Application Note 314-4

HEWLETT PACKARD

Radar/EW

Exceptionally-complex signal simulation for multi-signal environments in Radar/EW test

Testing technology for modern radar and EW receivers has been driven by operational scenerios which predict ultra-crowded signal environments. Such environments cause major signal overload and processing complexity for EW receivers, and multi-target discrimination problems in radar receivers. The basic testing problem, then, has been to find ways to combine multiple traditional signal sources with multiple modulation formats to meet those needs. Typical required parameters would be antenna-scan simulation, multiple lobing characteristics, and of course multiple emitters with multiple modulation formats mixed with fancy jittered PRI, staggered pulse trains and more.

Benchtop Simulation

Benchtop simulation technology took a significant step ahead in January 1986 with the introduction of the HP 8770A Arbitrary Waveform Synthesizer (AWS), a digital synthesizer with capability of 125 megasamples per second, 12-bit resolution and 512K byte memory. With a product strategy directly focused on RF simulation, and dc to 50 MHz range, critical design attention targetted very low distortion and intermodulation. This was accomplished with special data sample "de-glitching" and a brickwall filter with electrical characteristics that preserve the high-performance specifications of this RF simulator.

The HP 8770A Arbitrary Waveform Synthesizer has found application in a number of functional tests for modern receiver systems. It can be used to simulate complex baseband signals at the video stages or in the digital signal processors which are so common. Having a dc to 50 MHz output, it can directly stimulate the IF circuitry of many receivers. Or it can be up-converted into the RF bands or used to modulate signal generators for front end tests of the receivers. And to better recognize the actual signal performance of the unit, we recently re-named the combination of the HP 8770A AWS plus the HP 11776A Waveform Generation Software as the HP 8770S Signal Simulator System.

The next block of the testing puzzle fell into place in February 1987 with the introduction of the HP 8780A Vector Signal Generator. This 10 to 3000 MHz synthesized generator features a new step ahead in complex modulation capability. In addition to accepting digital data streams for PSK modulation, it can also control the complete phase plane of the carrier by the scalar inputs of the in-phase and quadrature-phase at remarkable modulation rates from dc to 350 MHz. In fact, the combined modulation bandwidth when using both I and Q inputs is 700 MHz.

Leave it to some innovative user to suggest the marriage of these two significant introductions for an exceptional signal capability. If two HP 8770A AWS synthesizers are first synchronized by connecting their clocks, and one AWS inputs to the I-channel and the other to the Q-channel, complete programmable control of the carrier phase plane is possible. And since each HP 8770A has 50 MHz coverage, the combined modulation bandwidth is 100 MHz. Further, the carrier of the HP 8780A can be programmed from 10 to 3000 MHz. Figure 1 shows the basic layout, with the HP 8770A synthesizers driving the I and Q input for the Vector Generator. The I and Q baseband signals are also available for simulation tests of the video baseband and signal processor portions of the receiver as the connections show.

The Vector Generator can directly simulate the IF signals for input to that portion of the receiver. Or as shown in Figure 1, the complex vector signal can be further up-converted to the receiver's front-end microwave band, using an HP 8671B Synthesized CW Generator as the local oscillator. One of the nice traits of the Vector Signal Generator in that application is that the IF carrier frequency can be chosen to be near 3000 MHz, so that the up-conversion image frequencies will be well-separated (6000 MHz) for easy filtering at the input. That's an

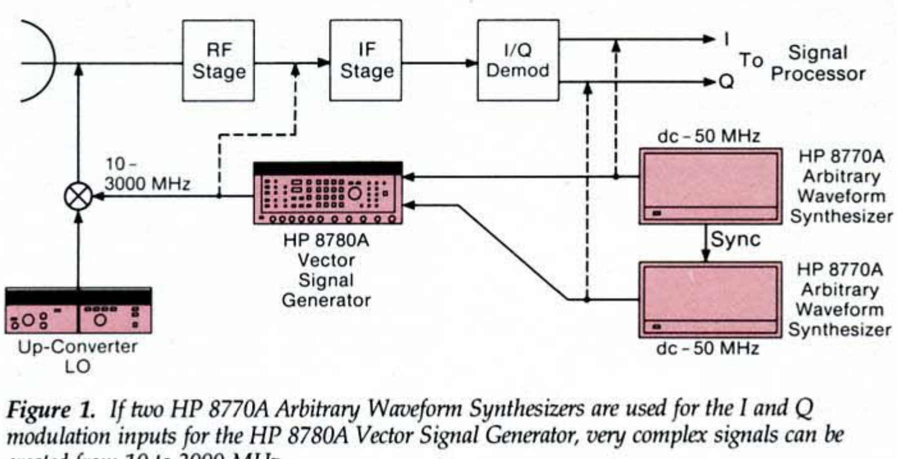


Figure 1. If two HP 8770A Arbitrary Waveform Synthesizers are used for the I and Q modulation inputs for the HP 8780A Vector Signal Generator, very complex signals can be created from 10 to 3000 MHz.

important consideration since these modulated carriers can be quite broadband. Many receivers have their own input pre-selection filtering as well, which rejects the unwanted image.

Once assembled, the system gives powerful and lifelike stress-testing to receivers under test. For example, the two AWS's can simulate the I and Q characteristics of a Gaussian-shaped chirp pulse. Chirp is a pulse compression technique used to spread the spectrum of a radar to permit longer pulse-widths with a given peak power capability (more average power), thus providing a better S/N ratio and better target information. However, the additional complexity in the receiver to re-compress the target return signals means more difficulty to the design and test engineers in simulating those spread-spectrum illumination signals.

Impressive chirp parameters are achieved with the test system setup of Figure 1. With the HP instruments shown, a 100 MHz chirp bandwidth may be achieved with pulse widths in the low microseconds. Recognize that the I/Q driving signals are directly related to the desired chirp pulse. If the I and Q synthesizers are both running at 50 MHz, with a 90-degree quadrature between them, then the modulated carrier from the HP 8780A is 50 MHz offset from the unmodulated carrier (offset up or down, depending arbitrarily on the quadrature phase).

By rapidly sequencing both AWS synthesizers down to zero frequency (while maintaining a 90 quadrature), the carrier returns to its programmed frequency. At the carrier crossover, the quadrature is reversed to place the offset on the opposite side of the carrier, and both AWS frequencies sequenced from zero back up to 50 MHz, thus moving the carrier a total of 100 MHz during the pulse-on time period.

Such a signal would have a flat-top amplitude characteristic. System engineers often wish to use a Gaussian amplitude envelope to reduce sidelobes and required system bandwidth. This is easy to do since both AWS synthesizer signals can be designed for amplitude changes concurrent with the frequency chirp. Figure 2 shows the time-domain waveforms of both the I and Q representations of those I & Q modulating signals from the two AWS on the same digital oscilloscope display. As expected, the zero frequency occurs in the center, and at the edges, where the offset frequency is 50 MHz, the amplitude has been reduced to represent a Gaussian envelope.

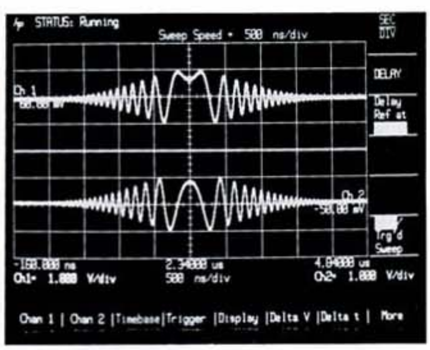


Figure 2. *Time domain waveforms of the I and Q inputs for a 4-microsecond chirp pulse, 100 MHz wide, with Gaussian envelope, showing the 90-degree phase relationship.*

When up-converted to the intermediate frequency, the HP 8780A Generator time-domain waveform appears as shown in Figure 3. It has a Gaussian amplitude envelope, as expected.

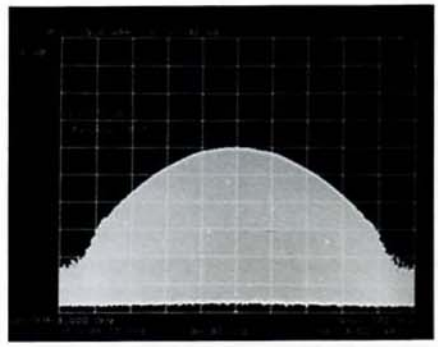


Figure 3. *Spectral distribution of the Vector Generator at 3000 MHz shows span of 120 MHz, which can then be up-converted for microwave testing at the system input.*

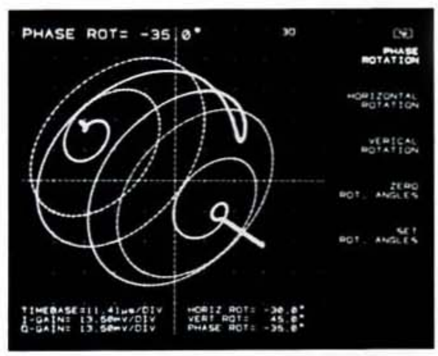


Figure 4. *Three-dimensional view of the chirped pulse shown on an HP 8980A Vector Analyzer.*

With the advent of the recently-introduced HP 8980A Vector Analyzer, an X-Y sampling oscilloscope with dc to 350 MHz matched channels, very powerful diagnostic insights can be gained when analyzing such complex microwave modulation and spectra. For example, the chirp waveform described above can be displayed in three-dimension format. Figure 4 shows a typical chirped pulse with 10 MHz per microsecond characteristics.

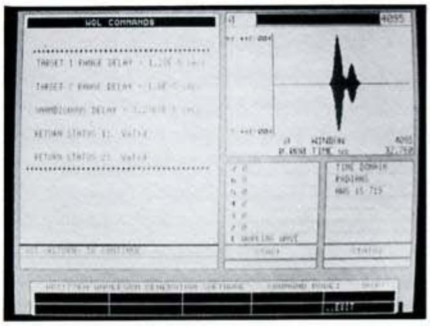
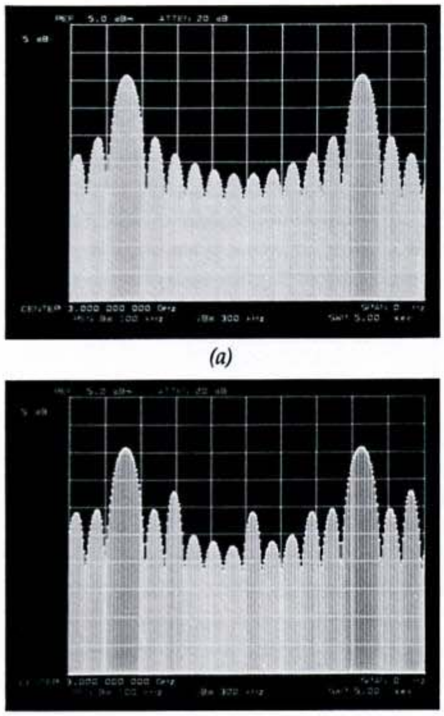


Figure 5. Typical waveform workstation used with HP 11776A Waveform Generation Software showing a multi-target representation.

Multiple targets

Another important receiver stress test is multiple-target discrimination. Just as simulations for single target returns can be programmed for amplitude glint or near/far dynamic ranges to stress the receiver, multiple targets can be defined with software and programmed into the AWS I/Q driver synthesizers. Figure 5 shows the time-domain waveform of two Gaussian pulses which represent multiple targets, each of which may be controlled in amplitude or phase as required. This particular waveform is shown on the waveform creation workscreen of the HP 11776A Waveform Generation Software.

Target returns can be simulated for their ideal spectrum as shown in the above examples. These, of course, represent stationary targets. Then, one would like to add realistic Doppler shifts to simulate target motion. Some of this is slow-moving Doppler offset to represent a tangential target. Some of the Doppler offset must be programmed on a pulse-to-pulse basis if there is intermingling of multiple target Dopplers.



(a)

(b)

Figure 6. Antenna-scan test patterns: (a) 3.5 second scan; (b) same pattern with modified sidelobe levels as needed by system test requirements.

This is a generally-difficult simulation job in real-life because of the complexity of handling the various permutations of multiple target signals in arbitrary phases and with pulse-to-pulse changes. Just how complex a multi-signal simulation can be accomplished with the setup of Figure 1 depends critically on how much HP 8770A synthesizer sequencing memory size is used up with a desired signal scenario.

All new HP 8770A AWS now carry 512K byte waveform memory as a standard feature. The sequencing feature of the HP 8770A substantially increases the amount of time the AWS can run complex pulse sequences before the total memory "runs down" which would require a new download of code to continue the test. By sequencing, the HP 8770A allows "re-use" of stored waveform segments that will be needed repetitively in the final simulations.

The ability to predict the complexity of multiple-signal environments to the exact limits on the available HP 8770A memory and sequencing size is difficult. Certainly a powerful capability exists to produce extraordinarily-difficult spectra with relatively simple software. And this available commercial instrumentation literally sits right on a bench-top. When compared to hard-wiring of multiple-signal sources, modulation sources and RF/microwave signal combiners, the new simulation is more powerful and more flexible.

Scan simulation

Another important simulation function is that involving antenna scan characteristics. As a radar search antenna azimuth-scans across an EW receiver (typically called a radar-warning-receiver RWR), the illuminating radar antenna side and backlobes cut across the receiving antenna and produce a lobe pattern much like the waveform displayed in Figure 6. In the simplest case, the main lobes are obvious and the side and back lobes appear in-between.

Such simple lobe patterns can be done with relatively easy dual modulation of a traditional AM-FM-pulse microwave synthesizer. The amplitude envelope is modulated with low frequency on the AM input, and the microwave pulsing is applied to the pulse input. In the simple case, the AM envelope signal could be developed with a simple D/A converter, and a bench pulse generator used at the pulse input.

But life isn't that simple. All receivers must handle multiple threat scanning antennas. That means that the input sees multiple antenna lobes at various amplitude ratios, and with a variety of phase angles on the microwave pulses, representing a high-speed aircraft tangentially passing through a landscape of threat ground antennas, each with its own azimuth scans at perhaps different rates.

An example of the simulation problem would be the situation of two ground radar signals arriving at an airborne receiver with a 30 dB signal difference. As the two pulsed sin x/x spectra phase past each other at the receiver input, signal processing must still maintain processing on the smaller of the signals even though their relative signal strengths differ by a factor of 1000. This means that the simulation signal generator involved must not distort either spectra in the presence of such wide dynamic ranges.

The HP 8770A synthesizer is able to provide just that sort of low-distortion output of multiple signals. Its 12-bit amplitude resolution can resolve 1 part in 4096, a full 72 dB of dynamic range. That means that the simulator can handle a tiny sin x/x signal with its own phase and amplitude characteristics phasing through a much larger signal with its own phase and amplitude, without distortion or degradation in the source itself.

In addition to the threat antenna(s) characteristics, the receiver antenna(s) also modify the threat signals with their own antenna pattern(s). Thus the simulation signal may need to have mathematically-adjusted amplitude or phase corrections placed on the microwave test signal before input to the receiver-under-test. The AWS can do this easily.

Summary

Since so many modern receivers now use exceptionally-sophisticated digital signal processing circuits, the stress-testing of all those magical pattern-recognition algorithms is literally the name-of-the-game in high-performance systems. So the Vector-AWS combination described gives just the sort of measurement leverage to step up the system designers ability to assure performance needed in this industry.

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