SOFTWARE RADIO:

PRINCIPLES AND OVERVIEW

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I INTRODUCTION

An immense growth of mobile teleco-mmunication systems in the last two decades, has produced variety of analog and digital standards. As a consequence, today we are not able to use services of all mobile operators across the world with a single user terminal. Significant step in that direction was made with the European GSM (Global Standard for Mobile). With today's GSM dual-band mobile phones, we are capable of using services across whole Europe and much of the world through the 'Roaming' service. On the other hand, the US has expirienced later transition from analog to multiple competing digital standards. Asia has employed their own standards. So, although market analysts emphasize the trading benefits of a common worldwide standard, there is very small chance that one unique standard will ever be accepted throughout the world. Main reasons for that are enormous investments in a new infrastructure and fast technology expansion, so that one suitable solution is being replaced by another in a short time.

It is therefore in this field that the software radio concept emerges as a pragmatic solution. The term 'software radio' presents software implementation of the user terminal able to dinamically adapt to the radio environment in which is, time by time, located. It means that the radio interface functionalities of Tx and Rx usually implemented by dedicated hardware can be software defined. Dedicated hardware would be replaced with DSP (Digital Signal processing engines), which will execute the necessary software.

II DEFINITION AND BASIC CONCEPT

Beside the :'Software Radio' term, the 'Software Defined Radio' (SDR) term is also used. The most appropriate definition for software radio is as follows:

Software radio is an emerging technology intended to build flexible radio systems, multiservice, multistandard, multiband, reconfigurable and software - reprogrammable.

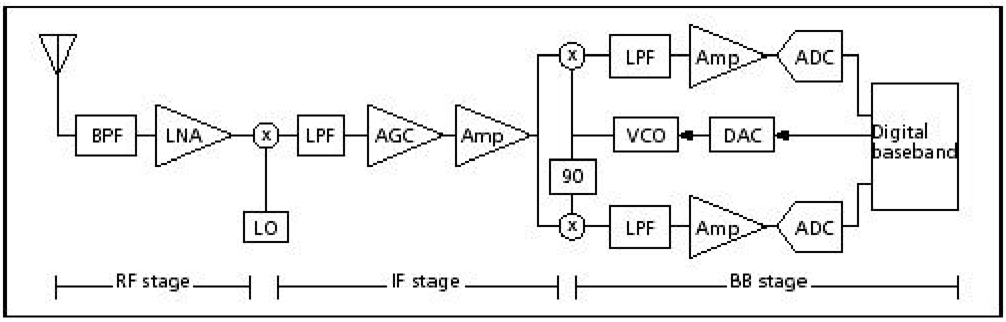
Conventional receiver architecture is shown in figure 1. It is a classic super-heterodyne approach. Creating multichannel and multistandard receiver using this architecture will require separate receiver chain for every channel. This solution will not be suitable because of the increased dimensions, complexity and cost, and for every new standard, adding of new receiver chain will be necessary.

In figure 2., the ideal scheme of Software Defined Radio is illustrated. It has very reduced analog stage. Only analog components are antenna, the bandpass filter and low noise amplifier (LNA). A/D conversion is done immediately after LNA, and from that point in receiver chain, signal processing is in digital domain. This early digitalization of input signal allows software digital processing which replaces conventional analog frequency downconversion and channel selection. Software defined signal processing enables processing in accordance with radio environment. For example, digital signal processing for demodulation of CDMA and FDMA (frequency hopping) modulated signals can be executed within the same reprogrammable device with simple changing of software. For executing same operations in conventional manner, two completely different hardware architectures are required.

Reprogrammable digital signal processing engines (DSP) are suitable for performing processing task.

Development of software defined radio is directed in achieving two goals:

- Moving border between analog and digital domain of tranceivers toward antenna and RF stage. That provides device reprogrammability by using software defined DSPs.

- 

- *Figure 1. A traditional super-heperodyne receiver*

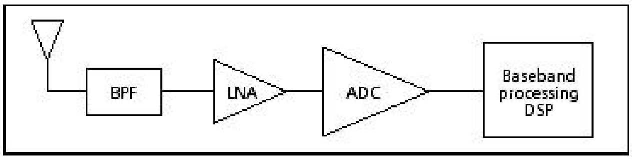


Figure 2. An ideal software radio receiver

- Replacing dedicated hardware with general purpose digital signal processing engines (DSP) for digital baseband processing.

As mentioned before, main advantage of SDR systems is their ability to adapt to every radio environment. It is guaranteed by its reconfigurability caused by DSP. Reprogrammable DSP engines implement radio interface and upper layer protocols in a real time. Switching from one radio environment to another is executed by simple changing of software that runs the DSP.
Beside DSPs, reprogrammable devices like FPGA (field programmable gate arrays) and general-purpose processors can be used for performing some of the processing tasks.
Software which contains radio interface personality, can be downloaded from the network through the air interface. That will allow fast and easy adaptation to radio environment, especially in handoff situations.

III TECHNICAL CHALLENGES

There are many problems in realization of the SDR systems. Much higher demands are placed on implementation of handheld terminals than to the base stations because the handheld terminals' architecture requires low disipation, complexity, weight and small dimensions.

It is very difficult to produce RF stage and antenna which are frequency independent. There is an antenna array solution for SDR base stations, but for handheld terminals some other solutions are needed.

One of the weakest links in SDR architectures are ADCs. In the basic implementation of SDR, analog to digital conversion is required in the early stages of receiver chain. It means that the ADC has to sample signal on RF or IF, which requires high sampling rates (over 100 Msamples/S). High dynamic range of received signals (example, in GSM , from -104 to 13 dBm) orders high number of resolution bits. Today's technology offers converters with sampling rates of 1 Gsamples/s and resolution of 6-8 bits.With the resolution increasement, the sampling rate is decreasing exponentially. For 10 bits resolution commercially avaliable sampling rate is 100 Msamples/s, and for 16 bits 150 Ksamples/s. Other parameters of ADC performance in sense of error generators, like jitter, termal noise, comparator ambiguity only decrease number of effective resolution bits. ADC are meant to perform baseband or passband sampling where spectar of sampled signal does not extend to DC. Present ADC are able to comply only certain level of required performances.

The processing power of SDR components has to allow real-time execution of software implemented radio interface sufficiently. This could require the use of several DSPs in parallel, depending of complexity of the radio interface to be implemented. One of the biggest problems of DSP usage is its high disipation., and DSPs are not adequate for every baseband processing function (ex. filtering).

Reconfigurable processing can also be achieved with FPGA. FPGA is an array of gates with programmable interconnections and logic functions that can be redefined after manufacture. FPGA usually consists of an array of blocks. Every one of them contains logic blocks and an interconnection resource to connect logic blocks. FPGA logic usually contains lookup tables (LUT) of n (3-6) inputs and flip-flops to store data. Figure 3. Inputs to the logic blocks are connected to either LUT input ports or flip-flop input ports. Outputs of the LUT are either connected to output ports of the logic block or connected to the flip-flop input ports.

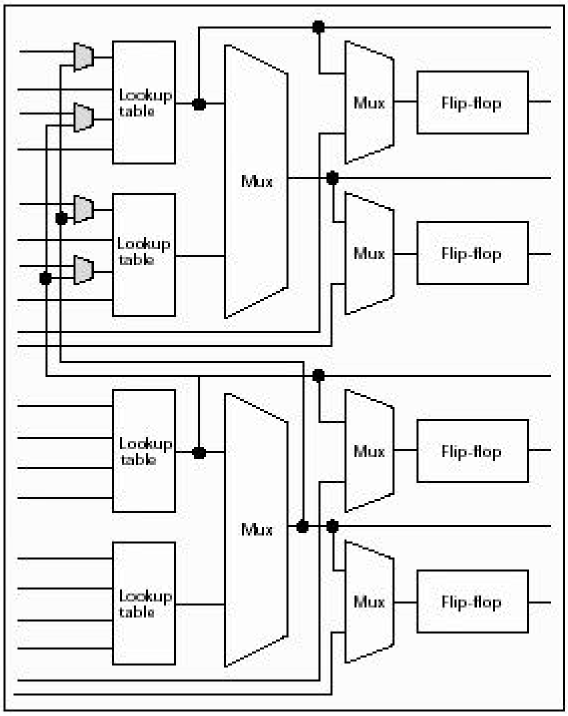


Figure 3. Example of FPGA logic block

Various combinations of input signals can be chosen by using multiplexers. LUT can implement any Boolean functions of n inputs by feeding address signals (input signals) to get data output signals. Unfortunatelly, gate count for the given function implemented in FPGA is ten times gate count for the same function implemented in a custom application-specific integrated circuit (ASIC, dedicated) hardware. FPGA also requires development of new tools which will enable dynamic, real time, reconfiguration of FPGA.

Soft core ASIC is new technology which can find its place in SDR implementation. Soft cores are circuits designed in a high-level language that are transferable between foundry processes. Cores can be interconnected to form complex systems in a chip. Soft DSP, microprocessor, and dedicated function (e.g. filter) cores are available. The

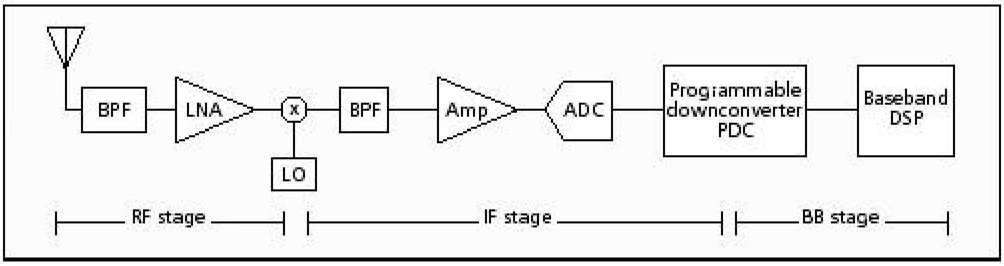


Figure 4. A digital radio receiver

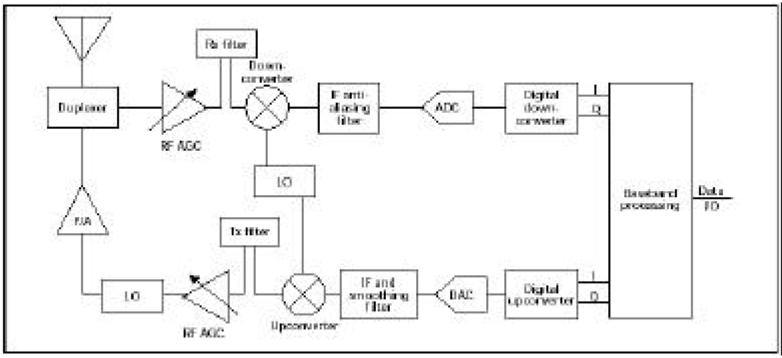


Figure 5. Digital IF configuration

suitable solution for SDR signal processing is very likely to be a combination of DSP, FPGA and soft core ASIC.

Basic demands for a software download from the network include dedicated channel and transmission without errors. But even in using strong coding schemes and repetition techniques on dedicated channel, transmission errors are possible.

IV SDR IMPLEMENTATIONS

Because of the technical problems, it is still not possible to realize functionally 'ideal' software architecture from figure 2., so many other approaches are proposed. In a figure 4., *digital radio transceiver* solution is presented. Analog to digital conversion at radio frequencies (RF) is hard to employ because of the rigorous requirements needed for A/D converter (high sampling rate, high resoglution, jitter effect, etc.). It is more likely that the signal will be converted into a digital domain after analog downconversion from RF to IF (Intermediate Frequency). In this realization, output of ADC, signal streams, are fed into the programmable downcoverter (PDC) which provides the following operations: downconversion, channelization and sample rate adaptation.

Downconversion in this issue means digital conve rsion from IF to BB (Baseband) by using a lookup tables containing the sinusoidal samples. This tables are performing the same functions as the local oscillator used in analog downconverters.

Channelization is selection of the carrier and channel of interest. In analog receivers, this operation is done by the analog filters before BB conversion

Sample rate adaptation means undersampling of the channelization filter's signal output in order to match the sample rate of the channel rate, because the channel bandwidth is narrow compared to the wider-spectrum A/D input sample, and its sampling rate is adequately lower.

After PDC, the signal is baseband processed.

Figure 5. presents SDR IF processing architecture. It has traditional analog conversion of the signal of interest from RF to IF in downconversion side, and from IF to RF in the upconversion side. A digital downconverter tipically consists of a digital local oscillator, a digital mixer and decimacion filter. When operating on multiple channels is needed, these operations can be performed in distributed manner by using transmultiplexer. On the other hand, digital upconverter consists of a digital local oscillator, a digital mixer and interpolation filter. Transmultiplexer can be used in upconversion of multiple chanels, too.

For IF is important, whether the downconverter is operating on a narrowband, wideband or a multiple narrowband signal. Narrowband signal has bandwidth significantly narrower than input signal's bandwidth, whereas bandwidth of wideband signal is greater than 10 percent of a whole input signal's bandwidth. Multiple narrow- band signals have similar charateristics to narrow- band signals. This characterization defines constrains for signal processing components. Narrowband digital IF processing is suitable for applications in which the large dynamic range and accurate selectivity are required, and where are multiple signals of interest with different bandwidth.

Principle of narrowband IF processing is to sample a real IF signal and to mix it digitally with a quadrature local oscillator set to the signal of interest's frequency. After this central frequency of the signal of interest is translated to DC. Signal derived as a mixing result is than low pass filtered (LPF) and decimated to achieve a narrowband quadrature baseband signal with a baseband sampling rate commensurate with its bandwidth. Advantage of digital LO is that their phase offset and center frequency can be changed to any desired value within the one clock cycle.

Narrowband multichannel digital IF is sutable for situations where multiple channels of the same bandwidth and equal spacing are of interest (i.e. cellular BS). It is realized through a transmultiplexer based on a discrete Fourier transform (DFT) filter bank. Tmux receiver translates one wideband IF sampled signal stream into multiple quadrature baseband streams, one per subscriber channel.

The advantages of wideband single-chanel digital IF include: large dynamic range, accurate frequency selection, accurate filter characteristics and flexibility in the capture of multiple signal with different bandwidths. Implementation is same as for the narrowband signal. Only difference is in decimation factor, which is much lower for a wideband processing.

Direct conversion receiver (DCR) architecture is another possible solution for SDR. A figure 6. presents a basic DCR configuration where the received signal is directly downconverted to baseband by a quadrature mixer. The downconverted in-phase and quadrature (IQ) signals are filtered with anti-aliasing LPFs, which have variable cut-off frequencies. After that, signals are converted from analog to a digital form by IQ ADC. Output of ADC is fed to digital

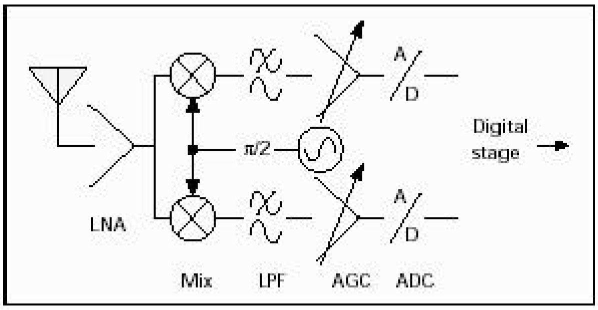


Figure 6. Basic DCR configuration

stage where selection of desirable channels is performed by software defined filter with programmable cutoff frequency. At the end, an origin data sequence is recovered. Advantage of DCR configuration over classic heterorodyne is that DCR architecture has no image response, so the image rejection filters are not needed. On the other hand imperfect components of DCR cause residual or latent image response

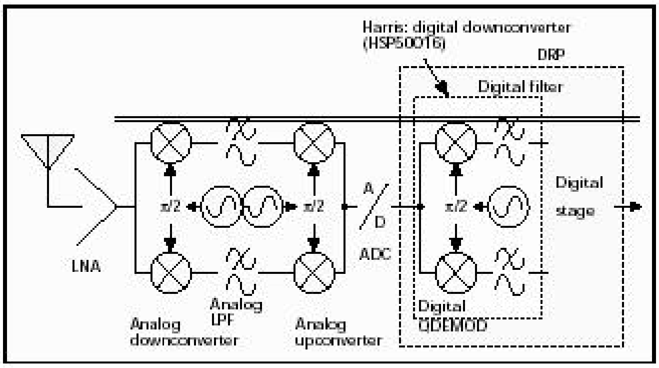


Figure 7. An upconversion DCR configuration

at zero frequency (DC). Second thing is that in-band linearly modulated large signals cause non-linear distortion around DC in downconverter mixer (linearly modulated signals have constant anvelope). Therefore, system level compensation metod for a suppression of the nonlinear distortions is required.

In a figure 7., another DCR configuration is shown. The received signal is first directly downconverted to baseband, where the entire input band is roughly selected by anti-aliasing LPF.After filtering,a whole signal bandwidth is reconverted to programmable IF. Resultant IF signal has limited bandwidth. From that point, signal can be directly digitalized and than digitally downconverted to baseband for the selection of desired channels.

Suitable characteristic of this approach is the ability to select a desirable frequency for the IF in order to employ ADC with suitable power consumption for portable terminals.

Direct conversion architecture is attractive for handset application because of its suitability for achieving a miniature low-cost transceiver, since bulky and high cost passive filters for receiver and transmitter chains are not necessary, and it is compatibile with multiple standards. This approach is effective for single channel applications, but multiple simultaneous channels have fewer spurs and better S/N ratio in near-far conditions through the digital IF architecture.

V CONCLUSION

Main characteristic of software define radio system is dynamic adaptation to radio enviroment through reconfigurability of its components. Software guided components provide necessary reconfigurability. Simple changing of software that runs DSP and its installation change complete radio interface. This characteristic gives SDR systems ability to support wide range of mobile radio standars. Present technologies don't have suitable solutions for implementing conventional, widely accepted cost-effective SDR systems. It is not likely that suitable solutions will be proposed in next 5 years, but despite that, SDR has great perspective, and its development can be very suitable for areas in which variety of different communication standards can co-exist. Also, SDR can be a strong support for development of 3G (Europe).

VI REFERENCES

[1] E. Buracchini The Software Radio Concept, *IEEE Communication Magazine*, September 2000
[2] H. Tsurumi, Y. Suzuki Broadband RF Stage Architecture for Software-Defined Radio in Handheld Terminal Applications, *IEEE Communication Magazine*, February 1999
[3] W. Tuttlebee Software Radio Tehnology: An European Perspective, *IEEE Communication Magazine*, February 1999
[4] J.Mitola Technical Challenges in the Globalization of Software Radio, *IEEE Communication Magazine*, February 1999
[5] M. Cummings, S. Haruyama Fpga in the SoftwareRadio,*IEEE Communication Magazine*, February 1999
[6] D. B. Chester Digital IF Filter technology for 3G Systems: An Introduction, *IEEE Communication Magazine*, February 1999
[7] R. H. Walden Performance Trends for Analog-to-Digital Converters, *IEEE Communication Magazine*, February 1999

Abstract: Purpose of this paper was to present basic Software Radio concept. Software defined radio systems are very attractive for modern mobile telecommunications because of their ability to adapt to every radio environment in which they are, time by time, located. Ideal realization of SDR systems still doesn’t exist. Therefore, possible implementation solutions and technical challenges are described in here.

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