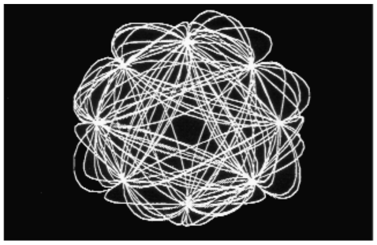
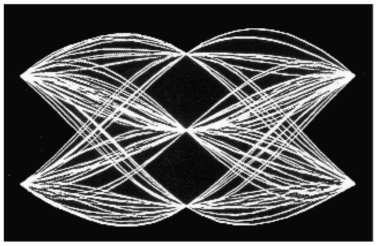
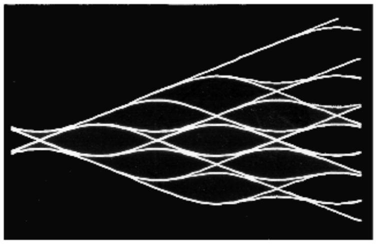
Agilent PN 89400-8

Using Vector Modulation Analysis in the Integration, Troubleshooting, and Design of Digital RF Communications Systems

Product Note







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EVM         = 348.4    m%rms    642.51    m%   pk at Sym  95
Mag Err     = 227.57   m%rms    -555.43   m%   pk at Sym  12
Phase Err   = 151.17    mdeg    347.17  mdeg   pk at Sym  50
Freq Err    = 31.043     mHz
IQ Offset   = -65.176     dB       Amp Droop = 186.1 udB/sym

  0   1101110111  1011000011  1001101011  0101010000  0001001001
 50   1101101101  0101001100  0001000101  1100111111  1010101100
100   0110011011  0100100011  0111000001  0111011010  0110001000
150   1101001011  1001000000  1110010011  1011011010  0000001010
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Introduction

The Agilent Technologies 89400 Series vector signal analyzers (VSAs) with vector modulation analysis (Option AYA) provide the numerical and visual tools to help quickly identify and quantify impairments to digitally modulated signals, whether using standard or several nonstandard modulation formats. Measurements are possible on continuous or burst carriers (such as TDMA) at baseband, IF, and RF locations throughout a system block diagram. There is no need for external filtering, coherent carrier signals, or symbol clock tinting signals. The 89400 Series VSAs with Option AYA have built-in Gaussian, raised-cosine, root-raised-cosine, and user-definable filters (with adjustable alpha or BT) and lock to the carrier and a defined symbol rate.

Although it is useful to measure the signal being transmitted, imagine the benefit of being able to detect, quantify, and locate the errors in the transmitted signal when compared to an ideal reference signal. Common vector modulation analysis tools such as eye and constellation displays are supported as well as new analysis tools including the ability to compare measured signals to ideal signals. Measurements update as fast as two times per second, allowing the effects of changes to an active system to be quickly analyzed. Advanced spectrum analysis rounds out the 89400 Series VSAs' measurement contributions (additional information is in the reference list). By reducing the amount of external equipment or the need for developing custom solutions, accuracy is preserved and system development time can be simplified and minimized.

Basic vector modulation and measurement concepts are presented, followed by example measurements and setups. A transmitter system is used as the foundation for the measuements; however, any system with I and Q signals can use the principles and tools presented. These applications are intended to serve as examples of the measurement power and ease of use of the analyzer.

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Background

Modulation is a method of carrying information from a transmitter to one or more receivers. Communication systems use modulation to superimpose or "piggyback" low-frequency voice or data signals onto an RF wave (high-frequency carrier) which can be transmitted long distances. The information (voice or data) is used to modulate the carrier, usually by altering its phase, frequency, amplitude, or some combination of these. The receiver extracts or decodes the modulation from the incoming signal to recover the desired information.

Due to the propagation characteristics of electromagnetic waves with different frequencies, certain portions of the spectrum are more desirable for some applications. With the applications explosion in consumer communications, a desire for direct and reliable transmission of digital information, and a drive for improved quality and privacy, there has been increased need for more efficient and smarter use of the already crowded RF frequency spectrum. Digital modulation has been used for many years, however, now it is being used more widely to address the aforementioned needs in a variety of applications. Digital (also called complex or IQ) modulation uses a combination of amplitude and phase modulation.

Many digital modulation communications schemes make better use of the available spectrum by allowing multiple users per carrier frequency (i.e., to access the same portion of spectrum) and take advantage of compression gains in digital signal processing (DSP) portions of the systems. Time-division multiple access (TDMA) is one method of spectrum sharing. It uses burst carriers which only transmit for short periods and are off while other users occupy the channel. A second method of sharing is to combine the desired signal with a code sequence that results in spread spectrum or code-division multiple access (CDMA) signals. CDMA signals simultaneously occupy the same spectrum and affect each other like broadband noise.

Figure 1 shows the basic block diagram of a digital RF communications system, which could be the core of personal communications systems, cordless telephones, digital special services systems, cellular telephones, pagers, wireless LANs, private trunked mobile systems, satellite communications services, global positioning, digital audio broadcast, fleet dispatching networks, digital video, and radar systems. Developing, testing, integrating, and troubleshooting these new systems requires flexible testing capabilities to locate the probable causes of any signal degradation.
In many cases, modulation formats that are not standardized are used.

Modulation concepts

In most digital radio systems, the frequency of the carrier is fixed so only phase and magnitude need to be considered. The phase and magnitude can be represented in polar or vector coordinates as a discrete point in the I-Q plane (Figure 2). I represents in-phase (phase reference) and Q represents quadrature (90° out of phase). By forcing the carrier to one of several predetermined positions in the I-Q plane, we can then transmit encoded information. Each position or state (or transitions between the states in some systems) represents a certain bit pattern that can be decoded at the receiver. The mapping of the states at each symbol timing instant (when the receiver interprets the signal) on the I-Q plane is referred to as a constellation diagram. Theoretically, there should be single points, but a practical system suffers from various impairments and noise that cause a spreading of the states (a dispersal of dots around each state).

An example modulation format is 16 QAM (16-state quadrature amplitude modulation). This format takes four bits of serial data and encodes them as single amplitude/phase states, or symbols. A state diagram is shown in Figure 3. In order to generate this modulation format, the I and Q carriers

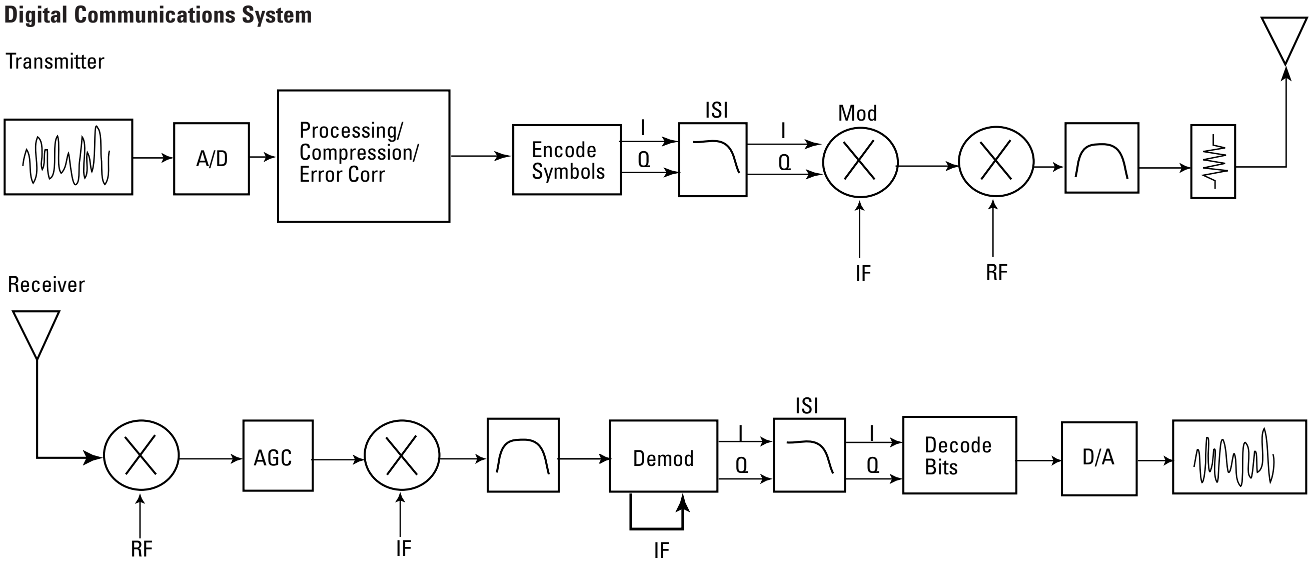


Figure 1. Many systems use this block diagram, including cellular radios, wireless LANs, fleet dispatch networks, and others.

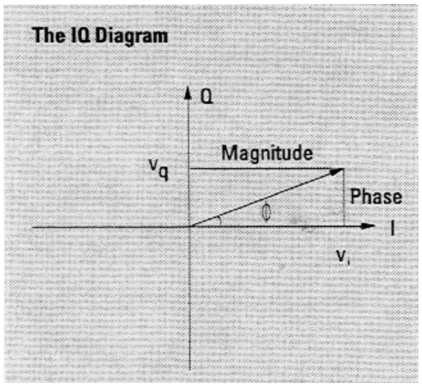


Figure 2. Digital communications systems use the magnitude and phase of signals to transmit encoded information.

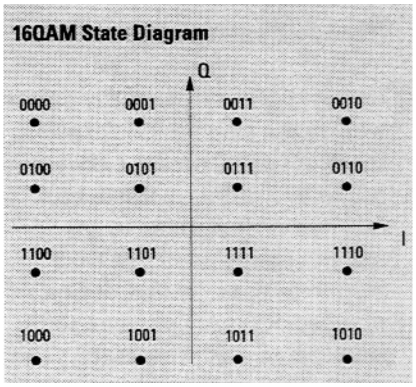


Figure 3. The binary representation for each state is user-definable in the Agilent 89400 Series VSAs.

each need to take four different levels of amplitude depending on the code being transmitted. In addition to 16 QAM, the Agilent 89400 Series VSAs with Option AYA can demodulate 32 QAM, QPSK, DQPSK, π/4 DQPSK GMSK, MSK, BPSK, and 8PSK modulation formats (Figure 4).

Symbol rate is the rate at which the carrier moves between points in the constellation. The more constellation states that are used, the lower the required symbol rate for a given bit rate. The symbol rate is important because it tells you the bandwidth required to transmit the signal. The lower the symbol rate, the lower the bandwidth required for transmission. After the user enters the nominal symbol rate, the 89440A dc to 1.8 GHz VSA with Option AYA automatically locks to signals transmitting data (symbols) at rates up to 6.67 MHz (9.52 MHz for the 89410A dc to 10 MHz VSA with Option AYA). When in the receiver mode of Chl + jCh2, the analyzer can lock to symbol rates up to 19.04 MHz.

$$\frac{\text{(Transmission rate in bits per second)}}{\text{(Number of bits per state)}} = \text{Symbol rate (in Hertz or states/sec)}$$

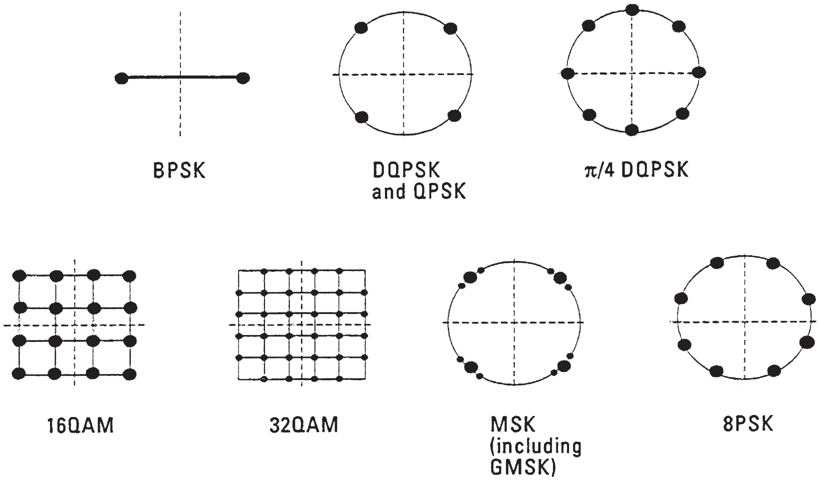


Figure 4. Modulation formats supported in the Agilent 89400 Series VSAs

Measurement concepts

Vector diagrams show the states as well as the transitions between them. A vector drawn between the origin to a point on the vector diagram corresponds to the instantaneous power at that instant in time, with a definable number of points per symbol (maximum = 20) displayed. The maximum number of symbols that can be measured and displayed is 4096 (requires Option UFG 4-Mbytes extended RAM) assuming one point per symbol is used. This is true regardless of the display type (constellation, vector, eye, etc.) selected. To determine the maximum number of symbols that can be measured with N points of resolution between the symbols the following equation is helpful:

$$\text{Maximum number of symbols} = \frac{\text{Maximum time points}}{\text{N points/Symbol}}$$

where, maximum time points is selected in the System Utility hardkey menu of [memory usage] followed by softkey menu [configure meas. memory].

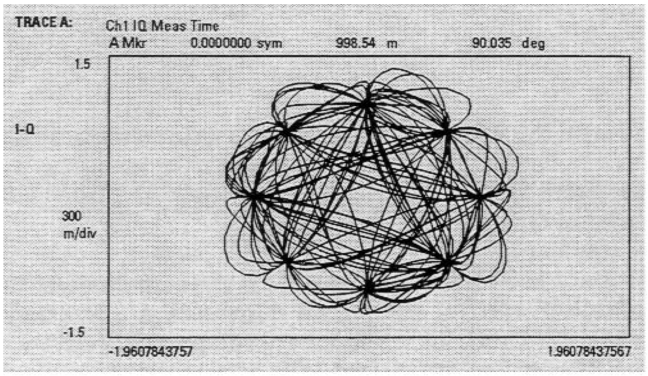


Figure 5a. The vector diagram shows power levels during state transitions.

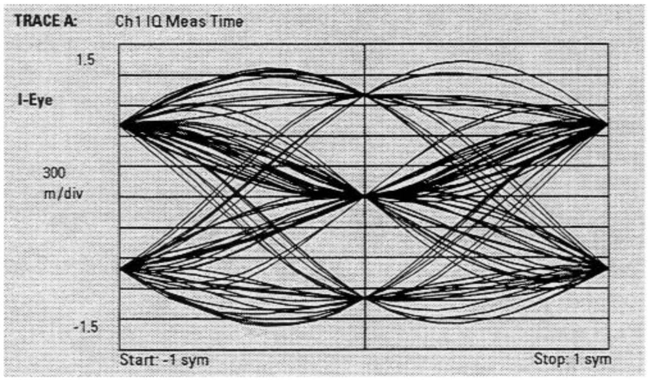


Figure 5b. The I-Eye diagram (π/4 DQPSK signal) shows the I component as it varies over time.

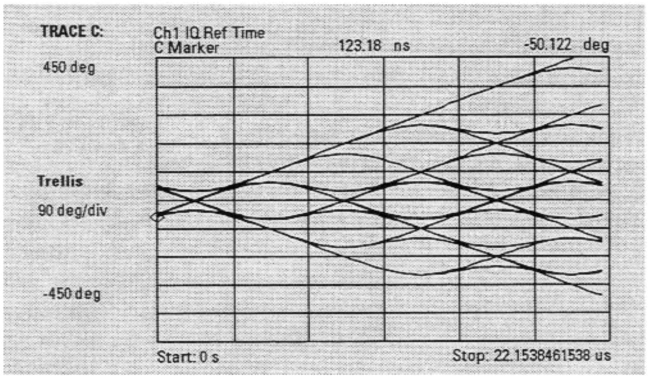
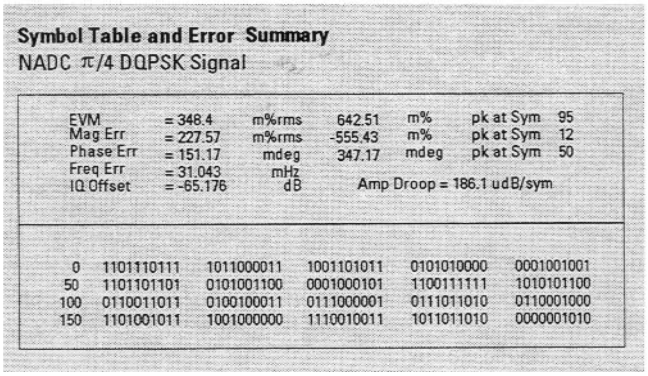


Figure 5c. The trellis diagram (GSM signal) shows phase trajectories between symbol states.



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Symbol Table and Error  Summary
NADC π/4 DQPSK Signal

EVM          = 348.4     m%rms    642.51   m%     pk at Sym   95
Mag Err      = 227.57    m%rms   -555.43   m%     pk at Sym   12
Phase Err    = 151.17     mdeg    347.17   mdeg   pk at Sym   50
Freq Err     = 31.043      mHz
IQ Offset    = -65.176      dB       Amp Droop = 186.1 udB/sym

  0  1101110111  1011000011  1001101011  0101010000  0001001001
 50  1101101101  0101001100  0001000101  1100111111  1010101100
100  0110011011  0100100011  0111000001  0111011010  0110001000
150  1101001011  1001000000  1110010011  1011011010  0000001010
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Figure 5d. The symbol table and error summary display includes the demodulated bit stream and important error measurements. Detailed error measurements such as EVM and IQ magnitude (or phase) errors are also available.

I and Q eye diagrams are another common analysis display. These diagrams are simply a mapping of I magnitude versus time and Q magnitude versus time as these waveforms would appear on an oscilloscope which is triggered at the symbol timing instants. The 89400 Series VSAs with Option AYA can display these as well as trellis diagrams which map phase versus time (the phase trajectory per symbol) for the measured or the ideal (reference) signal. MSK (minimum shift key) signals have constant amplitude but vary phase to transmit information. Trellis diagrams are often used to characterize these signals because of their ability to map phase transitions and trajectories at each symbol. Eye and trellis diagrams represent the symbol clock detection points by the vertical lines displayed.

A symbol table shows the final product of the demodulation—the binary bits for each symbol detected. Simultaneous multiple display grids with their markers coupled can compare the bit pattern detected with the data's position in the constellation, vector, or eye diagrams. When displaying the symbol table, a numerical error summary is also listed which lists parameters such as overall magnitude and phase error (and the peak error with its symbol location), frequency error, amplitude droop, origin (or IQ) offset, and error vector magnitude (% rms and peak).

Detect, quantify, and locate the errors in the transmitted signal by comparing it to an ideal reference signal. The ideal reference is the signal that would result after demodulating your signal if it contained no errors. The generation of an ideal reference signal is shown in Figure 17.

Error Vector Magnitude
The 89400 Series VSAs with Option AYA measure and display magnitude and phase errors (IQ magnitude and IQ phase error) as well as the error vector magnitude (EVM) at and between each state. A measure of EVM (rms) is now included in NADC and PDC specifications; however, it is also a useful means for quantifying errors for other digital modulation formats.

The EVM is the magnitude of the phasor difference as a function of time between an ideal reference signal and the measured transmitter signal after it has been compensated in timing, amplitude, frequency, phase, and dc offset. Figure 6 illustrates this concept.

Error Vector Concept

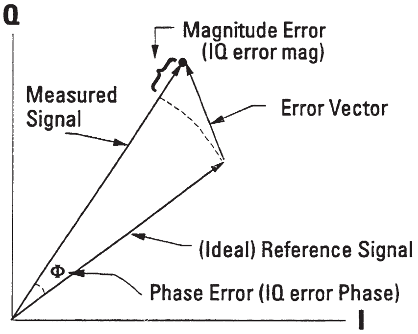


Figure 6. Error vector magnitude (EVM) is a sensitive measure of modulation quality.

Error Analysis using EVM Function
NADC π/4 DQPSK, Fs = 24.3 kHz

- Symbol rate off by error of 100 Hz
- Eye diagram does not show significant changes.

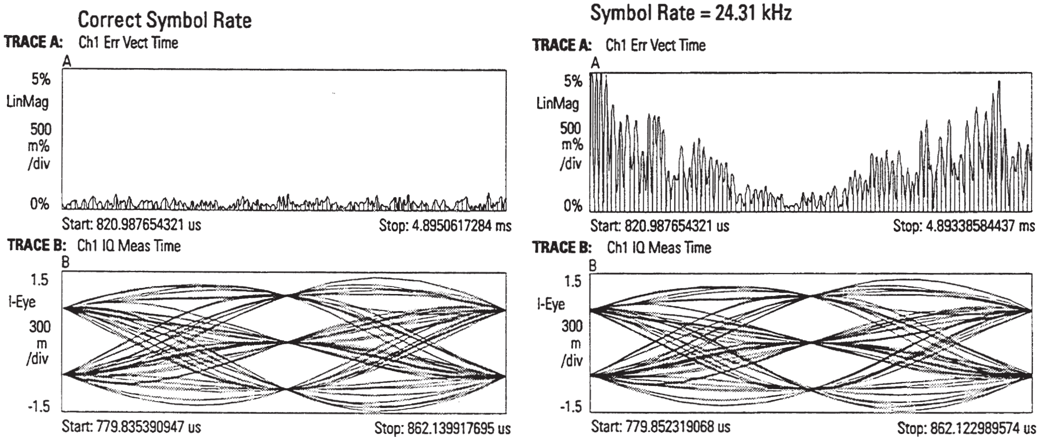


Figure 7a. Error analysis using the EVM function.

The error vector magnitude (error vector time) can detect errors in a signal's transmission that may not be apparent using traditional analysis displays. As an example, Figure 7a shows an NADC signal with and without an error in the symbol rate used. Notice that the eye diagram is not able to detect the error. Figure 7b illustrates an error that could not be detected by either an eye or a constellation diagram.

Error vector spectrum is the spectrum/frequency domain representation of error vector time. The center frequency of this measurement's display is typically the transmitter carrier frequency (refer to "Setting Up the Measurements—Tune" on page 16). Traditionally, spurious signals that are offset from the carrier were detected using a constellation diagram. In these instances, the constellation may show the states scattered in a circle or crescent around each of the ideal state locations. This is not necessarily the case for close-in spurs. Error vector spectrum can indicate and measure the frequency of spurious signals which may be offset from the carriers that could not be observed on traditional spectrum analyzers or by using a constellation display. An example showing a spur that is offset approximately 7 kHz from the carrier is illustrated in Figure 8.

Error Analysis using EVM Function

- NADC signal with wrong filter coefficient alpha=0.4 causes large errors in between symbol points.
- These types of errors are hard to discover in eye diagram, vector, and constellation diagram displays.

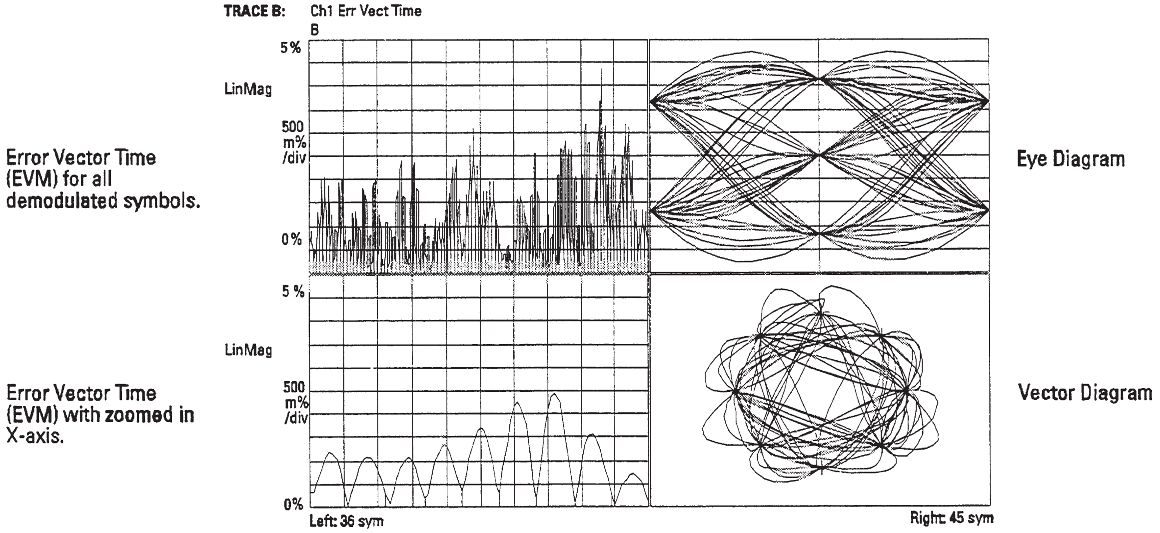


Figure 7b. Another example of error analysis using the EVM function

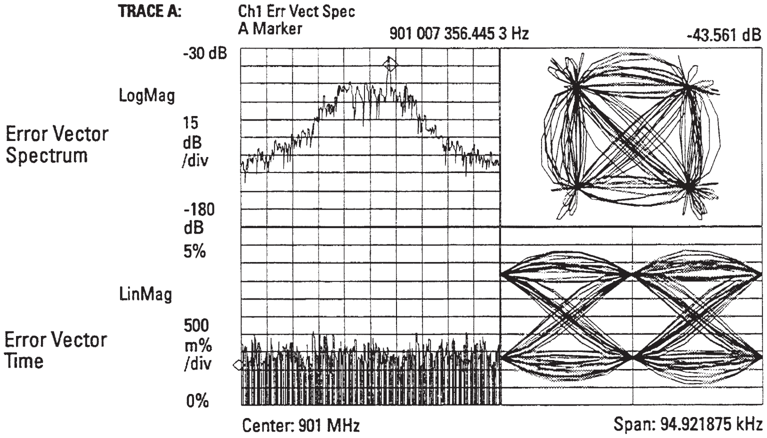


Figure 8. Error vector spectrum reveals a close-in spur that can't be seen in the traditional measurements.

Problems that can occur during transmission, integration, and design

In digital communications, the modulated signal carries the information from the transmitter to the receiver. Therefore, the signal's quality throughout the transmission path of the system block diagram is critical. Many test solutions indicate that the final received signal is degraded somewhere in the transmitter and receiver chain. But, they may not have a full set of built-in tools to help isolate the source of the degradation or to analyze the quality of the digital modulator and demodulators.

Poor quality transmission can be seen as low signal quality which may result in a high bit-error rate (BER). BER testers count the number of errors which cross certain limits. They do not tell why or how far out of limit the signal is, or even if the error occurred in the transmitter or receiver. The Agilent 89400 Series VSAs have several unique capabilities that allow not only error detection, but also the ability to locate where in the transmitter or receiver chain the errors are occurring. The analyzer's vector modulation error measurements and some of the measurement techniques discussed in the remainder of this product note are examples of locating errors.

Transmitter problems (or impairments) can cause signal power splatter, thus occupying more bandwidth than allowed and causing interference with adjacent channels. The transmitting system can be overdriven, especially in pulsed systems. Pulsing takes its toll on power amplifiers in the system and can affect the integrity of the transmitted signal. In both transmitters and receivers, problems with flatness in the amplitude response and group-delay variations over the transmitted frequency band can distort digital signals at the output stages of the power amplifiers or at the input stages of the receiver.

The key to troubleshooting is to identify the possible impairments within a transmitter or receiver system that can cause signal degradation. By knowing something about the types of errors that can occur, the causes of these errors can be traced. The remainder of this product note will show specific measurement examples of troubleshooting using the advanced analysis capabilities of the 89400 Series VSAs with Option AYA for locating impairments that can occur in the transmission chain. Impairments discussed include compression, LO feedthrough, IQ origin offset, IQ gain imbalance, quadrature error, phase noise, symbol timing errors, and intersymbol interference. Similar techniques can be used when integrating and troubleshooting throughout the receiver.

Identifying problems: Using measurement and display tools

Let's say that during the measurement setup, signals at the amplifier were observed that may already indicate a problem in the transmission. Perhaps a BER tester has indicated a failure in the system. Now it is important to troubleshoot the problem by stepping backwards through the system block diagram, measuring both after and before devices or system "blocks" to determine the cause of the problem.

At the power amplifier

The first step is to troubleshoot the power amplifier in the output section of the transmitter. Problems the power amplifier can cause include signal compression, overdriving signals at or between states (too much power transmitted), and channel splatter. Refer to the "Anywhere Throughout the Transmitter or Receiver" section, page 12, regarding other problems that can occur in the power amplifier.

- *Compression*

Designers of power amplifiers must consider the power levels needed to drive the amplifiers. The power amplifiers must be linear. To avoid distortion of the signal, the levels and output section gains in the amplifier must be tightly controlled in order to avoid compression. Compression occurs when the instantaneous power levels are too high, thus driving the amplifier into saturation. MSK modulation schemes, like FM transmitters, are more efficient when slightly saturated. But in most digitally modulated systems, compression can cause clipping and distortion. This may result in a loss of signal transmission efficiency. Compression that occurs at one state will most likely interfere with the next symbol state because it may take some finite amount of time to discharge the parasitic capacitances of some components in the amplifier. Signs of compression occurring can be best seen when observing the vector diagram of the IQ measured time overlayed on the IQ referenced time (Figure 9). Another measure of when extreme levels of compression occur is that the EVM will begin to deteriorate. A statistical measure of EVM is included in the symbol table and error summary display.

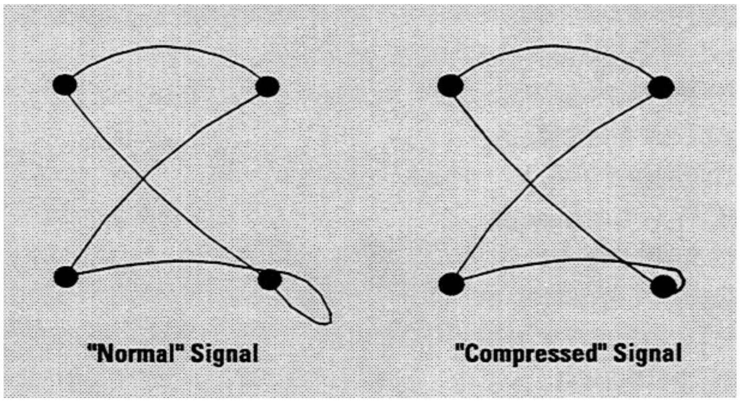


Figure 9. Compression may affect a signal's transitions between states.

- *Power splatter*

Power splatter can be caused by amplifier distortion which results in power in adjacent channels. In analog modulation systems (and even in some digital modulation systems), third- and fifth-order intermodulation rejection or similar tests have been used in the past to measure amplifier distortion. These CW (continuous wave) analog tests may not be valid representations of splatter in digitally modulated systems where much higher order distortion products can play a significant role in adjacent channel splatter. Another potential concern for digital systems is that the base stations may actually have several signals randomly added together and measuring the distortion of individual signals may not accurately reflect the composite result. Especially in digital systems, it is best to determine if splatter is occurring by measuring the adjacent channel power (ACP) directly.

Swept LO techniques for measuring ACP presume essentially stationary signals and are not well suited for time-variant signals. "Gated sweep" approaches improve this situation but at the cost of greatly increased sweep times. Also, these gated sweep techniques assume repetitive signals.

The Agilent 89400 Series VSAs have frequency-selective, band power markers which can measure the power of specific channels. Furthermore, these analyzers avoid the concerns and restrictions of swept LO or gated techniques by digitizing the entire signal. The signal processing in the 89400 Series VSAs can characterize rapidly changing signals—this is important when dealing with burst signals.

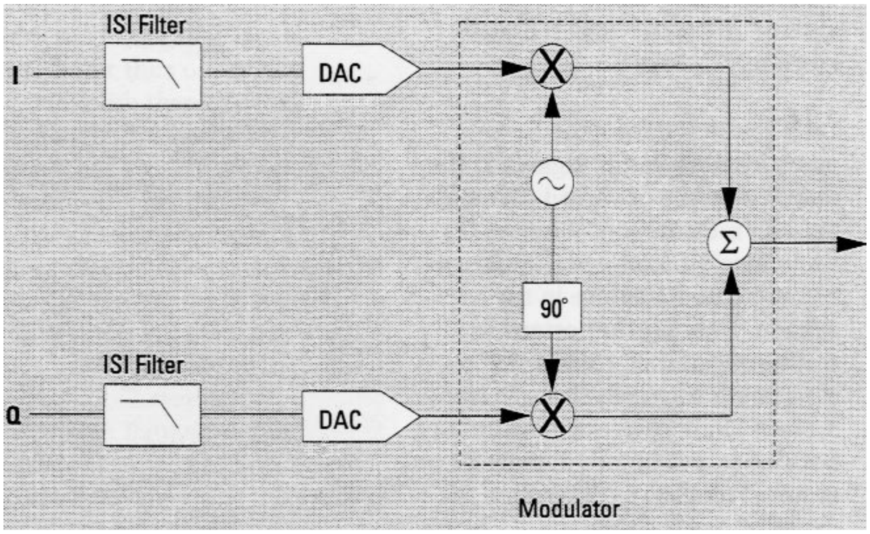


Figure 10. Modulator block diagram

At and "before" the modulator

Ideally, two independent baseband stimulus signals should be input to I and Q at the input to the modulator. The output of the modulator is at RF. In most actual transmitters, the I and Q signals are generated digitally then passed through inter-symbol interference (ISI) filters (also digital) and DACs which convert the signals to analog before they are used to modulate a carrier signal. These filters control the spectral occupancy of the signal. Without filtering, the modulator would output infinite bandwidth signals which would interfere with other channels and waste spectrum. The ISI filters are designed specifically so that the signals are not only bandlimited, but also so that they do not distort the transmitted pulses/signals and interfere with subsequent signals at the symbol detection times. ISI filters force the impulse response to zero at integer multiples of symbol period such that transmitted symbols won't interfere with each other.

For the DSP designer, ideal matching filters and the 89400 Series VSAs with Option AYA's implementation of an ideal modulator can be used to verify the digitally implemented I and Q signals' compatibility with an ideal modulator before integrating with the actual system modulator. You can test the output of the DACs by inputting the baseband analog I and Q signals directly into channels 1 and 2 of the analyzer's IF section, respectively.

Selecting the instrument receiver mode as [IF section (Chl + j*Ch2)] removes the quadrature mixer from the analyzer's block diagram. Thus, the analyzer interprets channel 1 data as the real part of your signal and channel 2 data as the imaginary part. With Options AYA and AY9 (second baseband input channel), the 89400 Series VSAs interpret channel 1 as the I (in-phase component) and channel 2 as the Q (quadrature-phase) component.

Traditional swept spectrum analyzers provide good numerical characterizations of much of a modulator's performance during the design phase. Measurements that can be made include linearity and distortion, among others. The Agilent 89400 Series VSAs also make these measurements (spectrum mode) and can show the performance characteristics visually, such as shifted constellation diagrams (refer to "Gain Imbalance and Quadrature Error," page 13). In addition, due to the digitizing and signal processing techniques used by the 89400 Series VSAs, phase information is preserved. Therefore, phase can be measured at the output of the mixers and throughout the modulator. Simply phase lock the analyzer to the modulator's LO reference and measure the phase of each channel (I or Q input) relative to the LO. These measurements are a method of directly measuring the phase balance relative to the LO for each channel throughout the mixers and modulator. Pulses in the power amplifier (such as when transmitting information from a mobile to a base unit) can adversely affect the phase and/or frequency stability of the LO. The quick and large level changes can affect how the transmitted signal is handled and may result in high EVM. For example, this may happen because the turn-on pulse can drain large amounts of instantaneous current from the power supply. In small transmitters such as handheld radios, because of the close proximity of components, large signals in the presence of smaller ones may cause magnetic couplings between circuits. These couplings could cause distortion in the signals being transmitted.

It is possible to measure the phase stability of the LO by synchronizing the PM demodulation measurement with the transmitter pulses. Essentially, this results in a measure of instantaneous phase versus time. Typically, sync signals (control logic lines such as "Tx_on") are available in radios. Such sync signals can be used when determining the frequency stability of the LO by measuring instantaneous frequency versus time (FM demodulation).

Some mobile radios receive and transmit signals at different frequencies. Also, commands may be sent from the base station to the mobile unit directing it to change frequencies for a quick hand-off to the next base station. The LO of the modulator contains a phase-locked loop (PLL) to maintain frequency stability. The closed-loop response of the PLL determines how fast the LO can change frequencies. The 89400 Series VSAs can directly measure the closed-loop response of the modulator's PLL in the correct domain-modulation. An external signal generator which is modulated using the analyzer's built-in source serves as a baseband reference input signal for the PLL. The analyzer's demodulator is applied at the output of the PLL which is translated up in frequency. The closed-loop response is measured and displayed directly and the open-loop response can be derived using the analyzer's built-in math functions. The benefit is that you don't have to tap into the loop or open it. Product Note 89400-6, *Translated Frequency Response Measurements Using the Agilent 89440A* provides details on this measurement and others used to characterize the performance of PLLs.

Anywhere throughout the transmitter or receiver

Errors can occur anywhere throughout the transmitter or receiver which can impair the signal or data integrity. An example is when LO feedthrough can cause the symbol detector threshold to be set incorrectly thus causing the wrong states and bits to be detected. Other typical sources of error include gain or phase imbalances, interfering or spurious signals, jamming, noise, symbol timing errors, amplitude or phase nonlinearities, carrier frequency offset, and AM to PM conversions.

A skillful eye can easily detect many types of errors by using the flexible display formatting (such as overlaying traces) and comparing measured signals to their ideal counterparts. However, for faster and more conclusive determination of problems, a quantitative measure is most beneficial. The error vector magnitude (time) trace (Figure 11) is the best measure of signal quality and should be used whenever troubleshooting through a system.

Vertical bars or dots can be activated to identify the symbol locations. The EVM trace identifies when errors occur during the signal's transmission. This trace can show whether errors occur at one or a few particular states or during the transition between them. By tracking this measure when troubleshooting at several points, you can look for consistencies or patterns in errors to help locate the cause. These errors typically do not get any better (EVM does not get smaller) as a signal progresses down the system's transmission path. X-axis scaling can be used to spread out closely spaced points to ease viewing. EVM is important because at each point in the signal train where the measurement is made, the contribution to the overall "error budget" is characterized. An overall measure of EVM (% rms over all symbol detection/clock locations) is included in the error summary table. The remaining paragraphs in this product note describe examples of other troubleshooting techniques that can be used to detect some of the typical transmitter or receiver errors that occur.

Error Vector Time Display

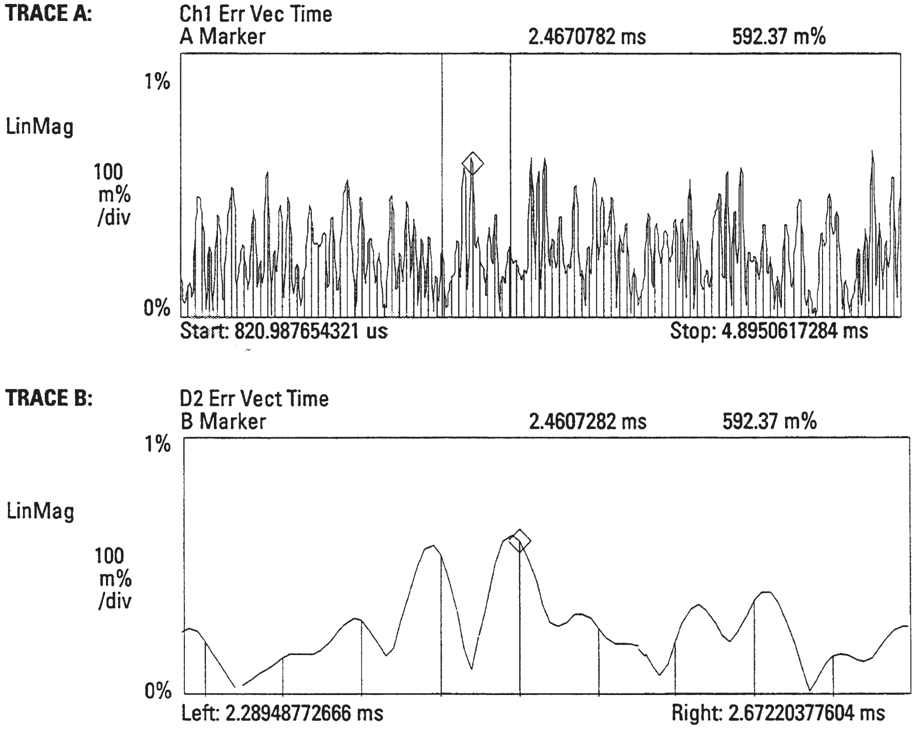


Figure 11. Error vector time and x-axis scaled displays: the top trace shows how the measured signal varies from the ideal both at and between symbols and decision times (shown by the vertical bars); and the bottom trace shows an expanded view of the area delineated by the vertical band markers in the upper trace.

Gain imbalance and quadrature error

Constellation diagrams can often tell you many things about the characteristics of signal impairments. Gain imbalance or quadrature errors can be caused by matching problems due to component differences (filters, DACs, etc.) between the I side and Q side of a network. Imbalances can also be caused by errors in IF filtering, for example, when a filter response isn't flat. These errors may be due to AM to PM conversion as well and can result in constellation distortion and, therefore, an increase in EVM. To detect even subtle imbalances, view the constellation diagram of the IQ measured time and compare with the "ideal grids" (crossed lines in Figure 12).

The ideal grids indicate where the ideal reference states should occur. IQ gain imbalance results in a distorted measured constellation relative to the reference. IQ quadrature errors (other than 90° between I and Q) result in a "tipped" or skewed constellation. Without the ideal grids, it would be very difficult to detect imbalances. Even subtle imbalances are often visually detected by zooming in (magnifying the scale) on the constellation and using the markers. Figure l3 illustrates gain imbalance (the gain of Q is low relative to 1) and quadrature error. In each, the dotted lines represent the ideal (reference) constellation.

The analyzer can help determine the correct orientation of the symbol states by using a sync search with a defined sync word. This ability can assist you in determining the relative levels of I and Q such that the appropriate adjustments can be made in the system. In other words, you can determine whether or not the gain of I is low relative to that of Q, or vice versa. Refer to "Setting Up the Measurements–Pulse Modulated Signals" on page 18 for information on using sync search.

Instantaneous power—at and between symbols

Vector diagrams show a signal's transitions between symbol states. The magnitude of a vector between the origin of the IQ complex plane and the trace at any point corresponds to the instantaneous power level. This is an excellent way to observe and measure levels that may be detrimental to parts of the system, such as overdriving a transmitter. By stacking the vector display on the upper trace with the symbol table on the lower trace and coupling the markers, you can see where any excessive signal levels occurred and the detected bits (the ls and 0s received) for the symbols.

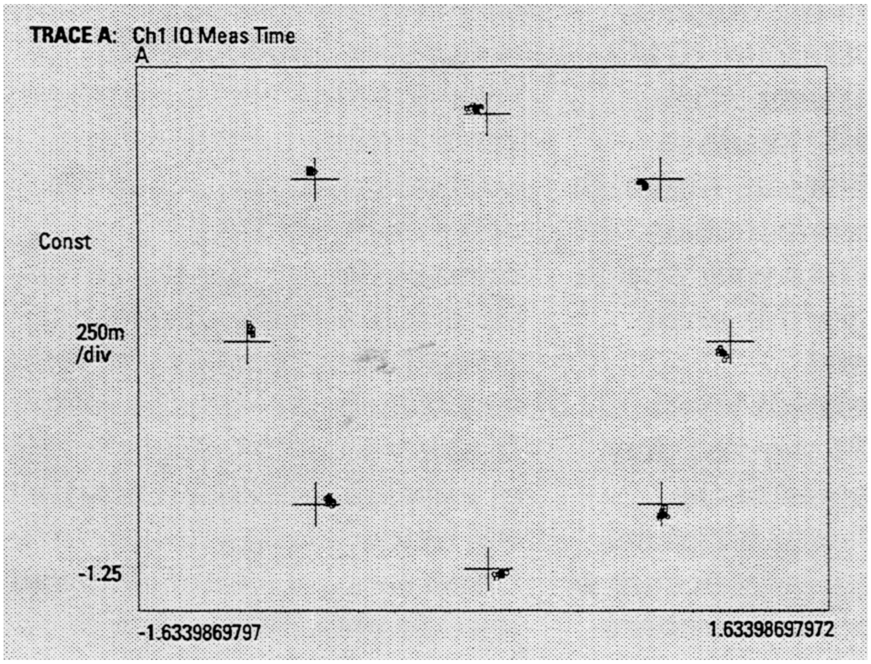
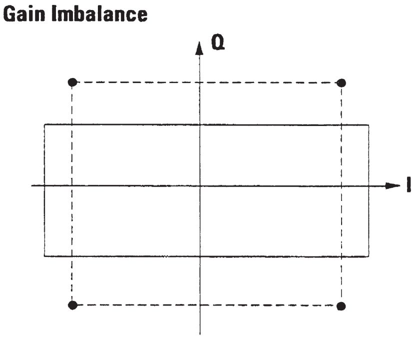


Figure 12. A constellation diagram with ideal grids. Note how easily the distortion from ideal state locations is visible.



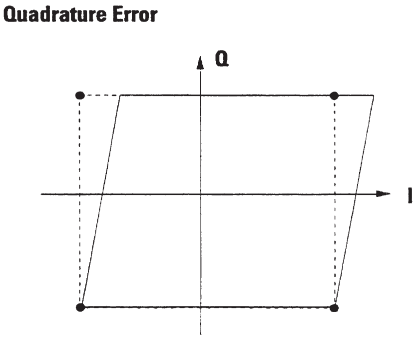


Figure 13. Imbalance or quadrature errors will often distort the shape of constellations.

This may indicate a particular symbol pattern or state transition that is causing the error. As mentioned earlier in this product note, the symbol table (Figure 5d) also includes an error summary which displays quantitative measures of the quality of the signal received that could lead to bit errors. The statistics or error measures include EVM (% rms and peak including symbol location), IQ phase and magnitude errors, carrier frequency error, amplitude droop, and IQ origin offset.

Interfering signals, feedthrough, and noise

An interfering signal can cause the amplitude and phase of the transmitted signal to be different each time the signal passes through the same state. This will result in a spread at the symbol locations in the constellation diagram. It may be useful to determine what (and where) the quantitative error is by observing the IQ magnitude error or IQ phase error diagrams. Symbol spread can also be caused by inter-symbol interference, noise, origin offset, and symbol timing errors.

A “circling” of the symbols around the constellation states indicates that there may be a spur or interfering tone. The radius of the circle is proportional to the amplitude of the interfering signal, but this display format contains no information about the interfering frequency which may be the key to identifying the cause. To determine the presence of an interfering signal, first verify that the symbol timing recovery is correct by viewing the eye diagrams and look to see if the eye crossings occur other than at the symbol “lines.” Next, observe the IQ measurement error (linear magnitude and phase) displays. Watch for any characteristics or signs of periodicity to the error or bursting and pulsing effects.

Close-in and low-level spurs on digitally modulated carriers cannot be seen on a spectrum analyzer. This is because the digitally modulated signals look a lot like a random noise pedestal. Their presence may be difficult at times to determine on a constellation display.

The EVM trace may hint that the error observed is sinusoidal in nature, but what is really needed is a method to determine the frequency of the spur. The error vector spectrum indicates any spurious signals which may be offset from the carrier. Refer to Figure 8 (page 7) and “Measurement Concepts” (page 4).

IQ offset (a shift in the origin of the IQ plane) is a measure of LO feedthrough in a transmission system and typically needs to meet some specification. Although reported in the error summary, the 89400 Series VSAs with Option AYA compensate for this error both graphically and mathematically (except when demodulating GSM signals). Any offset does not appear in the constellation or vector diagrams. LO feedthrough typically occurs at RF but can also occur elsewhere in the system. This measure can indicate problems such as imbalance due to a bad mixer or extraneous dc terms.

When first integrating a system, coupling and interference mechanisms which do not occur in the ideal system simulations may appear and create problems. A few common problems include couplings between digital and analog sections, system nonlinearities, power supply interference, and environmental effects such as temperature drift. The 89440A with the optional second 10-MHz input channel (Option AY7) and its coherence measurement help to locate the sources of various interference and feedthrough problems. In many cases, simply using the RF input and AM, FM, or PM demodulation gives a picture which lets you recognize a problem’s source by the signal’s characteristics.

Coherence measurements isolate to a particular source of the problem. Figure 14 shows an example of how a noise source can be located. The RF input channel connected to the carrier was PM demodulated, while the second 10-MHz channel was used to probe around at various points in the system. The built-in coherence function then compares the two signals and gives a value between 0 (no coherence) and 1 (complete coherence) in the frequency domain. The closer the coherence is to a value of one, the greater the probability that the two signals are directly related. In this case, obviously, the noise at location 2 is coherent with the PM demodulation of the carrier. Coherence measurements can be used to locate the cause of other sources of error as well.

Setting up the measurements

This section describes how to set up measurements on vector (digitally) modulated signals when using the Agilent 89400 Series VSAs. An overview of the procedure is to first, set up an appropriate input range and frequency span. Then, connect the RF input channel to the desired carrier or IF, or connect the two 10-MHz input channels (assumes Option AY7 second baseband channel is installed) to two independent baseband I and Q signals. Next, select the signal's modulation format and symbol rate (typically predefined by the system being tested). Enter the number of symbols desired for analysis, and choose from a selection of ISI filter types with adjustable alpha. Finally, view and measure using a variety of display formats with flexible scaling and markers. The four basic steps are **connect** [inputs], **tune** [span], **select** [modulation format], and **view** [display].

Connect . . .

The block diagram in Figure 15 will be used as a reference for the hardware connections used to troubleshoot throughout a system. Each of the geometrical shapes in this diagram correspond to the matching analyzer inputs which are used for measurements. Measurements can be performed at any of these locations to isolate the cause of signal degradation. When measuring baseband I and Q input signals directly into channels 1 and 2, set the analyzer's receiver (a softkey in the Instrument Mode hardkey menu) for the IF section equal to [Chl + j*Ch2].

Interference and Feedthrough Measurement Results

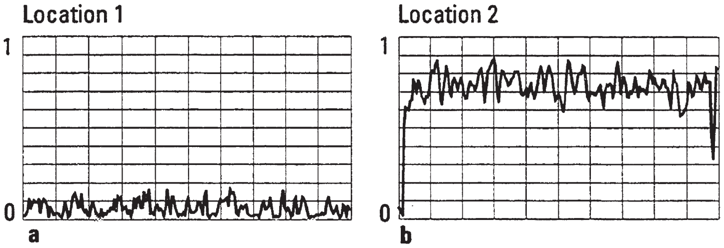


Figure 14. Using the second 10-MHz input to probe two baseband locations, PM demodulation on the RF input, and coherence to compare them, the noise source is determined to be location 2.

How to Measure Vector Modulated Signals

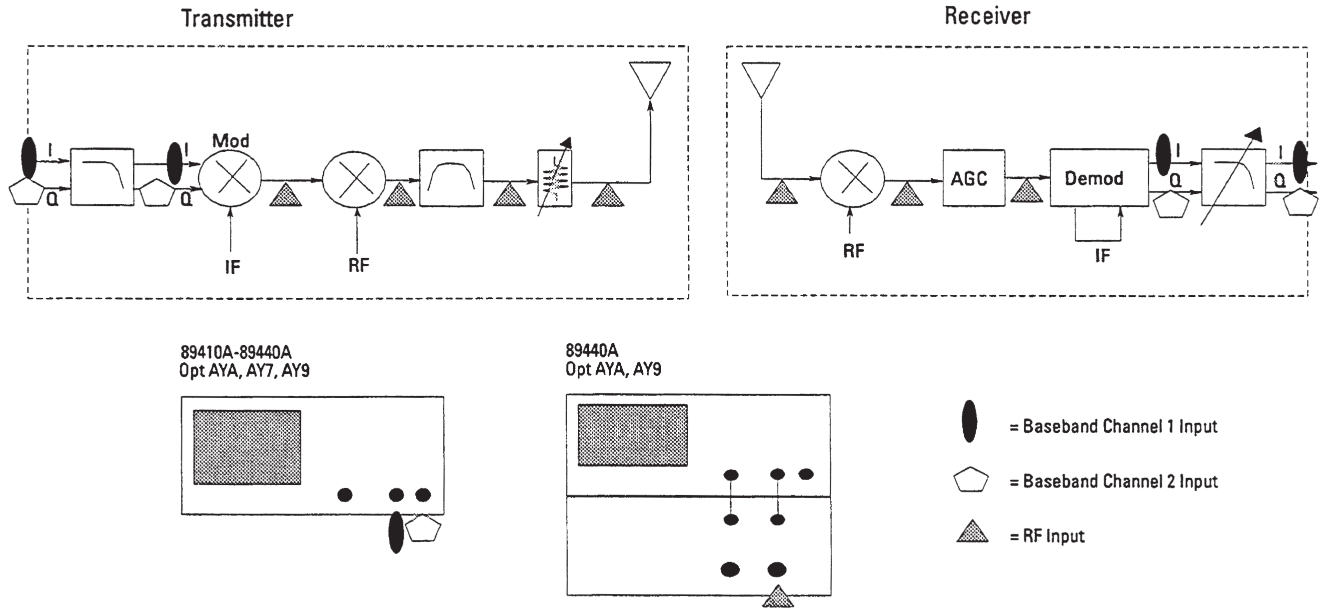


Figure 15. The analyzer's inputs used to measure at various points in a system block diagram from baseband to RF.

Tune . . .
Measure the antenna's received signal over the air by connecting an antenna or cable to the analyzer's RF input. Set the analyzer for Vector Instrument Mode and the center frequency to be the transmitter carrier frequency.

A narrow frequency span should be used to reject extraneous noise; however, the span must also be wide enough to view the full power spectrum and for the analyzer to obtain carrier lock. The analyzer automatically locks to a carrier signal without the necessity of providing an external coherent carrier. Typically, the center frequency used in the measurements should be within 2% of the symbol clock frequency to achieve and maintain lock. (Some modulation formats such as π/4DQPSK can lock with a center frequency tolerance of less than approximately 10% of the symbol clock rate.) For example, if the symbol clock frequency is 10 kHz, then 2% is 200 Hz. Therefore, the center frequency must be within 200 Hz of the true carrier frequency of the signal. A guideline for determining the appropriate analyzer frequency span is:

$$\frac{20^*(\text{Symbol rate})}{1.28} > \text{Frequency span} > (1 + \text{alpha})(\text{Symbol rate})$$

The "span factor" is 1.28 and is related to the analyzer's internal sample rate. Alpha is the shape factor (or rolloff) of the ISI filter being used. For example, using the NADC standard, the symbol rate is 24.3 kHz and alpha is 0.35, therefore the frequency span must be less than approximately 380 kHz but greater than 32.8 kHz.

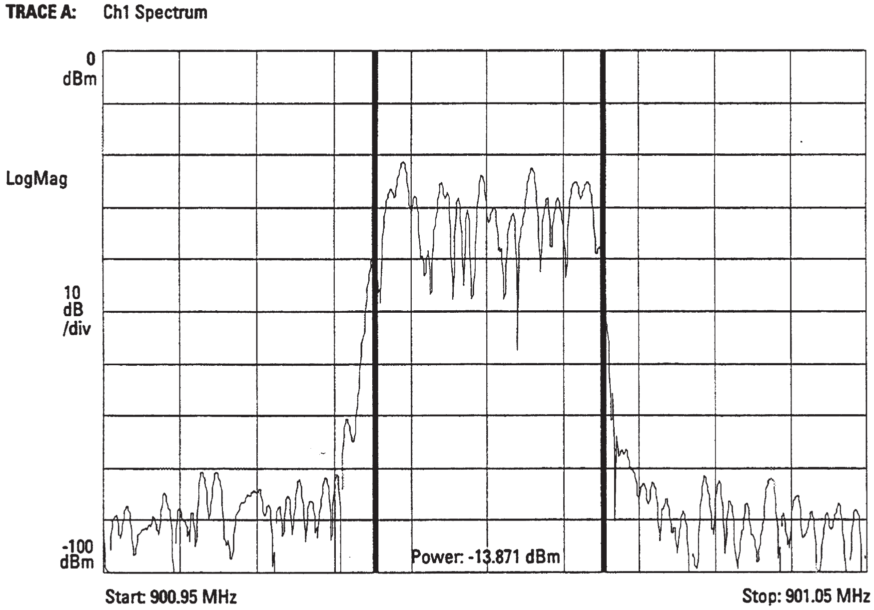


Figure 16. Power spectrum of a NADC signal with band-power markers. The true RMS-power detection and precise noise bandwidths in the 89400 Series VSAs provide the accuracy and versatility needed to measure modern digital communication signals.

For burst or pulsed signals, triggering is needed. IF triggering is a form of envelope triggering and looks for magnitude changes in the signal. It is impossible to trigger off of CW (continuous wave, or sinusoidal) or constant envelope signals since their magnitude does not change. Also, IF triggering does not work on some digital signals because their power levels fluctuate during state transitions. If an external trigger signal (TTL level) is available in the system it can be used to trigger the measurement. (Refer to the "Select" section on the next page regarding demodulating pulsed signals.)

After the instrument mode, analyzer's receiver type, center frequency, frequency span, and triggering are set, observe the power spectrum of the transmitted signal to confirm that you are looking at the correct signal and verify that the system is operating. This is also a good preliminary indicator of system problems. Assuming that the transmitted digitally modulated signal looks like noise, and given that the inter-symbol interference (ISI) filter shape used is known, the power spectrum should look approximately like the shape of the filter (Figure 16). Now, it is possible and convenient to look for problems at the side lobes of the power spectrum using x-axis scaling to measure the turn-on and turn-off characteristics of the transmitter. Product Note 89400-5, *Measuring Transmitter Transients with the 89440A* describes how to capture transient signals and how to make instantaneous power, frequency, and phase measurements on such signals.

Select . . .
Demodulate the incoming signal by selecting the appropriate modulation format. Press in order the keys [Digital demodulation], [Demodulation setup], [Demod format] and select one of the many modulation formats supported. If you are using either NADC, PDC, or GSM formats, the one-key standard setup configurations automatically set the analyzer for the correct modulation format, symbol rate, frequency span, measured and reference filter types, alpha (or BT) and a predetermined number of symbols (result length). Any or all of these variables can be set manually when using non-standard modulation formats.

The 89400 Series VSAs with Option AYA have two predefined ISI matching filter types, Nyquist (raised cosine or root-raised cosine) and Gaussian. User-defined filters can be loaded into the analyzer from a PC, for example, by inputting the time series impulse response of the filter using 20 points/symbol for 20 symbols (401 time data points). Both the "measured" and "reference" filters must be provided to complete the analyzer's ideal receiver (Figure 17). Using the user-defined filters reduces the time and cost of having to build custom matching filters for testing purposes.

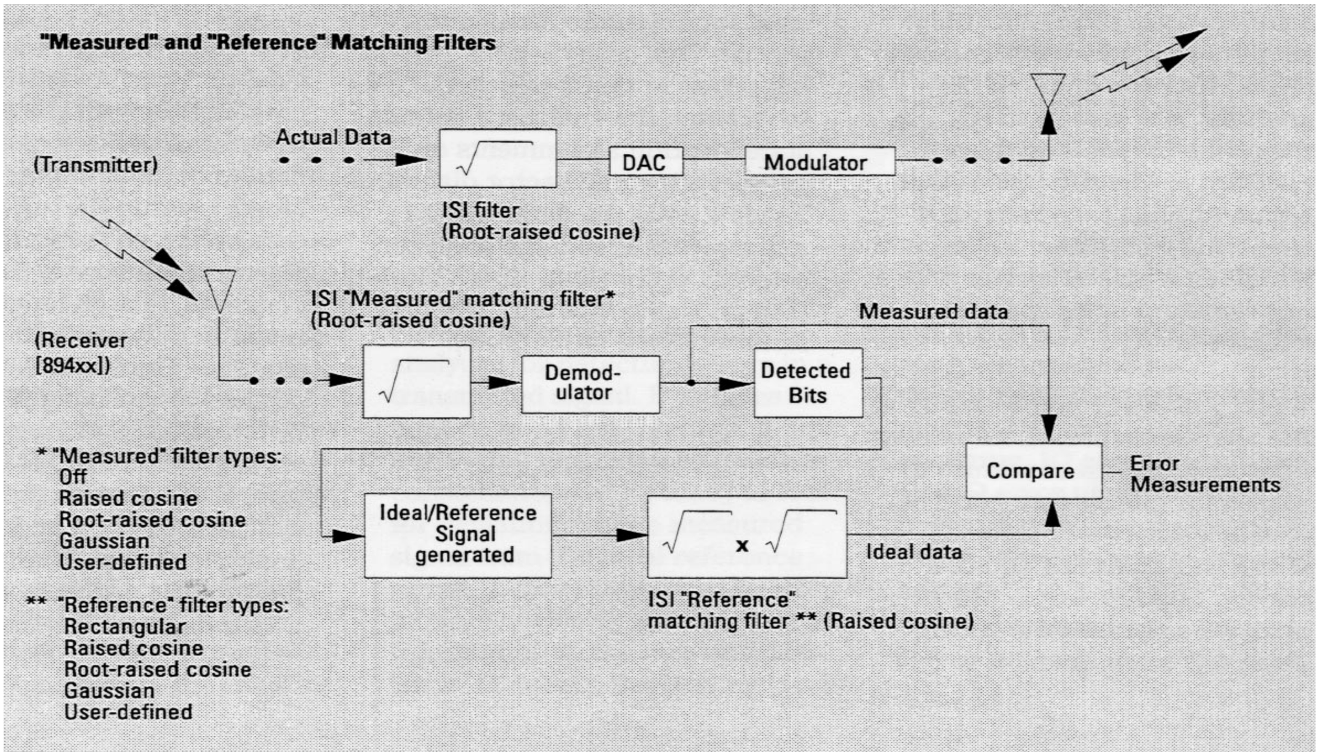


Figure 17. Selectable matching filters are used to represent the filtering in the transmitter and receiver. The detected bits are used in conjunction with knowledge of the modulation type and filtering to determine the ideal signal.

Pulsed modulated signals

Typically, such as for many TDMA and E-TDMA systems, the signals from a mobile unit to the base station are pulsed. In other words, the carrier turns on and off. *On* being when the receiver transmits data and *off* when it finishes transmitting data. In these instances, it is important to measure only during the information of interest. To verify that a pulsed signal is being measured, first set the analyzer for Vector mode and the display format to main time. Look for pulses or bursts. When using digital demodulation mode, “pulse search” is an advanced triggering capability which detects the leading and trailing edges of a pulsed carrier with a non-constant envelope characteristic. Pulse search is a toggled softkey in the [Time] hardkey menu of the analyzer. It is similar to IF triggering in that it enables the analyzer to identify pulses that occur within a time record. IF triggering will falsely trigger in the middle of a pulsed carrier with a non-constant envelope characteristic.

When you select pulse search *on*, the analyzer searches for carrier turn-on, and then continues to search for carrier turn-off. The analyzer displays “Pulse not found” if it does not detect a carrier. In other words, the analyzer must find the entire pulse (*off* to *on*, then *on* to *off*).

If a single measurement contains more than one pulse, the analyzer examines only the first pulse. It ignores all other pulses in the measurement. This situation can occur for large search lengths. The search length (user definable) determines how much data the analyzer collects. Use triggering and “sync search” to align the desired pulse near the beginning of the search record. “Sync search” (also under the [Time] hardkey) aligns the bits to be analyzed relative to a specified sync word.

Shipped with vector modulation analysis (Option AYA) is a utility that uses an editor in the analyzer to assign custom softkeys to quickly switch between several different sync words that may be used for a specific modulation format. This utility is also important in that it allows the user to redefine the analyzer’s default state location assignments on constellation and vector diagrams. To view what the default state assignments are on the analyzer, select in order [Instrument Mode], [Digital Demodulation], [Demod format], [State definitions].

Sync search is valid whether using pulse search or not. In other words, sync search can be used to position the analysis region for either continuous or pulsed signals. When using sync search, make sure the search length is large enough to capture the entire pulse, including any guard and ramp bits. For best results, set the search length to at least 1.5 times the length of the pulse. The search length must be set to be longer than the amount of information to be demodulated and displayed (the result length). That is, you will be instructing the analyzer to search over at least the number of symbols being analyzed. Refer to the analyzer’s help text for more information regarding search length.

Finally, an offset (in number of symbols) can be defined in conjunction with the sync word to determine the location of the data to be demodulated (result length) within the amount of data collected (search length). Figure 18 illustrates these concepts. Search length and result length are defined by pressing the [Time] hardkey. Offset is defined by pressing [Time] followed by [Sync setup]. This softkey menu level is also where the sync pattern is defined. If sync search is on and the analyzer cannot find your sync pattern, the analyzer displays the message “Sync Not Found.”

View . . .
The flexible display and marker formatting of the Agilent 89400 Series VSAs with Option AYA makes locating errors easy. Observe one, two (stacked or overlayed), or four (stacked or quad) color displays simultaneously. Couple the markers between them to locate where certain symbols translate into errors, for example.

Several methods exist in the analyzer for detecting errors in a transmitted signal. Examples include using the "ideal grids" or overlaying like displays (such as constellations of IQ time) to look for deviations of the measured signal from the ideal reference signal. X-axis scaling can be used to resolve closely spaced information in the measurement trace. However, the best methods for accurately detecting errors are by using the error measurements–error vector magnitude (time), error vector spectrum, IQ error magnitude, and IQ error phase. These measurements were discussed in the "Measurement Concepts" section of this product note (page 4).

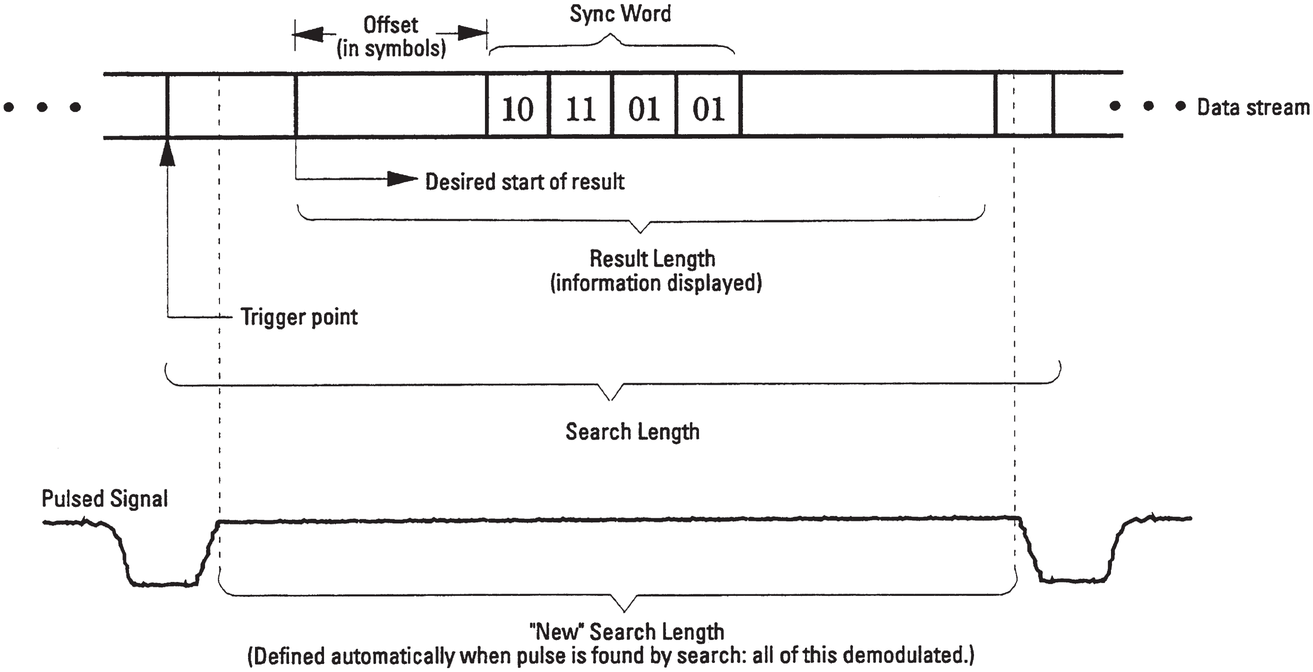


Figure 18. Pulse search and sync search can be used when measuring bursted signals.

Generating digitally modulated signals

The Agilent 89410A includes a built-in baseband source (and the 89440A has an optional RF source) that can be used as a stimulus for digitally modulated systems and demodulated by the analyzer. Fixed sine, noise, chirp, and arbitrary signal types are available. For arbitrary signals, a 8192 real (4096 complex) point time record of any measured signal can be recorded and played back as stimulus. The same time record is played over and over contiguously. Although this is not representative of continuous data or "live" signals, it may be in many cases sufficient for testing.

Creating the arbitrary source

To generate a digitally modulated source signal, you can use a software package to create the data mathematically and load it into the analyzer's arbitrary source from a computer using the Standard Data Format Utilities (supplied standard with each 89400 Series VSA). Examples of these software packages include MATLAB, a product of The Mathworks, and MathCAD, a product of Mathsoft. Alternatively, you can measure your own test signal, save it to a data register, and output it via the arbitrary source. You can also generate a digitally modulated source signal within the analyzer by using the demodulated ideal reference signal (Figure 17). This signal will be output via the arbitrary source. It will consist of one time record that is played continuously and repeatedly. The procedure for creating the source internally is as follows:

1. Preset the analyzer and select vector mode.

2. Set the desired center frequency (usually equal to the approximate carrier frequency).

3. Set the frequency span. A span of two or three times the symbol rate is a good guideline. This step is not necessary for generating the reference signal, but it will be important in the analysis of the signal.

4. Disconnect all signal inputs from the analyzer. Only input noise will be used to generate the reference signal.

5. Set the instrument mode for Digital Demodulation. Using the softkeys in the Demodulation Setup menu select the desired modulation parameters such as modulation type, symbol rate, and alpha/BT.

6. For systems with distributed transmitter and receiver raised-cosine (Nyquist) filtering, set both the Measurement Filter and the Reference Filter as "Root" filter. The filter type setups are also in the Demodulation Setup softkey menu. For all other systems, a good guideline is to choose the reference filter setting to be the same as the filtering that is used for the actual system transmitter. In generating a reference signal using this procedure, only the reference filter affects the result.

7. The Result Length should be set to be 25 symbols longer than the number of symbols that are to be analyzed.

8. The number of Points/Symbol should be a minimum of five (5). This minimum is adequate for many signals, but those using Gaussian filtering and a BT greater than 0.3 will require more. Ten to 20 points/symbol is recommended, especially where BT is much greater than 0.3.

9. Set the Measurement Data to be IQ Reference Time and the Data Format for Constellation. You should see large, noisy imperfections.

10. Save this IQ reference time trace into a file or data register. Signal generation is now complete.

Measuring a signal (using the arbitrary source)

1. The analyzer should be set according to steps 1-3 and 5 in the procedure outlined previously for creating digitally modulated signals.

2. Using a cable, connect the source output to the analyzer's input. Turn the analyzer's source *on* and select Source Type as Arbitrary. The arbitrary data register used should be the one where the digitally modulated signal was saved. If the signal was instead saved to a file, then recall the file to a data register.

3. Set the input range to the lowest value that does not result in an overload condition. To do this, select [Range] and repeatedly press the down arrow (in the numeric keypad on the front panel) until the green overload indicator light turns on. Then, press the up arrow once (until the overload light turns off).

4. Systems which used raised-cosine (Nyquist) filtering should use the analyzer's raised cosine reference measurement filter. In systems that use Gaussian filtering, set the reference filter type to Gaussian. Applications that use a user-defined filter should use this same filter as the reference filter.

5. Also as part of the demodulation setup, set the Result Length to be at least 25 symbols less than was used to generate the signal.

6. Change the Trigger type to Internal Source. Use a Trigger Delay that corresponds to approximately 20 symbols. This delay will need to be set as a unit of time. To determine the equivalent time corresponding to 20 symbols, display Measurement Data as IQ Measured Time and the Data Format as Log or Linear Magnitude. Select the softkey More Data Format and then select "dots" or "bars." These dots or bars that are now displayed indicate each symbol. Using the marker and the front panel knob, scroll over 20 symbols. If the marker's x value currently reads in "units of seconds," you will need to change it to "units of symbols" by pressing in order the keys [Ref Level/Scale], [X & Y units setup], [X units]. Now toggle from seconds to symbols. Using the knob, scroll out 20 symbols, then toggle back to seconds. Use this time as the trigger delay.

7. The signal can be demodulated just as any "live" signal by setting the defined signal parameters via Measurement Data and Data Format.

Other tools

In time capture mode, the analyzer samples the input and stores the information in RAM. Up to 1 Msample of one-channel data can be recorded (with Option AY9 extended time capture) and 500 ksamples of two-channel baseband data (using the receiver type [Chl + j*Ch2]) can be recorded. This data can then be transferred to the internal floppy disk drive or to an external drive for postprocessing in the analyzer either back in the lab or at another site. All of the on-line measurements can be made on captured data. Although these measurements can be made on time captured data, this data cannot be played back (in full) through the source output. Only one of the time records (8192 real points or 4096 complex points) can be played back via the arbitrary source output. Product Note 89400-10, *Time Capture Capabilities of the 89400 Series Vector Signal Analyzers*, provides more information on this useful tool.

View the analyzer's display in real time from across the building or across the world using Options UG7 (advanced LAN) and UFG (4-Mbytes extended RAM and additional I/O). Operating as an X Windows application, a 89400 Series VSA can open a display window on a user-designated X Windows server anywhere on the network. The X Windows display not only shows the actual measurement traces, but also simulates the analyzer's front panel. To operate the analyzer from a remote workstation, simply press the desired keys with the mouse or other pointing device. Now, an R&D lab can assist in troubleshooting problems at a manufacturing site across the country.

Finally, a few more features round out the application. The analyzer can save and recall important measurement setups and traces to memory or to disk. With Instrument BASIC (Option 1C2), keystroke recording can be used to create custom measurements which can be accessed with softkeys built into the program. The operating manual ("Help Text") is built into the analyzer and includes theory of operation, setup descriptions, and a full index. And, report generation is simple by direct output to a large array of Agilent Technologies peripherals, or by printing or plotting to DOS files that can be easily incorporated into word processing packages.

Summary

The Agilent 89400 Series VSAs with vector modulation analysis (Option AYA) utilize an architecture that is similar to the digital receivers used in today's advanced communications systems. Powerful measurement capability lets these analyzers characterize and troubleshoot throughout the entire block diagram of a digital system (any system using I and Q signals). In addition to supporting a wide array of modulation formats, both traditional and new measurements reduce integration, troubleshooting, and design time at baseband, IF, and RF frequencies.

Standard Agilent 89400 Series VSAs

- Superior accuracy
- High performance spectrum analysis
- Frequency, phase, time, and modulation (AM, PM, FM) domains
- Burst and transient signal analysis
- Instantaneous power measurements
- Frequency and time selective power measurements
- Time capture for postprocessing of data
- Coherence measurements
- Group delay measurements
- Built-in source

Vector Modulation Analysis (Option AYA)

- Eye, constellation, vector (polar) diagrams
- Automatic carrier and symbol lock
- Modulation types:
  QPSK, DQPSK, π/4 DQPSK, 16QAM, 32QAM, MSK, GMSK, 8PSK, BPSK
- User-selectable filtering
  - Gaussian
  - Raised cosine, root-raised cosine
  - Adjustable alpha (or BT)
  - User-defined shaping filter
- Powerful Analysis
  - IQ magnitude & phase error
  - Error Vector Magnitude
  - Ideal vs measured data
- RF, IF, and baseband measurements
  - RF input
  - Baseband [Ch1 + j*Ch2]
- Measurements on continuous and burst signals

Configuration Guide

To make the measurements described in this product note, the following configuration is strongly recommended:

89440A	1.8 GHz vector signal analyzer (or the 89410A dc to 10 MHz vector signal analyzer)
Option AYA	Vector modulation analysis
Option AY7	Second 10-MHz input channel
Option UFG	4-Mbytes extended RAM and additional I/O
Option AY9	Extend time capture to 1 Msample

For measurements above 1.8 GHz, the following configuration is strongly recommended:

89410A	dc to 10 MHz vector signal analyzer
Option AYA	Vector modulation analysis
Option AY7	Second 10-MHz input channel
Option UFG	4-Mbytes extended RAM and additional I/O
Option AY9	Extend time capture to 1 Msample
89411A	21.4 MHz down-converter

Spectrum analyzer with a 21.4 MHz IF (for example, the Agilent 8566B or the 70000 Series)

The following options may be useful and included in the configurations above:

Option AY8	RF Source
Option UG7	Advanced LAN support

Glossary

ACP: Adjacent channel power. The power in specified frequency bands is easily measured with the band power markers in the Agilent 89400 Series VSAs. Also refer to Agilent Product Note 89400-1 in the References.

Alpha or BT (bandwidth time product): The filter shape factor; also called the roll-off. The smaller the alpha, the sharper the filter. If alpha equals zero (a brick wall filter), the bandwidth equals the symbol rate. The actual bandwidth required in the carrier section (the occupied bandwidth) is equal to: (symbol rate)*(l + alpha).

Amplitude droop: Also called “burst amplitude droop.” A measure of the change in the magnitude of the signal at the detection-decision points over the measured burst in units of dB per symbol. This parameter is most significant for pulsed signals. A high number most likely indicates a problem with the pulse modulation process.

Band power: The total power (between two selected frequencies or times) with units of dBm, dBVrms, Watts or $Vrms^2$.

BT (bandwidth time product): *See Alpha.*

Carrier frequency error: This parameter is a measure of the frequency error between the measured IF signal and the expected IF signal. Errors in the RF frequency, LO frequency or digitizer clock rate could all appear as carrier frequency error.

Carrier lock: The 89400 series VSAs automatically lock to carrier signals without providing an external coherent carrier. The center frequency of the analyzer should be set to be within 5% of the symbol clock frequency to achieve and maintain lock.

Center frequency: This frequency should typically be set to the modulation carrier frequency.

Coherence: A two-channel measurement that indicates the similarity between two signals. Specifically, it measures the power in the output signal caused by the input. A value of 1.0 equals perfect coherence (all of the output power is caused by the input signal) whereas a value less than 1.0 may indicate the presence of extraneous noise, system nonlinearities or unexpected input signals.

Constellation diagram: A polar mapping of the state positions on the IQ plane. Constellation diagrams reveal spurious signals as states in a circular pattern (rotating) around (versus a cluster at) their ideal positions at the symbol decision timing points. Here, the frequency of the spur is directly proportional to a vector if drawn radially from the ideal state position to the circle (actual measured states). Close-in spurs are difficult to identify using this technique. Also, this same vector is equivalent to the error vector. The spectrum of this vector as it varies over time is called the error vector spectrum.

Error Vector Magnitude (EVM): The magnitude of the vector drawn between the ideal (reference) state position and the measured state position. Two numbers are measured, % rms and peak (with the symbol number displayed for the peak position).

Error vector spectrum: The frequency spectrum of the error vector time. This measurement clearly identifies the frequencies of close-in spurious signals present in a digital modulation system.

Error vector time: This measurement shows the error vector magnitude variations as a signal changes over time—that is, at and between symbol decision timing points.

Eye diagrams: A mapping of I (or Q) magnitude versus time wrapped around a defined number of symbols. Traditionally, these diagrams have been measured with an oscilloscope which is triggered at the timing instants. On the 89400 Series VSAs, the symbol clock detection points are represented by vertical lines on the display.

Eye length: The number of symbols that the eye diagram displays (wraps around).

Filter shape: The shape of the receiver's filter (ISI) used to match the transmitter's filter (example: "root-raised-cosine"). For many modulation types, two receiver filters are used—the "measured" filter is the same as that used at the transmitter whereas the "reference" filter is the squared product of the filter used at the transmitter.

Ideal (reference) signal: Also called the IQ reference signal. This is the signal that would result after demodulating your signal if your signal were ideal (contained no errors). It is the ideal signal against which the IQ measured signal is compared for all of the error measurements (EVM, error vector time, error vector spectrum, IQ error magnitude, and phase). The 89400 Series VSAs create this signal from the detected bits and knowledge of the filtering used, modulation format, symbol rate, etc.

IF trigger: A form of envelope triggering. Looks for magnitude/power level changes in each time record of the signal measured. IF triggering is difficult on some digital signals because their power levels tend to fluctuate as the signal transitions between states. It is also not possible to trigger on CW or fixed amplitude signals such as MSK formats. In these cases, if an external trigger signal (TTL) is available in the system it can be used to trigger the measurement. Or, when performing vector demodulation, consider using pulse and/or sync search.

Input range: The 89400 Series VSAs have specified ranges of allowable input levels (see the technical data sheet). These ranges should be set to maximize the sensitivity to the input signal. To assist this process the analyzers have half-range and overload indicator LEDs next to each input channel. One method to set the range is to step down the input range until the overload indicator comes on, then step the range back up once or until the overload LED is off. Some signals which are too low for the analyzer to measure, may need to be amplified prior to inputting them into the analyzer. The opposite is true for signals which are too large, here attenuation is necessary.

IQ error (magnitude error): The magnitude of the vector of the measured state and the magnitude of the vector of the ideal (reference) state with each vector having been drawn from the IQ plane origin. Two numbers are measured, % rms and peak (with the symbol number displayed for the peak position).

IQ error (phase error): The angle between the vector of the measured state and the vector of the ideal (reference) state with each vector having been drawn from the IQ plane origin. Two numbers are measured in degrees and % magnitude (with the symbol number displayed for the peak position).

IQ offset: Also called "IQ origin offset." It is the magnitude of the carrier feedthrough signal, relative to the magnitude of the modulated carrier at the detection decision points. Carrier feedthrough is an indication of the balance of the IQ modulator used to generate the modulated signal. Imbalance in the modulator results in carrier feedthrough and appears as a dc offset on the demodulated IQ signal.

ISI filter: The I and Q signals are generated digitally then passed through an inter-symbol interference (ISI) filter before being converted to an analog signal which is modulated. Without filtering, the modulator would output infinite bandwidth signals which cannot be transmitted. The ISI filters are designed specifically so that the signals are not only band-limited, but also so that they do not distort the transmitted pulses/signals and interfere with subsequent signals. ISI filters force the impulse response to zero at integer multiples of symbols such that transmitted symbols won't interfere with each other.

Magnitude error: *See IQ error.*

Measurement filter: The ISI matching filter applied in the 89400 Series VSAs. This filter should be selected to match the filter used when transmitting the data. Selectable filter types include raised cosine, root-raised cosine, Gaussian, user-defined, and "off." The "off" filter type is used in systems such as MSK which do not transmit with an ISI filter in order to obtain (controlled/ desired) inter-symbol interference. Another term sometimes used for the measurement filter is "half filter."

Offset (QPSK or other): Some radio and satellite systems use so called offset keyed or staggered modulation. In these systems a delay of half a symbol-time is introduced between the I and Q data streams, so that the modulation envelope is not synchronized on both I and Q carriers. This has the advantage of slightly reducing the peak power handled by the transmitter.

Phase error: *See IQ error.*

Pulse search: Searches through the transmitted data for pulses of data (such as transmit signals from mobile units to base stations). When pulse search is used, sync search with a defined sync word must also be used to help the analyzer to identify the desired pulse.

Quadrature error: A measure of the error from the ideal quadrature (90 degree) angle between I and Q.

Reference filter: The filter applied in the 89400 Series VSAs to match the ISI filter used in a system's receiver. This filter is typically the squared product of the filter used to transmit the data (transmit filter)^2. Another term sometimes used for the reference filter is "whole filter."

Result length: The total amount of data (symbols) displayed. The maximum number of symbols that can be displayed in the 89400 Series VSAs is 4096 (assuming Option UFG 4-Mbyte extended RAM is installed).

Search length: The total amount of data (symbols) that is demodulated. This amount must be greater than the amount of information displayed (result length).

Symbol lock: The 89400 Series VSAs can lock to symbols transmitted at rates up to 6.36 MHz measuring with the 89440A (9.09 MHz with the 89410A).

Symbol rate: The rate at which the carrier moves between points in the constellation. For example, if a radio operates at a frequency of 16 Mbits/ second, and the digital modulation format uses 4 bits/ state, then the carrier must change states at a rate of 4 MBaud, so the symbol rate = 4 MHz.

Symbol table and error summary: This display has two parts. The upper portion is the error summary which displays various measured parameters of the received signal. Included are: EVM (% rms and % peak at symbol #), magnitude error (% rms and % peak at symbol #), phase error (degrees and peak degrees at symbol #), frequency (carrier) error, IQ offset, and amplitude droop. The lower portion of this display is a table of the bits of the symbols, in ls and 0s, detected by the receiver (the 89400 Series VSA). The maximum number of symbols displayed is defined by the "result length" selected. If sync search is used, the sync word will be highlighted when detected (otherwise, the message "sync not found" will be shown in part of the display).

Sync offset: The offset (in symbols) from the sync word used to define the start of the result or information displayed.

Sync word: A specific bit pattern located within the transmitted data stream that is typically used to align the bits and locate the information of interest.

Time capture: Continuous streams of data are sampled and passed directly to time-capture RAM (maximum = 1 Msamples) for postprocessing. When postprocessing, all of the measurements available in "normal" operation and on-line measurements are possible.

Time record: A block of time data samples used to calculate each measurement. The length of the time record is variable and is inversely proportional to the frequency span (stop frequency minus start frequency) selected.

Trellis diagram: A mapping of phase versus time which is wrapped around a defined number of symbols. On the 89400 Series VSAs, the symbol clock detection points are represented by vertical lines on the display. Trellis diagrams are a useful means of showing the phase trajectory at each symbol.

User-defined filter: ISI matching filters which can be downloaded into the 89400 Series VSAs. *Also see Measured Filter and Reference Filter.*

Vector diagram: A polar mapping of the state positions and the transitional paths (signal power) between the states on the IQ plane.

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