

# Radar Signal Processing Models

Generating Realistic and Flexible Radar Pulsed Signals with SystemVue Radar Library

# 1.0 Introduction

Modern civil and military A/D radar systems use complex signal waveforms operating in wide bandwidths and various frequency bands (e.g., X, Ku and Ka bands). They also use advanced digital signal processing techniques to extract useful target information and overcome external factors such as strong clutter and interferences <sup>1</sup>. Addressing this complexity requires the generation of realistic radar signals and system-level scenarios that can create and verify the signal/data processing algorithms with simulation and test consistencies maintained overtime <sup>2</sup>.

In general practice, dedicated hardware simulators and field testing are typically used to generate these signals, both are costly, time consuming and usually conducted in late design processes <sup>3</sup>. This application note presents a less expensive, more flexible option for generating radar signals early in system development process. It provides guidance to a digital-twin version of a complete radar system with realistic radar pulse behaviors together with the virtual scenario designs, which are very useful for both algorithm and hardware verifications <sup>4</sup>.

## 2.0 Design Problem (Radar Pulse Timing Characteristics)

Verification of radar signal processing algorithms is a critical mission in advanced high-performance and multi-mode radar system designs, while creating a realistic test signal waveform with sufficient flexibility and fidelity is one significant milestone. The signal behavior characteristic at various system “test spots” are very useful for trouble shooting and diagnostics <sup>5</sup>.

Generally speaking, any radar signal possesses the following characteristic parameters: carrier frequency, modulation format, pulse width, Pulse Repetition Frequency (PRF), and more complicated behavioral parameters such as rise time, fall time, droop and overshoot. Creating a realistic radar transmit pulse and combining with the system-level influences such as Tx and Rx RF characterizations, antenna beam weights, target profiles, clutter and interferences to obtain accurate received echoes could be a difficult task for radar system engineers <sup>6</sup>.

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<sup>1</sup> Merrill L. Skolnik, Introduction to Radar Systems (3rd Edition), McGraw Hill Education, 2017.

David K. Barton, Radar System Analysis and Modeling, Artech House, 2005.

Mark A. Richards, Principles of Modern Radar, SciTech Publishing, 2010.

<sup>2</sup> G. Richard Curry, Radar System Performance Modeling (2nd Edition), Artech House, 2005.

Bassem R. Mahafza, Radar Systems Analysis and Design Using MATLAB (3rd Edition), CRC Press, 2013.

<sup>3</sup> Nadav Levanon and Eli Mozeson, Radar Signals, John Wiley and Sons, 2004.

Paul J. Hannen, Radar and Electronic Warfare Principles for Non-Specialist (4th Edition), SciTech Publishing, 2014.

<sup>4</sup> Keysight Application Note (5990-5393), “Radar System Design and Interference Analysis Using Keysight SystemVue”, <https://www.keysight.com/us/en/assets/7018-02464/application-notes/5990-5393.pdf>

Keysight Application Note (5990-6919), “Using SystemVue’s Radar Library to Generate Signals for Radar Design and Verification”, <https://www.keysight.com/us/en/assets/7018-02782/application-notes/5990-6919.pdf>

Keysight Application Note (5989-7575), “Radar Measurements”, <https://www.keysight.com/us/en/assets/7018-01694/application-notes/5989-7575.pdf>

<sup>5</sup> G. Richard Curry, Radar System Performance Modeling (2nd Edition), Artech House, 2005.

Bassem R. Mahafza, Radar Systems Analysis and Design Using MATLAB (3rd Edition), CRC Press, 2013.

Nadav Levanon and Eli Mozeson, Radar Signals, John Wiley and Sons, 2004.

<sup>6</sup> Keysight Application Note (5989-7575), “Radar Measurements”, <https://www.keysight.com/us/en/assets/7018-01694/application-notes/5989-7575.pdf>

SystemVue Aerospace Defense (A/D) library has long been proved as a useful tool to generate and verify radar signals, much more than its basic capabilities in system-level simulation. The generation of radar test signals, at any system-level “checkpoint”, is one of the most widely accepted features of the A/D library <sup>7</sup>. We will see the new radar source modeling features and their impact on radar system performance.

## 3.0 Generating Realistic and Flexible Radar Pulsed Signals

Since SystemVue 2024, we have updated most radar pulsed source models with Rise/Fall Time modeling and PRF Staggering capabilities, which are of vital significance to generate realistic signal with sufficient flexibility and fidelity. The new features for the A/D library radar sources can be summarized as:

| Name               | Category             | Symbol                                                                              | Rise/Fall Time Modeling | PRF Staggering | Application Example                                                                                   | Ambiguity Function Example            | VSA Analysis Template                            |
|--------------------|----------------------|-------------------------------------------------------------------------------------|-------------------------|----------------|-------------------------------------------------------------------------------------------------------|---------------------------------------|--------------------------------------------------|
| RADAR_PULSE        | General              |    | YES                     | YES            | PulseGen_Test.wsv                                                                                     | AF_Pulse.wsv                          | N/A                                              |
| RADAR_LFM          | Frequency Modulation |   | YES                     | YES            | PulseGen_Test.wsv<br>Frequency_Modulation_Signal.wsv                                                  | AF_LFM.wsv                            | YES                                              |
| RADAR_NLFM         | Frequency Modulation |  | YES                     | YES            | PulseGen_Test.wsv<br>Frequency_Modulation_Signal.wsv                                                  | AF_Advanced.wsv                       | YES                                              |
| RADAR_FSK          | Frequency Modulation |  | YES                     | YES            | Frequency_Modulation_Signal.wsv<br>3 Modes Available:<br>Generic FSK<br>Costas Code<br>Hybrid FSK/PSK | AF_Advanced.wsv<br>(Costas Code ONLY) | 2 Modes Available:<br>Generic FSK<br>Costas Code |
| RADAR_StepFreq     | Frequency Modulation |  | YES                     | YES            | Frequency_Modulation_Signal.wsv                                                                       | N/A                                   | N/A                                              |
| RADAR_BarkerCode   | Phase Coding         |  | YES                     | YES            | Phase_Coding_Signal.wsv                                                                               | AF_Advanced.wsv                       | YES                                              |
| RADAR_FrankCode    | Phase Coding         |  | YES                     | YES            | Phase_Coding_Signal.wsv<br>6 Modes Available:<br>Frank, P1, P2, P3, P4, Px                            | N/A                                   | YES                                              |
| RADAR_PolyTimeCode | Phase Coding         |  | YES                     | YES            | Phase_Coding_Signal.wsv<br>4 Modes Available:<br>T1, T2, T3, T4                                       | N/A                                   | YES                                              |
| RADAR_ZCCode       | Phase Coding         |  | YES                     | YES            | Phase_Coding_Signal.wsv                                                                               | N/A                                   | N/A                                              |

**Table 1.** Radar Source Capabilities in Radar Library

<sup>7</sup> Keysight Application Note (5990-5393), “Radar System Design and Interference Analysis Using Keysight SystemVue”, <https://www.keysight.com/us/en/assets/7018-02464/application-notes/5990-5393.pdf>  
Keysight Application Note (5990-6919), “Using SystemVue’s Radar Library to Generate Signals for Radar Design and Verification”, <https://www.keysight.com/us/en/assets/7018-02782/application-notes/5990-6919.pdf>

From the above table we can see that most sources have been updated with the Rise/Fall Time modeling and PRF Staggering features. Also, we have provided VSA signal analysis template and ambiguity demo examples for commonly encountered sources.

As we focus on the waveform modeling capabilities in this application note, one typical advanced time behavior of a pulse envelop could be presented as <sup>8</sup> :

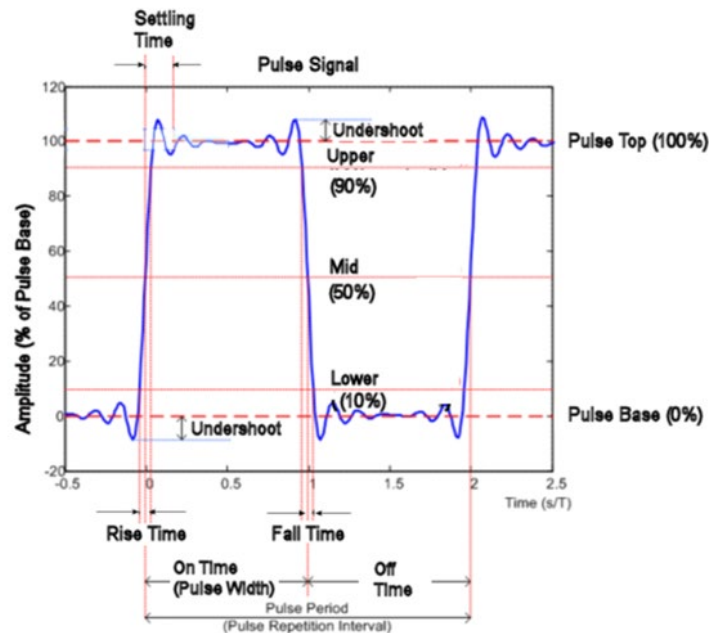


**Figure 1.** The Time Metrics of a common pulse

In the following sections we will present how to model some of these pulse behaviors using SystemVue A/D library.

## 3.1 Rise/Fall Time Modeling

In general terms, Rise (Fall) Times refer to the time taken by a pulse to change from a specified low (high) value to a specified high (low) value. In analog/digital electronics, the low/high values are usually defined as 10% and 90% of the pulse amplitude <sup>9</sup> . A more zoom-in figure of Rise/Fall Time could be given in a single positive valued pulsed waveform as <sup>10</sup> :

<sup>8</sup> Keysight VSA Online Documentation, page entitled “Time Metrics (Pulse)” : <https://www.keysight.com/us/en/lib/resources/help-files/pathwave-vector-signal-analysis-89600-vsa-software-help-documentation-zip-file-2021000.html>

<sup>9</sup> Rise/Fall Time definitions from Wikipedia: [https://en.wikipedia.org/wiki/Rise\\_time](https://en.wikipedia.org/wiki/Rise_time) and [https://en.wikipedia.org/wiki/Fall\\_time](https://en.wikipedia.org/wiki/Fall_time)

<sup>10</sup> Keysight VSA online documentation, page entitled “Pulse Signal Definitions”: <https://www.keysight.com/us/en/lib/resources/help-files/pathwave-vector-signal-analysis-89600-vsa-software-help-documentation-zip-file-2021000.html>

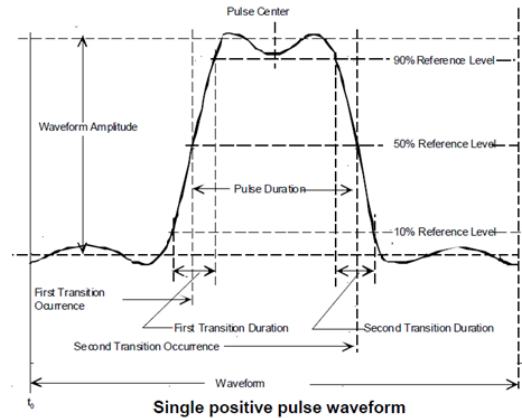


**Figure 2.** Rise/Fall Time and other waveform behavioral parameters

The modern radar pulses often apply raised-cosine, exponential or Gaussian shaping to minimize spectral splatter, but In SystemVue A/D library, we have a simplified solution: the Rise Time of pulsed sources start from 0 Volt as the low value and rise up to 1 Volt as the high value (and backward for Fall Time). (Note that the source assumes normalized output amplitude (from 0 Volt to 1 Volt), while in later RF stages we scale to realistic transmitter output power).

Prior to SystemVue 2024, the pulse starts at 0 Volt and jumps directly to 1 Volt in just 1 sample, and falls in the same manner, which is NOT physical for any real-world sources. Now the linear ramp has been realized as (take Costas Code example):

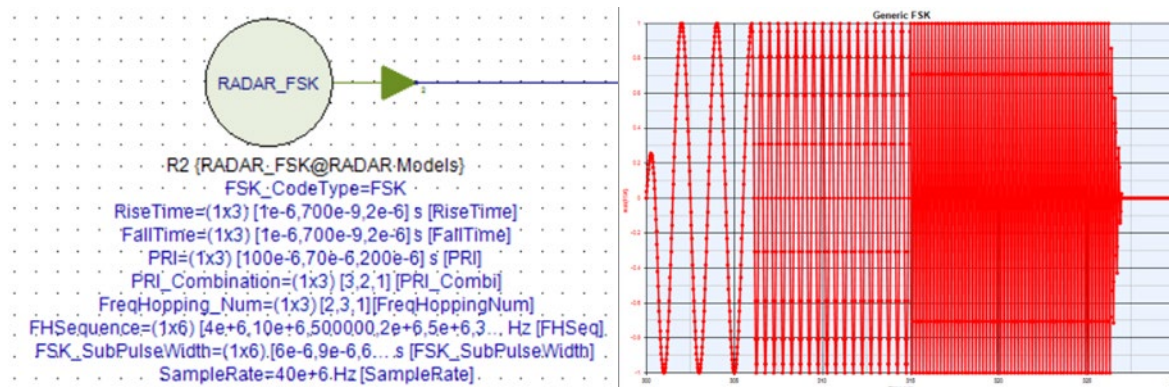


**Figure 3 (a)**

**Figure 3 (b)**

**Figure 3 (a).** Source Model Setup, Frequency Hopping Sequence = [0.5, 2, 5] MHz, SubPulseWidth = [6, 9, 12] uSec

**Figure 3 (b).** Generated complex envelope waveforms (real part)

We can see the subpulse frequency changes from a low value (0.5 MHz) to a high value (5 MHz). At the beginning of the 1<sup>st</sup> subpulse and 3<sup>rd</sup> (last) subpulse, clear Rise/Fall Time caused amplitude ramps are observed, while for other time samples the pulse envelop is kept constant as usual. Next, we present the impact of Rise/Fall Time on the signal spectrum plots:

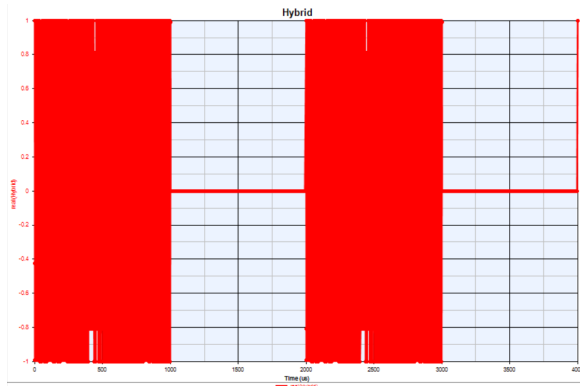


Figure 4 (a)

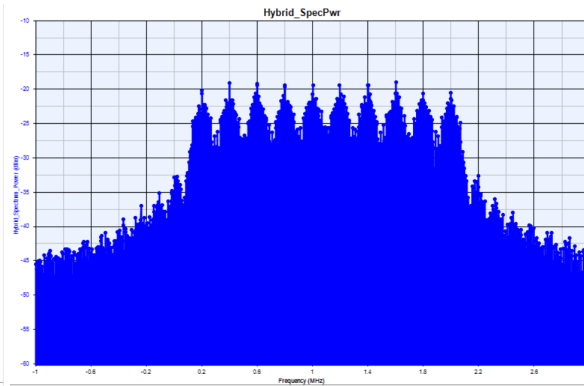


Figure 4 (b)

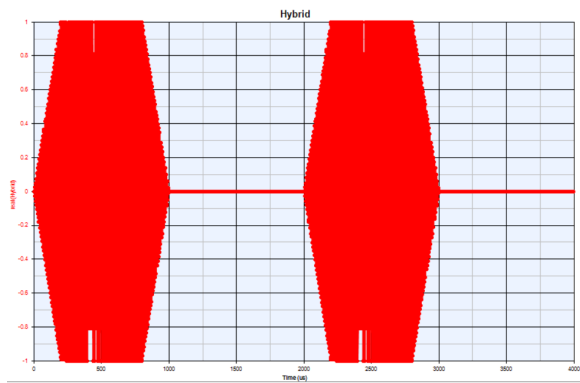


Fig.4 (c)

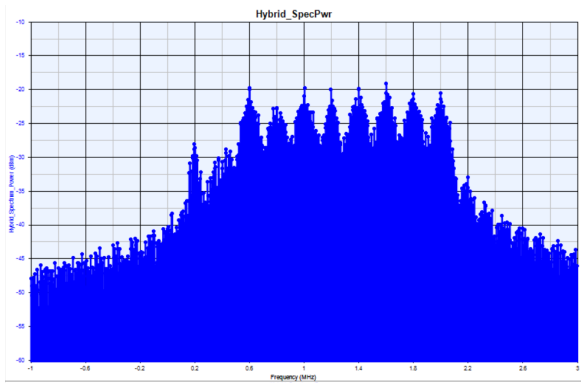


Fig.4 (d)

**Figure 4 (a), (b).** Hybrid FSK/PSK Waveform (Without Rise/Fall Time pulses) and Spectrum Plot

**Figure 4 (c), (d).** Hybrid FSK/PSK Waveform (With Rise/Fall Time pulses) and Spectrum Plot

Firstly we look at Fig.4 (b), the spectrum plot without Rise/Fall Time modeling is well organized with symmetric spectrum distribution and almost constant peak values. However, from Fig.4 (d), we observe non-symmetric spectrum with varying peak values (due to finite rise/fall shaping and spectral leakage), also a separate side peak is seen on the left side of the spectrum. Therefore, Rise/Fall Time modeling is very important for users to validate complex waveform and spectrum behaviors at the beginning of the system design. (NOTE: both the Costas and Hybrid FSK/PSK signal formats described above ignored timing synchronization or code orthogonality since these are simplified signal generation demonstrations, not fully compliant radar codes. Also, this hybrid waveform may introduce phase discontinuities across the sub-pulse boundaries.)

Next, we start looking at the system-level performance impact. We apply the “Radar Modeling Template.wsv” template workspace and investigate the LFM source rise/fall time modeling impacts on target detections. We did the following trials with intentional pulse timing setups:

| Test Case No. | Simulation Start Time | Rise/Fall Time Setup(sec) |          |            | PAA Setup PatternType = Cosine | Detected Target No. | Target Detections |                        |                        | Range-Doppler Map |               |
|---------------|-----------------------|---------------------------|----------|------------|--------------------------------|---------------------|-------------------|------------------------|------------------------|-------------------|---------------|
|               |                       | RiseTime                  | FallTime | PulseWidth |                                |                     | Echo Pwr (dBm)    | Range (km)             | Velocity (m/s)         | Peak Range        | Peak Velocity |
| Case-01 (Ref) | 50                    | 0                         | 0        | 16e-6      | Isotropic                      | 3                   | -151.4            | [58.425 17.962 16.762] | [-64.45 -70.31 -70.31] | 58.425            | -64.45        |
| Case-02 (Ref) | 50                    | 0                         | 0        | 16e-6      | URA (8*16)                     | 2                   | -126.1            | [58.425 17.962]        | [-64.45 -70.31]        | 17.962            | -70.31        |
| Case-03 (Ref) | 50                    | 0                         | 0        | 16e-6      | URA (16*16)                    | 1                   | -130.5            | 17.962                 | -70.31                 | 17.962            | -70.31        |
| Case-4        | 50                    | 2e-6                      | 2e-6     | 12e-6      | Isotropic                      | 3                   | -152.2            | [58.425 17.962 16.762] | [-64.45 -70.31 -70.31] | 58.425            | -64.45        |
| Case-5        | 50                    | 2e-6                      | 2e-6     | 12e-6      | URA (8*16)                     | 3                   | -126.9            | [58.425 17.962 16.762] | [-64.45 -70.31 -70.31] | 17.962            | -70.31        |
| Case-6        | 50                    | 2e-6                      | 2e-6     | 12e-6      | URA (16*16)                    | 1                   | -131.3            | 17.962                 | -70.31                 | 17.962            | -70.31        |
| Case-7        | 50                    | 3e-6                      | 3e-6     | 10e-6      | Isotropic                      | 2                   | -152.7            | [17.962 16.762]        | [-70.31 -70.31]        | 58.410            | -64.45        |
| Case-8        | 50                    | 3e-6                      | 3e-6     | 10e-6      | URA (8*16)                     | 3                   | -127.3            | [58.406 17.962 16.744] | [-64.45 -70.31 -70.31] | 17.962            | -70.31        |
| Case-9        | 50                    | 3e-6                      | 3e-6     | 10e-6      | URA (16*16)                    | 1                   | -131.8            | 17.962                 | -70.31                 | 17.962            | -70.31        |

**Table 2.** LFM source rise/fall time modeling impacts on target detections

The first three cases are with no rise/fall times as in SystemVue earlier versions. We then set up the rise/fall times to be 2 us and 3 us but still keep the total pulse width equal to reference cases of 16 us (Total pulsewidth = risetime + pulsewidth + falltime), and we found two abnormal cases. While keeping the signal processing chain and other system designs unchanged, strangely enough, case-5 using URA of 8 by 16 elements “restores” the nearby target at 16.76 km (other possible sensitivity factors may include windowing, noise level and antenna tapering, etc). For case-7, the isotropic antenna misses the long-range target at 58.42 km. Therefore, the rise and fall times are impacting radar system performance under specific conditions.

## 3.1 PRF Staggering

PRF staggering is a well-established technique in Pulse-Doppler radars used in order to increase the unambiguous range and doppler (velocity) to minimize blind spots in the Range-Doppler (Velocity) Maps <sup>11</sup>. Since modern Pulse-Doppler radars often use nonuniform PRI sequence designs for ambiguity reduction, SystemVue supports arbitrary PRI vectors or stochastic staggering patterns through scripting. As A/D library already has a simplified unambiguous range/velocity resolving example (see PDRADAR\_AmbiguityResolution.wsv for more details), here we focus on the source PRF staggering feature for waveform generation.

Two vivid and straight-forward PRF Staggering examples are proposed in Keysight Signal Studio (N7607C) help documentation as <sup>12</sup>:

<sup>11</sup> Merrill L. Skolnik, Introduction to Radar Systems (3<sup>rd</sup> Edition), McGraw Hill Education, 2017.  
David K. Barton, Radar System Analysis and Modeling, Artech House, 2005.  
Mark A. Richards, Principles of Modern Radar, SciTech Publishing, 2010.

<sup>12</sup> Keysight Signal Studio N7607C online help documentation:  
[https://rfmw.em.keysight.com/wireless/helpfiles/n7607/n7607.htm#DFS/ETSI\\_concept.htm](https://rfmw.em.keysight.com/wireless/helpfiles/n7607/n7607.htm#DFS/ETSI_concept.htm)

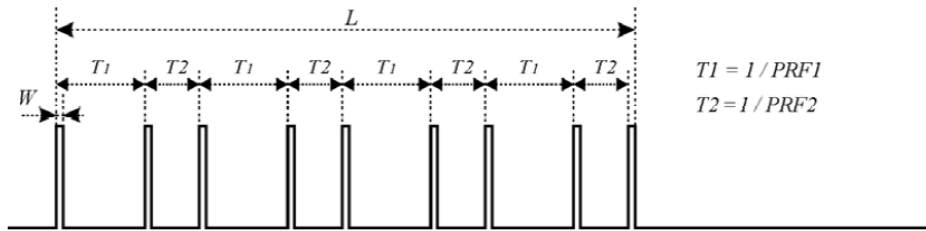


Figure 5 (a)

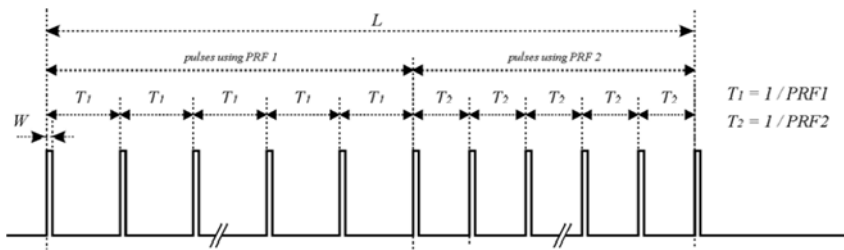


Figure 5 (b)

**Figure 5(a).** Single Burst, Single Pulse based Stagger PRF Test Signal (Single Pulse Staggering T1 -> T2 )

**Figure 5(b).** Single Burst, Packet based Stagger PRF Test Signal (Pulse Group Staggering mT1 -> nT2)

We give two vivid examples using the A/D library sources, one for frequency modulation and the other for phase coded waveform. Firstly the LFM (Linear FM) and NLFM (Nonlinear FM) waveform generations are designed as:

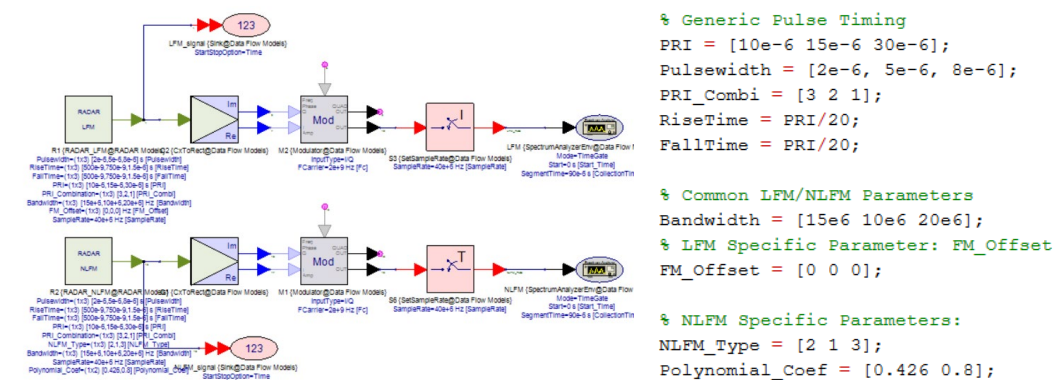


Figure 6 (a)

Figure 6 (b)

**Figure 6 (a).** LFM & NLFM RF envelop signal generation schematic

**Figure 6 (b).** PRF Staggering Pulse Timing Setups by MATLAB script

Here we give detailed parameter setup explanations in the following table as:

| Waveform Type | PRI Index | No. of Pulses | PRI   | Pulsewidth | Bandwidth | RiseTime | FallTime | FM Offset | NLFM Type |
|---------------|-----------|---------------|-------|------------|-----------|----------|----------|-----------|-----------|
| LFM           | 1         | 3             | 10 us | 2 us       | 15 MHz    | 500 ns   | 500 ns   | 0 Hz      | N/A       |
|               | 2         | 2             | 15 us | 5 us       | 10 MHz    | 750 ns   | 750 ns   | 0 Hz      |           |
|               | 3         | 1             | 30 us | 8 us       | 20 MHz    | 1.5 us   | 1.5 us   | 0 Hz      |           |
|               |           |               |       |            |           |          |          |           |           |
| NLFM          | 1         | 3             | 10 us | 2 us       | 15 MHz    | 500 ns   | 500 ns   | N/A       | 2         |
|               | 2         | 2             | 15 us | 5 us       | 10 MHz    | 750 ns   | 750 ns   |           | 1         |
|               | 3         | 1             | 30 us | 8 us       | 20 MHz    | 1.5 us   | 1.5 us   |           | 3         |

**Table 2.** LFM and NLFM PRF Staggering Configurations

After simulation, the LFM and NLFM staggered PRF waveforms are shown as (real part only):

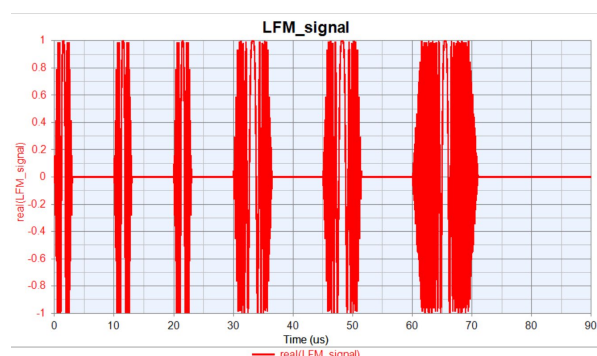


**Figure 7(a).** LFM Waveform

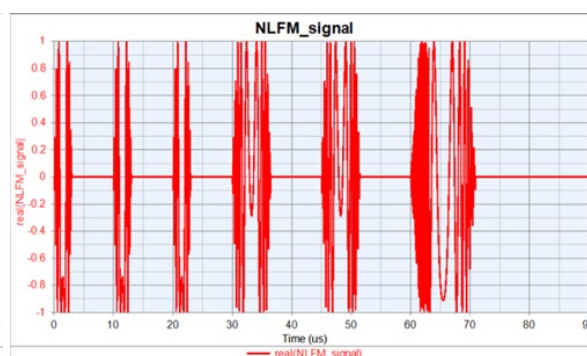


**Figure 7(b).** NLFM Waveform

For both sources, the PRF staggering has been designed as PRI = [10, 15, 30] uSec, Pulsewidth = [2, 5, 8] uSec, total pulse width (per pulse) = [3, 6.5, 11] uSec (with additions of rise/fall times), with staggering variation pattern of [3, 2, 1] (3 transmission of the 1<sup>st</sup> pulse, 2 transmission of the 2<sup>nd</sup> pulse, and 1 single transmission of the last pulse). With this methodology, we realize much more complex waveform in one simulation run.

We also use similar implementation for the phase coded source models. Similarly we give detailed parameter setup explanations in the following table as:

| Waveform Type | PRI Index | No. of Pulses | PRI    | Total Pulsewidth | Frequency Step Num | RiseTime | FallTime | FM Offset | Code Type |
|---------------|-----------|---------------|--------|------------------|--------------------|----------|----------|-----------|-----------|
| Frank         | 1         | 1             | 48 us  | 16 us            | 4                  | 200ns    | 200 ns   | N/A       | 0         |
|               | 2         | 2             | 128 us | 72 us            | 6                  | 150 ns   | 300 ns   |           | 2         |
|               | 3         | 3             | 192 us | 64 us            | 8                  | 300 ns   | 150 ns   |           | 5         |

**Table 3.** Frank Code PRF Staggering Configurations

The following figures present the FrankCode waveform schematic and related results with both rise/fall time modeling and PRF staggering:

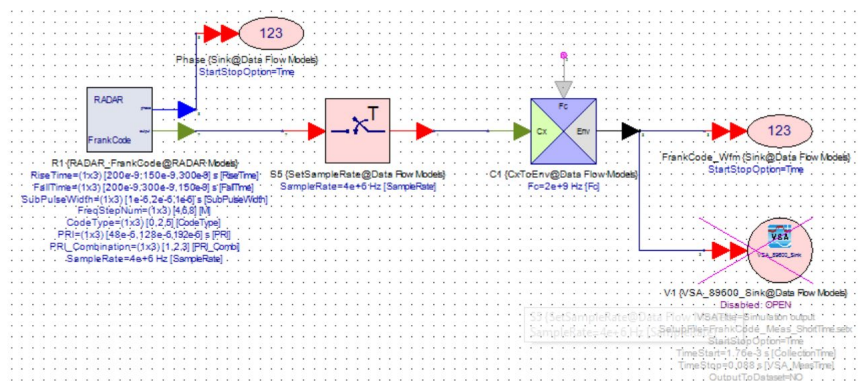


Figure 8 (a). FrankCode Waveform Generation Schematic

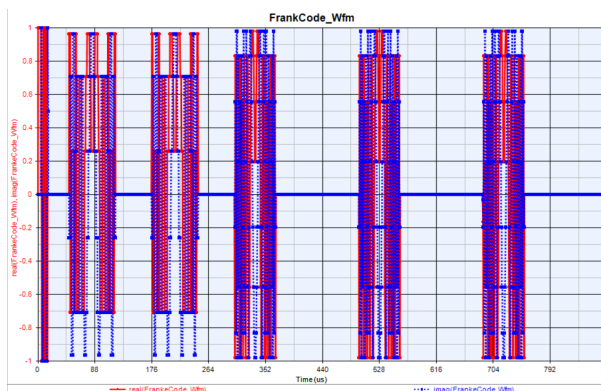


Figure 8 (b). FrankCode Waveform

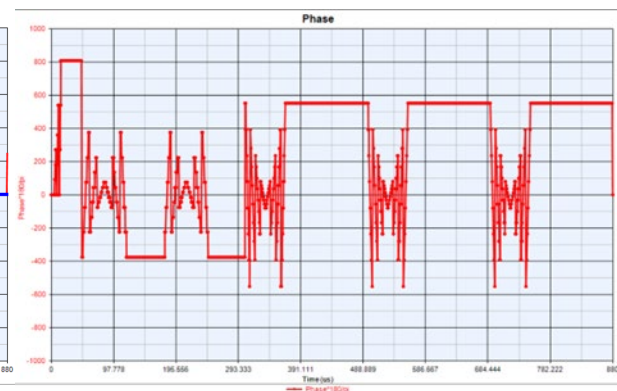


Figure 8 (c). FrankCode Phase Pattern

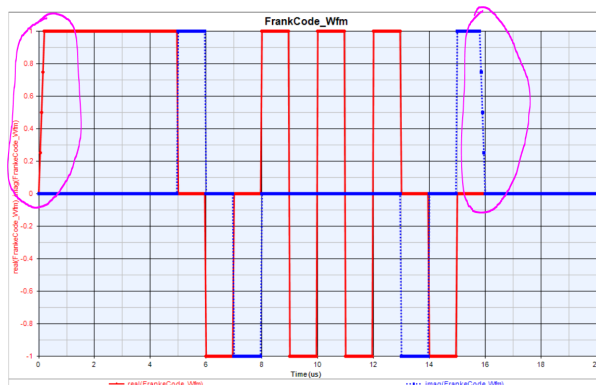


Figure 8 (d). Zoom-in to 1<sup>st</sup> pulse -> Rise/Fall Times

Similar as the frequency modulated case, from Fig.8 (b), the PRF staggering pattern is transmit 1 pulse for the 1<sup>st</sup> pulse, 2 pulses for the 2<sup>nd</sup> pulse, 3 pulses for the 3<sup>rd</sup> pulse. The frequency step numbers are set as 4, 6, 8, and the code types are 0 (Generic FrankCode), 2 (P2 Code) and 5 (Px Code). The phase variation pattern in Fig.8 (c) follows the same timing scheme, while the phase will stay at its original value until the next pre-planned phase change comes <sup>13</sup>. From Fig.8 (d), we zoom-in to the 1<sup>st</sup> pulse and the rise/fall times are clearly visible.

### 3.3 Complex Time Domain Waveform Modeling (MATLAB script example)

Users may also wonder how to model more complex pulse amplitude variations. We provide a generic time-based waveform modeling method with MATLAB script on a sample-by-sample basis. With the rough time-based pulse envelop shaping defined in reference, we have referenced a segmented amplitude modeling method throughout one PRI <sup>14</sup>:

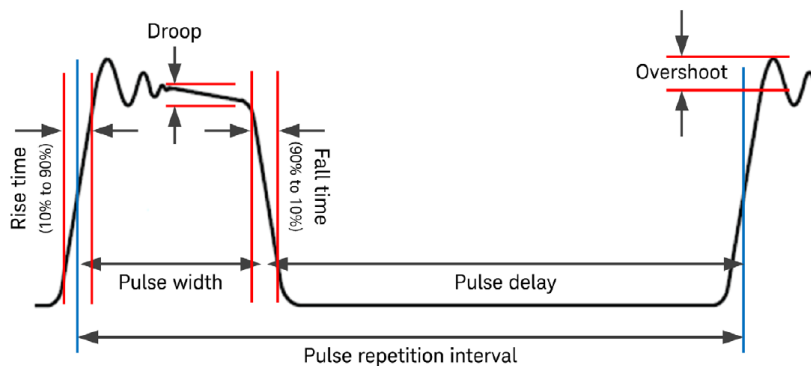


Figure 9. More complex and real-world pulse behaviors

For more flexibility and better user experience, we have applied the MATLAB script for the above modeling method to generate more complex and single-PRI pulse amplitude behaviors. Specifically, we have divided the above whole PRI into a segmented amplitude shaping:

#### 1. Rise time section

We use the Nyquist Filter to generate the nonlinear rise time (here Nyquist Filter is applied to control time-domain smoothness, not strictly for ISI control as in communication pulse shaping applications).

#### 2. Pulse width section

The overshoot and ripple damping effects are characterized for the pulse envelop through this in-pulse period.

<sup>13</sup> Keysight SystemVue online help documentation (for FrankCode part): [https://docs.keysight.com/display/svss/.RADAR\\_FrankCode+v2025](https://docs.keysight.com/display/svss/.RADAR_FrankCode+v2025)

<sup>14</sup> Keysight Application Note (5992-1484EN), "Defining the Pulsed Radar Signal and the Essential Measurements of Signal Power (Part-2)" <https://www.keysight.com/us/en/assets/7018-05197/application-notes/5992-1484.pdf>

### 3. Fall time section

We apply one interpolation algorithm-based fall time modeling method.

#### 4. Pulse-off section

The undershoot and ripple damping effects are characterized for the pulse envelop through this out-of-pulse period.

The workspace schematic details are proposed as:

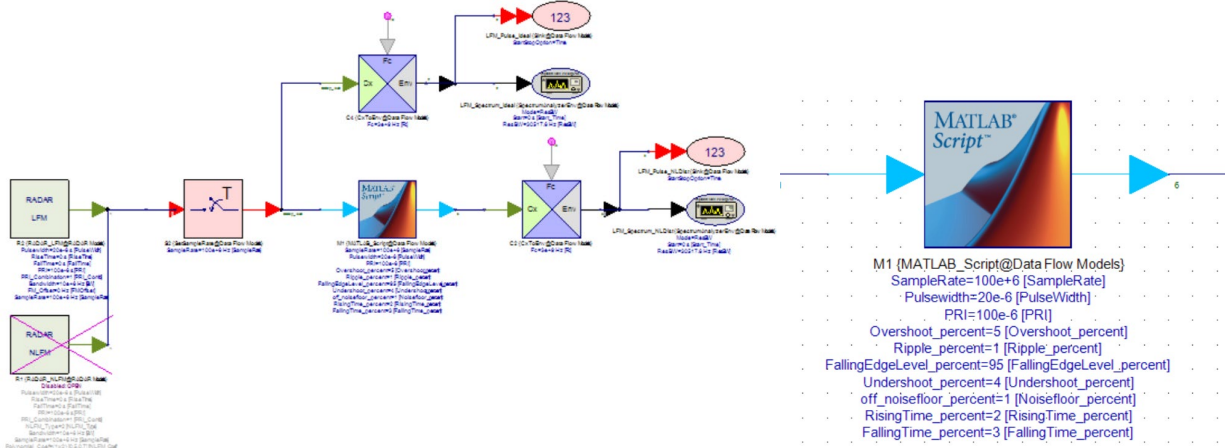


**Figure 10 (a).** Complex Waveform Modeling-Schematic Overview    **(b).** MATLAB Script Model Zoom-In

For the ideal waveform models, we have selected LFM and NLFM models for demonstration. The time-domain pulse waveform details are given below respectively as:

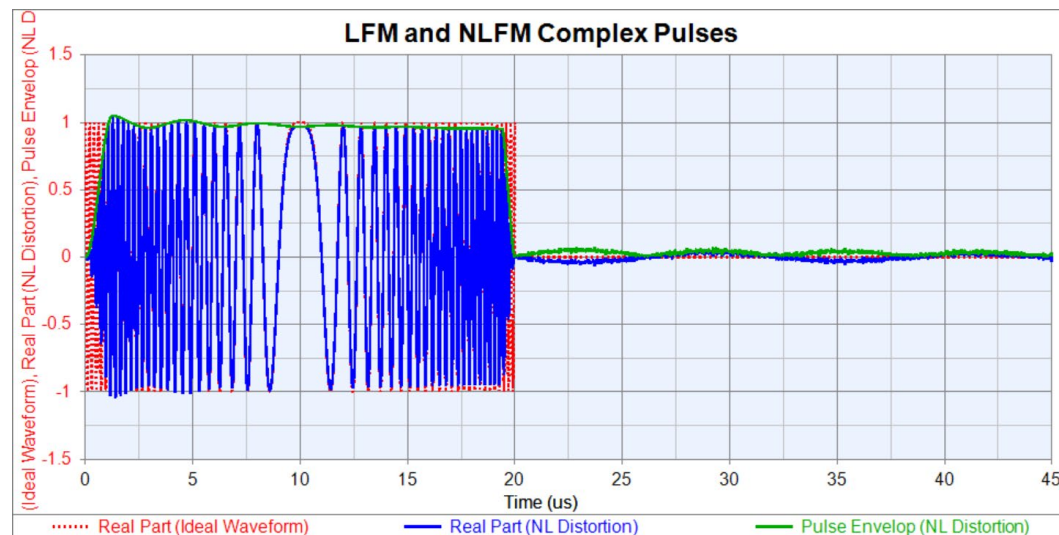


**Figure 11 (a).** LFM Complex Pulse Behavior

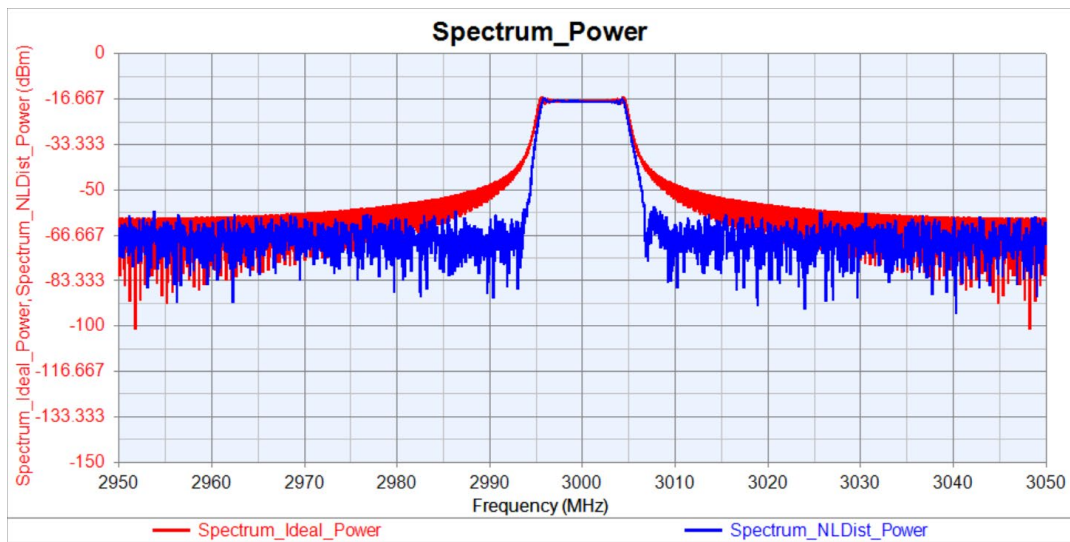


Figure 11 (b). LFM Complex Pulse Spectrum (Compared with Ideal LFM spectrum)

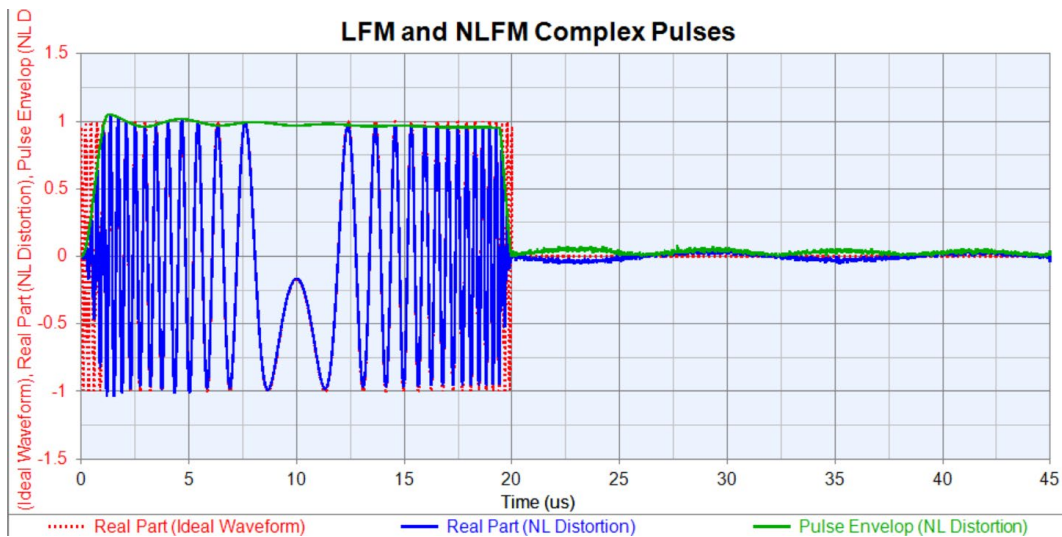


Figure 11 (c). NLFM Complex Pulse Behavior

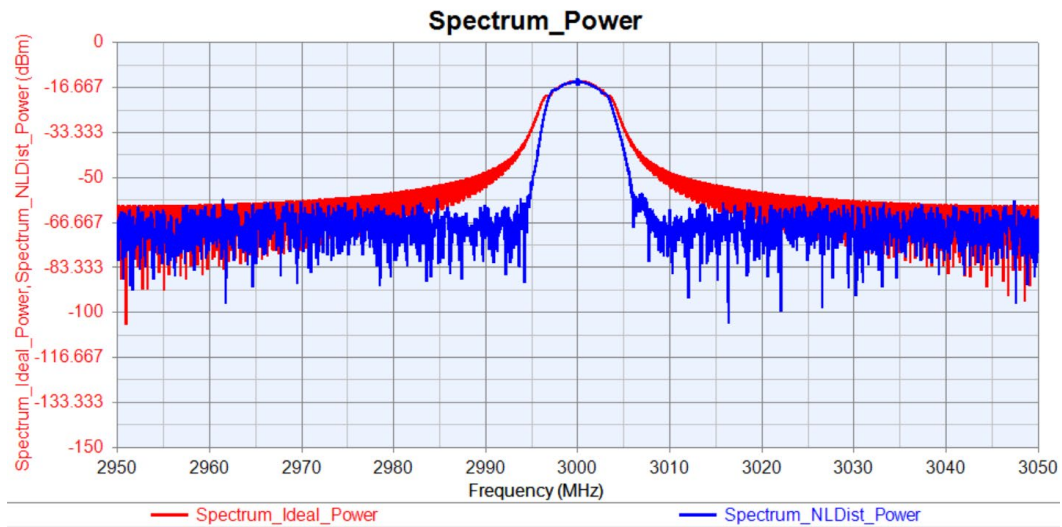


**Figure 11 (d).** NLFM Complex Pulse Spectrum (Compared with Ideal NLFM spectrum)

From Figure 11 (a) and (c), we have mimicked the amplitude nonlinear distortions (red curve for ideal waveform, blue curve for nonlinear pulse modeling, and green curve for the nonlinearly shaped envelop), and from frequency domain the nonlinear distortion spectrum distortions are also clearly visible.

## 4.0 Summary

Modeling the baseband source with sufficient accuracy is one of the first milestones in establishing a trustful virtual system. The new rise/fall time modeling and PRF staggering features in radar (A/D) library, plus the more flexible MATLAB script pulse modeling methodology, have made the design work much easier for the radar system designers when higher fidelity baseband/RF signal behaviors are desired.

Moreover, now SystemVue can support more features related to A/D radar simulations:

1. SystemVue plans to provide Spectrasys II integration, which allows radar waveforms to be simulated with realistic RF impairments and hardware nonlinearities.
2. SystemVue's Phased Array Analysis (PA) engine can now co-simulate radar sources with beamforming networks and antenna patterns – since version 2024.
3. Python API support for automated waveform generation: MATLAB scripting is still valid but now SystemVue supports Python as a new and preferred workflow.
4. VSA integration supports advanced radar/communication joint metrics like EVM, ACPR, ambiguity function analysis and aligning simulation with test instrumentation.

Equipped with these renowned capabilities, SystemVue enables a digital twin radar environment supporting high-fidelity pulse modeling and radar system-level verifications.

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