Simulation and Synthesis of an AM Software Radio Receiver

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ABSTRACT
This paper describes the implementation of an AM/FM radio receiver in Field Programmable Gate Array (FPGA). Using FPGA as the hardware platform, this approach brings together the flexibility of software and the speed of hardware to build a reconfigurable system, i.e. the behavior of the radio receiver can be changed by simply modifying the software without new hardware. RF modulated signals are digitally sampled and demodulated in real time using digital circuits of the FPGA. To program the FPGA, the receiver structure is described in HDL software which is used to synthesize the system into the FPGA. The design, simulation and initial testing of the AM/FM radio receiver will be presented with emphasis on the concepts and techniques being employed.

[1] INTRODUCTION
The purpose of this project is to create a software defined radio that can take in an AM or FM modulated signal from a common RF front end and demodulate it appropriately before sending the baseband signal to a computer over an Ethernet interface. The baseband signal would be encoded using a software compression algorithm to increase bandwidth efficiency across the Ethernet link. Since an appropriate front end could not be reasonably obtained for this project, the input signal is simulated using 2 function generators that are capable of providing AM/FM modulation. The simulated input signal uses a 10.7MHz IF frequency, which was typical for AM/FM combination RF front ends. The IF signal is sampled using the high speed ADC on the Terasic ADA add-on for the DE2 development board. After IF digitization, all demodulation and signal processing are performed in the FPGA until the baseband signal is ultimately transmitted over Ethernet.

Recent advancement in semiconductor technology has made it possible to process high speed communication signals in radio systems using as much digital technology as possible. This makes the system very flexible and adaptive. Such a technology is called Software Defined Radio (SDR). Traditional analog radio receivers and transmitters consist of dedicated analog circuits for filtering, tuning, and demodulating/modulating a specific type of waveform. These hardware based radio systems are inflexible and hard to modify if changes are to be made to its fundamental characteristics such as demodulation/modulation types. To make the system more flexible, SDR technology facilitates implementation of some of these functions in software. This results in reconfigurable software radio systems where changes to its fundamental characteristics can be made simply by modifying the software, whereas a complete hardware based radio system would require hardware modification in order to change these parameters.

With its reconfigurability, the potential applications of SDR are numerous. One example is in wireless communication industry, where due to the many communication standards being used around the world, there is a need to build multimode handsets capable of connectivity irrespective of the underlying network technology used. SDR technology could be applied here as radio functions are implemented in software, multiple software modules implementing different standards can co-exist in a handset. An appropriate software module can be chosen to run depending on the network requirements.

While there are a variety of hardware platforms for implementing SDR, FPGA is an attractive option due to its performance and configurability. The logic fabric of today’s FPGAs is not only made up of look-up tables, registers, multiplexers, distributed and block memory, but also dedicated circuitry for fast adders, multipliers, and I/O processing (e.g., giga-bit I/O). Furthermore, the memory bandwidth of a modern FPGA far surpasses that of a microprocessor or DSP processor running at clock rates two to ten times that of the FPGA. In addition, FPGA has a capability for implementing highly parallel arithmetic architectures, making it perfectly suited for tasks such as digital filtering, fast Fourier transforms and forward error correction. In this paper, to demonstrate the feasibility of SDR, we present the implementation an FPGA-based software AM/FM radio receiver.

The detailed implementation of the AM and FM receivers are different in term of the sampling techniques and demodulation techniques employed as will be presented in subsequent sections, this section aims to present some general concepts and key components pertinent to both AM and FM receivers.

Figure 1 shows the system overview of the Digital AM/FM Receiver being implemented. Radio signals received by an antenna first go through an Anti-Aliasing Filter to remove all signals out of AM/FM bands. This analog filter is necessary in order to avoid aliasing problems in digital implementation. The analog input is then
digitized into digital samples by an A/D (analog-to-digital) converter. From this point, all subsequent operations including mixing, filtering and demodulation is done using digital signal processing techniques to extract radio channels of interest. These operations are supported by key components of the digital receiver including Digital Mixer, Digital Local Oscillator, Digital Low Pass Filter and Digital Demodulation. After demodulation, digital samples of radio channels of interest are converted back to analog format using a D/A (digital-to-analog) converter. The radio signal is amplified and played by a loudspeaker.

AM DIGITAL RADIO RECEIVER DESIGN
AM band frequency ranges from 526.5 kHz to 1606.5 kHz. To avoid aliasing, the ADC (analog-to-digital converter) needs to sample signal at sampling rate at least twice the highest frequency in the AM spectrum, thus a sampling rate of 4 MHz was chosen for the ADC to allow for some margin. Figure 7 shows the structure of the AM Digital Receiver. As mentioned previously, an ADC is used to digitize the analog signal received from the antenna into digital representation. And in Figure 7, $s_{AM}(n)$ represents the digital samples of the modulated AM signal whose spectrum contains all AM channels. These samples are multiplied with digital sinusoidal samples $(\cos (2\pi f_c n))$ of a local oscillator whose frequency is that of the channel of interest. In other words, the frequency of the sinusoidal signal generated by the local oscillator is dependent upon the channel selected by the user. The effect of this multiplication is to shift the spectrum of the AM signal down to DC level so that a low pass filter having a fixed cut-off frequency can be used to pass the baseband message of the radio channel of interest.

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 wanted radio frequency signal from all other signals, an electronic amplifier to increase the power of the signal for further processing, and finally recovers the desired information through demodulation. The information produced by the receiver may be in the form of sound (an audio signal), images (a video signal) or data (a digital signal). A radio receiver may be a separate piece of electronic equipment, or an electronic circuit within another device. Devices that contain radio receivers include television sets, radar equipment, two-way radios, cell phones, wireless computer networks, GPS navigation devices, satellite dishes, radio telescopes, Bluetooth enabled devices, garage door openers, and baby monitors.
The Synthesize Results of our Proposed Radio Receiver system is shown in the tabulation below.

<table>
<thead>
<tr>
<th>Logic Utilization</th>
<th>Used</th>
<th>Available</th>
<th>Utilization</th>
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</thead>
<tbody>
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<td>1320</td>
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<tr>
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<td>1%</td>
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<tr>
<td>Number of 4 input</td>
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<td>1%</td>
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<td>27%</td>
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<tr>
<td>Number of 5LUTs</td>
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<td>0</td>
<td>12%</td>
</tr>
</tbody>
</table>

[3] CONCLUSIONS

In this project, we have looked into the concepts and design techniques of a new digital technology called Software Defined Radio by implementing an AM/FM Digital Radio Receiver in software running on a FPGA platform. We have developed two models for demodulating AM and FM signals, respectively, using all digital circuit technology right from the antenna. Simulation of our models using both double precision and fixed precision has shown that the general concepts and techniques of software radio are feasible in general and in particular to the implementation of an AM/FM radio receiver.

The two most important findings in this project are the use of multistage filtering technique to reduce the filter order, and the use of under sampling technique to lower the sampling rate requirement for the ADC. Firstly, in applying multistage filtering technique, we have mathematically formulated a formula for estimating the total filter order in an N-stage filter. We also proved mathematically that compared to single stage filtering, multistage filtering reduces the number of filter taps approximately by a factor of \( \frac{F_s}{4 \log_2 F_s} \) where \( F_s \) is the sampling rate of the filter input data. Secondly, in employing undersampling technique for our FM receiver, we have confirmed that it is a powerful technique for lowering the sampling rate requirement for the ADC, and thus lowering the computational requirements for the entire system (e.g. lowering filter taps requirements). Undersampling can be an extremely valuable tool, especially for designing receivers operating at high frequency spectrum.

Due to the scope of this project, only preliminary testing of the designed system in FPGA was carried out. Therefore, the most important future work extending on from this project would have to be a comprehensive testing of the designed system. All software required for testing the AM and FM receiver in actual FPGA have been developed in this project, ready to be synthesized into the targeted FPGA. Of particular note to individual pursuing the testing phase of this project is the design of Anti-aliasing filters, which for our AM receiver system should have a passband from 0-2 MHz, whereas for our FM receiver system, the filter should be a bandpass analog filter with passband from 88-108 MHz. These filters should ideally be high order analog filters with large stopband attenuation. Finally, from our experience during the initial testing phase of this project, a good advice to students continuing this project is that it is important to get all the necessary hardware components ready at the beginning of the year so that experimental testing can be carried out at the end of the development cycle. These include an AM/FM antenna with a suitable matching circuit to 50 Ohm input of the ADC, two anti-aliasing filters as mentioned above, a low noise audio amplifier and a loud speaker.
REFERENCES
www.mathworks.fr/applications/dsp_comm/xilinx_ref_guide.pdf

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