

SYNTHESIZING FPGA CORES FOR SOFTWARE-DEFINED RADIO

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ABSTRACT

The paper describes the integration of two separate waveforms utilized in a new prototype development for a software-defined radio. The FM modulator and demodulator were integrated into one signal processing core capable of performing the modulation and demodulation of a 5KHz audio spread.

Band 3 waveform processing for the Soldier Radio Waveform (SRW) proved to be a challenge due to the wide and narrow bandwidth performance of the waveform, and high data rates greater than 10Mbps. Since the waveform is going through an evolutionary change during its development cycle, the present design will meet the preliminary waveform requirements at the time of the development.

1. BACKGROUND

The concept of Software-defined radio (SDR) has been around for many years. The ability to perform field upgrades and reconfiguration of waveforms has a large benefit to the military community. But, only recently has semiconductor technology evolved to make SDR possible. Typical architectures implement waveforms in the digital domain using Microprocessors, FPGAs, and DSP Processors. This paper focuses on implementation using a single FPGA. FPGAs have specific features that enable SDR implementation. These include: high-bandwidth memories, embedded DSP Blocks, phase-locked loops (PLL), and high-speed interfaces. In addition, soft processors plus FPGA co-processors enable reconfiguration of the digital waveforms.

2. DIGITAL RADIO ARCHITECTURE

Figure 1 shows a figure of a common FM radio architecture. In traditional radio architectures, all of the FM modulation and demodulation is performed in the analog domain. The processing power of digital components can now easily perform these operations. The first step in digital radio

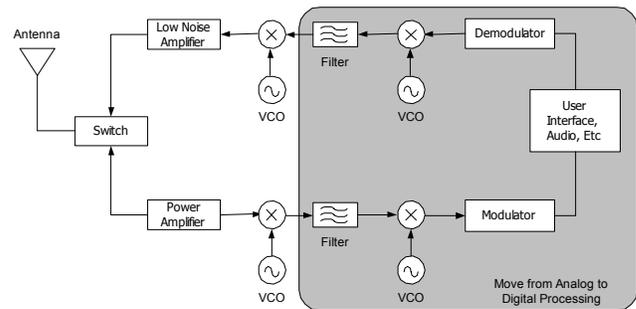


Figure 1: FM Radio Architecture

architecture is to perform the exact analog functions in the digital domain. This can be done in two ways: 1) perform digital operation on a microprocessor, or 2) create analog equivalent function in digital domain. The most flexible solution is to use a microprocessor (or DSP) to perform the radio functions. This allows the waveform developer to use a standard language, and remain hardware independent. Unfortunately, only low data rate waveforms can be processed using a DSP. The second solution allows for higher processing rates, but is not as flexible. Fortunately, an FPGA's flexibility allows for either solution (or combination of these solutions).

3. PROCESSOR BASED DEMODULATION

Figure 2 shows a typical radio system using a microprocessor (or DSP) as the baseband processor. In this case the processing is performed by a 'soft core' microprocessor. Soft Core processors are built using the generally available resources in an FPGA. Typically these processors can provide 100 – 150 MIPS. This is enough processing power to perform modulation and demodulation for low bandwidth signals.

When the processing power needed exceeds that of the soft core processor, co-processing elements can be added. Figure 3 shows an example of the same FM radio that uses a CORDIC (COordinate Rotation DIGital Computer) co-processor. The CORDIC co-processor implements a vector rotation engine that can be used to calculate trigonometric

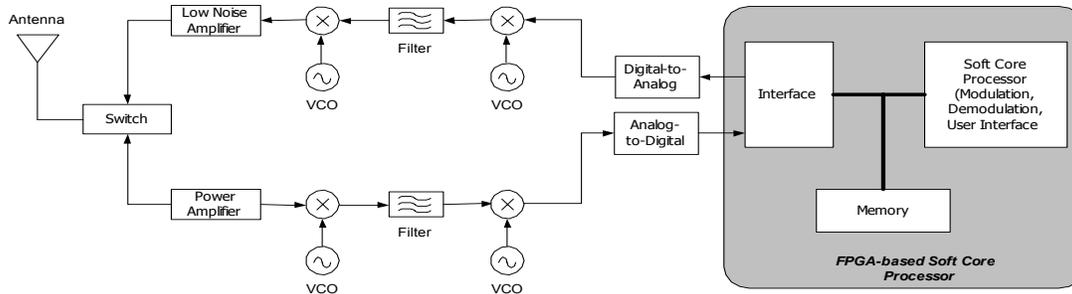


Figure 2: Processor Based FM Radio

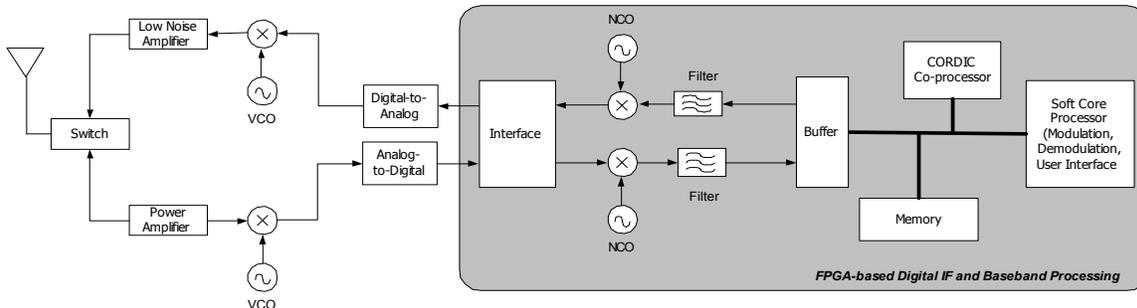


Figure 3: FM Radio with Digital IF

functions [1]. In the case of FM, the CORDIC provides the arctangent function needed to demodulate FM waveforms. Table 1 shows typical performance of soft core processors and CORDIC co-processors.

Table 1: FM Radio Components

Function	Speed	Resources
Soft Core (Altera NIOS)	100 MHz	1500 LE
CORDIC	219 MHz	966 LE

4. DIGITAL IF PROCESSING

FPGAs are capable of more than baseband modulation and demodulation. Today's advanced FPGAs have the capability to provide IF (Intermediate Frequency) processing as well as baseband processing. Figure 2 shows the FM radio architecture with IF processing. In this implementation the VCO (Voltage Controlled Oscillator) is replaced with an NCO (Numerically Controlled Oscillator). The analog filtering functions are now replaced by digital FIR (Finite Impulse Response) filters. The Soft Core processor (along with the CORDIC co-processor) still performs the baseband processing functions. The Soft Core processor also changes the parameters of the various IF components. For example, the Soft Core processor can update the output frequency of the NCO, or change the coefficients of the FIR Filter.

Today's FPGAs are capable of supporting IF rates up to 150 MHz. Table 2 shows some utilization and clock rates for the IF processing functions. The utilizations are based on Altera's Stratix FPGA Family. The resources are as follows:

- LE: Logic Element, basic element of an FPGA
- Mult: The number of 18x18 Multipliers used
- M4K: Embedded 4 Kbit memories

Table 2: Digital IF Components

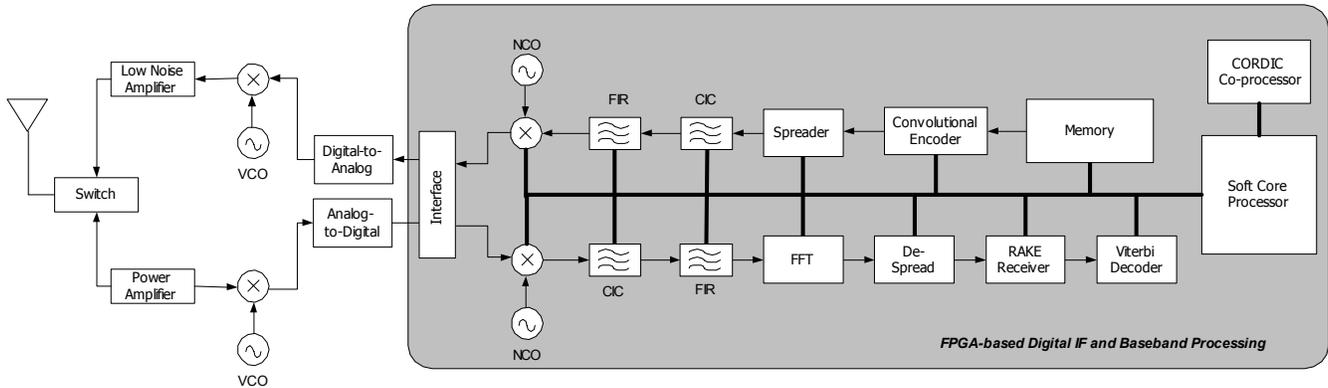
Function	Speed	Resources (LE/Mult/M4K)
Parallel FIR (48 taps, 14-bit)	244.26 MSPS*	1375 / 0 / 30
Serial FIR (48 taps, 14-bit)	19.33 MSPS*	360 / 0 / 6
NCO (24-bit)	278.78 MHz	67 / 8 / 12
CIC (6 th order, 14-bit)	200 MHz	1138 / 0 / 0

* MSPS: Million Samples Per Second

Note: Resources based on [2], [3]

5. IMPLEMENTING SRW

The concept of 'co-processing' can be extended to support more computationally intensive waveforms, like SRW. The SRW waveform requires processing rates that are far beyond the reach of microprocessors. Figure 4 shows the block diagram of the SRW implementation in an FPGA. In



this implementation, most of the waveform processing is performed by co-processing components. But, as in the FM

case, the Soft Core processor performs the initialization and

Figure 4: SRW Implementation

parameterization of the co-processors. Notice that the CORDIC coprocessor is still available to perform FM waveform processing.

Table 3 shows the performance of the various co-processors used in the SRW waveform.

Table 3: SRW Components

Function	Speed	Resources (LE/Mult/M4K)
FFT* (128 points)	1.03 μ sec	4838 / 9 / 19
FFT* (2048 point)	8.38 μ sec	7952 / 18 / 44
FFT* (8192 point)	38.73 μ sec	8388 / 18 / 176
Viterbi Decoder**	10 Mbps	2600 / 0 / 0

* Two Radix 4 Engines, 16-bit operation

** Constraint length = 7, number ACS = 8

Note: Resources based on [4], [5]

6. SYSTEM IMPLEMENTATION

The software-defined radio (SDR) form factor drives the design and power requirements for the design. The SDR system comprises of two modules, the digital baseband module and the RF module. The antenna and Human Machine Interface (HMI) are part of the chassis frame that encloses the RF and Digital module. Through the advancements in package technologies the RF and Digital components on the module can fit into two separate IC packages. Using mixed signal technologies the RF and Digital can fit into one substrate with challenging requirements to minimize interference between the two systems. Limitations in semiconductor technologies can prevent some of the passive components such as capacitors and inductors to meet the stringent RF requirements.

A small form factor prototype baseband module measuring 5 square inches, 14 layers, .062 inch thick, three power planes and three supply ground planes, two signal

ground planes (analog and digital), and six signal layers provides the necessary isolation to minimize coupling to the RF module. Minimizing the pin count connectivity for the HMI interface and the RF module can do further reduction to the board size.

High speed signals around the FPGA are integrated into the inner layers to reduce EMI coupling throughout the digital board. Matched length signal traces for high speed signals ensure the impedance of the signal traces is 50 ohms. The six signal layers are interleaved between the supply planes. All static and control signals with low clock edge rates are routed on the top and bottom layer of the digital board. SMPS (Switch Mode Power Supply) provides 1.5V, 3.3V, and 5V for the digital board. A 7.2V to 12V DC input voltage provides the main input voltage for the digital board. The design efficiency of the supply design is 90%.

A simple discrete reset circuit is used to initialize the FPGA, Flash, UART transceivers, HMI interface, and RF interface. Also a soft reset is provided through the RF module interface to prevent continuous transmission to the 5 watt PA greater than 1 minute. A 100ms delay is used to ensure stabilization of the supply voltages prior to loading the FPGA configuration bit stream.

The incoming I and Q data from the data converter of the RF module is processed through the FPGA (modem) and then sent through the transceiver interface into a handheld personal assistant, similar to the HP IPAQ model 5550. Due to time restrictions on the project, the server/client WiFi connectivity for streaming audio on demand was not completed for this program. Based on the overall throughput rate and latency in the system, WLAN should support streaming audio on demand. The handheld personal assistant is the HMI for the prototype SDR. Outgoing data from the handheld personal assistant is sent through the transceiver interface. The FPGA (modem)

prepares the data for transmission, then sends the I and Q data to the data converters of the RF module.

The flash on the SDR prototype baseband module holds the configuration bit stream for the FPGA and the integrated compiled code for the soft core processors. During power-up a small CPLD bootloads the stored flash data into the FPGA. To initially load the data into the flash the CPLD is jumper selectable during power-up to either read or verify blank/erase/program the flash. The SDR prototype baseband module can also load configuration data for the FPGA through the JTAG port.

7. SUMMARY

Software-defined radio has become a reality for military radio. Using the latest FPGA technology, implementation of SDR is now possible. FPGAs provide a design environment that allows for true architectural trade-offs. Soft core processors are a good alternative that allow flexible implementation options. Soft core processors do have performance limits. When these limits are reached, FPGA intellectual property (IP) can be used to implement co-processors.

References

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