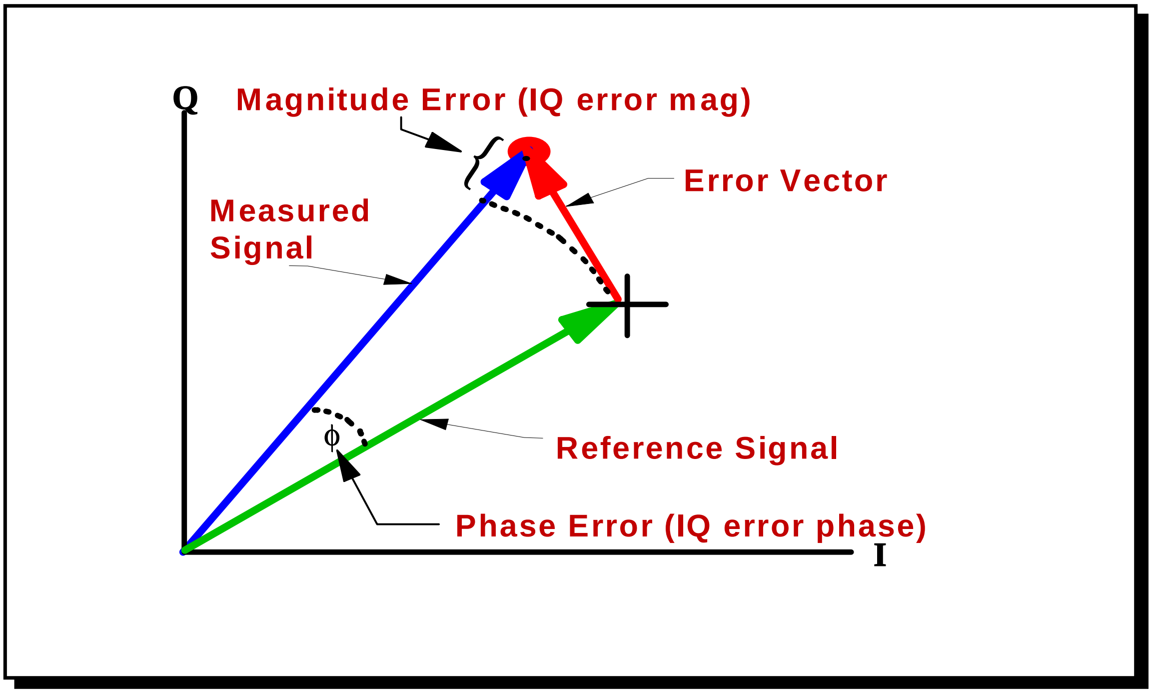
Notes on Error Vector Measurements with the HP89400 Vector Signal Analyzers



- **Ten Steps to a Perfect Digital Demod Measurement**
- **Troubleshooting With EVM**
- **Digital Demod Help**

January 1996

Ten Steps to a Perfect Digital Demod Measurement

1. Set center frequency and span for the signal under test (vector mode).

HINT: the center frequencies of the analyzer and input signal must match to within ±3% of the symbol rate (±1% for 64QAM and ±0.2% for 256QAM).

CHECK: The signal's spectrum should occupy 50-90% of the span, and *not* extend beyond the edges. It should appear as a distinct, elevated region of noise 20 dB or more above the analyzer noise floor. Broad, glitching sidebands indicate bursts or other transients, which can be handled with triggering or the Pulse Search function.

2. Set input range as low as possible without overload.

HINT: green LED may or may not be on; yellow LED (overrange) must <u>not</u> be on.

CHECK: Downrange by one step; overload indicators should turn on.

3. Set up Triggering, if required.

HINT: Triggering is unnecessary for most signals (but see notes below regarding use of the 89400's internal arb source). For TDMA and other bursted signals, use Pulse Search instead (activated in step #8, below). Otherwise, choose trigger mode, level, delay, holdoff and arming just as you would with an oscilloscope, in accordance with the characteristics of your specific signal.

HINT: With the Trigger menu selected, a display of Main Time:Magnitude shows the current trigger level as a horizontal cursor, superimposed on the input waveform.

CHECK: With triggering in use, the time domain display should show a stable signal that occupies >50% of the time span.

4. Select Digital Demodulation mode.

HINT: Be aware that this mode retains the settings from its previous digital demod measurement. If, for example, the previous symbol rate setting is incompatible with your current frequency span, the analyzer may automatically increase or decrease your frequency span.

CHECK: make certain that the frequency span is still the same as you set in step #1.

5. Enter the correct modulation format under Demodulation Setup.

HINT: This is simple unless no one knows the modulation format. Identifying an unknown signal format is a significant challenge requiring specialized expertise.

6. Enter the correct symbol rate.

HINT: Symbol rate needs to be entered to an accuracy of 10-100 ppm!

HINT: Identifying an unknown symbol rate is difficult, but it sometimes helps to AM demodulate the signal and look at the high end of the demod spectrum for a discrete signal at the symbol rate (it's easier to see with averaging). Also remember that the 3 dB bandwidth of the signal is approximately equal to the symbol rate. (Neither technique will yield the accuracy required, but the results may help someone remember the actual numbers).

7. **Set the result length and points/symbol for the desired display.**

   HINT: Result length is important for bursted signals, as you don't want to include data symbols taken before or after the burst (i.e. you don't want to demodulate noise).

   HINT: More points/symbol reveals more detail of the inter-symbol waveforms (for viewing eye diagrams, error peaks, etc.). Fewer points/symbol allows you to demodulate more symbols per measurement (remember: result length * points/symbol must always be less than max time points).

8. **Turn on Pulse Search and set the Search Length (burst signals only).**

   HINT: Maximum search length can be many times longer than a time record; set it to the burst "off" time plus twice the burst "on" time to insure that there's always a complete burst in every search.

   HINT: This is also a good time to set up the "Sync Search" function if needed. Check online Help for a good description of its capabilities.

9. **Select the filter shapes and alpha.**

   HINT: To choose the right filters, remember: the "measured" filter should match the receiver, while the "reference" filter should match the combination of transmitter × receiver.

   HINT: If the alpha is unknown, estimate it from (60dB BW/3dB BW) - 1. EVM peaks between symbols mean an incorrect alpha, but won't usually affect the EVM% readout (except in GSM). In the worst case, start with 0.3 and manually adjust up or down for lowest inter-symbol peaks.

10. **Final Checks.**

    Look for the following:

    – overall shape of eye and/or constellation diagrams is regular and stable (even if individual symbols are very noisy, the characteristic shape should be evident). Eye opening should line up precisely with the display center line -- if not, tweak "clock adjust" for best centering (lowest EVM).

    – on the data table display, the EVM% readout is fairly consistent from measurement to measurement.

    – EVM vs. symbol trace is noise-like, but fairly uniform (short peaks are OK). Abrupt changes within the EVM trace signify problems, as do sloping or V-shaped distributions.

    If problems exist, consult the analyzer's on-line Help under "digital demodulation troubleshooting".

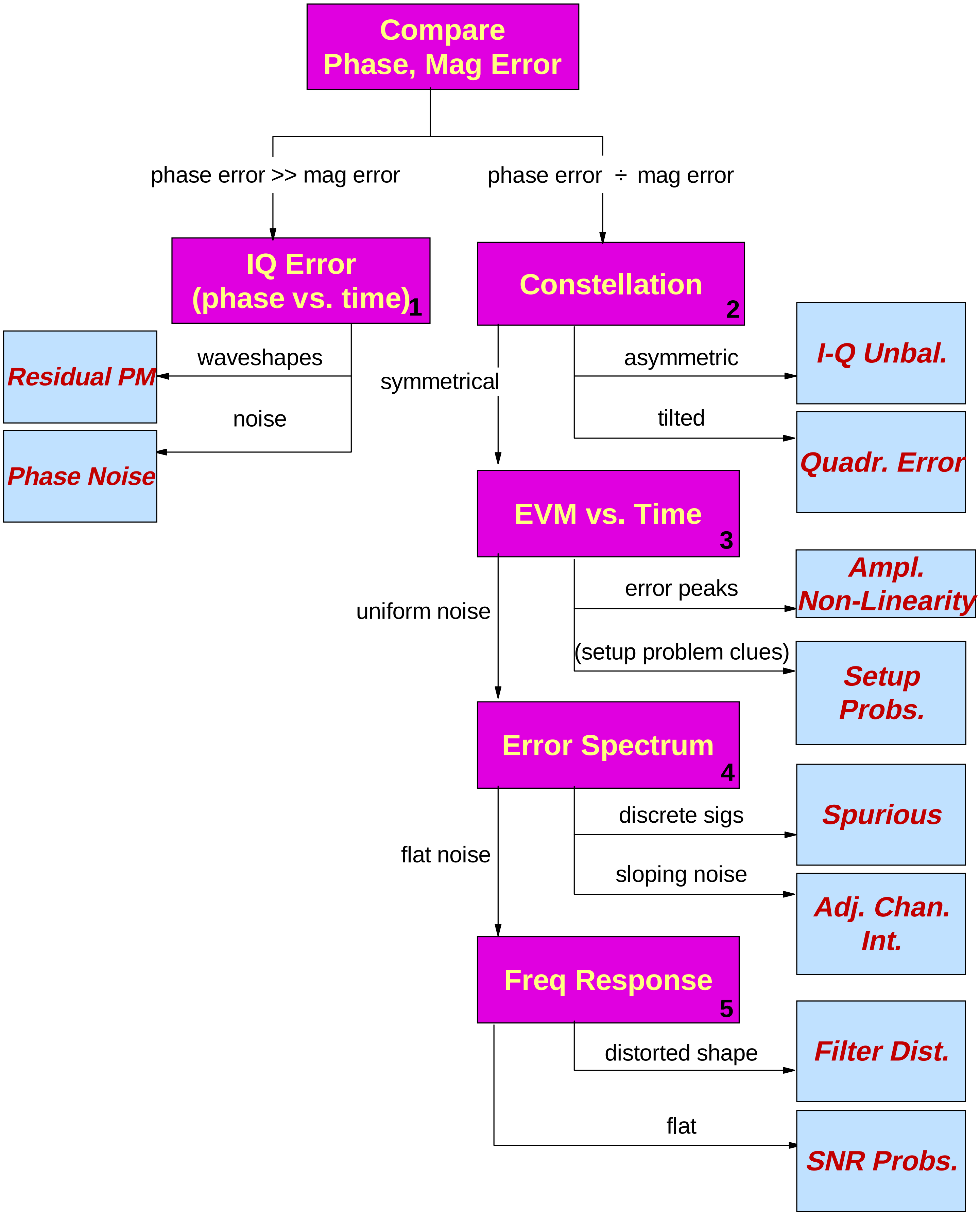
SPECIAL PROCEDURES FOR USING THE 89400 ARB SOURCE

Demodulating signals created by the 89400's internal arbitrary waveform source involves constraints not found with "real-world" signals. This is due to the fact that the arb signal is not continuous, but subject to discontinuities in amplitude, phase and/or timing each time the waveform wraps around from end to beginning. Therefore, in addition to the above steps, always perform the following:

– set trigger type = Internal Source

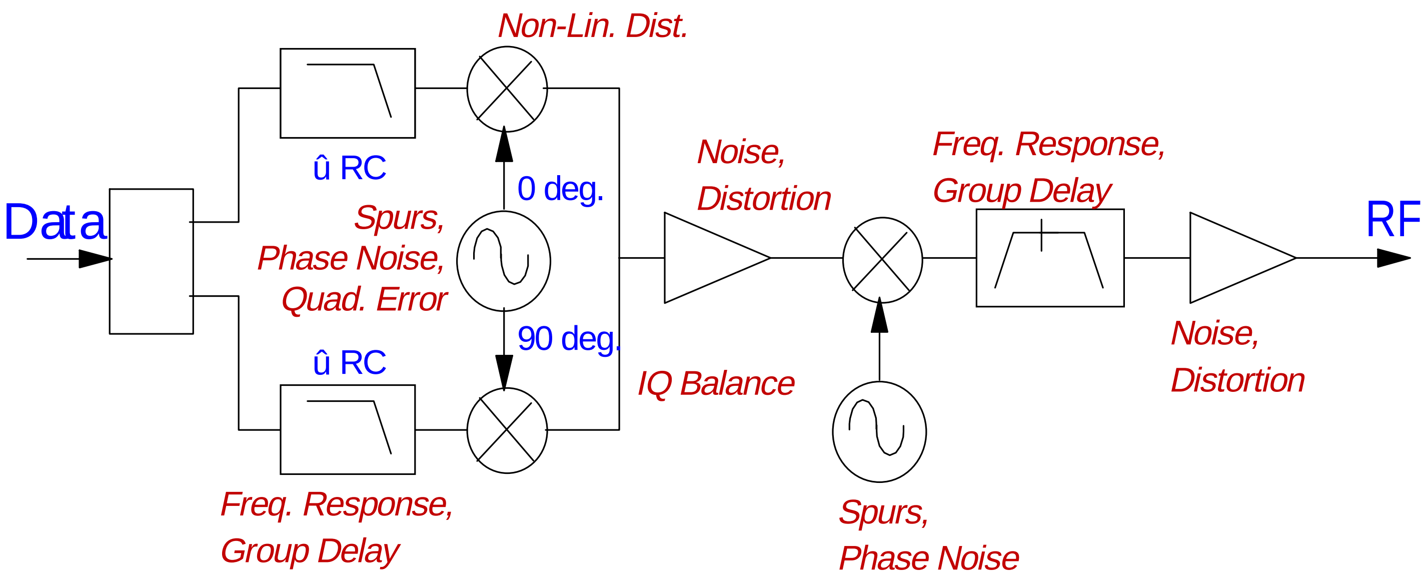
– set a positive trigger delay to avoid the first 5-10 symbols of the waveform

– choose a result length shorter than the arb waveform duration (you can determine the length of the arb waveform empirically by increasing result length until demod abruptly loses lock).

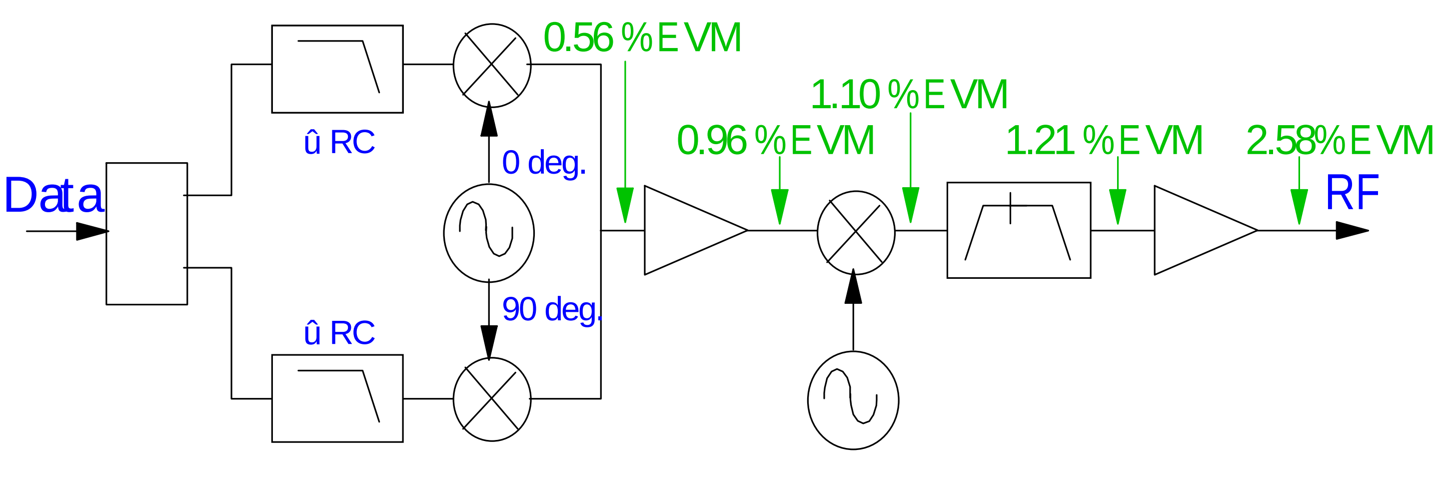

Compare
Phase, Mag Error
phase error >> mag error
phase error ÷ mag error
IQ Error
(phase vs. time)
1
Constellation
2
waveshapes
Residual PM
noise
Phase Noise
symmetrical
asymmetric
I-Q Unbal.
tilted
Quadr. Error
EVM vs. Time
3
error peaks
Ampl.
Non-Linearity
uniform noise
(setup problem clues)
Setup
Probs.
Error Spectrum
4
discrete sigs
Spurious
flat noise
sloping noise
Adj. Chan.
Int.
Freq Response
5
distorted shape
Filter Dist.
flat
SNR Probs.

EVM Application: Quantifying Modulation Quality

Localizing Problem Areas



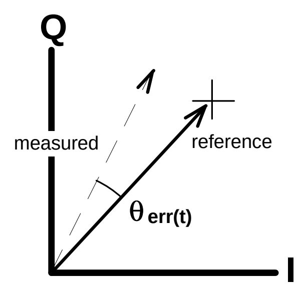
Localizing a Modulation Quality Problem

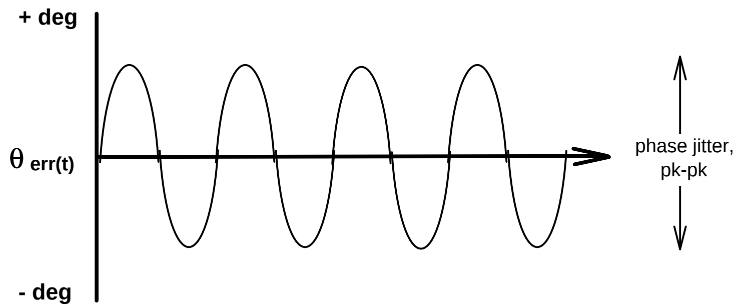


1. IQ Phase Error vs. Time

- **Description:**

Phase error is the instantaneous angle difference between the measured signal and the ideal reference signal. When viewed as a function of time or symbol, it shows the waveform of any residual phase modulation.

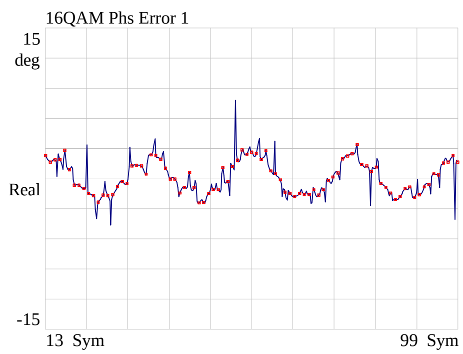




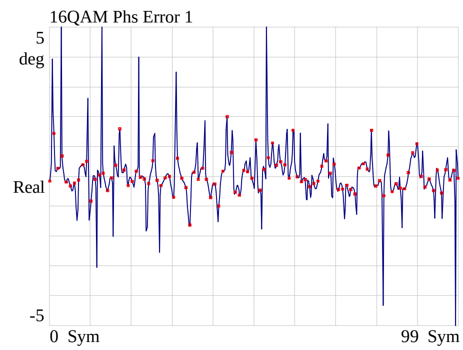
- **Setup:** From digital demodulation mode:

MEAS DATA	**IQ Error: Phase**
DATA FORMAT	**Phase**

- **Examples:**



Incidental (inband) PM sinewave is clearly visible - even at 4 degrees pk-pk.



Phase noise appears random in the time domain.

- **Notes:**

- X-axis is scaled in symbols. To get absolute time, divide by the **symbol rate.**

- to expand the waveform, reduce **result length** or use **X scale markers.**

- practical limit for waveform displays is dc to approximately (symbol rate)/2.

- to precisely determine the frequency of a phase jitter spur, create and display a math function FFT(PHASEERROR). For best frequency resolution, reduce **points/symbol** and increase **result length**.

2. Constellation Diagram

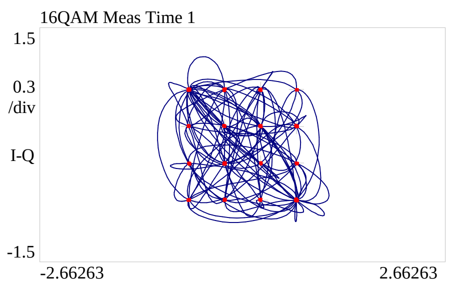
- **Description:**

A graphical analysis technique utilizing a polar plot to display a vector modulated signal's magnitude and phase *relative to the carrier*, as a function of time or symbol. The phasor values at the symbol clock times are particularly important, and are highlighted with a dot. In order to accomplish this, a constellation analyzer must thus know the precise carrier and symbol clock frequencies and phases, either through automatic locking (HP89400's) or an external input (HP8981B).

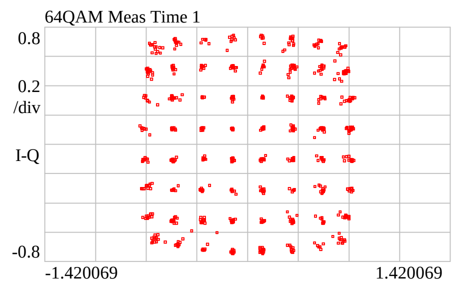
- **Setup:** From digital demodulation mode:

MEAS DATA	**IQ Measured Time**	
DATA FORMAT	**Polar: Constellation**	(dots only)
	Polar: Vector	(dots plus intersymbol paths)

- **Examples:**



Vector display shows signal path (including peaks) between symbols.



Constellation display shows symbol points only, revealing problems such as compression (shown here).

- **Notes:**

- **result length** (number of symbols) determines how many dots will appear on the constellation. Increase it to populate the constellation states more completely.

- **points/symbol** determines how much detail is shown between symbols. To see peaks and overshoot, use 4 or more. To allow a longer result length, use fewer points (in either case, **result length** * **points/symbol** must be less than **max time points**). One point per symbol creates trivial eye and constellation diagrams, because all symbol points are connected by straight, direct lines.

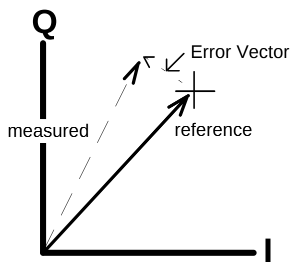
- to view the spreading of symbol dots more closely, move the marker to the desired state, press **mkr** → **ref lvl** and then decrease **Y/div**.

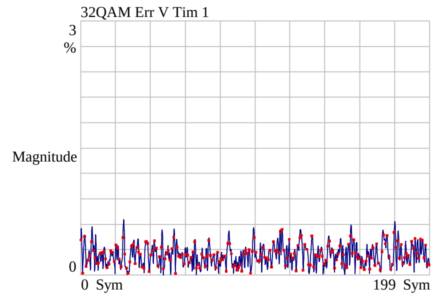
- with **normalize ON**, the outermost states will always have a value of 1. With **normalize OFF**, the values are absolute voltage levels.

3. Error Vector Magnitude vs. Time

- **Description:**

EVM is the difference between the input signal and the internally-generated ideal reference. When viewed as a function of symbol or time, errors may be correlated to specific points on the input waveform, such as peaks or zero-crossings. EVM is a scalar (magnitude-only) value.



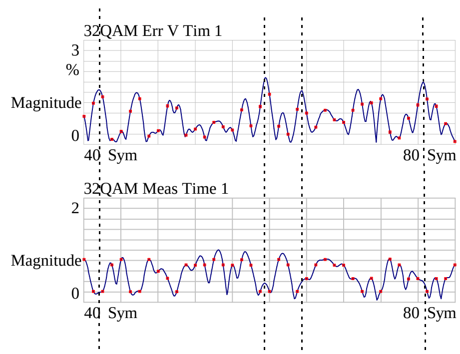


- **Setup:** From digital demodulation mode:

DISPLAY	**two grids**	
MEAS DATA	**(A) error vector: time**	**(B) IQ measured time**
DATA FORMAT	**(A) linear magnitude**	**(B) linear magnitude**
MARKER	**couple markers: ON**	

- **Example:**

EVM peaks on this signal (upper trace) occur every time the signal magnitude (lower trace) is near zero. This is probably a zero crossing error in the output amplifier.



- **Notes:**

- EVM is expressed as a percentage of the outermost (peak) state on the constellation diagram.

- don't confuse error vector phase (nearly meaningless) with IQ Phase Error (very useful).

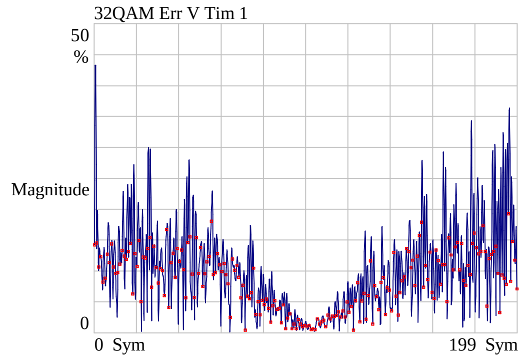
- the X-axis is scaled in symbols. To get absolute time, divide by the **symbol rate.**

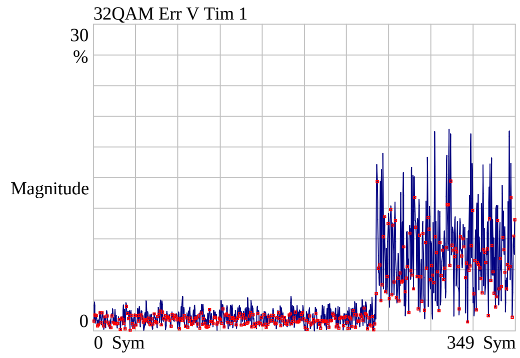
- to expand the waveform, reduce **result length** or use **X scale markers.**

- the EVM value given in the **data table** summary is the RMS average of the error at each displayed symbol point (except GSM or MSK type I, which also includes intersymbol errors).

- with **points/symbol** >1, error between symbol points can be seen. An EVM peak between each symbol usually indicates a problem with filter **alpha**. Peaks that coincide with signal peaks or zero crossings indicate non-linearity problems such as clipping or zero crossing errors.

- The EVM waveform can also highlight measurement setup problems:





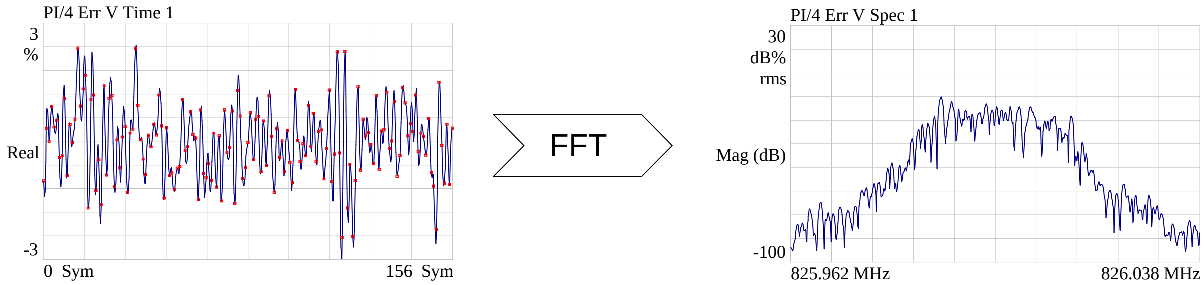
V-shaped EVM plot due to incorrect symbol clock rate.

*EVM becomes noise at end of TDMA burst -- use shorter **result length**.*

4. Error Spectrum (EVM vs. Frequency)

- **Description:**

Error spectrum is the FFT of the EVM waveform, and can show details not visible in the time domain, such as low-level spurious or uneven noise distribution.



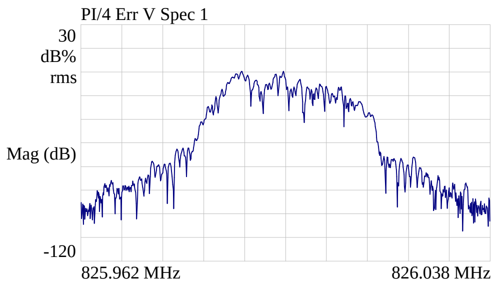
where: $\text{Freq. span} = \dfrac{\text{points/symbol} * \text{symbol rate}}{1.28}$

and: $\text{Freq. resolution} \propto \dfrac{\text{symbol rate}}{\text{result length}}$

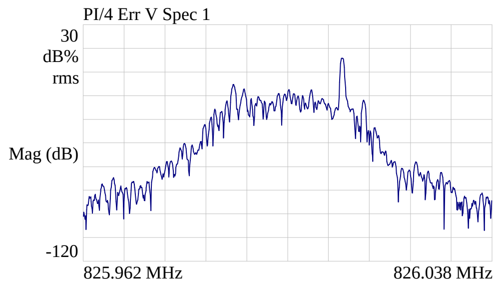
Setup: From digital demodulation mode:

MEAS DATA	**error vector: spectrum**
DATA FORMAT	**log magnitude**

- **Examples:**



Interference from adjacent (lower) channel causes uneven EVM spectral distribution.



Power supply ripple appears as EVM spur, offset from carrier by 10 kHz.

- **Notes:**

- to change span or resolution of the EVM spectrum, adjust only **points/symbol** or **result length**. Do not adjust the analyzer's center frequency or span, or the signal will be lost!

- with a linear magnitude display, spectrum calibration is EVM%. With log magnitude, it is "dB relative to 100% EVM".

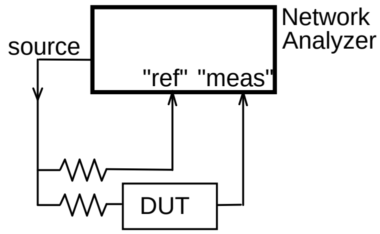
- averaging in the analyzer is applied prior to demodulation; thus the spectrum cannot be smoothed beyond what is shown.

- frequency calibration is absolute, with the carrier frequency in the center. Use the **offset marker** to determine baseband interference frequencies.

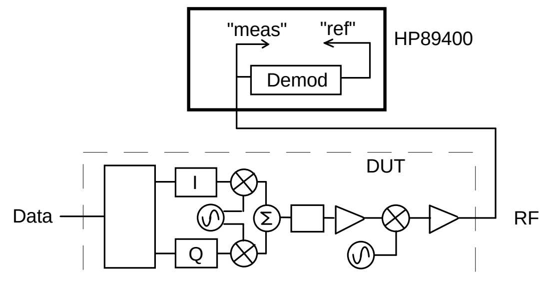
5. Channel Frequency Response

- **Description:**

This powerful, unique 89400 measurement calculates the ratio of the measured signal to the reference signal. Because the latter is internally-generated and is ideal, it allows a frequency response measurement to be made across an entire modulated system *without physically accessing the modulator input*. Having this “virtual” baseband input is important because, in most cases, such a stimulus point is unavailable because it is either a) inaccessible; b) digitally-implemented or c) the aggregate of separate I and Q signals.



In traditional two-sided network analysis, the DUT’s input signal is carefully measured so that any imperfections in the source signal can be mathematically removed.



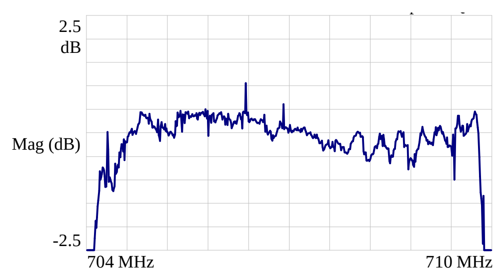
With an 89400, the DUT input signal doesn’t need to be supplied or measured, because it is calculated (regenerated) from the measured signal, and is thus already in ideal form.

- **Setup:** From digital demodulation mode:

MATH	**Define Function: F1 = MEASSPEC/REFSPEC**
MEAS DATA	**F1**
DATA FORMAT	**log magnitude, phase or group delay**

- **Example:**

The flatness of this digital TV transmitter is about ± 0.5 dB from the modulator input to IOT output, with transmit equalizer on. The measurement required no interruption of the video transmissions!



- **Notes:**

- see notes from #4 “Error Spectrum” regarding how to adjust the frequency span and resolution.

- use this technique primarily to measure passband flatness. Dynamic range is insufficient for stopband rejection measurements.

- with **data format: phase**, the deviation from linear phase response is especially easy to read, because automatic carrier locking has already removed any phase slope.

- this is usually a fairly noisy measurement, because the distribution of energy across the passband is uneven, and thus the SNR of any individual frequency point tends to vary dramatically. Averaging is applied prior to demodulation, so it will not help here! For **group delay** measurements, choose a wider **aperture** to smooth out the data.

- to manually average traces, try this trace math trick: save a measurement into D1; then change to a display of F2 = (F1+D1)/K1 (F1 as defined above); and save this trace into D1 for K1 measurements.