
SOFTWARE DEFINED RADIO

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Abstract

The flexibility provided by the software allows a radio to interoperate with other devices using different wireless physical layer technologies, by simply calling the appropriate software. A mobile device equipped with a software would have access to a wide range of connectivity options including cellular, wireless LAN and satellite systems. This would not only enable seamless anytime, anywhere connectivity, but also provide users the flexibility of choosing from the available connectivity options to best suit their price to performance requirements.

SDR technology can be used to implement military, commercial and civilian radio applications.
A wide range of radio applications like Bluetooth, WLAN, GPS, Radar, WCDMA, GPRS, etc. can be implemented using SDR technology. This paper provides an overview of generic SDR features and its architecture.

Introduction

Definition: Software-Defined radio (SDR) Forum [www.sdrforum.org] defines SDR technology as "radios that provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions (such as hopping), and waveform requirements of current & evolving standards over a broad frequency range."

In short, software modules running on a generic hardware platform of DSPs (Digital Signal processor) and general purpose microprocessors can implement radio functions such as modulation/demodulation, signal generation, coding and link-layer protocols. This helps in building reconfigurable software radio systems where dynamic selection of parameters is possible.

Features of Software Defined Radio: Regardless of the means by which the radio is reconfigured, a fully implemented SDR will have the ability to navigate a wide range of frequencies with programmable channel bandwidth and modulation characteristics. The following list outlines some of the possible dynamic characteristics of an SDR:

- Multiband
- Multicarrier
- Multimode
- Multirate
- Variable bandwidth
- Ubiquitous Connectivity

Multiband

The traditional radio architectures operate on a single band or range of frequencies. Applications like cellular communications, government and nongovernment agencies work on wide range of frequencies. A normal radio is designed to operate in one specified band. But a multiband radio can operate on two or more bands either sequentially or simultaneously.

Multicarrier

A multicarrier also called multichannel radio can simultaneously operate on more than one frequency. This may be within the same band or in two different bands. This is generally seen in a base station that may be servicing many users at once or a user terminal that may be processing both voice and data on different carriers.

Multimode

An SDR has the ability to work with many different standards and be continuously reprogrammed. Multimode implies the ability to process several different kinds of standards. Examples of standards are AM, FM, GMSK, and CDMA and many more.These modes may be implemented sequentially or simultaneously.

Multirate

Multirate is closely related to multimode. A multirate radio is one that can process different parts of the signal chain at different samples rates, as in a multirate filter. It can also work in different modes that require different data rates. An example is a radio that can process GSM at 270.833 kSPS (kilo Symbols Per Second) or CDMA at 1.2288 MCPS (Mega Chips Per Second). This can also be done sequentially or simultaneously on different carriers.

Variable Bandwidth

A traditional radio works in a fixed channel bandwidth with help of a analog filter such as an SAW (Surface Acoustic Wave) or ceramic filter. An SDR on the other hand uses digital filters where the bandwidth can be altered on the fly. Additionally, digital filters can compensate for transmission path distortion.

Ubiquitous Connectivity

If the terminal is incompatible with the network technology in a particular region, an appropriate software module needs to be installed onto the handset (possibly over-the-air) resulting in seamless network access across various geographies. Further, if the handset used by the subscriber is a legacy handset, the infrastructure equipment can use a software module implementing the older standard to communicate with the handset.

Scope of the SDR: The public cellular network is a market oriented service. It is extremely sensitive to public demands. Consider the introduction of a new network standard in a particular domain. And suddenly the market response changes towards another standard which has different communication standard and signal processing process. In this case it would be beneficial for any manufacturing company to be able to respond quickly to such situations. Software defined radio systems have the potential to allow short time to respond to the changes in the market.

Wireless network operators face deployment issues while rolling out new services or features to realize new revenue-streams since this may require large-scale customizations on subscribers' handsets. SDR technology supports over-the-air upload of software modules to subscriber handsets. This helps both network operators as well as handset manufacturers. Network operators can perform mass customizations on subscriber's handsets by just uploading appropriate software modules resulting in faster deployment of new services. Manufacturers can perform remote diagnostics and can perform fixes just by uploading a newer version of the software module to consumers' handsets as well in a base station.

According to Arnd-Ragnar Rhiemeier's article ' Modular Software-Defined Radio '
in EURASIP Journal onWireless Communications and Networking 2005:3, 333–342

" Critics generally claim that SDRs will always be notoriously power-inefficient and inherently overpriced, hence never prove competitive against carefully designed ASICs(Application Specific Integrated Chip). This may be true indeed if the flexibility of SDR is unconditionally passed on to the end user in the form of "future upgradability". "

Considering the power consumption, inplementing SDR in mobile handsets would be diffcult as compared to implementing the same in base station.Additional drawbacks are higher processing power requirement and higher initial costs.

Architecture:

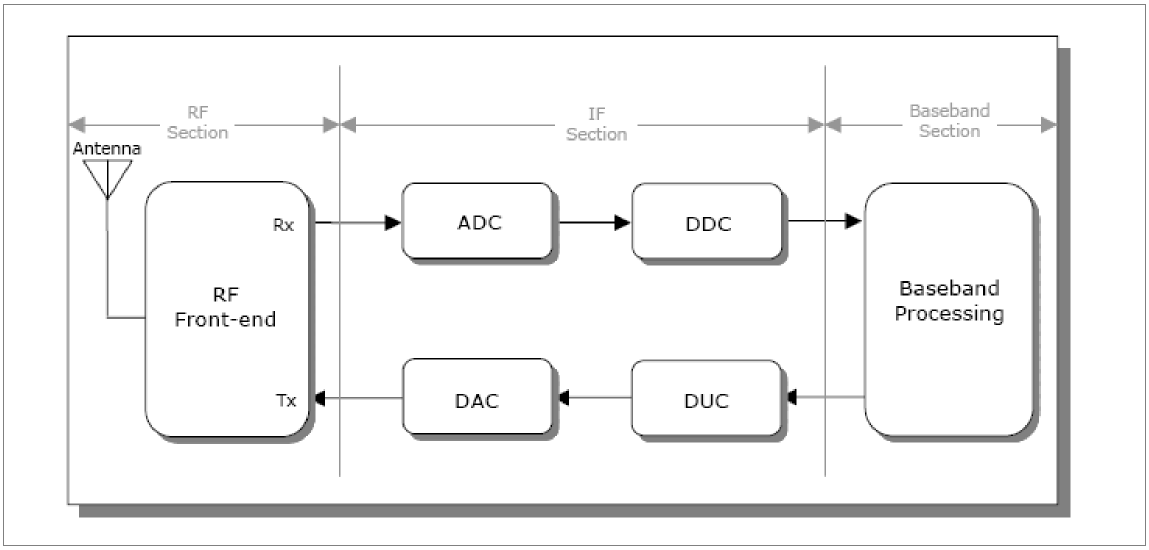

Figure 1: Block diagram of a generic digital transceiver

The digital radio system consists of three main functional blocks:

RF section, IF section and baseband section.

The RF section deals with up conversion from IF to RF and down conversion from RF to IF.

ADC/DAC blocks interface between the analog and digital sections of the radio system.The

ADC/DAC blocks perform analog-to-digital conversion and digital-to-analog conversion, respectively.

DDC/DUC blocks perform digital-down-conversion and digital-up-conversion, respectively.

Additionally it performs modulation and demodulation of the signal

The baseband section performs baseband operations (connection setup, equalization,

frequency hopping, timing recovery, correlation) and also implements the link layer protocol.

The DDC/DUC and baseband processor are implemented digitally in a SDR and they require large computing power. If the baseband section is implemented using ASICs, the function of the radio remains fixed reducing the flexibility of the radio. If DSPs are used for baseband processing, a programmable digital radio (PDR) system can be realized. In other words, in a PDR system baseband operations and link layer protocols are implemented in software. The limitation of this system is that any change made to the RF section of the system will impact the DDC/DUC operations and will require non-trivial changes to be made in DDC/DUC ASICs.

In comparison to that the software-defined radio (SDR) system is one in which the baseband processing as well as DDC/DUC modules are programmable. This is possible because of the availability of smart antennas, wideband RF front-end, wideband ADC/DAC technologies and ever increasing processing capacity of DSPs and general-purpose microprocessors.

In a SDR system, the link-layer protocols and modulation/demodulation operations are implemented in

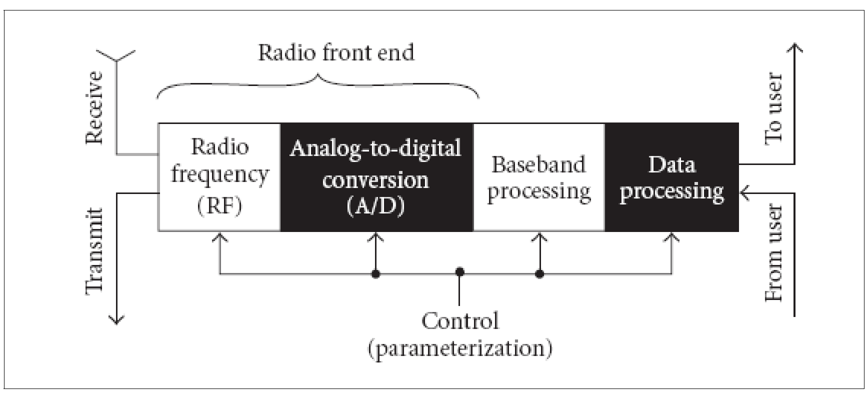

Figure 2: Transceiver of an Ideal SDR.

software. If the programmability is further extended to the RF section (i.e., performing analog-to-digital conversion and vice-versa right at the antenna) an ideal software radio systems can be implemented. However, the current state-of-the-art ADC/DAC devices cannot support the digital bandwidth, dynamic range and sampling rate required to implement this in a commercially viable manner. Figure 2 shows a parameter-controlled (PaC) SDR where the control bus supplies parameters for the desired operation.

Figure 3 illustrates the architecture of software components in a typical SDR system. The system uses a generic hardware platform with programmable modules (DSPs, FPGAs, microprocessors) and analog RF modules. The operating environment performs hardware resource management activities like allocation of hardware resources to different applications, memory management, interrupt servicing and providing a consistent interface to hardware modules for use by applications. In SDR system, the software modules that implement linklayer protocols and modulation/demodulation operations are called radio applications and these applications provide link-layer services to higher layer communication protocols such as WAP (Wireless Application Protocol) and TCP/IP.

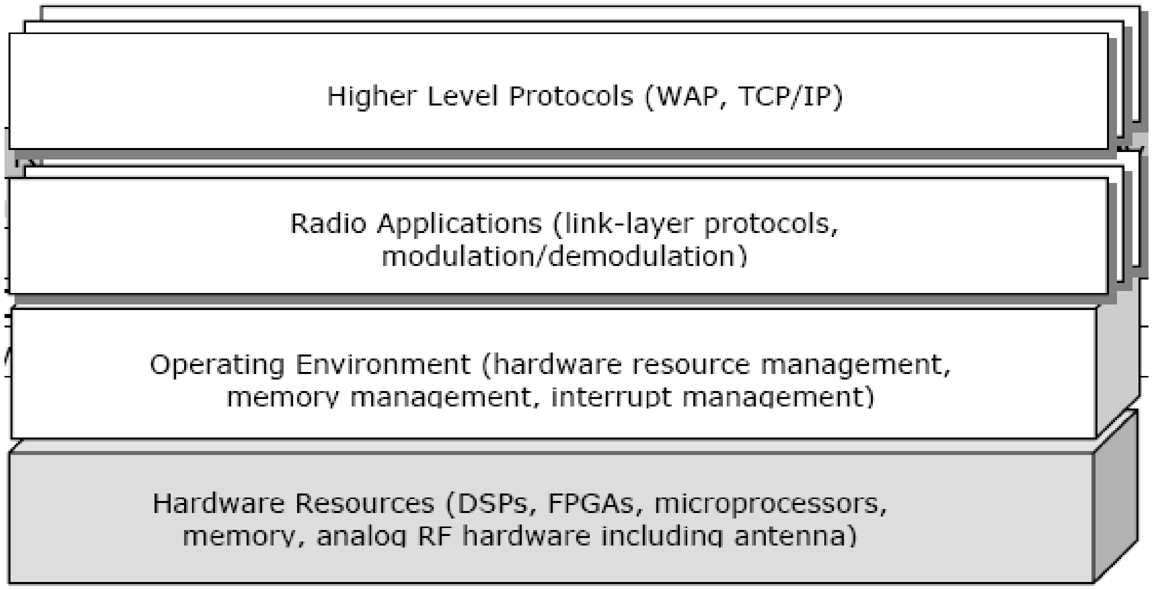

Figure 3: Architecture of software components of an SDR

Receiver Characteristics:

The most common of architectures for the receiver is the super-heterodyne architecture. This design allows good performance across large range of frequencies while maintaining good sensitivity and selectivity.

The receiver operates in Multicarrier Mode and uses an oversampled ADC with ample available bandwidth. An oversampled ADC is one in which the sample rate is operating beyond the requirement of Nyquist criterion, which states that the converter sample rate must be twice that of the information bandwidth.

Since an SDR may not have prior knowledge of the bandwidth of the incoming signal, the sample rate must be appropriately set high enough to sample all anticipated bandwidths. Current ADC technology allows high dynamic range bandwidths of up to 100 MHz to be digitized. With this much bandwidth, it is also possible to process multiple channels.

The typical available bandwidth is one-third the sample rate instead of the Nyquist one-half.

SDR Receiver Elements:

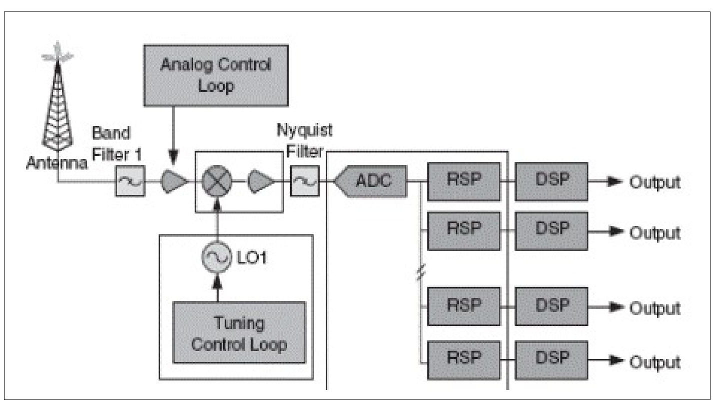

Figure 4: Elements in an SDR receiver

The antenna is one of the weakest elements in an SDR as it has a small bandwidth around its center frequency and hence multiband operation can become difficult. The antenna also has to has to maintain a balance between impedance matching and link gain. But tuning the electrical length of the antenna is considered more important than impedance matching of the antenna.

Next in the signal chain is the **band-select filter electronics**. This element is provided to limit the range of input frequencies presented to the high-gain stage to minimize the effects of intermodulation distortion and strong out-of-band signals

Most receivers require a **low-noise amplifier or LNA**. An SDR should ideally incorporate an LNA that is capable of operating over the desired range of frequencies. It helps in conditioning low NF and high IP3.

Mixers are used to translate the RF spectrum to a suitable IF frequency. Each successive stage also perform filtration of undesired signals that may have survived the mix-down process. The filtering should also be appropriate for the application. A traditional single-carrier receiver would generally apply channel filtering through the mixer stages to help control the IP3 requirements of each stage. Analog channel filtering is not possible in the case of a multicarrier receiver where the channel bandwidths are not known in advance.

Some receiver architectures utilize a **quadrature demodulator** in addition to, or instead of, a mixer. The purpose of the demodulator is to separate the I and Q components. Once they have been separated, the I and Q paths must maintain separate signal conditioning. In the digital domain, this is not a problem; in the analog domain, however, the signal paths must be perfectly matched, or I/Q imbalances will be introduced, potentially limiting the suitability of the system.

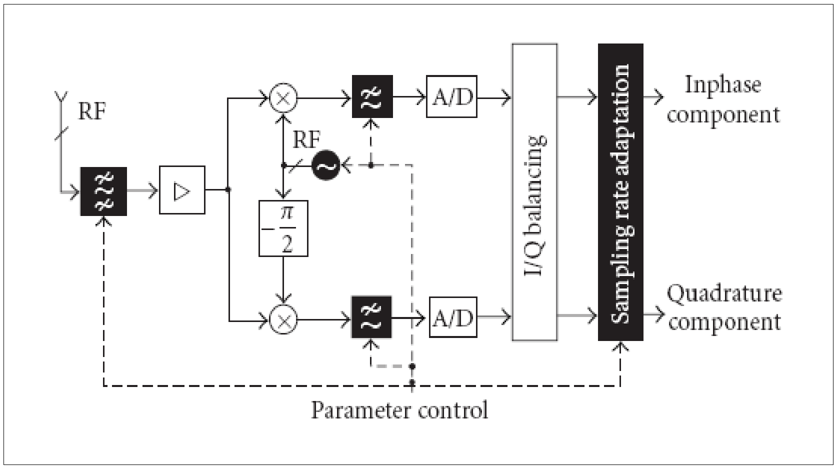

Figure 5: Structure of a SDR receiver

The local oscillator is used to generate the proper IF when mixed with the incoming RF signal. Generally, a local oscillator (LO) is variable in frequency and easily programmable via software control using PLL or DDS techniques. There are cases where the LO may not require frequency hopping. One such example is for receiving multiple carriers within a fixed band. In this case, the LO is fi xed, and the entire band is block-converted to the desired IF. It often may be desirable to change the LO drive level to optimize spurious performance under a variety of signal conditions.

Quite often the IF amplifier is in the form of an AGC. The goal of the AGC is to use the maximum gain possible without overdriving the remainder of the signal chain. Sometimes the AGC is controlled digitally or with analog feedback.

Transmitter Characteristics:

Transmit functions for software defined radio (SDR) are also based on some form of super-heterodyne or direct conversion. The heterodyne option is best suited to single and multicarrier applications, whereas the direct conversion offers an excellent, low-cost solution for single-carrier applications.

As integration technology improves, multicarrier direct conversion may become a possibility; however, such a transmit configuration requires sideband suppression that is about 15 dB better than the spurious requirements to prevent images on one side of the center frequency from overpowering a potentially weak carrier on the other.

SDR Transmitter elements:

The components used for transmitter are the same as shown in the figure below.

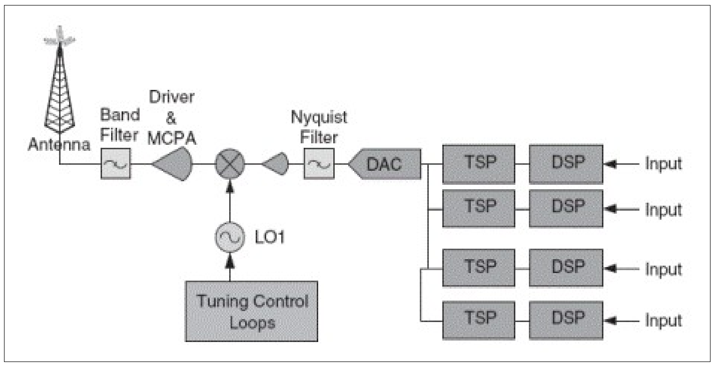

Figure 6: Elements in an SDR transmitter

A **digital signal processor (DSP)** or baseband ASIC is used to generate the modulated baseband data. This data is fed either directly to a pair of baseband digital/analog converters (DACs) (I and Q) for direct RF modulation or to a digital processor responsible for digitally translating them to a suitable digital intermediate frequency (IF).

Depending on the application a FPGA or ASIC or a traditional mixer or modulator may be used employ a RF stage. If multiple channels are required, they can be synthesized on one chip. After translation, each of the channels can be summed together and interpolated to the desired data rate and then sent to a DAC. If desired, digital predistortion can be added in conjunction with the DSP to correct for distortion later in the signal chain.

Either a mixer or a modulator is used for frequency translation to the final RF frequency. If direct RF modulation employed, an RF modulator will be used. If an IF is used (either directly from a DAC or a traditional IF upconversion), a mixer will be used to translate to the final RF frequency. As with the receive mixer/demodulator, it may be desirable to change the bias levels or the drive level of the data or local oscillator (LO) levels to optimize distortion.

Conclusion

The mobile technology has been evolving very rapidly. As new and more complex communication standards are developed transceiver architectures will also grow. New designs will increase the complexity and the cost. However, software radio technology aims to group these architectures and make them work on single platform

In the last decade semiconductor technology achieved impressive gains and now it is upto the SDR to futher increase the performance in terms of flexibility and efficiency.

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There are two main issues are cost and power. Without low power, user devices will not be able to take full advantage of SDR technology. Despite these challenges, the current state of performance is more than sufficient for engineers and manufacturers to seriously begin to investigate the possibilities of SDR.

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