Software Defined Radio

Applications and Challenges

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October 13, 2015

Introduction

- Advances within the wireless sector have always been closely coupled to corresponding improvements in digital technology.
- Until the 1950s, wireless systems operated exclusively in the analog domain, where communications functions such as modulation and filtering were performed using analog circuits and components.
- The process of designing a robust communication system was time consuming and costly.

Introduction

- With rapid evolution of digital technology, especially ADC and DAC, it became possible to perform these same communication functions within the digital domain.
- This resulted in reducing cost, enabling mass production of devices, and providing a greater flexibility and system functionality, e.g. cellular phones.
- However, these devices were programmed with a static set of operations to be performed such as filtering, data compression, modulation etc.

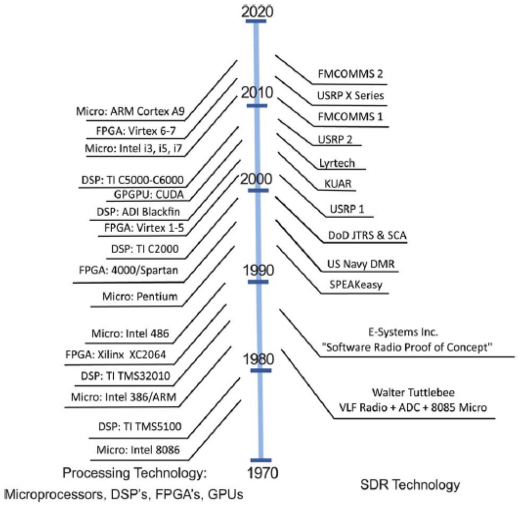
Introduction

- During the 1970s engineers began experimenting with wireless transceivers that possessed programmable, or software-defined, attributes.
- These platforms used computing technologies such as field programmable gate array (FPGA).
- Since then, there has been substantial research by industry, government, and academia, to create more versatile and powerful Software Defined platforms.

Brief History

- The term Software Radio was introduced by Joseph Mitola in 1992.
- The establishment of SDR as a technology came with the platform called SpeakEasy I/II by the U.S. military.
- But it was only after the year 2000, with powerful FPGAs, that most of the existing SDR platforms were developed.

Brief History



What is SDR

- In traditional radios, all functions are performed by specialized components that execute specific tasks. All signal processing happens within the specialized hardware.
- Software-defined radio technology replaces some of the traditional radio components with components implemented in software.
- This means that hardware like filters, amplifiers, modulators etc are implemented in software on personal computers or some embedding devices.

SDR Architecture

- A software-defined radio transceiver is divided into two main parts:

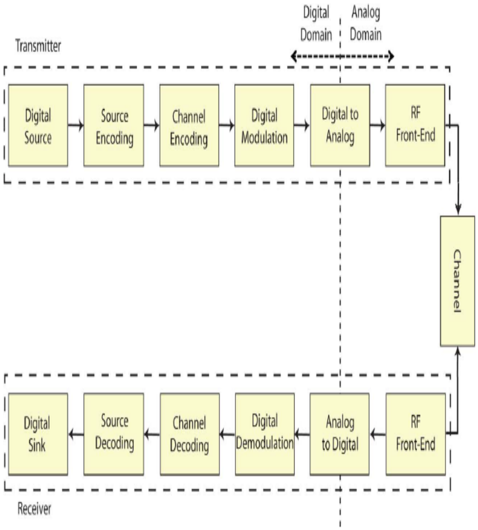
1. An analog front-end, which performs the frequency down-conversion followed by an analog-to-digital conversion.

2. The digital signal processing components in SW, which are responsible for the remaining signal processing flow.

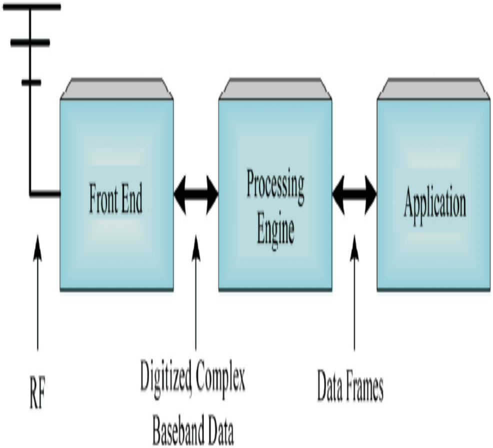
SDR Architecture

- Basically, a signal is captured by an antenna and converted into digital samples with regular intervals.
- These digital values are then processed in software, where the required application is written.
- The resulting output can be then converted back into audio, video or required form.

Signal Processing Blocks



SDR Block Diagram



Why SDR?

- The main advantage of having components implemented in software is flexibility.
- Different frequency bands, air interface protocols, and functionalities can be upgraded through software download instead of having to completely replace the hardware.
- Other benefits include: ease of design and manufacture, multi-mode operation, use of advanced signal processing techniques, fewer discrete components, reduced obsolescence and ubiquitous connectivity.

Why SDR?

- As an example, users could use SDR on personal wireless devices where vendors have integrated GSM, WCDMA, GPRS, IS-95, EV-DO, Wi-Fi, WiMAX or Bluetooth in a single device and they need only update the newest radio modules via download.
- In the military, application such as U.S. DoD Joint Tactical Radio System (JTRS) is still being developed as a device which supports more than 20 different standards to establish temporary communications in cases of emergency.

Challenges in developing SDR Technology

- **Interdisciplinary nature of SDR systems:** SDR platforms are complex systems, and designers must possess knowledge spanning several disciplines or work with a team of specialists.

- **Software design portability to new SDR platforms:** Given the amount of time, resources, and effort needed to design various modules of an SDR platform, it is advantageous if the same code can be ported to other SDR systems.

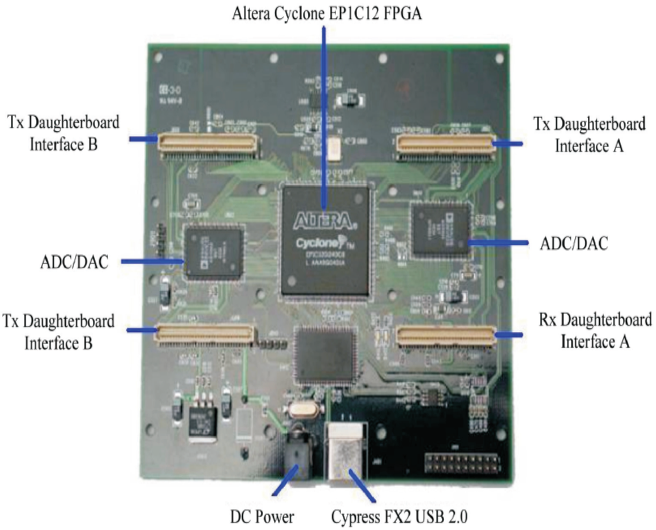
Challenges in developing SDR Technology

- **Software and driver limitations:** There exist issues with respect to the handling of large amounts of data in real time.
- **HW/SW interface:** The current “bottleneck” for SDR technology is the interface between samples on the SDR hardware and the software tools on computing device.

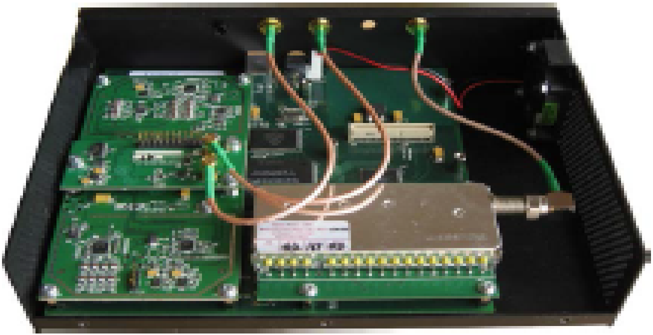
Universal Software Radio Peripheral

- An example of a device that implements the SDR concept is the Universal Software Radio Peripheral (USRP) which was designed by Matt Ettus.
- USRP has 4 ADCs which can sample $60x10^6$ times per second on each ADC, and 4 DACs which sample $128x10^6$ times per second on each DAC.
- Additionally, there is one Altera Cyclone EP1C12 FPGA chip and one programmable Cypress FX2USB 2.0 controller on the USRP motherboard.

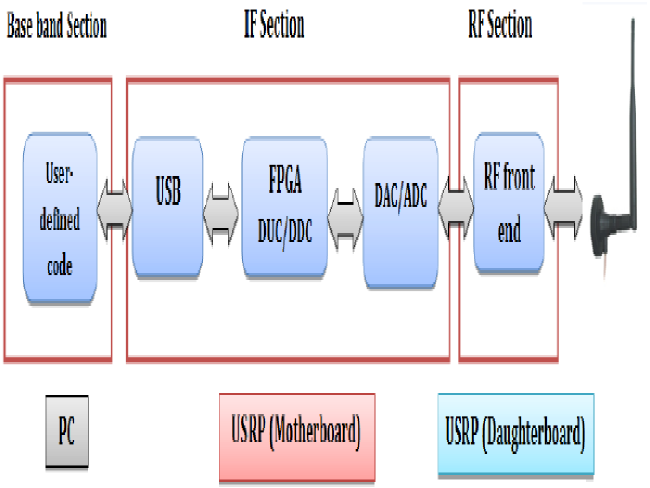
Universal Software Radio Peripheral



Universal Software Radio Peripheral



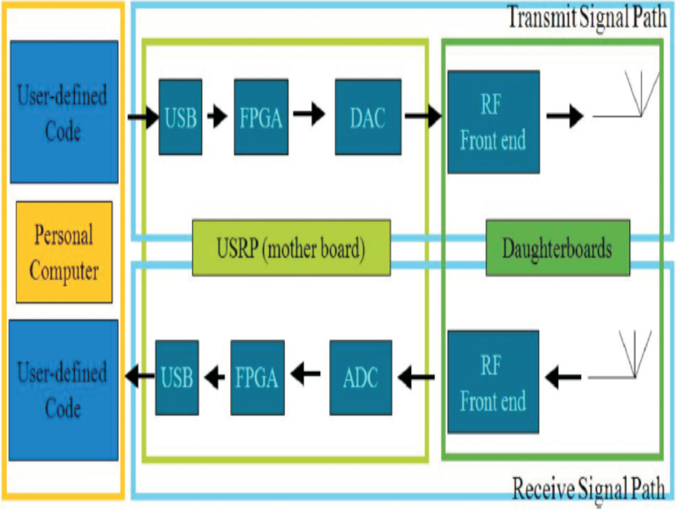
Universal Software Radio Peripheral



Universal Software Radio Peripheral

- The USRP has a transmitting signal path and a receiving signal path.
- On the transmit signal path, users can define parameters via personal computer - setting the radio protocols, modulation schemes, frequency of spectrum etc.
- Then the USRP receives the parameters, and the FPGA executes IF processing on DUC and DDC.
- The last step on the USRP motherboard is that DAC converts the digital signal into analog signal which is transmitted to the antenna.

Universal Software Radio Peripheral



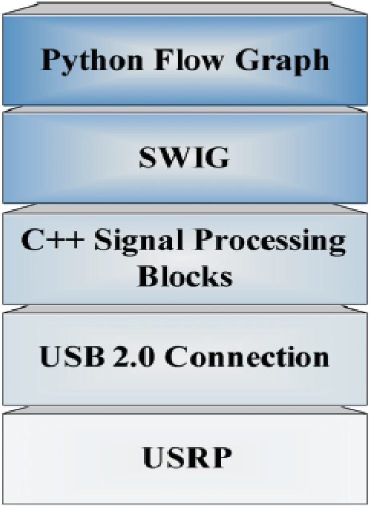
GNU Radio

- GNU Radio is a free software tool-kit licensed under the GPL for implementing software-defined radios.
- GNU Radio installed on a PC incorporates the library of communication functions that are implemented in software.
- This signal processing database includes the most of signal processing functions, such as signal waveform modulations and most kinds of filters.
- It is possible to use these components as building blocks of a communication system.

GNU Radio

- GNU Radio framework is built around graph design pattern. For each GNU Radio application a flow graph is constructed from nodes called blocks connected by edges called ports.
- GNU Radio is a hybrid system in which the signal processing blocks are written in C++ and the non-critical portions are written in high level language specifically python.
- GNU Radio application written in python access the C++ signal processing blocks through SWIG (Simple Wrapper Interface Generator) interface.

GNU Radio


Python Flow Graph
SWIG
C++ Signal Processing Blocks
USB 2.0 Connection
USRP

GNU Radio

There are many practical modules in GNU Radio as follows:

1. **GPS receiver:** daughter-board receives Global Positioning System (GPS) signal and can be integrated with Google Earth interfaces to a complete GPS receiver.

2. **DVB-T receiver:** daughter-board can receive Digital Video Broadcasting-Terrestrial (DVB-T) signal, then one can watch digital television channels through GNU Radio and USRP.

3. **FM receiver:** daughter-board can receive FM signals then demodulate and filter the FM signal by modules in GNU Radio.

GNU Radio

Other modules that are under development include:

1. **BBN 802.11 receiver:** This project implemented a fundamental 802.11 transmitter and receiver able to decode low rate 802.11 packets.
2. **Bluetooth receiver:** This project was set out to implement some functions of the Bluetooth protocol by using GNU Radio and USRP to replace the Bluetooth hardware.
3. **UCLA Zigbee receiver:** The physical layer and Media Access Control (MAC) layer modules on IEEE 802.15.4 protocol can be monitored and debugged by this project.

Applications of SDR

1 **Teaching Digital Communication Courses**

- The high cost of equipments used to execute a telecom lab might be prohibitive to universities that have low budget. By using software defined radio platforms, it would be possible to reduce the cost of those laboratories.
- The GNU Radio Companion is suited for creating a whole lab package to complement teaching Digital courses.

Applications of SDR

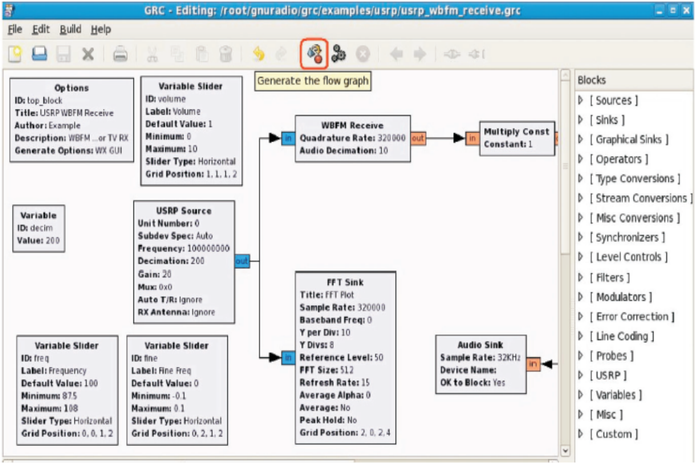


Figure: FM Receiver Block

Applications of SDR

2 **Spectrum Sensing**

- A large part of regulating spectrum usage to ensure compliance with regulations depends on being able to sense the usage of the spectrum at any given time. Conventional radars that accomplish this are costly and limited.
- One application for SDR is realizing a software-defined spectrum scanner using only a SDR board (such as USRP) and implementing sense algorithm in software.

Applications of SDR

- A simple way to sense spectrum can then form the basis for implementing Cognitive Radio.
- CR utilizes can utilize this intelligent sensing method to acquire the spectrum usage information and environment parameters.
- Cognitive Radio works by:
  1. Radio sensing and learning.
  2. Recognizing and allocating spectrum opportunity.
  3. Realizing spectrum opportunity.

Applications of SDR

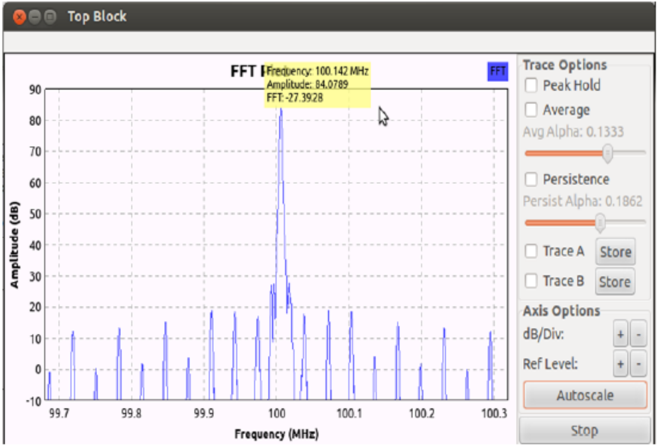


Figure: Frequency Spectrum sensed using SDR

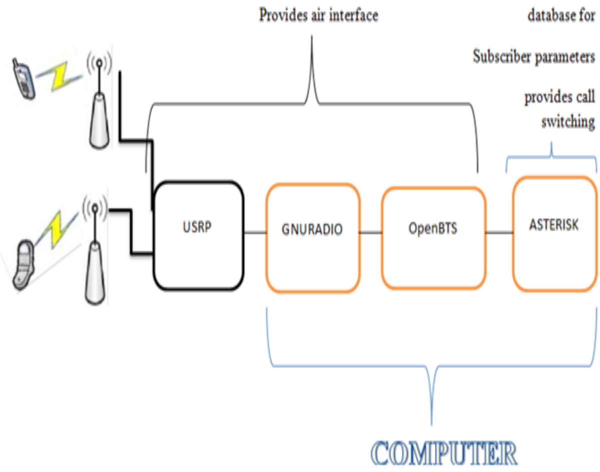
3 **Cellular Mobile Communication Systems**

Open Source Network

- OpenBTS is an open-source UNIX application that works with GNU Radio over the USRP to present a GSM air interface ("Um") to standard GSM handset and uses the Asterisk VoIP PBX to connect calls.

- In other words, it is a software-based GSM access point, allowing standard GSM-compatible mobile phones to make telephone calls.

Applications of SDR



Applications of SDR

Next Generation of Multi-Standard and Multi-Band Radio Base Station

- The widespread use of mobile devices has presented challenges with respect to the different wireless standards, services, and applications that all need to be supported.
- Several layers of wireless infrastructure are needed in order to support multiple concurrent networks within the same region, which requires a substantial investment in terms of equipment and other resources.
- Supporting multiple wireless networks simultaneously may result in a degradation in network performance due to issues such as interference.

Applications of SDR

- SDR provides an opportunity to reduce infrastructure costs, provide more efficient connectivity across various networks, and offer flexibility that can enhance performance.
- For example, a user can use a single device to receive signals of WiMAX, Wi-Fi, GSM, LTE, or any future technology, provided that the rules for use are embedded in the chip.
- An upgrade can be done by mere download of the latest standard modules.

1 **Power Consumption**

- A major challenge that needs to be solved to realize the transition from HW to SW processing is the substantial increase in computation, which leads to increased power consumption and reduced battery life.
- This is one of the key reasons why SDR's have not been widely deployed in end-user devices but instead used in BS's and AP's, which can take advantage of external power resources.

2 **Evolvability and Adaptiveness:**

- We need to evolve towards the separation of data plane and control plane in prospective implementations of Cellular SDR.
- This is by making sure SW networking algorithms can be easily, continuously and independently upgraded.
- This will allow adoption of emerging radio technologies (e.g., mm Wave, massive MIMO, and TeraHertz) while deploying novel traffic engineering, network management, and network optimization solutions at controllers.

3 **Infrastructure-as-a-Service:**

- Emerging network services, such as M2M, require highly differentiated networking capabilities to be integrated and deployed over the same network infrastructure.
- The network virtualizability of Cellular SDR can be designed to allow the wireless infrastructure to be offered as a service rather than as a physical asset.
- Specifically, in Cellular SDR, providers can have the ability to control, optimize, and customize the underlying operation without owning it and without interfering with the operations of other providers.

SDR and 5G Cellular Communication - Future Research

4 **Maximal Spectral Efficiency:**

- The aim in cellular SDR is for both macro and small-cell base stations to be implemented at a server.
- There, they can easily share control information, mobile data and channel state information (CSI) associated with different active users in the system.
- Therefore, with Cellular SDR, work must be done to design algorithms to mitigate or exploit inter-cell interference towards universal frequency reuse.