Keysight EEsof EDA

Generating Multi-Dimensional Signals to Test Radar/EW Systems

Application Note

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TECHNOLOGIES

Introduction

Modern Electronic Warfare (EW) systems are designed to monitor a specified environment for Radar and communication transmission stations, whether friend or foe. An important task for the EW receiver is to detect incoming signals (waveforms) and identify exactly which station or stations they are coming from. The information coming from a signal transmission station includes the station's location, speed, waveform types, and frequency bands. The EW receiver must be able to analyze signal information from all transmission stations.

In reality, the signal appearing at the EW receiver input is a combination of signals from different Radar or communication transmission stations with complex information for the location and speed of the stations, as well as time waveforms and the frequency bands of transmitted signals. To test the EW receiver, a test signal with the following characteristics is needed:

- It must come from multiple Radar and communication transmission stations.
- Each component of the EW receiving signal must include information from the transmission station on its location (e.g., longitude, latitude and attitude) and speed, as well as the time waveform from the station and the signal's frequency-domain information.
- It must form multi-emitter, overlapping or non-overlapping signals.

This type of test signal is called a Multi-Dimensional (MD) signal.

As an example of an EW receiver test, a test operation environment is shown in Figure 1. Here, an EW receiver (EW Rx) is used to monitor a space in which there are four Radar stations. The task for the EW receiver is to detect all of these signals, recognize each one and sort out the individual location, speed, time waveform, and frequency content for each transmission station.

To test the EW receiver, a test signal must be generated and that does not mean simply adding several time waveforms together. Instead, a MD signal must be created using the detailed setup shown in Figure 2. As a side note, because the EW receiver might be installed on an airplane, car or ship, the tool that's used to generate that test signal must allow the user to specify the EW Rx station's location, speed, time waveform, and frequency band. Also, for each Radar station, the tool must allow the user to specify its location, speed, time waveform, and frequency band, as all of this information is built into the MD signal.

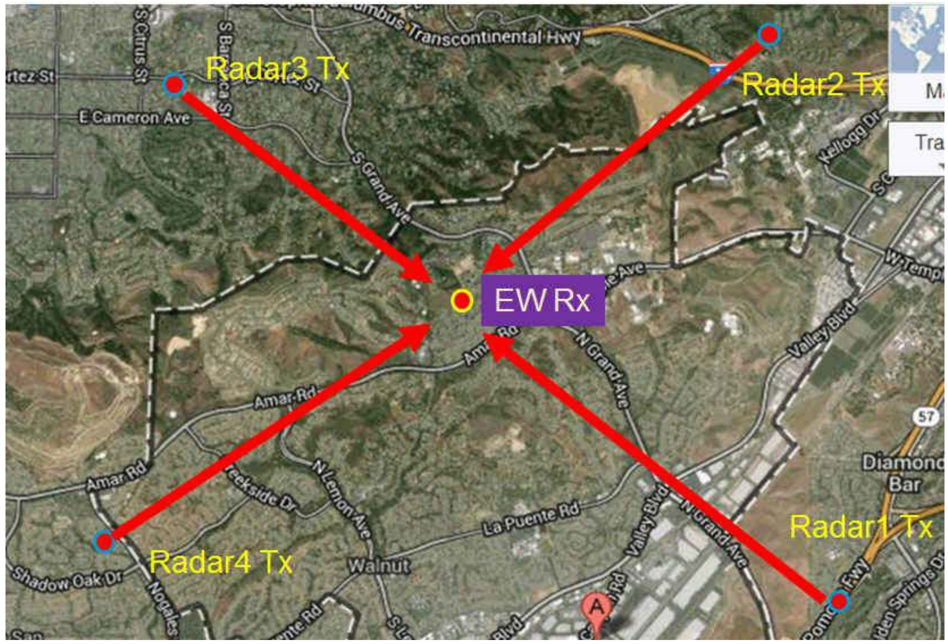

Figure 1. Shown here is an example of an EW receiver test environment, with several geographically dispersed emitters contributing to signal conditions at a centrally-located receiver. SystemVue helps make this modeling task easier, with lower NRE.

The steps required to generate the test signal are as follows:

Step 1. Generate the Tx signal for each Tx with location described by longitude, latitude and height, as well as speed, the proper time waveform and frequency content (carrier and Doppler frequency). The required complex Tx comprises:

- An antenna and active array antenna with beamforming
- Pulse and dynamic pulse
- Environment scenarios
- A multi-emitter from Radar and communication systems
- An EW receiver test signal with MD information from the Radar stations
- A long test sequence with a wide frequency band

Step 2. Determine EW receiver location. Speed also needs to be considered.

Step 3. Combine all Tx signals together to form the MD signal.

Step 4. Prior to test, verify the MD signal.

In the following section, an example will be shown to illustrate exactly how to generate the MD signal.

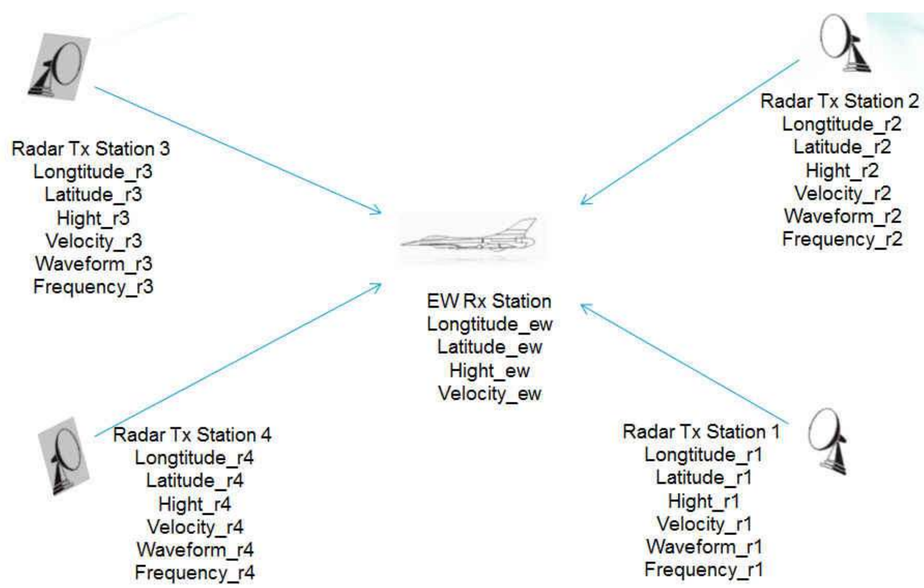

Figure 2. Here is the same scenario from Figure 1, but now shown schematically, in preparation for entry into the SystemVue environment.

EW Test Platform

To test the EW receiver, a test platform is needed in which the MD signal can be built and analyzed.

The proposed system will work under actual tactical situations with terrain, numerous threats and targets, plus multiple Radar signals and jammers.

SystemVue can provide a design and test platform with Radar/EW scenarios such as target Radar Cross Section (RCS), interference, jamming deception and clutter. With SystemVue, an AGI System Tool Kit (STK) link is provided. This link allows the user to describe complex Radar/EW environments under actual tactical situations with terrain, numerous threats and targets, plus multiple radar signals and jammers simultaneously occurring.

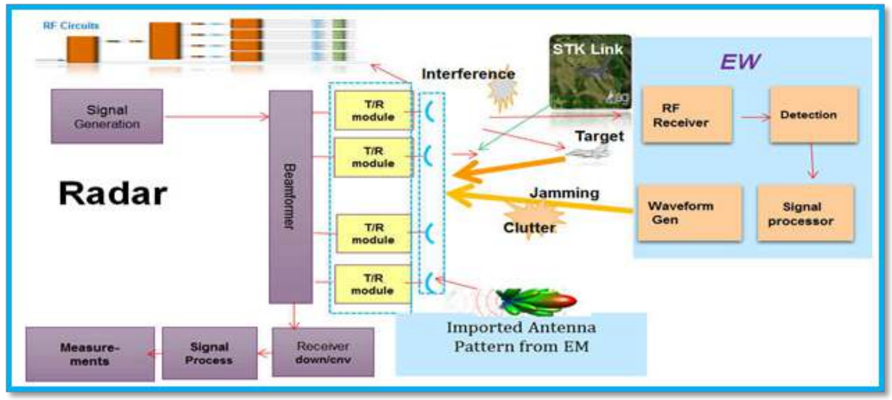

Figure 3. A proposed EW Radar system simulation setup, where SystemVue is used to model the baseband algorithms, the RF and beamforming, and the external environment in a wholistic system-level approach.

Simulation Setup

The basic simulation platform is shown in Figure 3. Signal sources are built in for Continuous Wave (CW) pulse or modulated pulses, followed by Transmit/Receive (T/R) modules with beamforming. An antenna or antenna array is available to simulate passive or active systems. On the receiver side, the RF receiver plus signal processing are considered. Basic and advanced measurements are available to measure system performance.

Keysight's SystemVue EW solution supports cross-domain simulation with RF and includes real- world environment scenarios such as interference, target RCS, clutter, jamming, and the AGI STK link for flight test. SystemVue also provides strong integration capabilities so the user can quickly and easily create new designs and proposals, and win new bids. This setup can be used for testing both EW and Radar systems.

When designing the EW system, its architecture can be specified by the user, including the RF receiver, detection, signal processing, and jamming/deception generation. The simulation platform can be used in the following two ways:

1. Test EW System

Using the setup in Figure 3 to test EW system, we can use Radar transmitter signal with interference form an EW test signal. And then the EW system generates Jamming or Deception to attach Radar.

To show the performance of the EW system, we can use the Radar receiver measurements such as probability of detection and false alarm to verify if the EW system works or not.

2. Test Radar System

In this case, the EW contributes the Jamming or deception for the environments and that affects the radar performance.

Test Setup

SystemVue provides platforms not only for design, but also for testing the EW/Radar system at all stages of the development process. In the test, the simulation platform shown in Figure 3 is extended to a test platform shown in Figure 4. Any simulation signal can be downloaded to a Vector Signal Generator (VSG) such as an ARB or wideband AWG for hardware test. Signals requiring further analysis can be brought back into the SystemVue environment via a hardware link. The link allows the raw signal data to be easily sent from a signal analyzer or oscilloscope to SystemVue for further processing or measurement using signal processing models.

How can SystemVue help you create a testbed that will enable you to improve or develop portions of Radar? In general, the Radar testbed includes the signal source, environment setup and measurements. For an advanced testbed, an automatic test capability is required. SystemVue provides a test platform in which test instruments and the Device-Under-Test (DUT) are integrated. SystemVue then provides test signals to the DUT, captures the DUT outputs, synchronizes signals, and uses advanced measurements for system performance evaluation. Without the integration and synchronization, each instrument would function on its own, making it difficult to perform complex tests. Figure 4 shows how to make a testbed using the SystemVue test platform.

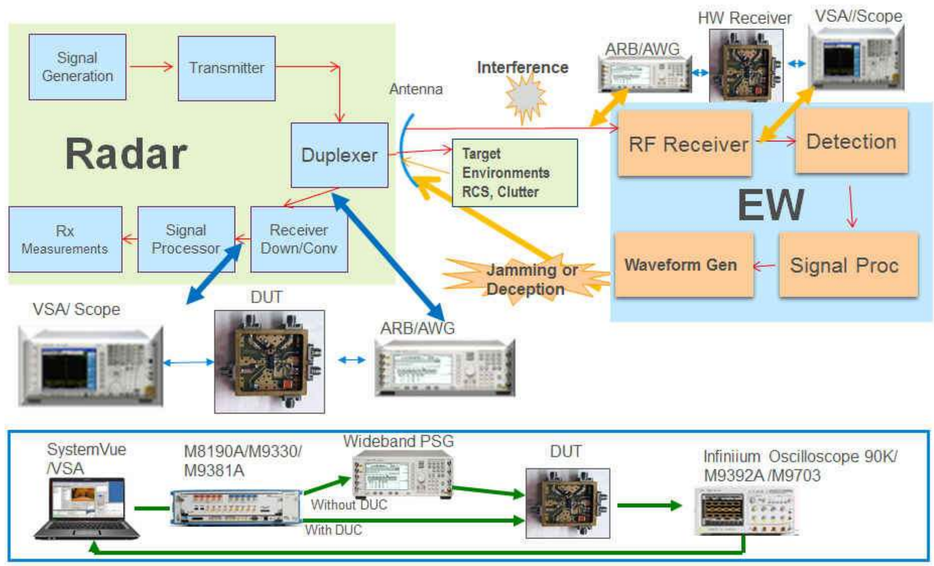

Figure 4. Waveforms at various locations in the simulation can be generated with live test equipment, or captured and brought into the simulation for further processing.

Key Models for EW Test

Test Signals with Antenna/Array Antenna

The antenna models, Radar_Antenna_Tx and Radar_Antenna_Rx are used to simulate the transmitter and receiver antennas with mechanical scan capability. When the Radar is a mono-static Radar, the same parameters are set to both models. This model supports two working modes: search and tracking. The antenna pattern can be imported as a user-defined pattern or calculated based on the size of the antenna and illuminating window function.

When the pattern is user-defined, the "AntennaPatternArray" parameter is used to accept the user-define model. The size of "AntennaPatternArray" parameter is the product of the number of azimuth angles (columns) and elevation angles (rows). The user-defined pattern format is a matrix. Each element value represents the antenna gain at the corresponding azimuth and elevation angle. "ThetaAngleStart" and "TheatAngleEnd" provide the scope of the elevation angle, while "PhiAngleStart" and "PhiAngleEnd" give the scope of the azimuth angle. AngleStep is the value of the angle step for the user-defined pattern.

Besides the UserDefinedPattern, there are several other commonly used patterns. The antenna radiated pattern is decided by the various aperture distributions. The aperture distributions include Uniform, Cosine, Parabolic, Triangle, Circular, CosineSquarePedestal, and Taylor. A detailed description of each of these distributions is provided in the table.

Figure 5 shows an example of how the antenna model can be used to generate scanned waveforms.

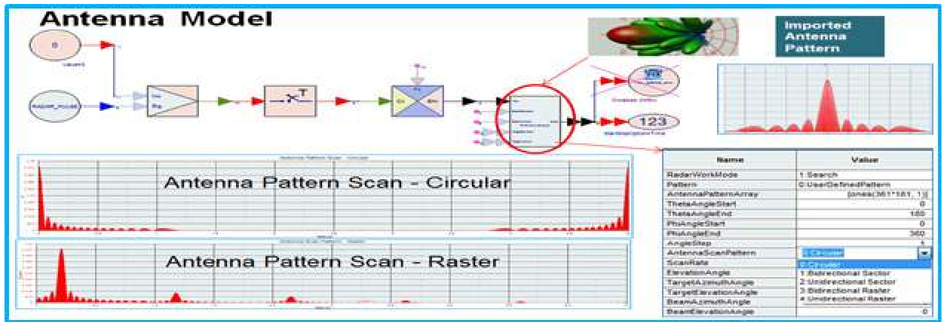

Figure 5. As an antenna scans in either search or tracking modes, the resulting signal will have repetitive characteristics. The simulation model makes this easy to re-create, reducing external scripting.

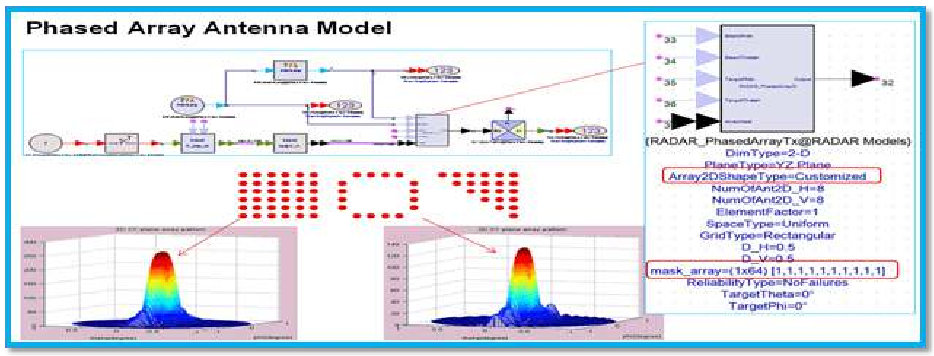

Figure 6. The phased-array antenna simulation model allows directional beamforming, with appropriate sidelobes, to impact the system-level performance of the overall radar.

The phased-array antenna simulation model, shown in Figure 6, allows beamforming and statistical effects to be modeled at the system level in a dynamically moving environment. The model affects the overall signal, side lobe, clutter, and jammer levels during the simulation. In other words, it influences system-level results like Probability of Detection (Pd).

Electronically scanned arrays (ESAs) provide “commandable,” agile, high-gain beams and are advantageous for applications such as Radar, weather surveillance and imaging. In contrast to reflector antennas, which require a gimbal for steering the array beam, ESAs electronically scan the array beam in space without physically moving the array. Scanning the beam with an ESA can be performed in microseconds, as opposed to milliseconds, for a reflector.

The RADAR_PhasedArrayTx and RADAR_PhasedArrayRx models are used to simulate ESA transmit and receive functions. Linear array and 2-D planar arrays are supported with these two models. Users can specify the array shape using a mask array parameter. Arbitrary antenna arrays are also supported.

Dynamic Signal Generation

The dynamic signal generation model, SignalX, is used to generate a waveform in which waveform type, Pulse Repetition Interval (PRI), carrier frequency, pulse width, bandwidth, phase, and the number of pulses in one Coherent Processing Interval (CPI) can be updated in runtime. This model is very useful for the jitter PRI and stagger PRI cases. Figure 7 shows a Linear FM pulse signal with random PRI that was generated using this model.

To support these flexible capabilities, generated waveforms are packed into one matrix and the data type of output is matrix. The data rate of the output is 1. Using the model DynamicUnpack_M with Format=RowMajor, the waveform matrix can be unpacked to the samples. The row number of the matrix is the number of pulses in one CPI, while the column number of the matrix is the number of samples in one PRI. The parameter PRI_jitter is the normalized value of PRI, which is the input port. When PRI_jitter = 0, there is no jitter.

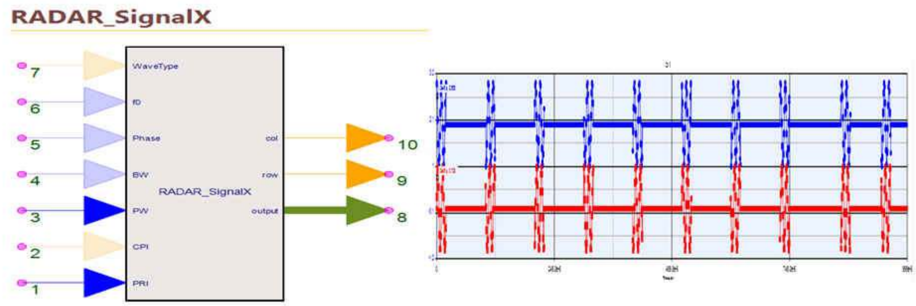

Figure 7. Dynamic pulse generation - Many of schematic parameters for radar pulse generation, such as repetition interval, carrier frequency, and phase, are externalized as live simulation pins using the "SignalX" component. This enables pulse characteristics to be encoded dynamically on each pulse, either from an external file, or from algorithms present in the simulation, which may be adapting to changing conditions.

Jamming and Deception

This model provides both cover jamming and deceptive jamming. There are four types of cover jamming: barrage, spot, multi-spot, and swept-spot.

For barrage jamming, the model generates the AWGN noise, with mean and standard deviation values determined by the parameters Mean and Stdev in the full bandwidth. For spot jamming, the model generates the band-limited AWGN noise, and the normalized bandwidth is determined by the parameter Bandwidth. FilterTapsLength is used to set up the maximum length of the low-pass filter. For multi-spot jamming, the model generates band-limited AWGN noise in the sub-bands determined by the parameter MultiSpotBand, which can be used to set up the normalized start and cut-off frequencies of several pass-bands. Lastly, for swept-spot jamming, the band-limited AWGN noise can sweep in the scope of the full band. The sweep rate is decided by the parameter SweepFreqStep. The spectrum figures of barrage, spot, multi-spot, and swept spot jamming are shown in Figure 8.

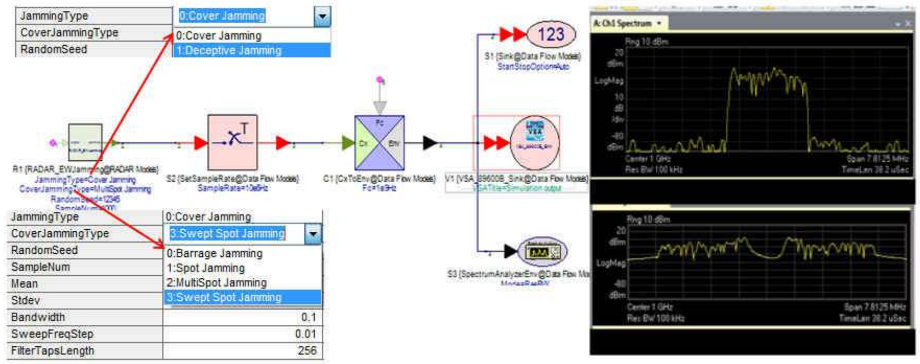

Figure 8. Common forms of jamming and counter-measures are selectable as a model parameter.

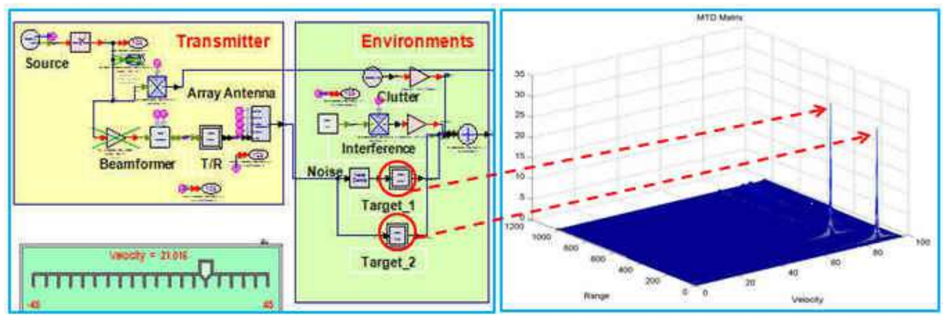

Figure 9. Multiple targets can be set up in the simulation framework, each with its own 3D position and velocity, in order to test the resolution of radar receiver algorithms and hardware prototypes.

Multi-Target Set in the EW/ Radar Operation Environment

Target models in SystemVue allow users to specify a multi-target scenario with clutter, jamming and interference. For each target, the user can specify its range, velocity and acceleration. Figure 9 shows how the user can put a multi-target in a Radar/EW environment such as clutter, interference and noise, and simulate a complex radar system. As is evident from the figure, through SystemVue 3-D measurement, two targets can be measured in the Range-Doppler plane.

Scenario Framework

There are many types of Radar systems, including: mono-static Moving Target Indication and Moving Target Detection (MTI/MTD) Radar, bi-static Radar, multi-static Radar, airborne Synthetic Aperture Radar (SAR), and space-borne SAR, ISAR, and phased-array Radar.

In general, the difference between two types of Radar systems is quite extensive. It's not practical for a simulation tool vendor to provide every type of Radar system, consequently, a generalized Radar simulation framework is created instead. This framework is derived from the basic concepts of Radar technology. No matter what type of Radar, signals are always transmitted from a Radar system, and received by the same or a different Radar system. Different types of Radar are determined by how the received signal is processed.

In the framework in Figure 10, there are three layers: trajectory, antenna and signal. In the trajectory layer, the RADAR_Platform and RADAR_TargetTrajectory models are used to compute their trajectories in the Earth-Centered Inertial (ECI) coordinate frame. Received Radar system signals are the signals from the transmitters and the echoes from the targets or the different scatters of targets. The distance between transmitters and targets, and between targets and receivers determines the delay value of each sample of echoes, which in turn determines the magnitude attenuation and Doppler.
In addition, the position between the transmitter and target, and the direction of the antenna's main lobe relative to the antenna carrier determine the transmitter antenna gain. The same applies for receiver antenna gain.

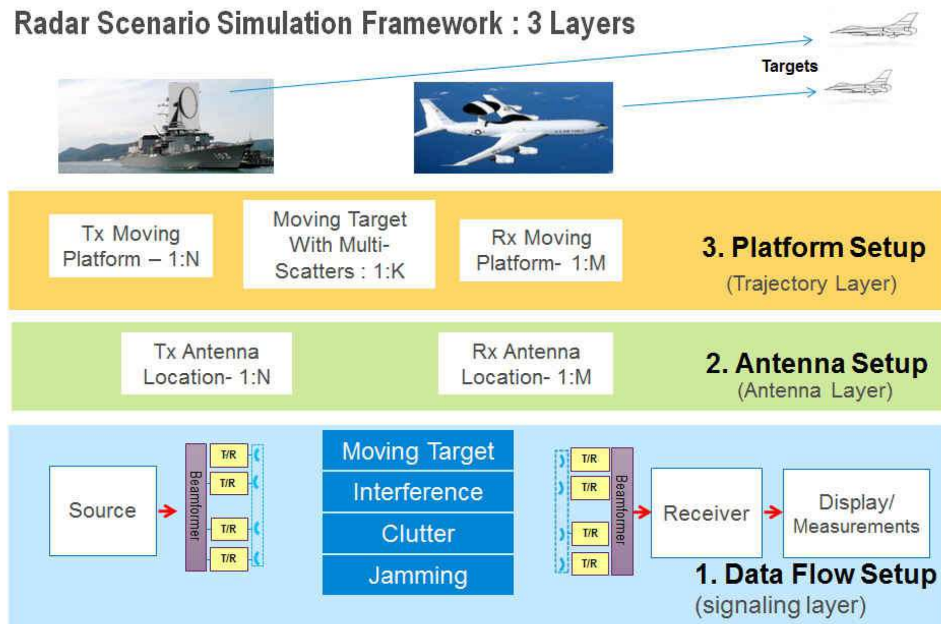

Figure 10. SystemVue offers additional layers for absolute position/velocity ("Platform") and beamforming/rotational direction ("Anetnna"). This enables the 3D motion necessary for evaluating air/sea/sky radar platforms under realistic conditions.

In the antenna layer, the azimuth angle and elevation angle of targets in the antenna frame is computed. These two angles are input into the antenna models or phased-array models to obtain the final antenna gain.

In the signal layer, the signals are delayed, attenuated, and amplified by the antenna and transmitting/receiving (Tx/Rx) chains, combining both RF and baseband signal processing. With this framework, users can set up many types of Radar systems. The next step is to process the received echoes for different types of Radar. Note that the generic scenario framework can also be used to setup EW systems to generate and analyze MD signals.

EW Receiver Test using a MD Signal

In the Introduction, an important EW test signal, MD signal has been discussed. In this section, we are going to discuss how the MD signal can be generated by using the Scenario Framework.

As an example, let's consider a design shown in Figure 11. Here, we assume two Radar Tx stations are located in the space monitored by the EW receiver.

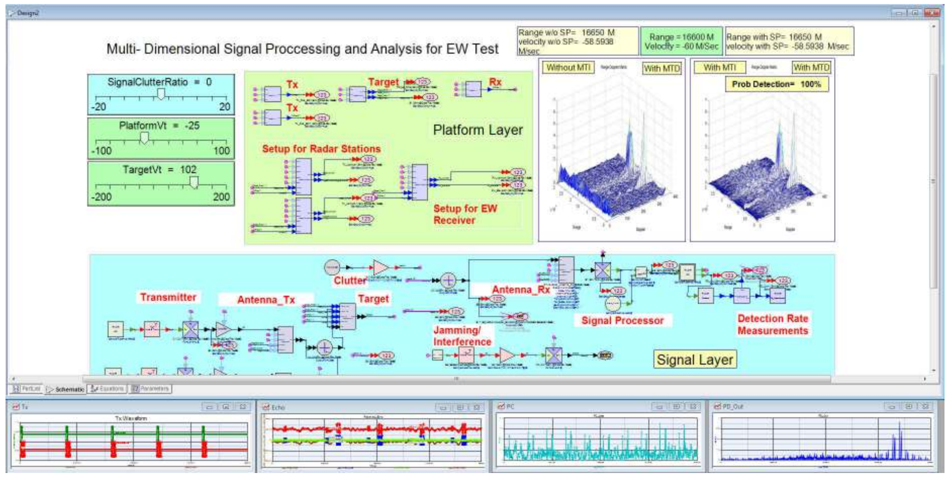

Figure 11. Multi-dimensional signal generation workspace, with key variables such as velocities and Signal/Clutter ratio enabled as interactive sliders.

Radar Station Setup in Platform Layer

The first step is to generate a signal for each Tx station with the location information described by longitude, latitude and height, as well as speed, the proper time waveform and frequency content (e.g., carrier, Doppler frequency). In Figure 12, two RADAR_Platform models are used to specify the Radar Tx. By opening the parameter list of the model, the user can specify the Tx position parameter by longitude, latitude and height

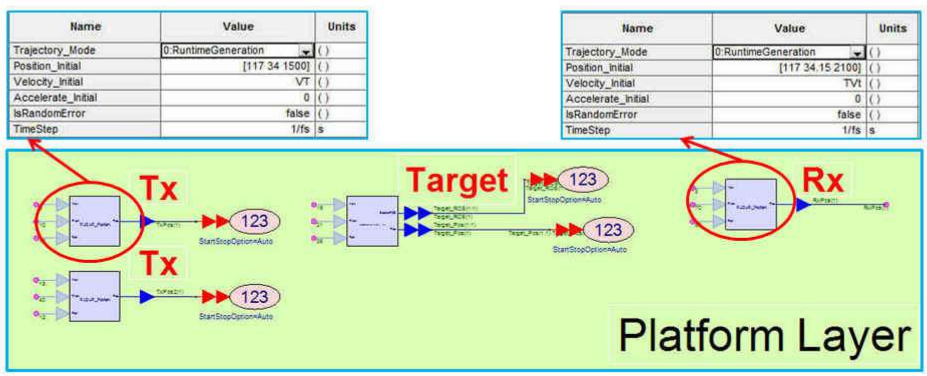

Figure 12. Each transmit and receive platform can be individually scripted and located in space.

Tx Signal Generated in Signal layer

As shown in Figure 13, we can zoom in on the Tx waveform generation design in the signal layer in Figure 11. Two LFM signals with different parameters are generated through modulators, power amplifiers and array antennas. In the figure, the generated Tx waveforms are displayed as the green and red lines.

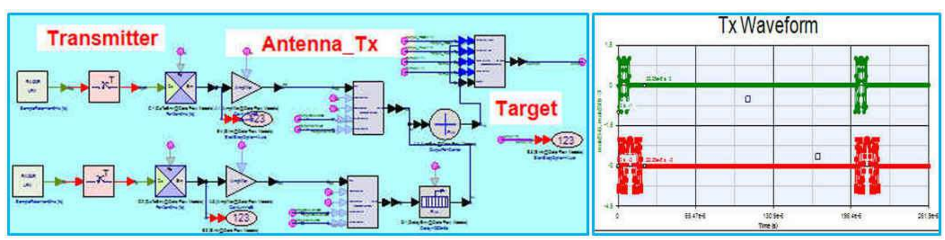

Figure 13. Waveform generation in the signal layer.

Form the MD Signal in the Signal Layer

In Figure 14, two LFM formatting transmission signals propagate through the EW operation environment, including random jamming/deception, RCS and interference, and combine to form the EW receiver test signal. The right side of the figure shows the waveforms for jamming (green), clutter (brown), Tx waveforms (blue), and the combination of all of these at the receiver input (red).

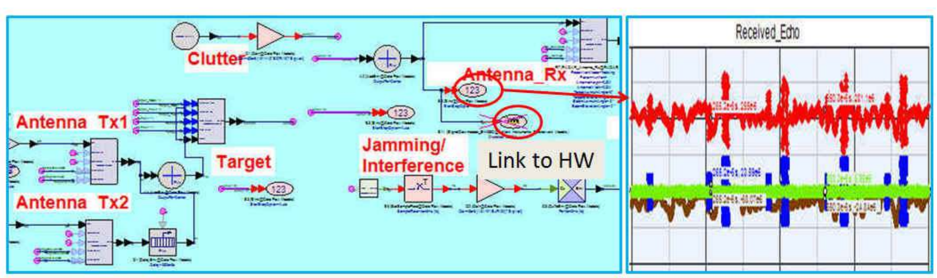

Figure 14. The multi-dimensional signals can be downloaded directly from the simulation into Keysight test equipment, enabling convenient evaluation of both algorithms and hardware under the same conditions.

Proof of the Right MD Signal

To prove the MD signal is right, the built-in Radar receiver is used to extract the waveform information to see if it makes sense (Figure 15). In this case, the information about the two Radar Tx stations being monitored by the EW receiver is extracted by following the waveform from the Radar receiver and array antenna, followed by the demodulator and then through the signal processor for Pulse Doppler Radar (MTI and MTD).

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In Figure 16, the detected Radar Tx signals are plotted in the Range-Doppler Plane for after MTI, and after MTI and MTD. As is apparent for both cases, the targets are detected with 100 percent detection probability. Range and velocity estimations were also made. The estimated results (Fig 17 yellow window) match well with the theoretical results (Fig. 17 green window).

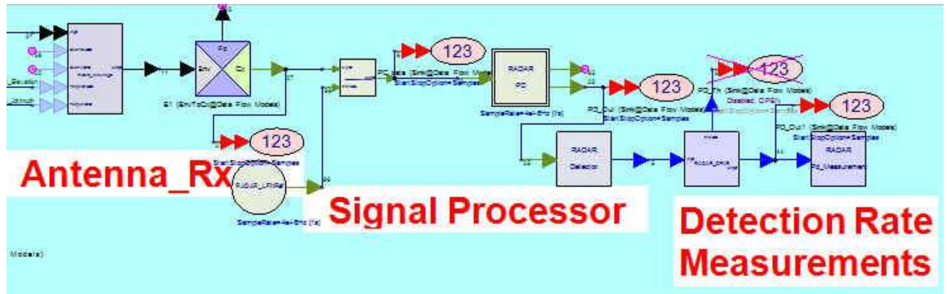

Figure 15. Software receiver to analyze the MD signal.

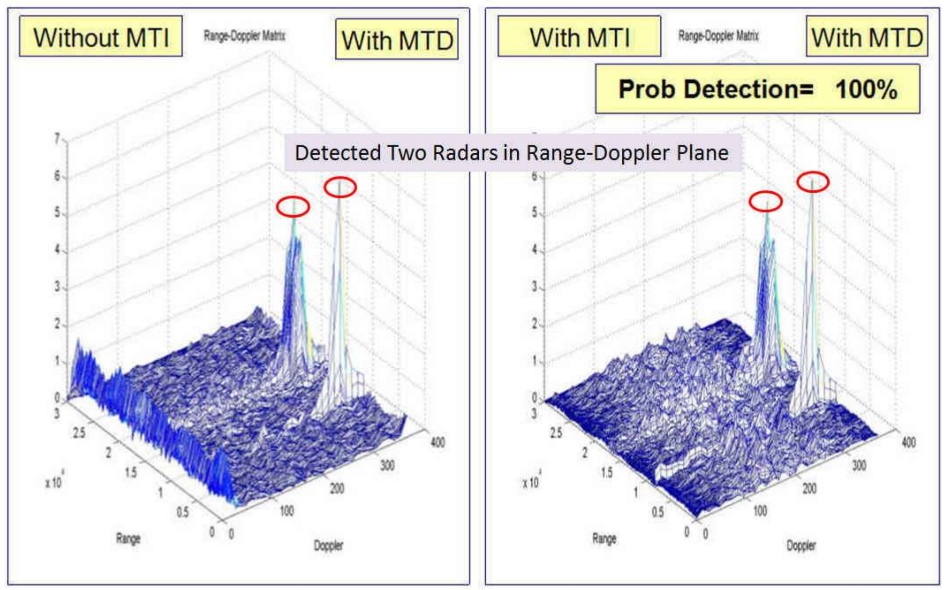

Figure 16. After signal processing, the multi-dimensional signal is plotted in the form of Range/Doppler bins, to visualize the estimates of target speed & distance by the radar receiver. It is also easy to understand the error margins encountered under specific environmental and jamming conditions.

Range w/o SP= 16650 M velocity w/o SP= -58.5938 M/sec	Range = 16600 M Velocity = -60 M/Sec	Range with SP= 16650 M velocity with SP= -58.5938 M/sec

Figure 17. Multi-dimensional signal measured parameters, estimated versus original.

Summary

This application note discussed some of the challenges encountered when testing Radar/EW systems. One of them is how to generate and analyze the MD signals, which include information about monitored Tx stations, such as location, velocity, time, and frequency. Radar/EW environments also include interference, jamming/deception and this must be taken into consideration when performing measurements under real-world scenarios.

A solution to address these issues using SystemVue has been proposed, and simulation and test platforms have been built. Using these platforms, engineers gain access to a myriad of benefits. They provide a true design-oriented value proposition to shorten the development cycle and allow users to save time and money by minimizing field tests. Moreover, SystemVue's multiple environment scenarios enable engineers to create real-world test environments that enable them to design high-quality products. Such capabilities and benefits are critical to ensuring successful development of modern Radar and EW systems. Simulation and test results show custom problems can be solved using the proposed method.

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