical computations
  - Potentially power inefficient
- Digital Signal Processor (DSP)
  - Specialized for performing mathematical computations
  - Easy to implement new digital communication modules
  - Potentially slow for computationally expensive processes
  - Can be power efficient (e.g., used in cellular telephones)
- Field Programmable Gate Array (FPGA)
  - Computationally powerful
  - Power inefficient
  - Not flexible nor easy to implement new modules
- Graphics Processing Unit (GPU)
  - Extremely powerful computationally
  - Difficult to use and implement new modules

SDR Definition

- A class of reconfigurable/reprogrammable radios whose physical layer characteristics can be significantly modified via software changes
  - Capable of implementing different functions at different times on the same platform
  - Defines in software baseband radio features, e.g., modulation, error correction coding
  - Possesses some software control over RF front-end operations, e.g., transmission carrier frequency
- Baseband radio functionality stored in memory
  - Different types of modulation, error correction coding, and other functional blocks are available to the SDR platform
  - Functional blocks can potentially be changed in real-time
- Operating parameters of functional blocks can be adjusted either by human operator or automated process

SDR Key Features[1]

- **Multifunctionality** – Possessing the ability to support multiple types of radio functions using the same digital communication system platform
- **Global Mobility** – Transparent operation with different communication networks located in different parts of the world, i.e., not confined to just one standard
- **Compactness and Power Efficiency** – Many communication standards can be supported with just one SDR platform
- **Ease of Manufacturing** – Baseband functions a software problem, not a hardware problem
- **Ease of Upgrading** – Firmware updates can be performed on SDR platform to enable functionality with latest communication standards

[1] From *Software Radio: A Modern Approach to Radio Engineering* by Jeffrey H. Reed (Prentice Hall, 2002).

Example of Multifunctionality

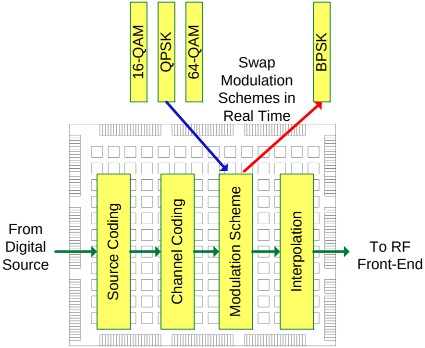

Figure : Swapping Different Modulation Schemes on the Same FPGA.

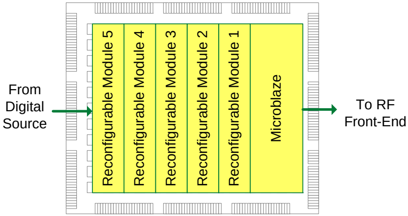

Figure : Digital Communication Transmitter Chain on FPGA using *Multiprocessor System-on-Chip* (MPSoC) Concept.

Digital Communication Transceiver – Revisted

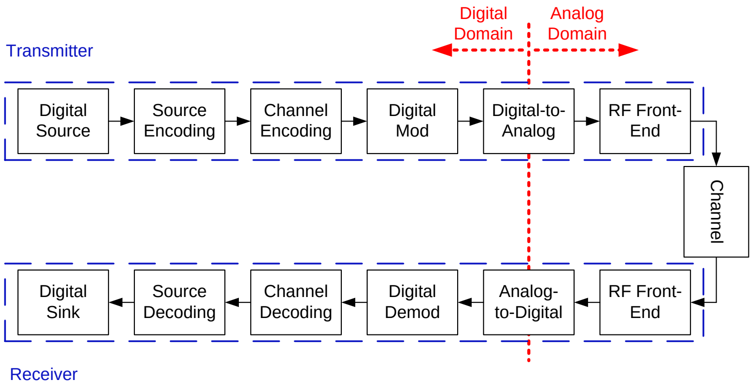

Figure : Generic representation of a digital communication transceiver.

Software Component

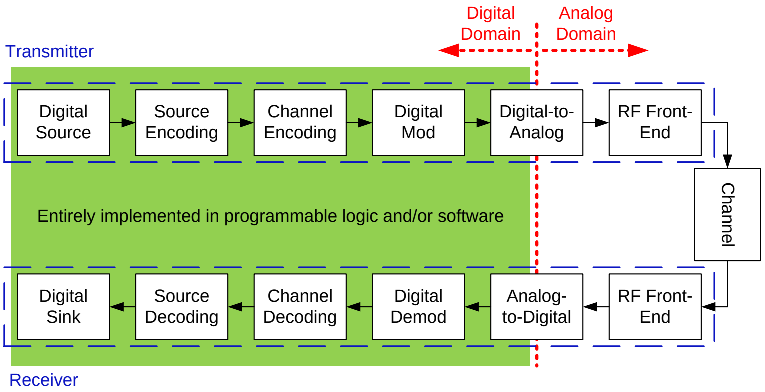

Figure : Generic representation of a digital communication transceiver.

Hardware Component

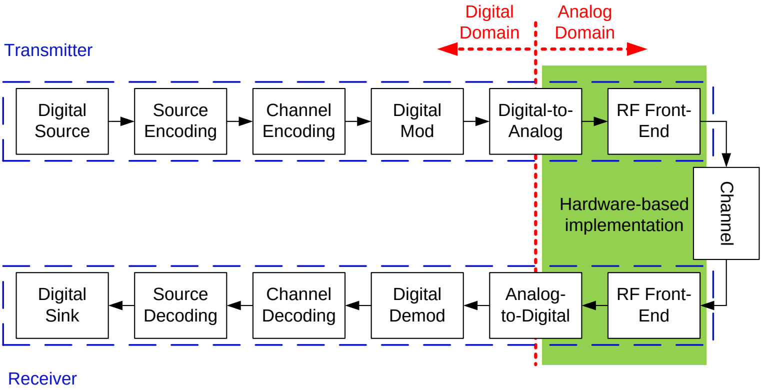

Figure : Generic representation of a digital communication transceiver.

History of SDR Development

- "Software-defined radio" first coined by Joseph Mitola in 1991 although SDR technology was available since the 1970s
- First publicly funded SDR development initiative was *SpeakEasy I/II* by the U.S. military
  - Employed programmable microprocessors for implementing more than ten military communication standards
  - Transmission carrier frequencies ranged from 2 MHz to 2 GHz
  - Allowed for upgrades of new functional blocks, such as modulation schemes and coding schemes
  - Initially used Texas Instruments TMS320C40 processor (40 MHz)
  - SpeakEasy II was the first SDR platform to involve FPGA modules for implementing digital baseband functionality
  - Physical size of prototype fit in the back of a truck
  - Read "SPEAKeasy, the Military Software Radio" by Upmal and Lackey in *IEEE Communications Magazine* (IEEE Press, 1995)

List of Currently Available SDR Platforms

- **Joint Tactical Radio System** – Next-generation voice-and-data radio used by the U.S. military and employs *software communications architecture* (SCA)
- **Berkeley BEE2** – BEE2 is targeted as a powerful reconfigurable computing engine with five Xilinx Virtex-II Pro FPGAs on the emulation board
- **Rice University WARP** – WARP radios include a Xilinx Virtex-II Pro FPGA board as well as a MAX2829 transceiver
- **Kansas University Agile Radio** – KUAR is a small form factor SDR platform containing a Xilinx Virtex-II Pro FPGA board and a PCI Express 1.4 GHz Pentium-M microprocessor
- **Lyrtech Small Form Factor SDR** – Industry collaboration between Texas Instruments and Xilinx
- **Universal Software Radio Peripheral 1/2** – Inexpensive, open source, modular, flexible SDR platform

The USRP Concept

- Relatively inexpensive hardware for enabling SDR design and development
- All baseband processing conducted on computer workstation "host"
  - USRP platform acts as a radio peripheral allowing for over-the-air transmissions
  - `libusrp` defines interface between USRP platform and host computer workstation
- USRP design is open source $\rightarrow$ allows for user customization
- Platform design is modular in terms of supported RF front-ends, referred to as *daughtercards*
- Two types of USRP platforms: **USRP1** and **USRP2**

Universal Software Radio Peripheral 1

- Designed and manufactured by Ettus Research LLC for a variety of different communities interested in an inexpensive SDR platform

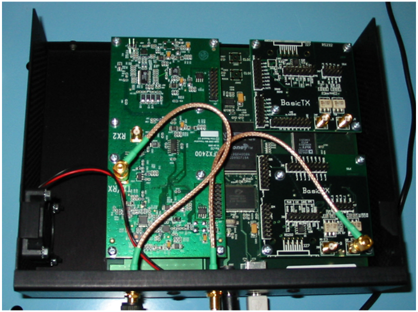

Figure : USRP1 motherboard.

USRP1 Features

- USB interface between host computer workstation and USRP1 platform → data bottleneck
- Supports up to two RF transceiver daughtercards
- Possesses an Altera Cyclone EP1C12Q240C8 FPGA for performing sampling and filtering
- Contains four high-speed analog-to-digital converters, each capable of 64 MS/s at a resolution of 12 bit, with 85dB SFDR (AD9862)
- Contains four high-speed digital-to-analog converters, each capable of 128 MS/s at a resolution of 14 bit, with 83dB SFDR (AD9862)

Universal Software Radio Peripheral 2

- Officially released in September 2008, the USRP2 platform provides a more capable SDR device for enabling digital communication system design and implementation

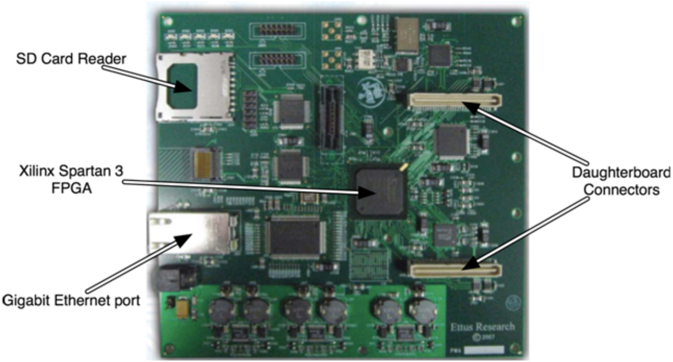

Figure : USRP2 motherboard.

USRP2 Features

- Gigabit Ethernet interface between host computer workstation and USRP2 platform
- Supports only one RF transceiver daughtercard
- Possesses a Xilinx Spartan 3-2000 FPGA for performing sampling and filtering
- Contains two 100 MS/s, 14 bit, analog-to-digital converters (LTC2284), with a 72.4dB SNR and 85dB SFDR for signals at the Nyquist frequency
- Contains two 400 MS/s, 16 bit, digital-to-analog converters (AD9777), with a 160 MSPS without interpolation, and up to 400 MSPS with 8x interpolation
- MIMO-capable for supporting the processing of digital communication system designs employing multiple antennas

RF Daughtercards

- RF front-ends are very difficult to design and are usually limited to a narrow range of transmission carrier frequencies
  - Properties of the RF circuit and components changes across different frequencies
  - RF filters constrained in sweep frequency range
- To support a wide range of transmission carrier frequencies, both USRP1 and USRP2 platforms can use an assortment of modular RF daughtercards
  - BasicTX, 1-250 MHz Transmitter, for use with external RF hardware
  - BasicRX, 1-250 MHz Receiver, for use with external RF hardware
  - RFX900, 800-1000 MHz Transceiver, 200+mW output
  - RFX2400, 2.3-2.9 GHz Transceiver, 20+mW output
  - XCVR2450, Dual-band Transceiver, 100+mW output at 2.4-2.5 GHz and 50+mW output 4.9-5.85 GHz

Software Environment for USRP 1/2 Platforms

- **GNU Radio** – Open source software consisting of C/C++ libraries wrapped with Python scripts used to define various digital communication modules
- **GNU Radio Companion** – A graphical user interface for GNU Radio that enables the end user to design digital communication baseband implementations
- **OSSIE** – Another graphical user interface devised by researchers at Virginia Tech
- **WPI/MathWorks Simulink Interface** – Simulink blocks that streamed data between the USRP2 platform and the Simulink environment