Software Defined Radio for Passive Sensor Interrogation

J.R. Humphries and D.C. Malocha
Department of Electrical Engineering and Computer Science

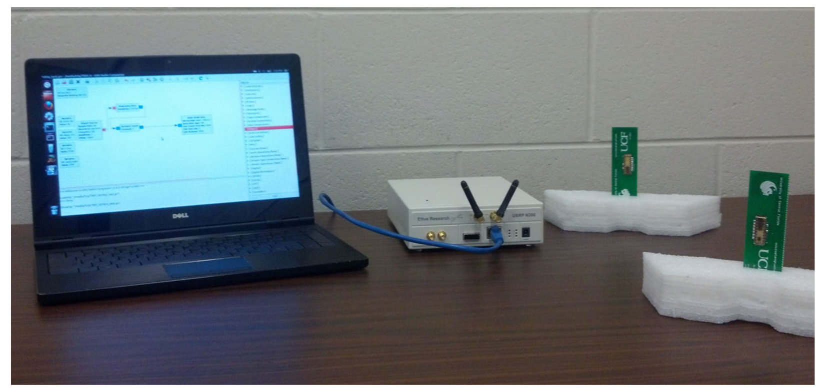
University of Central Florida

1 Introduction

The Universal Software Radio Peripheral (USRP) is an interesting platform for wireless applications. Designed by Ettus Research™, the USRP is a versatile software defined radio (SDR) platform that can be reconfigured easily using the USRP Hardware Drivers (UHD) and software libraries such as GNU Radio or MATLAB. The daughterboards (RF front-end electronics) are also programmable (gain, center frequency, and port configuration) and swappable, giving the end user many options for RF characteristics.

Project Goals

- Modify USRP FPGA design to communicate with passive SAW OFC sensors.
- Implement a FPGA chirp generator based on user defined bandwidth and sweep time.
- Synchronize receiver listen state with signal transmission state along with user defined receiver delay and listen time.
- Demonstrate chirp deconvolution using generated chirp samples by installing a delay line (SAW filter) between the TX and RX ports.
- Interrogate a single SAW OFC sensor and extract the correlation with its matched filter.

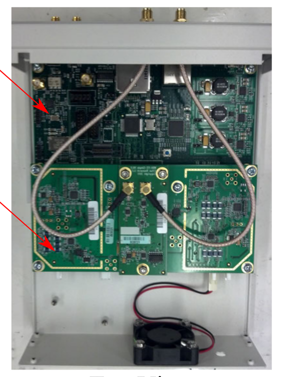


2 Experimental Setup

Universal Software Radio Peripheral

The N200 USRP was chosen for this project because it allows for the highest sampling rates. It is intended for research and high performance applications. The WBX daughterboard was chosen because it provides the highest RF bandwidth (40MHz) and works in this project's frequency range of interest (50MHz - 2.2GHz) for SAW sensors. The system dimensions are 20cm deep, 15cm wide, and 5cm tall.

N200 USRP	
Host Interface	Gigabit Ethernet
FPGA	Xilinx Spartan 3A-DSP 1800
ADC	100 MSPS, 14-bit
DAC	400 MSPS, 16-bit
Clock Rate	100MHz
WBX	
Type	Full Duplex Transceiver
Frequency Range (Programmable)	50MHz – 2.2GHz
Bandwidth	40MHz
Noise Figure	5-10dB
Output Power	+20dBm



Top View

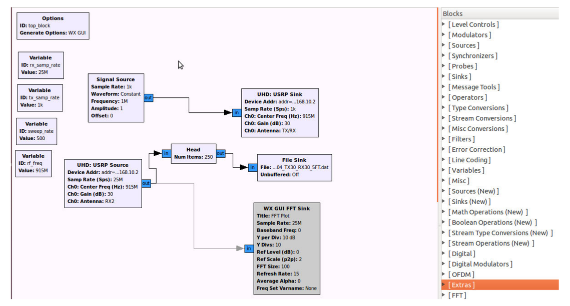
Front View

Rear View

Host Computer and Software

Proper selection of the host computer and software prevents packet loss over Ethernet and reduces compatibility issues with certain versions of the USRP and Xilinx. The setup below works with no known issues.

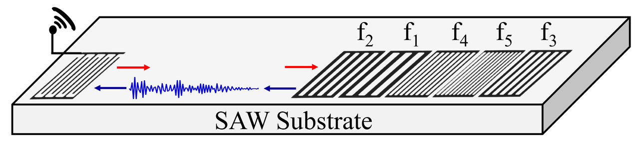
Host Computer	
Processor	2.8GHz, Dual-Core
Memory	4GB
Interface	Gigabit Ethernet
Software	
Operating System	Linux – Ubuntu 12.04
Xilinx Version	12.1
Post Processing	GNU Radio / MATLAB
USRP Programming	GNU Radio Companion (GRC)
UHD Version	003.005.001-25-ge134b863
GNU Radio Version	3.6.0



GNU Radio Companion

Passive, Wireless SAW OFC Sensors

- Spread spectrum coding technique with high processing gain.
- Uses array of SAW reflectors (chips) with different center frequencies. Each chip frequency is orthogonal to all other frequencies in the set.
- Chips are shuffled in time to create a code.
- 1-10μs response time (typical), >20MHz Bandwidth.



3 FPGA Modifications

FPGA Modifications

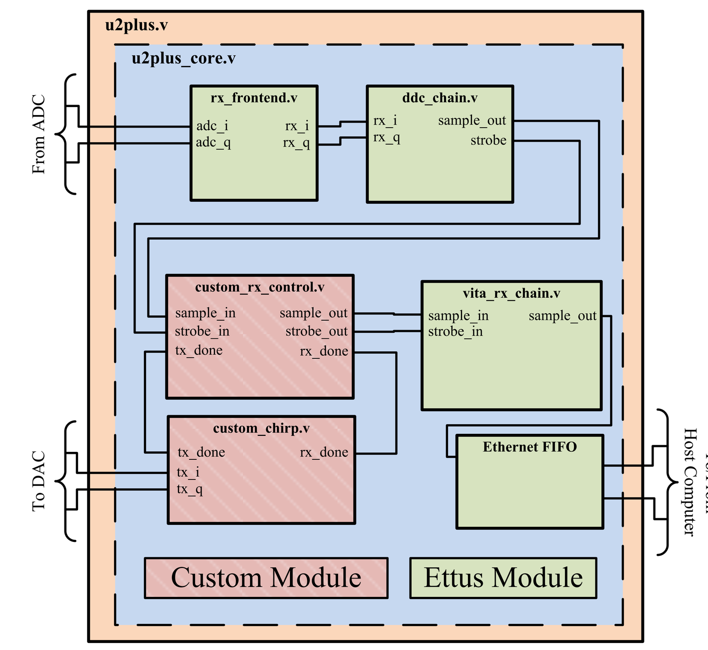
The system modification design is based on a synchronous correlator receiver approach using a pulsed interrogation signal. The USRP must capture the return signal from the target sensor and transfer the data back to the host computer for post processing and data extraction.

Transmitter Modifications

The default transmitter design (DUC, TX streaming, etc.) was removed completely and replaced by a custom chirp generator (custom_chirp.v).

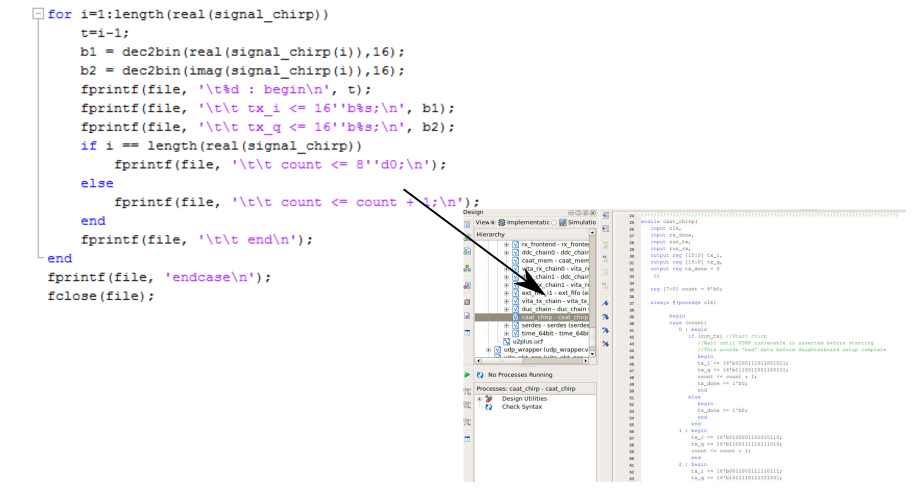
Receiver Modifications

A new module (custom_rx_control.v) was introduced in the receive chain to synchronize the listen state with the transmit state. Samples are only passed through for a user specified time after the transmit state has finished.



Automatic Verilog Code Generation

Generation of the I/Q chirp samples is accomplished using MATLAB. The user specifies the signal bandwidth and signal time length. Once the the signal components have been properly calculated and conditioned, they are converted to binary (two's complement). A custom script then generates the Verilog module that generates the user defined chirp.



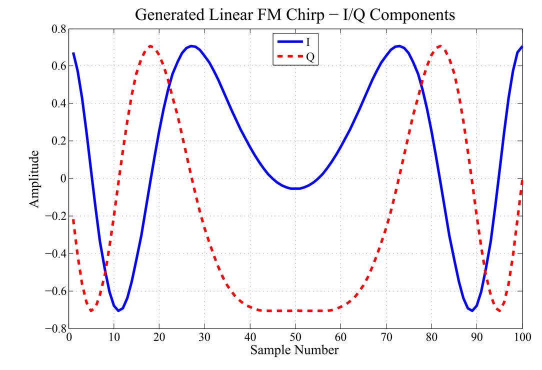
Generated Linear FM Chirp

10Mhz, 1μs linear chirp generated and samples output directly to DAC's on USRP.

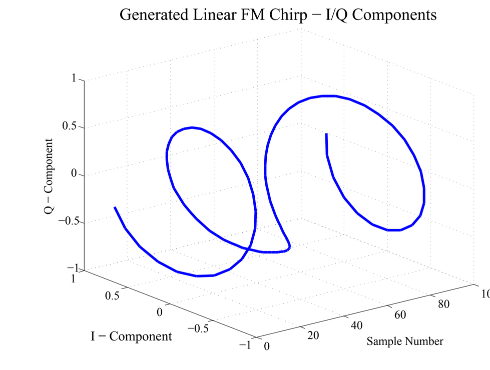
(a) 2D representation of I/Q sample streams for linear FM chirp.

(b) 3D representation of I/Q chirp components.

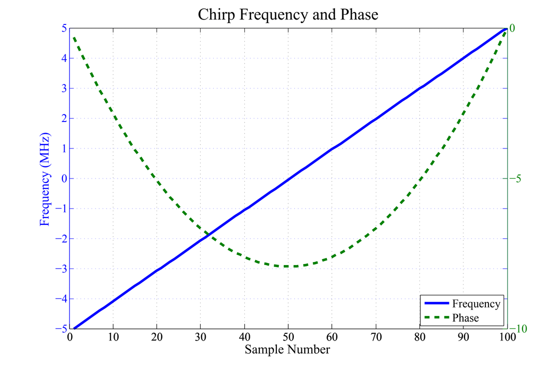
(c) Frequency offset and phase of generated chirp signal.



(a)



(b)



(c)

4 Characterization of Modified USRP

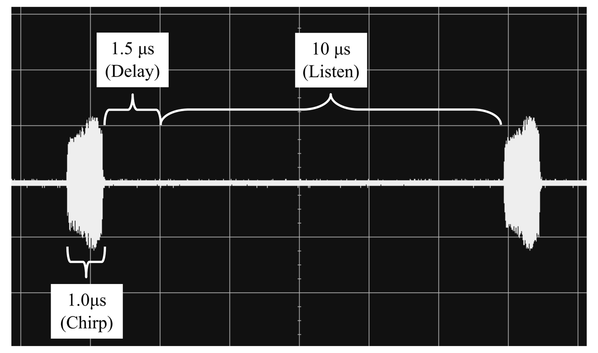
Receiver Settings

The receiver settings are configured by the UHD. The sampling rate was set to the maximum that the host computer could process. The sampling rate is set in the DDC in the FPGA of the USRP.

USRP Receiver Configuration	
Sampling Rate (DDC)	25 MSPS
T_{max} (Listen Time)	10μs
Samples per Sweep (N)	250
Δt (Resolution)	40ns
F_{max} (Baseband BW)	25MHz
Δf (Resolution)	100kHz

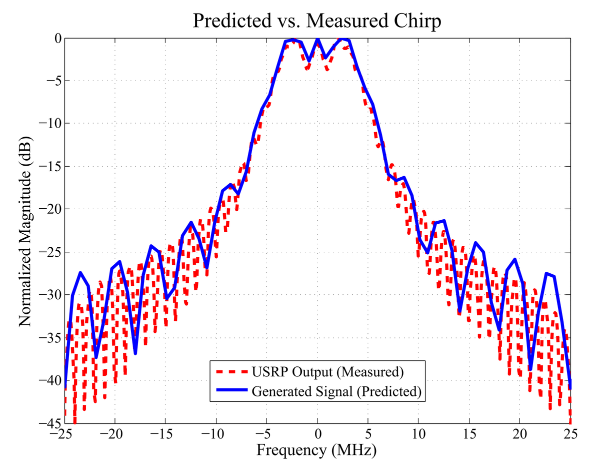
Synchronization Between TX and RX Chains

The transmit signal was output to an oscilloscope to ensure that the transmit was triggered after the specified delay (1.5μs) and the listen time (10μs). Each cycle takes 12.5μs to complete, equal to a pulse repetition frequency (PRF) of 80kHz.



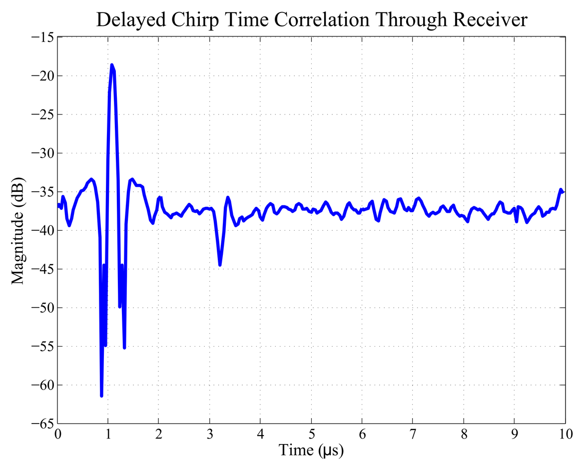
Transmitter

The transmitter was set to output the linear chirp with a center frequency of 915MHz. The output was measured on a spectrum analyzer and compared with the predicted spectrum from the generated chirp samples.



Chirp Deconvolution Through SAW Filter

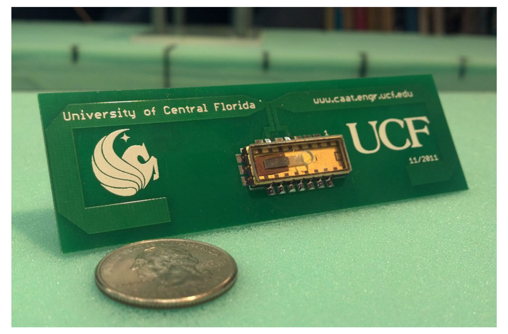
A 915MHz SAW filter was placed between the TX port and the RX port. A single sweep was recorded. The generated chirp samples were used to deconvolve the transmitted chirp signal from the SAW filter response.

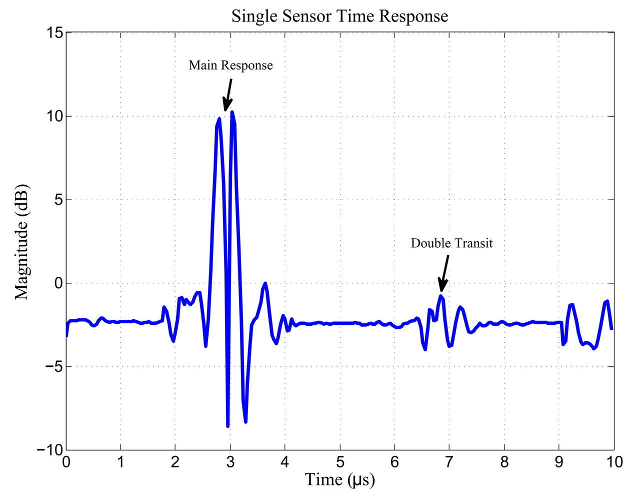


5 SAW Sensor Interrogation

Sensor Interrogation

A passive, wireless SAW OFC sensor was interrogated by the modified USRP at a frequency of 915MHz. The sensor is attached to a PCB dipole antenna of approximately 2dBi gain. The chirp signal was broadcast and the return signal was recorded for 10μs. The delay of the SAW sensor is approximately 3μs when the system delay is taken into account.





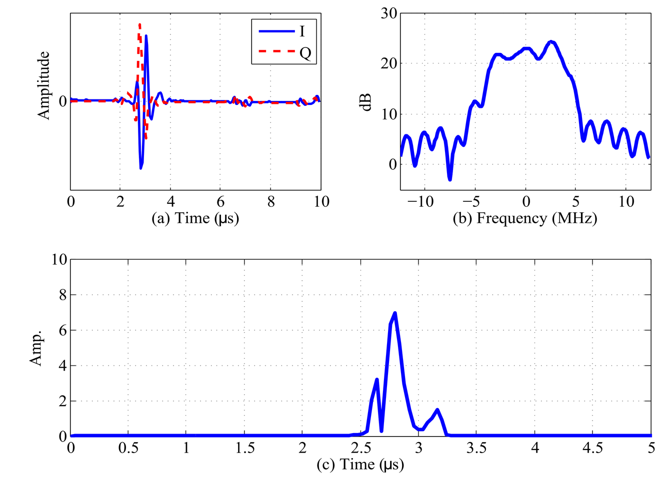
Correlation with Matched Filter

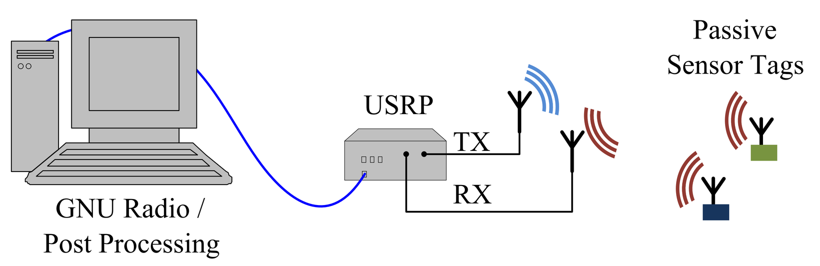
The received data was processed with a software correlator, developed at UCF, to correlate the sensor response with its matched filter. The sensor is a 5 chip design, but it is correlated to a single chip due to current bandwidth limitations.

(a) I/Q signal components of the received signal.

(b) Frequency response of the received signal.

(c) Demodulated time correlation of the sensor with its matched filter.





6 Conclusion

The USRP modifications were successfully implemented into the FPGA. A custom chirp generator allowed for a user defined chirp signal to be transmitted to interrogate the sensors. Additionally, a new receiver module was introduced that synchronizes the listen state with the transmit state. The system was demonstrated by interrogating a SAW OFC sensor and correlating to the sensor's matched filter.

Future modifications are planned to extend the functionality of the modified USRP design. These planned modifications include external hardware (such as TX/RX switching, LNA, and PA) for better signal conditioning and DDC alterations to increase receiver bandwidth. The full implementation of the modified USRP will prove to be a robust platform for passive sensor interrogation.

References

S. Heunis, Y. Paichard, and M. Inggs, "Passive radar using a software-defined radio platform and opensource software tools," in Radar Conference (RADAR), 2011 IEEE, 2011, pp. 879–884.

C. Valenta and G. Durgin, "R.E.S.T. - A flexible, semi-passive platform for developing RFID technologies," in Sensors, 2012 IEEE, 2012, pp. 1–4.

D. Malocha, D. Puccio, and D. Gallagher, "Orthogonal frequency coding for SAW device applications," in Ultrasonics Symposium, 2004 IEEE,vol. 2, 2004, pp. 1082–1085 Vol.2.

Downloads

James 'Trip' Humphries
James.Humphries@knights.ucf.edu
Orlando, FL, USA

Download Paper (PDF)

Download Poster (PDF)
Warning: ~35MB