3 Tactics for Configuring Phase-Coherent RF Signal Generation How to Overcome Multi-Antenna System Test Challenges

WHITE PAPER

Overview

As the number of higher throughput applications grows sharply, there is a need for wider bandwidth and network coverage in wireless systems. However, given limited spectrum allocation, you must look for ways to improve spectral efficiency and signal-to-noise ratio (SNR). Multi-antenna techniques, such as Multi-input Multi-output (MIMO) and beamforming, can help you achieve diversity, multiplexing, and antenna gain in order to improve spectral efficiency and signal-to-noise ratio (SNR).

This white paper will help you understand phase coherence and why it matters, and offer tactics for generating phase-coherent signals.

	KEYSIGHT VXQ Signal Generator Instein 1880-4400-2180-4400-	VXG
Contraction of the		
Displayfort	E C Outputs Prove Prove Prove Prove	o ? =
	Configuration 1 28.00Hz 10.048m 2 28.00Hz 15.048m	ar our (AB)
	Independent V ALCON ALCON	
	VQIn Modulation RF Out	
lance f	Signal 1 On Adjustments On Output Modulation On DF Datput On	
~ ~	Mode 52 MR 1/2 On AM Of 12 BPH 12 BPH12 BPH 12 BPH12 BPH12 BPH	
	Vector Modulation	Local tree Sector Deck
	Nodeton RF Out	
	Mode S95MR 10 On AM OT 28 GHz Sync Off Duke Off 13.40m	
		1 2 3 😳 😳 😳
0 0	Vector Modulation	
	RUTS NO AP 1000 MATE 2016 T1021 AM	
and the second s		Contract of the International Contra
100 March 100		

Testing multi-antenna systems requires a test system capable of providing multiple signals and a constant phase relationship between the signals. Employing different tactics for configuring phase-coherent signal generation leads to different measurement results.



What Is Phase Coherence?

Two signals are coherent if they have a constant relative phase at all times, as shown in Figure 1b. When present together, coherent signals will combine constructively or destructively, depending on their relative phase.

In cases where you characterize a multi-channel component such as a phased-array antenna, you need to control the phase angle relationship precisely between the channels (Figure 1c). For digitally modulated signals, phase coherence means both timing synchronization between baseband generators and coherence between RF carriers (see Figure 1d). Similarly, radar pulses require precise timing of the pulse bursts to simulate the appropriate spatial delays (see Figure 1e).





Why Phase Coherence Matters

Multiple antenna techniques for wireless communications can increase diversity, multiplexing, or antenna gains. The major multi-antenna techniques are spatial diversity, spatial multiplexing, and antenna array.

Spatial Diversity

In wireless communications systems, multipath results in radio signals reaching a receiver's antenna with two or more paths. When multipath signals arrive at a receiver, the signals will combine either constructively or destructively depending on their relative phase. Spatial diversity, also known as antenna diversity, offers a solution to multipath interference. By using two or more antennas, you can achieve improvements in the quality and reliability of a wireless link. This can be accomplished with channel switching, signal weighting, time delay, or transmit diversity, as shown in Figure 2.



Figure 2. Spatial diversity techniques for receiver diversity and transmitter diversity

To simulate the multipath signals for spatial diversity tests, you need a signal generator and a channel emulator to simulate the multi-path scenario for receiver diversity tests (Figure 3a), and multiple signal generators and a channel emulator for transmit diversity tests (Figure 3b). To accurately emulate the multipath scenarios, you must synchronize both signal generators' baseband and you must also align the phase of both carriers.



Figure 3. Spatial diversity test setups



Spatial Multiplexing

Spatial multiplexing is a transmission technique in a Multi-Input Multi-Output (MIMO) system. The system splits transmit data into multiple encoded data streams. The system transmits all data streams simultaneously, over the same radio channel, through different antennas. In order to recover the original data at the receiver, MIMO systems use computationally inverse channel property estimation algorithms. Figure 4 represents a 2x2 (two transmitters and two receivers) MIMO diagram where two symbols (b1 and b2) are transmitted simultaneously for double the data throughput. A simple formula appears below.

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$

where r is the received signal, s is the source signal, and h is the wireless channel response.

The receiver can perform channel estimation (the h matrix above) using training sequence algorithms. You can recover the transmit signals (s1 and s2) through signal processing with the formula below:

$\begin{bmatrix} S_1 \end{bmatrix}$	_	1	$[h_{11}]$	$-h_{01}$	$\begin{bmatrix} r_1 \end{bmatrix}$
S ₂	_	$h_{00}h_{11} - h_{01}h_{10}$	$[-h_{10}]$	h_{00}	$[r_2]$



Figure 4. A 2x2 MIMO system diagram

The calculation above uses timing-aligned signals and a common local oscillator (LO) to up-convert and down-convert multi-channel signals. This technique increases test challenges for simulating multi-channel RF signals, as most commercial signal generators have an individual baseband generator and a LO.

Antenna Array – Beamforming

An antenna array is a set of antenna elements used to transmit or receive signals. Coherently-driven antennas with the appropriate phase delay between antenna elements can form signal beams. Phased array antennas use phase shifters in the beamforming network (BFN) to produce a uniform wave front traveling in a specific direction. The uniform wave front allows a group of low directivity antenna elements to behave like a highly directional antenna for either transmit or receive applications. The phase delays between the channels decide the antenna pattern as shown in Figure 5.



Figure 5. A phased array of antennas forms a beam by adjusting the phase between coherent antennas

Figure 6 illustrates the impact of using multiple antenna elements at a specific spacing. As you increase the number of antenna elements (a half wavelength separation), the antenna beamwidth gets narrower (Figure 6a to 6d). By applying a 90-degree phase shift to the signal at each antenna, you can change the direction of the beam as shown in Figure 6e. By changing phase shifts between elements in different amounts, you are able to steer the beam in a range of directions. To simulate such multi-channel signals, you need to precisely control the phase difference between the channels for both transmitter and receiver tests.



Figure 6. Antenna pattern vs. the number of antenna elements

Generate Multiple Phase Coherent Signals

Testing multi-antenna systems such as spatial diversity, spatial multiplexing, and antenna array requires a test system capable of providing multiple signals with stable phase relationships between them. However, a commercial signal generator has an independent synthesizer to upconvert an IF signal to an RF signal. To simulate the multichannel test signals, the phase between test signals must be coherent and controllable. We explore different tactics to generate multichannel signals below, and assess the pros and cons of these tactics.

Independent Local Oscillator

The simplest way to achieve a certain amount of phase stability between signal generators is to lock a 10 MHz frequency reference. Figure 7 shows two signal generators with baseband generators synchronized using a triggering signal and a common 10 MHz time base. To learn more about time synchronization between instruments, download the white paper "Understanding and Testing Multi-Channel RF Systems with Signal Generators Part 1."



Figure 7. Phase drift between two time-synchronized signal generators

Phase Drift

The signal generators have separate oscillators, each with their own phase-locked loops (PLL). This results in phase drift between the signal generators, as shown in the right of Figure 7. Most of the time, PLL can lock the phase drift within the constraints of the loop bandwidth (PLL's loop filter). However, PLL cannot completely track out higher order responses.

In MIMO test systems, slow phase drift between channels is less of an issue, so test channels that share a common frequency reference may deliver acceptable performance.

Phase Noise

Uncorrelated phase noise contributes to phase error between reference-locked signal generators. Inside the loop bandwidth of PLL, the frequency reference has the most impact on phase noise performance. Outside the loop bandwidth, the PLL's oscillator determines the phase noise.

Using high-quality stable references and instruments with low phase noise can improve phase drift and phase error. Applications such as MIMO and spatial diversity can use these "phase-stable" multi-channel signals for testing. However, for precise component characteristics testing, a common LO may still be appropriate in order to achieve the best performance.



Share a Common Local Oscillator (LO)

To minimize the sources of coherency errors, use a common LO for multiple signal generators. Figure 8 represents two MXG N5182B vector signal generators configured for a phase-coherent test system. The system takes the LO of the top signal generator, then splits it and uses it as the LO input (red lines) for both signal generators. With this configuration, the RF paths of the two signal generators are fully coherent. This is confirmed on the right side of Figure 8, where you can see the phase difference between the two signal generators is less than one degree.



Figure 8. Setup for two phase-coherent RF channels with a common LO.

Phase Shift

Even if you are using a shared LO, you will still encounter some static time and phase skew between instrument channels. Cable lengths and connectors cause static time and phase variations. The delays and phase shift skew the phase relationship between the channels. You need to correct these offsets and ensure the measured differences come from the device under test, and not from the test system. To measure static time and phase skew of multiple VSGs, use a wide bandwidth oscilloscope as shown in Figure 9.



Figure 9. Measure channels time and phase skew with an oscilloscope



Be aware of the LO drive level when the number of channels increases. Splitting the LO output to accommodate more channels causes a loss of the LO inputs drive level.

Direct Digital Synthesis

Direct digital synthesis (DDS) produces an analog waveform by generating a time-varying signal in digital form and then performing a digital-to-analog conversion. DDS architecture provides an optimal path to low phase noise and fast frequency switching speed with extremely fine frequency tuning resolution.

DDS maintains a fixed phase relationship between its output for each frequency. The synchronization requires initial clock alignment (using a common reference clock) as shown in Figure 10. Synchronous reset (green line) to the phase accumulator can achieve the phase alignment. Apply this reset on every frequency update. The synchronous reset of the phase produces a fixed and repeatable phase relationship for each channel.



Figure 10. Shared reference clock for two DDS

New generation dual-channel signal generators such as Keysight VXG M9383B and M9384B have two DDS units on a synthesizer board. This provides two coherent channels with time alignment < 10 ps without touching any hardware, as shown in Figure 11. Table 1 summarizes the tactics for generating phase-coherent signals.





	Phase-stable test system	Phase-coherence test system		
Method	Independent LO	Share LO	Direct Digital Synthesis	
Implementation	Share a common 10 MHz time base	Share a common LO	Share an RF reference clock for DDS's	
Advantage	Easy setup	Phase coherence	Phase coherenceEasiest setup	
Challenge	Uncorrelated phase noisePhase drift	• Static time delays and phase shift corrections	High precision reference clock for DDS	
Resolution	High-quality stable referenceslinstruments with low phase noise	 Adjust I/Q Delay for time delays Adjust I/Q Phase for phase shifts 	 High-frequency reference clock. ¹ Adjust I/Q Delay for time delays 	
			• Adjust I/Q Phase for phase shifts	
Application	MIMO system tests	MIMO, beamforming, array antenna calibration	MIMO, beamforming, array antenna calibration	

Table 1. Various implementations for testing multi-antenna RF systems

1. Keysight VXG M9384B and M9383B's dual-channel signal generators use enhanced high-performance reference at 19.2 GHz as DDS's reference clock.

Conclusion

As multi-antenna technology matures and the demand for diversity, multiplexing, and antenna gains grows, test systems require tightly aligned channels for accurate tests. When performing a characterization test, you need to accurately recreate the operational environment. You need to create signals in such a way that they will coherently combine to simulate their real-world behavior.

For different multi-antenna test applications and requirements, there are different tactics for generating phase-coherent or phase-stable signals. Always strive to minimize the errors that various tactics cause. In addition, ensure test instruments are phase-coherent and phase-controllable for your test applications, such as beamforming tests.

References

Application note "Signal Source Solutions for Coherent and Phase Stable Multi-Channel Systems", July 31, 2014

White paper "Understanding and Testing Multi-Channel RF Systems with Signal Generators Part 1", October 20, 2018

White paper "Understanding and Testing Multi-Channel RF Systems with Signal Generators Part 2", October 20, 2018

White paper "Calibration Techniques for Improved MIMO and Beamsteering Characterization", June 13, 2017

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

