Speeding manufacturing test of WiMAX equipment

As WiMAX ramps to full volume production, reducing manufacturing test time becomes critical. But, WiMAX manufacturing test is still in its early stages. Hence, this article attempts to show that by optimizing the capability of the device under test's driver to generate special non-linked mode signals, in combination with advanced trigger and analysis methods, it can lead to test times that are many times faster than what is currently possible.

By Christian Olgaard

Testing of a wireless device under test (DUT) is critical for verification and validation so that the system correctly functions. However, the tests often include several different disciplines, and significant effort goes into making sure all functions of the DUT are validated, such as hardware, software and performance. WiMAX, as a relatively new standard, where devices are just becoming available, undergoes this type of testing.

Although much attention is given to the performance of DUT during development and characterization, little attention is typically given to the actual manufacturing test. Traditionally, manufacturing test is considered just a subset of the tests performed during the characterization and development. This may be correct to a certain degree, but the goal of manufacturing test is different.

Manufacturing test assumes that the device works correctly. And, therefore, offers a test procedure to identify assembly errors and bad components. After the design is released to manufacturing, it must be assumed that if assembled and calibrated correctly, the device will work correctly and according to specifications.

To optimize yield, a large portion of manufacturing test time is often devoted to calibration. Following the calibration, the calibration data results need to be verified in proper operation. In general, four categories of verification tests need to be performed:

1. System reference
2. Transmit
3. Receive
4. Dynamic switching (Tx to Rx and Rx to Tx)

Manufacturing tests should focus on verifying the performance of these blocks and not on testing the DUT operating as in the real system—again, the manufacturing test is to identify bad devices—not to verify good ones. A comparison between typical development test and manufacturing test is shown in Table 1.

Engineering Testing Objectives	Manufacturing Testing Objectives
■ Verify design theory ■ Verify product performance over temperature/voltages, etc. (DVT) ■ Verify standards compliance (FCC/ETSI, etc.)	■ Test for manufacturing defects, i.e., assembly errors (process/ components, etc.) ■ Calibration—increase yield (lower cost) ■ High coverage—test as many parameters as possible ■ Short test and calibration time

Table 1. Comparison between development tests and manufacturing tests.

Test of system reference

System reference requirements for base stations and subscriber stations are different. In a WiMAX system, the subscriber station locks its reference frequency to the base station's reference frequency. Therefore, the base station will use a fixed frequency, thus only the frequency accuracy of the reference matters. But, for the subscriber station, it must be verified that it can change its frequency reference to match the base station's.

The specification for the base station's reference is within 8 ppm over a period of 10 years. It is assumed that the base station manufacturer will use an expensive crystal oscillator (TCXO or possibly OCXO) that may be centered during manufacturing. As WiMAX equipment is relatively low cost, it is unlikely that the base station will be synchronized to, for example, a GPS signal. Hence, a simple one-time adjustment may be performed during manufacturing alignment.

Testing the subscriber station requires more testing. Naturally, the crystal should be centered as close as possible to 0 ppm error. However, it is easy to imagine a scenario where a component was defective, but the crystal frequency happens to be exact. The "adjustment" would pass, but in real operation, the frequency cannot be adjusted, so a link may not be established. Consequently, it is important to verify that the crystal can be adjusted ±8 ppm including some margin before, and the center frequency of the crystal to be close to 0 ppm. A traditional link-based test setup is not likely to fully verify the span of the crystal tuning, as it will simply check that the link can be established. A wrongly mounted component (e.g., reversed varactor) can, in some cases, result in a shift of the tuning range, causing only partial coverage of the tuning range.

Traditionally, frequency adjustment is performed using a spectrum analyzer with the DUT transmitting a CW signal. Using VSA-based test equipment combined with advanced signal analysis capability enables the equipment to extract the frequency error from a real WiMAX signal. Therefore, the crystal test can be combined with a transmitter measurement, which reduces the number of tests required.

Transmitter calibration and test

Testing the transmitter involves alignment of the gain and other parameters followed by some verification. WiMAX has significantly tighter requirements than 802.11. The transmit quality (EVM) limit is –30 dB (-31 dB for a base station DUT) compared to the –25 dB for the equivalent 802.11 signal. EVM combines contributions from phase noise, IQ mismatch, compression and available SNR into a single quality measure. However, only two parameters can normally be adjusted during manufacturing: compression and IQ mismatch.

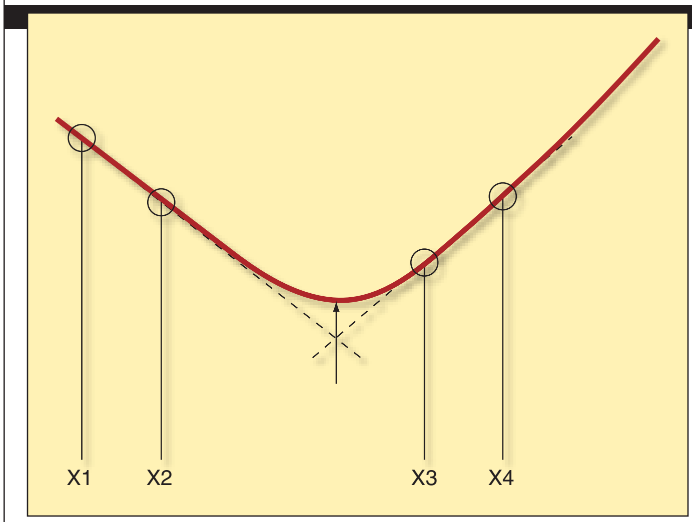

Figure 1. Illustration of optimization of dc offset.

Compression can be traded off vs. output power and power consumption by adjusting the gain of the different gain stages in the transmit chain. Depending on the RF architecture, an IQ mismatch adjustment may need to be included. Early WiMAX solutions use a digitized, relatively low-frequency IF interface (in the 40 MHz range). Digitized IF interface ensures perfect IQ mismatch. However, the digital IF architecture is usually higher cost due to the need for an IF filter, which cannot easily be included on-chip.

On the other hand, direct-conversion architecture enables full integration so it is often used in newer system architectures. In direct conversion, the translation from digital domain to analog happens before the IQ components are combined in the analog domain. This can introduce IQ-mismatch. However, these impairments can be compensated during the transmitter alignment by offsetting the IQ signals in the digital domain.

Traditionally, IQ mismatch has been measured and calibrated in terms of undesired sideband rejection of a CW signal. The undesired sideband suppression measurement has the problem that cannot be easily identified if the undesired sideband component originates from amplitude mismatch or phase mismatch. Therefore, the alignment is usually broken into an optimization of the amplitude mismatch followed by an optimization of the phase. In some cases, one will need to iterate several times before achieving the needed suppression. Additionally, the optimized values only work for a single frequency, which may not result in the optimal IQ mismatch for the full WiMAX signal.

Using a VSA and advanced analysis capability it is possible to derive the individual amplitude and phase error in a transmitted WiMAX signal. This opens the option of optimizing the amplitude and phase errors in parallel, thus faster test time. The compensation factors will usually exhibit a linear relationship with phase and amplitude, so simple algorithms can be used. Furthermore, as the alignment is performed on a WiMAX signal, alignment should yield the best overall IQ mismatch. Again, this can be combined with other measurements like EVM, frequency error, transmit power, etc.

WiMAX has a relatively relaxed requirement for carrier leakage of –15 dB relative to the total transmitted power. Most systems can usually reach this level by design. However, the carrier leakage can also be optimized by adjusting the dc offset on the I and Q signals. Traditionally, the dc offset adjustment can be performed using a CW signal. A commonly used algorithm uses four measurements to extrapolate the optimal register setting for either the I channel or the Q channel (Figure 1).

It should be stressed that the figure uses linear voltage scale on the Y axis, so if using a spectrum analyzer for optimization, the measured result will need to be transformed before extrapolating the optimum result. Four points are measured, and the optimal compensation value is derived for the I channel, where after the process is repeated for the Q channel (using the found I value). Alternatively, using advanced signal analysis it is possible to extract the individual I and Q contribution of the dc offset from a WiMAX signal, under the assumption that the offset is not excessive.

Relative Power Change	Accuracy
0-15 dB step	±1.5 dB
15-30 dB step	±3 dB
>30 dB step	±5 dB

Table 2. Relative power accuracy requirement.

Power accuracy

The transmit power calibration is usually the most complex. WiMAX has strict requirements on power accuracy. The specification defines that the subscriber station must report its maximum power capability to the base station along with the current transmit level. However, the real specification is defined in terms of accuracy of changes in power. This comes from the fact that WiMAX uses power control in the system, trying to control the power at the base station. The network will request the subscriber stations to change power in relative terms rather than in absolute terms.

In case of an 802.16d subscriber station, the output power must be controlled over a range of more than 50 dB with tight relative step accuracy. The latest specification has relaxed this somewhat to the accuracy depicted in Table 2.

Two types of transmit calibration may be needed. First of all, the output power capability must be adjusted so the needed transmit quality is maintained over the full transmit power range. In most cases, it will be sufficient to verify the transmit quality (EVM) at maximum power. This usually involves adjusting the power to the maximum level and then verifying that the transmitter does not compress too much at the peak levels of the transmitted signal.

Measuring absolute power is a problem because the WiMAX preamble has 3 dB higher power than the payload. As a result, the transmitted power will change with the length of the packet when measuring power of the full packet. Naturally, when measuring relative power this is less of an issue as long as the packet length remains constant. Still, the power properties of the payload portion must be considered. When transmitting QAM modulation (16 or 64), the power of each symbol will change with the data. Using traditional measurement methods will result in power variation from packet to packet; thus long averaging may be needed for accurate measurement. Subsequently, it is recommended to measure power using QPSK or BPSK modulated packets, as the power of each symbol is constant.

A still better way to measure the power is to measure the part of the preamble portion that contains a channel estimate symbol. This symbol has the property that all carriers have the same normalized power level. The preamble is 3 dB higher than the rms of the payload power. It should be stressed that the channel estimate symbol is designed to have significantly lower peak to average compared to the payload, so compression will not exist with the 3 dB higher power. Note, only the symbol itself should be measured, and not the full symbol duration (which includes additional guard time) to get the highest possible accuracy. Using a VSA combined with advanced signal analysis equipment enables analysis of specific symbols, thus the power can be measured fast with little need for averaging. The WiMAX specification also defines the spectral flatness. This measurement is also derived from the channel estimate symbol. Thus, the spectral flatness can be verified for free.

Traditionally, VSA-type instruments have lower power accuracy than power meters. This is usually correct in terms of absolute power compared to the best power meters (using thermal sensors to measure the higher peak to average of an OFDM signal). However, WiMAX specifies power accuracy in terms of relative power. In this case, the VSA can offer power measurement capabilities comparable to power meters. This comes from the fact that a linear receiver is used, so as

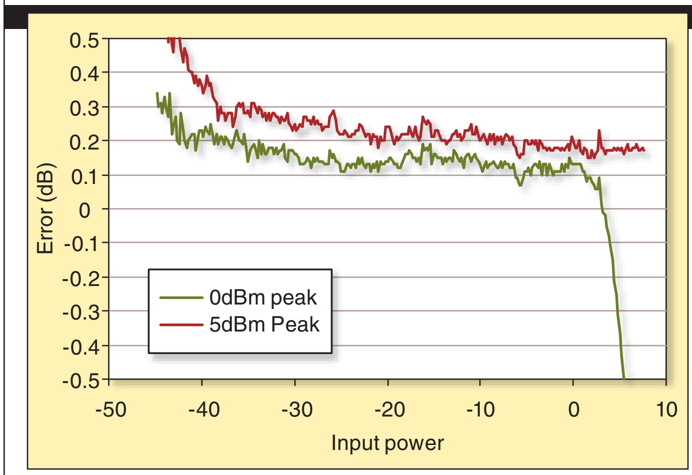

Figure 2. Example of measurement accuracy of VSA linear receiver.

long as the gain of the receiver is kept constant and the receiver will not compress, an accurate relative power measurement can be obtained. Figure 2 shows the input power swept for two constant VSA gains compared to a power meter. The measurement is performed using a CW input signal measured with the power meter and compared to the VSA reported power measured in 60 MHz bandwidth. As can be seen a small absolute error exists. However, it is clear that the relative accuracy of the input power is very high. At the low level, the power starts to deviate due to noise added from the high VSA measurement bandwidth. For the green curve (lower maximum input level), at high input power, the receiver enters compression causing the power to drop abruptly.

Receive calibration and test

For manufacturing test of a WiMAX receiver the receive noise figure (NF) needs to be verified that it is sufficient to meet the sensitivity requirements. As the analog bandwidth and number of carriers in the OFDM signal remain constant, the NF remains the same at all data rates. The only real variable in a manufacturing environment is the NF. The modem is implemented using DSP, and the analog filter does not change so the performance will not change. Given the receiver is tested at the same margin to the modem's PER curve for different data rates, it should only be necessary to test at a single data rate.

Typically, the receive NF will dominate the packet error rate (PER), but, in some cases, IQ mismatch and phase noise can further degrade the receiver's PER. Given this, the receiver should be tested at the highest data rate as the modem will be most sensitive to phase noise and IQ mismatch at this modulation.

As WiMAX uses power control, it must be ensured that the reported RSSI meets the specification. The specification calls for an absolute accuracy of ±4 dB over a –123 dBm to –40 dBm range and a relative accuracy of ±2 dB. Thus, the receiver's RSSI may need to be calibrated for accuracy, as well as calibrate the IQ mismatch for some receivers.

No standard way exists to perform these calibrations because they are chipset dependent. Therefore, it is important to have a flexible input source like a VSG during manufacturing, as it enables support of most chipsets by simply changing the input signal through software.

Non-link-based test

The above test can clearly be performed by monitoring communication between a subscriber station and a base station. For example, an attenuator and a power coupler can be added between the two and then "sniff" the signals going forward and back. A typical setup is shown in Figure 3. Alternatively, an instrument that implements one side of the link can be used to analyze the DUT. This is often considered the best possible setup as it tests the system as it will be used. However, manufacturing test is not to test the system, but to verify that the product assembly has been performed correctly and to calibrate the DUT. It should not be necessary to test the software portion during manufacturing. It must be assumed that the software works correctly.

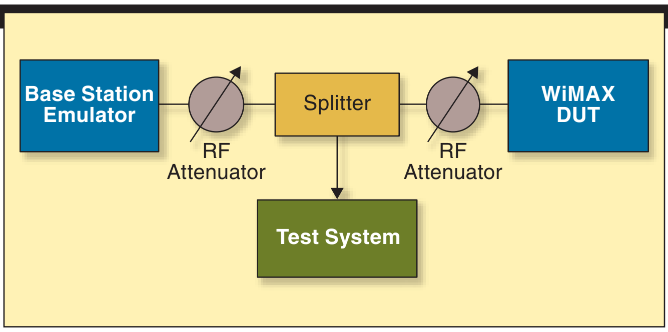

Figure 3. Typical link-based test.

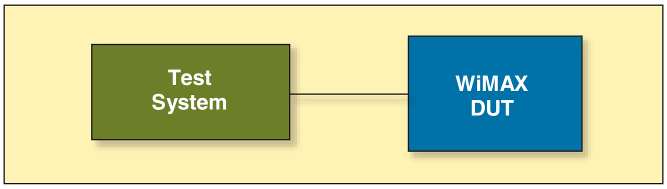

Figure 4. Typical non-link-based test setup.

The focus for manufacturing test should be to test as many parameters as possible in the time frame assigned to test. With this in mind, traditional link-based test does not offer a competitive solution. The link must be established before test can start, and this is essentially wasted time. Furthermore, establishing the link (which includes adjustment of the crystal) does not truly test the DUT's needed capability to adjust to ±8 ppm. If such a test is to be performed, a link will need to be established to link multiple times with different base station reference frequency. Compare this to two measurements of the reference frequency at the two extremes of the calibration range followed by a simple adjustment to a frequency close to the center. The latter is much faster and offers better test coverage.

It should also be clear from the above that all specified tests can be performed without an actual link established as long as the driver controlling the DUT supports a few simple commands. A typical non-link-based setup is shown in Figure 4. By forcing the operation using the driver commands, significantly more tests can be performed during the allocated test time. Furthermore, using advanced test equipment like the IQmax WiMAX test system, the test coverage can be increased further by using the advanced analysis features to obtain many test results from a single capture. For example, capturing a single WiMAX transmit packet can provide information about EVM, spectral mask, power, phase noise estimate, frequency error, spectral flatness etc. Compare this to using traditional instruments, where a power meter would first be used to measure power, a spectrum analyzer would then be used to measure spectral mask, after which it would be used in a different mode to measure frequency error (CW measurement).

A word of concern relates to Tx/Rx switching time. In some cases, PER is tested by sending a number of packets into the receiver and then request the number of packets received by the DUT. This is clearly a test verifying the receiver's NF (actually PER) is lower than a given value. Similarly, the transmitter can be requested to transmit WiMAX packets and analyze transmit quality, power, etc. to verify that the receiver can receive and the transmitter can transmit within specification ensures that the Tx/Rx switch can switch to both positions. However, it does not necessarily guarantee that it can do so fast enough. Therefore, it is highly desired that the PER test be performed as in a real link.

Using advanced test instruments enable multiple analysis results from a single capture, increasing test coverage and test throughput. After analyzing a typical test flow, it is often found that it is not the test instrument that is the bottleneck in the non-link mode—it is the driver. Significant time is spent preparing the DUT to transmit a desired signal.

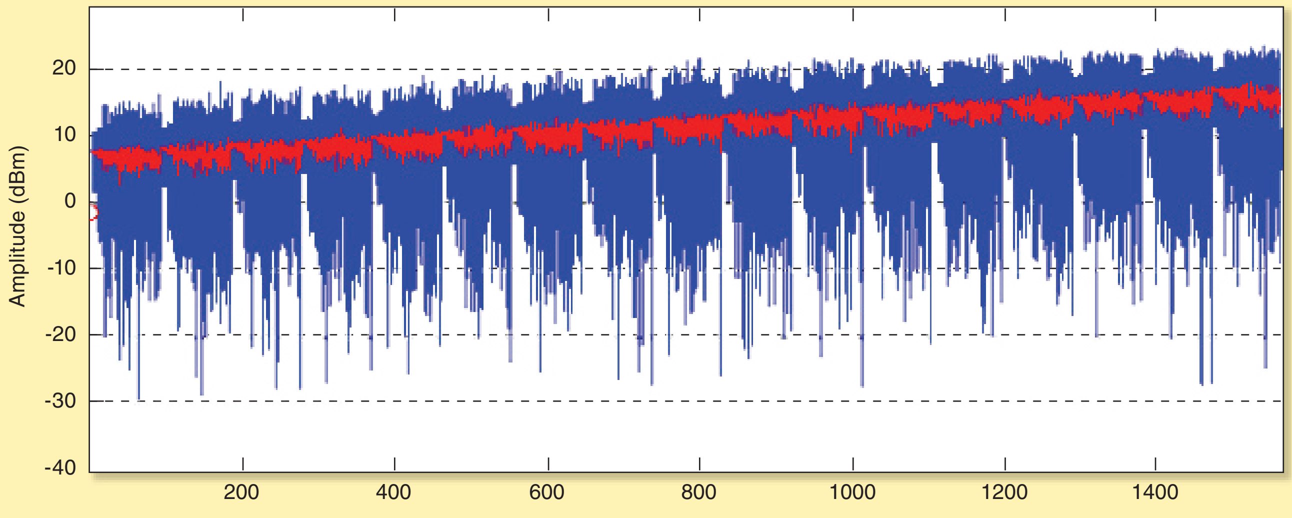

Figure 5. Example of captured signal with multiple power levels.

Having full control of the DUT through the driver and combining this with the capabilities of advanced test instruments opens new and significantly faster ways of testing. For example, rather than sending packets at a single transmit level a drive could define a function sending packets at different levels in a known sequence. By using advanced triggering schemes of IQmax the desired packets can be captured and obtain all test items for a single frequency in a single measurement.

Such test methods are currently being introduced for testing 802.11 devices where it shows great promise of dramatically reducing test time. An example of such a captured signal is shown in Figure 5. Such driver optimizations have yet to be introduced for WiMAX, but given the similarity between 802.11 and WiMAX, it should be possible to port the same type of driver call to a WiMAX DUT. The ability to generate such signals will yield test times much faster than what is currently possible. **RFD**

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