Designing, Verifying and Testing Stepped Frequency Radar Systems for Commercial and A/D Applications

Stepped Frequency Radar (SFR) is well known for non-destructive testing and ground searching applications. With SFR, the echoes of stepped frequency pulses are synthesized in the frequency domain to obtain shorter pulses in the time domain. Using frequency hopping, both high resolution and a high signal-to-clutter ratio can be achieved. As a high range resolution radar technique, SFR offers a number of key advantages over other techniques like regular pulse radar. Such advantages include target classification, resolution of multiple targets, accurate range profile, detection of low radar cross section (RCS) targets in clutter, and low cost. Because of these advantages, SFR is today widely used in both the commercial and aerospace/defense (A/D) industries.

This application note introduces a simulation platform—Agilent's SystemVue electronic system level (ESL) design software—which easily links to measurement tools to enable the design, validation and test of SFR systems under different environments. The simulation platform with test environment includes return signal RCS and background clutter. A template SFR design is also provided. SFR design is performed in SystemVue. Then, simulation results are evaluated with Tx and Rx measurements. Users can customize the template SFR design to their own systems and run simulations in the platform to evaluate the design's performance. The simulation platform also can be used as a test platform for SFR component test. As an example, an SFR system with target returns and ground clutter will be presented that uses the platform for both simulation and test. The proposed platform works very well for design, as well as for verification and testing of SFR systems.

RADAR_StepFreq

Anticipate ___*Accelerate* ___*Achieve*

Agilent Technologies

Problem

As shown in Figure 1, SFR transmits sequences of N pulses at a fixed pulse-repetition frequency, but not at a fixed radar frequency. Each pulse in the sequence of a stepped frequency waveform has the same pulse width and time duration, but different carrier frequency. That frequency is given by $f_i = f_o + N*dF$, where dF is the amount of frequency increased, indicating that frequency hopping and time division are used.
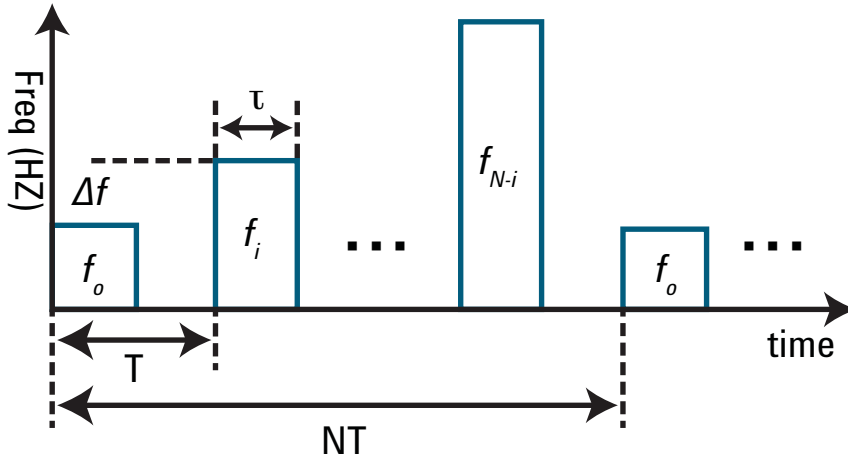

Figure 1. Shown here is a typical SFR waveform.

Using this approach, SFR systems are able to overcome the power and bandwidth limitations of simple pulsed radar. Transmitting longer pulses extends their range capability, while also retaining the wide bandwidth needed for high resolution. In any radar receiver, the received echo signals include both target returns and background clutter. In SFR radar, this clutter interferes with target detection, making it difficult to find the actual number of targets or even fail to detect small targets. In this case, it is hard to find a closed-form analytical solution, and as a result, simulation becomes very important.

Solution

Successfully designing, verifying and testing today's SFR systems under different real-world environments requires a simulation platform with links to a test environment that includes return RCS and background clutter. One such solution is the SystemVue ESL design software. As a comprehensive, model-based design environment for challenging physical layer (PHY) communications systems, it integrates modeling, simulation, reference intellectual property (IP), hardware generation, and measurement links into a single, versatile development platform across RF and baseband domains that transitions easily from algorithms into hardware verification.

SystemVue's platform-based design approach produces increased, early confidence that SFR system designs will not only work in the real world, but also achieve superior results, given available processing power, analog performance and environmental conditions. Connecting measurement equipment to SystemVue via its measurement links expands the concept to validation and test of SFR systems as well.

Using SystemVue, a working reference design of the SFR system is created and used to generate test vectors. The reference design also processes received signals captured from live measurements. A signal generator and arbitrary waveform generator (AWG) then render simulated signals for testing SFR hardware receivers and transmitters. A signal analyzer and signal analysis software (e.g., Agilent's 89600 Vector Signal Analysis (VSA) software), capture and analyze the signals. For further analysis and signal processing, measured signals can be brought back into SystemVue.

Example: Simulating a SFR System

As an example of how the SystemVue simulation platform can be used to design, verify and test SFR systems, consider the SFR system designed in Figures 2 and 3. In the signal generator, a SFR source is followed by an RF modulator, then two target models and a clutter model are set. The output of the signal generator simulates the SFR received signal, including target return and clutter.

Figure 2. A stepped frequency radar simulation design is shown here.

Figure 3. Illustrated here is the step frequency signal generation model.

The received signal is measured at the input of the SFR receiver and displayed in Figure 4. Note that the plot of frequency versus time in Figure 4C is in keeping with what one would expect for the SFR signals based on the carrier frequency calculation previously described. The unwrapped phase is also to be expected. Additionally, simulation shows that the SFR receiver works fine.
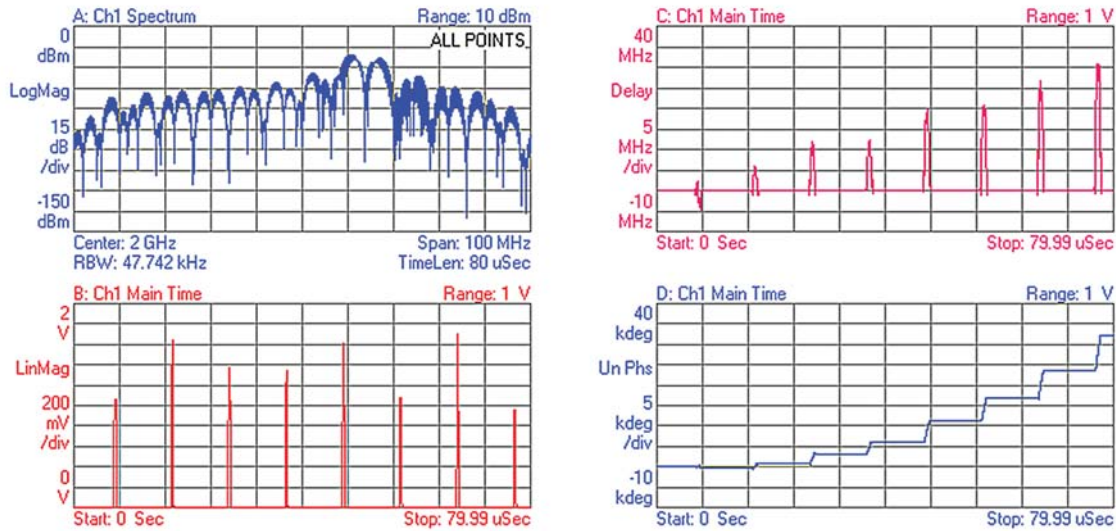
Figure 4. Shown here is the spectrum (A), magnitude of the waveform that reflects the random characters of the target return, as well as the clutter property (B), frequency hopping in the received signal (C), and the unwrapped phase (D) of a received SF radar signal measured at the receiver input.

The SFR waveforms resulting from the design in Figure 2 are shown in Figure 5. Note that in the red waveform (the transmission signal), the frequency content for each pulse is different. This is because the frequency content increases with the timing. The blue-colored waveform, the received RF signal, has a delay compared to the transmitted signal and is being affected by clutter and noise. The green-colored waveform is the demodulated signal.
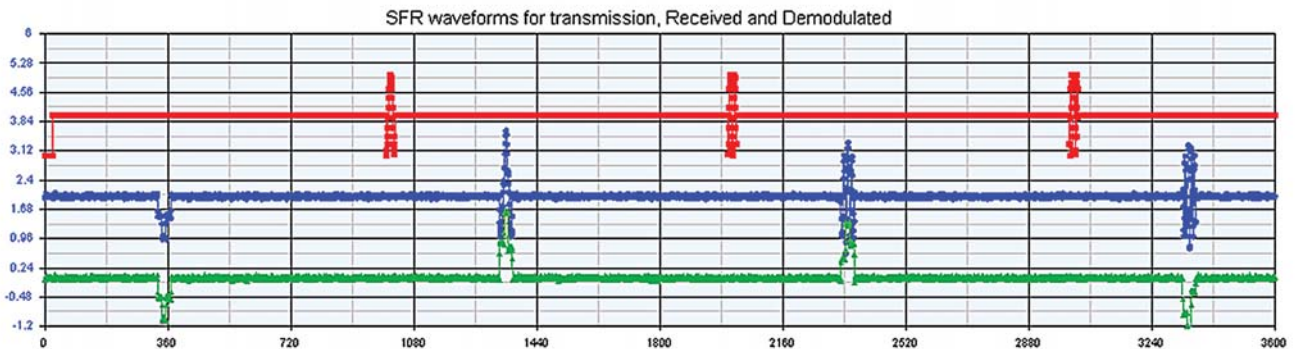
Figure 5. Shown here are transmitted (red), received (blue) and demodulated (green) SFR waveforms.

Using this high-resolution SFR design, two targets close to one another can be easily detected (Figure 6). To detect the same two targets using a pulse radar, the pulse width would have to be increased at least 8 times, significantly increasing system cost.
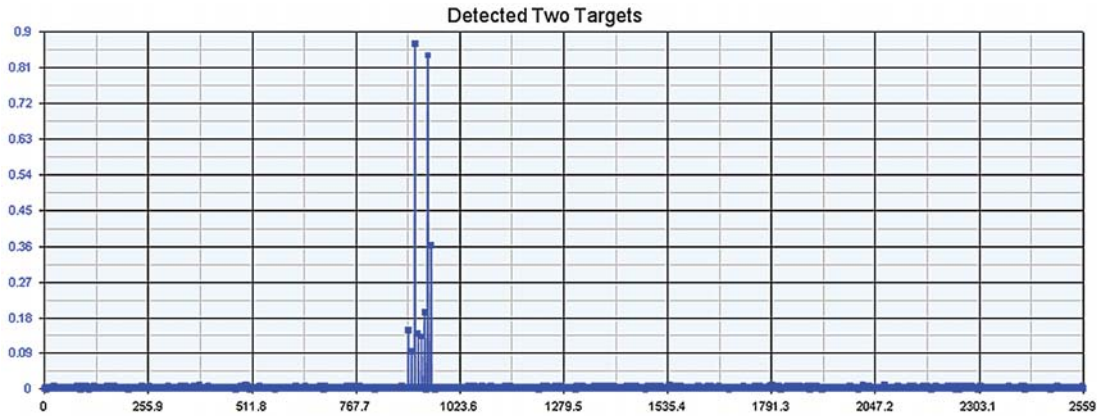

Figure 6. The high-resolution SFR design was used to detect these two targets near one another

Example: Testing a SFR System

Testing the SFR hardware receiver requires a SFR signal generator. The received signal includes target returns with environments such as ground clutter and noise.

Figure 7 shows the creation of a SFR test signal with two targets near each other and clutter using SystemVue. The signal is downloaded into a vector signal generator (e.g., Agilent's ESG/MXG/PSG Arb), via a vector signal generator link model, for upconversion to RF frequencies.
The generated test signal is verified using a signal analyzer.
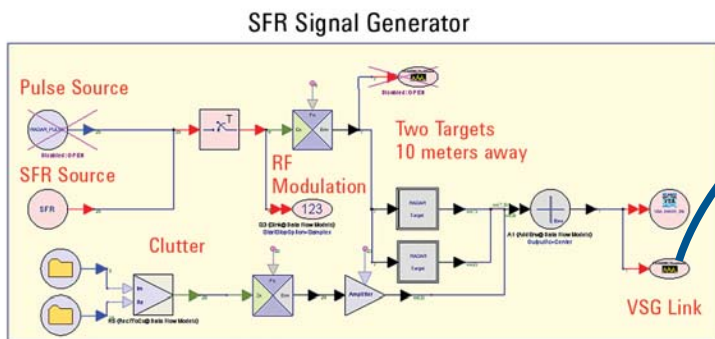
Figure 7. Shown here is a SFR receiver test signal generation for hardware test.

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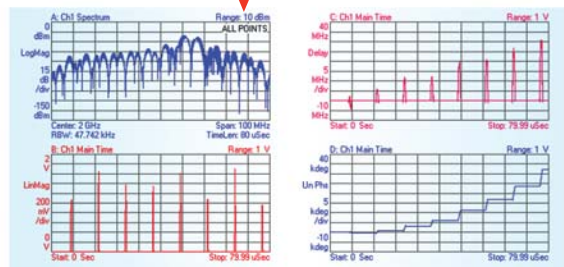
In Figure 8, the received SFR signal is measured at the input of the SFR receiver using a signal analyzer. Plot A shows the spectrum, while Plot B shows the waveform that reflects the random characters of the target returns and clutter property. To observe the frequency hopping in the received signal, look at the plot frequency versus time (Plot C). In plot D, the unwrapped phase is displayed.
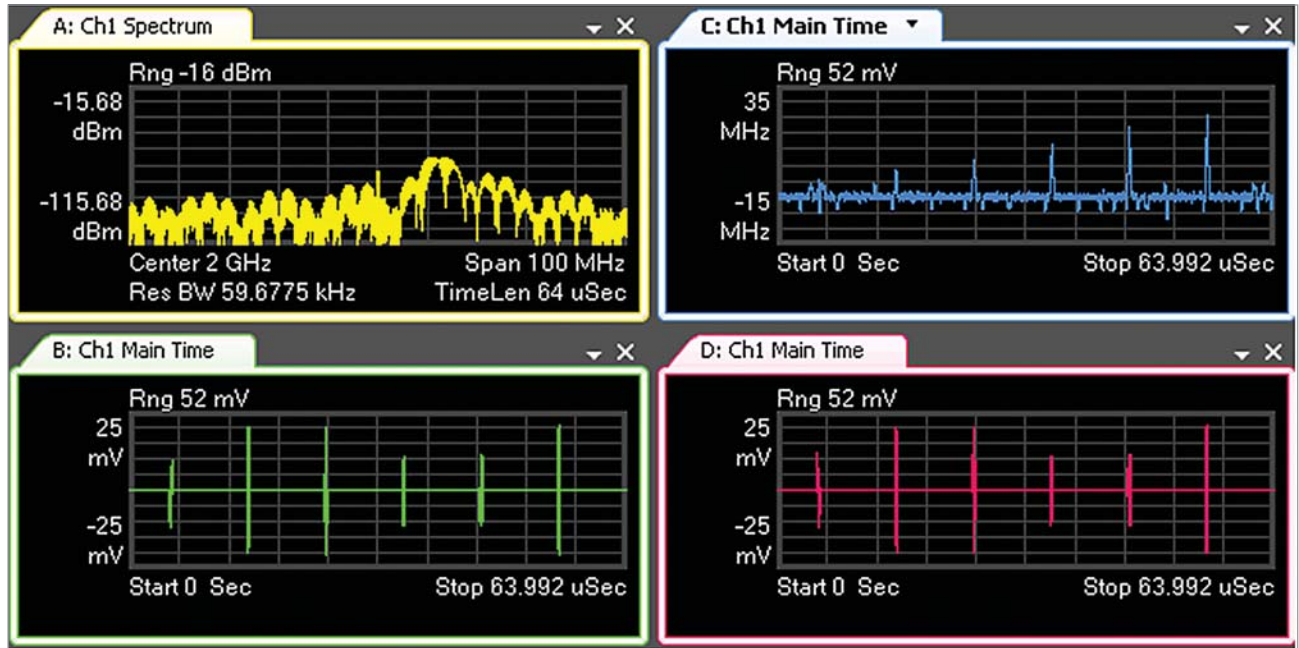

Figure 8. Here, a generated SFR receiver test signal was measured by using Agilent's VSA software.

For SFR transmitter test, a SFR receiver (created in SystemVue) is needed. Using a VSA link, the received waveform from the signal analyzer is acquired and sent into the SystemVue SFR receiver for demodulation, detection and recovery of the original target signals. Figure 9 shows an actual software receiver that was created and can be used to test real received SFR signals.
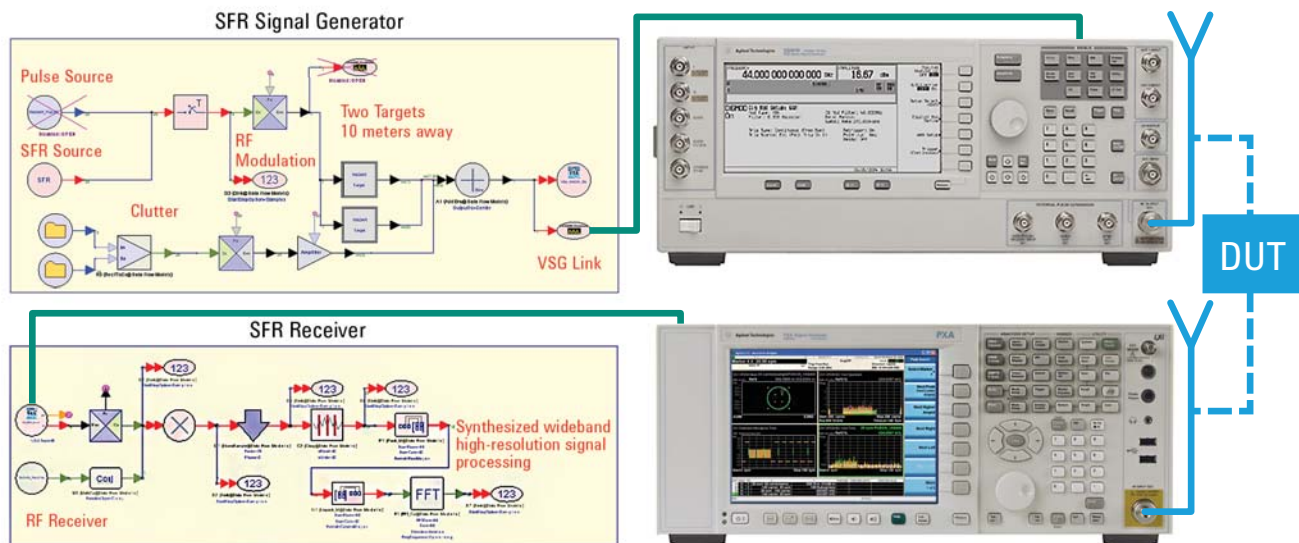

Figure 9. This test setup can be used for hardware test of the SFR transmitter and receiver.

Summary of Results

The low-cost, high range resolution SFR technique offers a number of key advantages for non-destructive testing and ground-searching applications in the commercial and A/D industries. However, quickly and accurately developing SFR systems requires a simulation-based solution.

The simulation platform presented here enables design, as well as verification and test of SFR systems under different real-world environments. SystemVue can provide both the software receiver to test a customer's transmitter and the software transmitter to test receiver components. Moreover, it provides the control and automation that's critical for systems test. This capability, coupled with the platform solution's flexibility and performance is key to allowing today's engineers to develop effective SFR systems with excellent real-world performance.

Related Information

SystemVue Radar application notes

- **http://cp.literature.agilent.com/litweb/pdf/5990-5392EN.pdf**
- **http://cp.literature.agilent.com/litweb/pdf/5990-5393EN.pdf**
- **http://cp.literature.agilent.com/litweb/pdf/5990-6919EN.pdf**
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SystemVue Radar product information

- W1905 Web page: **http://www.agilent.com/find/eesof-systemvue-radar-library**
- W1905 datasheet: **http://cp.literature.agilent.com/litweb/pdf/5990-6347EN.pdf**
- YouTube video: **http://www.youtube.com/watch?v=97Px9ByNyMI**
- Webcast: *"Uncovering the Hidden Impairments in Testing Advanced RADAR Systems"*

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