THE WIBEX SOLID STATE X-BAND RADAR SYSTEM

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INTRODUCTION

Weather radars using **low-power solid-state transmitters** are an emerging technology, and promise improved reliability. These transmitters are also an essential component of active phased-array antennas being developed for the CASA project. The primary drawback of a solid-state transmitter is the **low available peak power**, since the sensitivity of a weather radar is proportional to the product of the **pulse width** and **peak power,** and inversely proportional to the **receiver bandwidth**. However, solid-state transmitters have relaxed duty cycle restrictions.

The Wideband Experimental X-band (WiBEX) radar is designed as a test platform to validate various **pulse compression** waveforms being designed at Colorado State University. The radar employs **dual 100W solid-state power amplifier modules**, capable of 15% duty cycle, each driving the ports of a dual-polarization 2.4m X-band antenna. The transmitter is driven by a **programmable waveform and timing generator**. The **channelizing FPGA-based receiver** is designed for maximum flexibility with regard to pulse compression.

Pulse compression techniques are normally used in order to achieve sensitivity comparable to a conventional electron-tube transmitter; however, this introduces a **blind zone** across which the radar cannot make measurements, and also introduces **range sidelobes** which can compromise the measurements made by the radar.

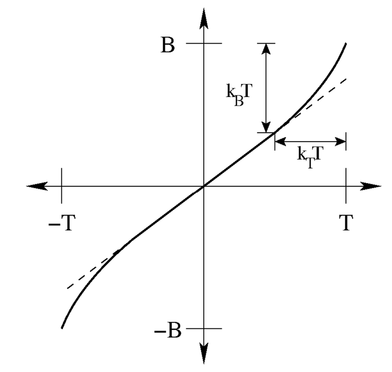
This poster outlines the range sidelobe suppression techniques used, and briefly presents the hardware design of the radar.

NONLINEAR-FM WAVEFORM AND COMPRESSION FILTER DESIGN

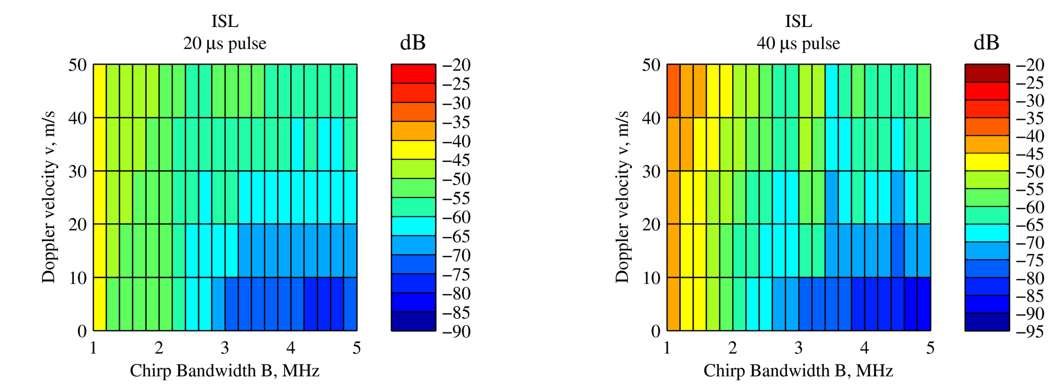
Waveforms for weather radars must be designed for low sidelobe levels, and are weighted both in frequency taper and amplitude. The nonlinear chirp used is defined by:

$$u(t)=rect\left(\frac{t}{T}\right)\exp\left(-j2\pi\int_0^t f(\tau)d\tau\right) \qquad f(t)=\begin{cases}\frac{B}{T}\left(\frac{1-k_B}{1-k_T}\right) & |t|\le T(1-k_T)\\ \phi(t) & |t|>T(1-k_T)\end{cases}$$

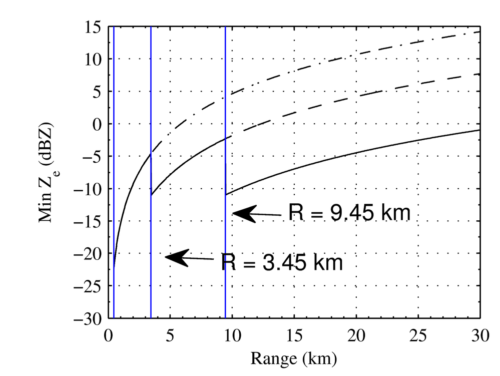
Here, $\phi(t)$ is a nonlinear function, k_B and k_T are nonlinearity parameters. The frequency taper function is illustrated below:

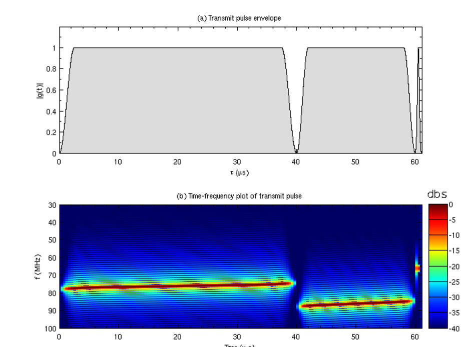


In order to minimize the Integrated Sidelobe (ISL) of the compressed results, an L_p-norm pulse compression filter is designed for 60 dB sidelobe suppression. The integrated sidelobe level is plotted vs. bandwidth for different Doppler velocities that are typically encountered by weather radars.



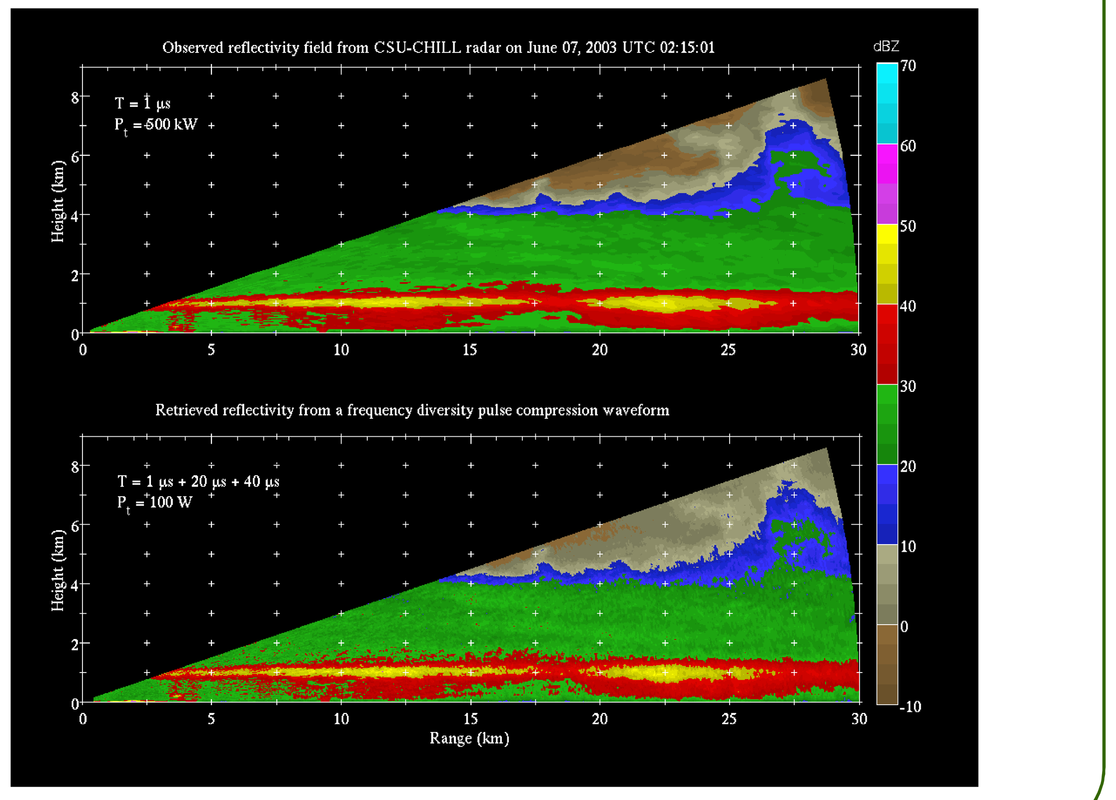
A frequency-diversity technique is then used to produce multiple chirps on transmit, in order to overcome the blind-range problem. Sub-pulse widths are chosen to maximize SNR at all ranges of interest





Frequency-diversity permits the digital receiver to separate returns from sub-pulses by frequency-domain filtering, while time staggering implies that the transmitter only radiates one waveform at a time, eliminating intermodulation issues.

An end-to-end simulation of the frequency-diversity pulse compression waveform was performed using data collected by the CSU-CHILL S-band radar. Simulated time-series was generated, and the pulse-compression filtering simulated. The compressed result was plotted, after processing through a pulse-pair algorithm. The results were seen to agree with the measurements made by CSU-CHILL.



THE WIBEX RADAR

The WiBEX radar trailer.

Left-right:
Generator control
Diesel backup generator
Air conditioner
SCR-584 pedestal
2.4m antenna
Motion control system
UPS enclosure
Signal processor enclosure

The characteristics of this radar are presented below:

Parameter	Value
Antenna	2.4m Parabolic, dual-polarized
Beamwidth	1 degree (3dB)
Transmitter	Dual-channel, 100 W solid-state
Frequency	9.3 – 9.5 GHz
Max. pulse width	70 µs
Max. PRF	3 kHz
Transmit Waveform	Programmable multi-frequency chirp
Bandwidth	32 MHz (1 dB)
Receiver (RF section)	Dual-channel, single-conversion
Noise Figure	2.2 dB
Digital IF Receiver	Multi-channel, FPGA-based pulse-compression

The radar is currently under development at Colorado State University

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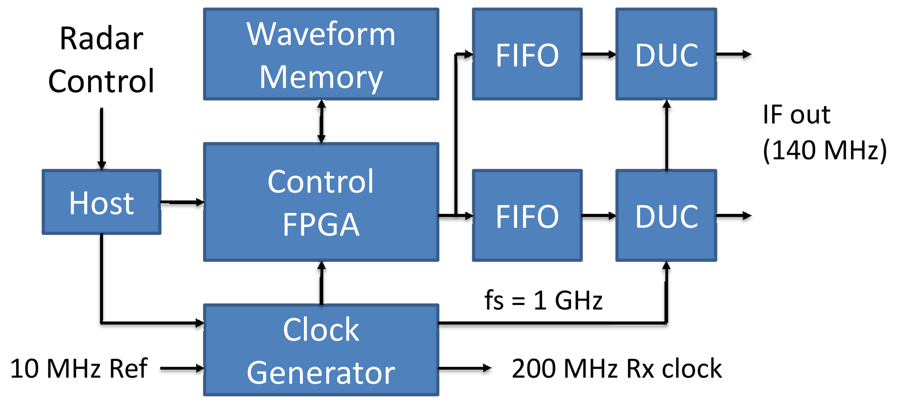
IMPLEMENTATION AND HARDWARE DESIGN

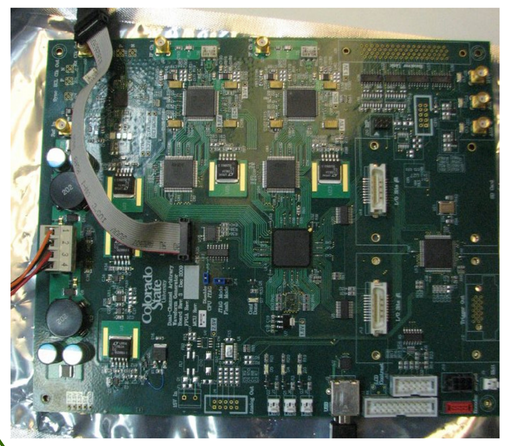
Transmit Waveform Generator (TWG)

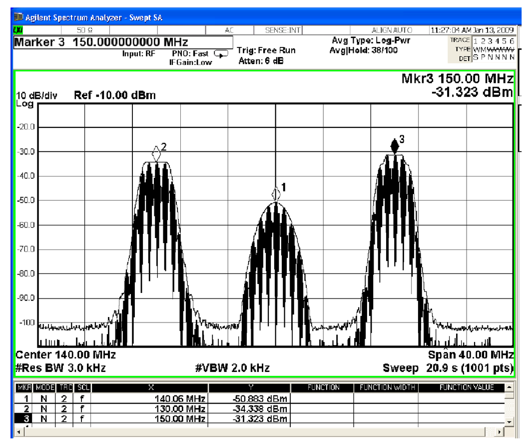
The TWG is a custom-designed dual-channel arbitrary waveform generator, capable of synthesizing waveforms with up to 40 MHz bandwidth, at a programmable center frequency up to 400 MHz. A block diagram is shown below.



A host controller receives commands from the radar control and programs the FPGA. Baseband waveforms can be stored in the waveform memory. On command, the FPGA reads out the waveforms to the digital upconverters, which interpolate to a 1 GHz rate, mix with a 140 MHz LO and convert to analog.

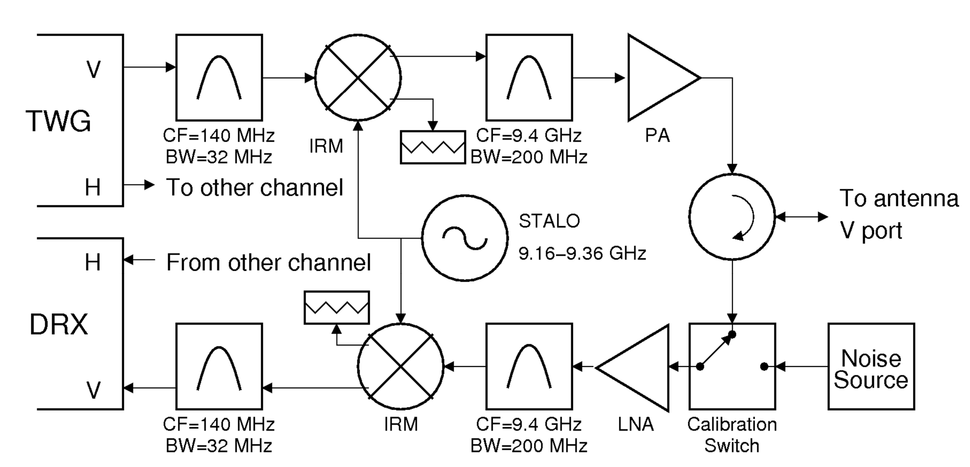
The completed board is illustrated below. Also shown are output spectra from the board, illustrating the frequency diversity waveform.





RF Hardware

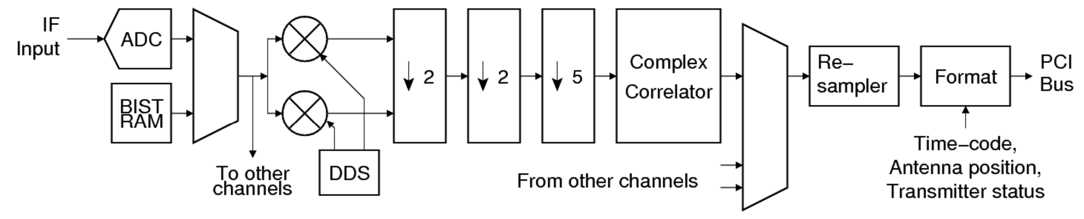
The RF chain is shown below. A single conversion stage is used from IF to 9.4 GHz. The X-band RF is amplified using a 100 W Solid-state power amplifier, which is then radiated through the 2.4 m antenna. Received signals pass through the cal switches and the LNA. A single-sideband mixer brings the frequency down to the 140 MHz IF for digitization.



Digital Receiver (DRX) and Pulse Compression

The digital receiver is implemented on a a Xilinx Virtex-5 FPGA on a Pentek 7150 digital receiver board. Two of the four available 16-bit ADCs are used to digitize the V and H polarization IF signals. The FPGA ingests these samples and implements a multi-channel digital receiver, to process data from each sub-pulse of the frequency-diversity pulse compression waveform.

Each receiver channel implements a decimation filter to reduce the sample rate and bandwidth to 10 MHz. This is then processed through a complex correlator to implement pulse compression.



The resulting data is then resampled to a desired data rate and formatted for output on the PCI bus. Formatting includes appending information such as antenna position, transmitter status and a time-code to time stamp the data for future reference. Data is output from the receiver over a Gigabit Ethernet link.

The output time-series data is then processed using off-the-shelf PC server hardware to compute the dual-polarization meteorological products such as Reflectivity, Mean Velocity and Differential Reflectivity.

Conclusions

A frequency-diversity chirp waveform for use with solid-state X-band weather radar has been developed. While it is expected theoretically to be a viable solution, the practical implementation issues of the frequency-diversity waveform have not been addressed before in the weather radar context.

The key objective is to implement this technique in hardware and establish practical limits.

The waveform has been successfully implemented in test versions of the hardware. Final versions of the hardware are at the integration stage, we expect to begin data collection later this year. The pulse compression data will be validated against existing reference radars such as CSU-CHILL