Programmable Radar Waveform Generator for Configurable Radar Systems

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Abstract— **This paper presents the simulation of a Direct Digital Synthesis (DDS)-based programmable radar waveform generator designed for radar simulator or configurable radar systems. The system enables flexible control of key radar signal parameters including carrier frequency, pulse width, and pulse repetition interval (PRI). DDS technology is leveraged to digitally generate high-precision waveforms with minimal latency and high spectral purity. Simulation results demonstrate the generation of a variety of radar waveforms under programmable settings, confirming the system's capability to support multiple radar modes through digital reconfiguration. The proposed DDS-based architecture provides a cost-effective and scalable solution for modern radar waveform generation, particularly in software-defined and cognitive radar environments**

Keywords— DDS, Frequency Resolution, Frequency Synthesis, Programmable Waveform Generation

I. INTRODUCTION

Radar simulators and configurable radar systems increasingly require waveform agility and configurability to adapt to diverse operational scenarios such as target detection, tracking, imaging, and clutter suppression. Traditional hardware-defined waveform generators offer limited flexibility and are often incapable of meeting the demands of multifunction or software-defined radar systems. To address this, a programmable radar waveform generator becomes essential, offering the ability to adjust parameters such as carrier frequency, pulse width, and pulse repetition interval (PRI) — and in more advanced systems, modulation schemes and bandwidth control.

One effective approach for implementing such a system is through Direct Digital Synthesis (DDS). DDS offers fine resolution, fast tuning, and phase-coherent waveform generation entirely in the digital domain. By manipulating the frequency tuning word and phase accumulator dynamically, DDS-based systems can generate programmable radar waveforms. This flexibility is particularly important for radar systems that rely on matched filtering and high range resolution. This paper focuses on the simulation of a DDS-based programmable radar waveform generator. The system is designed to generate configurable radar pulses with user-defined pulse parameters such as frequency, pulse width, PRI etc. A range of waveforms are implemented and analyzed using simulation tools to evaluate the system's capability and performance. The proposed simulation framework serves as a foundational model for future hardware realization and integration into adaptive radar platforms

II. DDS FUNDAMENTALS

Direct Digital Synthesis is a technique to generate analog waveforms, typically sine waves, from a digital representation. At its core, DDS employs a phase accumulator, a phase-to-amplitude conversion (often using a look-up table), a digital-to-analog converter (DAC) followed by low-pass filters to generate programmable signals.

Phase Accumulator is register that accumulates a phase increment value (also called the Frequency Tuning Word, FTW) at each clock cycle. The value in the phase accumulator represents the instantaneous phase of the output signal. Lookup Table (LUT) converts the phase value to corresponding amplitude, using a sine lookup table. Digital-to-Analog Converter converts the digital samples to analog signals. In MATLAB simulation, this step is virtual, and output samples are directly analyzed in the digital domain.

The output frequency f_{out} of the DDS is determined by the formula given in equation (1)

$$f_{out} = \frac{\mathrm{FTW} * \mathrm{f_{clk}}}{2^{\mathrm{N}}} \tag{1}$$

Where,

FTW = Frquency Tuning Word
f_{out} = Output Frequency,
f_{clk}= Clock Frequency,
N = No. of bits in accumulator register

The DDS is usually characterized by its frequency resolution and number of frequency spots. Frequency resolution in DDS is given by

$$\Delta f = \frac{\mathrm{f_{clk}}}{2^{\mathrm{N}}} \tag{2}$$

Where,

Δf = Frequency Resolution,
f_{clk}= Clock Frequency,
N = No. of bits in accumulator register

The numbers of frequency spots are given by

$$\mathrm{F_{spot}} = 2^{\mathrm{N}-1} \tag{3}$$

This digital approach allows for precise control over the output frequency and phase, enabling rapid frequency switching and fine resolution.

III. SYSTEM ARCHITECTURE

The architecture of the proposed programmable radar waveform generator is designed around a DDS core with additional blocks for timing control, and waveform configuration, as shown in Figure 1. The system is simulated in MATLAB, providing a flexible environment to evaluate waveform generation logic, timing accuracy, and signal characteristics. The system consists of the following major components:

DDS Core Generates baseband or RF-frequency waveforms. The DDS is driven by FTW and phase accumulator logic, allowing for fine frequency resolution and fast tuning.

Pulse Control Unit Controls the pulse width and PRI. It gates the DDS output to form pulsed waveforms, emulating radar transmit pulses.

Control Interface Simulates user input for parameters such as frequency, pulse width, PRI, and modulation type. In hardware, this would be managed via microcontroller or FPGA logic; in MATLAB, it is modeled through configuration scripts or GUI inputs.

User provided inputs such as frequency, pulse width, PRI are used by control logic to computes frequency tuning word and to set timing counters for pulse width and PRI. Based on these logics DDS produces sinusoidal samples which are windowed by the Pulse Control Unit to create radar pulses and final waveform is plotted or analyzed in MATLAB.

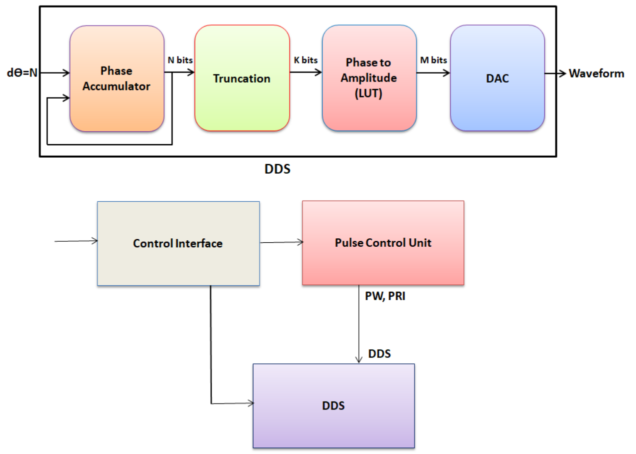

Fig. 1: DDS Based Programmable Waveform Generator

IV. Simulation Methodology

The system is simulated in MATLAB using a modular script-based structure. DDS logic is implemented using phase accumulation and lookup tables. Modulation is incorporated by tuning the DDS parameters, Timing and gating are managed using counters and conditional masking to model radar pulses. Output signals are visualized using time-domain plots and spectrograms to analyze waveform characteristics.

The strength of the proposed radar waveform generator lies in its ability to support real-time configurability of key transmission parameters. Using MATLAB as the simulation platform, the system allows flexible user-defined control over key parameters, which are critical for adapting radar waveforms to different mission requirements or environmental conditions.

Carrier frequency is controlled by adjusting the Frequency Tuning Word of the DDS. In MATLAB, frequency control is implemented either by changing this increment statically or by varying it over time for modulated signals (e.g., chirp).

Radar signals are transmitted in pulses, requiring control over pulse width (duration of each pulse) and PRI (time between consecutive pulses). In simulation, pulse width is implemented using gating logic that masks the DDS output after a specified number of samples (based on time and sampling rate). PRI is controlled by inserting idle (zero-valued) segments between pulses. This gating is modeled in MATLAB using logical indexing or time-windowing techniques.

This simulation architecture offers an efficient platform to evaluate waveform programmability and pulse parameters and optimize radar signal generation strategies before transitioning to hardware.

V. Simulation Results

This section presents MATLAB simulation results demonstrating the capability of the DDS-based programmable radar waveform generator to produce a variety of radar signals under configurable parameters. Waveforms generated include unmodulated and modulated CW and pulsed waveforms pulses, highlighting the flexibility and precision of the system.

Unmodulated CW Waveform

Simulation of CW waveform was carried out with different frequencies. CW waveforms generated with frequencies of 2 MHz and 4 MHz are plotted in Figure 2 and Figure 3 respectively.

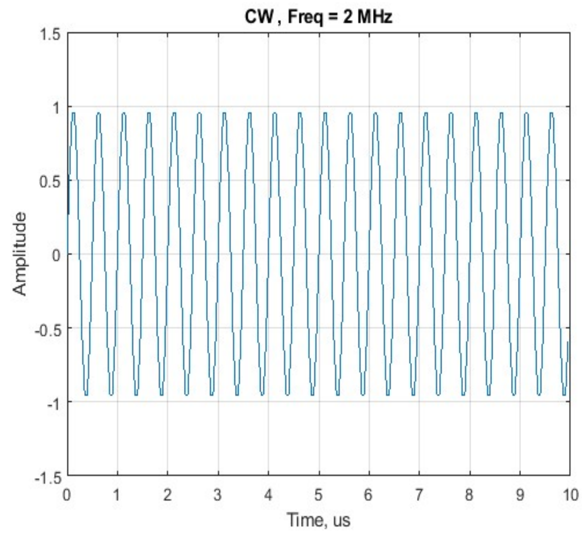

Fig. 2: CW Waveform with Frequency of 2 MHz

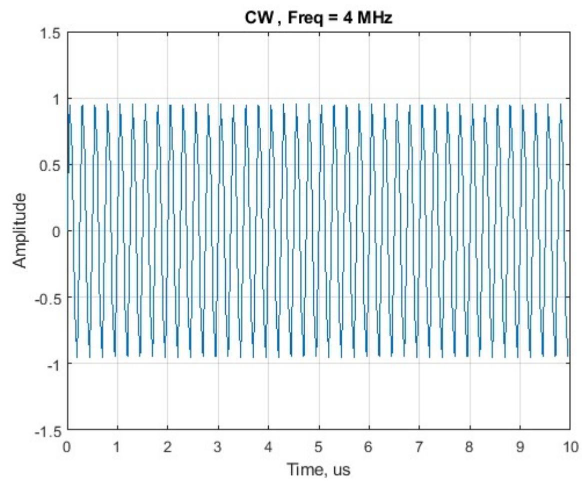

Fig. 3: CW Waveform with Frequency of 4 MHz

FMCW Waveforms

Simulation of FMCW was carried out with different parameters to check the efficacy of generation of FMCW waveforms with different parameters.

Figures 4, and 5 plot the generated FMCW waveforms with different parameters.

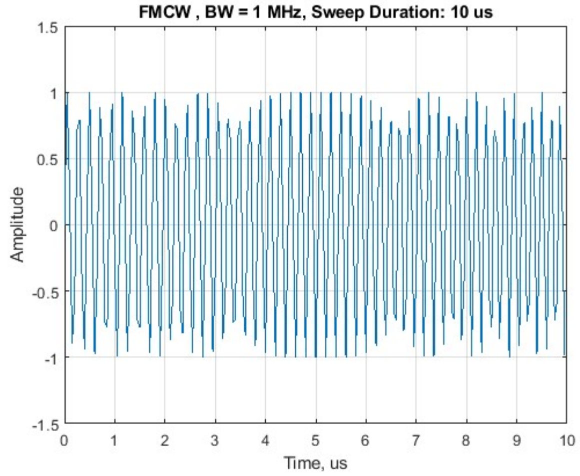

Fig. 4: FMCW - BW: 1 MHz, Sweep time: 10 micro sec

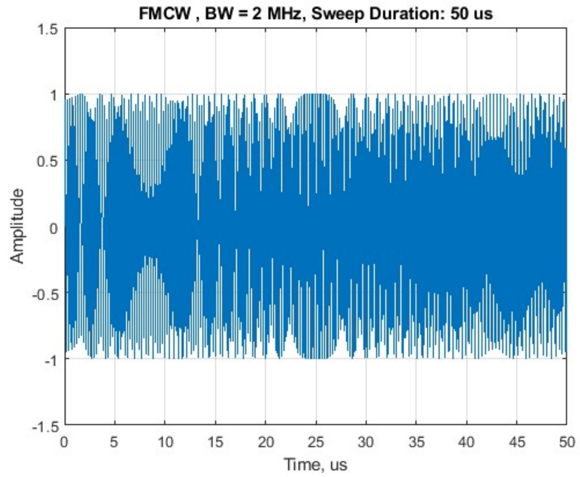

Fig. 5: FMCW - BW: 2 MHz, Sweep time : 50 micro sec

Frequency Modulated Pulses

In this section simulation results of radar waveforms with different pulse-width, Bandwidth and PRF combination are presented.

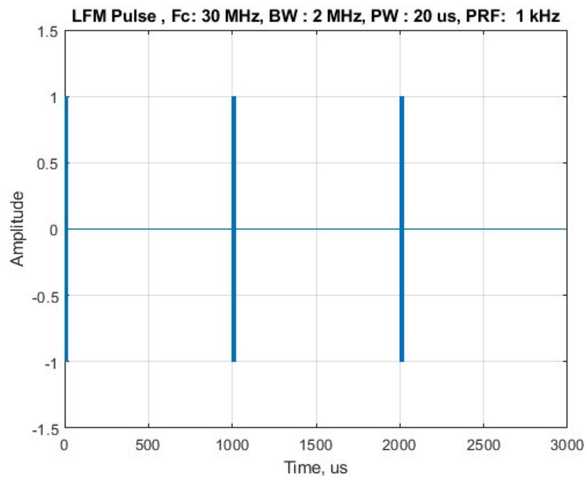

Fig. 6: LFM Pulses - BW: 2 MHz, PW: 20 us, PRI: 1 ms

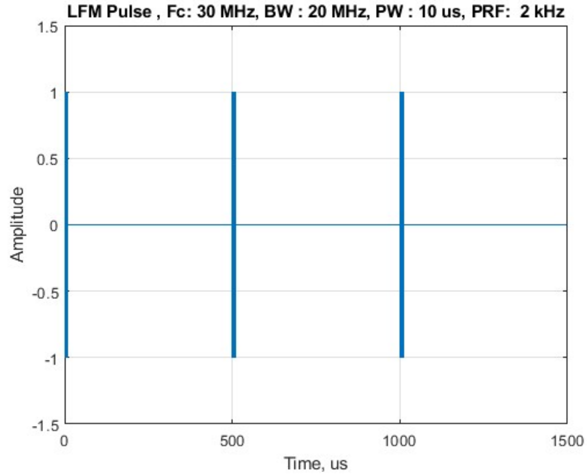

Fig. 7: LFM Pulses - BW: 20 MHz, PW: 10 us, PRI: 0.5 ms

VI. CONCLUSIONS

The MATLAB simulations validate that the DDS-based architecture supports flexible, high-fidelity radar waveform generation with programmable parameters. This confirms the potential of the proposed system for real-time radar signal synthesis in configurable radar platforms.

This paper presented a simulation study of a DDS-based programmable radar waveform generator designed for configurable radar and radar simulator systems. By leveraging the flexibility of Direct Digital Synthesis, the system enables precise and agile control over key radar parameters including carrier frequency, pulse width, pulse repetition interval, and modulation bandwidth.

Simulation results demonstrated the system's capability to generate high-quality radar waveforms with flexible parameter settings, confirming its suitability for modern software-defined and cognitive radar platforms. The DDS architecture provides a scalable, cost-effective solution for programmable waveform generation, facilitating rapid adaptation to varying radar operational scenarios.

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