# Analyzing Newly-Developed Signal Formats by Linking Design Software and Test Instrumentation

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Modern vector modulation schemes provide almost limitless freedom for the digital communications designer to tailor new signal formats to meet unique system requirements. Whether the design challenge centers on minimizing power consumption, maximizing data throughput, maintaining high security, or guaranteeing a robust link under adverse signal conditions, there are a wide variety of techniques and variations available to try. These may include new modulation types, advanced encoding schemes, choices of data rate and filtering topology, etc. The schemes may be well-established, or they may be newly-emerging or experimental.

Narrowing the pool of candidate signal formats down to a final selection is a science in itself. The successful designer will have to draw upon specialized expertise in fields ranging from physics and math all the way to economics and politics. Ultimately, when the day is done, the engineer will be called upon to verify actual signal performance under real-world conditions. The newer the signal format, the more difficult this task can be. This paper discusses techniques for addressing this problem by combining state of the art computational tools with advanced measurement and analysis tools.

# Agenda

- Design/Development Process and Available Tools
- Key Measurements for Digital Communications
- Case Study: Transmitter with New Signal Format
- Case Study: Wideband Receiver
- Practical Considerations for Simulation and Test
- Enhanced Connectivity Solutions



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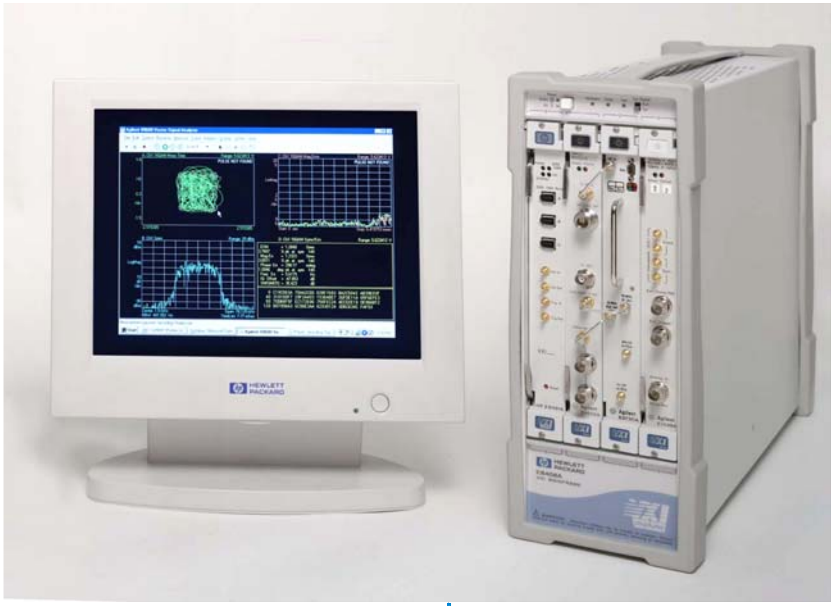
## Agilent 89600 Series Vector Signal Analyzers





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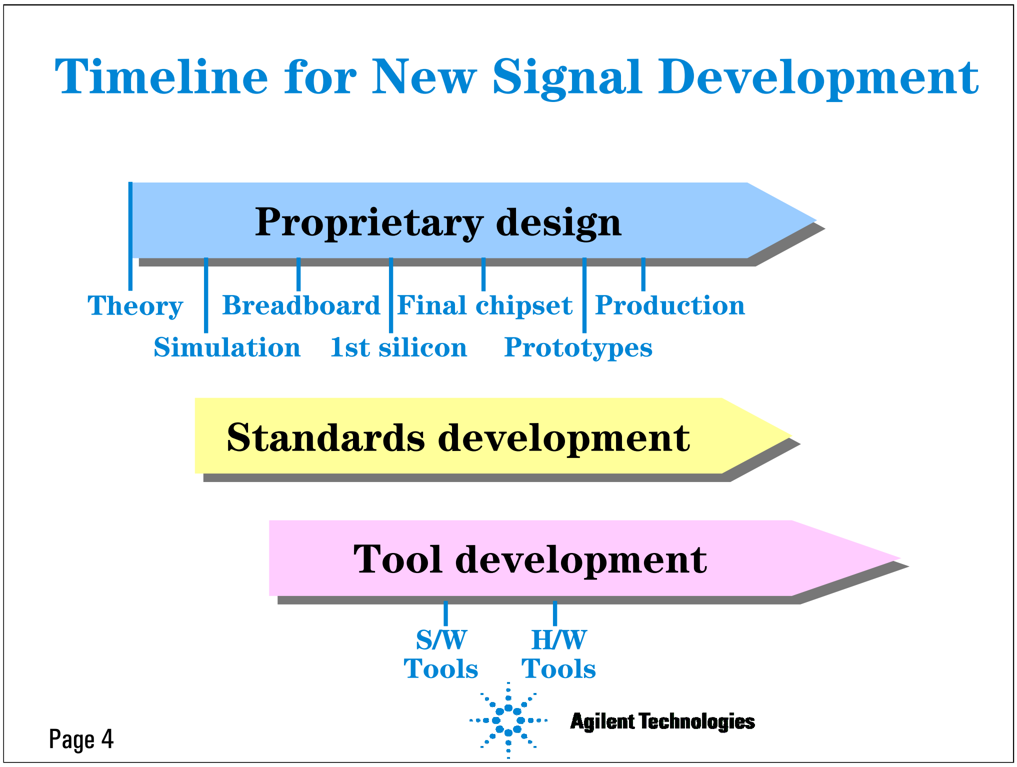
The concepts and examples in this presentation come from our customers' work with the 89400 series vector signal analyzers.

Extending and enhancing this connectivity (and making it much easier!) is one purpose of our newest vector signal analyzers, the 89600 series.

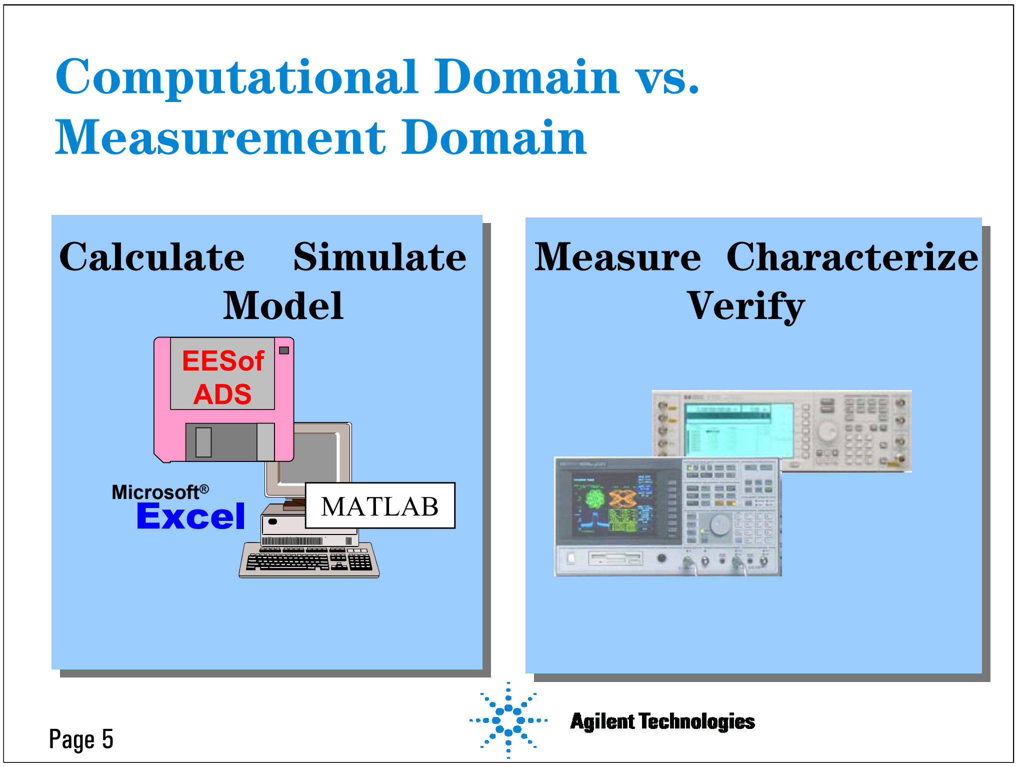
At the end of this presentation we will demonstrate several aspects of this enhanced connectivity, including a dynamic link of the new analyzer to Agilent's EESof Advanced Design System software.




Any new signal format is the product of evolution. Beginning from basic theories, the format is tweaked and verified mathematically. Breadboard models of a transmitter and receiver are then created and tested, first in the lab and eventually under field conditions. As the format is proven, it may be committed to silicon in the form of an RFIC, with or without an accompanying baseband DSP.

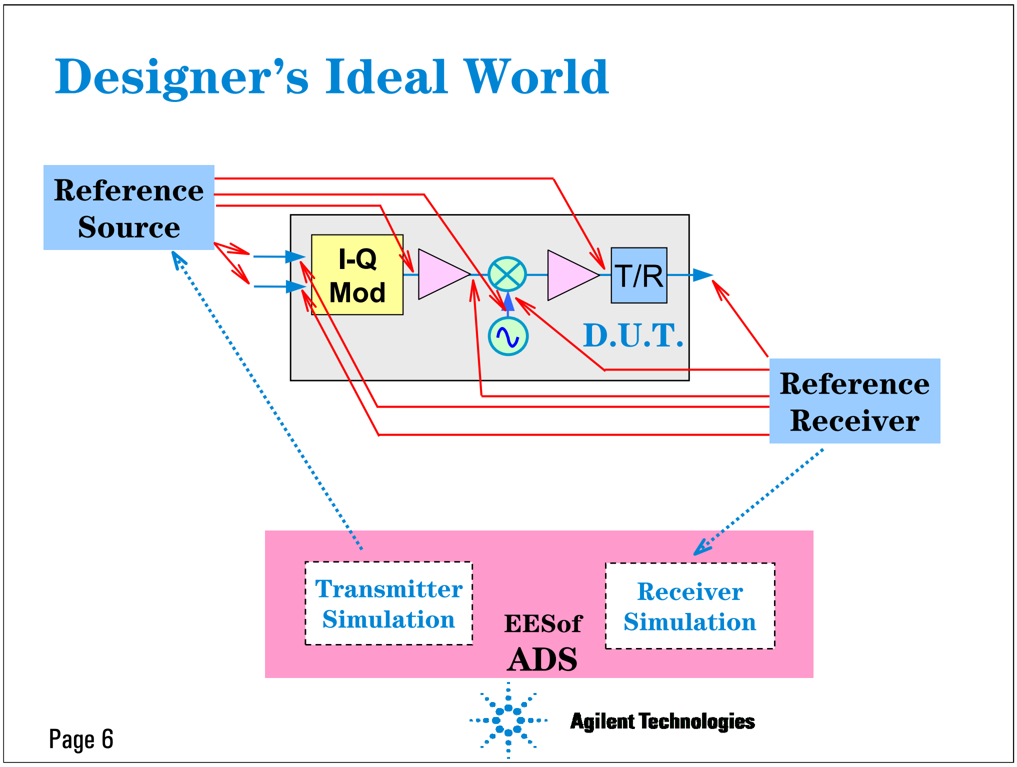
If the format is to progress beyond an in-house proprietary design, it is likely to join yet another evolutionary process, one associated with the development of industry standards. This may necessitate additional design, prototype and test cycles before a finished, fully compliant implementation is ready for the mass market.

During this period, there is yet another evolutionary process underway. Test and measurement companies such as Agilent Technologies are constantly scanning the market, trying to identify the upcoming new communication signal formats that their test instruments will need to accommodate. Developers of design automation software are doing the same, wanting to have the appropriate simulators, libraries and other tools ready to deliver as soon as the need develops.




In an ideal world, commercial design and test tools are available at the very instant the developers need them. To the degree that today's tools are highly flexible and quickly configurable to new signal formats, this ideal becomes actual reality in a good many cases. But in just as many other cases, the designer completes his/her first breadboard fully realizing that there is no signal analyzer sitting on the shelf that can measure and characterize the new signal format.

Fortunately, the situation is not hopeless. As described below, the same computational tools that enabled the new signal format to be developed and tested mathematically can be brought to bear on the testing of physical prototypes. In effect, we can bridge the gap between the purely *computational domain* of simulators and other math-based tools, and the *measurement domain* of physical signal sources and analyzers.




What are the benefits of enhanced connectivity and flexible measurement hardware? They could be described as better productivity and efficiency in the design process.

They might also be described as re-creating some of the best aspects of of the analog communications R&D environment, where a limited number of tools provided both ideal sources and receivers plus the ability to inject or measure signals almost anywhere in the block diagram.

In a design world of rapid, concurrent development these benefits can also be leveraged by the ability to move freely between simulation and hardware measurement. Prototype hardware elements can be measured as soon as they are created, even if other elements of the design exist only in simulation.

# Key Measurement Issue:
## Time vs. Frequency Domain

| Frequency Domain | Time Domain |
|---|---|
| • Average channel power | • Instantaneous power |
| • Adjacent, Alternate channel power | • Peak/average ratio, PDF |
| • Spurious, distortion | • Symbol timing & location |
| | • State transitions |
| | • I/Q offset, quadr. error |
| | • Coding errors |

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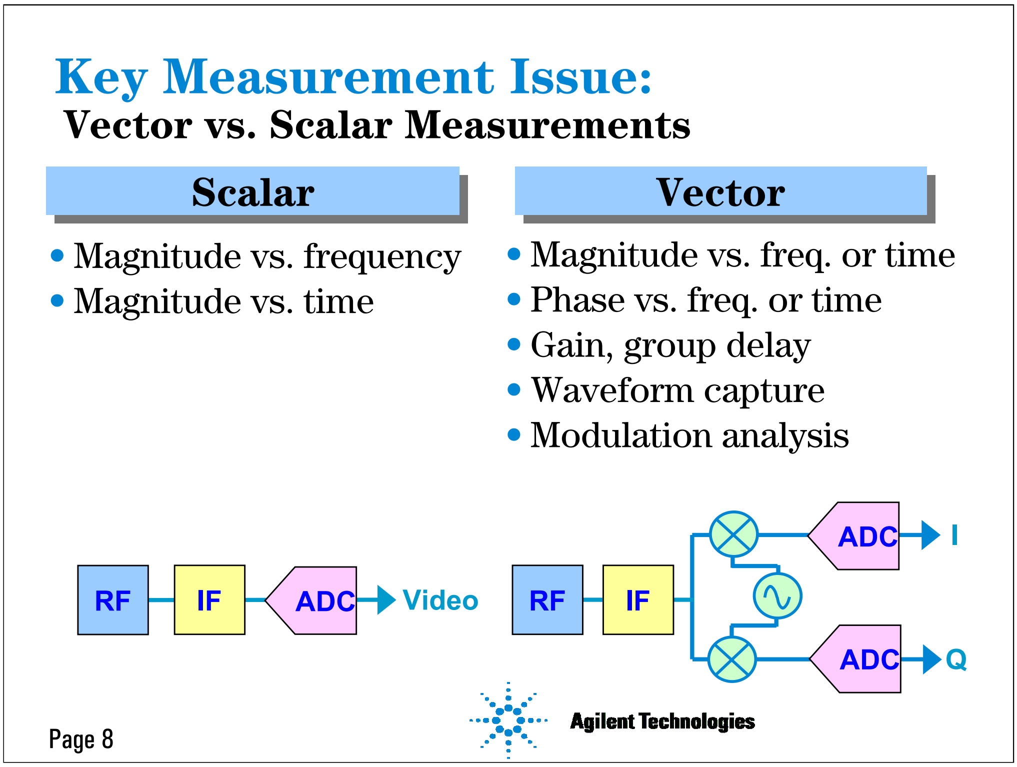
A few key concepts in digital comms signal measurements are worth reviewing.

Time and frequency domain representations of a signal are common and well-understood by all designers. However, it is worth noting the fact that, while many RF test instruments (e.g. traditional signal analyzers) are designed for frequency domain measurements, digital communications is largely a time domain problem. Most design automation tools do their fundamental work with time waveforms, not spectra. The signal will undoubtedly be realized in the time domain by the baseband DSP. And, its key measures of modulation quality are waveform-based.




Another concept with strong implications for the measurement domain test tools is the fact that vector-modulated signals are *complex*. Signals ranging from BPSK to 256QAM are alike in that their magnitude and phase vary simultaneously and independently. This presents two issues: first, it means that any signal analyzer, in order to be useful, must take care to detect, calibrate and display both the magnitude *and* the phase of the signal. Secondly, because it takes two channels (wires, cables, inputs, etc.) to carry a complex signal at baseband, a dual-channel architecture will always be needed to handle it.

# Quality Measures for Vector-Modulated Signals

| | Domain | Requirements Carr. Lock | Sym. Lock | Bits |
|---|---|---|---|---|
| Eye Diagram | time | yes | no | no |
| Constellation Diagram | time | yes | yes | no |
| Error Vector Magnitude | time | yes | yes | yes |
| Bit Error Rate | mod. | yes | yes | yes |

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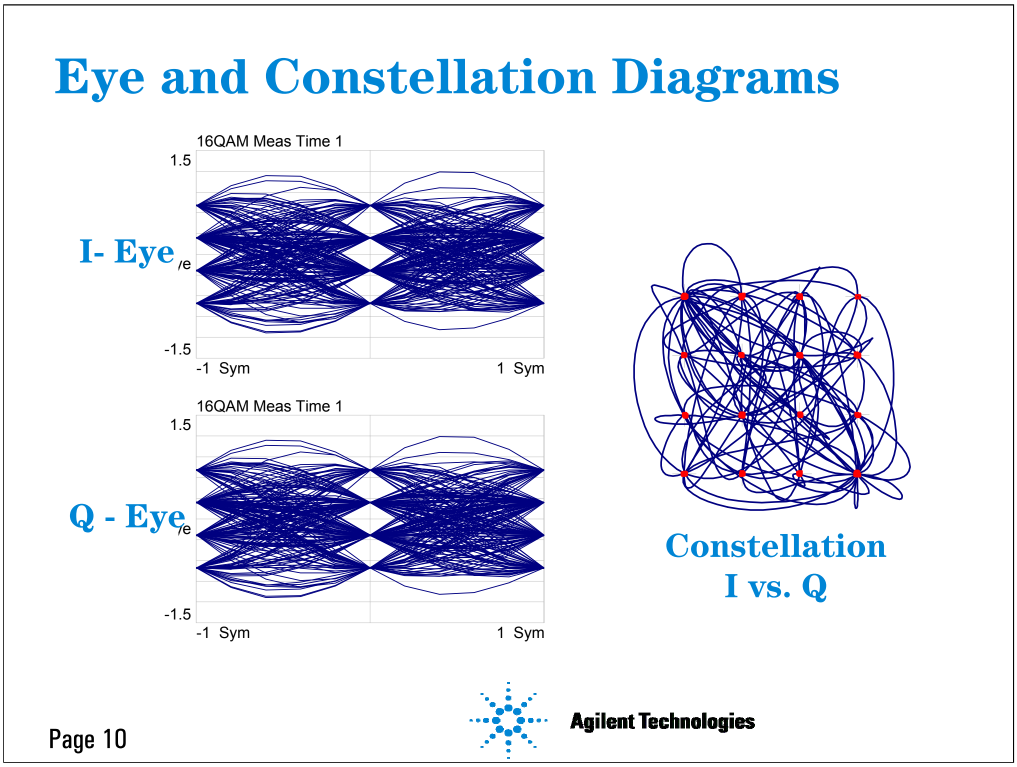
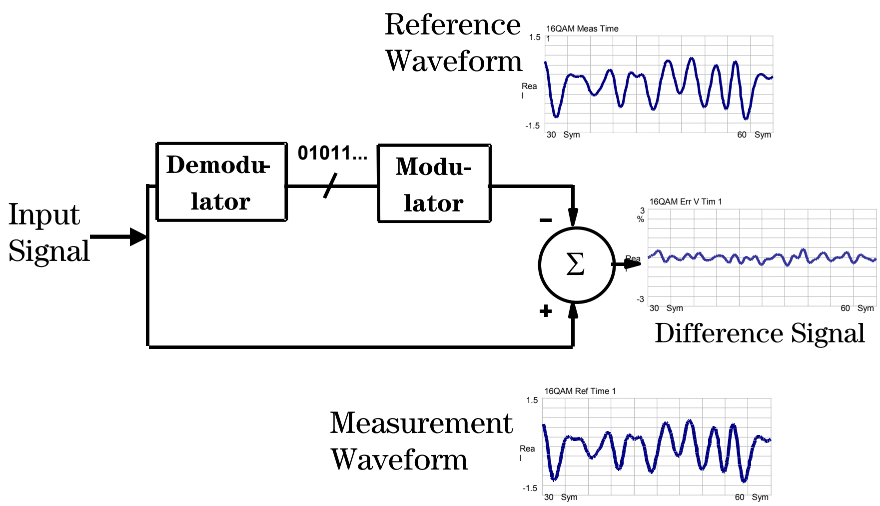
Finally, a review and comparison of the most common methods used to measure the quality of vector-modulated signals. Again, note that these are inherently based in the time domain.




The familiar eye diagram shows the amplitude separation of the symbol states. Creating this diagram requires only that the I and Q waveforms be recovered with a carrier-locked receiver and displayed, oscilloscope-like, in sync with the symbol clock.

The constellation diagram shows both I and Q, mapping both waveforms at once onto the I vs. Q plane. Creating dots at the precise symbol times adds measurement complexity, in that the symbol clock must either be supplied externally, or recovered and synchronized from the input signal itself.

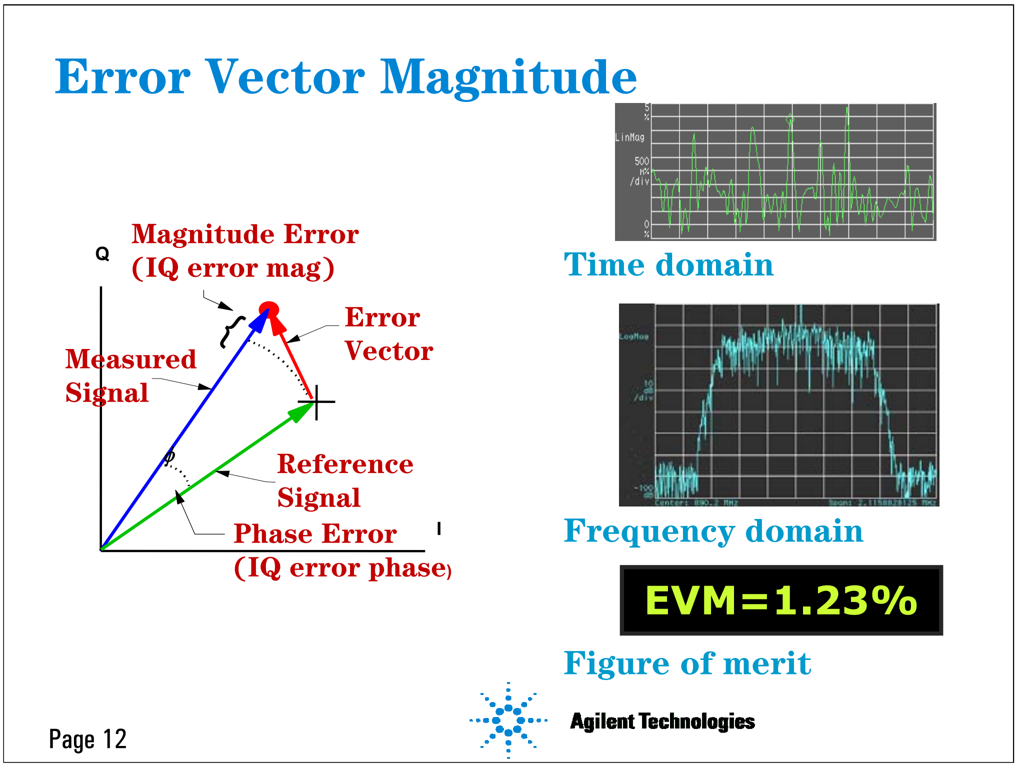
# Error Vector Magnitude








Error Vector Magnitude (EVM) is an increasingly important measure of modulation quality because: a) it is quantitative and repeatable; and b) displayed in various formats, it can be a highly sensitive indicator of exactly what types of problems are present in a signal. EVM measurements are made by recovering the incoming bitstream from the incoming signal, regenerating a perfect version of that signal, and calculating/displaying the vector difference between the real and ideal.




Error Vector Magnitude may be integrated in time to produce a single, average value, or it may displayed in the time or frequency domain.

# BER Measurements
## Measurement Characteristics

| Benefits | Drawbacks |
|---|---|
| • Intuitive, well-understood quality metric. | • Requires fully-operational systems receiver. |
| • Extremely sensitive to signal degradation. | • Sensitivity may require very long measurement times. |
| • Aggregates performance of multiple sub-systems. | • Does not provide much help in pin-pointing problems. |



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# Vector Signal Analysis

- RF downconversion and I-Q digitizing
- Obtain digitized baseband waveform files
- Spectrum, waveform, modulation analysis to 2.7 GHz
- Vector modulation analysis for nPSK, nFSK, MSK, nQAM, VSB, etc.

**Agilent 89400-series Vector Signal Analyzers**

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In answer to the measurement challenges of digital comms signals, Agilent/HP introduced the industry's first Vector Signal Analyzer several years ago. As the mainstay of many digital communications labs, it provides a wide variety of time, frequency and modulation domain measurements, and quickly characterizes most forms of modulated, bursted or even transient signals. As a modulation analyzer, it can be user-configured to make eye, constellation and EVM measurements on a wide variety of today's most common signal formats.

## Analyzing Newly-Developed Signal Formats by Linking Design Software and Test Instrumentation

- **Case Study #1:**
  Transmitter hardware characterization

- **Case Study #2:**
  Receiver hardware characterization

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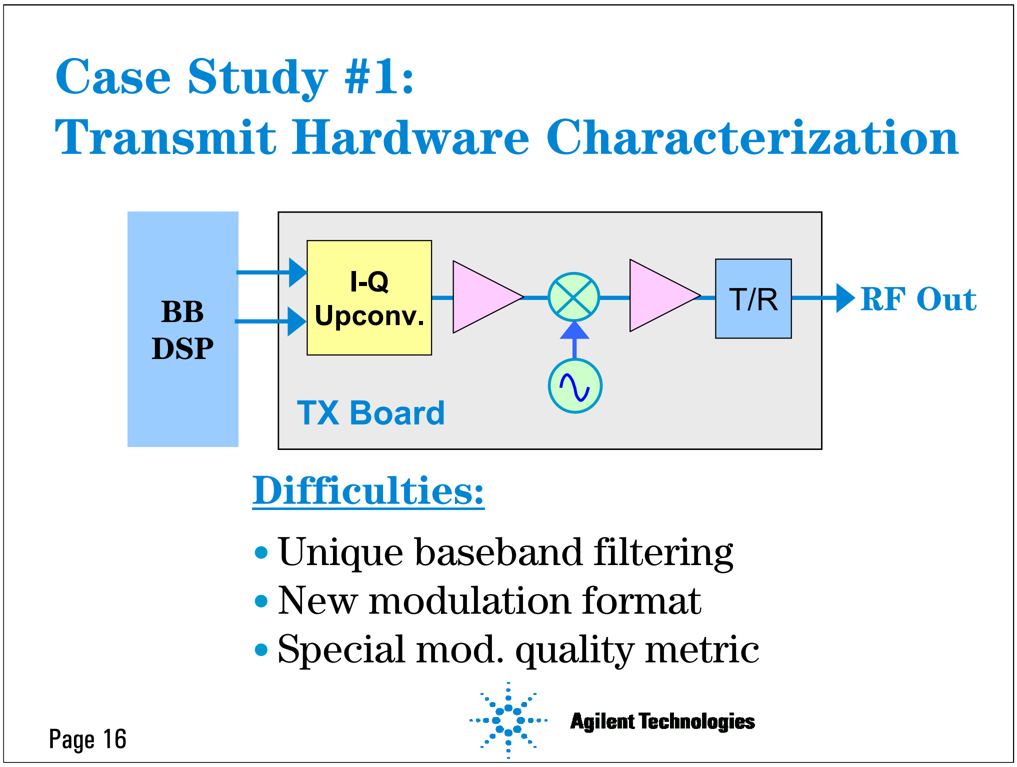
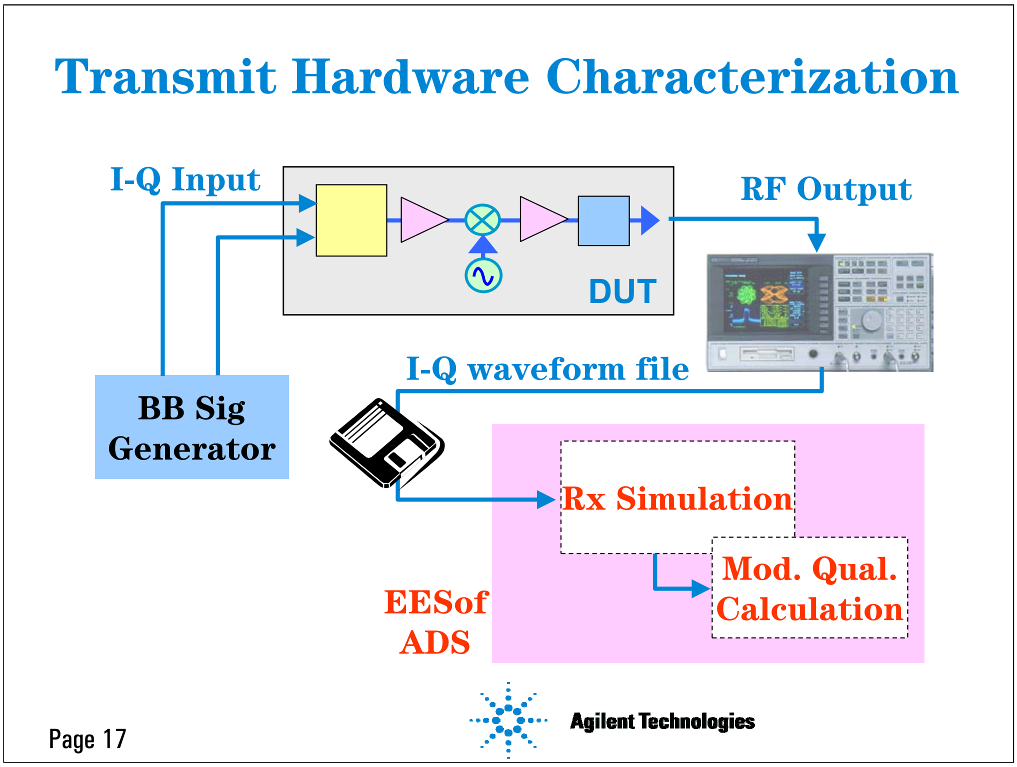
But what about signal formats that are outside the range of even today's most advanced signal analyzers? The remainder of this paper will present two case studies, showing how the capabilities of these analyzers can be linked to design automation software to provide answers to these challenges.



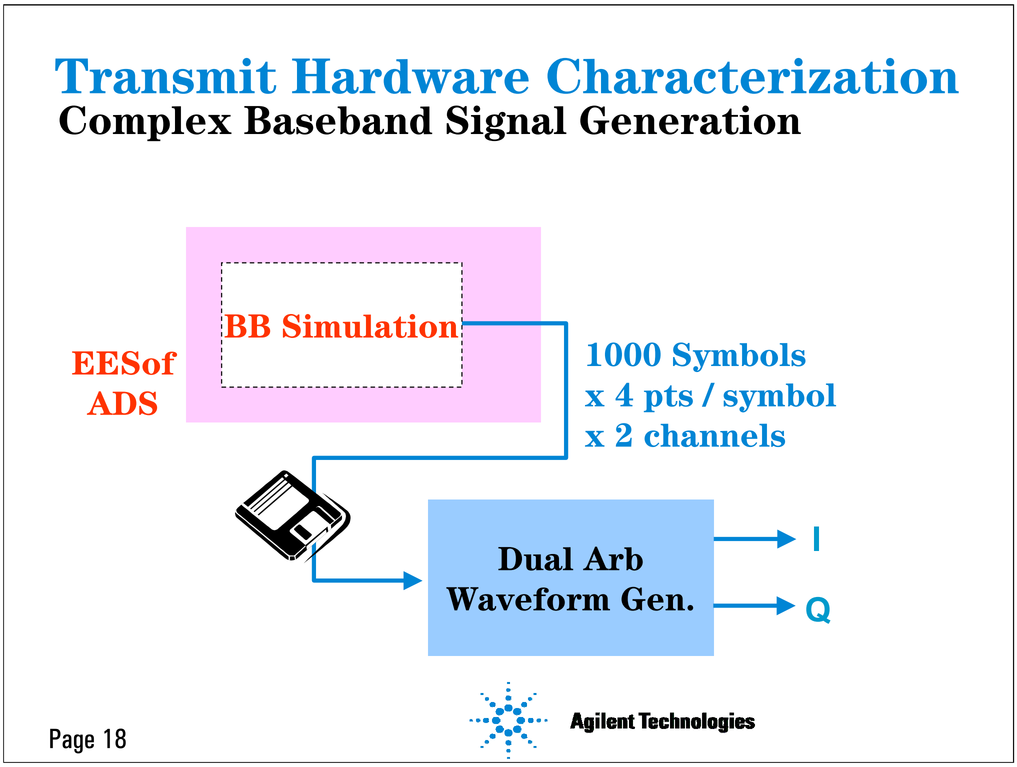

In this case study, the goal was to quantify how a modulated signal was being affected as it passed from the baseband IC through the upconversion and power amplification stages to the transmitter output. Error vector measurements are ideal for this characterization.

This task would normally be fairly straightforward for a vector signal analyzer, except that it involved an emerging-standard signal with some special requirements: first, the baseband filtering was unique, meaning that the matching filter on receiving/analysis side had likewise to be custom-defined. Secondly, the actual modulation format was brand new, and the required software-demodulator was not yet implemented in the VSA. Finally, the controlling body for this signal standard had decreed that the modulation error be calculated in a specific way of their own devising. While standard EVM measurements were still useful, they didn't numerically match the requirements of the standards body, making comparisons difficult.




Thus, testing needed to be performed on the transmit board, from (analog) I-Q baseband input to RF output. On the output side, a vector signal analyzer was used to first downconvert and demodulate the RF signal, and then digitize the resulting baseband. Just as in the actual system receiver, carrier lock and symbol clock timing had to then be recovered if any meaningful measurements were to be made. If this were a reasonably standard modulation format (nPSK, nFSK, nQAM, etc.), the analyzer's built-in algorithms would perform these function automatically, along with providing the receiver-side baseband filtering. However, for this case, these conditions were not true.

Instead, the recovered I and Q waveforms were saved as files, and passed to the user's design automation software – here, Agilent/EESof's Advanced Design System. Fortunately, at this stage of the design, the receiver baseband section had already been implemented, using the Ptolemy DSP simulator. It included the matching receive filter, plus the necessary synchronization and timing recovery loops. All that was required was: a) to add test points and display tools for viewing the eye and constellation diagrams, and b) creating a calculation to display the modulation quality metric, using the formula specified by the standards body.




In effect, the combination of the VSA front end hardware and the EESof receiver simulation became a single piece of test equipment. The simulator allowed a high degree of customization of the signal receive and recovery functions. The analyzer provided a flexible front end that could probe the transmitter signal path at virtually any point, from baseband I-Q to final RF. Of course, this same test topology could have been used for receiver testing as well, probing the various RF and IF stages and characterizing their impacts on signal quality.

Creating the stimulus signal for this test is another area where the computational and measurement sides of the problem had to be closely linked. Here, the simulation for the transmit baseband was used to create I and Q waveform files, which were then downloaded into a dual-channel arbitrary waveform generator. One thousand symbols, simulated at four samples per symbol, were sufficient to provide the necessary stimulus.

# Case Study #2: Receiver Front End Characterization