Sweep generation for FMCW radar applications.

Benita Russel, Prof.Savitha Bhosale.

Abstract— Especially for the long distance Frequency Modulated Continuous Wave(FMCW) radar applications, the non linear frequency sweep due to the Voltage Controlled Oscillators (VCO) results in range resolution degradation. Open loop control solutions like Voltage Pre-Distortion method are not adequate for the applications like FMCW Radar Altimeter because of the noisy and non-stationary structure of the system due to the environmental conditions. In these situations closed loop control systems like Phase Lock Loop (PLL) provide more sufficient results. In this research; a PLL structure is implemented on an Field Programmable Gate Array (FPGA) by a Direct Digital Synthesizer(DDS) as the Reference Signal Generator, an improved Phase Frequency Detector as Phase Detector and Kalman Filter as the Loop Filter. For design verification and analysis, FPGA –In the Loop (FIL) simulations are generated by the use of Math works Simulink.

Index Terms— FPGA, FMCW radar, frequency sweep, linearity, DDS, PLL,VCO.

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1 INTRODUCTION

LINEARLY swept Frequency Modulated Continuous Wave (FMCW) sources are widely used as the basis for RADAR systems. This approach enables good resolution and range without the need for short pulse, high peak power transmitters and is thus well suited to solid state systems and millimeter wave operation. Cobham Technical Services have developed a K-band sweep generator with the linearity and wide sweep range necessary to form the heart of a high resolution RADAR system. The sweep generator is fully synthesized using a hybrid architecture with both DDS (Direct Digital Synthesizer) and PLL (Phase Locked Loop) elements. This compact solution generates sweep rates of 1kHz, with a deviation of 1.5 GHz or 8%. The spurious levels are typically less than -80dBc and the sweep linearity better than 0.01%. The frequency source has been multiplied up to V-band (75 GHz) where it enables an instrumentation RADAR to achieve better than 3cm resolution. Especially in range detection applications the achievable accuracy directly depends on the linearity of the modulated radar signal. In general PLL based systems with digital generated reference signals are used to meet this requirement. FPGA controlled DDS based signal generator for highly linear frequency sweeps is introduced. Measurements demonstrate the approached linearity of an FMCW radar in the K-band with 1 GHz bandwidth and a sweep time of 50 µs. In addition signal processing aspects for measurements and evaluation are derived.

2 OBJECTIVE

Despite of establishment radar technologies in various application the development of superior techniques is still going on. Modern field programmable gate array provide a powerful and cheap solution for radar signal processing. Therefore low cost radar based sensors become more attractive for industrial application as range measurements.

In comparison to optical sensors disadvantageous calibration and adjustments are minimized. The accuracy is less influenced by external contaminations in the measurement environment and additionally to the higher robustness also high flexibility is possible.

3 LITERATURE REVIEW

A radar based approach of range detection depends mainly on the utilized radar principle which allows either high accuracy or high unambiguous ranges. For the most widely used FMCW radar the entire distance is not restricted in the meter range whereas the achievable accuracy directly depends on the bandwidth. An improvement is only possible if system parameters are changed or a smart signal processing is applied. In this paper an approach is described which extends the FMCW radar with an additional phase evaluation to facilitate also high accuracy using low-cost radar components and none intensive processing methods. Therefore requirements for frequency and phase evaluation must be kept which are investigated and solved using special algorithms. The performance of these proceedings is confirmed with measurements using a developed radio frequency circuit for the K-band. Moreover the possibility to combine the frequency and phase information for range detection is described and also validated by measurements.

The FMCW radar is the most versatile radar principle used today. Depending on the system configuration, it is possible to use FMCW radar to detect targets in the range from hundreds of kilometers down to a few centimeters. This paper describes an algorithm, which can be applied to improve the FMCW range accuracy down to a few mm. Numerical system simulations are used to evaluate the possibility of using a combination between an FMCW and a phase radar for a line based range detection at 24 GHz.

The history of perimeter protection is based on building

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fences. That basic concept evolved into detecting activity along fences using a variety of sensors. Today a wide variety of fiber and wire- based sensors are available to mount on a fence, and many different types of IR, radar, optical, seismic and acoustic sensors to place along the fence line. Generally some camera support is provided, with the cameras programmed to point to pre-set locations along the fence. A more robust perimeter protection would consist of wide area sensors with the capability to look out beyond the fence to detect potential intrusion and track intruders. In looking beyond the perimeter, wide area sensors can provide precious time to plan and initiate the appropriate response. In addition, because they sweep a 360-degree circle, the sensors can provide continued tracking of the intrusion, greatly enhancing the effectiveness and safety of the response team. The new wide-area concept consists of using modern radar technology for wide area detection of objects which are moving, and then using the precise location information from the radar to point a camera for assessment. Without having to continually stare at a bank of video monitors, the operator is presented with the location, direction of travel and identification and number of potential intruders, all in a matter of seconds. This paper presents the features of this new wide area system, followed by an overview of radar technology. It closes with a discussion on the benefits of the FMCW topology over Pulse Doppler in security and surveillance applications.

This paper presents an algorithm for 60GHz FMCW radar detection system providing precise distance and velocity measurements. A digital simulation environment based on the radar hardware setup is built to evaluate and demonstrate the applicability and performance of the detection system under laboratory conditions. The system first incorporates a normal FFT for general frequency estimation, based on which the Radar Cross Section of detected targets will be calculated for further processing. Then Constant False Alarm Rate (CFAR) Threshold algorithm is used for detecting radar targets in background full of noises and reflections for which all parameters in the statistical distribution are not known and may be non-stationary. Finally the Complex Spectral Phase Evolution (CSPE) method is applied as a tool to obtain super Doppler and distance accuracy, which can provide for super-resolution of frequencies by examining the evolution of the phase of the signal spectrum over time –shifted windows. The functionality of the system is demonstrated by simulation based on the 60GHz FMCW radar hardware system and will also be tested on the real hardware system. The paper illustrates, that the combination of advanced signal processing scheme with a cost-effective front-end can provide high performance microwave sensors.

4 FMCW RADAR PRINCIPLES

An FMCW RADAR continuously transmits a swept frequency carrier. The propagation delay to the target and back causes a frequency difference between the transmitted signal and the received signal. Mixing a sample of the TX signal with the RX signal results in an IF waveform containing frequency difference components. With a linear sweep the frequency difference between the TX and RX signals is proportional to the target range. Digital FFT analysis can be used to partition the IF signal into a number of frequency or range bins. Figure shows the basic hardware configuration, while Figure 2 illustrates a sweep waveform.

Various sweep patterns are possible. In this instance a symmetrical triangular sweep has been employed. This has two features that are of particular interest:

Doppler Discrimination: The symmetrical up and down sweep enables the Doppler frequency of a moving target to be separated from the range related terms by using appropriate IF processing.

Ease of Realization: The triangular waveform avoids the sharp transitions inherent with other popular waveforms, such as the saw tooth, which are difficult to achieve in a well controlled manner.

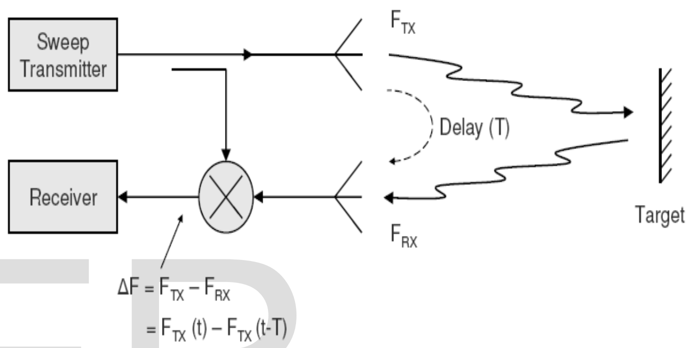

Fig 1(a): FMCW radar architecture

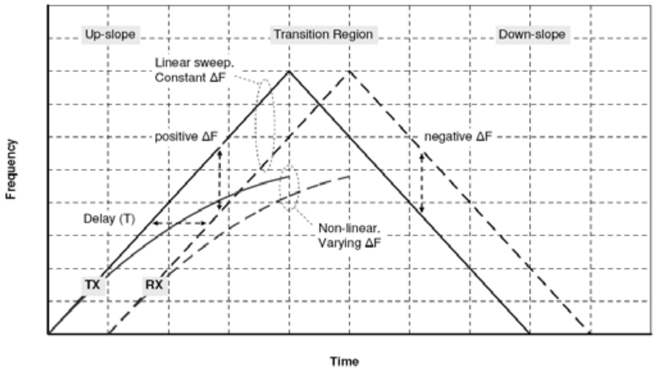

Figure 1(b): Triangular sweep

5 TYPICAL SWEEPER IMPLEMENTATIONS

5.1 Open loop VCO

A Voltage Controlled Oscillator (VCO) is controlled by a linear ramp voltage or a ramp that has some form of polynomial correction added to counteract the inherent non-linearity of the VCO transfer function. The correction can also be performed digitally by using a Look Up Table (LUT) and DAC to store pre-calibrated control data. This approach is capable of modest linearity and high sweep speeds. The main drawback is that the required calibration/correction is not static over time and temperature and thus limits the achievable linearity.

5.2 VCO and Frequency discriminator.

The basic ramp driven VCO is supplemented with a frequency discriminator that generates a voltage output proportional to frequency. This provides a feedback signal that can be used to implement closed loop correction and overcome the VCO non-linearity. Unfortunately the analogue frequency discriminator has limited performance and cannot achieve the accuracy required for high resolution, wide-band systems.

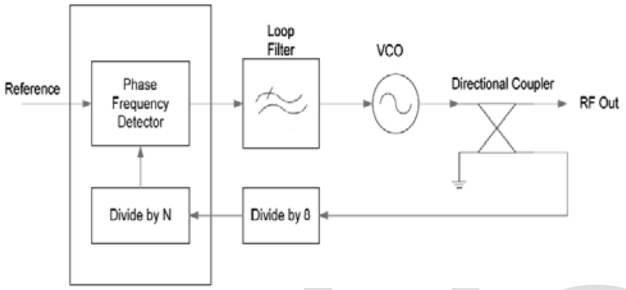

Figure 1(c): Block diagram of PLL with VCO

VCO is used to generate the RF output. The RF output is divided by 8 using the divide down internal to the VCO. The divided output of the VCO is given as an RF input to the Phase detector. The 5-bit counter is used to further divide the RF input to the Phase detector.

The Phase Detector compares the phase of the divided RF with the reference and generates a current proportional to the phase error. The loop filter transforms this current to a tune voltage which is given as an input to the VCO. This tune voltage locks the VCO to the given reference.

6 PROPOSED WORK METHODOLOGY

For a versatile application of the signal generator in radar systems DDS is chosen which provides a high output frequency. The FMCW radar require reference signal with minimum jitter in term of frequency and phase. This required signal is generated by the DDs working at the clock frequency 1.6 GHz. The control data of DDS consist of a 32 bits control vector and strobe signal. The control vector dictates the DDs output frequency, while the strobe signal determines when this vector is latched into the DDS. To synchronize the data communication the DDS provides a reference signal is used to clock the control logic in the FPGA. Within FPGA, a state machine is used to control the output of 32 bits control vector. Since a chirp modulation of the DDS output frequency is required for frequency modulation, the output vector has to be modified accordingly. In this case, a forward and backward counter with predefined counter step and pause periods is used.

The precision at the level of clock cycles is guaranteed by VHDL implementation of the control algorithm. To improve the usability, configuration setups are predefined and stored in memory module within the FPGA. These sets consist of the start / end frequencies, the frequency steps, their periods in term of clock cycles and the chirp form. In that way the user can easily switch between those configurations without reconfiguring the FPGA itself.

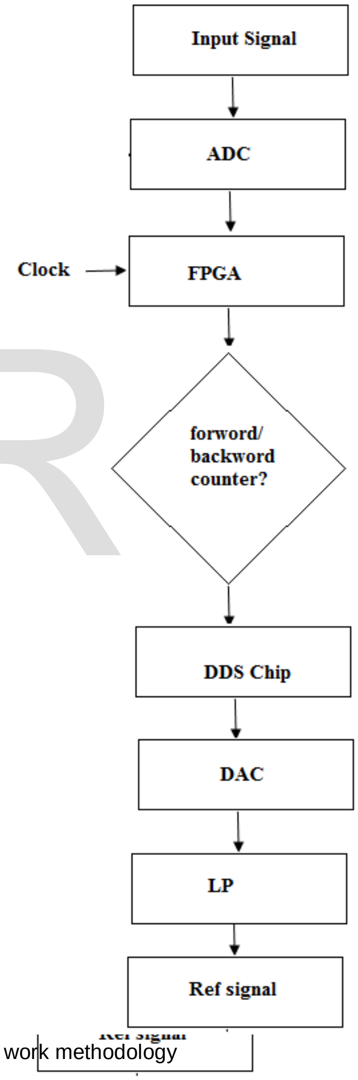

Figure 2:Proposed work methodology

For the evaluation the baseband signal coming from the radar subsystem must be sampled using an analog-digital convertor and transformed with FFT to extract the required data. The FFT is a very demanding algorithm in terms of computation performance. A software implementation of this algorithm would not be fast enough to process the incoming data and provide the results in real time.

In the present system a 128 bit FFT at working frequency of 100 MHz is implemented which provides the result after no longer than 10us. Since the ADC only delivers data at the much lower frequency of 5 MHz a FIFO module buffering the data transfer between the FPGA input coming from ADC and FFT module is implemented.

Using FPGA in this system yields several advantage compared to other solutions. The nature of an FPGA allows a completely parallel implementation of the control logic and the evolution algorithm. That means during the signal processing period, a new scan can be initiated and the time between two scans can be shortened. This leads to faster information updates and allows a faster reaction in critical solution.

7 MEASUREMENT RESULTS

In Fig. 3(a) and Fig. 3(b) the results for the two modulation schemes are shown. The resulting errors in Fig. 3(c) compared to the assumed ideal frequency sweep show a mean deviation of about 2 MHz. The deviation of the sawtooth modulation scheme at the beginning or at the end of the frequency sweep is very large and has a duration of up to half of the sweep time. By including continuous wave sections into the modulation the errors at the modulation borders are decreased from 10 MHz to approximately 2 MHz with a transient oscillation of less than 5 µs.

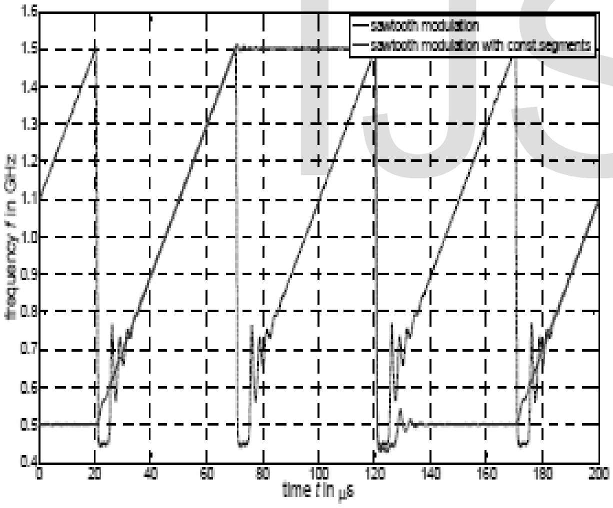

Figure 3(a): Frequency verses time for FMCW sawtooth modulation using a bandwidth 1Ghz within 200 microseconds.

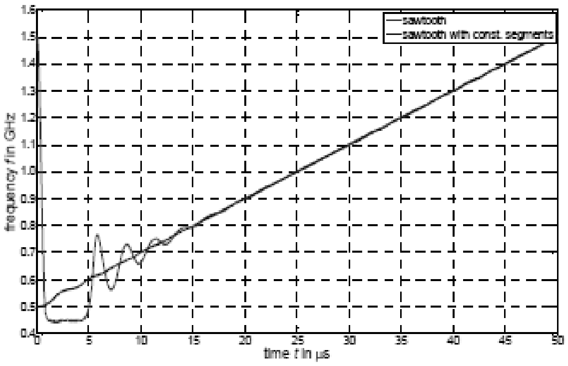

Figure 3(b): Frequency verses time for FMCW sawtooth modulation using a bandwidth of 1 Ghz with 50 microseconds.

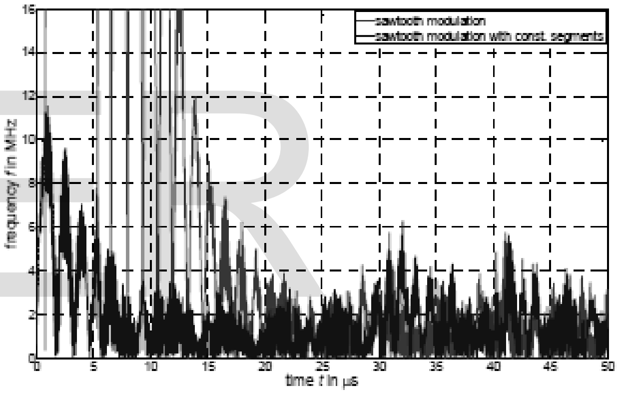

Figure 2(c): Frequency deviation of measured and ideal sweep

9 CONCLUSION

The performance of an FMCW radar system highly depends on the linearity of the generated frequency sweep. In this paper a digital based approach using direct digital synthesis for highly linear sweep generation with small deviations of 2 MHz is presented. Content of this paper is:

☐ PLL stabilized K-band radar system with 1 GHz bandwidth and 50 µs sweep time

☐ FPGA controlled signal generation based on DDS

☐ Signal processing requirements, measurement setup and results for frequency sweep linearity

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