SIMPLE TECHNIQUES TO CORRECT FOR VCO NONLINEARITIES IN SHORT RANGE FMCW RADARS

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ABSTRACT

Standard hardware techniques for the linearization of the frequency sweep in FMCW radars are difficult to implement and often offer only moderate improvement in linearity. A simple software-based linearization technique is introduced for short-range FMCW radars, and compared with a simple hardware linearization scheme. These techniques have been verified in an existing C-band FMCW scatterometer, and result in a dramatic focusing of the point return. The resulting range resolution (measured) approaches the theoretical limit, with a >20dB reduction in sidelobes.

1. INTRODUCTION

One of the main problems with obtaining a sharp point spread function with a FMCW radar system (focused return of a point target) is the nonlinearity of the FM sweep signal. Two commonly used lineariation methods are hardware phase-locked loop circuitry and digital synthesis of a corrected VCO tuning curve. The software resampling method introduced in this paper is ideal for short range FMCW scatterometers. It is very easy to implement, uses a dynamic rather than a static calibration of the VCO and results in a well focused point spread function. We will describe our C-band FMCW system, configured for scatterometry measurements in UCSB's Ocean Engineering wave tank (fig. 1), and a combination of a simple hardware linearization technique and the software resampling scheme. The efficiency of both methods will be compared using a delay line and a more realistic measurement of a metal calibration sphere suspended above the wave tank.

2. FMCW RADAR DESIGN

The configuration of the FMCW radar is essentially of textbook topology [1] with some modifications to customize it for our application (fig. 2). The sweep oscillator is a packaged GaAs MMIC design from Avantek (HTO-4000), covering the range 4-8 GHz with a hyperabrupt varactor tuning element. Separate antennas for transmit and receive were used to reduce transmit-to-receive leakage. The 3 foot diameter parabolic dishes are fed by Tecom dual polarized horns, which provides separate horizontal and vertical polarization. An FM sweep rate of 1 msec was used with a 2GHz bandwidth, alternately switching the transmitter polarization between horizontal and vertical polarization, giving and effective PRF of 500 Hz. With zero range chosen to be at the antennas, quadrature detection was not required for unambiguous range and Doppler information. Two identical homodyne receiver channels based on a triple-balanced mixer were employed for simultaneous measurement of the co- and cross-polarization return. Background clutter associated with short range returns near the radar set and distant scatterers beyond the viewing range were reduced with a bandpass filter in the preamplifier. The filtered signals are digitized with 12-bit A/D converters, with a sampling rate of up to 2 MHz per channel, which is equivalent to a transfer rate of 8 Mbytes per second to a hard disk array.

3. VCO LINEARIZATION

The software linearization scheme uses a simple measurement of transmission through a coaxial delay line in place of the antennas, with a length equivalent to a point target at the center of the radar footprint in the wavetank

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(10 meters range). Phase information of the measured time-domain signal is obtained by a Hilbert transform [2]. For a TEM delay line, the phase should be a linear function of time if the VCO sweep is linear; this gives a direct measurement of VCO linearity. Figure 4 (top) shows a measurement of the phase deviation from linearity for the real VCO. The measured curve of time versus unfolded phase is interpolated and resampled at equidistant phase increments to obtain the new sampling points in time for a linear sweep. Focusing the radar then amounts to resampling the measured time domain waveform at these new sampling points by a cubic spline interpolation. It should be mentioned that an additional simple calibration step was required to remove the mixer's frequency dependent DC offset from the delay line return; this was done by subtracting the mixer signal measured with a terminated RF input.

A simple hardware linearization was also explored for comparison, using a programmable waveform generator to correct the VCO tuning curve. This is possible here because we are using a varactor tuned oscillator with a tuning port bandwidth well above the radar PRF. The DC tuning voltage versus RF frequency calibration curve of the VCO was characterized with a spectrum analyzer/frequency counter, at 50 points over the full 4 to 8 GHz range (figure 3). The interpolated voltages at equidistant frequency increments were digitized and downloaded to an HP 33120A programmable waveform generator (12-bit direct digital synthesis of the waveform) to generate the VCO sweep.

4. MEASURED RESULTS

The scatterometer was designed for wave scattering experiments at the Ocean engineering lab of UCSB. The wind-wave tank is 175 feet long and 12 feet wide. Figure 1 shows the experimental setup at the lab. For the experiments presented here the antennas were positioned for six degrees grazing angle, the footprint was centered at 10 meters from the antennas, and the 3dB beamwidth was 60 cm wide at 10 meters range. The 2GHz bandwidth (4-6GHz) yields a theoretical range resolution of 7.5 cm. With 1024 samples per burst the maximum unambiguous range is roughly 35 meters. The sampling frequency is higher than Nyquist to allow the the unfolding of the signal phase needed for the resampling technique.

Fig 5a shows the measured return versus range using the delay line (point target at 10 meters) with a linear VCO sweep voltage; that is, an uncorrected sweep. The resulting spread in range at 20dB below the peak is 70 range cells wide. In figure 5b the same measurement is shown with the hardware linearized ramp. The peak is higher and sharper, with the spread at 20 dB below the peak of 50 range cells wide. This technique could possibly be further improved with more accurate measurement of the VCO tuning curve. Figure 5c shows the same measurement using the software focusing technique, and shows a dramatic improvement in the point spread. The width at 20dB below the peak is 3 rangecells. Fig. 4 (bottom) shows the corrected phase deviation of the VCO sweep using a combination of the two methods.

More realistic measurements were made to test the technique with a small metal calibration sphere suspended *in situ* above the wave tank. Here the measurement is complicated by close-in clutter (associated with imperfect transmit-reciver isolation and reflections from the "beach" end of the tank) and scattering from the wind tunnel beyond the target range (see fig. 1). These unwanted signals are removed by subtracting a measured response with no target in a still tank; this approach fails at distant range due to oscillator phase noise, but is fine for the range of interest. Figure 6a shows the sphere with a hardware linearized ramp and figure 6b shows the same dataset with the software resampling. The focusing effect is again observed.

It should be pointed out, that not only targets at a range equivalent to the delay line length are focussed, but also targets well outside the radar footprint appear sharp.This software resampling technique pushes the real range resolution of the radar close to the theoretical prediction.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] M.I. Skolnik, ed. *Radar Handbook*, McGraw-Hill: New York, 1970

[2] D.L. Mensa, *High Resolution Radar Cross-Section Imaging*, Artech House: Boston, 1991

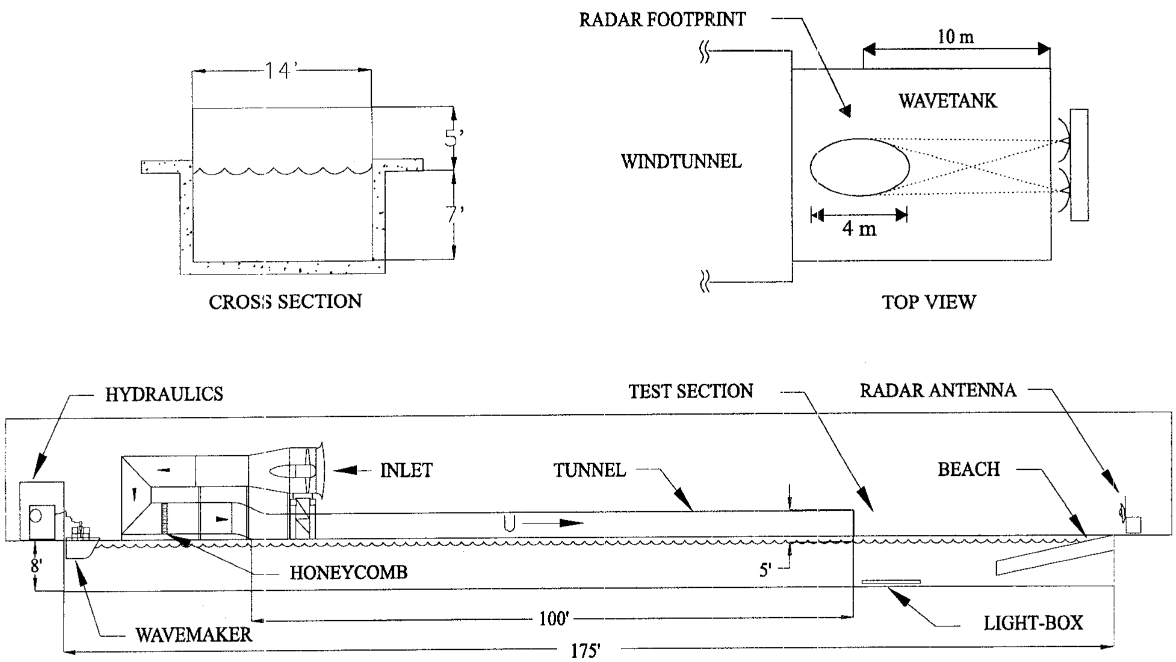

Figure 1- Experimental setup at the Large Wind-Wave Facility (LW^{2}F) of UCSB

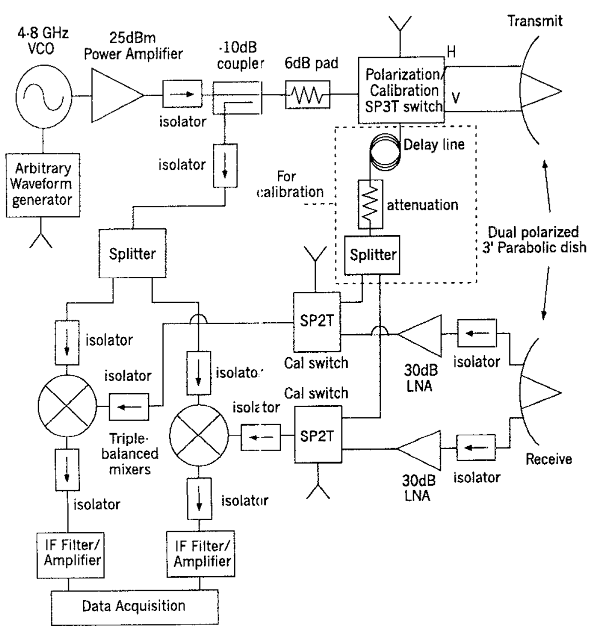

Figure 2 - C-band FMCW radar configuration. Dashed box encloses hardware used in software linearization of the VCO.

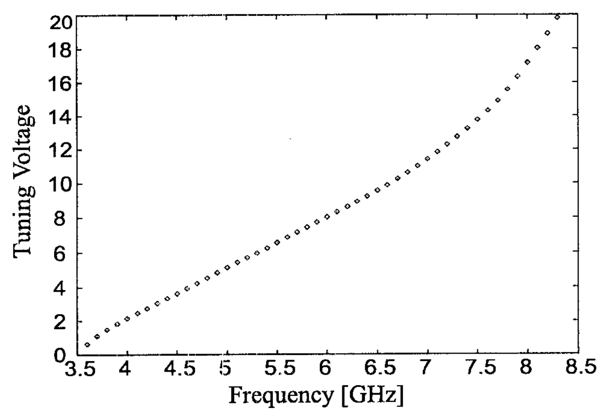

Figure 3 - VCO tuning curve

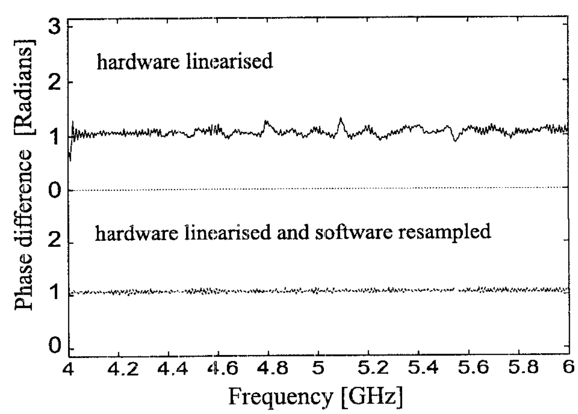

Figure 4 - Delay line, phase differences between samples

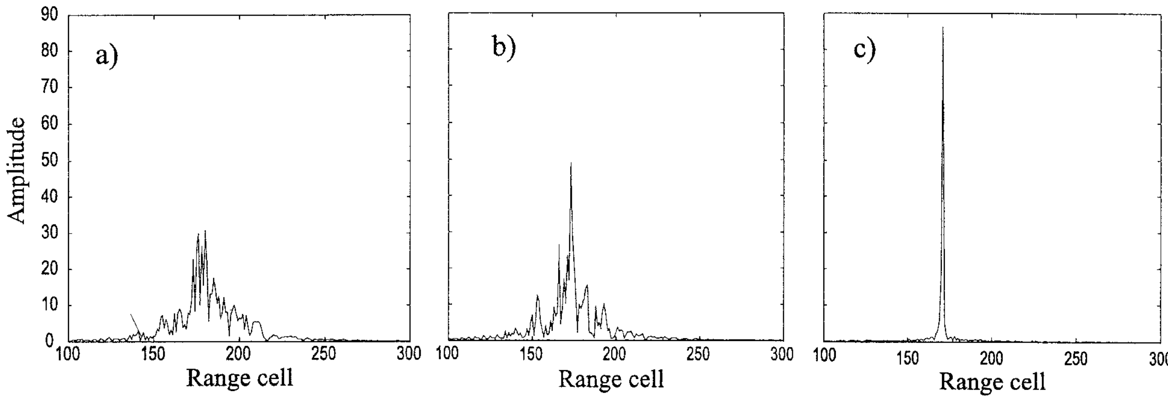

Figure 5 a,b,c - Range profile of the delay line. The VCO was fed with a linear tuning voltage in Figure 5a. Hardware linearisation of the frequency sweep shows some improvement in the point spread in 5b. In Figure 5c the hardware linearised return signal of 5b was further compressed with the software resampling technique.

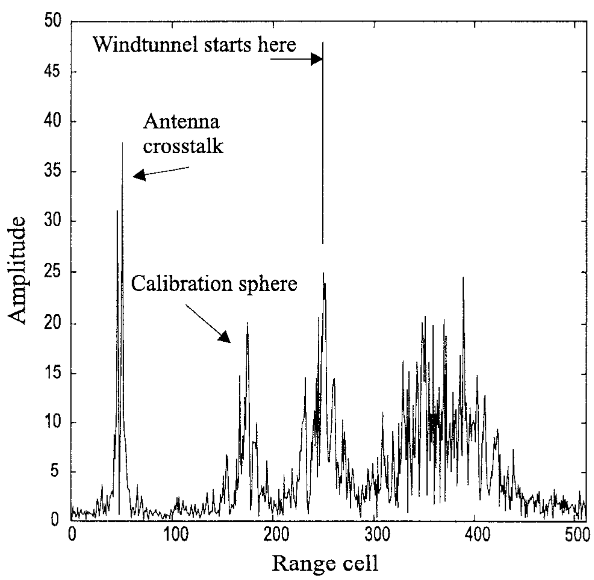

Figure 6- Range profile of the wavetank with a calibration sphere suspended above the water surface at 10 meter range. The RF sweep is hardware linearised. This plot incudes the static background. Compare the profile of the sphere to 5b.

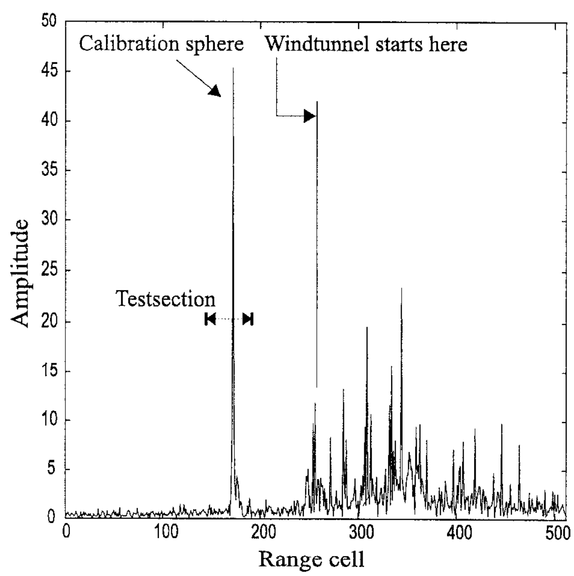

Figure 7 - The data set of Figure 6 software resampled.The static background is subtracted.Phase noise of the VCO prevents the background removal at long ranges.