

Advanced Design System Connected Solutions for Radar and EW Systems

The process for developing advanced Radar and EW systems often begins with component design and system simulation using software tools, which is followed by prototyping the design and evaluation using test instrumentation. In the past, there has been minimal connection between the software simulations and hardware prototype evaluation because the tools required to bridge the gap between simulation and physical test did not exist. It is now possible to integrate Agilent test instrumentation, such as signal generators and analyzers, directly into the Agilent Advanced Design System (ADS) simulation environment, which results in innovative design and verification capabilities as virtual and real world signals are shared between the two domains. As an example, this paper will show the benefits of combining a simulated ADS radar model with physical test equipment to create what is referred to as a “connected solution”.

Connected solutions can provide several benefits. A connected solution lets designers quickly perform simulations to evaluate component and system performance and then turn the simulated signals into real RF signals for hardware testing. Conversely, designers can take the measured output from a system or Device Under Test (DUT) and bring that signal into ADS for additional analysis. With connected solutions, a hardware component, finished before the rest of the system, can be evaluated in the context of the entire system. Figure 1 shows a simplified block diagram of one possible configuration for using the ADS software tool connected to an Agilent ESG vector signal generator and Agilent PSA spectrum analyzer. There are a variety of Agilent signal generators and analyzers that will work in a connected solution. In this figure, the ADS source model

drives the simulator’s transmitter, channel and receiver, and it is also used as the input to the Arbitrary Waveform Generator (AWG) in the ESG signal generator. The signal generator becomes the real world equivalent of the source used in the simulation. This “live” signal can then be transmitted or applied to the system hardware under test. Using an Agilent PSA, the measured waveform can be downloaded into ADS and processed using the detection algorithms inside the software, which facilitates comparisons between simulated and physical system performance. The connected solution is an excellent tool for designing, simulating and experimenting with a variety of radar and EW configurations including environments with co-channel and adjacent interference, multipath fading and denial of service scenarios.

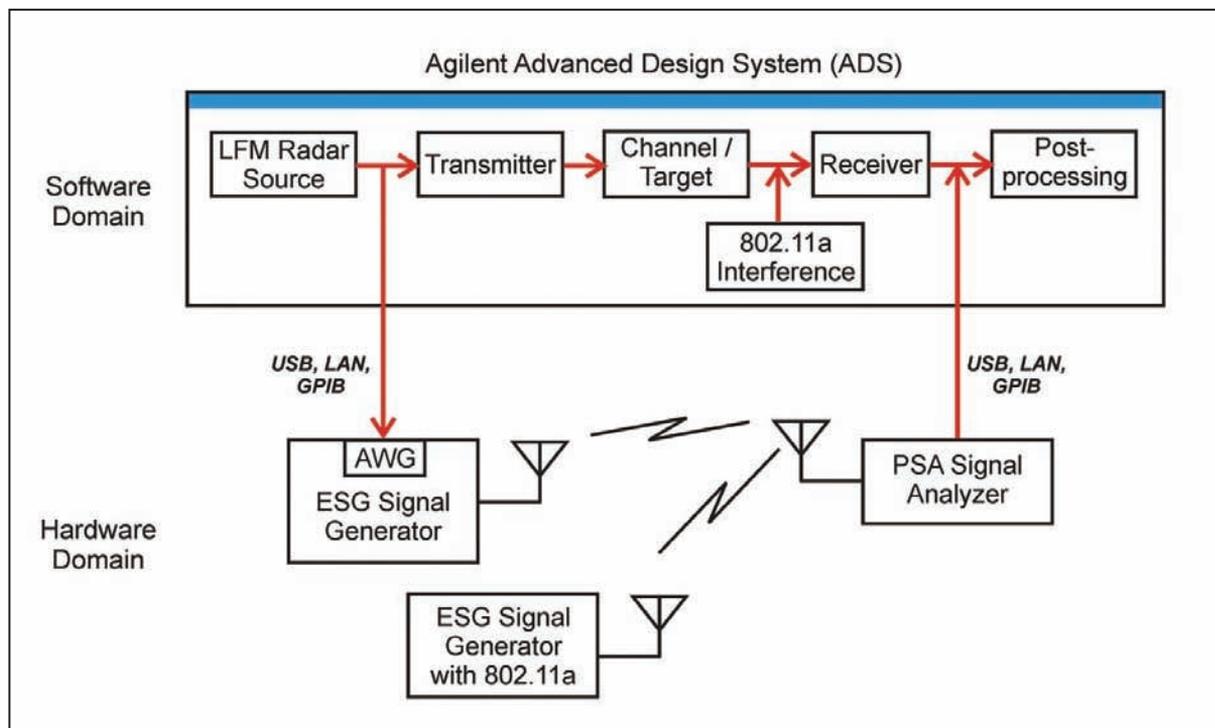


Figure 1 Simplified block diagram of an Agilent connected solution

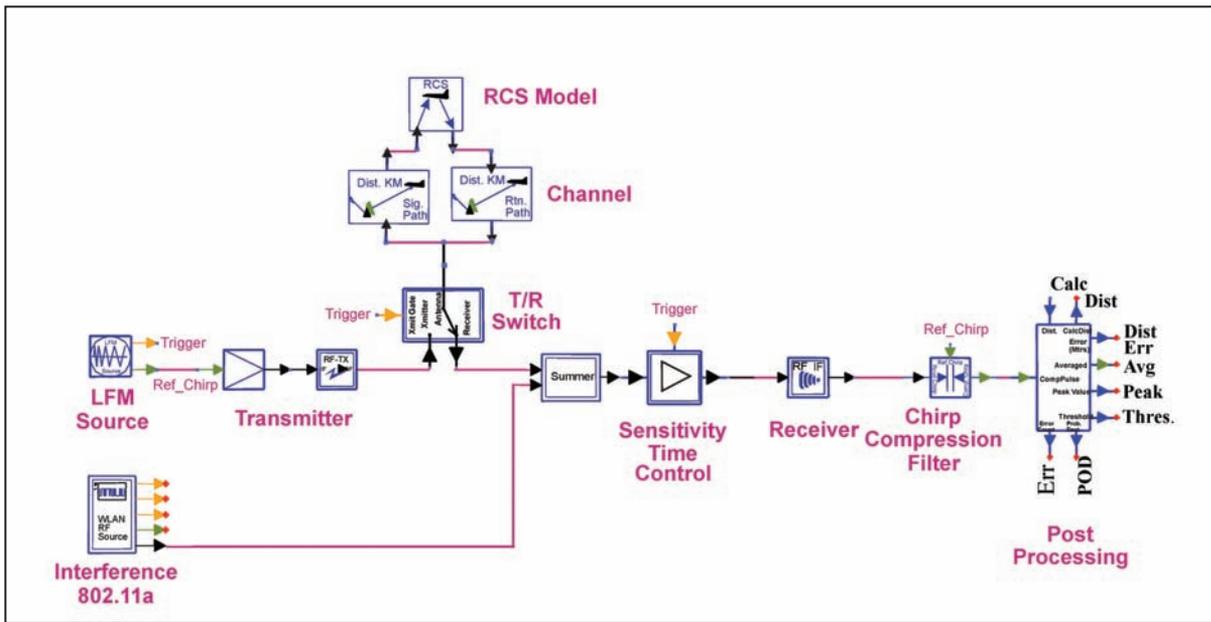


Figure 2 ADS radar system model including 802.11a interference

Radar System Model

The ADS software tool provides a method for creating a hierarchical model of the radar system using predefined and customizable blocks. Each block may represent a unique component, such as the Linear Frequency Modulated (LFM) signal source, or a complete subsystem such as an RF upconverter. The software model can be configured to include all the impairments of a physically implemented system such as phase noise and amplifier compression. Many commercially available simulation tools perform system analysis using a baseband equivalent model for the modulated RF signal in order to increase simulation speed. Most of these baseband equivalent simulations do not include circuit impairment effects, such as non-linearities, which result in reduced model accuracy. For the highest level of accuracy and simulation speed, the software simulation tool should use a combination of frequency and time domain simulations, simulated at RF frequencies, such as the harmonic balance and circuit envelope simulators found in Agilent's ADS software.

Figure 2 shows the ADS model for a complete C-band radar system with a single target and a single interferer. This model will be used to study the system performance when an interfering 802.11a WLAN signal is introduced into the wireless channel. The radar transmitter includes an LFM source that is upconverted, amplified and transmitted into the channel. The channel model includes antenna gain, path loss, delay and multipath. The target is modeled having a specific Radar Cross Section (RCS) and velocity. The radar receiver includes a transmit/receive switch, variable gain amplifier and downconverter. Signal detection is performed at baseband using chirp compression. Post detection processing will be implemented to determine the target range, velocity, detection threshold, Probability of Detection (POD) and Probability of False Alarm (PFA). All of the blocks and subsystems are available as part of the ADS simulation tool.

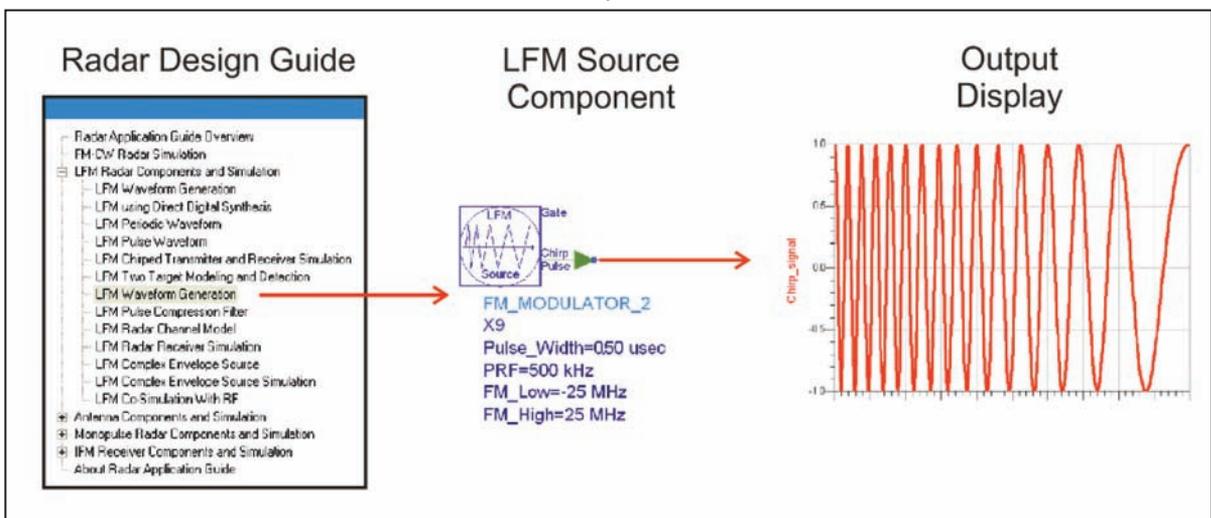


Figure 3 LFM source model and output waveform

LFM Signal Generation

Agilent ADS has a variety of useful built-in signal sources for simulating radar and EW systems including a model for a LFM signal using Pulse Compression. Pulse Compression enables a radar to achieve the high range resolution of a short pulse without the need for a high peak transmit power through the use of a modulated long pulse. The LFM model generates a complex pulse with configurable parameters such as pulse width, repetition frequency, chirp frequency range, and rise and fall times. The ADS component for the LFM source is shown in figure 3. This source is configured with a pulse duration of 0.5 μs , a PRF of 500 kHz and an instantaneous frequency change of ± 25 MHz from the nominal carrier frequency. The simulated output from the LFM generator is also shown in this figure.

The LFM source is part of the Radar Applications DesignGuide within ADS. DesignGuides are collections of preconfigured simulation models that can be modified as needed [1]. Figure 3 shows a list of available LFM radar models including the LFM waveform generator used in this simulation. ADS also provides numerous other DesignGuides including a WLAN source that will be used later in this paper as a source of interference to the radar system model. Another important feature of ADS is that signal sources are not limited to those in the DesignGuide but can be created using other ADS components, using measured data from a signal analyzer, imported data from Matlab[®] or driven from a file possibly created by a DSP or systems engineer.

Receiver and Post Detection

Once the LFM signal is generated and transmitted toward the target, the receiver must measure and detect the presence of reflected energy from that target. The target's reflectivity is determined by its RCS and modeled using an ADS schematic component as shown in figure 2. The target return enters the receiver through a T/R switch followed by a variable gain block called the sensitivity time control. The T/R switch is used to isolate the high power transmitter from the receiver front-end. The sensitivity time control provides additional isolation when the transmitter is active and provides gain when the transmitter is off. The receive gain increases with a log function of the time, thus for a given target RCS, the signal level at the receiver front-end will remain fairly constant as distance to the target increases.

The received IF waveforms as a function of time at two different target distances are shown in figure 4. The received signal at a target distance of 1.0 km from the radar system is shown on the top. In this plot, the chirped pulse is received after the two-way trip through the channel. In this case, the pulse is received 6.7 μs after the pulse is transmitted. The transmitted pulse is not observed on this plot due to the high isolation between the transmitter and receiver provided by the T/R switch and sensitivity control. The lower plot shows the received signal at a target distance of 7.0 km. In this case, the two-way trip takes 46.7 μs . Note that both simulations show an increase in the noise level over time as the sensitivity control increases the receive gain as the log of the time.

After down-conversion, the IF signal passes through the chirp compression filter that performs a convolution with a reference chirp. A peak in the filter's output corresponds to the target distance measured in time. Any noise that passes through the compression filter is greatly reduced as it is uncorrelated to the reference chirp. After chirp compression, the correlated signal is further processed using a post-detection processing block as shown in figure 2 above. This block performs several calculations including the POD and missed detection count. Additional measurements such as Constant False Alarm Rate (CFAR) can also be added to the model as required. In an actual radar system the post-detection algorithms will be presented with a variety of signal impairments including interference, phase noise, compression and other real-world non-linear effects. For the simulations using the waveforms in figure 4, the probability of detection was calculated at 100% at target distance of 1.0 km with a 1.0 Meter Radar Cross Section (RCS) and around 85% at 7.0 km with a 0.2 Meter RCS. In the next section of this paper, degradation in system performance will be observed with the introduction of a WLAN interfering signal.

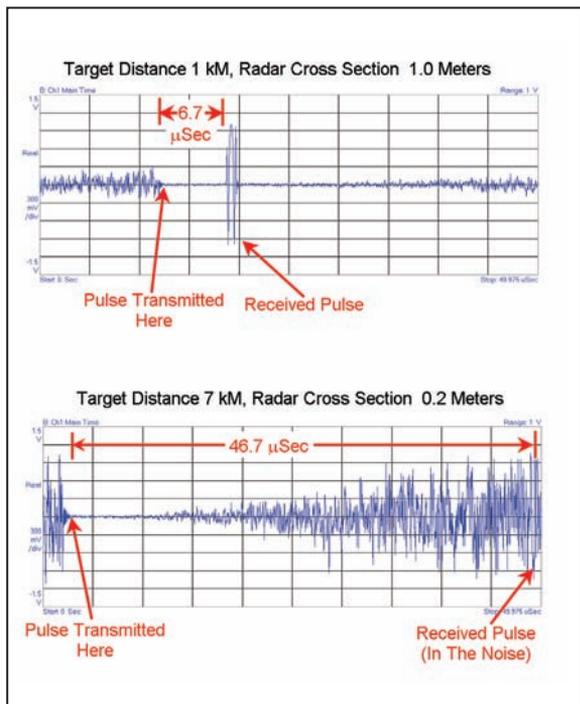


Figure 4 Received IF waveforms for target range of 1.0 km and 7.0 km

Radar Interference

In this section, the performance of a radar system's ability to detect weak target returns in the presence of a commercial WLAN radio will be observed. In practice, the radar and WLAN signals could potentially occupy the same frequency bands at the same time, resulting in interference and degraded performance for both systems. For this example, an IEEE 802.11a WLAN will be operating within the frequency range of the C-band radar system [2]. The radar chirp

is configured with a pulse width of 0.5 μ s and a PRF of 25 kHz. The WLAN packet length, as specified by the IEEE 802.11a standard, can be hundreds of microseconds depending on the packet type and modulation. Under these conditions there will be times when the radar signal and WLAN signal will collide. When these “hits” occur, the radar’s signal detection capability is greatly reduced. Figure 5 shows the Probability of Detection (POD) for the radar system as a function of WLAN power. For a specified POD of 90% or greater, the received WLAN signal must be below -87 dBm. For this example, the WLAN center frequency is the same as the nominal carrier frequency of the chirp. It is also possible to simulate the results when the WLAN center frequency is offset from the radar’s center frequency. Figure 5 also shows the POD when the WLAN center frequency is adjusted over the range of +/- 12 MHz. For this case, the WLAN output power is set to -82 dBm. When the two signals are lined up in frequency, which represents a worst-case condition, the POD is at 50%. As the WLAN center frequency moves away from the radar’s nominal frequency, the POD rapidly improves to 100% at a 12 MHz offset.

“Connected” Signal Generation

Connecting the ADS software to an Agilent signal generator as a connected solution turns a simulated signal into a real world RF signal. As previously mentioned, ADS signals can be shared as complex inputs to a vector signal generator containing a two-channel AWG such as that found in the Agilent E4438C, E8267D and N5182A [3]. In this case, ADS connects to the signal generator via the USB, LAN or GPIB to download complex

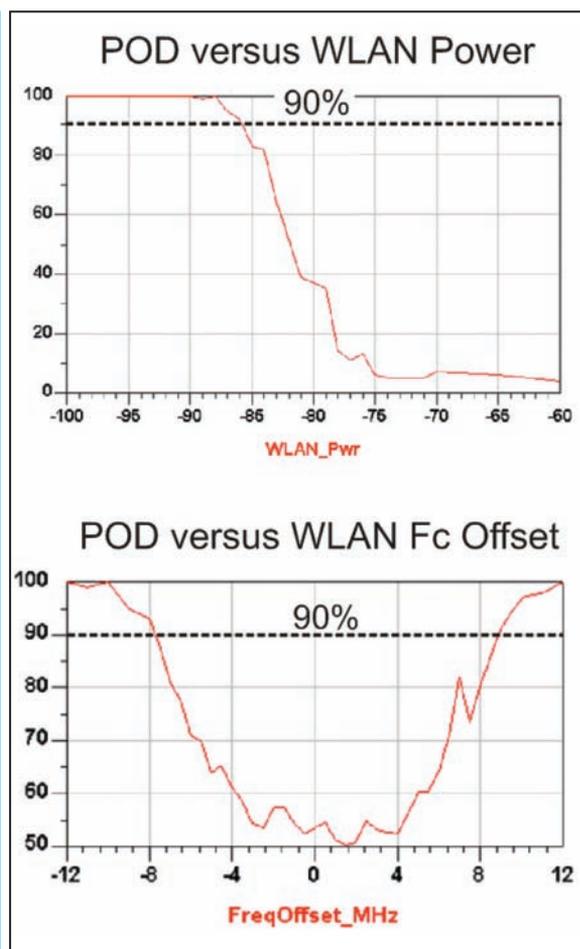


Figure 5 Probability of detection curves with WLAN interference

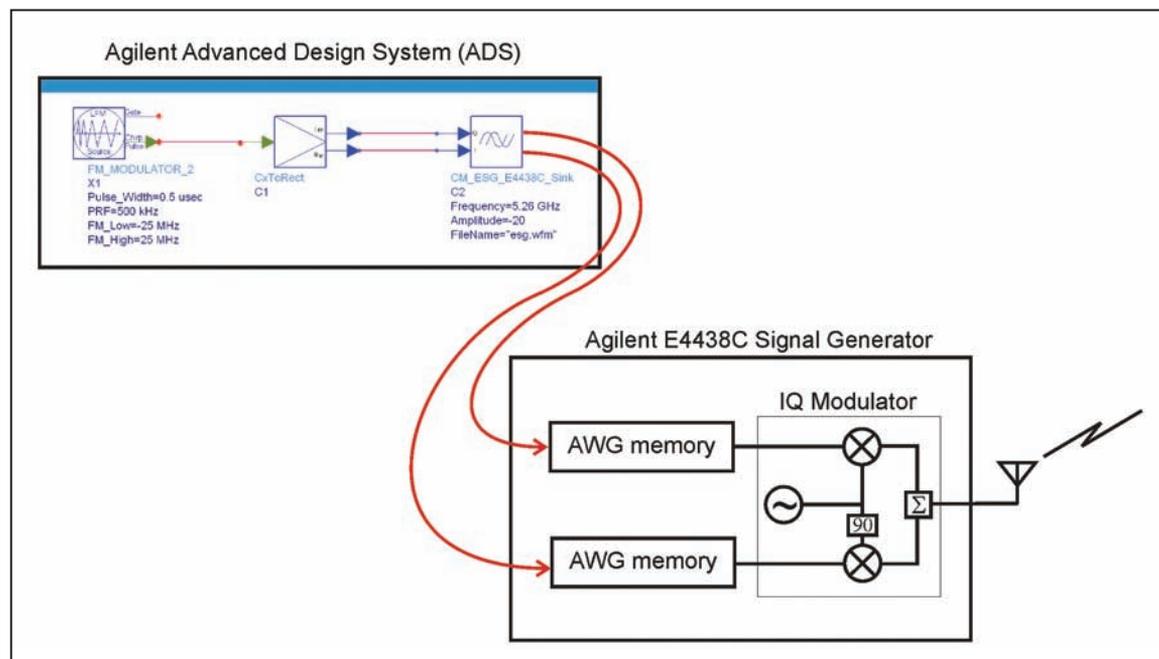


Figure 6 ADS to Agilent E4438C ESG signal generator connected solution

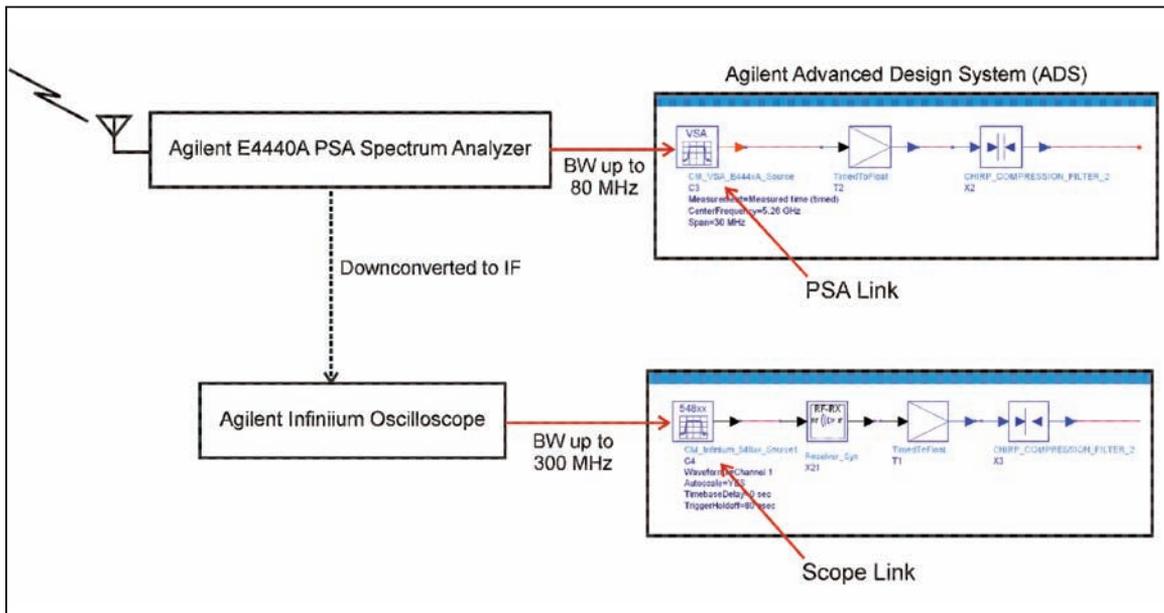


Figure 7 ADS to Agilent E4440A PSA spectrum analyzer connected solution

(IQ) samples of the chirp waveform into the AWG memory for playback through the signal generator. Figure 6 shows the ADS source connected to an instrument control for the Agilent E4438C signal generator. The complex LFM source is converted to I and Q data paths that are downloaded in the AWG memory in the signal generator. The signal generator uses the AWG for input to the internal IQ modulator. The modulated signal can then be applied to a DUT or transmitted into the surrounding environment with an antenna attached to the generator as shown in figure 1. Using ADS to directly control the test instrumentation greatly facilitates the process of loading waveforms into the signal generator's AWG memory. Agilent's vector signal generator family can provide predefined and custom waveform generation with carrier frequencies up to 44 GHz and modulation bandwidths of 1 GHz. The same process can be used for generating the WLAN interference, or, as will be shown in a later section, using the built-in 802.11a signal generation capability available in the Agilent E4438C signal generator.

"Connected" Signal Analysis

Once the radar pulse is applied to the DUT or transmitted over-the-air, a correlation analysis of the received chirp signal may be performed once the RF signal is captured using a signal analyzer. The connected solution shown in the upper portion of figure 7 uses an Agilent E4440A PSA series spectrum analyzer to capture the radar signal. ADS supports an instrument link to the PSA that allows direct download of the measured signal into the software. The waveform can be downloaded as frequency or time domain samples. The sampled waveform can then be processed by ADS using the same chirp compression filter. The PSA series analyzer provides signal analysis with an RF carrier frequency up to 50 GHz and bandwidths up to 80 MHz. The Agilent 89600 series VSA may also be used to capture the radar signal with RF carriers up to 6 GHz and bandwidths to 36 MHz. If wider bandwidths are

required, the PSA series spectrum analyzer can be connected to an Agilent oscilloscope to achieve measurement bandwidths of 300 MHz. In this configuration, as shown in figure 7, the PSA operates as a downconverter and an Agilent Infiniium oscilloscope captures the IF waveform for download into ADS. This signal is further downconverted to baseband using ADS and then correlated with the reference chirp for post processing. As in the case for signal generation, this ADS connected solution accelerates data capture and analysis of complex waveforms between the real and virtual domains.

"Connected" Radar System with Interference

As a measurement example for a complete over-the-air radar system with interference, an Agilent ESG signal generator is connected to ADS for generation of the LFM signal. A second ESG is configured as an 802.11a interfering signal. The WLAN interference could also be created using a commercially available WLAN card, but using a signal generator with built-in WLAN personality provides greater control over the interferer's output power and center frequency. The Agilent PSA series analyzer captures the chirp and interfering signals for processing in the ADS environment. Figure 8 shows the measured signal containing both the radar chirp and the WLAN signal. In this figure, the peak amplitude for both waveforms is approximately the same but the WLAN signal overlaps several of the periodic radar pulses. During this overlap, the radar detection capability may be reduced. The equipment and software configuration for this example was previously shown in the simplified block diagram in figure 1.

Once the signal is captured using the Agilent PSA, the waveforms are connected to the ADS software for additional processing. Figure 9 shows the correlated output from the ADS chirp compression filter for measurements with and without the 802.11a interference. For the measurement without interference

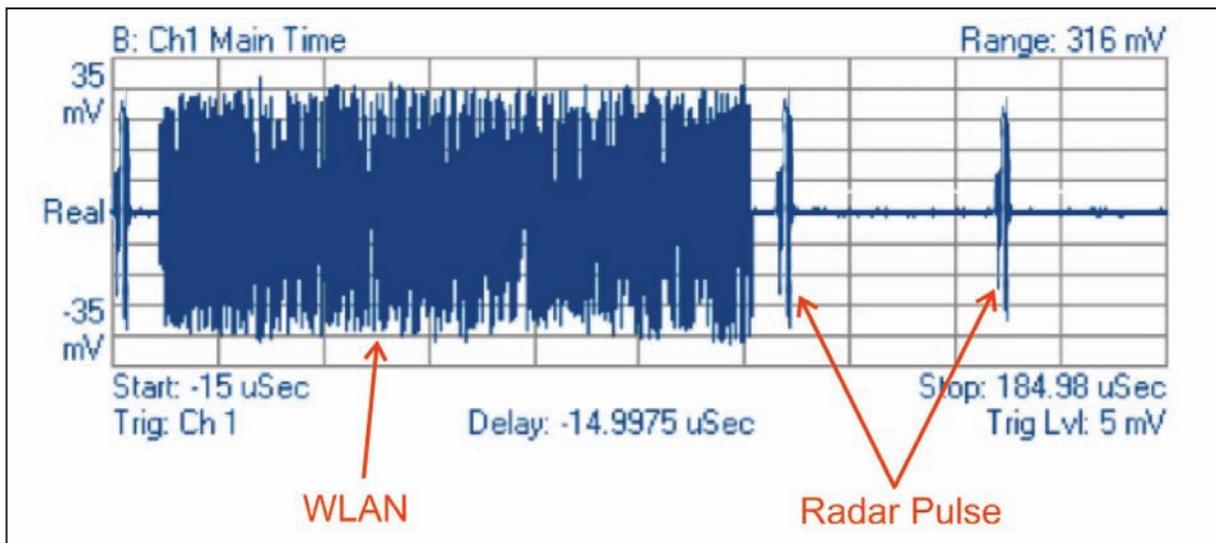


Figure 8 Measured IF waveform including chirp and WLAN signals

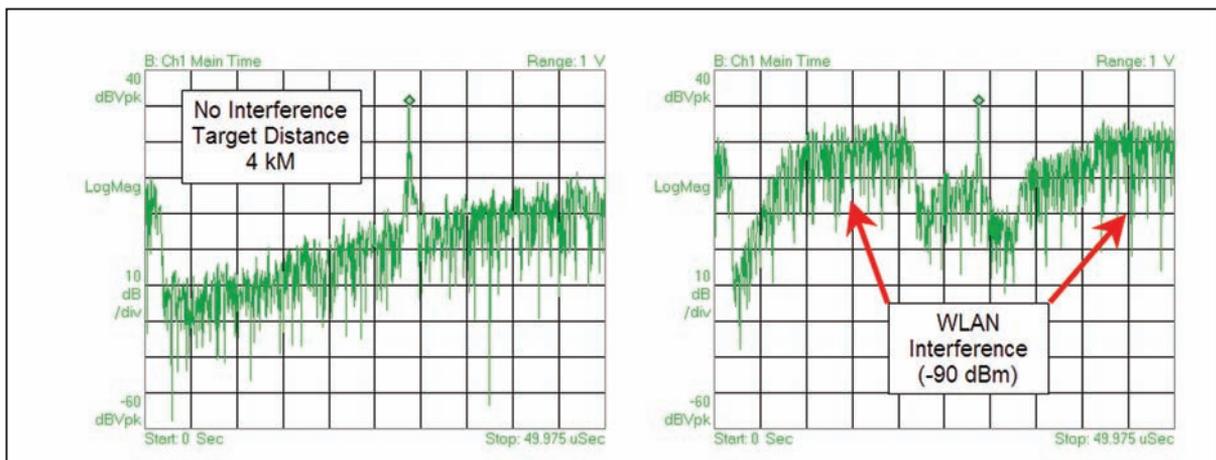


Figure 9 ADS chirp compression filter output using measured data with and without WLAN interference

(shown on the left in figure 9), the correlation peak is approximately 20 dB above the filter's output noise. For the measurement with interference (on the right), the correlated peak output is only 6 dB higher than the maximum peak of the interference. Under this test condition, the radar sensitivity and range is greatly reduced with the introduction of 802.11a interference.

Conclusion

Agilent's connected solutions provide an excellent technique to bridge the gap between software modeling and hardware test. Connected solutions allow signals, algorithms, and data to be shared between the two domains thus enabling new design and verification capabilities. Additional information concerning connected solutions can be found at the Agilent website [4]. For further assistance, Agilent field representatives are trained to assist in selecting the right connected solution for those demanding aerospace and defense applications.

References:

- [1] http://eesof.tm.agilent.com/products/e5600a_radar_app_guide.html
- [2] "Co-interference between military radars and 802.11a WLAN networks", Leiss, David, AUTOTESTCON 2003. IEEE Systems Readiness Technology Conference. Proceedings, 22-25 Sept. 2003 Page(s):290 - 293.
- [3] Agilent Application Note, Number 1394, "Connected Simulation and Test Solutions Using the Advanced Design System", Literature number 5988-6044EN, August 2002.
- [4] http://eesof.tm.agilent.com/products/connected_solutions_main.html

Product specifications and descriptions in this document subject to change without notice.

© Agilent Technologies, Inc. 2008
Printed in USA, January 24, 2008
5989-7743EN

Useful Resources from Agilent

To order your free copies of Agilent's new Radar Poster and Application Note please visit:

www.agilent.com/find/radarprogram

For more information on Agilent's Aerospace/Defense design and test solutions please visit:

www.agilent.com/find/ad