# Multi-Emitter Scenario Simulation with DDS-Based Independent Radar Waveform Generation

**J.S. Mangat, Dr. Ravindra Kumar Sharma**

*Abstract*— **This paper presents the simulation of a Direct Digital Synthesis (DDS)-based programmable independent radar waveform generator designed for simulation of multi-emitter scenario. The system enables flexible control of key radar signal parameters including carrier frequency, pulse width, and pulse repetition interval (PRI) for each of the emitters. 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 emitters through digital reconfiguration. The proposed DDS-based architecture provides a cost-effective and scalable solution for modern muti-emitter radar waveform generation, particularly for simulation of intense EW scenario for testing and training purposes.**

***Keywords— DDS, Muti-Emitter Simulation, Frequency Synthesis, Programmable Waveform Generation***

## I. Introduction

Radar systems play a critical role in modern surveillance, navigation, and defense applications by detecting and tracking objects through the transmission and reception of electromagnetic waves. With the increasing complexity of operational environments, multi-emitter radar scenarios—where multiple radar transmitters operate simultaneously within the same area—have become a key area of study. These scenarios pose unique challenges, such as signal interference and waveform management that can significantly impact radar performance.

One effective approach to address these challenges is the generation of multiple independent radar waveforms, which helps in minimizing mutual interference and improving target detection and identification capabilities. Direct Digital Synthesis (DDS) offers a flexible and precise method for generating such waveforms with high spectral purity and rapid configurability, making it ideal for simulating and implementing complex radar signal structures. This paper presents a MATLAB-based simulation framework for multi-emitter radar scenarios utilizing DDS for the generation of multiple independent radar waveforms. The objective is to model realistic multi-emitter environments and analyze the effectiveness of DDS-generated waveforms in maintaining signal independence and mitigating interference. Through this simulation, insights into waveform design parameters and their impact on multi-emitter radar performance are explored.

## II. Background and Motivation

The evolution of radar technology has led to increasingly complex operational environments where multiple radar emitters coexist and operate simultaneously. These multi-emitter radar scenarios are common in modern defense systems, surveillance networks, and electronic warfare, where numerous radar platforms may be deployed in overlapping regions. To simulate such scenario multiple signal simulators may be required. To circumvent this, one of the key strategies to mitigate these challenges is the use of independent radar waveform generation with same simulator. Direct Digital Synthesis (DDS) is a powerful technology widely used in radar waveform generation due to its ability to produce highly flexible, stable, and spectrally pure signals. DDS allows for rapid changes in waveform parameters, enabling the creation of multiple distinct waveforms suitable for multi-emitter environments. This flexibility is essential for simulating realistic radar scenarios where waveform agility and independence are crucial.

## III. 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), and a digital-to-analog converter (DAC) to generate programmable signals, as shown in figure 1.

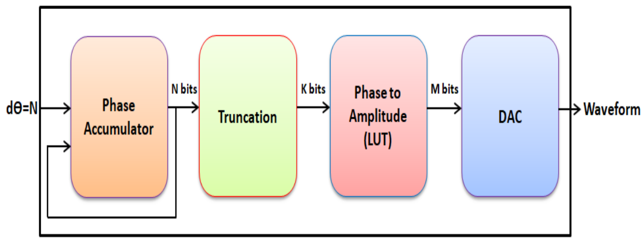


**Fig. 1: Block Diagram of DDS**

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)

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

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

$$\Delta f = \frac{f_{clk}}{2^N} \quad (2)$$

Where,

$\Delta f$ = Frequency Resolution,
$f_{clk}$ = Clock Frequency,
N = No. of bits in accumulator register

The numbers of frequency spots are given by

$$F_{spot} = 2^{N-1} \quad (3)$$

This digital approach allows for precise control over the output frequency and phase, enabling rapid frequency switching and fine resolution. We will investigate generation of independent waveforms using this architecture in the following sections.

## IV. Generation of Multiple Independent Signals

The flexibility and digital control inherent in DDS make it particularly well-suited for generating multiple independent signals from a single hardware platform. This capability is essential in applications such as multi-emitter simulation, where the goal is to emulate the behavior of numerous simultaneous RF sources—each with unique frequency, phase, amplitude, and modulation characteristics.

One common approach to generating multiple signals using DDS is through parallel instantiation of multiple DDS cores, each configured with its own set of control parameters. Because DDS systems are inherently digital and deterministic, each core can be assigned a distinct frequency tuning word, phase offset, and amplitude control, enabling the synthesis of independent and precisely defined waveforms. These cores can operate synchronously or asynchronously, depending on the timing and coherence requirements of the simulation environment. Modern DDS implementations often support channelization, where multiple DDS channels share a common system clock and reference, ensuring high phase coherence while allowing independent frequency and phase control. This is particularly useful in simulating coordinated emitters or scenarios where relative timing between signals is important. Alternatively, fully independent DDS instances—each with separate timing references—can be used to model uncoordinated emitters or signal sources operating on unrelated clocks. In hardware, multiple DDS channels can be realized using field-programmable gate arrays (FPGAs), system-on-chip (SoC) platforms, or dedicated multi-channel DDS ICs. These platforms allow for real-time reconfiguration of signal parameters, enabling rapid switching, frequency hopping, or modulation changes on a per-channel basis. This level of control is crucial for emulating dynamic electromagnetic environments where signal conditions evolve over time.

In pulse radar and similar systems, signal activity is often sparse and periodic, with each emitter transmitting short-duration pulses followed by relatively long silent intervals defined by the PRI. This characteristic can be exploited to reduce the hardware complexity of multi-emitter simulation by time-interleaving pulse generation for multiple emitters using a single DDS core. Instead of instantiating separate DDS cores for each emitter—which would consume significant logic resources—this approach dynamically schedules the generation of pulses from multiple virtual emitters within the unused PRIs of others. During the active period, the DDS is configured to generate a pulse for one emitter. As soon as that pulse ends, the DDS state is updated, and a new pulse is generated for another emitter during the off-period of the first. This process continues, with the DDS cycling through multiple virtual emitters, each assigned a specific time slot based on its PRI and pulse width.

This method is particularly efficient for scenarios where the PRIs of emitters are not synchronized, allowing for even more flexible packing of pulse events. Since pulses are typically short in duration compared to the PRI, many virtual emitters can be supported using a single DDS core, as long as their pulse schedules do not overlap. The key to implementing this scheme is a scheduler or controller that manages emitter timing, updates DDS parameters (such as frequency, phase, and amplitude) between pulses, and ensures correct timing alignment. Advantages of this time-interleaved approach include:

**Reduced hardware resource usage**, as only one DDS core is required.

**Scalability**, since more emitters can be added by optimizing the interleaving schedule.

**Flexibility**, as each pulse can be configured independently.

**Simplified synchronization**, since all signal generation is managed through a centralized time controller.

This technique is especially effective when simulating high emitter densities in environments where full signal concurrency is not required, or when modeling scenarios where emitters are naturally sparse in time. When paired with precise timing control and fast reconfiguration logic, this method enables realistic and resource-efficient emulation of complex RF pulse environments.

## V. Simulation Methodology

MATLAB provides a versatile platform for signal processing and system simulation, allowing for the implementation of complex radar signal models and analysis tools. The DDS architecture is implemented in MATLAB to generate multiple radar waveforms with independently controllable parameters such as frequency, phase, and amplitude. A phase accumulator and lookup table approach is used to simulate the digital generation of sinusoidal and modulated signals. This enables rapid waveform reconfiguration suitable for simulating agile radar emitters. The simulation allows the generation of multiple waveforms utilizing the same DDS when other emitters are in Pulse-OFF (off period in their respective PRI). These waveforms can have different modulation types, frequencies, and pulse width etc. to ensure waveform independence.

Simulation parameters such as sampling frequency, waveform duration, frequency hopping patterns, and phase codes are defined and adjustable to explore different multi-emitter configurations. The system is simulated in MATLAB. The simulation operates at scaled-down intermediate frequencies (typically in the MHz range) due to MATLAB's computational limitations, whereas real radar systems often operate at carrier frequencies in the GHz range. Despite this frequency scaling, critical radar parameters such as pulse width, bandwidth (BW), pulse repetition frequency (PRF), and waveform modulation characteristics are accurately modeled.

## VI. Simulation Results

This section presents MATLAB simulation results from simulation of muti-emitter scenario using DDS based independent radar waveform generation. Simulation of 3 and 4 emitters operating at different pulse widths, bandwidths but at same PRF is shown in Figure 2 and Figure 3 respectively. As clear from figures all emitters are generated successfully and as their PRF are same, relative placement of their pulses on time scale is same for all bursts.

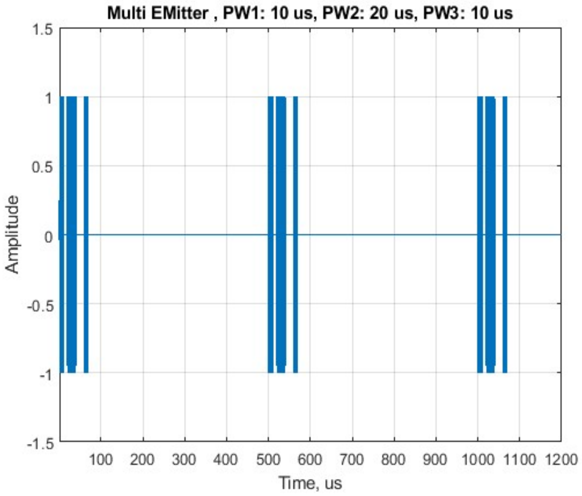


**Fig. 2: Multi Emitter Scenario with 3 Emitters**

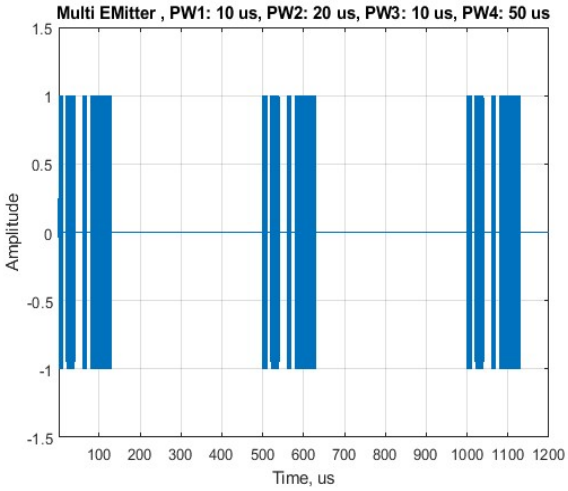


**Fig. 3: Fig. 2: Multi Emitter Scenario with 4 Emitters**

Simulation of emitters operating at different pulse widths and different PRFs is shown in Figure 4 and Figure 5 for 2-emitters and 4-emitters cases respectively. As clear from figure, all emitters are generated successfully and as their PRF are different in this case, relative placement of their pulses on time scale varies with time.

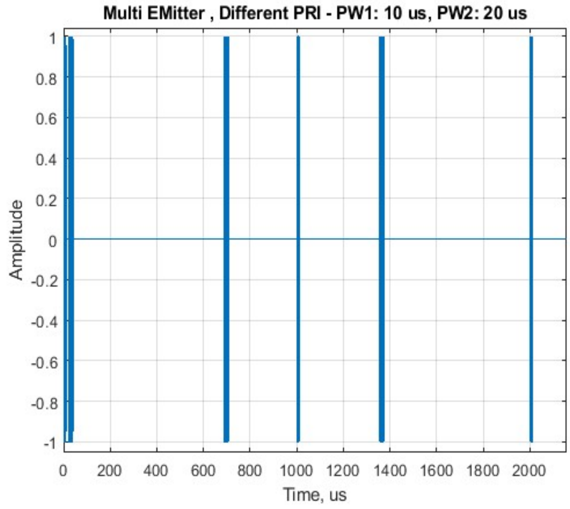


**Fig. 4: Multi Emitter Scenario with 2 Emitters at different PRFs**

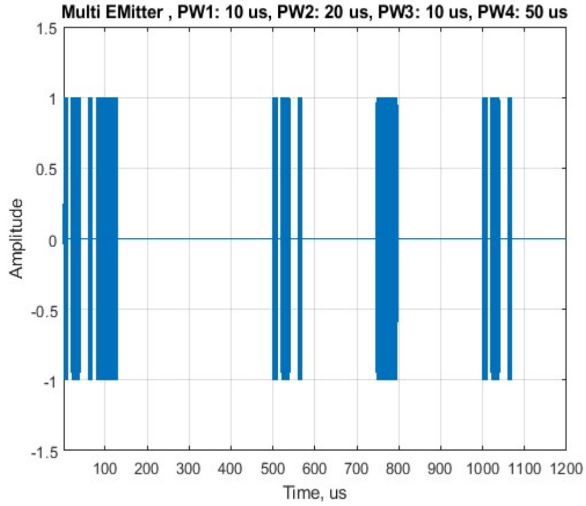


**Fig. 4: Multi Emitter Scenario with 4 Emitters at different PRFs**

## VII. Conclusions

Multi-emitter scenario was simulated using MATLAB.AS evident from simulation results DDS-based architecture supports time interleaving simulation of multi-emitter scenario by generating independent radar waveforms for each of the emitters. This confirms the potential of the proposed system for multi-emitter scenario simulation.

This paper presented a simulation study of a DDS-based DDS-Based independent radar waveform generator designed for multi-emitter scenatio simulation. By leveraging the flexibility of Direct Digital Synthesis, the system enables precise and agile control over key radar parameters of each of the emitters, 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 simulation system.

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