Next-Generation Wireless

Addressing the new challenges of MIMO wireless LAN manufacturing test

Using MIMO architectures, it is possible to extend the data rate or range of WLAN components. However, there are multiple transmitters and receivers in this architecture with stringent specifications, which complicates the design and manufacture of these systems. Nevertheless, new equipment and techniques can keep the testing costs within the range of that for 802.11a/g systems.

By Ewan Shepherd

Multi-in, multi-out (MIMO) could prove to be the next major advance in radio technology since the advent of digital communication. Many of the new radio communication standards include MIMO options, but the standard that has had the greatest visibility is the Institute of Electrical and Electronics Engineers (IEEE) 802.11n wireless local area network (WLAN).

Although the standard is currently in draft form, it is already possible to purchase pre-802.11n WLAN equipment that provides the benefits of MIMO operation. Various reviews of this equipment have shown that the technology really works[1]; it is possible, using this technique, to significantly increase the data rate and/or range of WLAN equipment without increasing bandwidth or output power.

But MIMO does not come for free. To achieve MIMO capability, it is necessary to have multiple transmitters and receivers at each end of the link. Apart from the cost and extra complexity that this brings to the product, it can also have a multiplying effect on the cost of manufacturing and final test.

Also, to get the benefit of the performance improvement possible in a MIMO system, the performance of the transmitters and receivers themselves has to be significantly better than what we have come to expect from the existing orthogonal frequency-division multiplex (OFDM) WLAN standards such as 802.11g.

With the new performance requirement comes new challenges for the manufacturing test systems used in order to ensure products meet the quality and performance goals. Is it possible to double, triple or even quadruple the number of transmitters and receivers and demand even tighter specifications, while maintaining the cost of test achieved with 802.11a/g systems?

Comparison of manufacturing test methods

WLAN manufacturers have a choice of test equipment types and suppliers for MIMO test. To avoid increased test time, it is necessary to carefully choose the approach that will maintain quality and limit the cost of test. Most of the arguments used to select equipment for legacy test still apply to MIMO[2,3]. However, apart from maintaining an acceptable test time, it is also necessary to test the device under test (DUT) to ensure adequate MIMO performance. The test configuration typically has four options:

1. Legacy—Golden Radio (GR), spectrum analyzer and power meter.
2. GR and single-channel one box tester (OBT).
3. Single-channel OBT.
4. Multichannel OBT or multiple OBTs.

The legacy approach has been tried and tested over many years of WLAN manufacturing. This approach was followed in the early years simply because there were no dedicated test instruments available for WLAN. This approach has a number of weakness, including poor transmitter (TX) test coverage and supportability of the GR. There is no easy way to verify the quality of the Tx. It is also likely that the GR will only work with a matching device type, due to the use of proprietary test modes. The GR approach is often used when a new type of device or a new standard appears. This is partly because there may not be adequate test equipment available to demodulate the new signals. Use of a GR also allows additional verification of the protocol and media access controller (MAC) during early manufacture. After a period of time,
MIMO specific tests

1. Calibration and alignment. As with 802.11abg WLAN devices, MIMO devices will need to be calibrated or aligned. This involves measuring the raw performance of the DUT under specific predefined conditions, storing the test data within the test station or server and then downloading a processed version of this data to the DUT. Each silicon vendor has a unique method of calibration. A general trend has been observed where less and less calibration is carried out as new devices appear. It is expected that this trend will continue and eventually it may be possible to avoid all calibration thus radically improving the total test time per device.

2. Parametric tests. Once the MIMO DUT has successfully completed the calibration process, it should be in a position to be fully tested with a reasonably high probability of passing. The tests carried out at this stage of the process are carefully chosen to maximize the test coverage of known manufacturing failure mechanisms. Many of the tests are in common with 802.11abg WLAN DUTs with the addition of appropriate tests to ensure adequate MIMO performance (Table 2).

Test time considerations

Figure 2 shows the typical breakdown of test times for an 802.11a/g device tested with an OBT.

The total test time for an 802.11a/g DUT is typically between 50 and 80 seconds depending on the test plan and equipment used. One might expect that unless the test equipment is duplicated for each MIMO channel, the test time would increase in proportion to the number of channels plus an additional period of time for the MIMO specific tests. However, in reality, the test time is highly dependent on the architecture of the test instrument and the way the tests are configured within the instrument. From Figure 2, it can be seen that power and spectrum measurements are the biggest contributors to the total test time. Rx cal and sensitivity are next. The remainder of tests make up only a small proportion of the total test time.

Further analysis of the bottlenecks has shown that significant improvements can be made by optimizing the architecture of the OBT to minimize the need to transfer large blocks of data within the OBT or, as in some cases, out of the OBT to a single-channel OBT needs to be addressed. Good test coverage and test time are essential. These will be addressed later in this article.

Table 2. MIMO tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
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<tbody>
<tr>
<td>Tx Spectrum Test</td>
<td>Measure the transmitter outputs, usually at the high output power setting over a number of frequencies and ensure the spectral components of each MIMO channel are within the pre-defined mask specification. Ideally, this test should be carried out with a bursted signal.</td>
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<tr>
<td>Tx Power Verify</td>
<td>Measure Tx output power on a number of frequencies and ensure it is within the specified limits for each MIMO channel.</td>
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<tr>
<td>Tx EVM</td>
<td>Measure the individual Tx outputs at a preset power level and verify the error vector magnitude (EVM), carrier leakage, spectral flatness and frequency are within the specified limits. This may be tested with a number of different modulation formats and at several frequencies.</td>
</tr>
<tr>
<td>Rx Sensitivity</td>
<td>Feed a modulated signal into each Rx and set to a specific power level just above the sensitivity threshold. Check the packet error rate (PER) via a direct data connection to the DUT. This may be carried out for a number of modulation formats and frequencies.</td>
</tr>
<tr>
<td>MIMO Tx Isolation</td>
<td>This is a MIMO specific measurement where the coupling between Tx channels is measured. This can be achieved by capturing a packet from each transmitter and extracting the channel isolation from the MIMO training sequence. Additionally, transient MIMO isolation can be measured using MIMO EVM.</td>
</tr>
<tr>
<td>MIMO Rx Isolation</td>
<td>This is a MIMO specific measurement where the coupling between Rx channels is tested. This can be measured using test modes in the Rx. Alternatively, this can be tested by feeding a signal into each channel independently and verifying that the signal does not appear on the unconnected channels using either PER or the RSSI.</td>
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</table>

Figure 2. Test time contribution for a typical 802.11a/g device.

With increased volumes, it often makes sense to switch to an OBT and phase out the GR.

Using a GR and single OBT can bring some benefits compared with legacy test. It should be possible to provide high-performance demodulation capability in the OBT to allow all the critical Tx parameters to be tested including error vector magnitude (EVM), carrier leakage and spectral flatness, in addition to power and spectrum measurements. The GR output can be accurately calibrated using the OBT and the GR used to measure receiver sensitivity under simulated MIMO conditions. This could involve a simple channel simulation network or be direct DUT receiver (Rx) to GR Tx connections with appropriate attenuation. The question of how to measure the multiple MIMO channels with a multi-channel OBT needs to be addressed. Good test coverage and test time are essential. These will be addressed later in this article.

The single OBT is the simplest approach from a production test viewpoint. There are none of the disadvantages of maintaining a GR and all the other key measurements available with the legacy approach are possible. However, methods to obtain acceptable test time and MIMO test coverage have to be understood.

Multichannel OBTS or multiple OBTS should, in theory, solve all of the issues previously described—but at a price. Test time can be similar to a non-MIMO device if the OBTS can be triggered to measure or generate signals in parallel. Complete MIMO coverage is possible as the multichannel generator or analyzer can test the real MIMO
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**An optimal WLAN OBT design**

Table 1 shows that a single OBT for MIMO testing is the best approach provided the throughput limitation can be addressed. In order to show how this is possible, it is necessary to consider the internal architecture of the OBT.

Most of the measurement time encountered with a WLAN OBT is based on transferring acquisition data rather than signal processing. It is, therefore, necessary to create an internal architecture that limits the quantity and frequency of data transferred to the signal processor. Some rules can be defined that help us to create the optimal OBT:

1. Avoid passing acquisition data (e.g., I/Q samples) over a local area network (LAN) or universal serial bus (USB) either within the OBT or externally to a personal computer (PC). Ideally, the acquisition memory should be directly accessible by the signal processor.
2. Make as many measurements as possible from a single data capture. This includes any multichannel MIMO measurements.
3. Choose a digital signal processor (DSP) that is designed specifically for fast processing of OFDM signals.
4. Push as much signal processing as possible into “real-time” hardware such as field-programmable gate arrays (FPGAs).
5. Simplify the power measurement algorithm as much as possible and optimize the spectrum measurements to make best use of the DSP and also provide authentic spectrum measurements that match the IEEE specification.
6. Optimize frequency and power switching speeds within the OBT.
7. Allow fast packet selection and generation within the OBT generator.
8. Ensure the OBT has a power accuracy specification that eliminates the need for a power meter within the test station.

When all these criteria are met, it becomes possible to measure a WLAN DUT in a highly efficient way with optimal test time. In addition, with appropriate channel connectivity hardware, a MIMO DUT can be tested with little increase in test time.

**Fast MIMO measurements**

As previously discussed, there are extra measurements required due to the additional transmitters and receivers within the MIMO DUT and the MIMO-specific tests. A method is needed to allow the additional tests to be performed while maintaining the integrity of the measurements. This could be achieved using multiple OBTs. However, the cost of this approach may be prohibitive to many manufacturers. An alternative is to use a single OBT and devise a method to connect the DUT to the OBT that optimizes the measurement speed while maintaining measurement integrity. Two approaches are as follows:

**Power splitter/combiner.** Use a power splitter/combiner to connect each MIMO channel to the OBT (upper diagram in Figure 1). The combining technique may be attractive to some manufacturers. By using specific and known payload data on each channel, it may be possible to provide pseudo EVM measurements that give a rough indication of the performance of each TX. However, it is likely that failures in the MIMO performance due to poor channel isolation or transients cannot be determined. It is not possible to check the MIMO performance of the Rx paths.
Switch matrix. The switch matrix approach (lower diagram in Figure 1) avoids these weaknesses, but can a significant increase in test time be avoided? Using this approach, it is also unclear how true MIMO performance could be measured. The issue of test time can be answered by reference back to the OBT architecture.

Remember that test time is more dependent on how the acquisition data is handled rather than the time to process the data. Once this is understood, it is a logical next step to ensure that all the MIMO Tx signals are presented to the DSP memory when they are sampled. The additional test time is then only limited by the power of the DSP. It is also possible to recover true MIMO performance such as channel isolation and EVM. It also becomes possible to test the Rx channels for isolation. This can be done in two ways; either the raw MIMO data from the DUT is processed externally and the channel isolation calculated, or isolation is determined by watching the received signal strength indicator (RSSI) or packet error rate (PER) of a channel with no input while another channel is connected to the generator.

Measurement and planning
To realize the benefit of MIMO WLAN products, it is essential that factors that impact MIMO performance are measured during manufacturing. All the traditional WLAN measurements are required to ensure each MIMO channel is functioning correctly but crosstalk (or isolation) between channels must also be checked. It is easy to see how manufacturing failure mechanisms that could seriously degrade MIMO capability could go undetected if test plans do not verify specific MIMO performance. The quality, reliability and performance of the new MIMO WLAN products depend on robust test techniques.

With optimal OBT architecture, it is possible to provide test plans for both 802.11abg and MIMO devices that avoid significant increases in test time while ensuring adequate MIMO-specific test coverage.

The Agilent Technologies N4010A wireless networking test set is “MIMO ready,” and has been designed specifically for WLAN and Bluetooth manufacturing test. The architecture of the N4010A is based on fast data acquisition and processing as described in this article and has been optimized for fast measurement speed of OFDM signals. Visit the N4010A web site at www.agilent.com/find/n4010a or www.agilent.com/find/mimo for more information.

References
3. Agilent Technologies Application Note: Next Generation of WLAN Manufacturing Test Solutions (5989-1194EN).

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Ewan Shepherd received a bachelor’s degree in electrical and electronic engineering in 1980. In the period between 1980 and 1989, he held the position of senior R&D engineer at Ferranti Defense Systems Ltd, responsible for radar receiver subsystem design. Between 1989 and 1998 he worked at Hewlett-Packard, responsible for leading a team developing RF and microwave test equipment. Since 1998, he has held the position of development project manager at Agilent Technologies, responsible for a number of test and measurement products including noise figure analyzers and wireless test sets.