Agilent MIMO Manufacturing Solution

Application Note

Agilent Technologies

Introduction

This application note provides detailed information on the capabilities of the Agilent 802.11n multiple in, multiple out (MIMO) test solution which consists of the Agilent N4010A Wireless Connectivity Test Set Option 108 and the Agilent N4011A MIMO/multi-port adaptor. It is aimed primarily at manufacturing managers and engineers involved in high-volume manufacturing of MIMO devices, modules, and subsystems. This test equipment provides cost-effective, comprehensive test coverage and fault diagnosis in a fast, accurate, and reliable test solution. The enhanced diagnostic capabilities of the N4010A/N4011A instrument are also of value to late-stage research and development (R&D) and design verification engineers.

Manufacturers of MIMO devices have a choice of test equipment types, suppliers, and configurations to suit their test needs. This document presents a comparison of two of the most popular manufacturing test methodologies available, with examples provided to illustrate the relative merits of the Agilent N4010A/N4011A solution.

Manufacturing Test Methodologies

The multiple-channel architecture and stringent performance requirements of MIMO radio devices present certain challenges in the design of manufacturing test systems. The increase in the number of transmitters and receivers on each device implies a linear increase in test time and complexity when compared to single-channel 802.11a/b/g wireless local area network (WLAN) devices. Since cost of test is directly proportional to test time, one should ideally choose a test methodology that minimizes any increase in test time, while maintaining quality, accuracy, and repeatability.

Typically, there are four different types of test configuration:

1. Legacy – Golden radio (GR), spectrum analyzer, signal generator, and power meter
2. Multi-channel, one-box tester (OBT) or multiple synchronized OBTs
3. Single-channel OBT plus a GR
4. Single-channel OBT

For a detailed comparison of these test configurations, refer to "Addressing the New Challenges of MIMO Wireless LAN Manufacturing Test" by Ewan Shepherd, **www.agilent.com/find/mimo_manufacturing**.

Although the multi-channel/multi-box configuration offers true MIMO testing with the most complete test coverage, the higher cost of test equipment generally restricts such solutions to the R&D lab. The majority of MIMO device manufacturers therefore choose the single-channel, single-box OBT test configuration, together with some means to connect a multi-channel device under test (DUT) to the single-channel OBT. This test configuration offers the possibility of acceptable MIMO test coverage, adequately fast test times, and simplified cost of ownership.

The two most common approaches to MIMO manufacturing test use either a power splitter/combiner or a switch matrix, in combination with the OBT (Figure 1).

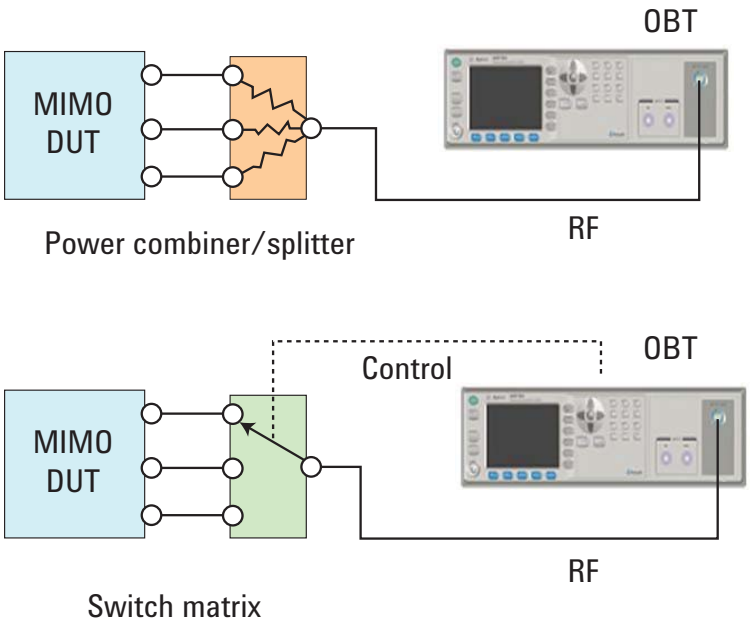

Figure 1. MIMO test configurations using a single-channel OBT

The N4010A/N4011A MIMO manufacturing test solution uses the switch matrix method to provide fully-calibrated measurements controlled by the N4010A and its associated software.

The N4010A/N4011A Description and Method of Operation

The N4011A multi-port adaptor is a ¼-width, two-unit-high module that fits on the side of the N4010A WLAN test set, to form a single 19-inch width composite instrument (Figure 2). RF connection from the N4011A to the N4010A is via a short length of semi-rigid cable. Power, data, and signal control lines are provided by a multi-way serial cable connecting the two instruments.

Figure 2. The Agilent N4010A and N4011A MIMO manufacturing test solution

The N4011A allows up to four DUT channels to be connected simultaneously, using fast solid-state switches to route the signals to the N4010A. In addition, REF ports are provided to allow the connection of a golden radio either directly to the DUT ports or to the N4010A.

All of the radio frequency (RF) paths in the N4011A are individually characterized, with the S-parameters stored in EEPROM in the instrument. Upon connection, the N4010A downloads these parameters and subsequently applies them automatically during measurements as path loss compensation, thus ensuring optimum accuracy at all times. The RF design of the N4011A also offers channel-to-channel isolation of > 50 dB.

To perform MIMO transmit (Tx) measurements, the N4010A/N4011A follows a multiple-capture, single analysis methodology. Consider the example of a two-channel device set up to transmit continuously on both channels simultaneously. The DUT is connected to DUT ports 1 and 2 of the N4011A. The N4010A is configured to trigger on the first RF pulse (or frame), which is captured on port 1. The N4010A automatically switches the N4011A to port 2, re-arms the trigger, and a second frame is captured. Although these frames have been captured sequentially, the switching process itself is extremely fast. This process is shown in Figure 3.

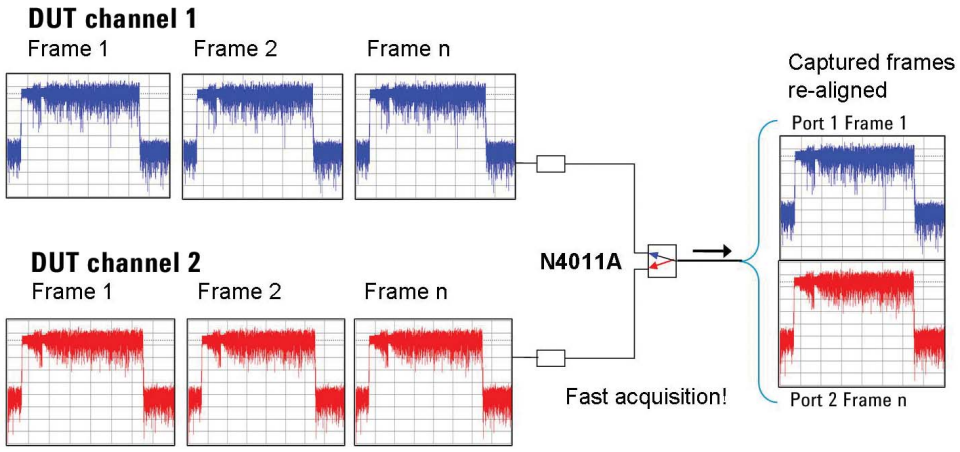

Figure 3. Sequential capture process of a 2-channel MIMO signal

The acquired data is then concatenated and passed to the demodulation algorithm. This algorithm is the same as the one used in the industry-standard Agilent 89601A Vector Signal Analysis (VSA) Software. The algorithm therefore demodulates the data as *if it had been acquired simultaneously*, which yields a full range of demodulation results, including channel and stream error vector magnitude (EVM), burst power, cross power, channel response, and burst information. In effect, the algorithm solves the MIMO channel matrix, aided by the channel isolation performance of the N4011A.

Tx Measurements

The first part of a DUT test plan will normally involve calibration and alignment of the DUT. After the DUT has successfully completed this part of the test process, the test plan typically progresses to parametric testing. The tests carried out at this stage should be carefully chosen to maximize the test coverage of known failure mechanisms, while maintaining an adequately short overall test time. In this section we will examine the typical Tx measurements required, and present an assessment of the test coverage, resolution, and speed offered by the Agilent N4010A/N4011A test solution. Where applicable a comparison will be made with the power splitter/combiner method shown in Figure 1.

Tx EVM

Relative constellation error or transmit EVM is a key measurement as it provides a measure of the transmission modulation quality of the device. It is not a pure parametric test, as EVM performance is influenced by the functional (digital) operation of the MIMO radio as well as analog RF effects. Using the Agilent sequential capture process allows the measurement of individual channel EVM while allowing the DUT to transmit continuously on all channels, a configuration which resembles the actual operation of the device. Since the Agilent demodulation algorithm effectively solves the channel matrix, individual stream EVM results are also available (Figure 4).

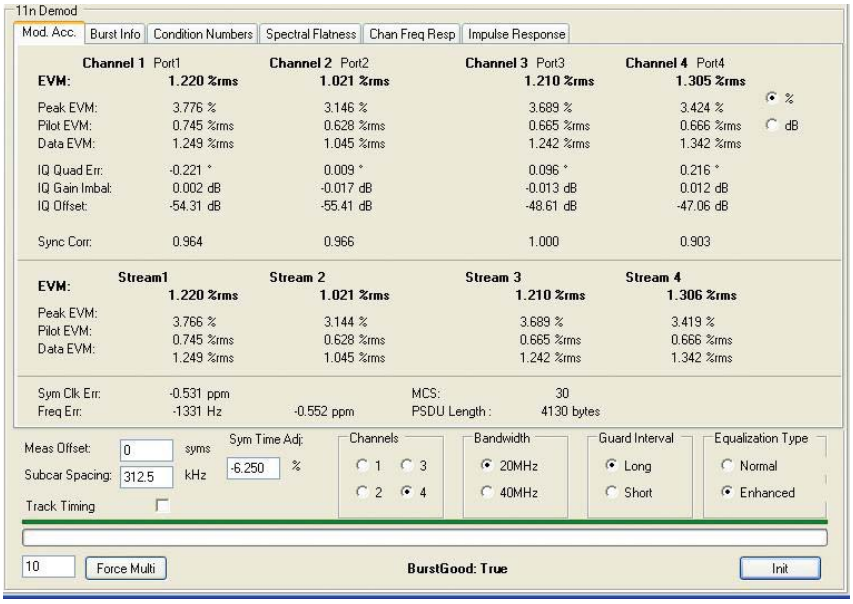

Figure 4. EVM results presented in the Agilent N4010A Virtual Front Panel

Demodulation is most straightforward when the DUT is in direct-mapped mode (each spatial stream is mapped directly to its corresponding transmitter channel). This is obvious from the example shown in Figure 4, where the channel and stream EVM values are the same. Despite the fact that the sequential capture technique necessarily captures pulses on different channels at different times (i.e. not simultaneously), spatially-mapped signals can be successfully demodulated provided the payload data and scrambler seed value remain constant from pulse to pulse. Figure 5 illustrates the differences between direct-mapped and spatially-mapped (spatial expansion) signals.

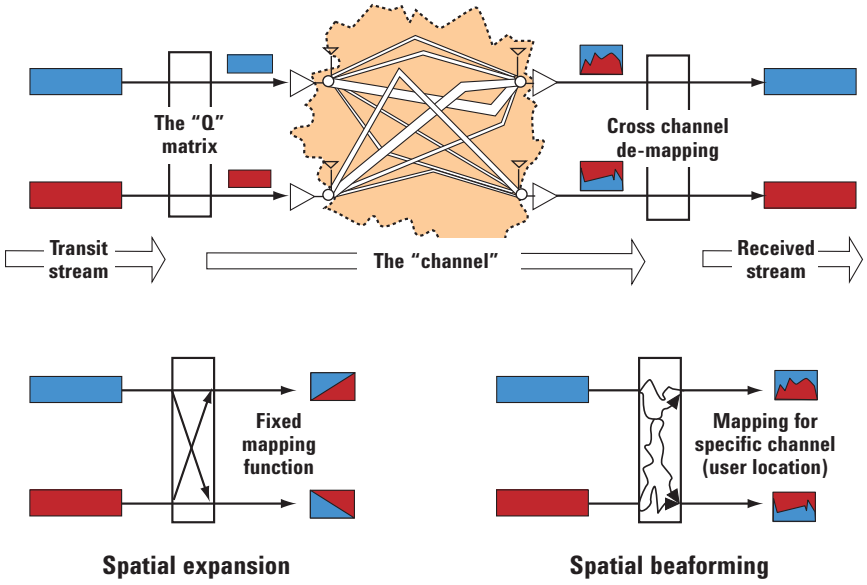

Figure 5. Direct-mapped, spatial expansion, and beam-formed signals

The demodulation results calculated from a single analysis also provide other useful data. Figure 4 shows that in addition to peak, pilot, and data EVM for each channel and stream, IQ quad error, gain imbalance, and offset are calculated. (Note that all of these results are also available when using multiple digitizers with the Agilent 89601A VSA software.)

In comparison, using the OBT with a power splitter/combiner to measure the EVM of multichannel DUTs presents some challenges. The data present at the OBT will be a superposition of individual transmit channels, resulting in vector addition of I and Q values. It is possible to arrange for the DUT to transmit known data in order to create a "composite" constellation from which a "composite" EVM may be calculated. However, it is generally much more difficult to identify sources of error that may contribute to a poor EVM and it is not possible to extract a cross power measurement (see "Tx cross-power and channel isolation").

Tx cross-power and channel isolation

One of the most useful results in diagnosing DUT faults is the cross power value, which is a measure of the amount of power from Channel 2 leaking into Channel 1 (and vice versa) in the case of a two-channel MIMO device operating in direct-mapped mode. The cross power result, together with the EVM results, can accurately diagnose unwanted signal leakage between transmitters caused, for example, by poor grounding, RF leakage, and printed circuit assembly (PCA) manufacturing faults. The Agilent WLAN driver software also displays the channel frequency response in graphical form. Figure 6 shows a typical set of results from a two-channel DUT operating in direct-mapped mode. The two circled plots give an indication of the amount of signal leakage between channels, which in turn represents the amount of isolation between transmit channels.

In the particular case of a DUT operating in spatially-mapped mode (spatial expansion), any channel isolation or leakage effects will be masked by the deliberate mapping of spatial streams across transmitter channels. In this situation, the cross power values will provide a measure of the degree of spatial expansion used (dependant on the Q-matrix).

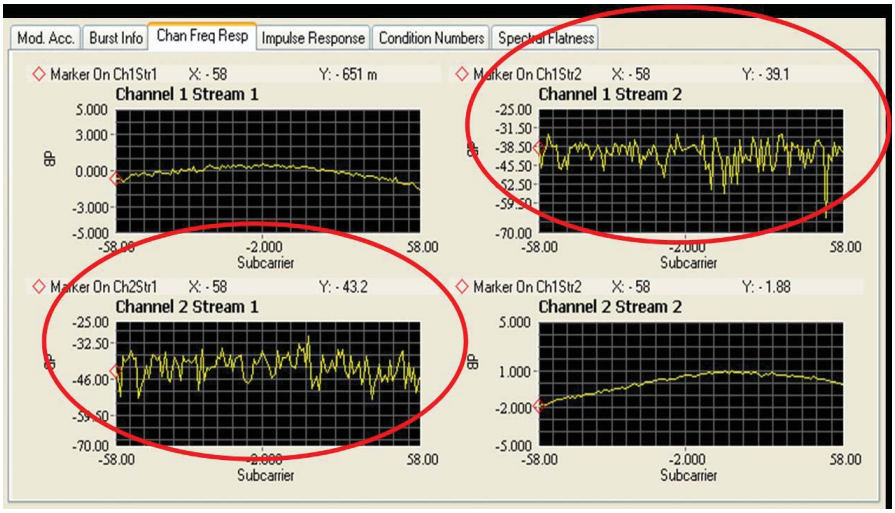

Figure 6. Channel response graphs showing channel isolation

By comparison, if the OBT is used with a power splitter/combiner it will not be possible to extract information about channel isolation or individual channel frequency response in this manner. Manufacturing or design faults affecting these parameters are therefore less likely to be quickly diagnosed and corrected when using that test configuration.

Tx power

Transmit power measurements using the Agilent N4010A/N4011A test solution are calculated automatically during the same data demodulation process which returned the EVM results—there is no need to make a second measurement on the DUT. Using the Agilent N4010A/N4011A solution therefore allows the individual DUT channel powers to be quickly measured while the DUT is transmitting on all channels simultaneously. Figure 7 shows a detail from the Burst Info page of the 11n Demod tab of the Agilent N4010 WLAN Virtual Front Panel (Figure 8).

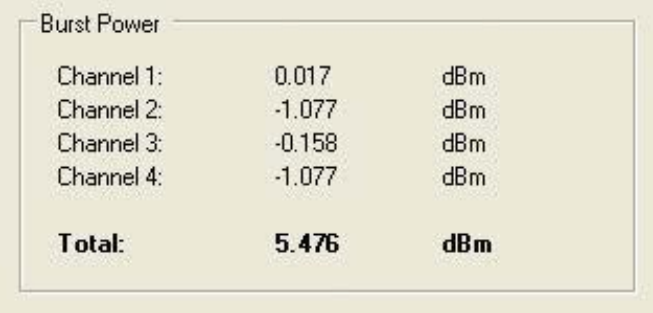

Figure 7. Detail showing burst power and total power results

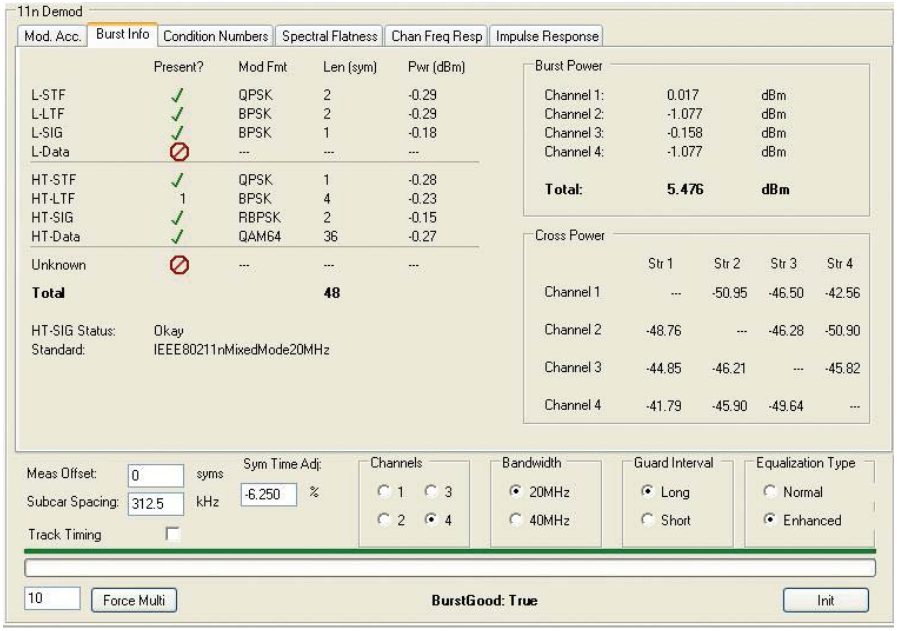

Figure 8. The Burst Info page of the 11n Demod tab; 20 MHz greenfield signal, direct-mapped

With the OBT and power splitter/combiner test configuration, individual channel powers can only be measured if the DUT is controlled to switch its transmitters on and off. Such a process could potentially mask unwanted interactions between active transmitters. Furthermore, any test plan that requires more DUT control is likely to incur a test time penalty in DUT control time and DUT settling time. If one chooses to avoid switching DUT transmitters however, then the power measured using a power combiner will be a summed power over all transmitters. However, there is a risk that a test pass in this configuration could potentially be the result of some transmitters running at too high a power and some transmitters running at too low a power.

Tx spectral mask test

Tx spectral mask measurements such as mask margin and mask violation are typically made "per channel". The Agilent N4010A/N4011A test solution allows individual DUT transmitter spectral emissions to be measured while the DUT continuously transmits, which helps minimize DUT control time, and in turn helps to optimize the overall test time.

Using an OBT and power splitter/combiner test configuration, individual channel spectra can only be measured if the DUT is controlled to switch its transmitters on and off. Similarly to the power measurement test, this process could mask interactions between active transmitters as well as increasing DUT control time. An alternative is simply to measure the combined spectra from all transmitters using a proprietary mask profile. Once again, there is a risk that individual transmitter faults will not be detected when using this test configuration.

Table 1 compares the Tx test coverage offered by the Agilent N4010A/N4011A test solution with the OBT and power splitter/combiner test solution. The table shows the DUT control requirements relevant to that particular test solution and test item. In general, DUT control will increase test times, indicated by the shaded cells in the table.

Table 1. Comparison of Tx test coverage by test methodology

Test item		N4010A and N4011A		OBT plus splitter/combiner	
		Test	DUT control required?	Test	DUT control required?
Tx	Individual channel EVM	✓	No	✓	Yes
	Combined EVM	✓ (average or peak of channel EVM)	No	✓	Ref. file
	Individual channel power	✓	No	✓	Yes
	Total power (all channels)	✓	No	✓	No
	Tx freq error	✓	No	✓	No
	Channel cross power/isolation	✓	No	X	N/A
	Channel response	✓	No	X	N/A
	Individual transmitter mask margin	✓	No	✓	Yes
	Individual transmitter mask violation	✓	No	✓	Yes
	Combined channel mask margin	N/A	N/A	✓	No

Rx Measurements

A fundamental limitation of using a single-channel OBT to perform receiver tests on a multi-channel DUT is that the MIMO signals used must be restricted to single-channel signals, i.e. those with modulation indices MCS0-MCS7. Although any competent OBT will be able to play out one channel of a multi-channel signal at a time, a DUT will generally not be able to demodulate the received signal as it only contains partial information.

Receiver (Rx) sensitivity

The Agilent N4010A/N4011A test solution transmits a single-stream signal to each DUT Rx antenna individually, using the N4011A multi-port adaptor to switch rapidly between ports. In this way, the minimum input levels can be measured by the DUT at the antenna connectors, and referenced as the average power per Rx antenna. The results will typically be returned as packet error rate (PER). This method supports the requirement of the IEEE 802.11n Draft 2.00 standard (February 2007), section 20.3.21.1, Receiver minimum input sensitivity. The standard states that:

"the number of spatial streams under test shall be equal to the number of utilized transmitting STA antenna (output) ports and also equal to the number of utilized device under test ports. Each output port of the transmitting STA shall be connected through a cable to one input port of the device under test."

Since the single-channel OBT is a transmitting standard test antenna (STA) with only one output port transmitting a single spatial stream signal (MCS0-MCS7), testing the DUT Rx performance per antenna follows the requirements of the draft standard.

Using an OBT with a power splitter/combiner allows the same signal to be transmitted to all DUT Rx antennae simultaneously. Initially this seems to be an attractive approach as it would appear to be closer to a "real-world" scenario. The DUT will return an overall PER result in a single measurement. However, individual DUT topologies generally use combining techniques such as maximal ratio combining (MRC) which provide enhanced sensitivity over the single-receiver case. Although it may be acceptable to set manufacturing test limits for a particular DUT, depending on its antenna number and arrangement, and its digital signal processing (DSP) algorithm, these limits should be carefully referenced back to the "per antenna" limits specified in the standard.

If required, the Agilent N4010A/N4011A can be configured to transmit simultaneously to all DUT Rx ports using an external splitter. This configuration can support DUTs with two and three receivers. However, this method is not recommended for the reasons given above.

Rx isolation

In the case where it is possible to enable DUT receivers separately, the N4010A/N4011A may be used to perform Rx isolation measurements. In this test configuration, leakage from one receiver to another may be measured using the DUT's RSSI. For example, if the N4011A output is switched to Rx antenna one of the DUT, then the received signal on the other Rx antennae may be measured. Similarly to the measurement of Tx isolation, such measurements may reveal problems with signal leakage between Rx paths.

Golden radio support

A unique feature of the Agilent N4011A Multi-Port Adaptor is the provision of REF ports to which a GR may be connected. Solid-state switches in the N4011A can route the RF signals directly to the DUT. This extends the Rx test coverage to include true MIMO multi-channel signals with modulation indices MCS8-MCS31 (Figure 9). Since a Golden Radio is by definition a product of its own manufacturing processes, the N4010A /N4011A can be used to characterize the GR performance periodically.

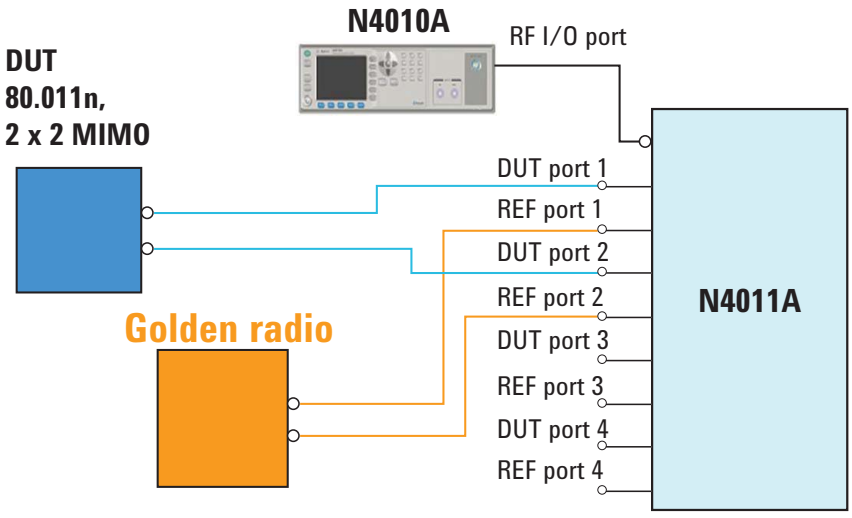

Figure 9. Example of golden radio support provided by the N4011A with a 2 x 2 DUT

Table 2 compares the Rx test coverage offered by the Agilent N4010A/N4011A test solution with the OBT and power splitter/combiner test solution.

Table 2. Comparison of Rx test coverage by test methodology

	Test item	N4010A and N4011A	OBT plus splitter/ combiner
Rx	Individual Rx channel PER, all DUT channels active	✓	X
	Individual Rx channel PER, measured channel only active	✓ (with DUT control)	✓ (with DUT control)
	Combined channel (DUT) PER*	✓ (up to 3 x 3)	✓
	Rx isolation (adjacent channel)	✓	X
	Multi-channel test with MCS8-MCS31 signals	✓ (with golden radio)	X

*Not recommended

Conclusion

The Agilent N4010A/N4011A MIMO manufacturing test solution offers comprehensive, accurate, fast, flexible, and reliable test coverage of MIMO devices, modules, and subsystems. It provides manufacturing managers and engineers with the confidence that they can access optimum test coverage, increase their product quality, and lower their cost of test, while maintaining compliance with the 802.11n Draft 2.00 standard.

For More Information

Regarding the Agilent N4010A and N4011A, including configuration guides, pricing and availability, visit **www.agilent.com/find/n4010a** and **www.agilent.com/find/n4011A**

Other pertinent information can be found at
MIMO internet page:
http://www.agilent.com/find/MIMO

N4019C *Bluetooth*/WLAN Wireless Test Manager Internet Page:
http://www.agilent.com/find/N4019C

Webcast recording: "Moving 802.11n MIMO from R&D to Manufacturing Test" at:
http://seminar2.techonline.com/s/agilent_jan2307

Addressing the new challenges of MIMO wireless LAN manufacturing test,
Shepherd, Ewan:
www.agilent.com/find/mimo_manufacturing

Related Literature

N4010A Programming Made Easy for WLAN Applications, application note, literature number 5989-6233EN

MIMO Wireless LAN PHY Layer (RF) Operation and Measurement, application note 1509, literature number 5989-3443EN

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