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Design of a Multichannel RF Communication System using Delta-Sigma Modulation

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***Abstract*—Wireless communication is an emerging technology, leading to an additional research towards the development of new smart radios like cognitive radio. Cognitive radio is very complex and inefficient to implement using conventional approaches. since they do not support simultaneous transmission of multichannel and multiband signals. The all-digital multichannel architecture using delta-sigma modulation is suitable for this. The multichannel property of this architecture increases the speed of data transfer by adding more number of channels for communication. The complete design can be coded using VHDL and simulated usingModelSim 6.2c.**

Keywords—*Delta-sigma modulation, Field-programmable gate array (FPGA), RF communication system.*

I. INTRODUCTION

Communication involves implicitly the transfer of information from one place to another. Communication can be broadly classified as analog communication and digital communication. In analog communication, the message signal is analog in nature and in digital communication, the message signal is digital in nature. The basic communication system consists of a transmitter, channel and the receiver. Transmitter operates on the message signal to produce a signal suitable for transmission. Thechannel is merely a medium for transmitting the signal from transmitter to receiver. The receiver performs the inverse operation to reconstruct the original message signal.

A communication system can be considered to be "wired" or "wireless"(eg. conventional telephone, radio communications etc). A wired system is technically known as a hard-line system and can be thought of as a localized, private telephone system that uses wires to operate over a limited area. A wireless system uses radio frequencies to connect users and is capable of operating over a much larger geographical area than a wired system. The major advantages of RF communication systems over wired communication systems are their ability to provide communication over large distances, through some obstacles (depending on the frequency), and to an almost unlimited number of users.

Wireless communications gained unprecedented attention over the last years leading to the proliferation of different wireless standards and pushing an additional research effort towards the development of new smart radios, like cognitive radio and software defined radio, capable to adapt to different communication scenario.RF communication systems use advanced forms of modulation to increase the amount of data that can be transmitted ina given amount of frequency spectrum. If the modulator replaces the continually varying signal by pulses, which corresponds to sampled values of the analog signals in the time domain. This implies that the continually varying amplitude of the analog signal is quantized to a set of discrete signal levels. This discrete-time modulation is referred to as pulse code modulation (PCM).

The delta-sigma modulator is an offspring of the PCM family and combines the quantization operation within a feedback loop configuration. The delta-sigma modulators are predominantly applied in high-resolution data conversion systems.

The well-known Cognitive Radio (CR) concept holds the potential for implementing the supreme universal radio. However, in order to achieve such a new deployment, the physical layer of CR transmitters must be able to support the simultaneous transmission of multi-band, multi-rate, and multi-standard signals. This can be implemented by combining multichannel with multiband, multi standard data transmission capabilities in a new $\Delta\sum$-based all-digital RF communication system architecture.

Here, an all-digital multichannel RF communication system is proposed. It consists of all-digital multichannel RF transmitter, channel and the all-digital multichannel RF receiver. The all-digital multichannel RF transmitter consists of a source, delta-sigma modulator, interconnection network and the serializer. An in-phase and quadrature data is given to the RF transmitter, where the data path is digital from the baseband up to the RF stage and the bit stream is modulated using delta-sigma modulation. Then, the resulting bit stream is passed through a channel where noise will be added. The RF receiver performs the inverse operation of the RF transmitter to reconstruct the original message signal.

II. RELATED WORKS

The well-known Cognitive Radio (CR) concept [1] holds the potential for implementing the supreme universal radio. The main works related to this paper are FPGA Based All-Digital Transmitter with Radio Frequency Output for Software Defined Radio [1] and the conventional $\Delta\sum$-based digital transmitter architecture.

The conventional delta-sigma based digital transmitter architecture use low-pass $\Delta\sum$-modulators operating at the sampling frequency $f_s$to generate the bi-level outputs v_i and $v_q$from the baseband In-phase (I) and Quadrature (Q) data,

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respectively. The three multiplexers are then used to digitally up-convert and mix the bi-level v_i and v_q signals for in order to generate an RF output signal centered at f_c=N×f_s. In [2]–[6], the authors present digital transmitters identical to the presented architecture.

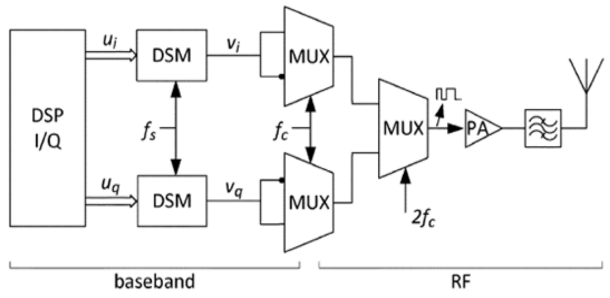

Figure1. Block diagram of a conventional Δ∑- based transmitter.

However, current state-of-the-art all-digital transmitters are still very restrictive for supporting multichannel data transmission. In [3], the authors present simulation results for a dual-band transmitter using modulators clocked at a frequency of several GHz, which is very hard to implement using current technology. The remaining architectures all fail to transmit two or more different carriers at a time. Moreover, such transmitters are only able to generate low RF frequencies or require external multiplexers for enabling carriers operating in the gigahertz frequency range.

III. SYSTEM ARCHITECTURE

The proposed all-digital multichannel Δ∑-based RF architecture extends the conventional Δ∑-based RF architecture by adding the following two main contributions:

a) It enables the simultaneous transmission of multiple carriers with different standards, frequencies, modulations and spectral masks, and

b) It provides an integrated solution where the digital up-conversion to RF operating in the gigahertz frequency range and the multichannel capacity are embedded into a single device, such as a Field-Programmable Gate Array (FPGA).

The proposed system consists of a communication system. In a communication system, modulation is an important process. Modulation is the process of changing the characteristics of carrier according to the data. Here delta-sigma modulation is used for modulation.

A. RF communication system

Here the new all-digital multichannel RF communication system is been proposed. An in-phase and quadrature data is given to the RF transmitter and the bit stream is modulated using delta-sigma modulation. Then the resulting bit stream is passed through a channel where noise will be added. The RF receiver performs the inverse operation of the RF transmitter to reconstruct the original message signal.

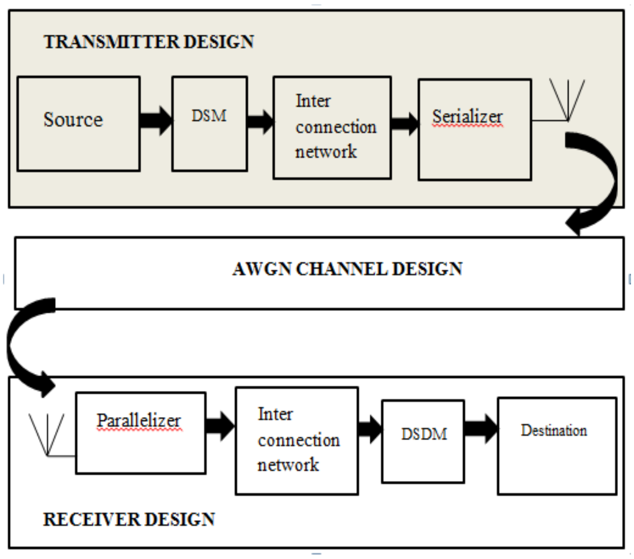

Figure 2. Block diagram of the RF communication system

B. All-digital multichannel RF transmitter

In this architecture, the signal data is represented as I-Q format.ie the data is represented as two signals. The signal with 0 degree phase shift is in phase component and the signal with 90 degree phase shift is quadrature component. I-Q data is highly prevalent in RF communication systems. It is a convenient way to modulate signals. Because, the I-Q data shows the changes in magnitude and phase of a signal.

The all-digital transmitter architecture is multichannel and each channel consists of a delta-sigma pair. Each Δ∑-pair is used to process the I and Q data from each channel. The resulting signals of the Δ∑-modulators and its inverted versions are then connected to a multi-gigabit serializer through an interconnection network. This network allows to combine and replicate the output signal of the Δ∑-modulators for generating a parallel output word (W). The multi-gigabit serializer used in the RF transmitter is capable of operating at serial bit rates above 1 gigabit/sec.

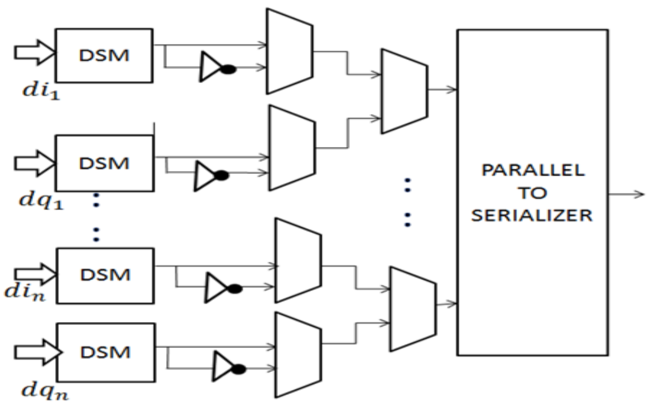

Figure 3.Block diagram of the All-Digital Multichannel RF Transmitter Architecture

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C. Delta-sigma modulator

Modulation can be defined as the systematic alteration of a carrier in accordance with a message. Modulation of a signal by a periodic sequence of impulses plays an important role in conversion of analog, time varying signals in to a digital format for storage, transmission, processing, coding etc. In this case, the modulator replaces the continually varying signal by pulses, which correspond to sampled values of the analog signals in the time domain. This implies that the continually varying amplitude of the analog signal is approximated to a set of discrete signal levels. This discrete time modulation is referred to a pulse code modulation (PCM). The delta-sigma modulator is an offspring of the PCM family [1] and combines the quantization operation within a feedback loop configuration. In contrast to conventional PCM, which represents the sampled signal levels in the form of multi-bit digital words, the delta-sigma modulator encodes the signal levels in the time domain by generating a corresponding sequence of pulses. Hence, the modulator output, often limited to a single amplitude level (ie, quantized to one bit), represents a pulse density modulated (PDM) version of the input signal. Consequently, the original signal can be reconstructed by time averaging, or low pass filtering, this PDM signal.

Digital modulation schemes have greater capacity to convey large amount of information than analog modulation schemes. RF communication system use advanced forms of modulation to increase the amount of data that can be transmitted in a given amount of frequency spectrum. Due to the specific sequence of operations in the feedback loop configuration, the Δ∑-modulator sharply discriminates between the signal and the resulting quantization error. Despite the low number of output signals levels, this can provide a Δ∑-modulated signal with an extremely high dynamic range. Δ∑-modulators are therefore predominantly applied in high-resolution data-conversion systems.

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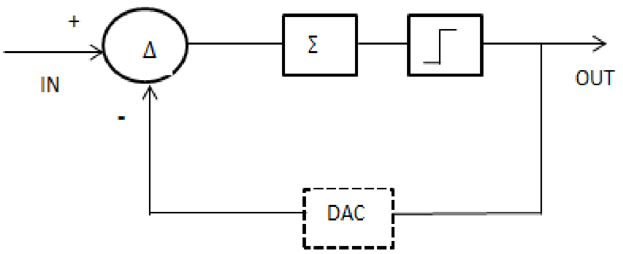

Figure 4. Basic block diagram of delta-sigma modulator

The basic Δ∑-modulator uses a feedback loop, which computes the difference between the instantaneous input signal and the previous (quantized) output (hence the name delta), followed by a discrete-time integrator or accumulator (denoted by the symbol sigma). Figure shows a simplified block diagram of a single integrator or first-order Δ∑-modulator loop. If the input is a digital signal, the Δ∑-modulator can be realized using digital signal processing only and the digital-to-analog converter (DAC), shown by dashed lines, is not required [9].

The most prominent feature of a delta-sigma modulator is its capability to shape the quantization noise. It does this by altering the spectral shape of the error.ie, by putting the quantization error in the feedback loop. Its main purpose is to increase the signal-to-noise ratio(SNR) of the resultant signal. The delta-sigma modulator can be made from ordinary digital circuits.

There are a lot of different ways to realize a delta-sigma modulator [6]. Here the delta-sigma modulator used is a cascade of resonators with distributed feed forward type (CRFF). The use of CRFF delta-sigma modulator permits a high operating frequency which consequently enables a higher usable bandwidth.

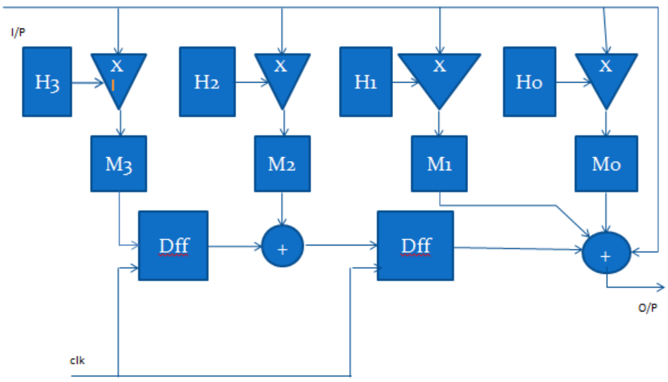

Figure 5. Second-order CRFF delta-sigma modulator

D. RF Receiver

In radio communications, a radio receiver is an electronic device that receives radio waves and converts the information carried by them to a usable form. It is used with an antenna. The antenna intercepts radio waves (electromagnetic waves) and converts them to tiny alternating currents which are applied to the receiver, and the receiver extracts the desired information. The receiver uses electronic filters to separate the desired radio frequency signal from all the other signals picked up by the antenna, an electronic amplifier to increase the power of the signal for further processing, and finally recovers the desired information through demodulation.

The all-digital multichannel RF receiver should operate at the same frequency as that of the RF transmitter.

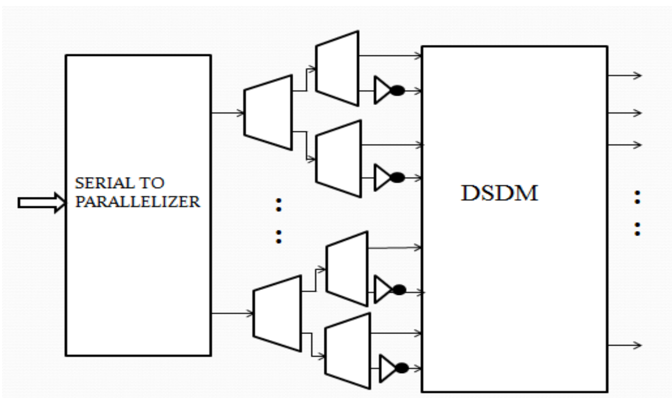

Figure 6. Block diagram of the multichannel RF Receiver architecture

IV. CONCLUSIONS

Software-defined radios have become the dominant technology in radio communications. A mobile phone able to operate all over the world and to travel on most of the wireless networks should become a reality with the growth of the software-defined radio. To achieve these developments, it must be able to support the simultaneous transmission and reception of multi-band, multi-rate and multi-standard signals. This can be achieved by combining multichannel with multi-band and multi-standard data transmission capabilities in RF communication system.

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