The test process for complete wireless systems, subsystems, and components is very complex. Ensuring successful testing from design optimization, troubleshooting, and validation through wireless standards compliance, in a way that is time- and cost-efficient, requires a comprehensive test approach.

The most productive approach must combine quick and easy standards-compliance tests with more thorough analysis and troubleshooting. It should be more comprehensive and stringent than is required by the standards, allowing problems to be directly linked to their cause so that engineers can manage margins and yields in manufacturing. This application brief will discuss techniques for isolating problems and optimizing wireless designs using comprehensive, high performance modulation analysis and troubleshooting beyond pass/fail testing. We will also cover considerations for selecting measurement tools capable of performing this type of testing.
Using EVM (Error Vector Magnitude) for Wireless System Troubleshooting and Optimization

Limitations of pass/fail testing

Pass/fail tests are very limiting in design environments where troubleshooting and optimization require the ability to:

- Understand error versus frequency or carrier and subcarrier
- Understand error versus time, symbol, or slot/frame for effective problem isolation
- Separate signal quality for different users in multiple-access schemes
- Account for incremental errors that can stack up in subsystems, margin for integration, and manufacturing tolerances

Benefits of breaking down EVM into separate elements

To illustrate the benefits of separating the error signal into its components, consider two examples that provide clear, intuitive insight by isolating errors in an orthogonal frequency-division multiplexing (OFDM) signal in the time and frequency domains.

Example 1: Error spectrum

As you can see in Figure 1, separate displays of error versus time and frequency clearly show the major source of error. In this OFDM example, error peaks are fairly evenly distributed over the OFDM slot or frame in the display on the left, but are concentrated on a single subcarrier or frequency in the trace on the right. The frequency-specific nature of the impairment suggests a strong internal spur or external interference at a frequency below the channel center, allowing us to draw the conclusion that the problem is narrowband interference.

Figure 1. Two error displays of the same OFDM signal frame. Error is plotted vs. time or symbol number (left) and vs. frequency or subcarrier number (right).
Example 2: Error time

Here, multiple channels are present sequentially in a single frame, and they use different modulation types. In Figure 2, the error peaks are spread across the error vector spectrum trace (right trace), but are concentrated at specific time intervals in the error vector time trace (left trace). Using the same blue color coding for an individual user in both displays, we can see here that the error arises from a single channel and modulation type, making it easy to isolate the problem.

![Figure 2. Two error displays of the same OFDM frame. The color makes it easy to separate the signal components and identify the source of the error](image-url)
Benefits of low EVM floor in signal analysis

Perhaps the major benefits of EVM are its sensitivity and linearity. It easily quantifies a range of small to medium errors, and can be evaluated at many points in the block diagram of wireless systems. It can also be separated into a number of error elements, as shown in the examples 1 and 2. Evaluating these error contributors and their relationship to others or to time and frequency can be very powerful aids in troubleshooting and system optimization.

The lowest EVM measurable by a signal analyzer is often called the EVM floor or residual EVM. While the EVM limits in wireless standards may be several percentage points higher, choosing a signal analyzer with the lowest EVM floor possible (well below 1%, even for wideband signals) will provide the most accurate results. A low EVM floor improves system margin, supports tighter specifications, and is compatible with higher-order modulation schemes. A signal analyzer with a low EVM floor can also be used to isolate the incremental error contributed by each individual stage in a wireless system.

It is important to select a signal analyzer with an EVM floor, specified at the frequency and bandwidth of your signal, which is at least 10 dB better than the standard defines for your signal. This margin ensures that the measurement error is not significant in modulation quality tests, and that results can be used with confidence in troubleshooting and system optimization.

Figure 3. An EVM measurement of a 160 MHz 802.11ac signal. The right signal analyzer should have adequate analysis bandwidth and the lowest EVM floor
Analyzer phase noise and EVM

Many modern wireless systems such as LTE and WLAN use an OFDM scheme for the physical layer. The implementation specifics vary widely, but all OFDM modulation schemes use a large number of closely-spaced subcarriers which are independently modulated. While OFDM has many benefits for practical wireless implementation, it places stringent demands on oscillator/synthesizer phase noise. Phase noise spreads the subcarriers out in the frequency domain and creates inter-carrier interference.

To understand the interaction of phase noise and pilot phase tracking in various elements of a wireless system, it is important to select a signal analyzer with minimal phase noise. As with EVM floor, excellent phase noise performance in the signal analyzer allows its contribution to measurement results to be ignored when measuring component and system performance, including EVM. Choosing a signal analyzer with minimal phase noise will also allow for flexibility in meeting more stringent standards and demanding signals in the future.

Figure 4. Choose a signal analyzer with the best phase noise in order to ensure the lowest EVM floor.
Effectively measuring wideband signals, multi-carrier signals, and carrier aggregation

While swept spectrum measurements may be made with maximum resolution bandwidths of 1-10 MHz, the digitizing bandwidths of signal analyzers for demodulation must be wide enough to handle the full bandwidth of the signals under test. For signal analyzers, the bandwidth specification is often called the maximum analysis bandwidth or maximum IF bandwidth.

The widest single-carrier bandwidth for many telecommunications signals and 802.11 a/b WLAN is approximately 20 MHz. Several newer standards, however, require even wider bandwidths. IEEE 802.11n and 802.11ac may use up to 40 and 160 MHz, respectively. Techniques such as carrier aggregation in LTE-advanced can involve multiple component carriers (CCs) spread across up to 100 MHz in contiguous configurations, and much wider bandwidths in noncontiguous configurations. Figure 5 shows demodulation of 5 CCs simultaneously, with multiple modulation schemes and constellations.

![Figure 5](image)

For power and space efficiency, some systems such as cellular base stations will support multiple independent carriers simultaneously, and these carriers may use independent modulation and multiple access schemes. If a signal analyzer has adequate digitizing bandwidth, specialized software in the signal analyzer can be used to demodulate these carriers simultaneously. Multi-carrier demodulation can be very useful in troubleshooting and optimizing complete system performance, where carriers may interact due to power, power supply, and thermal effects.
Use advanced demodulation and multiple displays to find problems and determine causes

Standard-specific measurement applications make it easy to configure compliant spectrum and modulation quality measurements and can also provide more in-depth measurements and displays, such as error spectrum and error summaries, color coded to help focus on specific signal elements. Signal analyzer measurement applications are typically optimized to provide embedded format-specific one-button measurements that are ideally suited for automated design verification and manufacturing test. Key attributes are simplicity of operation, speed, and pass/fail testing that complies with wireless standards.

Some measurement applications extend their analysis to combined time/frequency/modulation domain analysis, with multiple color-coded traces to provide better visibility into system operation and potential problems, well beyond spectrum and modulation quality measurements, as shown in Figure 6.

For the most advanced R&D and troubleshooting applications, modern wireless standards pose challenges that may be better addressed by powerful vector signal analysis software. This software may run as an embedded or external application in PC-based signal analyzers, along with other instruments and software that are used at different points in the wireless system and design cycle. The additional benefit is thus consistency in measurement algorithms and results, from baseband to RF, and from simulation to design validation.

Many wireless systems are implementing more complex physical layers including multiple carriers and subcarriers, multiple simultaneous users and modulation types, and capacity enhancement schemes such as MIMO. The appropriate vector signal analysis software is capable of more sophisticated analysis and display of signal environments, and can be used to find the root cause of issues in even the most complex systems.
For example, the display in Figure 7, includes measurement traces, detailed tables of errors and frame contents, and a detected allocations graphic (lower right) summarizing the LTE resource allocations and allowing a marker to correlate the resources with other signal elements. This multi-measurement, multi-display approach meets the challenges of highly multiplexed signals and MIMO schemes. With these easy-to-analyze displays, your knowledge about the system under test, and your ability to spot patterns, you can isolate your analysis to a particular user, modulation type, time interval, or other system resource.

Figure 7. Multiple, flexible modulation analysis results provide deeper insight into complex signals. Markers can be coupled across multiple traces and tabular results to correlate signal elements, timing, and impairments.
Optimize Your Wireless Designs with the Keysight MXA X-Series Signal Analyzer

The MXA is the optimum choice as you take new-generation wireless devices to market. It has the flexibility to quickly adapt to evolving test requirements, today and tomorrow. In R&D, characterize signals from virtually any wireless device quickly and confidently with up-to-date parametric or RF functional tests. To shorten design verification test times, the intuitive multi-touch interface minimizes measurement complexity, even when working with cutting-edge devices. In 4G manufacturing, the MXA helps you increase throughput and yield while minimizing costs with the fastest, most accurate signal and spectrum measurements in a midrange benchtop analyzer.

### N9020B MXA Signal Analyzer Configuration for Optimizing Wireless Designs

**Step 1. Select maximum frequency range (required option)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
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<tbody>
<tr>
<td>503</td>
<td>10 Hz to 3.6 GHz</td>
</tr>
<tr>
<td>508</td>
<td>10 Hz to 8.4 GHz</td>
</tr>
<tr>
<td>513</td>
<td>10 Hz to 13.6 GHz</td>
</tr>
<tr>
<td>526</td>
<td>10 Hz to 26.5 GHz</td>
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**Step 2. Add a preamplifier**

<table>
<thead>
<tr>
<th>Preamplifier options (select one)</th>
<th>Description</th>
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<tbody>
<tr>
<td>P03</td>
<td>100 kHz to 3.6 GHz</td>
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<tr>
<td>P08</td>
<td>100 kHz to 8.4 GHz</td>
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<tr>
<td>P13</td>
<td>100 kHz to 13.6 GHz</td>
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<td>P26</td>
<td>100 kHz to 26.5 GHz</td>
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**Step 3. Choose analysis bandwidth**

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<td>N9020B-B1X</td>
<td>125 MHz</td>
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<tr>
<td>N9020B-B1A</td>
<td>160 MHz</td>
</tr>
<tr>
<td>N9020B-B40</td>
<td>40 MHz</td>
</tr>
<tr>
<td>N9020B-B85</td>
<td>85 MHz</td>
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</table>

**Microwave preselector bypass**

| N9020B-MPB

**Step 4. Select software for testing the latest wireless standards**

<table>
<thead>
<tr>
<th>LTE/LTE-A FDD Measurement Application, Multi-touch UI</th>
<th>N9080C</th>
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<tbody>
<tr>
<td>LTE-Advanced TDD Measurement Application, Multi-touch UI</td>
<td>N9082C</td>
</tr>
<tr>
<td>W-CDMA/HSPA/HSPA+ Measurement Application, Multi-touch UI</td>
<td>N9073C</td>
</tr>
</tbody>
</table>

| 89600 VSA software for advanced multi-domain/standards analysis | 89601B |

**Other options**

| Noise floor extension (NFE) | NF2 |

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