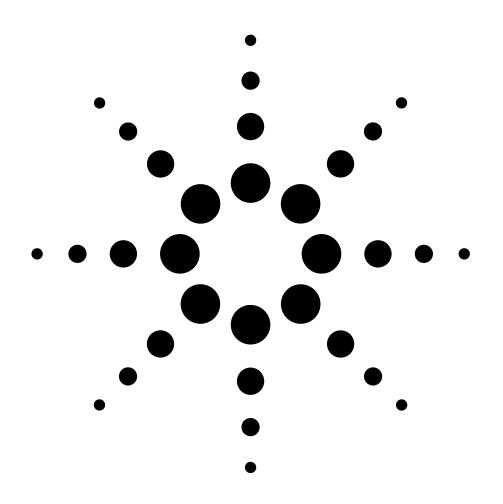# Agilent
802.11a/g Manufacturing Test Application Note – A Guide to Getting Started

Application Note 1380-3
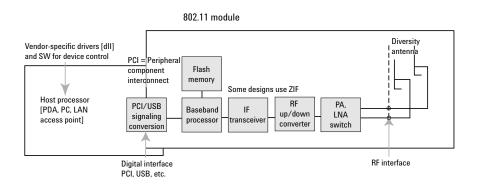
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Agilent Technologies

Introduction

This application note is intended for those planning to manufacture IEEE 802.11a,h[1] and g wireless radio modules. It covers the selection and execution of physical layer (RF) tests. In this note, modules are defined to have an RF interface and a host interface (see Figure 1). The host contains the driver software to control the module's operation. Examples of modules are a PC card [PCMCIA] NIC (network interface card), mini-PCI card, USB card and emerging formats such as the secure digital card. The component parts of these modules may be integrated directly into the host device, which will change the test configuration. However, much of the material in this note will still be applicable.

Figure 1. 802.11 module

This application note begins with an introduction to IEEE 802.11a/g technologies. This is followed by a brief overview of manufacturing processes, which cites specific challenges that 802.11a/g radio modules pose to manufacturing engineers. Recommended 802.11a/g manufacturing tests and test conditions are then described. This is followed by a discussion of manufacturing test metrics (including cost of test) and approaches to manufacturing 802.11a/g radios. In recognition that cost of test is greatly affected by the manufacturing approach, this document then reviews the two basic approaches to manufacturing test: golden radio and standard test equipment. Appropriate test equipment from Agilent Technologies is highlighted in the appendix .

Implementation of IEEE 802.11b networks is well underway in homes and offices, setting the stage for IEEE 802.11a/g. These technologies span a diverse set of applications, including replacement of wired LAN connections, campus connectivity and remote database access in manufacturing. Wireless LAN (WLAN) is also providing public access to the Internet and is speedily being deployed in conjunction with virtual private networks.

1. These are treated as the same, since h is an extension of a.

Limited radio spectrum is available, but the demand for higher performance is unrelenting. This has increased concerns about interference at 2.4 GHz. Users of business applications are raising their expectations with regard to performance from the physical layer. IEEE 802.11a/g and dual-band solutions are attractive candidates to fulfill such expectations, but they demand higher performance from the radio circuitry. Therefore, test margins will be lower and manufacturing yields may not easily reach expected levels. Wider acceptance of multi-format and dual band devices means a more sophisticated test system and a more flexible test plan may be needed.

IEEE 802.11a/g are members of the family of wireless LAN standards. Both specify peak data rates of 54 Mb/s, much higher than the 11 Mb/s that 802.11b currently handles. The new standards aim to provide the performance and increased capacity that network administrators are constantly seeking.

For any vendor of consumer devices, product differentiation is key to profitable sales. Price alone is rarely a satisfactory or sustainable factor. For WLAN in particular, ease of configuration and good system performance are the characteristics that will help ensure a brand's success. A positive end-user experience is essential for mass adoption of high-speed WLAN devices, and the manufacturing process plays an important role in achieving this. If, users find inconsistency in the performance of different WLAN cards, they will be left wondering if some of the hardware should be returned.

While radio specifications may be quoted and compared, data rate and range are the two most important measures of system performance to the average consumer. Consumers must be careful when shopping for a WLAN device – the data rate and range figures shown in advertising are often specified in a way to give the largest apparent coverage, which increases the potential for user disappointment. In addition, the "WiFi" label from WECA (Wireless Ethernet Compatibility Alliance) provides no guarantee of device performance.

Building an effective manufacturing process is very demanding, because it requires a thorough understanding of what is happening upstream and downstream – from the design strengths and weaknesses to the cost of customer dissatisfaction and product returns.

Ultimately, it is the radio designers who have to make the design trade-offs that will set performance limits. The job of the manufacturing engineer is to ensure every device shipped performs consistently. The tests in this application note are described with this in mind.

1. An introduction to IEEE 802.11a/g WLAN standards

As the name implies, wireless LAN was designed to extend the data transfer function of a wired LAN. Although the standards that define how it works continue to evolve, WLAN is basically a system for transferring packets of digital data wirelessly and without error whenever an originating computer can send them.

The most widely used WLAN systems are replacing CAT5 cables. Users can create individual wireless-to-wired LAN links from the fixed access points (APs) to the mobile network interface cards (NICs). Throughput for individual users is usually a fraction of the peak data rates that WLAN systems advertise. Typically, it is half the nominal peak rate and drops further as clients are added or as the NIC moves away from the AP. Coverage depends on both the physical environment and frequency band.

The high transmission data rates are achieved using 18 MHz (or higher) bandwidth radio transmissions, and in the case of 802.11a/g, complex modulation formats such as 64QAM.

For more information on the IEEE 802.11 physical layer, please refer to application notes 1380-1 and 1380-2.

System	Frequency band	Maximum data rate (Mb/s)	Transmit scheme		Modulation				
			CCK	PBCC	OFDM	BPSK	QPSK	16 QAM	64 QAM
802.11a	5 GHz	(Option to go to 54)			x	x	x	x	x
802.11b	2.4 GHz	11	x	Option[2]		DIFF[1]	DIFF[1]		
802.11g	2.4 GHz	(Option to go to 54)	x	Option[2,3]	x	DIFF[1]	DIFF[1]	x	x

Notes:
1. DIFF = Differential modulation encoding.
2. 802.11g includes an option for mixed CCK-OFDM.
3. PBCC may operate up to 33 Mbps

Table 1. System frequency bands, data rates and modulation schemes

1.1. Evolution of the physical layer

Both 802.11a and g have a peak data rate of 54 Mb/s – nearly five times faster than 802.11b. This is accomplished at the physical layer mainly by changing the modulation type to 64QAM. OFDM (orthogonal frequency division multiplexing) has been adopted to improve multi-path signal fading found in indoor environments targeted for 802.11 use. Forward error correction is also applied

802.11a has also moved up in frequency to the 5 GHz band. This differs from 802.11g, which remains in the 2.4 GHz band to maintain backward compatibility with existing 802.11b networks. Many chip set vendors are actively developing dual band designs for 802.11a/g, which increases the potential for interoperability issues in the industry.

802.11a,g radios are less tolerant of hardware imperfections, such as non-linearity and noise. Numerous factors can prevent the radio from achieving the performance needed to meet the transmit power and modulation accuracy specifications laid down in the standard.
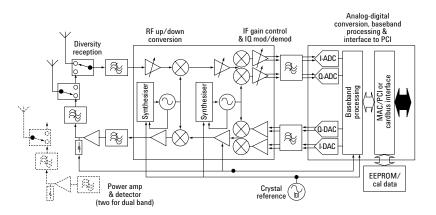

Figure 2. Typical internal components for a WLAN card.

1.2. Effects of standards evolution on manufacturing processes

With so much churn in the WLAN development arena, manufacturing entities must be ready to handle a variety of frequency ranges, bandwidths and modulation types. Dual-mode or multi-mode WLAN chips further complicate the manufacturing process.

Capital test equipment for new manufacturing lines should satisfy today's requirements for frequency range, modulation formats and bandwidth while providing expandability for the future.

For existing manufacturing lines such as for 802.11b or even cellular technologies, it means test equipment configurations should be evaluated to see if they will meet the needs of 802.11a/g. Also, existing test processes should be checked to ensure they optimize both the throughput and cost of test metrics on which manufacturing lines are measured while ensuring expected performance for the end user.
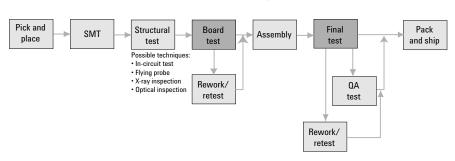
The remainder of this application note shows how to maximize the value of 802.11 radio manufacturing test while ensuring that ease of configuration and system performance (data rate and range) are optimized for differentiation in the market.

2. Generalized 802.11a/g manufacturing

The basic manufacturing processes for electronics communication devices are very similar. A generalized flow diagram is shown in Figure 3. This same manufacturing process is typically used for WLAN devices. In the following sections a number of issues related to cost-effective testing are examined. As the focus of this application note is on the physical layer, emphasis will be placed on the board test and final test functions.

2.1. Overview of the manufacturing process

This diagram is applicable for many types of electronics products. Since WLAN technologies present a unique and challenging set of performance requirements, this application note focuses on the board test and final test stages.

Overview of the manufacturing process

Figure 3. Generic manufacturing process

2.1.1. Board test

Radio alignment (calibration) and parametric testing are the primary reasons for board test. Radio alignment often requires access to test points that are not available in the device's final configuration because the device will be in some kind of housing or case. Thus, it is performed prior to final assembly. Parametric testing is performed prior to assembly in an effort to reduce the cost of rework or repair of poorly performing units. Parametric testing confirms the device meets defined performance limits and provides the data to monitor the consequences of variations in the build process.

At this stage in the manufacturing process, RF shield cans may or may not be soldered to the board (per engineering discretion). The RF link to the device under test (DUT) is typically via some type of probed connection, which gives better accuracy and fewer noise and interference problems. There is typically a special test control interface available on the device. Using this device, driver software in the board test system can place the device in test mode, which allows the board test system to make measurements.

The test sequence for board test is generally the following:

- Perform basic dc current measurements to ensure device is functioning (no shorts or opens).
- Load the firmware and/or microcode – the host device will have special control software to provide the test functions required.
- Perform radio alignment (including crystal oscillator tuning, output power adjustment and received signal strength calibration).
- Perform parametric testing.
- Load MAC address and radio alignment parameters to the flash.

2.1.2. Final test

The final test stage includes the final firmware load and a functional test of the DUT. Final testing can be used to recreate actual conditions in which the device will be used. In addition, it provides a useful check that nothing was damaged during the assembly process.

If the test is constructed carefully, it can act as an effective filter for a wide range of HW defects. It can also be an aid to detecting defects due to software changes. This is because the radio performance has a complex dependency between hardware and software. SW changes may be needed to improve performance or modify operation. An example would be where the change was needed to match change in the standard. Often there is a limited amount of QA time available. The effect of changes may only become clear when testing in combination with the hardware characteristics of thousands of slightly different DUTs, as found on any manufacturing line.

At this stage in the manufacturing process, the DUT has been assembled into its final mechanical housing. Some WLAN devices allow for wired connection to the RF path. Other devices need to use a coupled RF signal, which means using a separate antenna for connection to test or other equipment. Access to the special test input is typically still available.

The test sequence for final test is generally the following:

• Perform basic dc current measurements to ensure device is functioning.
• Load firmware.
• Verify the MAC address.
• Perform functional testing.

2.2. Cost impacts

Manufacturing metrics play an important role in establishing the process and requirements for a manufacturing line. A discussion of manufacturing metrics, particularly cost of test, can be found in Section 5. Although the cost is not always seen in manufacturing, for the device supplier the cost of customer returns must also be considered. In the worst case, this can result in a very expensive product recall. Simply having dissatisfied customers also costs money, in the form of lost revenue.

3. 802.11a/g manufacturing issues and concerns

3.1. Configuring the RF input

WLAN devices employ a pair of antennas for diversity reception, and sometimes transmission. It is essential to test the diversity function. To do this, the test controller must have some method of selecting the receive antenna on the DUT. Selection of the active antenna can be accomplished with a switch internal to the DUT. This requires that the control software have the ability to configure the DUT to select one antenna or the other.

3.2. RF isolation

To perform receiver testing, it is essential to minimize unwanted RF energy that may leak in and out of the DUT. Two sources of unwanted RF energy are 1) the ambient environment (an over-the-air RF link) and 2) RF coupling onto DUT signal lines. Consequently, the DUT and any cables need to be shielded. Otherwise, there will be variations in measured performance that will make it difficult to determine if a particular DUT is passing or failing. This could lead to false failures, and erratic changes in yield.

As noted earlier, there are a finite number of host device interfaces currently being used with wireless LAN. The most common is the PCMCIA format. These high-speed digital interfaces are very sensitive to changes in the signal path (such as reflections, lumped capacitance and increased electrical length). This can present problems when trying to get signals to the DUT while maintaining an RF shielded environment for testing. Fixtures that address these problems are part of Agilent's offerings.

3.3. Calibration

Calibration involves the storage of data in the DUT based on external equipment measurements. This process provides the absolute accuracy of frequency and transmit power required for the DUT to work with devices from many different suppliers. During calibration, it is usual for the parameters to be adjusted as close as possible to the ideal, since this improves the margins and yields.

3.4. Test limits

The DUT is measured at only one temperature, even though its performance will vary as the temperature changes. For example, when an NIC card is placed in a laptop computer it can get noticeably hot, and output power can change. When making measurements, and deciding on appropriate test limits, it is important to be aware of the variation in DUT performance over temperature. This variation should be subtracted from the manufacturing test limit.

For more detail, please refer to *Application Note 1333-4, Bluetooth Manufacturing Test–A Getting Started Guide* (Publication Number 5988-5412EN).

3.5. Effects of packaging

The performance of the DUT can also change when packaging is added. Some parameters can vary in complex ways according to manufacturing process variations. These are typically less-specified parameters such as non-ideal "parasitic" components, signal coupling due to physical proximity of the components inside the DUT, and radiated electrical signals. It is possible to minimize these effects by design, but this is often only achievable by choosing more expensive components or adding expensive screening/ isolation. The consequence of needing to test the device in as complete a form as possible, is that a number of performance tests are required even after calibration has taken place.

4. Identifying 802.11a/g manufacturing tests and conditions

4.1. Initial operability check

The first stage of testing consists of a high-level check of DUT operability. This includes loading the firmware, testing the interface drivers and either loading or verifying the MAC address and radio alignment parameters. In addition, DUT supply current is monitored to detect latent defects in components or assembly, such as a short in the circuit.

4.2. Radio calibration

The absolute accuracy of the components in an 802.11 device is usually inadequate to meet the performance goals for frequency, power level and other parameters. One way to reduce the variations in system performance is to use more expensive components. However, cost pressures often push the designer in the opposite direction. Calibration is the alternative, with its visible impact on a reduced bill of materials. In Table 2, we show the most frequently calibrated parameters.

4.3. Parametric test on transmission chain

Figure 4 shows the basic configuration for making transmitter tests. A test executive runs on the PC. It controls the DUT via a digital interface and the test equipment via GPIB or LAN. A second PC is usually required if a golden radio is included in the test configuration. Device-specific drivers, provided by the IC vendor, must be loaded onto the PCs to allow the user to generate the RF signals needed for specific tests. A screened RF fixture holds the DUT to ensure interference from nearby lines does not affect the results. The Agilent ESA spectrum analyzer is shown making a spectrum emission mask, and average power measurement. Several measurement techniques may be used, depending on the equipment available. These are described in Table 3.
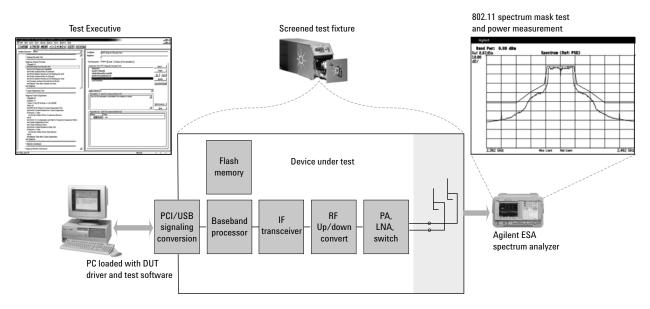
The equipment configuration shown in Figure 4 allows spectrum and power measurements to be made. The highest accuracy can be achieved if a power meter is used in conjunction with the spectrum analyzer. Making wideband measurements allows more thorough tests of the DUT. Specifically, traceable modulation analysis and power/frequency measurements from a bursted signal. The latter is important because it is the dynamic performance of the radio that is more likely to degrade as components and processes change over time. It requires a choice of system configuration. A direct 6 GHz RF input vector analyzer, such as the 89641A, may be used. A lower cost approach, that combines the use of a signal generator as both local oscillator [LO] and signal source for receiver testing, is shown in Figure 4. Using the ESG as a "low-side" LO, with the frequency below that of the DUT, the frequency mixer down-converts the input signal to 70 MHz. This suits the fixed input frequency of the 89611A.
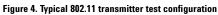
When receiver testing is to be carried out, the ESG signal path is switched through to the DUT. The modulation and RF level changes are also made.

Item	Objective	Method/process
Power level	Remove variations in transmit power due to normal component value differences. Users will be affected if power is too low (range/performance in noisy environment) or too high (battery current/interference between users). Transmission power must be kept below certain regulatory limits. If power control is implemented, optimum network performance may require accurate control of the mean transmit power of the devices within the network.	1. Choose bottom, middle and top channels (or others according to known design performance limitations from initial batch tests). 2. Transmit a modulated signal on a non-bursted carrier [An unmodulated carrier would be simpler, but applying modulation can give an earlier indication of device problems.] 3. CW measurement (thermal sensor most accurate), defined modulation/data pattern. 4. Adjust signal path gain or level control as design requires. 5. Program data into DUT's nonvolatile memory.
Spectrum mask	Some manufacturers choose to maximize the output power while staying within the spectrum emission limits.	Similar process to that above, except the spectrum emissions are measured while the output power is changed.
Frequency	Apply absolute frequency accuracy to the internal crystal oscillator. Ensure the receiver in another card/Access Point can recover the signal from the DUT, and vice-versa. Avoid interference in multi-user systems.	1. Make a single-channel, unmodulated, non-bursted transmission with measurement at RF, or direct measurement from crystal oscillator. Ideal: Use wideband signal analyzer to provide direct readout of frequency error. A narrow band spectrum analyzer may also be used: • Zero span, 100 kHz RBW, frequency counter function from marker. • Narrow span with center at desired channel. Use peak search / marker function. **Or:** Use a dedicated frequency counter. This has the advantage of simplicity, but delays the time when the DUT's RF generator circuits are tested . 2. Adjust tuning factor. Store result into DUT's non-volatile memory.
Modulation	Correct distortion in modulation path, or non-linearity errors in the entire transmit chain. The need and process for this calibration step depends on the radio design.	1. Transmit test pattern on worst frequency (known from initial batch testing or design simulation). 2. Ideal: Make EVM measurement using IQ error results to adjust calibration factors. **Or:** Use spectrum mask or spot frequency measurements to adjust sideband levels.
RSSI (received signal strength intensity)	Provide absolute accuracy to receiver RF level readings for dynamic frequency selection or system power control functions. Some degree of consistency is needed for the signal level readout provided to the user.	1. Use a non-bursted, modulated signal source. The data pattern choice depends on vendor-specific software working with DUT. 2. The DUT SW makes reading of the measured level. The system controller, then programs corrected factors into non-volatile memory.

Table 2. Module calibration objectives and parameters

Item	Objective	Method/process
Average power	Ensure all devices conform to regulatory requirements. Ensure the NIC or AP's transmission range meets customer expectations. Confirm power level reaches minimum acceptable level, and there are no unexpected changes in performance after calibration; e.g., due to poor power supply decoupling or the effect of screening.	1. The ideal configuration uses a bursted waveform, because this stresses the device. Use the longest transmission frame available to maximize the stress on the DUT. 2. Use wideband measurement equipment with time-gated power function Or: Use power meter 3. Set the device to operate in different modulation formats if this affects performance. 4. Record results and compare to upper and lower limits.
Frequency error	Avoid interoperability and range problems between devices. Check that variations in less-controlled parameters, such as power supply decoupling and spurious signal coupling, are not causing unexpected performance changes.	1. The ideal configuration uses a bursted waveform. 2. Set the DUT to transmit the longest frame, with random data. 3. Use wideband signal analyzer to perform a gated measurement during the preamble. Or: Use a conventional spectrum analyzer, and look for the location of a peak or null in the spectrum. This depends on the data pattern being transmitted.
Modulation error (EVM)	Ensure the combination of all the noise and distortion products in the transmit path (which varies with components, power level and frequency) does not degrade the range or data transmission speed seen by the user.	EVM provides a composite reading of numerous errors. 1. Transmit longest frame with PN data. 2. Use most complex modulation format (64 QAM), at the highest transmit power. 3. Use a wideband signal analyzer to provide EVM reading directly. 4. Compare with upper limit.
Spectrum mask	Ensure that at maximum power, with complex modulation, the spectrum is within regulatory/specification limits. Otherwise there will be a degradation in system performance, or the supplying company will be liable to an infringement penalty.	1. Use a swept- or FFT-based spectrum analyzer, with 100 kHz RBW and average detection. 2. Ideally the DUT will be set to transmit a bursted signal. This will help to uncover any dynamic performance problems. 3. Set to lowest channel, maximum power. Test using spot, or narrowed sweep measurement with 1 MHz RBW, around break points in test limits; for example 2370 MHz /2390 MHz. 4. Set the sweep time long enough to minimize sweep-to-sweep fluctuations due to data.
Tx frame (packet) error rate	The objectives are similar to modulation error. While apparently simple, this test may be difficult to control or reproduce when using different golden radios. Changing the receiver performance though a FW upgrade can shift the level of the readings, even thought the DUT transmitter is unchanged.	1. Control the DUT with vendor-specific SW to make it transmit packets with known MAC address/payload. 2. Attenuate transmit signal and input to "known good" receiver. 3. Check that unexpected noise/distortion on the signal does not degrade the PER (packet error rate) measured using SW connected to the drop input level.
Antenna diversity	Ensure the switching path is operational.	Often this will use a coupled RF connection. The test method depends on the availability of diversity transmission. 1. If diversity transmission is available, transmit a normal signal. 2. Switch between the two transmit antenna ports. 3. Confirm that the difference in measured power is within acceptable limits. If only diversity reception is available, the receiver must be controlled directly to select between the ports while performing a receiver PER or BER (bit error ratio) test.

Table 3. Transmitter parametric test list

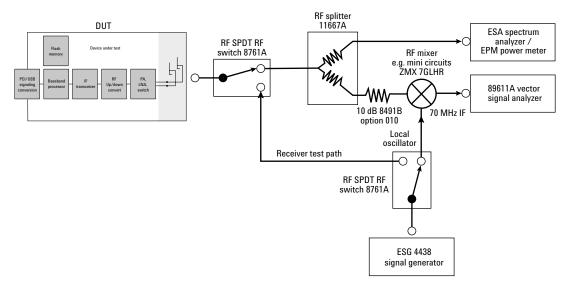**Figure 4. Typical 802.11 transmitter test configuration**

Figure 5. A flexible, dual-band test configuration providing EVM results and with the potential to remove the need for a golden radio

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4.4. Receiver test

Figure 6 shows the basic configuration for receiver testing. The DUT is configured to accept packets from the RF source. If a golden radio is used (along with a second PC and internal RF components), it replaces the signal generator. There are a number of ways the Agilent ESG signal generator can provide suitable packets. Signal Studio SW is shown. The use of the signal generator ensures tight control over the signal levels used for testing. Packets recovered by the DUT, or failures, are counted using software running on the PC, which then calculates the PER (packet error rate). Table 4 lists the main receiver tests for manufacturing.

Figure 6. Configuration for testing an 802.11 receiver

4.5. Tests common in initial manufacturing

Some tests are commonly incorporated into initial manufacturing test plans to help establish the product specifications or provide increased confidence for the manufacturing team. But as the manufacturing line matures, these tests are no longer needed and can be dropped from the test plan to increase throughput. In Table 5, some of these tests are described. Whether a test is in this table or used for normal manufacturing is also influenced by the hardware radio design.

4.6. DC power measurements

Table 6 contains tests that are related to the dc power taken by the DUT. Most DUT tests are made on the radio transmitter and receiver. These tests check the overall "health" of the DUT by looking at the current drawn by the DUT in each of its operating states. The current measurement can tell you if the device is generally operating properly. These current tests can be challenging because WLAN transceivers generate pulsed currents that require specialized equipment to accurately measure the current.

Item	Objective	Method/process
Absolute PER/FER (frame error rate)	Ensure the consumer is not left disappointed at their system performance.	The receiver's performance is tested at a specified input level.
	In systems with power control, radios with good sensitivity require less transmit power from the sender, which avoids unnecessary interference and extends battery life.	802.11 receivers are "one-way." This is in contrast to loop back techniques used in GSM and *Bluetooth.* The test signal applied to the DUT's RF receiver is recovered by the DUT baseband DSP (digital signal processor) and fed to vendor- specific software, which provides the result. The measurement process needs to be synchronized by external software.
		Generally, the receiver will be placed in a special mode that will inhibit normal 802.11 MAC system responses, and remove the need for association/authentication.
		1. Place DUT receiver in test mode according to the software supplied.
		2. Perform the test on B, M and T channels, or (if known from design) worst channel; for example, a channel that is at a multiple of a clock harmonic.
		3. Transmit a test pattern that will be recognized by the DUT and SW. Ideally, this will use a combination of modulation formats (for example, BPSK and 64QAM) to give process control information.
		4. Adjust RF signal level to suit the modulation format.
		5. Transmit sufficient number of packets(often > 1000) to provide stable reading.
Receiver sensitivity	Get the process information needed to optimize device performance, and provide evidence to support the marketing and sales processes.	The RF level is varied to find where the receiver reaches a specific BER/PER level. The test process is very similar to the absolute measurement. Instead of a simple stepping down in RF level, several techniques, such as binary search, may be used to speed up the process.
Absolute BER	Same as PER/FER above. BER testing is usually faster than PER testing.	The possibility of BER testing depends on the availability of test software from the IC vendor. The process will be very similar to PER testing.
		Test limits should be based on the relationship between BER and PER. This information should come from the design team. For the same RF level going into the receiver, the BER level should be orders of magnitude lower than the PER/FER level.
		Setting a low test limit (for example, 10^{-5}) for the BER test will reduce some of the benefit of fast test time, because more bits have to be recovered before a stable result is achieved.
Max input level	The user may find it difficult to understand performance problems when devices are close to each other, and therefore believe a device to be faulty. This would result in it being returned to the supplier, and the costs associated with tracking down a "false" failure. A screening test prevents this possibility.	The same process is used as for absolute sensitivity.

Table 4. Test application

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Item	Objective	Method/process
Power versus time	Avoid interoperability problems between 802.11 devices. Ensure variations in devices (and interaction with firmware) do not cause unexpected burst profile.	A bursted signal is transmitted, and a check made for preburst energy, extended transmission time or slow power ramping. 1. Transmit framed sequence with PN payload. 2. Use wideband analyzer to capture signal and synchronize to training sequence. 3. Confirm the burst fits within predefined mask.
Peak power	Ensure the user sees fastest data transfers possible, and reduced battery consumption for certain amount of work. Ensure transmit chain is capable of delivering undistorted signal, and therefore capable of delivering most complex signal (for example, 64QAM) at the expected power level.	NOTE: Peak measurements are generally susceptible to variations due to length of measurement, noise and deliberately reduce the peak-average power ratio using signal pre-distortion. 1. Transmit a bursted signal at highest power, on Top channel, with most complex modulation format. Use PN payload. 2. Measure at least 100 bursts, and use CCDF display to assess performance. 3. Compare to predetermined limits.
Out-of-band spurious	Ensure that unexpected component performance variations and interaction (especially through signal coupling) do not cause failure of regulatory limits.	This kind of test can be time-consuming to run, and therefore requires attention to minimize the need for it. Understanding of the design and early testing will have identified the frequency ranges most prone to being close to acceptable performance limits. The test margins that should be applied will also depend on a knowledge of the change in the level of unwanted signals with temperature. 1. Transmit signal using the channel most prone to create unwanted frequency components. 2. Perform swept- or spot-frequency level checks 3. Compare with test limits.
Harmonics	As above. Poor harmonic performance can cause power detection / measurement problems.	As above.
Spectral flatness	Ensure overall system performance is not degraded because of signal equalizing problems in the receiver.	Measure the variations in level between OFMD subcarriers using the equalizer corrections known to the tester. 1. Transmit test pattern. 2. Use wideband analyzer to provide flatness result. 3. Compare to predetermined limits.
Center frequency leakage	This may be used as part of the normal testing. Avoid interoperability problems with systems using zero IF receiver chains.	Ideally, there will be no signal at the channel center frequency. A comparison is made of the actual level and that of the rest of the sub-carriers. 1. Transmit test pattern. 2. Use wideband signal analyzer to compare level of channel 0 with total signal reference level. 3. Compare to predetermined limits.

Table 5. Tests used during initial manufacture, or when any part of the process or component supply changes

Item	Objective	Method/process
Initial operability check	Determine if DUT has manufacturing flaws that cause it to draw excessive current when in initial power-up state.	Apply power to the DUT. Measure dc current. If above expected value, the DUT has an internal short or unexpected current draw.
Active / transmit - receive current	Determine if DUT is operating within expected parameters during active operation.	Place DUT in active state (via test interface or by simulating network operation over RF). Measure the dc value and peak value. Requires: • Ability to capture and measure ampere-level peak current. • Ability to control integration time of pulsed-current measurement to simultaneously ensure fast test throughput and maintain measurement accuracy.
Standby/doze current	Determine if DUT is operating within expected parameters during standby/doze operation. dc value and peak value.	Place DUT in standby state (via test interface or by simulating network operation over RF). Measure the Requires: • Ability to capture and measure milliamp-level dc current with hundreds s of mAs of peak current. • Ability to control integration time of pulsed-current measurement to simultaneously ensure fast test throughput and maintain measurement accuracy.
Off / power-down current	Determine if DUT is operating within expected parameters during off state.	Place DUT in off/power-down state. Measure the dc value. Requires the ability to accurately measure currents in the microampere range.

Table 6. Common current consumption tests

5. Manufacturing test approaches

This application note is geared towards running performance tests that are reliable, flexible and repeatable, even in very high volume. The equipment described is "off-the-shelf". An alternative approach is often used for 802.11 devices. It involves a mix of test equipment and the use of "Golden Radios". These are proprietary units, designed to test WLAN devices using one specific IC vendor's components. The benefits and drawbacks of the two approaches are described in some detail in table 6. Direct capital cost is frequently considered the biggest factor, but the reader is urged to consider carefully the issues in this section, before finally making a decision. Particularly if it is likely more than one type of WLAN card is to be manufactured.

5.1. Manufacturing test metrics

The manufacturing metrics for most electronics products are applicable for WLAN devices. While this document does not address all of them, two of the most important – yield and cost of test – are discussed below. Since this application note focuses on board test and final test of WLAN devices, it is important to examine how the selection of the test system affects yield and cost of test.

Yield is defined as follows:

(# of shipped units) / (# of manufactured units) *100 = percentage yield

One key aspect of the test system is measurement uncertainty. The amount of measurement uncertainty in the system has a direct effect on the test limits used to determine pass/fail criteria. Test limits are based on the WLAN specification. Engineering judgment is applied to determine how those test limits change due to factors such as DUT design and measurement uncertainty in the test system. Often, the IC vendor will recommend these test limits, and care may be needed to avoid problems due to differences in test equipment performance between the vendor's configuration and your manufacturing line's test configuration.

Engineering has two choices in addressing measurement uncertainty: 1) maintaining test limits according to the specification, or 2) altering them. As measurement uncertainty becomes larger, holding the test limits to the specification translates to less margin for DUT performance. This decreased margin can lead to false failures – devices that are within specification but fail test due to measurement uncertainty in the test system. False failures have a direct impact on yield since they reduce the number of shipped units. The absolute accuracy of test equipment can improve yield because of the consistency it gives.

Figure 7 shows how DUT performance and measurement uncertainty combine to determine the Test limits.

Figure 7. Measuring for uncertainty.

To lower the number of false failures, engineering could decide to alter the test limit to make it easier for units to pass. Altering the test limit could result in false passes – devices that do not meet specification but pass test due to a measurement anomaly. This results in a poorly performing device and a dissatisfied customer. Neither false passes nor false failures are desired on the manufacturing test line.
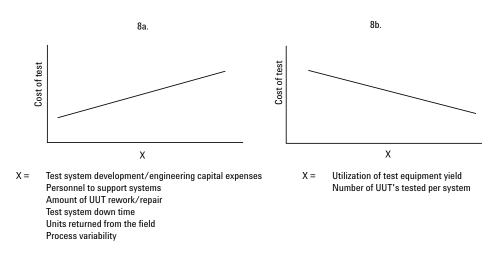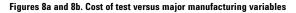
5.2. Cost of test

Cost of test is loosely defined as follows:

  (Σ factors that contribute to testing overhead) / (# of units tested) = cost of test

Cost of test is a large subject on its own, so this document will only mention some of the factors that affect cost of test. These factors include:

- test system development/engineering (that is, engineering invested in creating the system and getting it running)
- capital expenses for test equipment
- number of different WLAN devices that can be tested (requires system flexibility)
- utilization of test equipment (including idle time during test and test time optimization)
- personnel required to support systems (that is, number of technicians and engineers)
- amount of DUT rework/repair
- test system downtime due to calibration, repair, maintenance, line change over or other causes
- units returned from the field (such as false passes and DOAs)
- quantity of passing DUTs tested per system (yield)
- process variability

8a.

8b.

X =   Test system development/engineering capital expenses
Personnel to support systems
Amount of UUT rework/repair
Test system down time
Units returned from the field
Process variability

X =   Utilization of test equipment yield
Number of UUT's tested per system

Figures 8a and 8b. Cost of test versus major manufacturing variables

Ideally, manufacturing test systems would have the best performance available, allowing the largest test limit margins and resulting in the lowest number of false failures. The test system should also be able to test complete functionality of the DUT, guaranteeing superior performance. Of course, a balance between yield, testing performance parameters (thoroughness of test) and cost of test is also desirable. How much test is required to provide confidence in the final product while achieving an acceptable profit margin? A careful trade off is needed to avoid restricting the budget for test equipment if it means poorer yields.

5.3. Deciding on a manufacturing test approach

The selection of the test approach will have a significant impact on the capital equipment costs of the test system. The architecture of the test system will impact the test limit margin, throughput, test coverage, and flexibility of the test system to test new designs.

As noted earlier, the two major approaches are: test systems based on a golden radio, and test systems based on standard test equipment.

5.3.1. Golden radio

This approach uses the "golden radio" to generate RF signals for testing the DUT's receiver, and recovering data from the DUT to make a transmitter packet error test. It gives a test system that is usually only suitable for one manufacturer's devices. Historically this has reflected the small number of suppliers of 802.11 ICs, but the situation is changing rapidly.

The "golden radio" is another WLAN device, from the manufacturer of the one you want to test. It is specially adapted to have the connections [e.g., RF] and test signals needed. These vary from one manufacturer to another, as does the exact test process and tests provided. All of these must be provided and supported by the IC vendor. Externally, the RF signals have to be fed through step attenuators and other connections to mate with the DUT. The golden radio must be in an RF screened enclosure to give repeatable results. For example there must be no RF leakage from the golden radio to the DUT that would bypass the external attenuators. Test equipment, typically a spectrum analyzer and power meter, is also used.

The non-standard tests used include TxPER and RxPER. Transmitter modulation is measured using TxPER, instead of EVM. The golden radio's receiver is used to recover the signal, and the result therefore depends on the performance from the particular device and manufacturer.

The DUT receiver sensitivity is measured by using the golden radio's transmitter, with external attenuation, as a test source. Any imperfections have to allowed for, and variations may be seen if the RF test signal is not well controlled.

5.3.2 Standard test equipment

This approach uses a standard signal generator to create the RF signals for the DUT receiver test. Adding new bands of modulation formats becomes a matter of modifying the software.

Equipment that is capable of analyzing signals of 20 MHz bandwidth or wider is only relatively recently available. The capital costs can be higher, but provide a system that is flexible in terms of the devices and technologies it can test. Figure 4 shows a possible equipment configuration. Relevant tests are described in Section 4.

Switching from using a golden radio for receiver testing can be made easier using the wide capabilities of the ESG signal generator. For example, feeding the golden radio's base-band signals to the ESG modulation inputs will remove the uncertainty due to RF variations.

Table 7 may help you decide how to implement manufacturing test for 802.11a/g modules.

Issue	Using a golden radio	Using standard test equipment
Ease of introduction of a new technology into manufacturing	Can be fast and effective, if it is possible to define and implement test modes that are designed with knowledge of a specific DUT. The cost in engineering effort to support proprietary systems quickly mounts as manufacturing volume increases.	General purpose equipment gives the best basis for dealing with changing requirements. Technology-specific test equipment must be able to operate with multiple designs; needs broad agreement on how the test cases will work; and implementation detail has to be worked through.
Extending coverage for new technologies/ frequencies	Additional radio hardware has to be added, which will complicate the system configuration, calibration and support. Finely tuned radio circuitry may have problems tuning across wide RF bands, such as those found at 5 GHz, and providing adequate performance.	This may require some enhancements to the test equipment, but otherwise can be quite straightforward. For example, testing an 802.11g PHY (physical layer device) simply involves programming in a new frequency when using the Agilent 89641A signal analyzer. Once acquired, the use of flexible equipment can give significant pay back if the test requirements change when a new device is to be built.
Knowledge transfer – Learning and debugging new products to be tested	Requires intimate knowledge of the way the DUT is controlled. It can be difficult to get the information needed to understand why performance is changing, unless the Test Software used with the golden radio is designed with this in mind.	Allows a user to start with a familiar environment, and know what to expect. It is possible to analyze both acceptable and unacceptable test signals, and understand what has changed. The test equipment gives a device-independent view of performance.
Measurement techniques	There is a cost in explaining to customers/ users what proprietary techniques are doing, why they are needed, and what they involve. The techniques adopted are likely to be very specific to an individual design, and therefore change if a customer needs to deal with multiple vendors' devices.	Numerous measurement methods have been developed to suit new generation radio standards. A lot of effort is invested in algorithm proving and development. Use of industry standard approaches, such as EVM for OFDM in video and 802.11, makes it more straightforward for engineers to migrate from one technology to another, and therefore less time is spent understanding the measurement.
Calibration of the system / repeatability of results	Anything that is not calibrated in the measurement system will lead to variations both in that system, and from one system to another. This can give indeterminate differences in yield. The amount and frequency of calibration required will depend on the performance of the golden radio. It also depends on all the associated RF cables, combiners and attenuators. This can cause considerable cost and delays when inexperienced operators fail to use the system correctly. False failures may require expensive engineering time to resolve. Shipment of incorrectly tested equipment may be even more costly.	One of the main values of test equipment is that it addresses the issues associated with calibration. It is designed to meet certain specifications, and processes have been established to make calibration straightforward.

Table 7. Issues relating to the use of a golden radio or standard test equipment

Issue	Using a golden radio	Using standard test equipment
Worldwide support	With more narrowly targeted technologies, the number of people who need to learn about the manufacturing process is constrained. For standards looking to large-scale deployment, it takes considerable effort for the vendor to provide the level of support needed. Priority calls between customers and conflicts with main-stream product development have been known to cause delays.	It is possible to rely on the support processes that have been established worldwide for all the other test equipment being supplied. Supplying test equipment also involves explaining how it operates, and providing services to improve how well it is used. Experience can also be brought from one technology to another. For example, wide experience in the manufacturing test of GSM cellular phones can give an excellent basis for understanding the issues with manufacturing other radio transceivers.
Speed of test/ throughput	Some initial optimization is possible, depending on what test functions are available. How far this proceeds depends on customer demand and engineering availability. Due to the proprietary nature of the test configurations, it can be more difficult to enhance the test routines as manufacturing becomes more mature.	Measurements can capture and analyze all the data from individual bursts, giving the potential for the fastest possible measurements.
Cost of equipment	This can look attractive early on when considering capital expenditure. It is far less clear what the true costs are when the engineering to create and support the system is factored in. This is likely to be a distraction from areas of core importance.	The total costs are usually more clearly understood. Depending on what kind of equipment is used, it can be (re-)applied to deal with many different technologies as the manufacturing line requirements change. This flexibility can be vital in some manufacturing environments, especially contract manufacturing.
Process control feedback	This depends entirely on what the system was designed to deal with. As golden radios tend to lack flexibility, it is difficult to expand test cases when it becomes clear a process variation has occurred and needs to be monitored.	Standard test equipment provides the basis for creating traceable measurements. The equipment will have been developed through a process that is designed to allow problem analysis. It is therefore far more likely to provide the information needed for process improvements.
Accuracy of results	The golden radio will not be built under the controlled, traceable conditions of standard test devices. Providing accurate results requires proprietary development effort to ensure sufficient performance is provided and maintained over time.	Calibration is a fundamental element of providing test equipment.

Table 7 (continued). Issues relating to the use of a golden radio or standard test equipment

Appendix – equipment selection guide

	ESG Signal Generator	ESA Spectrum Analyzer	E8421A Wireless Test Fixture	Mobile Comms. DC Source	89600 VSA	EPM-P Power Meter	55181A Frequency Counter
Radio Calibration							
Power Level		X	X		X	X	
Frequency		X	X		X		X
Modulation		X	X		X		
RSSI	X		X				
Parametric Test on Transmitter Chain							
Power (Average)		X	X		X	X	
Frequency Error		X	X		X		
Modulation Error (EVM)					X		
Spectrum Mask		X	X		X		
Tx Packet Error Rate			X				
Antenna Diversity		X	X				
Receiver Test							
Absolute PER/FER	X		X				
Receiver Sensitivity	X		X				
Absolute BER	X		X				
Max Input Level	X		X				
Tests Common on Initial Mfg							
Power Vs Time					X		
Power (Peak)					X		
Spurious		X	X				
Harmonics		X	X				
Spectral Flatness					X		
Center Frequency Leakage		X	X		X		
DC Power Measurements							
Initial Operation Check		X	X	X			
Active/Transmit-Receive Current		X	X	X			
Standby/Doze Current		X	X	X			
Off/Power-Down current				X			

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