Precision Measurements on Modulated Signals Using VNA Methods

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MAY 15, 2024

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KEYSIGHT TECHNOLOGIES

Modern Methods of Wideband Modulation Test

FOR 5G AND 6G COMPONENTS: ABSTRACT

Speaker: Joel Dunsmore, Ph.D., Keysight Fellow

Abstract: Recent requirements for characterizing components such as amplifiers, frequency converters, digital-to-RF transceivers and other components for 5G and 6G systems have pushed test methods to, and beyond, their limits.

This paper introduces modern methods of testing wideband modulation signals; precision source signal-generation and optimization and precision measurements using Vector Signal Analysis (VSA) software for demodulation and evaluation of component contributions to channel response, error-vector-magnitude (EVM) and Adjacent Channel Power Ratio (ACPR) are presented, based on Vector Network Analyzer hardware.

Methods that include test system pre-distortion of signal generators and drive amplifiers, precise and traceable calibration of vector receivers, and the use of advanced noise reduction techniques are presented with extension to sub-THz (D-band) frequencies

Modern Methods of Wideband Modulation Test

AGENDA

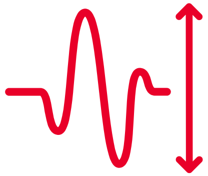
- Introduction to Modulated Signals, and their Attributes
- Using a VNA for Spectrum Analysis (VSA) Mode
- Calibrating for Magnitude and Phase across a bandwidth
- Vector Signal Analysis with VNA (comparison with wideband Spectrum Analyzer)
- Extensions to Sub-THz frequency range.

Why do we need Precise Measurements of Modulated Signals

WHAT'S OUR MOTIVATION.

- Using a precisely-measured signal to measure a wideband receiver
  - Create a wide band signal
  - Carefully measure it for mag and phase across frequency
  - Apply this to a receiver under test, and check the processed data against the applied signal

- Characterize the distortion of an Amplifier for DPD
  - The signal needs to be very clean to apply to the amplifier
  - The output signal must be very precisely measured to find the proper non-linear response
    - 0.01 dB compression equates to about 0.3% EVM; noise will affect DPD results



- Applications to Radar, High-speed Pulse Profile, even Phased-Array Calibration

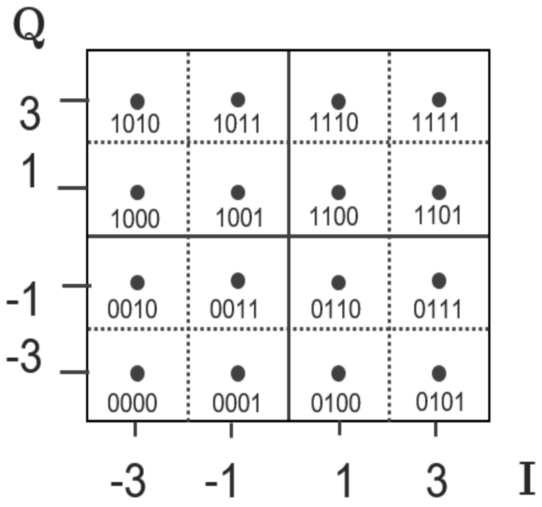
Review: Creating the Signal for 16 QAM

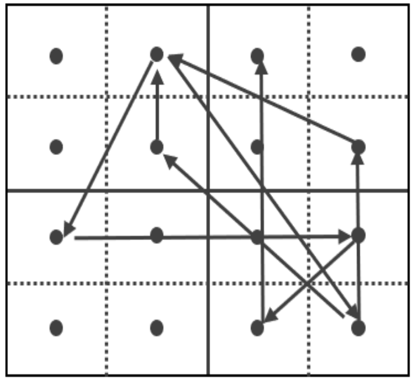
CREATING IQ WAVEFORM FROM DATA

0101100110110101110110110010011101001110
0101 1001 1011 0101 11011 1011 0010 0111 0100 1110

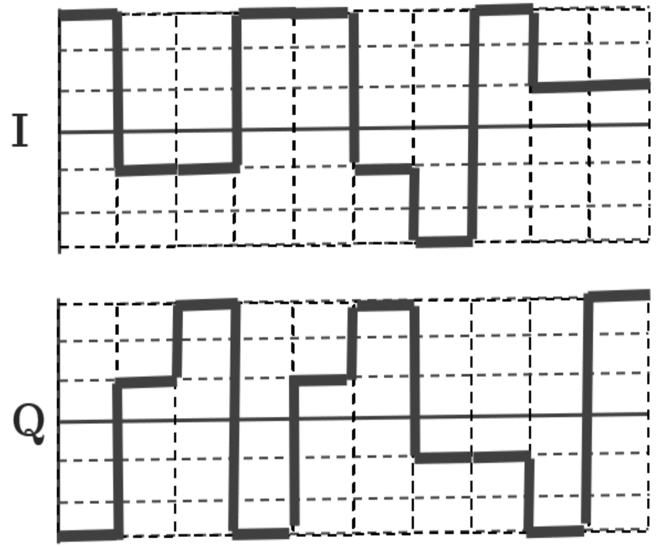
5 → 9 → B → 5 → D → B → 2 → 7 → 4 → E

Map to a QAM Quadrant



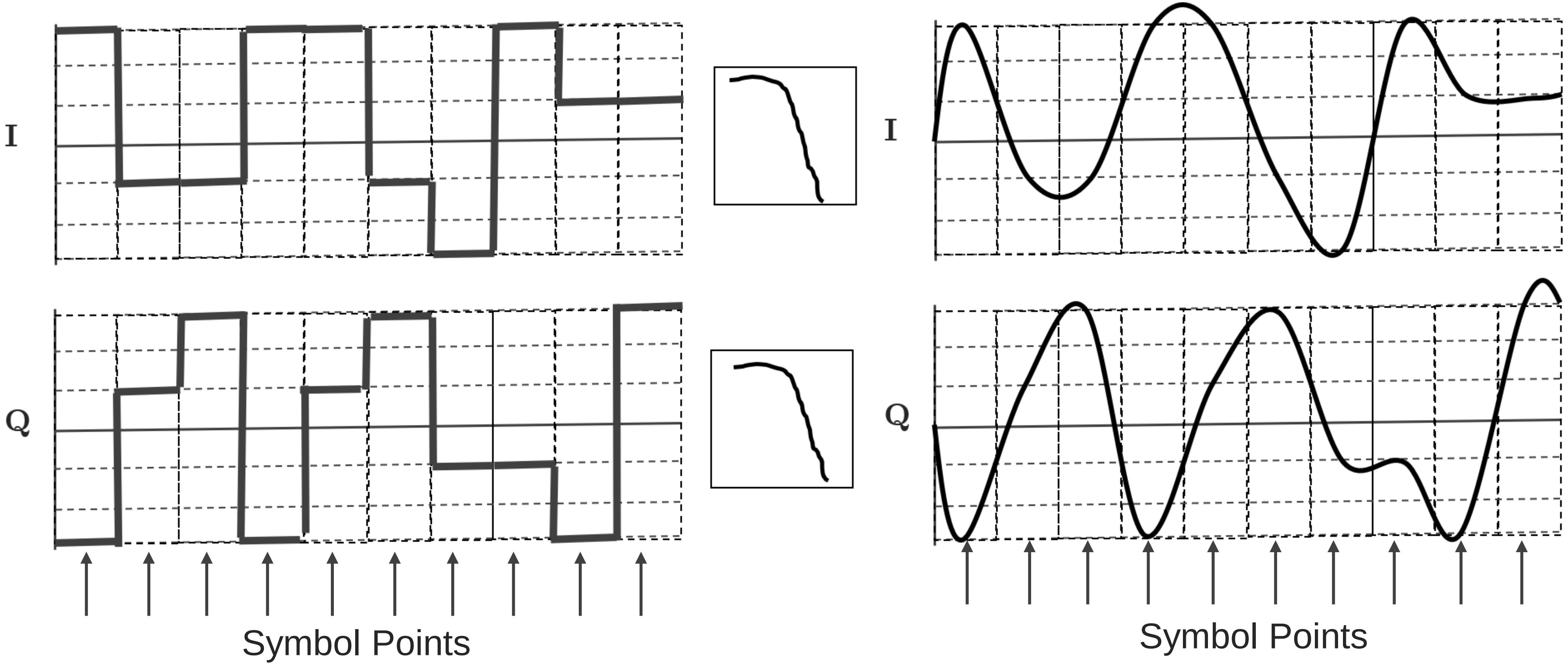


Map to I/Q Waveforms



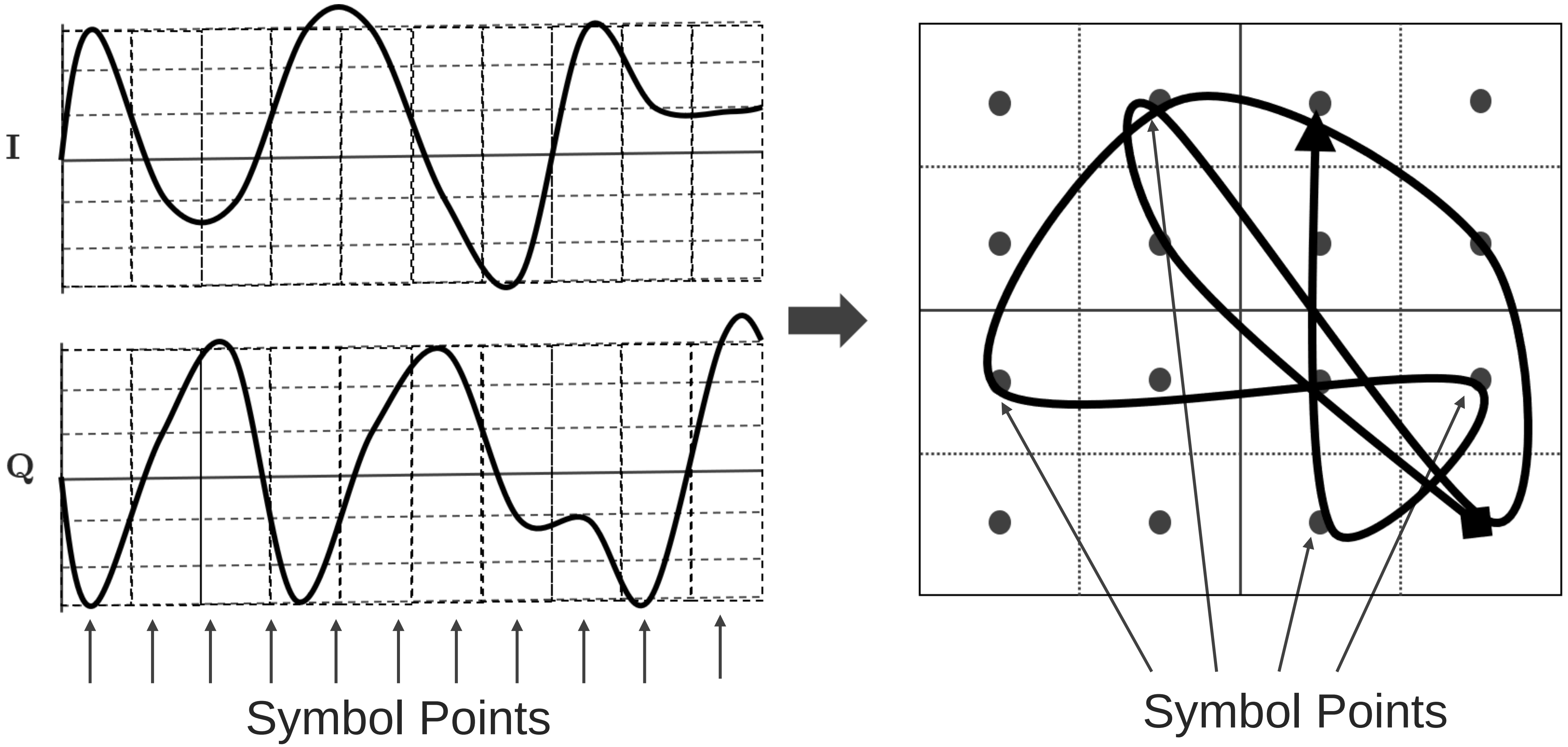
EVM Measurements: Filtering

A ROOT RAISED COSINE AVOIDS INTER-SYMBOL INTERFERENCE



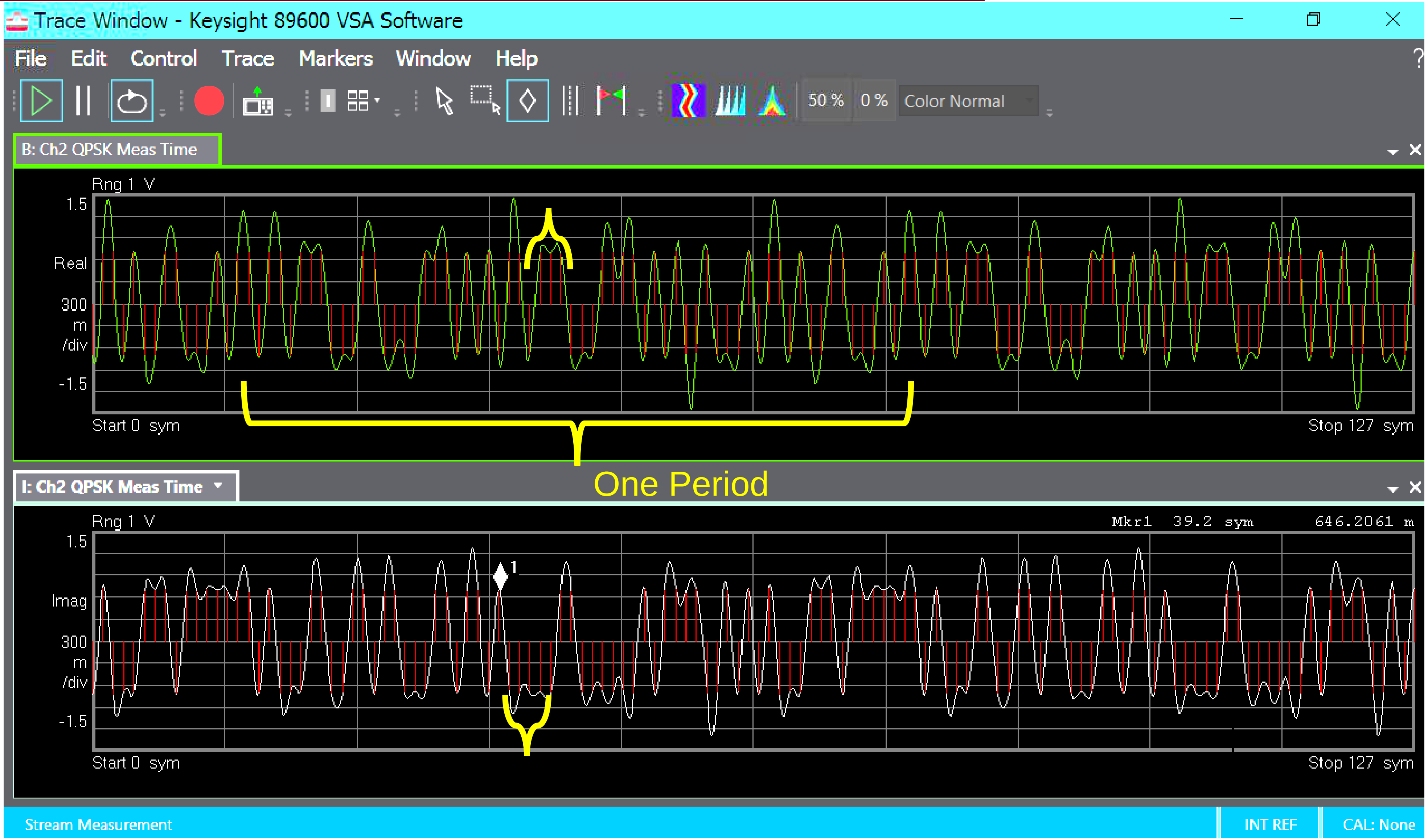
EVM Measurements: Constellation View

A THIS CONSTELLATION IS THE IDEAL OR REFERENCE WAVEFORM



Notice and IQ Waveform: I (real) and Q (imag)

64 SYMBOLS, REPEATED TWICE, QPSK



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Notice and IQ Waveform: I (real) and Q (imag)

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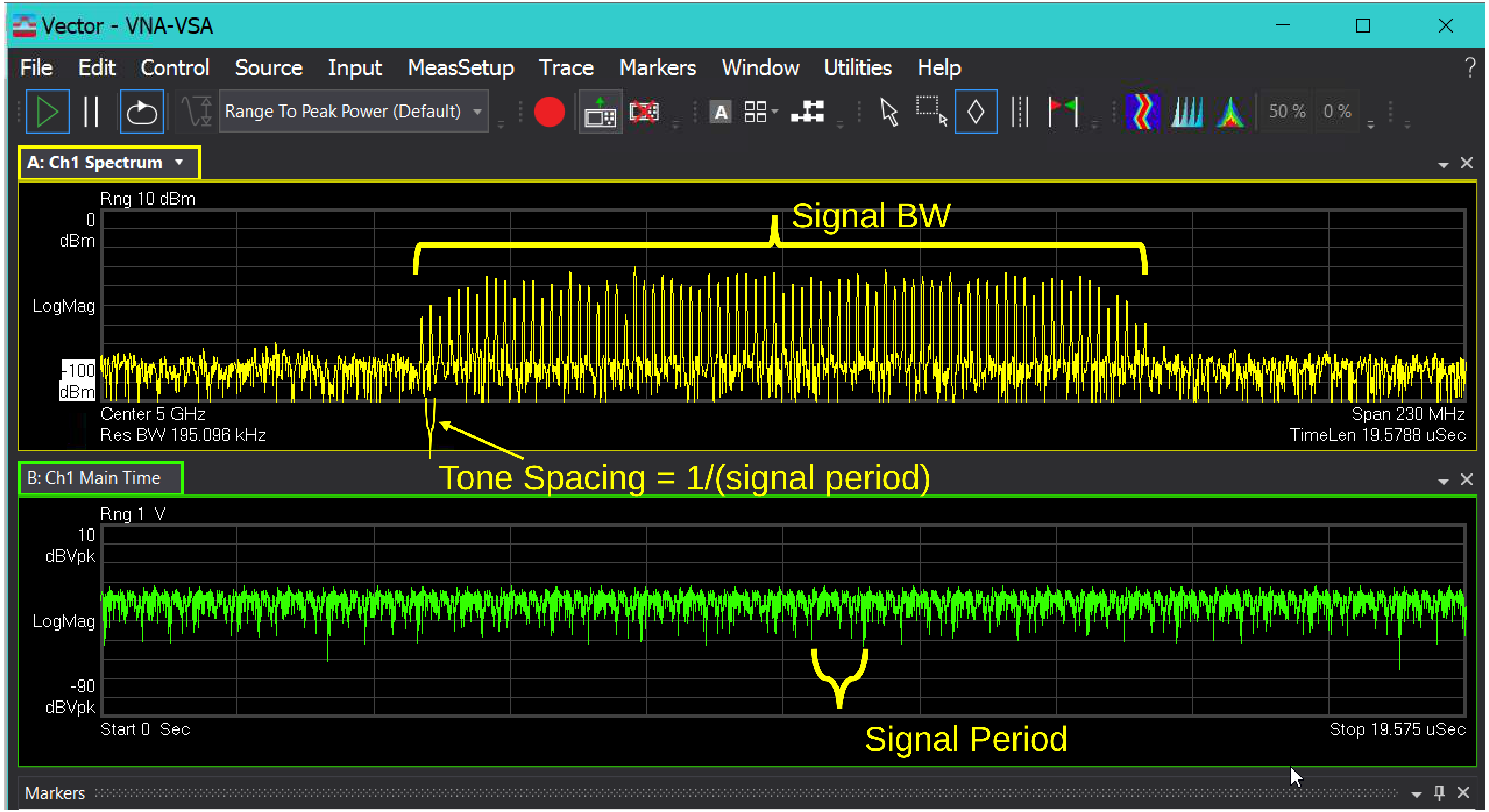
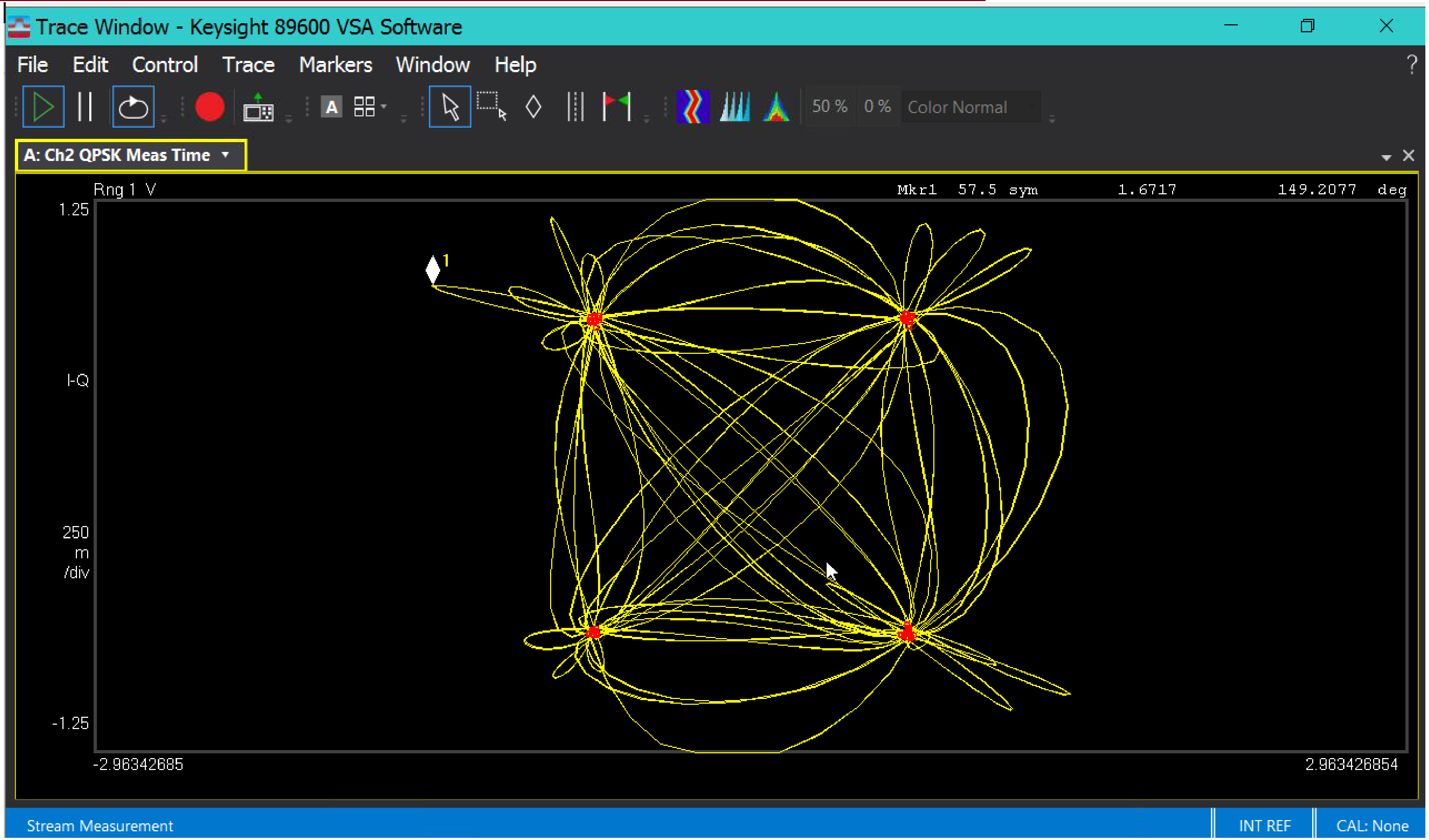


Notice and IQ Waveform: Polar (Constellation) view

64 SYMBOLS, REPEATED TWICE



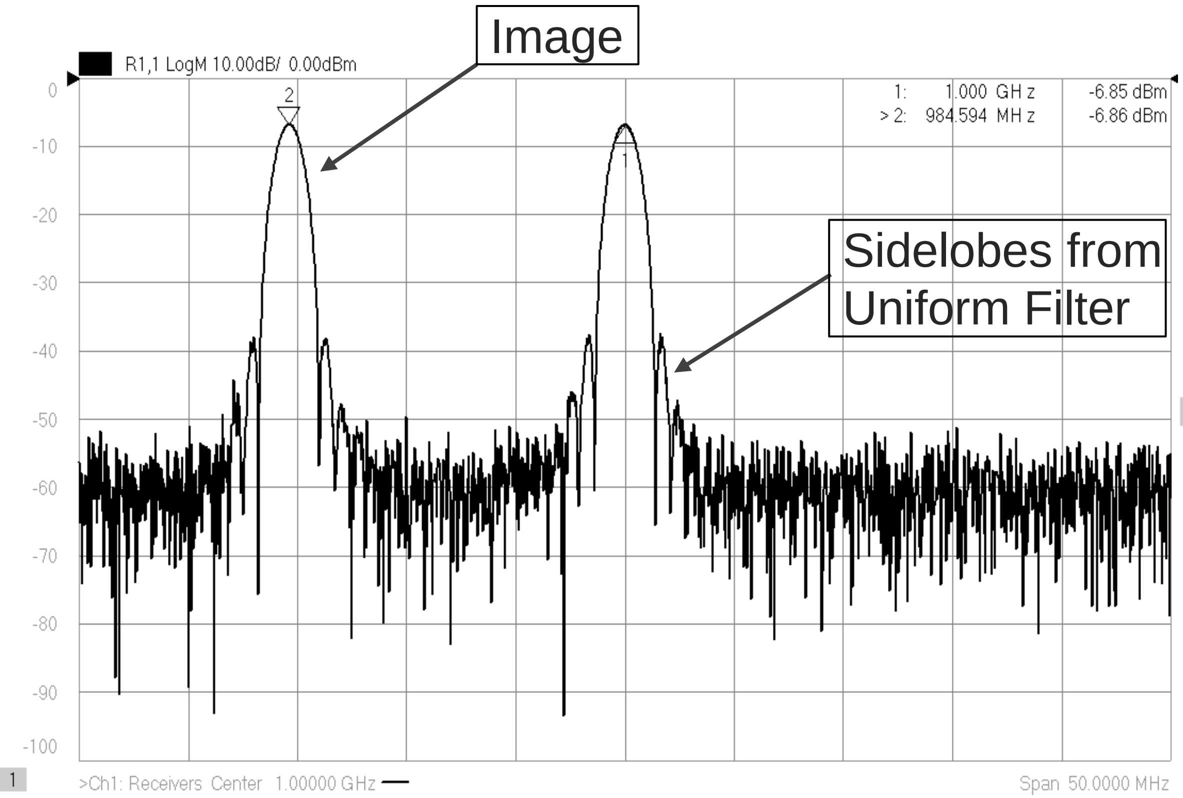
Can a VNA be used as a Precision Spectrum Analyzer

SOME EXAMPLES PNA, M9393, MM-WAVE SA

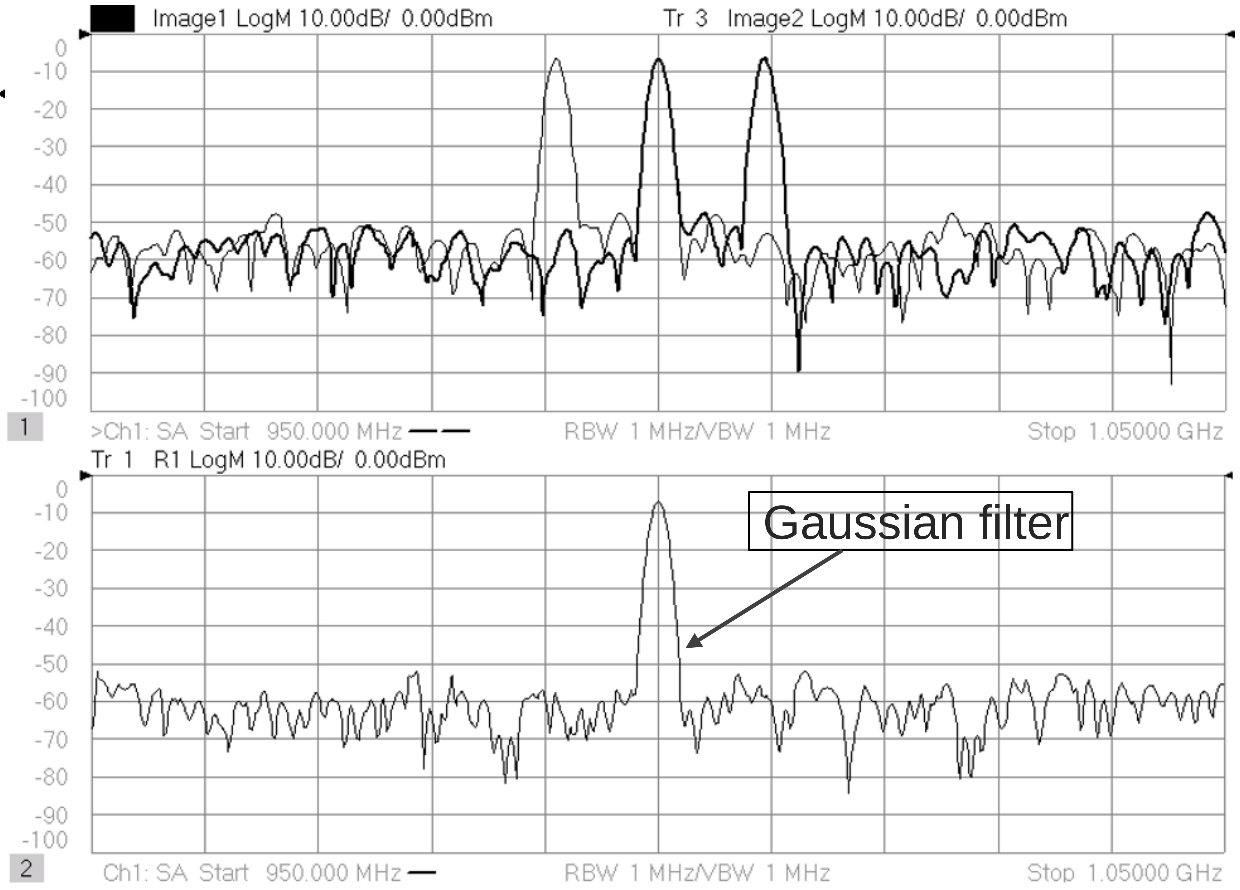
- Swept Frequency or FFT?
- Filtering and/or Windowing of Data
- Dealing with Receivers that are Not Image Protected
  - Basic Concept: Measure the same signal with different LO frequencies
  - “True Signals” remain in the same relative RF frequency
  - Image Signals jump around as the LO is changed
  - Processing the signals (simplest example taking the minimum of two acquisitions) reveals the true signal.
- Potential for advanced image reject with multiple, overlapped LO acquisitions
  - Adjustable number of overlaps from none to 9
  - Higher overlaps reject better in dense spectral content
  - Different “strength” of image rejection
- Main Drawback: the signal must be stable over the time it takes to make 2 acquisitions
- Remember: All Waveforms from AWG have a STATIC spectrum

Making Spectrum Measurements with a VNA

AND DEALING WITH THE IMAGE PROBLEM: STOCHASTIC IMAGE REJECTION

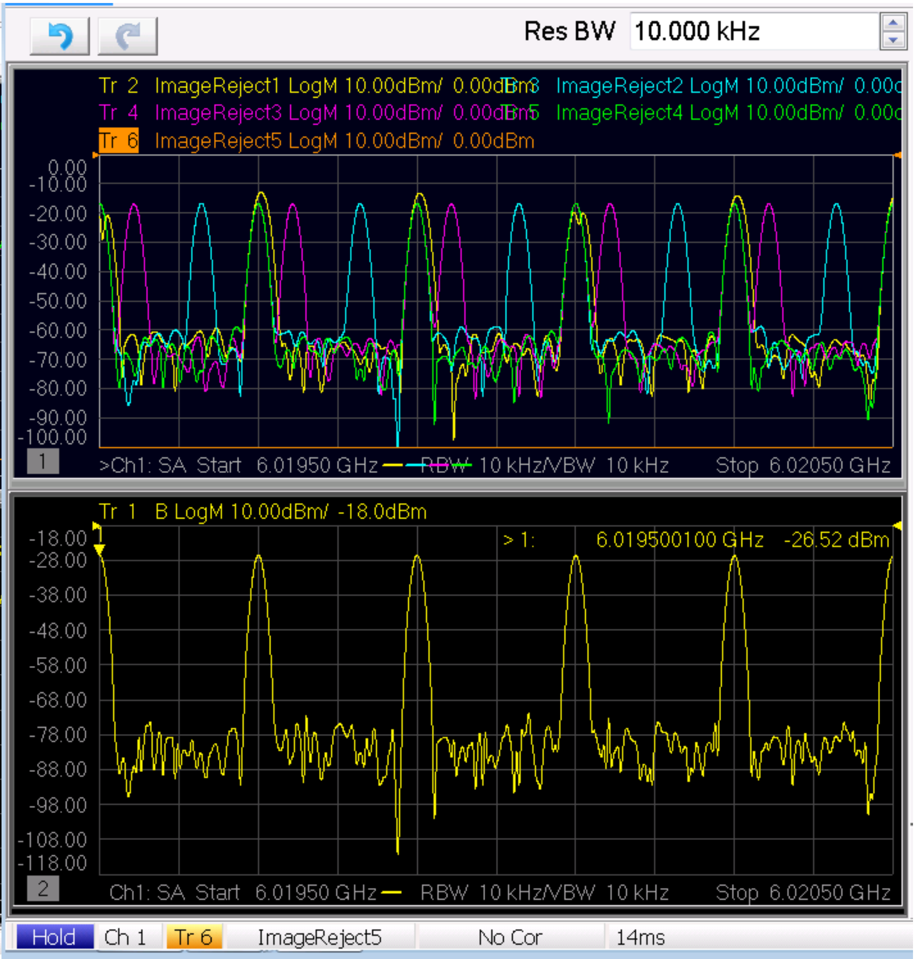


Measuring a CW signal with a swept VNA receiver



Upper: Overlapped measurements w/different LO Freqs.
Lower: After image rejection algorithms

Understanding Image Reject on Dense Signals: Lets span in very close and look at 2 different RBW



At 30 kHz, RBW, sometimes images overlap

At 10 kHz, RBW, images almost never overlap

Wideband Vector Spectrum Analysis (VSA)

MAKING A NARROWBAND RECEIVER WIDEBAND

For Each Sub-band

Coherent Time-Capture a Signal over a Narrowband Portion of Frequency

Compute the exact FFT (mag and phase)

Correct for Magnitude and Phase Response of the Receiver

Image Reject Process the signal

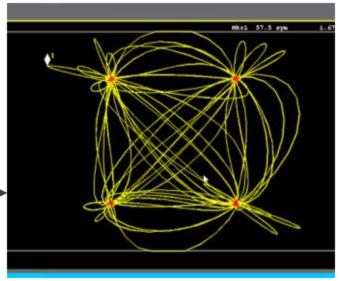
Phase stitch to the previous FFT bins

Display the full spectrum

IFFT the full spectrum to the time domain

Pass the time domain record to the VSA

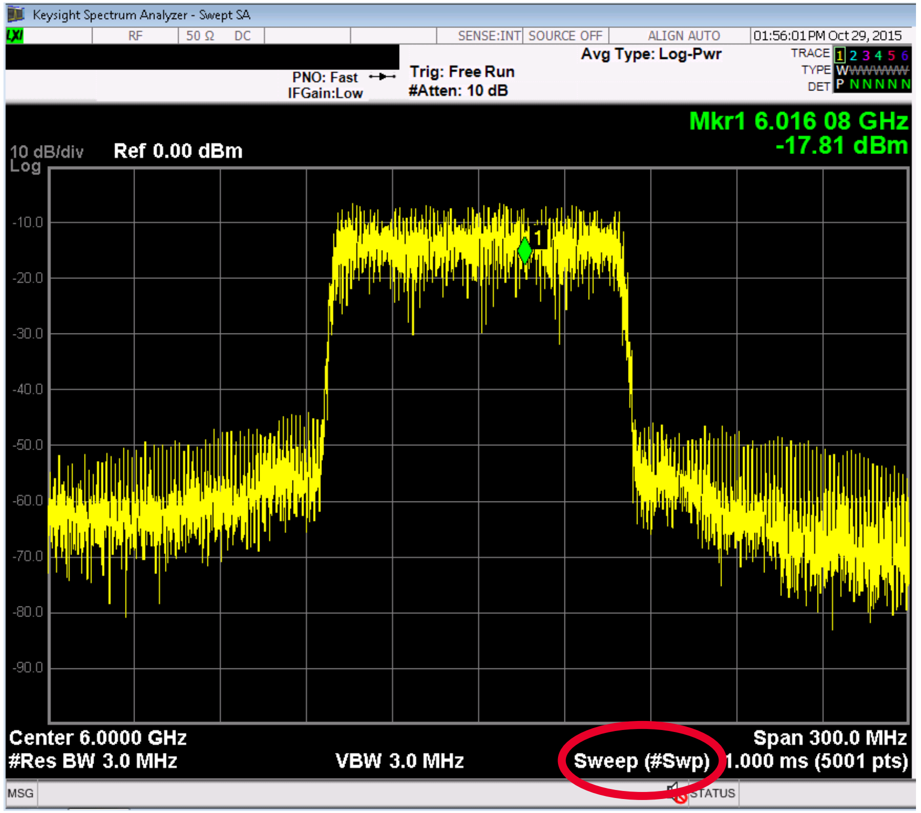
Demodulate the Signal and Display EVM

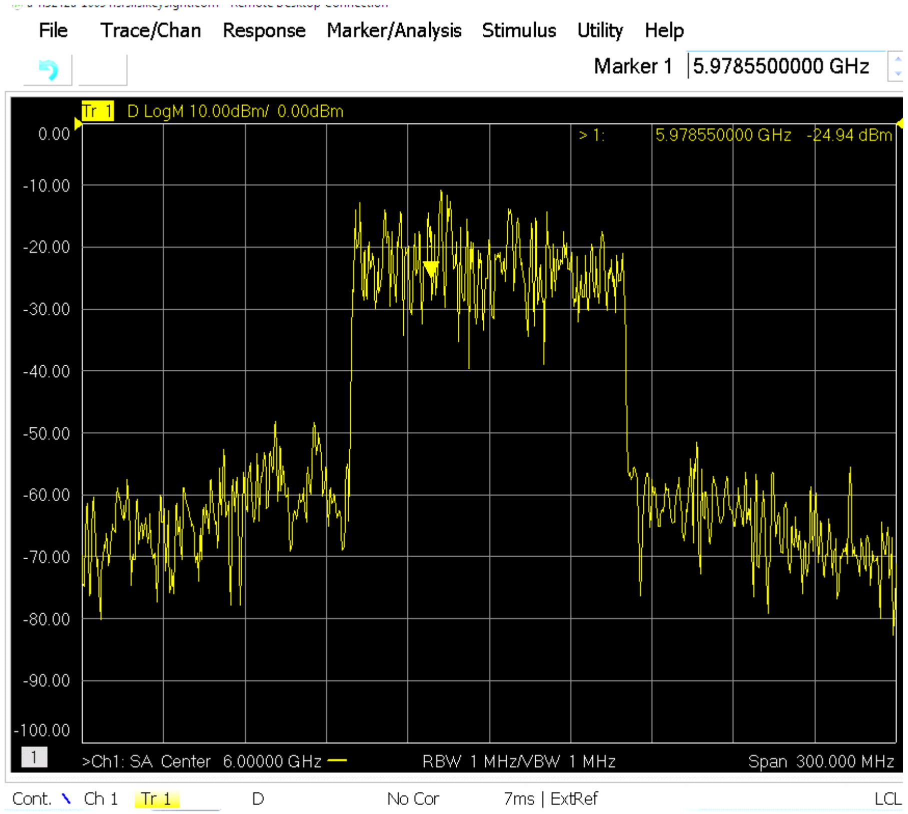


How does a VNA SA mode Compare to UXA or PXA SA

- Comments:
  - The PNA SA display of modulated signals looks different from UXA
  - What about Image Rejection?
  - Band Power errors for wider RBW
- Advantages
  - Faster in narrow resolution bandwidths (RBW)
  - Modulated Waveform Coherent Power Detection
    - Lower noise floor
    - Better accuracy
- Some Limitations
  - Instantaneous or real-time power detection may fail image rejection
  - Noise power measurements have some issues; use the noise receiver mode.

5 usec AWGN Waveform: 100 MHz wide signal, 500 tones, 200 kHz separation.





PXA: Swept Mode Default

PNA: FFT Mode 15 MHz acquisition

Very different images between Swept and FFT;
Which is right? Neither!

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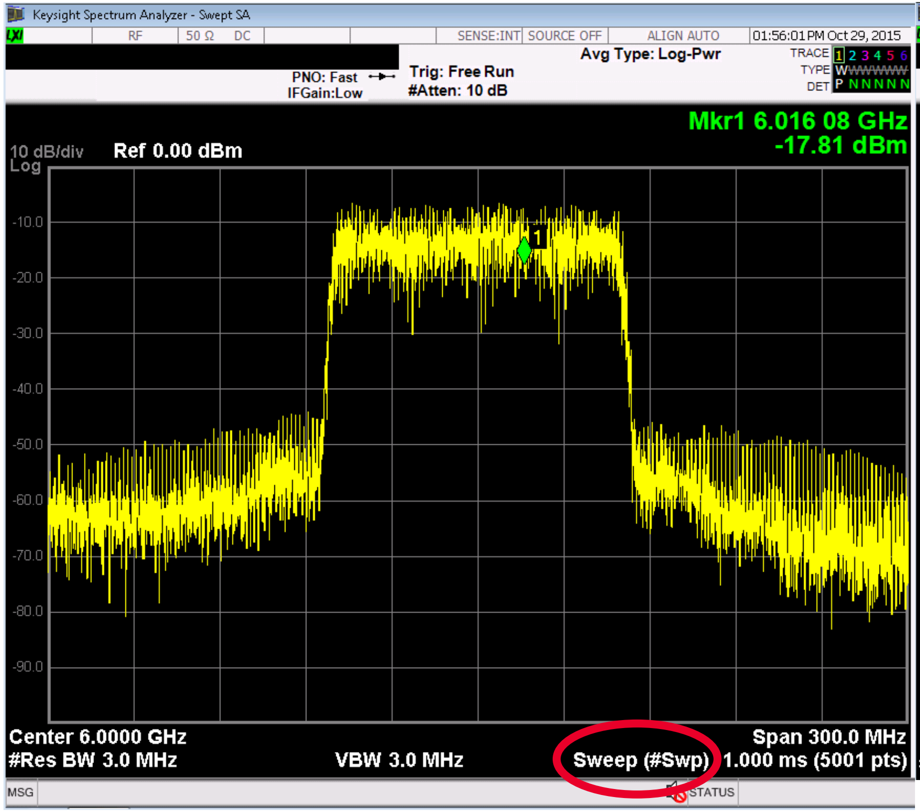
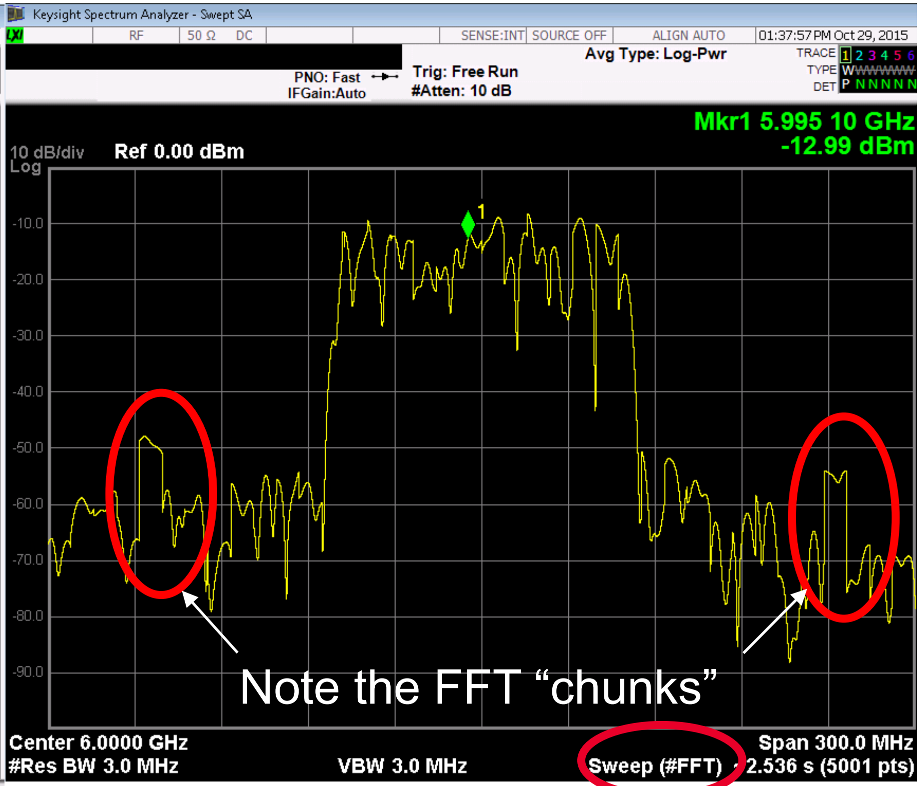
Standard Spectrum Analyzer: Swept vs. FFT mode





PXA: Swept Mode Default

PXA: FFT Mode 8 MHz

Very different images between Swept and FFT;
Which is right? Neither!

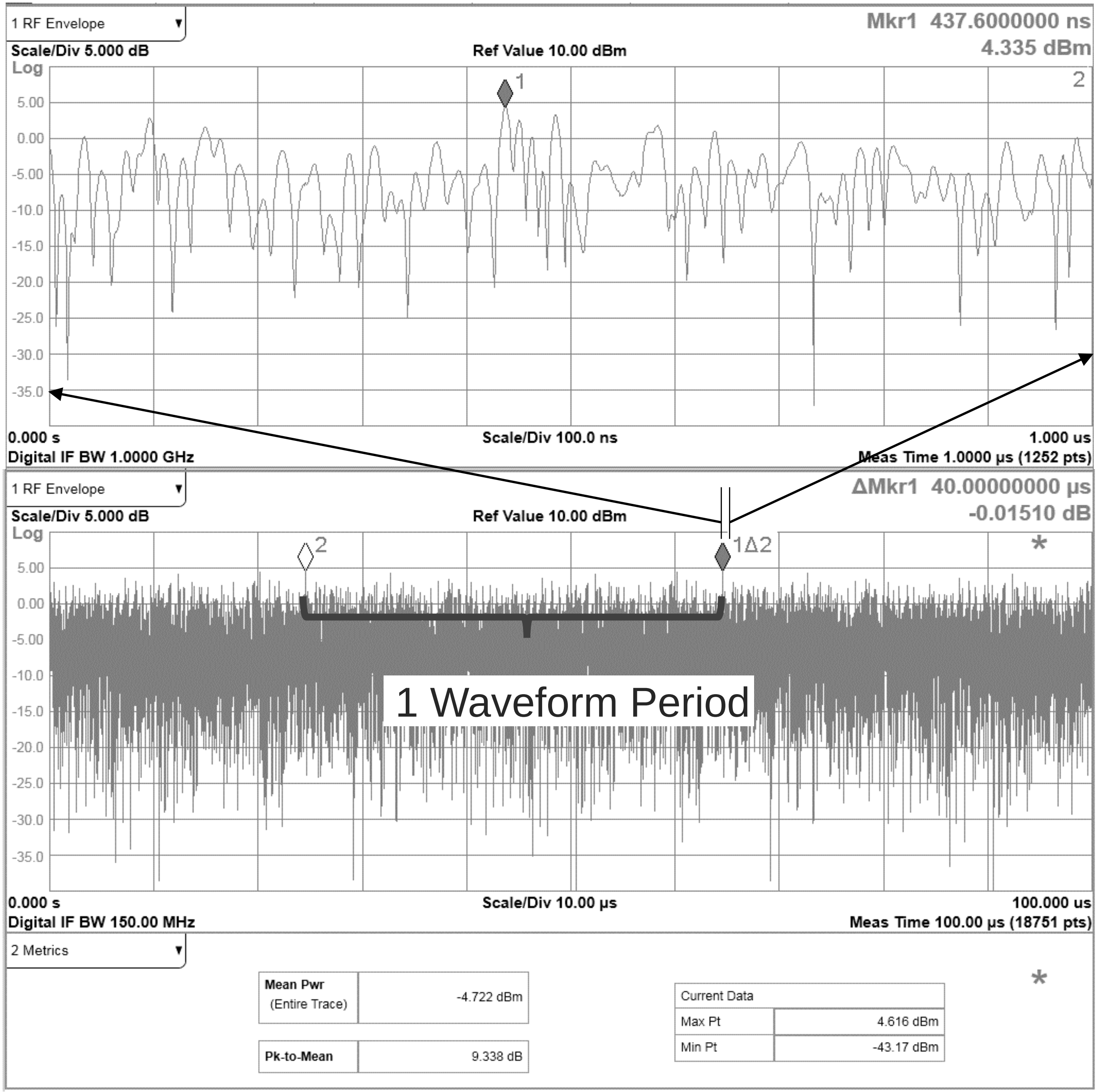
Here is the Power vs. Time

In swept mode, each display point measures at a different time.
So each point represents a different part of the waveform.

Spectrum varies sweep-to-sweep because the whole waveform is not measured.

FFT: every 8 MHz span has a different portion. Still only a 1 -usec portion.

Much of the waveform is not measured.



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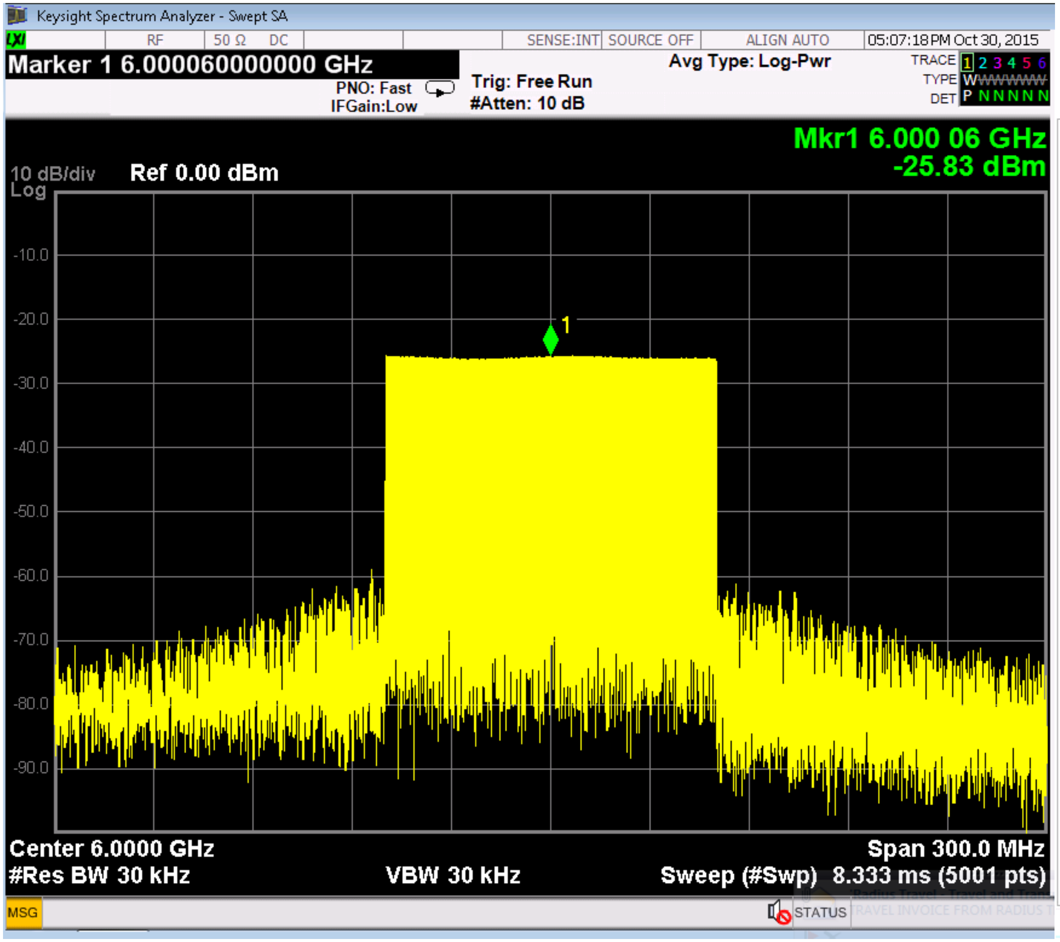
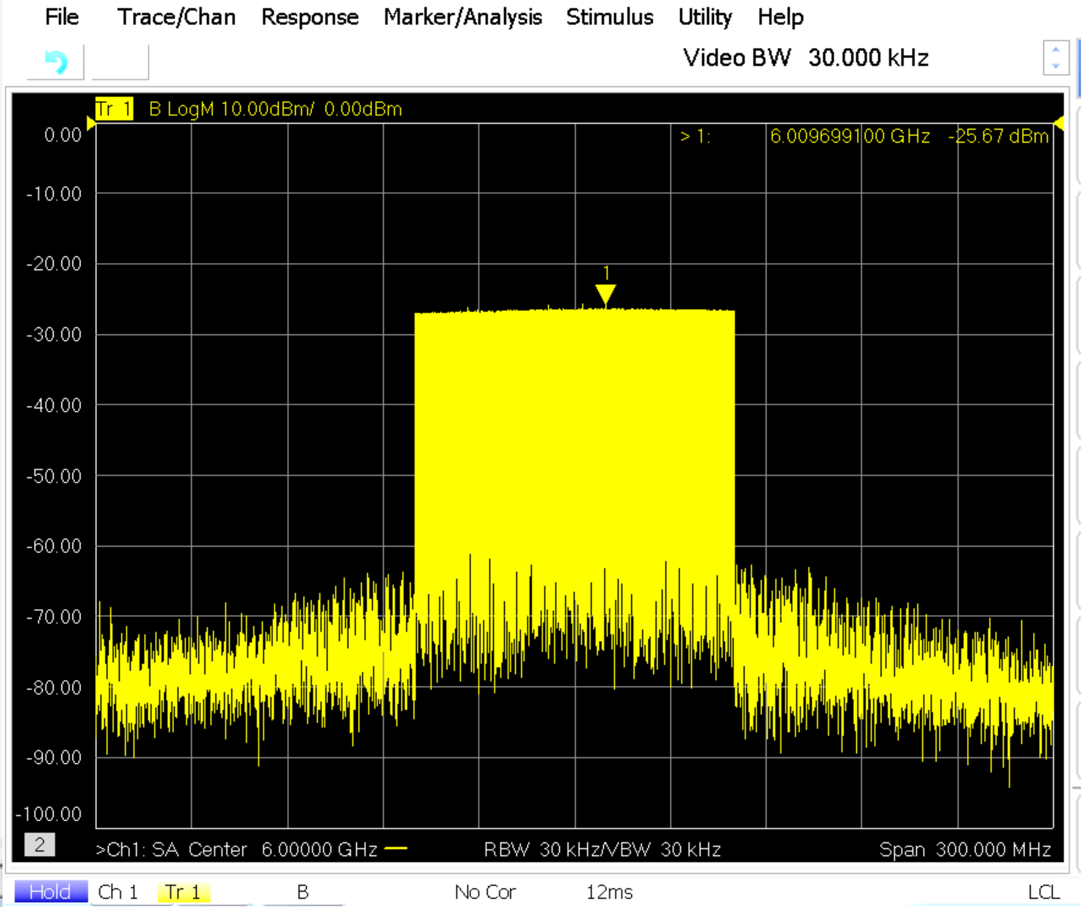
At 30kHz PXA and PNA Match Exactly (PNA is a little flatter).





PXA: 30 kHz RBW, Swept **PNA: 30 kHz RBW**

Now, with the RBW capturing the entire waveform period, both give the same result (except noise)

Which is right? Both!

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Using VNA based calibration to correct SA measurements

MAGNITUDE AND PHASE CAN BE CORRECTED

New paper accepted for 2024 ARFTG Conference describes the calibration method, as well as computes uncertainty for magnitude an phase response of the receivers.

This gives the corrections for CW based measurements; modulation based measurements require a second step of wide-band IF response calibration

Uncertainty in Vector Mixer Measurements using Harmonic Phase Reference Calibration

Joel Dunsmore*

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Abstract —Frequency converters and mixers used in RF, microwave and mm-wave applications are often characterized for their magnitude, phase and group-delay performance. One method, the "SMC+Phase" method, utilizes a harmonic-phase-reference to calibrate one portion of a Vector Network Analyzer response, along with power-meter measurements of magnitude correction and S-parameter calibration method for match and tracking response. Methods for characterizing the uncertainty in amplitude response are well known, but here for the uncertainty in the phase response is formulated.

Index Terms — Mixer, Frequency Converters, SMC, VMC.

I. INTRODUCTION

Measurements of mixers and frequency converters for magnitude, phase deviation and group delay have gone through many iterations of implementation, but to date no discussion of uncertainty, particularly uncertainty in phase deviation, has been put forward. Some of the methods for determining mixer phase response required the measurement of 3 mixers, with at least one mixer pre-supposed to be reciprocal in its phase response[1]. Another method utilized the time domain reflection response of a mixer, while also requiring the mixer to

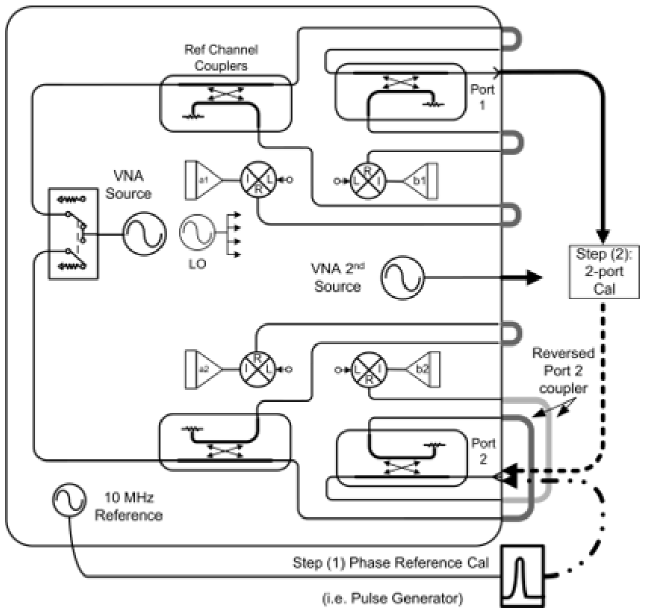


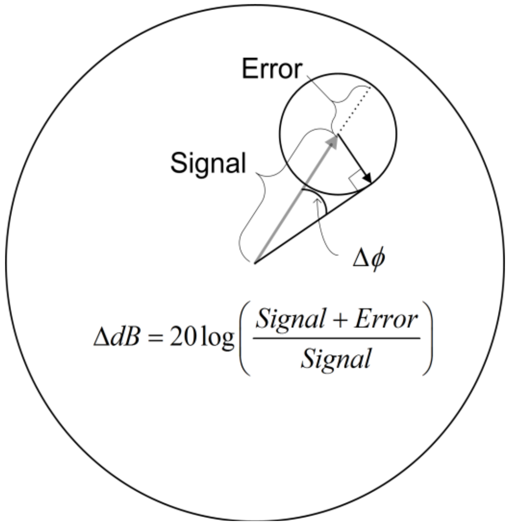
Figure 1: Phase reference calibration steps for a VNA

Dunsmore; Joel P, "System For Characterizing Mixer Or Converter Response"
US 8744370 B2 2014-06-03

Uncertainty Spread Sheet for Mag and Phase

PHASE ERROR CAN BE COMPUTED FROM MAG COMING FROM COMMON SOURCCE

Units	Cal Pwr dBm	Meas Pwr dBm		Coverage; K		
dB	-5	-24		2.7		
	Dut S21	Dut S11	Dut S22			
dB	30	-16	-20			
	PNA SMFraw	PNA LMFraw	S11 Tracking	S22 Tracking		
dB	-12	-12	0.01	0.01		
	Power Meter	Input				
	Ref Err	Zero Error (dBm)	Cal Factor %	Linearity/10 db	Meter Acc'y	
dB	0.017	-50	1.5	0.003	0.04	
	Power Meter	Output				
	Ref Err	Zero Error dBm)	Cal Factor	Linearity/10 db	Meter Acc'y	
dB	0.017	-50	1.5	0.003	0.04	
	1 Port Errors	Input				
	Directivity	Source Match	Tracking	Linearity/10 db		
dB	-48	-28	0.01	0.002		
	S21 Error	Input				
	Tracking	Linearity/10 dB				
dB	0.2	0.002				
	1 Port Errors	Output				
	Directivity	Source Match	Tracking	Linearity		
dB	-48	-30	0.01	0.002		
	S21 Error	Output				
	Tracking	Linearity				
	0.14	0.002				
Results:	Max Pin Err	**Pin RSS*K**	Max Pout Err	**Pout RSS*K**	Max Gain Err	**Gain RSS*K**
Match Corr	0.17	**0.15**	0.28	**0.25**	0.42	**0.29**
Resp Corr	0.46	**0.56**	0.47	**0.42**	0.89	**0.70**



$$\Delta dB = 20\log\left(\frac{Signal + Error}{Signal}\right)$$

$$\frac{\Delta\phi_{\deg}}{\Delta dB} = \frac{180}{\pi}\cdot\frac{\arcsin\left(10^{\frac{\Delta dB}{20}}-1\right)}{\Delta dB} \approx \frac{180}{\pi}\left(\frac{10^{\frac{\Delta dB}{20}}-1}{\Delta dB}\right)\Bigg|_{\arcsin(x)\approx x\ for\ small\ x}$$

$$= \frac{180}{\pi}\cdot\lim_{\Delta dB\to 0}\left(\frac{10^{\frac{\Delta dB}{20}}-1}{\Delta dB}\right) = \frac{180}{\pi}\frac{\lim_{\Delta dB\to 0}\frac{d}{d\Delta dB}\left(10^{\frac{\Delta dB}{20}}-1\right)}{\lim_{\Delta dB\to 0}\frac{d}{d\Delta dB}(\Delta dB)} = \frac{180}{\pi}\frac{\lim_{\Delta dB\to 0}\left(\frac{10^{\frac{\Delta dB}{20}}\log_e 10}{20}\right)}{1}$$

$$since\ \lim_{x\to 0}\left(10^x\right) = 1,$$

$$\frac{\Delta\phi_{\deg}}{\Delta dB} = \frac{9}{\pi}\log_e(10) = 6.6,\ or\quad \Delta\phi_{\deg} = 6.6\cdot\Delta dB$$

Units	Cal Pwr dBm	Meas Pwr dBm		Coverage; K		
dB	-5	-24		2.77		
	Dut S21	Dut S11	Dut S22			
dB	30	-16	-20			
	PNA SMFraw	PNA LMFraw	S11 Tracking	S22 Tracking		
dB	-12	-12	0.01	0.01		
	Phase Reference	Input				
	Ref Err	PhaseRef Match				
deg	1	-10				
	Phase Reference	Output				
	Ref Err	PhaseRef Match				
deg	1	-10				
	1 Port Errors	Input				
	Directivity	Source Match	Tracking	Linearity/10 db		
dB	-48	-28	0.01	0.002		
	S21 Error	Input				
	Tracking	Linearity/10 dB				
dB	0.2	0.002				
	1 Port Errors	Output				
	Directivity	Source Match	Tracking	Linearity		
dB	-48	-30	0.01	0.002		
	S21 Error	Output				
	Tracking	Linearity				
	0.14	0.002				
Results:	Max PinPh Err	**PinPh RSS*K**	Max PoutPh Err	**PoutPh RSS*K**	Max Ph Err	**Phase RSS*K**
Match Corr	2.91	**2.44**	1.39	**1.39**	4.30	**2.96**
Resp Corr	4.80	**4.40**	2.74	**2.85**	7.55	**5.24**

Figure 3: Amplitude and Phase Uncertainty Spread Sheet

$$\Delta a_{1M} = \Delta PM\cdot\left(1+\sqrt{\left(ESF\cdot EDF_{Res}\right)^2+\left(\Gamma_{1M}\cdot EDF_{Res}\right)^2}\right)$$

$$\Delta RcvrPower = \left|20\log_{10}\left(\frac{b_{2A}}{b_{2M}}\right)\right| = \left|20\log_{10}\left\{\frac{\left(1-\left|ELF\cdot\Gamma_2\right|\right)}{BTF}\left[\left(b_{2M}/b_{2R}\right)\cdot R_{DA}\right]\right\}\right|$$

$$\Delta\phi_{P2} = \left|\arctan\left(\Gamma_{HPF}\cdot ELF\right)\right| + \Delta\phi_{HPF}$$

$$\Delta\phi_{P1} = \Delta\phi_{P2} + \left|\arctan\left(ESF\cdot ELF_{res} \pm ESF_{res}ELF\right)\right|$$

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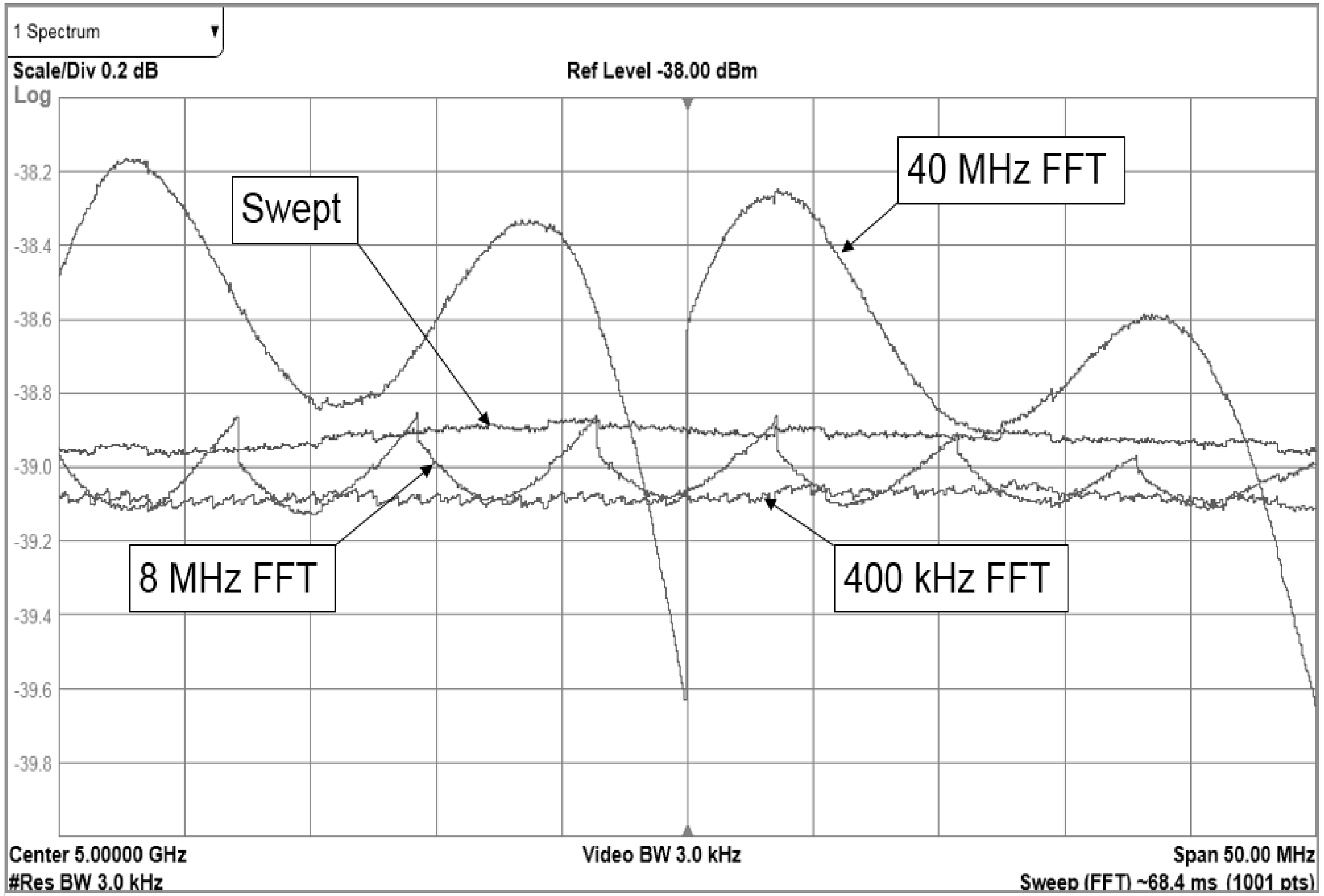
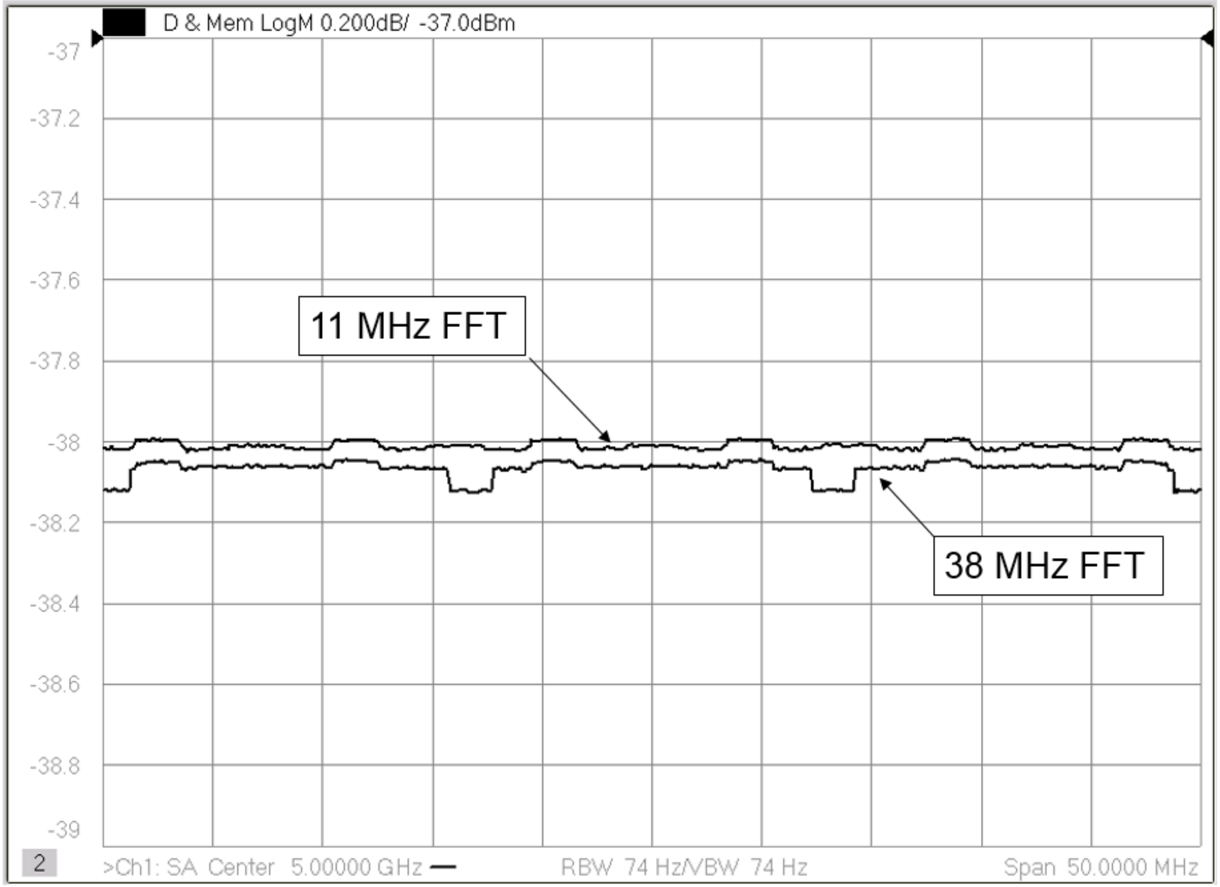
*Joel P. Dunsmore, "VNA Measurement Systems," in *Handbook of Microwave Component Measurements: with Advanced VNA Techniques* , Wiley, 2020, pp.71-126,

The effects of FFT Width on Power Accuracy

NARROWER FFT WIDTHS IMPROVE ACCURACY, VNA-SA IS FULLY CORRECTED



UXA Power Accuracy with FFT Width



PNA Power Accuracy with FFT Width

Coherent Measurements for Modulated Signals

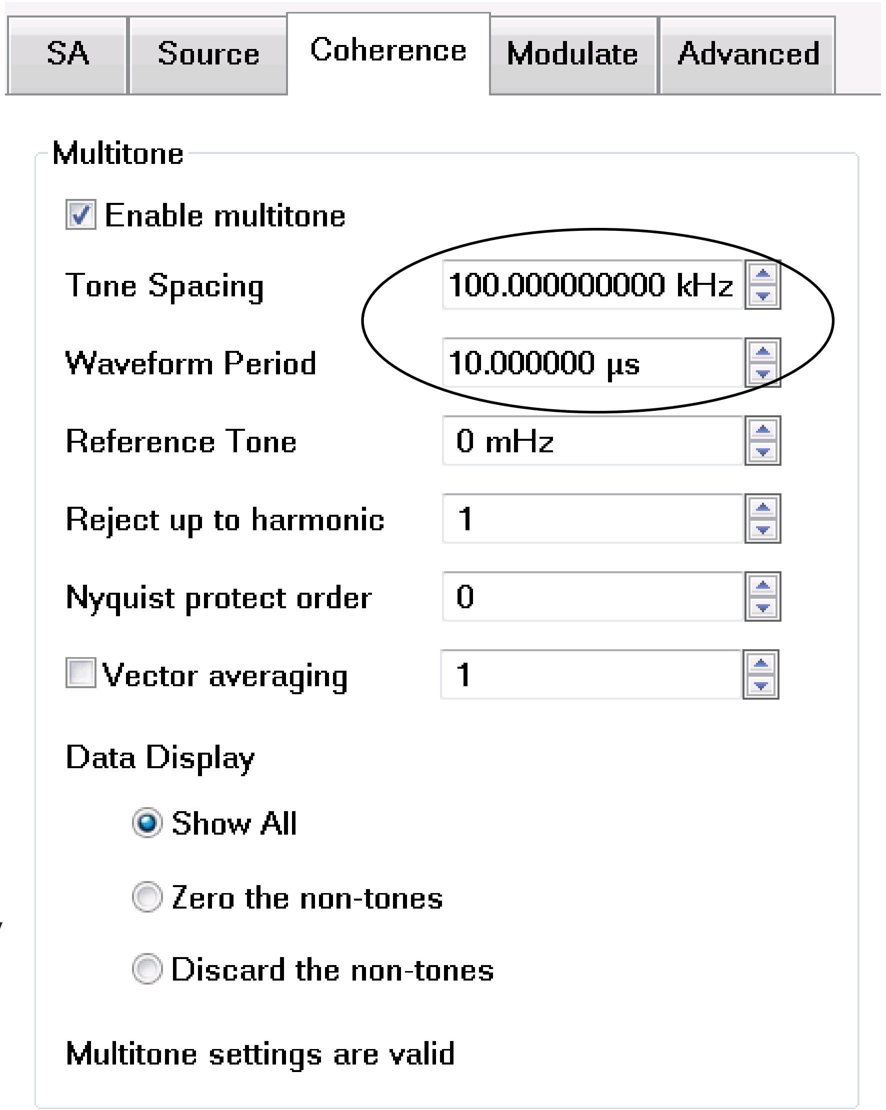
IMPROVE NOISE FLOOR AND POWER DETECTION

- New Coherent SA mode designed for Modulated Signals
  - Dramatically improved ACPR measurements
  - Optimized power detection for low-level modulated signals
  - Dramatically improved Noise Power Ration (NPR)
  - Dramatically improved IMD noise floor
- Improved Band Power marker readouts based on Coherency
  - Band Power markers in Absolute or in relative (dBc) for NPR and ACPR measurements
  - Occupied Bandwidth marker function based on 99% (typical) power detection
    - Find signal power even at low levels
  - Autotune function: supported by the Occupied Bandwidth.

Coherent Measurements for Modulated Signals

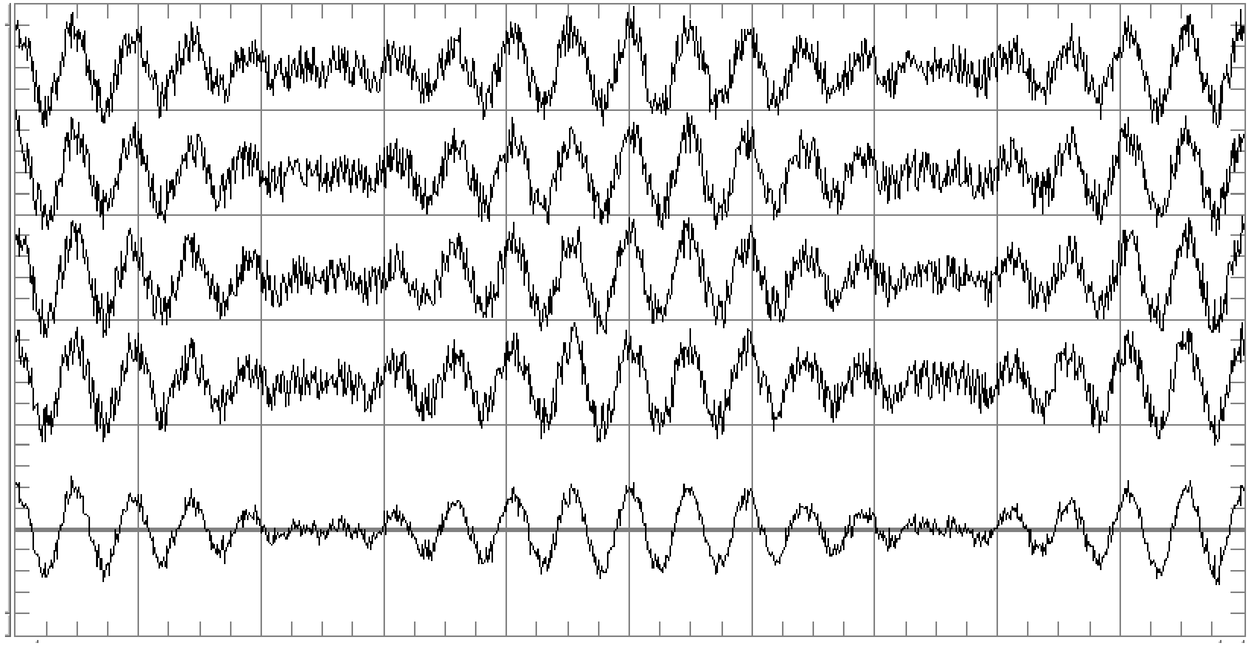
COHERENT MEANS THE ADC SAMPLE SIZE MATCHES WAVEFORM PERIOD

- In coherent detection mode, the period of the modulated waveform must be known.
- (This waveform will also have a periodic tone spacing, which is equivalent).
- Coherent detection allows one to “Zero the non-tones” meaning sets the values of FFT bins to zero, if they don’t fall on the waveform period.
- This eliminates systematic noise between signal FFT bins.
- “Discard Non-tones” means the display only shows the results of tones, so display points equal the number of tones
- IEEE 1765-2022 Recommended Practice for Estimating the Uncertainty in Error Vector Magnitude of Measured Digitally Modulated Signals for Wireless Communications

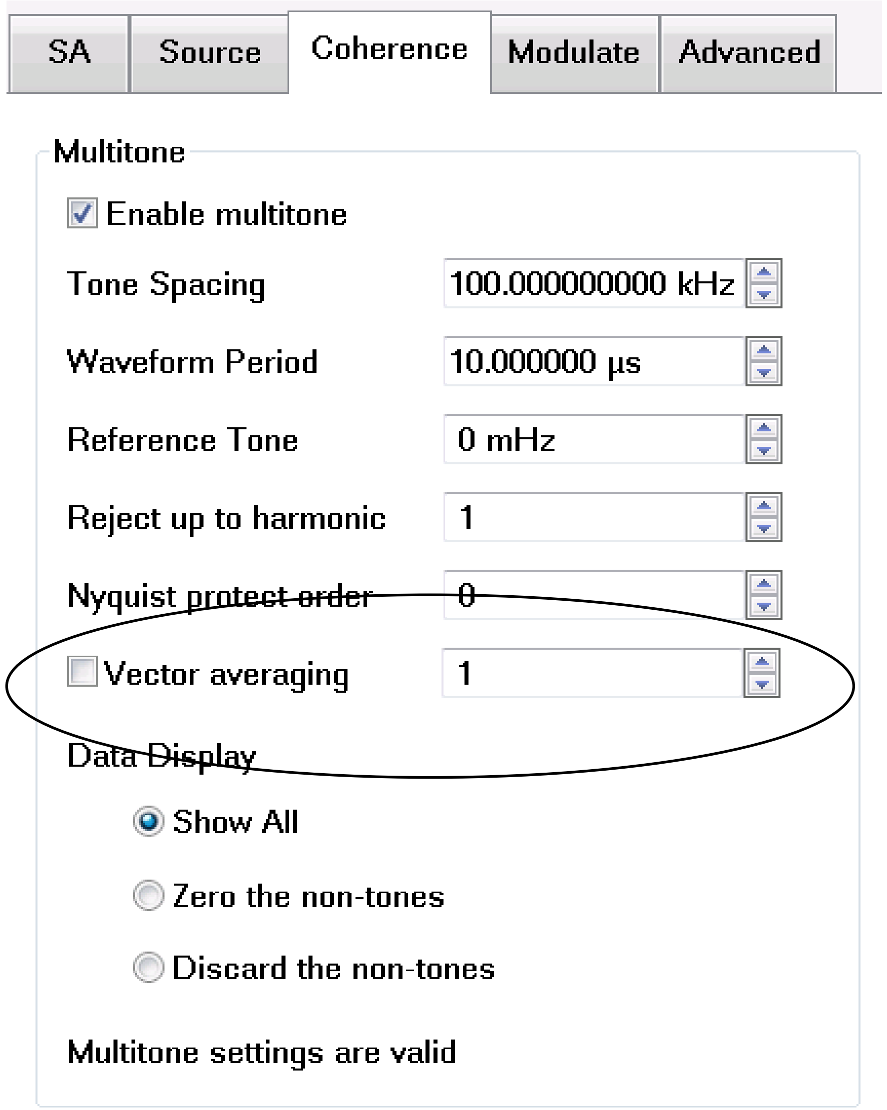


Coherent Measurements for Modulated Signals

VECTOR AVERAGING REMOVES NOISE (ALSO CALLED COHERENT TIME AVG)

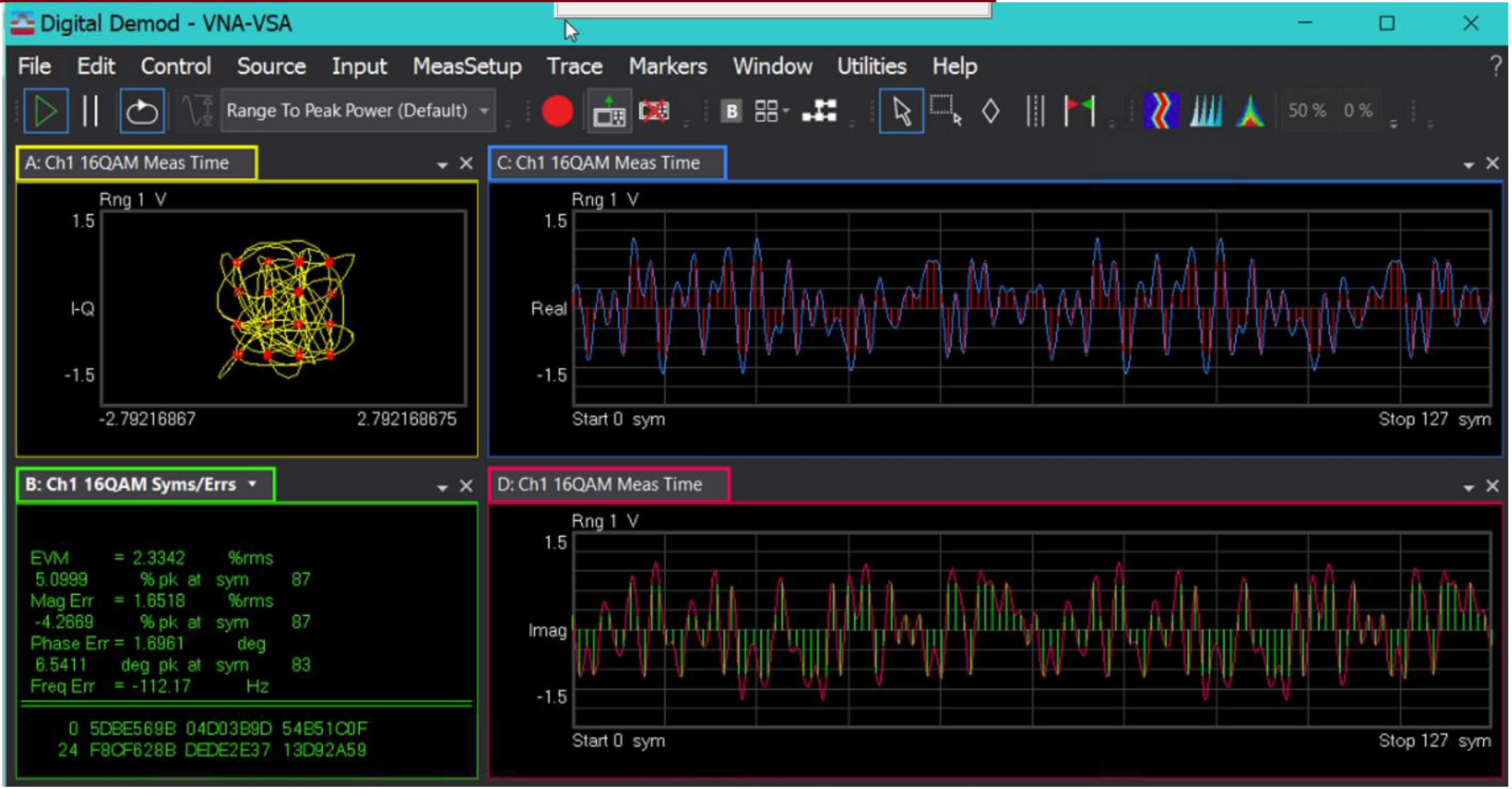


Coherent Measurements forces the receiver ADC to sample on exactly N*period of the waveform. We can use N samples, taken in the time domain, to sum together sample-by-sample and divide the result by N. The signal is coherent but noise is not and thus reduced. This can be done at high speed using FPGA memory so processing does not slow data acquisition.



Here is a 16 QAM signal, we are viewing 128 symbols

THIS IS TYPICAL, ASYNCHRONOUS ACQUISITION



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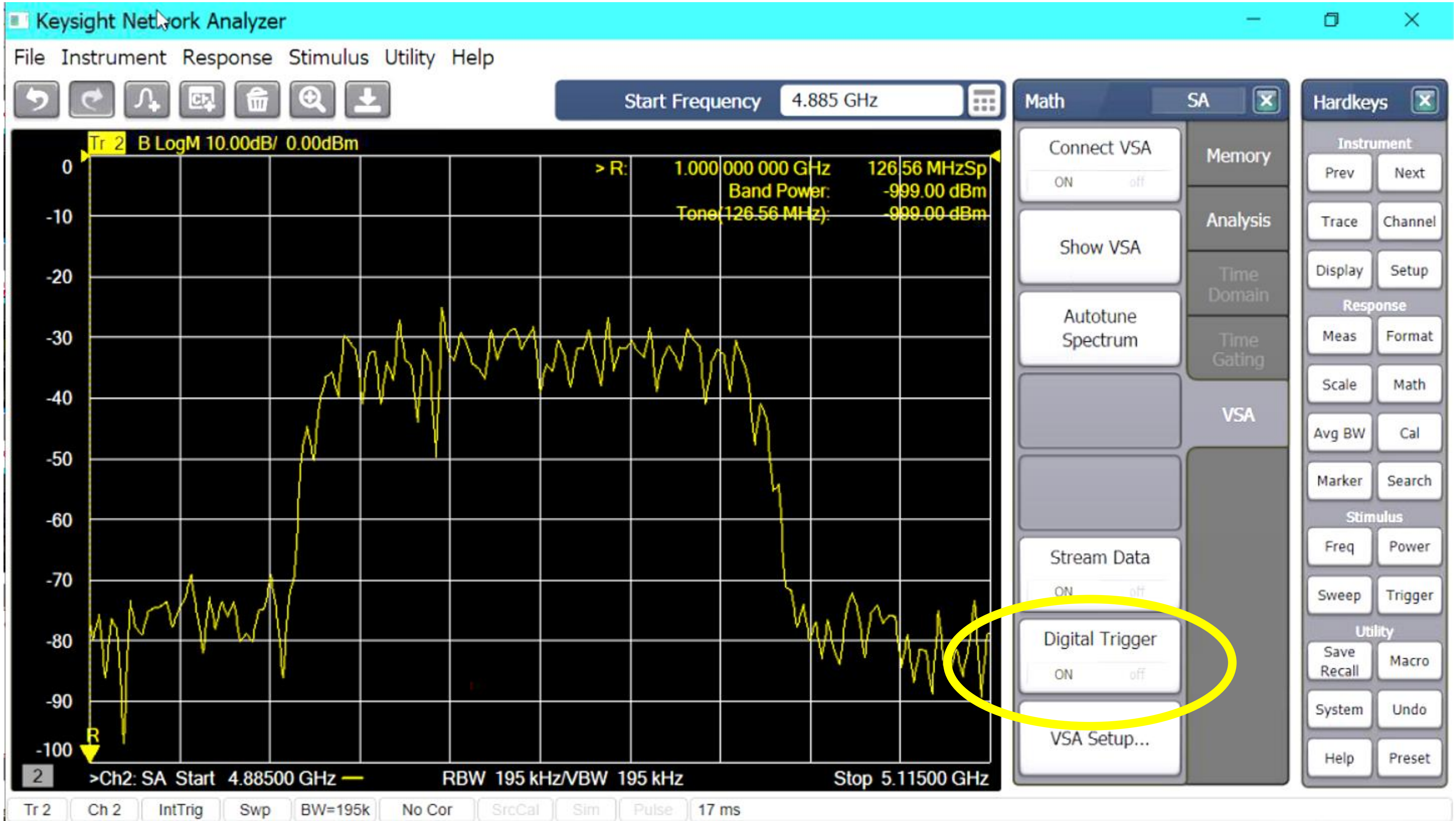
With PNA based VSA, we can digitally trigger

DATA SYNCHRONIZED TO THE WAVEFORM PERIOD



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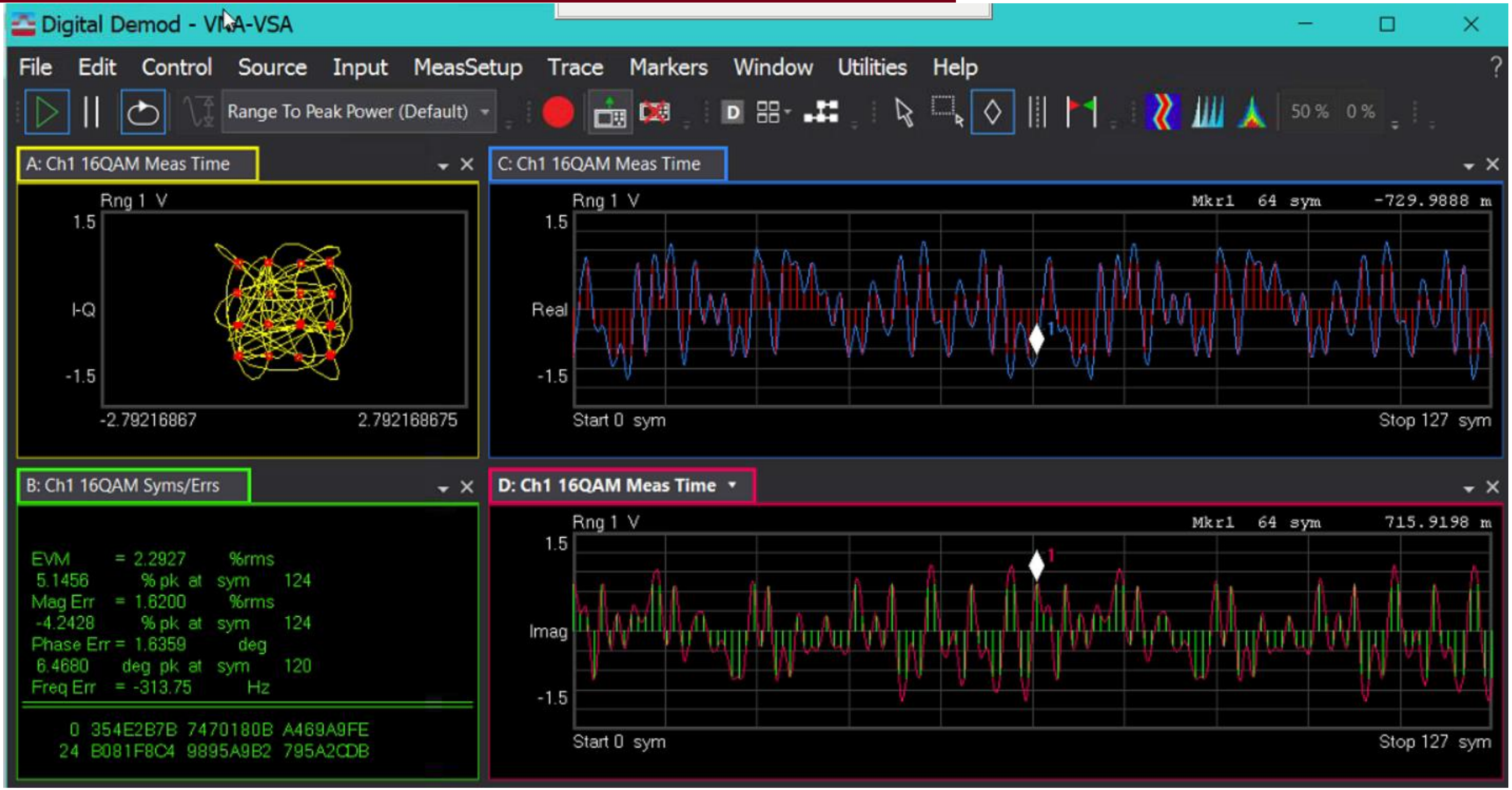
Here is a 16 QAM signal, we are viewing 128 symbols

THIS IS WITH A DIGITAL (COMPUTED) TRIGGER



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Coherent Measurements for Modulated Signals

+ NEW BAND POWER MEASUREMENT CAPABILITIES

- Two methods to reduce the systematic noise in the measurement*
  - Only measure the signals from the spectrum that lands on the signal-FFT tones of the spectrum**
    - With narrow RBW, many SA "bins" are between each signal-FFT tone of the spectrum
    - The band power density of each bin is the same, regardless of the bin width in Hz
    - Eliminating the contribution of noise in the "in-between" bins removes the noise from the power calculation
  - Use vector averaging to lower the overall noise floor of the system by using time-coherent averaging to emphasize the signal and remove the noise
    - The noise floor goes down as a direct factor of the averaging factor
    - The measurement time goes up as a direct factor of the averaging factor
    - This is an improvement over lower the RBW, which increases the FFT bins of the SA computation and slows the measurement by a larger factor, which is N*log(N) of the averaging factor
- Band Power markers can determine the noise in a band by summing the SA FFT bins
  - Note: lower the SA RBW does not lower the noise power of the SA as each bin is smaller (lower total noise) but there are many more bins
- *Presumes noise is caused by instrumentation noise and that signal is substantially noise free

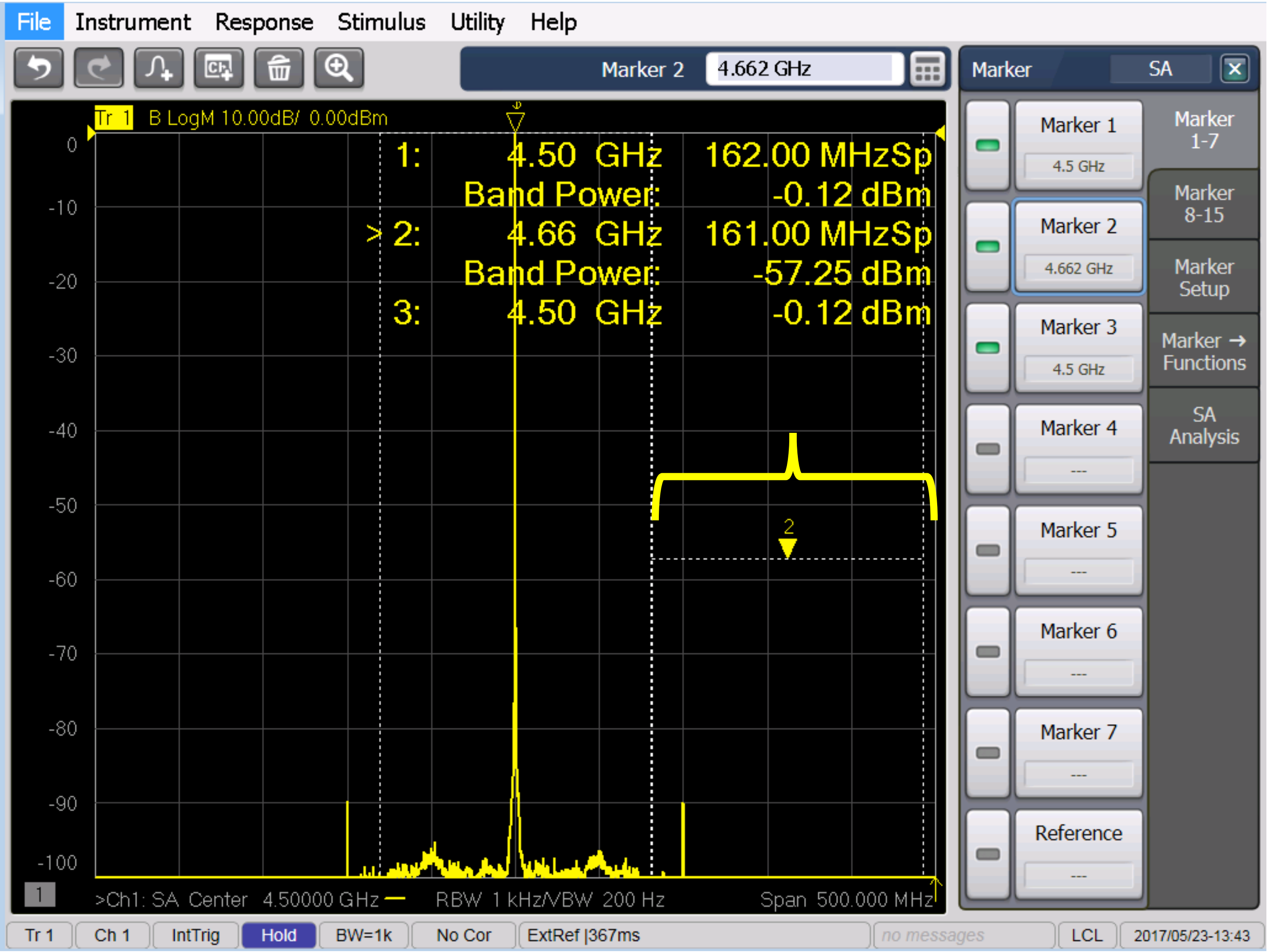
**Dunsmore, Joel P., Teyssier, Jean-Pierre, "Method And Device For Detecting Power Of A Periodic Signal In A Band Of Interest" US Patent 11121784 2021-09-14

Test a high power CW signal: 0 dBm (set within 2 dB of overload). PNA display:

Band Power Marker around CW measures Exactly Correct Power.

Band Power for noise floor:
-57 dBm.

(160 MHz band)

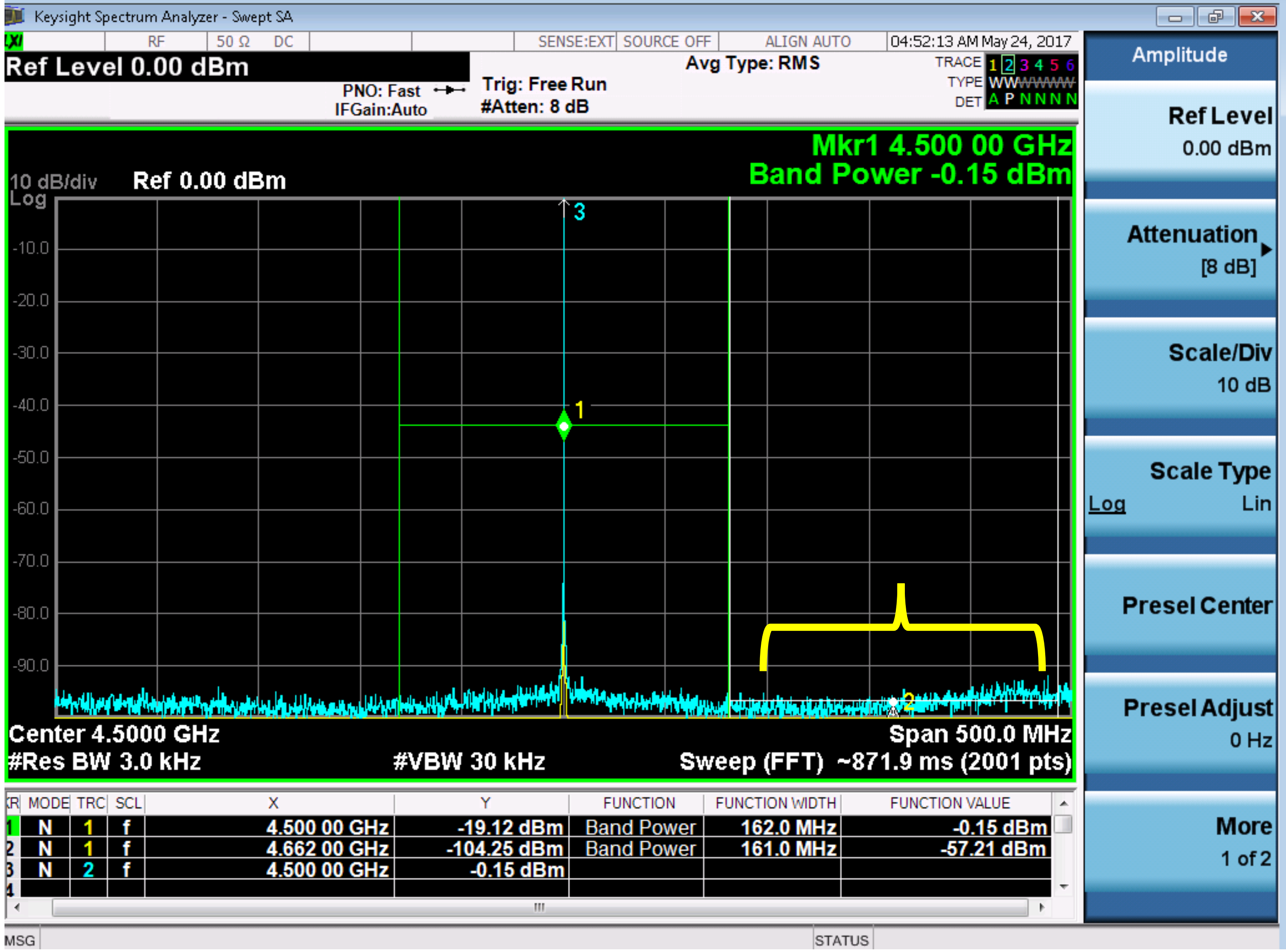


Compare to Traditional SA: Test a high power CW signal: 0 dBm (set within 2 dB of overload). PXA display:

PXA gives almost identical results
Band noise:
-57 dBm.

(160 MHz band)

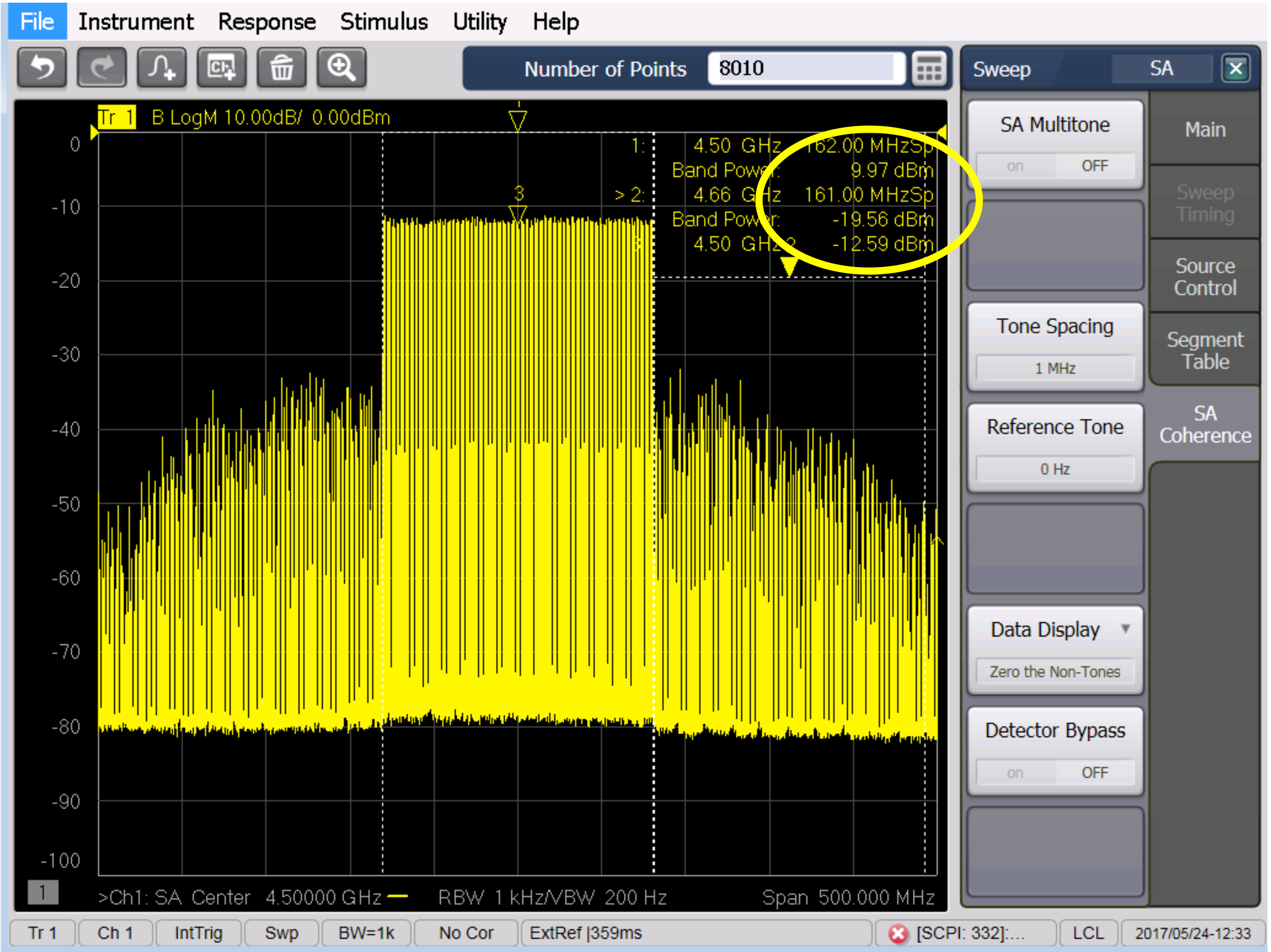
Note higher RBW so higher apparent noise floor, but band power is the same



Now turn on modulated signal: Normal detection High Power (10 dBm) 160 MHz BW. (PNA)

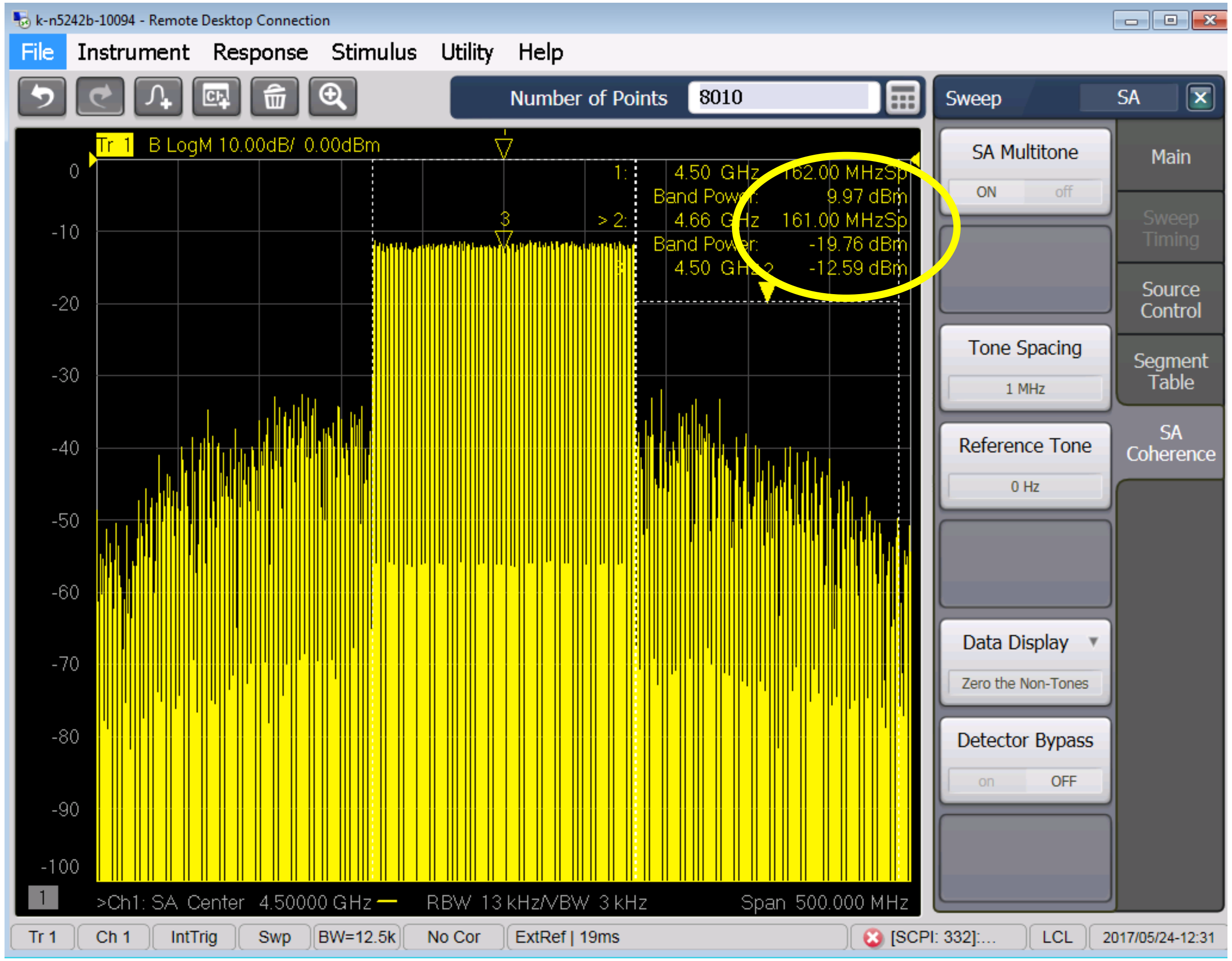
Main Carrier Band Power is 10 dBm
ACPL Band Power -20 dBm.
ACPR is 30 dBc

Note: this level of ACP indicates near 1 dB compression.



Now turn on modulated signal: Coherent Power Detect. High Power (10 dBm) 160 MHz BW. (PNA)

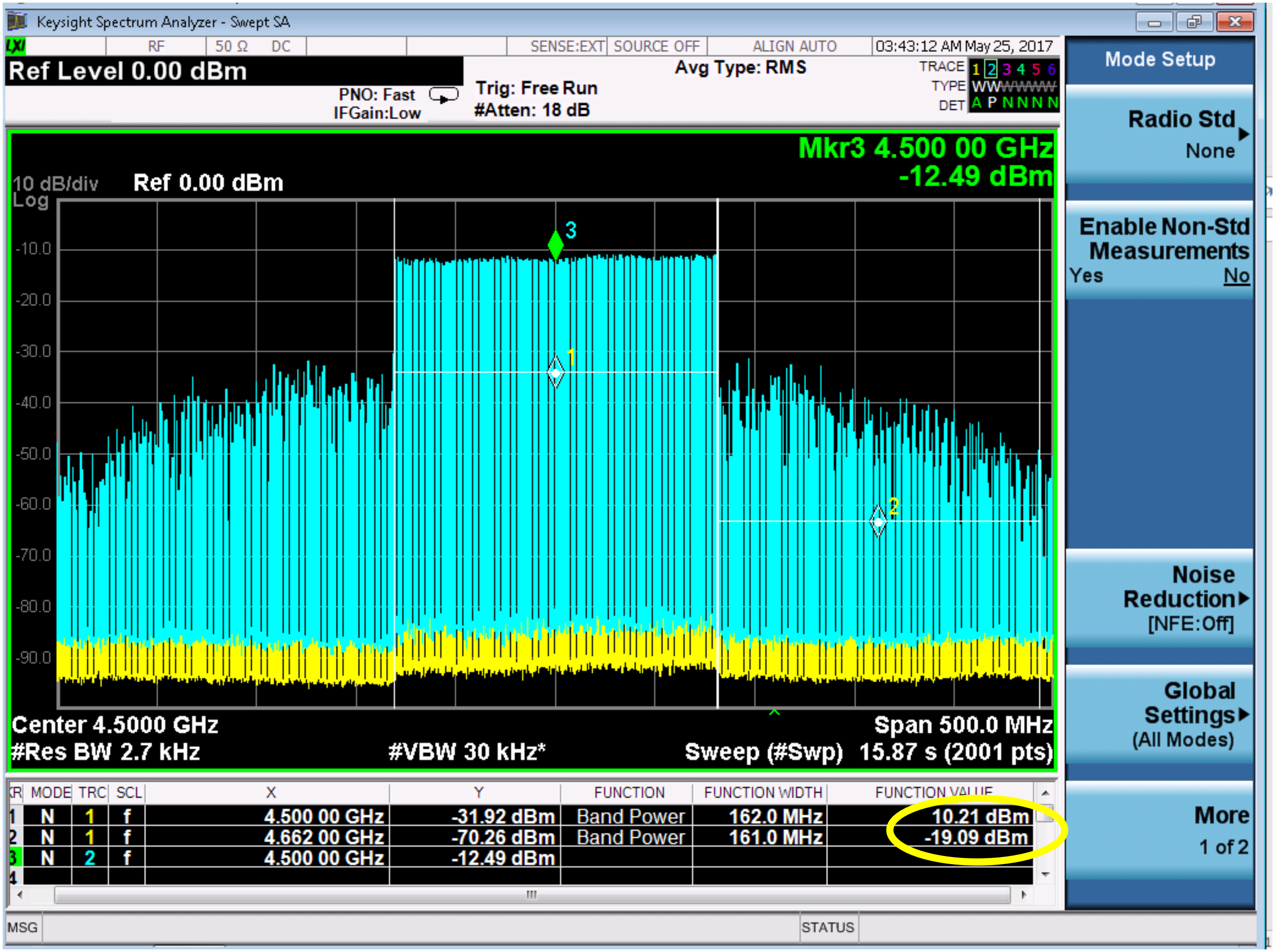
Only sum the powers in the FFT grid of the signal



Traditional SA: Now turn on modulated signal: Normal Detection High Power (10 dBm) 160 MHz BW. (PXA)

Main Carrier Band
Power is 10 dBm
ACPL Band
Power -20 dBm.
ACPR is 30 dBc

Matches nearly exactly PNA results



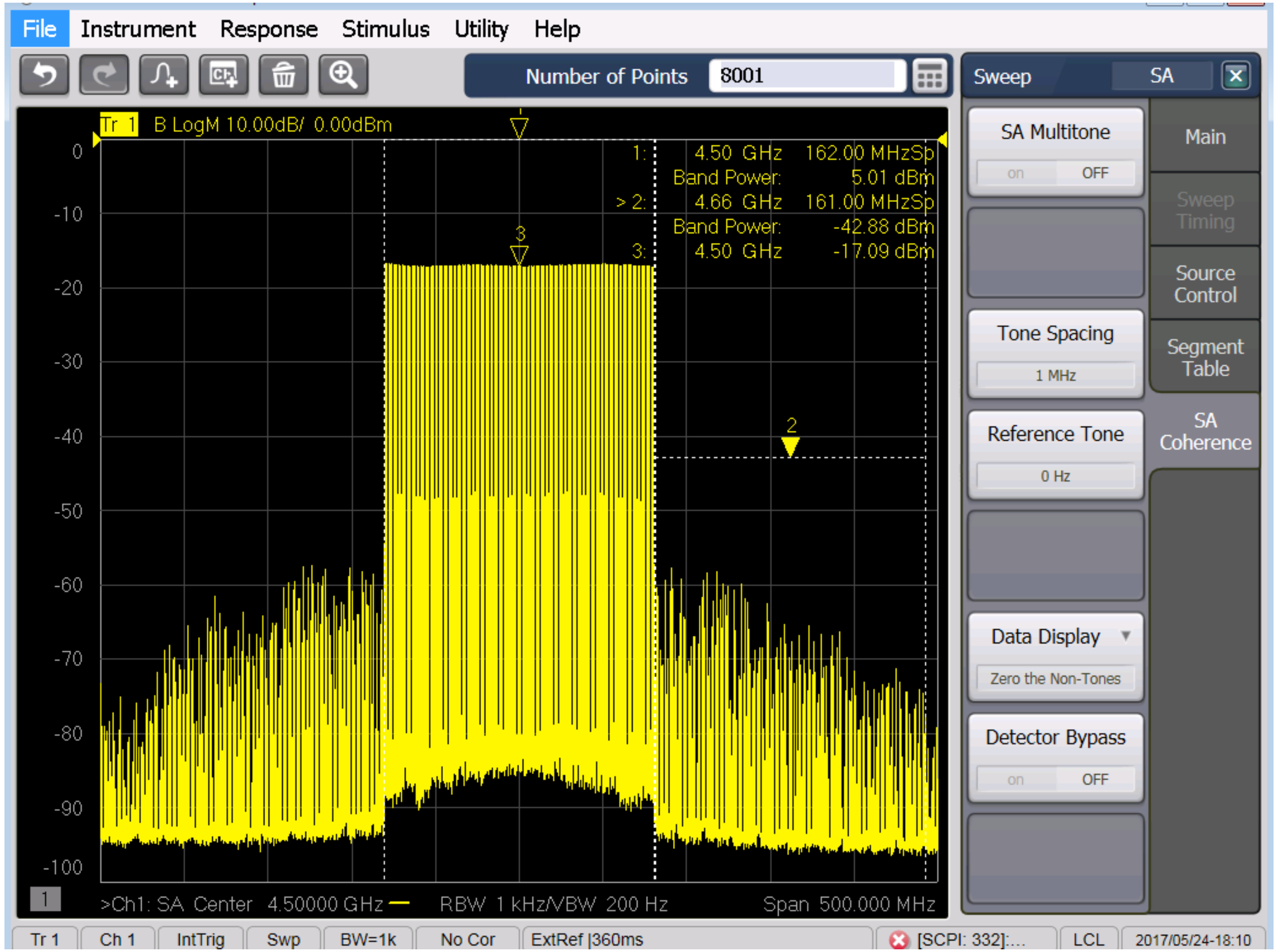
KEYSIGHT TECHNOLOGIES

Now turn on modulated signal: Normal detection Power (5 dBm) 160 MHz BW. (PNA)

Main power is no +5 dBm

ACP Level is -43 dBm

Coming out of strong compression into the Volterra region of compression

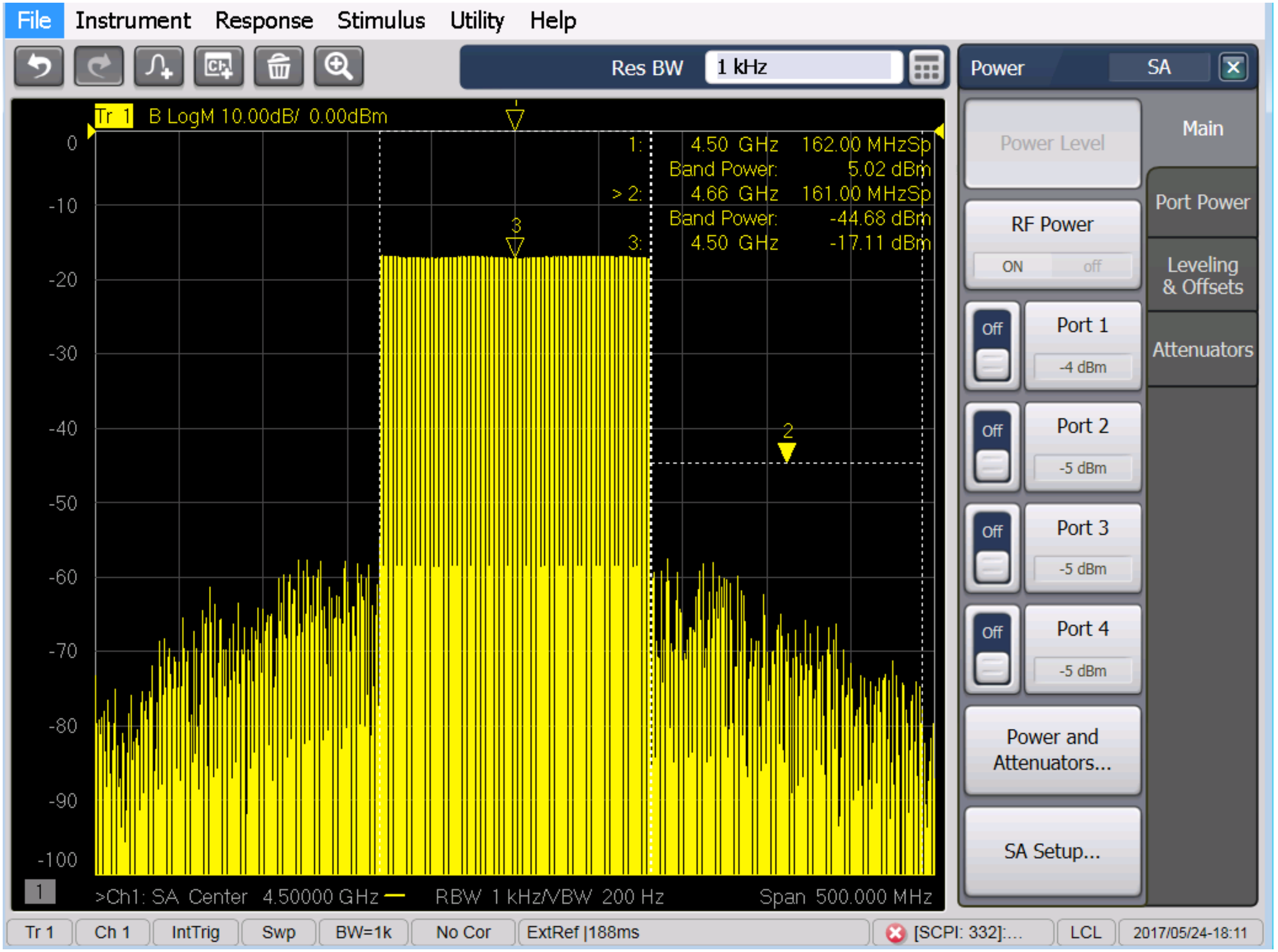


Now turn on modulated signal: Coherent Power Detect Power (5 dBm) 160 MHz BW. (PNA)

With Zero-non-tones:

Main Power = -5 dBm
ACPL = -45 dBm
.

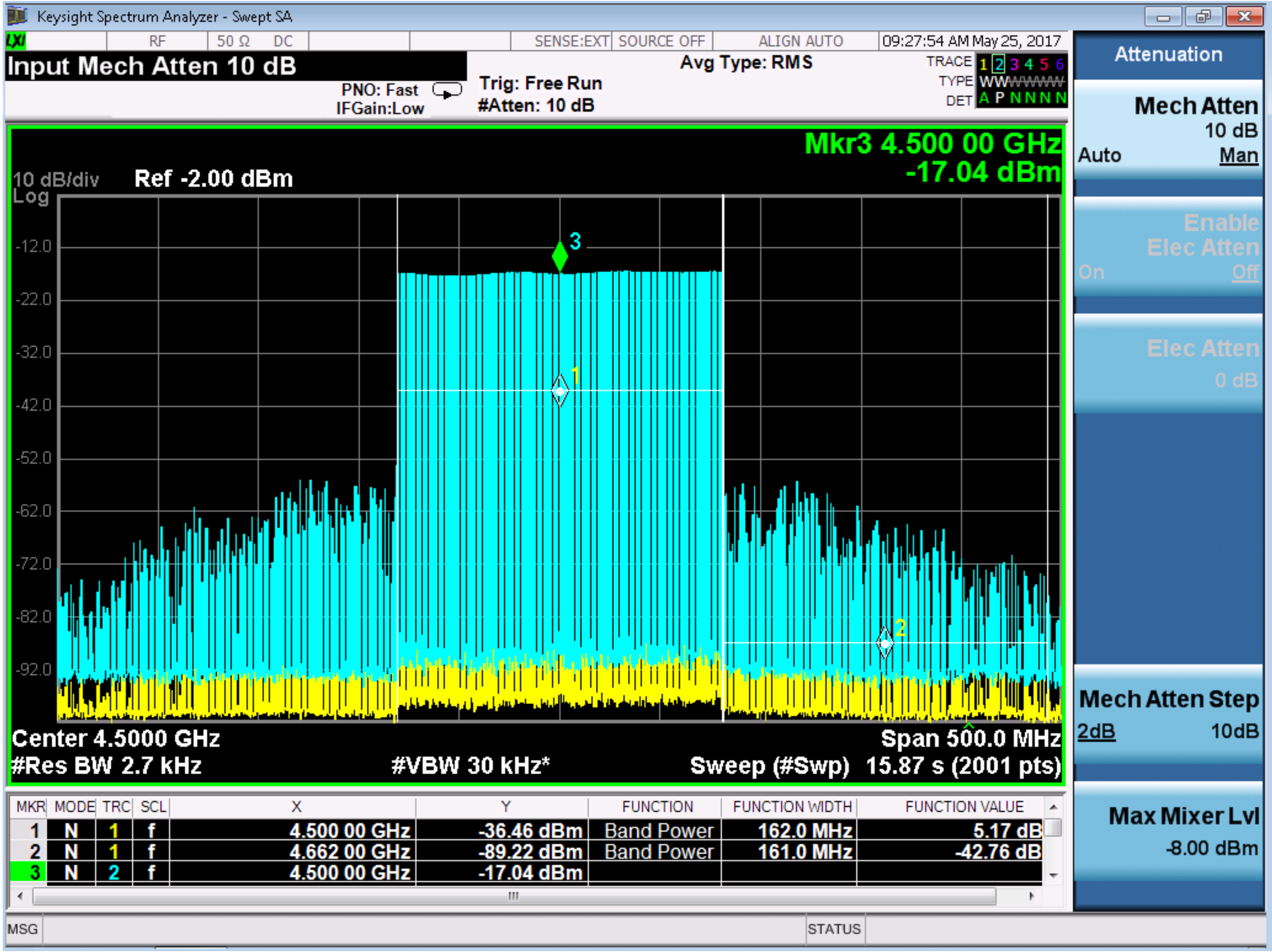
The noise floor contribution is reduced by removing the power between tones



Traditional SA: turn on modulated signal: Power (5 dBm) 160 MHz BW. (PXA)

PXA measures similar to PNA

Almost same ACP as PNA in normal

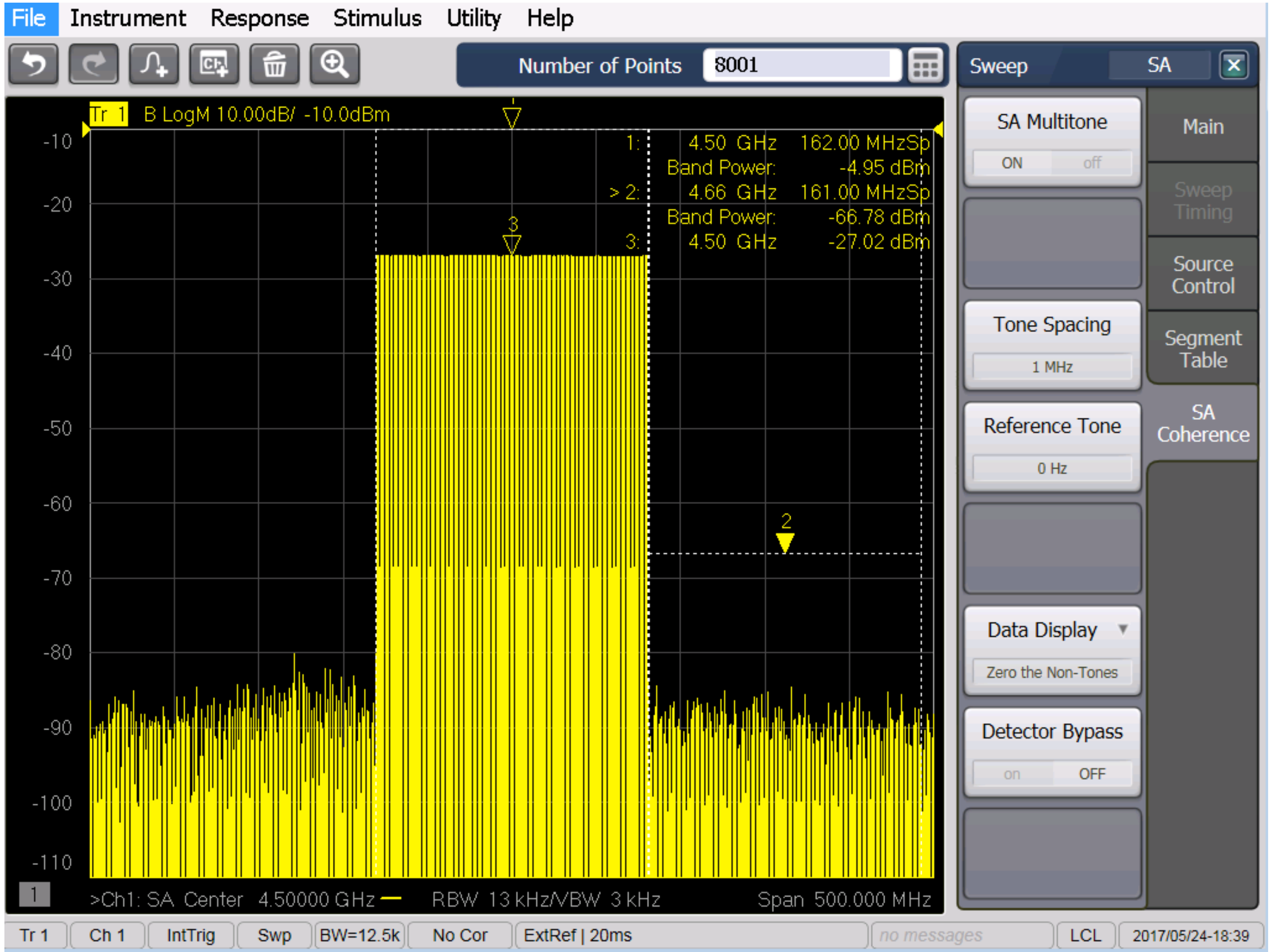


Modulated Signal: New Coherent Detection Power -5 dBm. 160 MHz BW, (PNA)

Main Carrier Band Power dropped to -5 dBm. Expected ACP is -77 dBm

With Coherent detection the level is -67 dBm

This is the noise floor at the tone positions



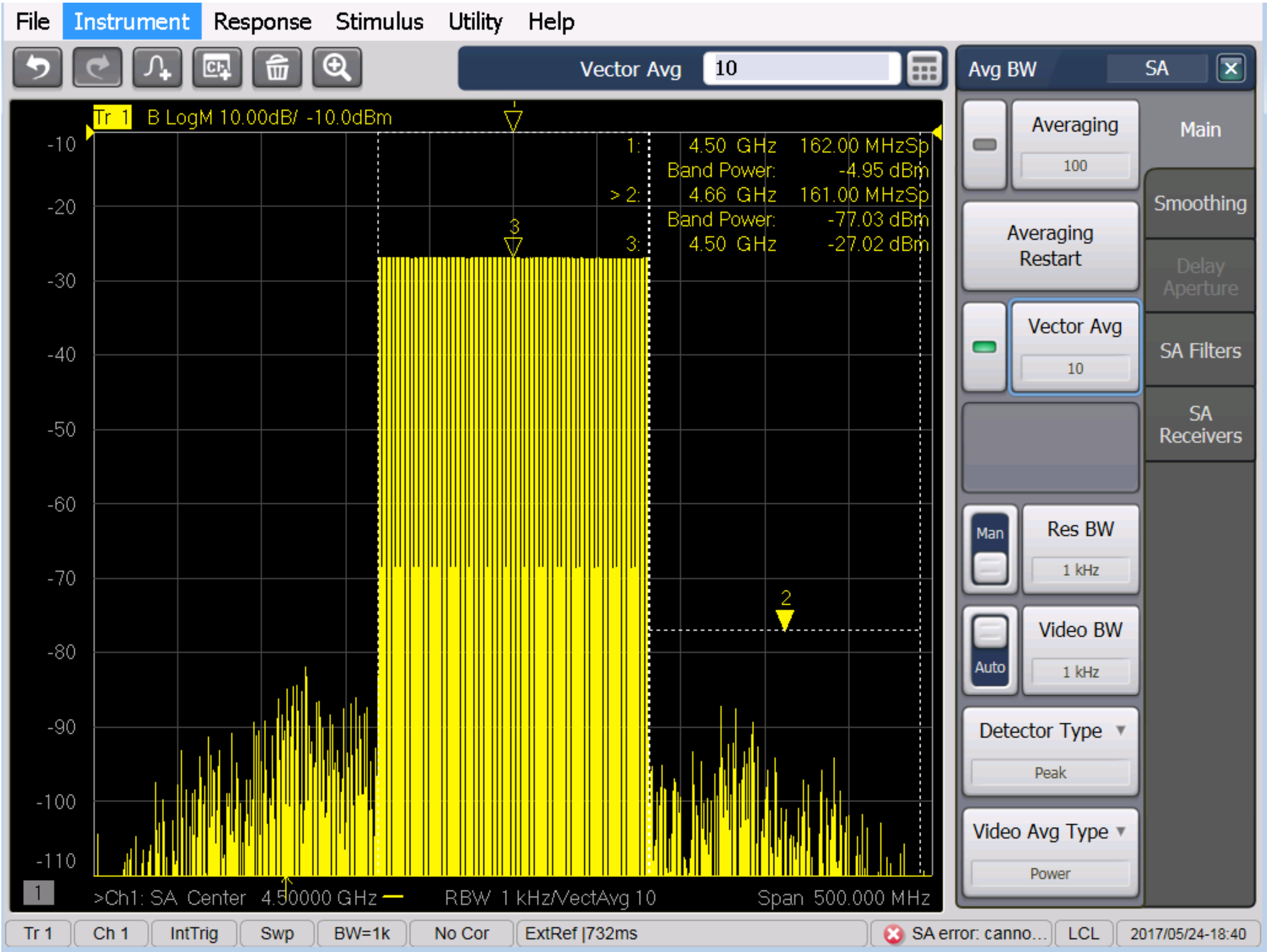
KEYSIGHT TECHNOLOGIES

Modulated Signal: New Coherent Detection Power -5 dBm with 10 Vector Average

Main Carrier Band Power is at -5 dB. Expected ACP is -77 dBm.

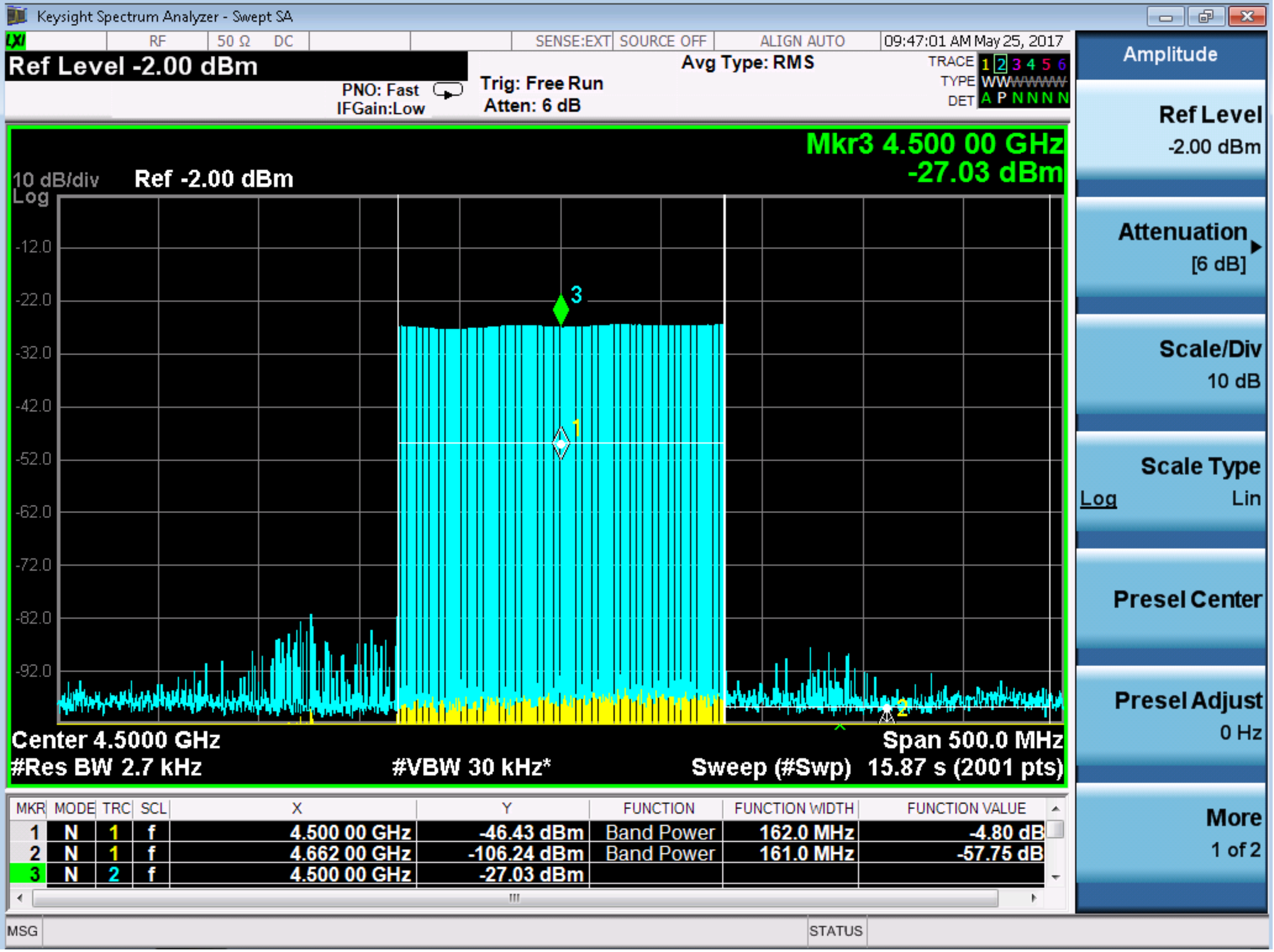
Measured level is -77 dBm

Adding in the process of Vector averaging is a coherent technique to lower noise floor.



Compare to Traditional SA - Modulated Signal: Normal Detection

Power -5 dBm.



Main Carrier Band Power dropped 15 dB. Expected ACP is -77 dBm

Measured is the noise floor, -57 with no way to reduce it. Note the signal is apparent above the noise floor, but the density of the noise floor dominates the total band power.

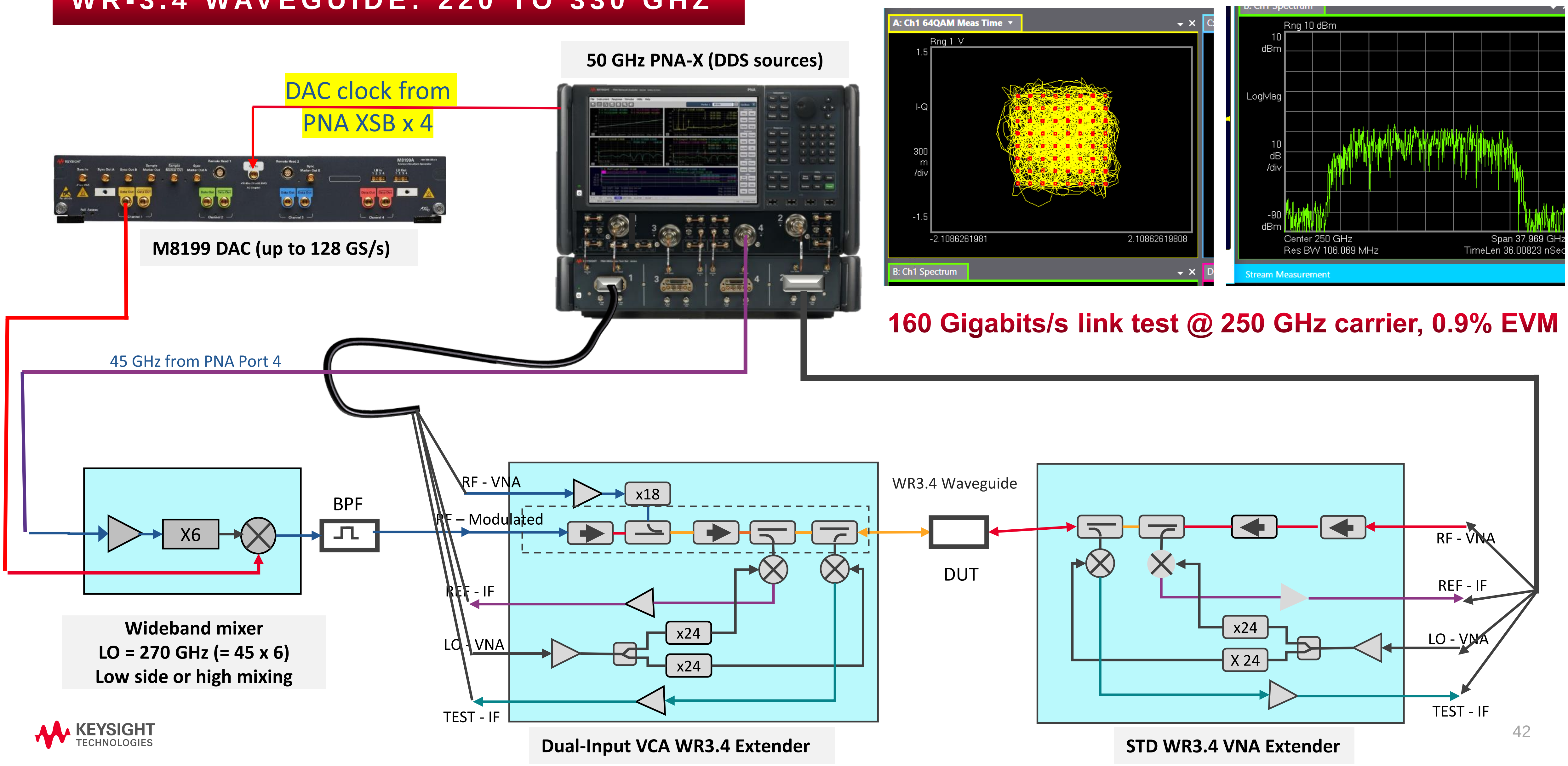
Extending to 6 GH applications

HIGHER FREQUENCY, WIDER BANDWIDTHS

- 6G applications will move in the D and G bands
  - Wider Bandwidths (wider than existing signal generators)
  - Phase noise becomes a dominant effect
- Test Equipment performance is sometimes the limitation
- Combining Coherent Measurement Methods might be the solution
  - Coherency allows noise reduction
  - Coherent can be between both Signal Generator and Test Receivers.

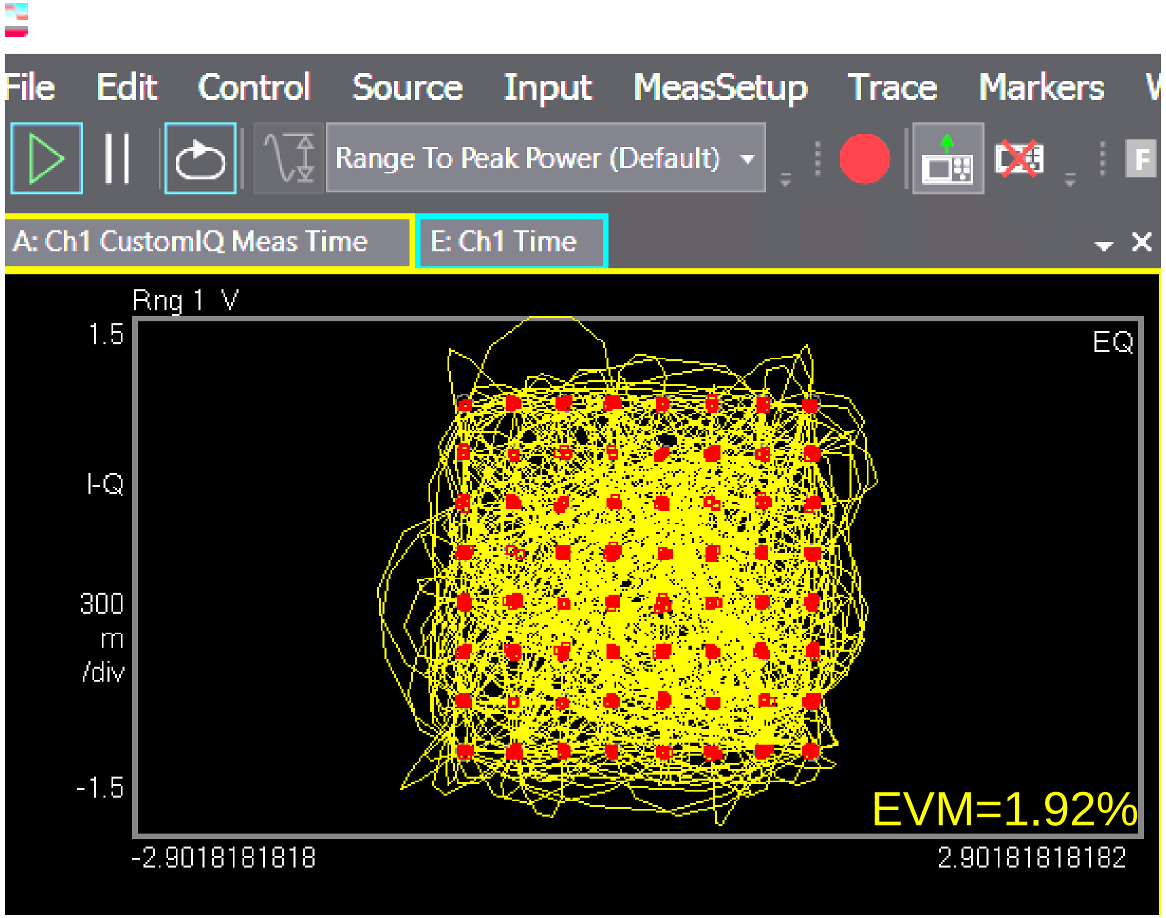
Clock-Locking: WR 3.4 Wideband Modulated 20 GHz bandwidth:

WR-3.4 WAVEGUIDE: 220 TO 330 GHZ

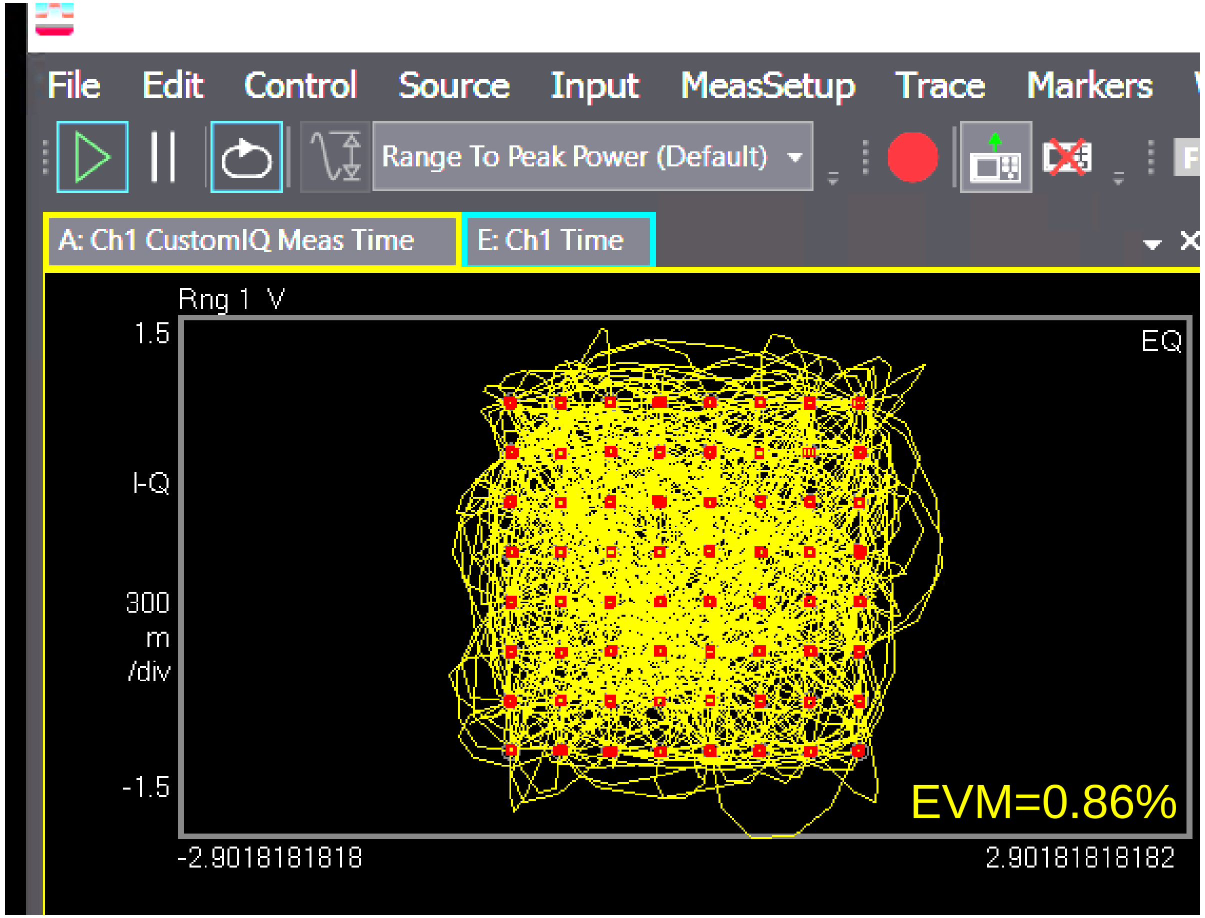


Clock-locking vs. using 10 MHz reference lock

CLOCK-LOCKING = COMMON CLOCK TO ALL SOURCES, RECEIVERS, AND ADC



Phase-Locked 10 MHz Reference



Using Common Clock (no phase locking)

J. Dunsmore and J. -P. Teyssier, "Improvements in 6G (D-band) Amplifier EVM Measurements using Clock-Locked Sources," *2023 100th ARFTG Microwave Measurement Conference (ARFTG)*, Las Vegas, NV, USA, 2023, pp. 1-4,

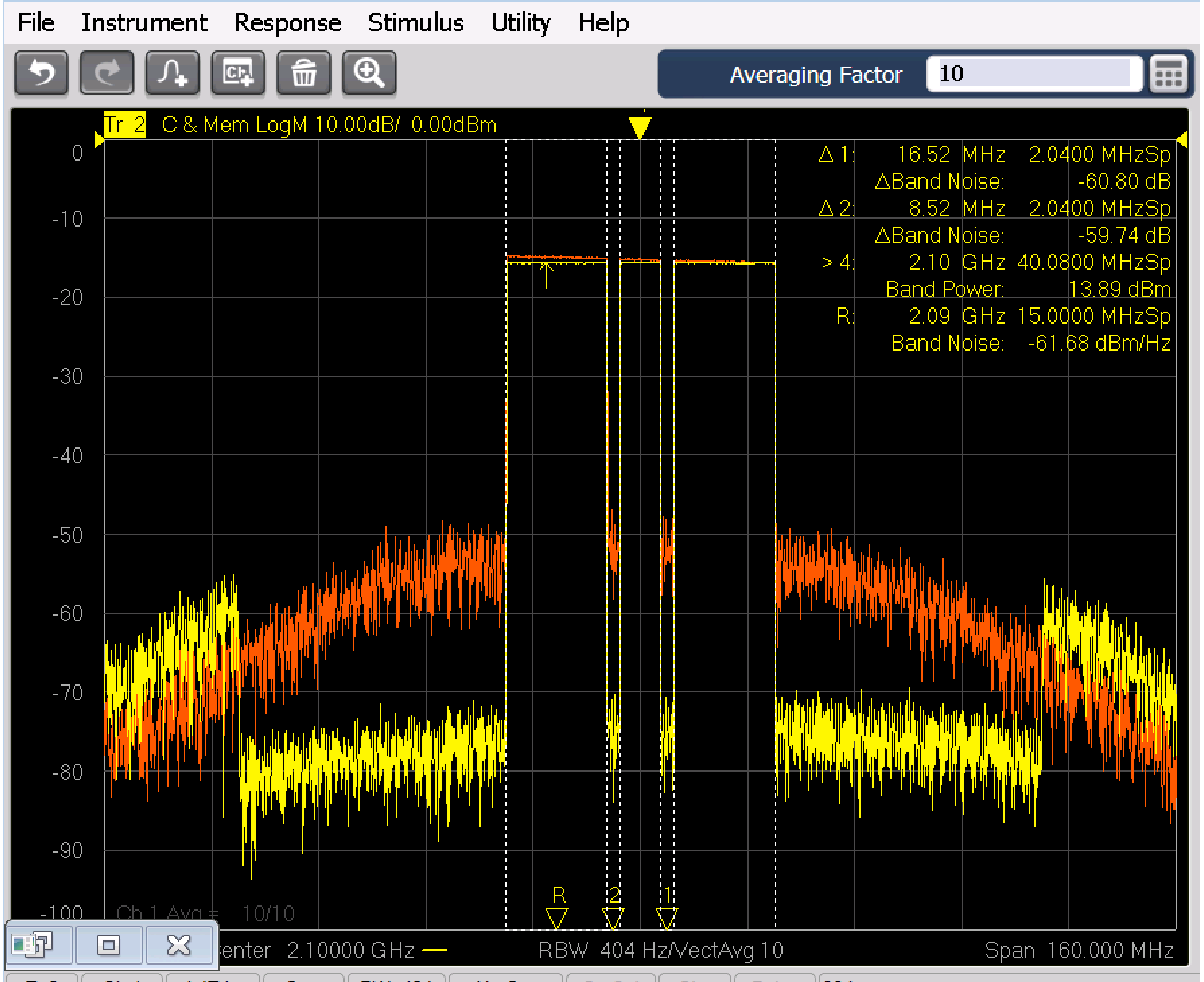
Finally: Creating Precision Signals

OFTEN THE QUALITY OF THE SIGNAL SOURCE LIMITS A MEASUREMENT RESULT

- The ability to precisely measure modulated signals provides for the possibility of also precisely correcting modulated signals
- Generating high quality signals at high power requires significant “back-off” from P1dB power
  - For a 50 dBc EVM, typically need 15 dB back-off
  - Using Digital Pre-Distortion (DPD) can correct for this.
- Frequency response errors (flatness, phase linearity) can also be improved with

Multi-Notch Example, including out-of-band cancellation

THIS PROVIDES A METHOD TO EMULATED MULTI-CARRIER SIGNALS



KEYSIGHT TECHNOLOGIES

PNA-X SA Mode: Fast, Deep FFTs To Capture Waveforms

WORLDS FASTEST SA*

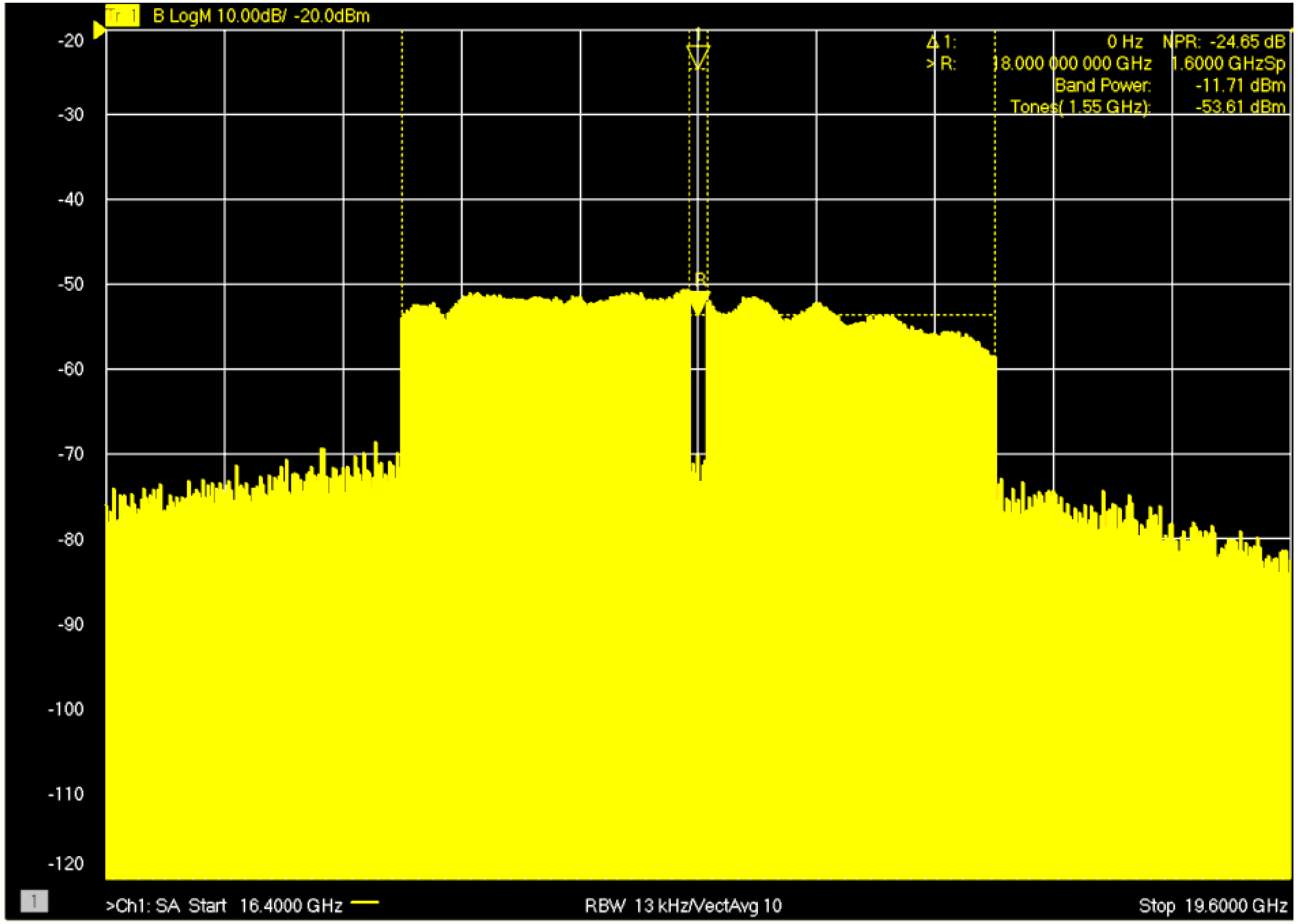
Here we measure a 1.6 GHz bandwidth signal, comprised of 16001 tones, with a 50 MHz notch of 500 tones.

Total measurement time is 5.52 seconds on a 1 kHz RBW, FFT is about 2,000,000 points

We can overcome distortion in our PNA receiver by increasing the internal attenuator.

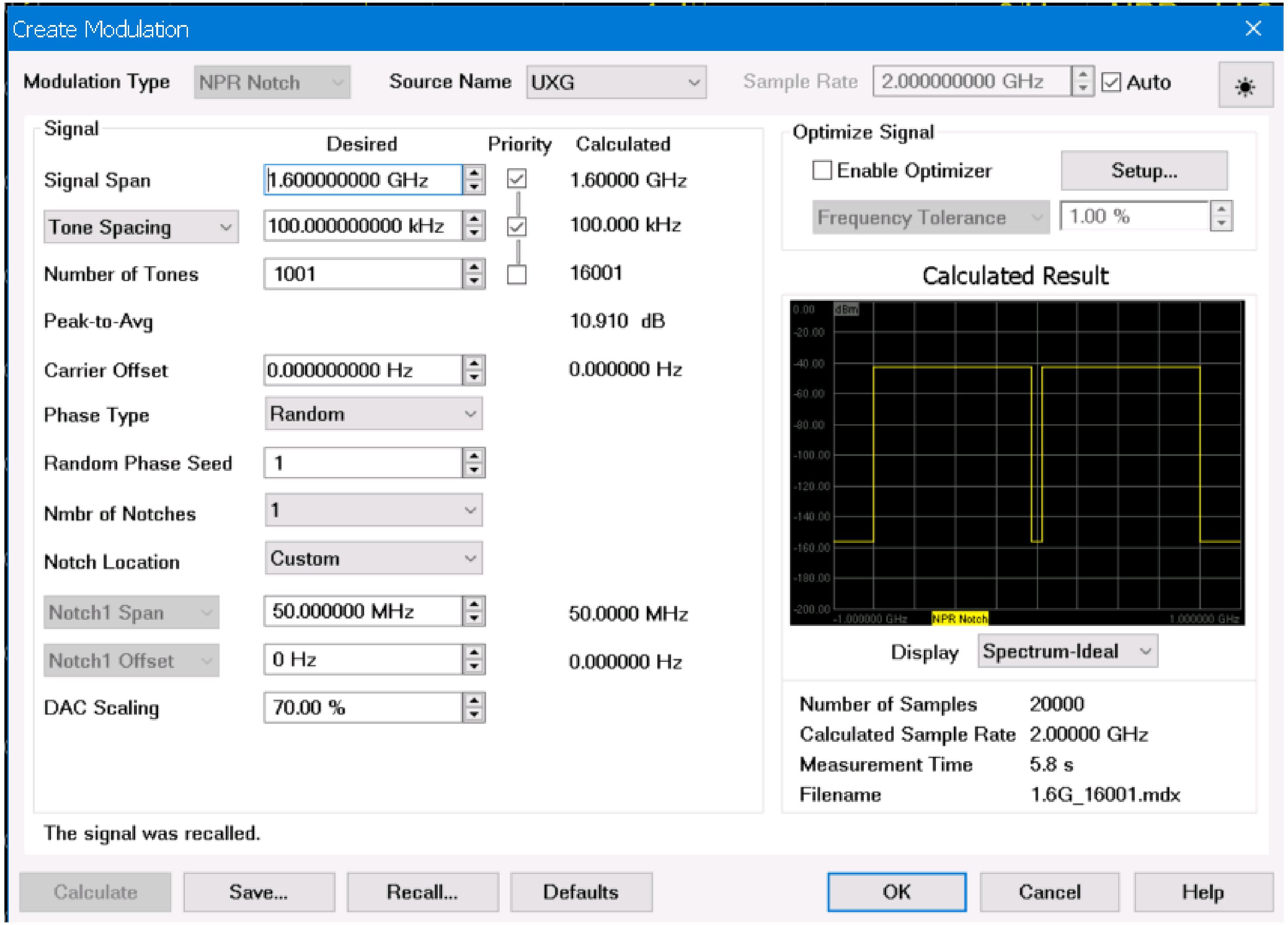
But now we are limited by noise!

How do we perfect the signal?



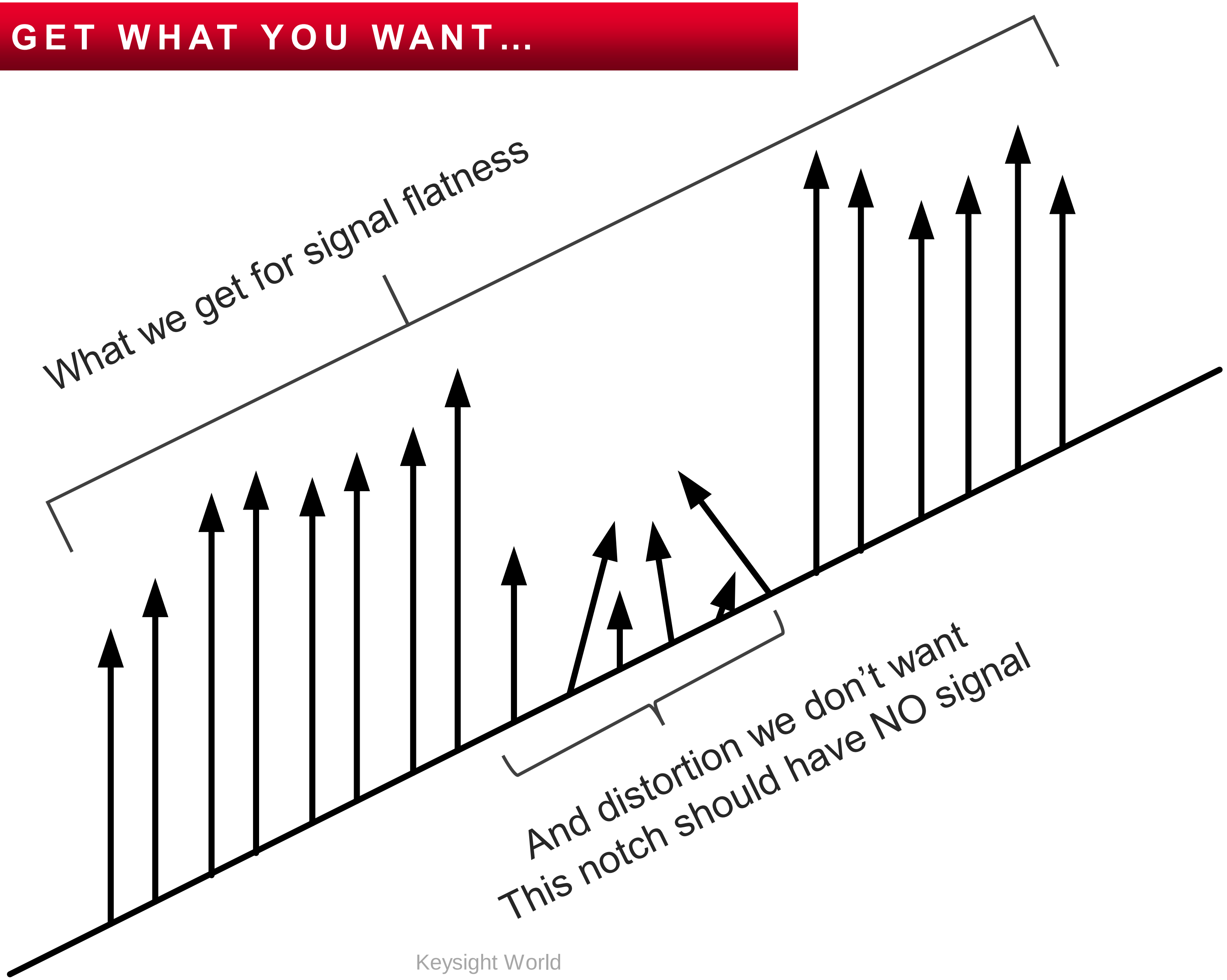
Setting Up An NPR Signal: Flat Amplitude With A Notch

CREATE FROM DEFINED SETTINGS



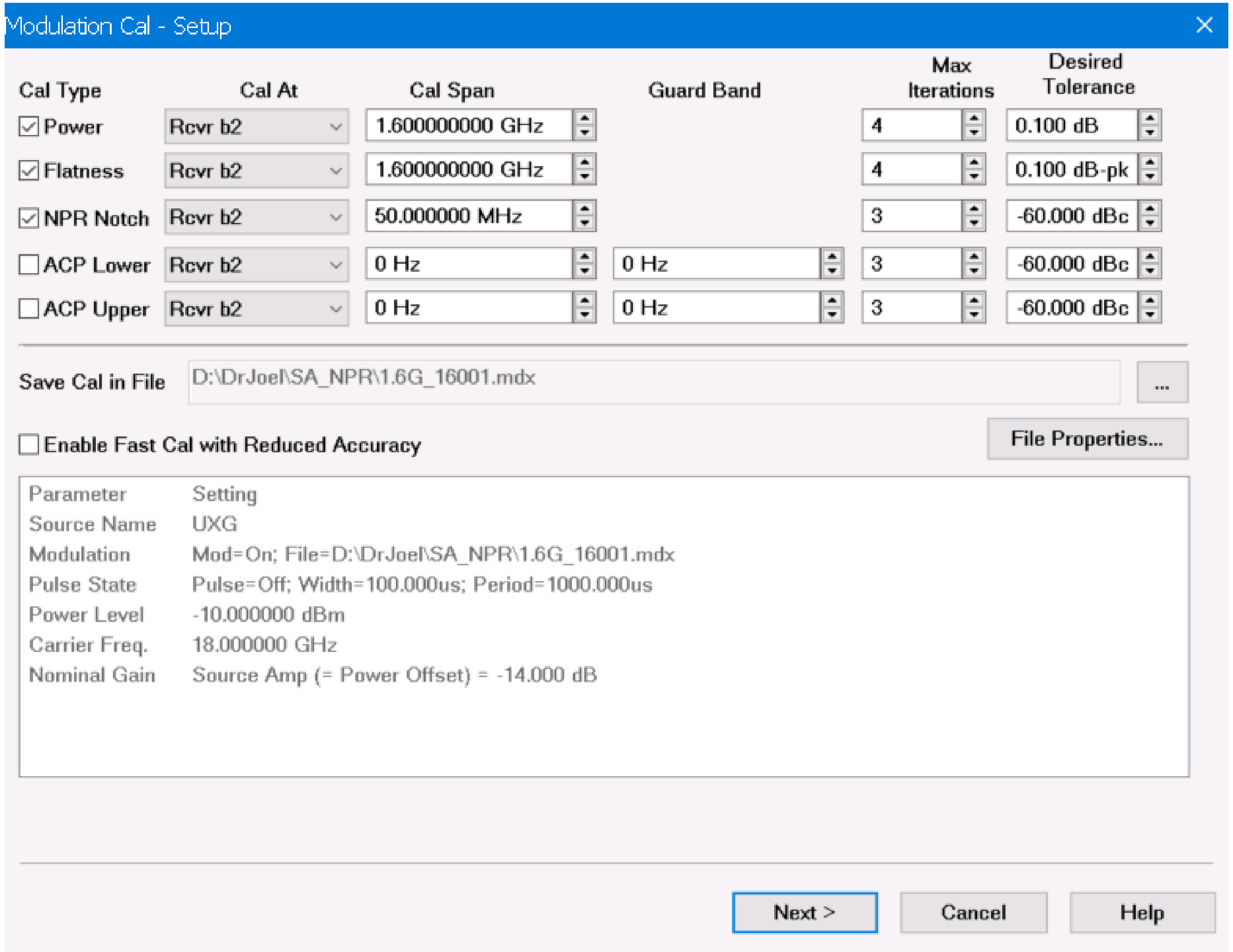
Program Source For Flat Amplitude With A Notch (NPR)

YOU DON'T ALWAYS GET WHAT YOU WANT…



Flatness And Distortion Correction

ITERATE TO THE BEST FIT VALUE

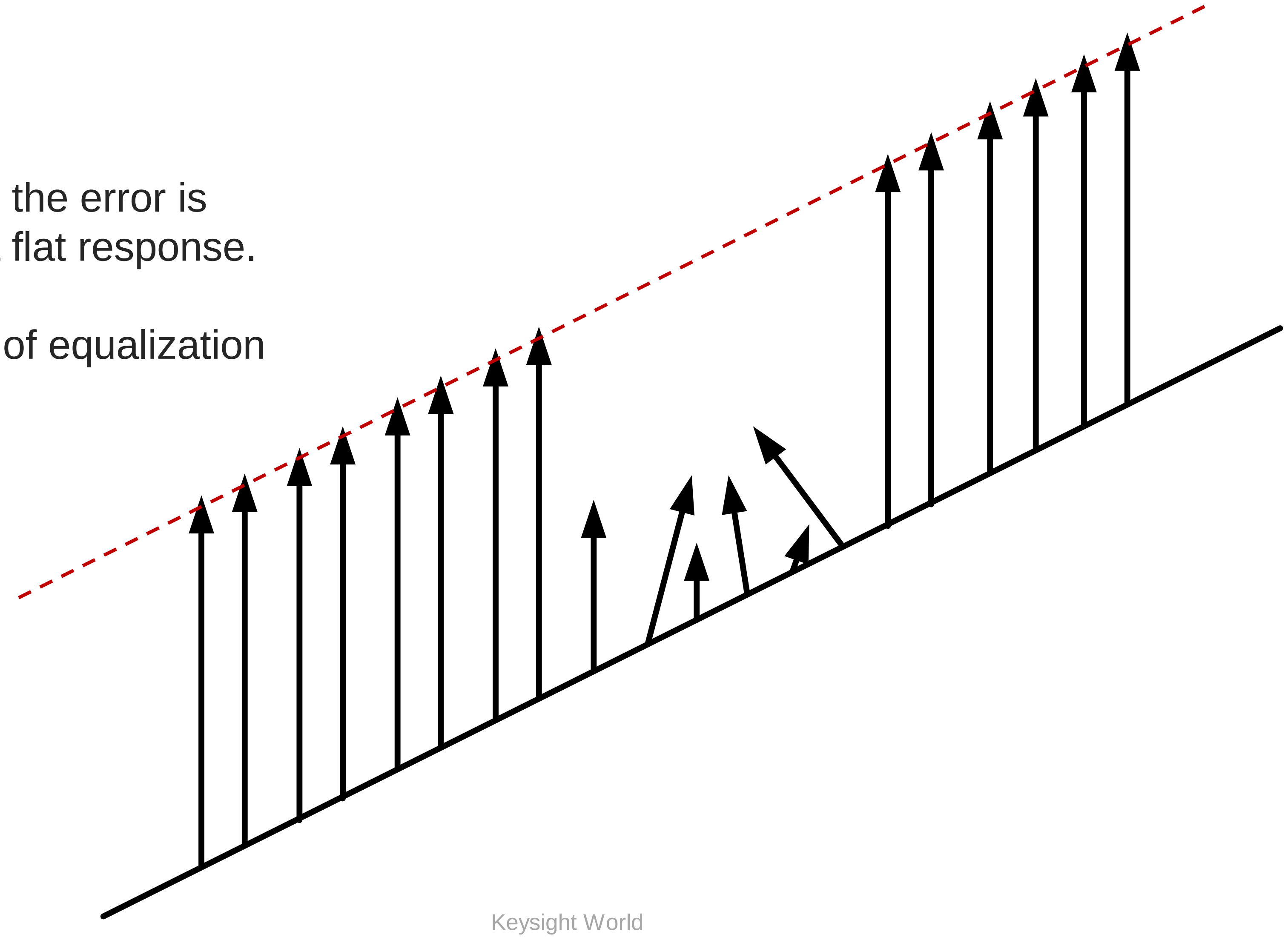


Correct For Flatness In Multitone

OBTAINING PERFECT SIGNALING

Measuring each tone, the error is adjusted to produce a flat response.

This is the equivalent of equalization

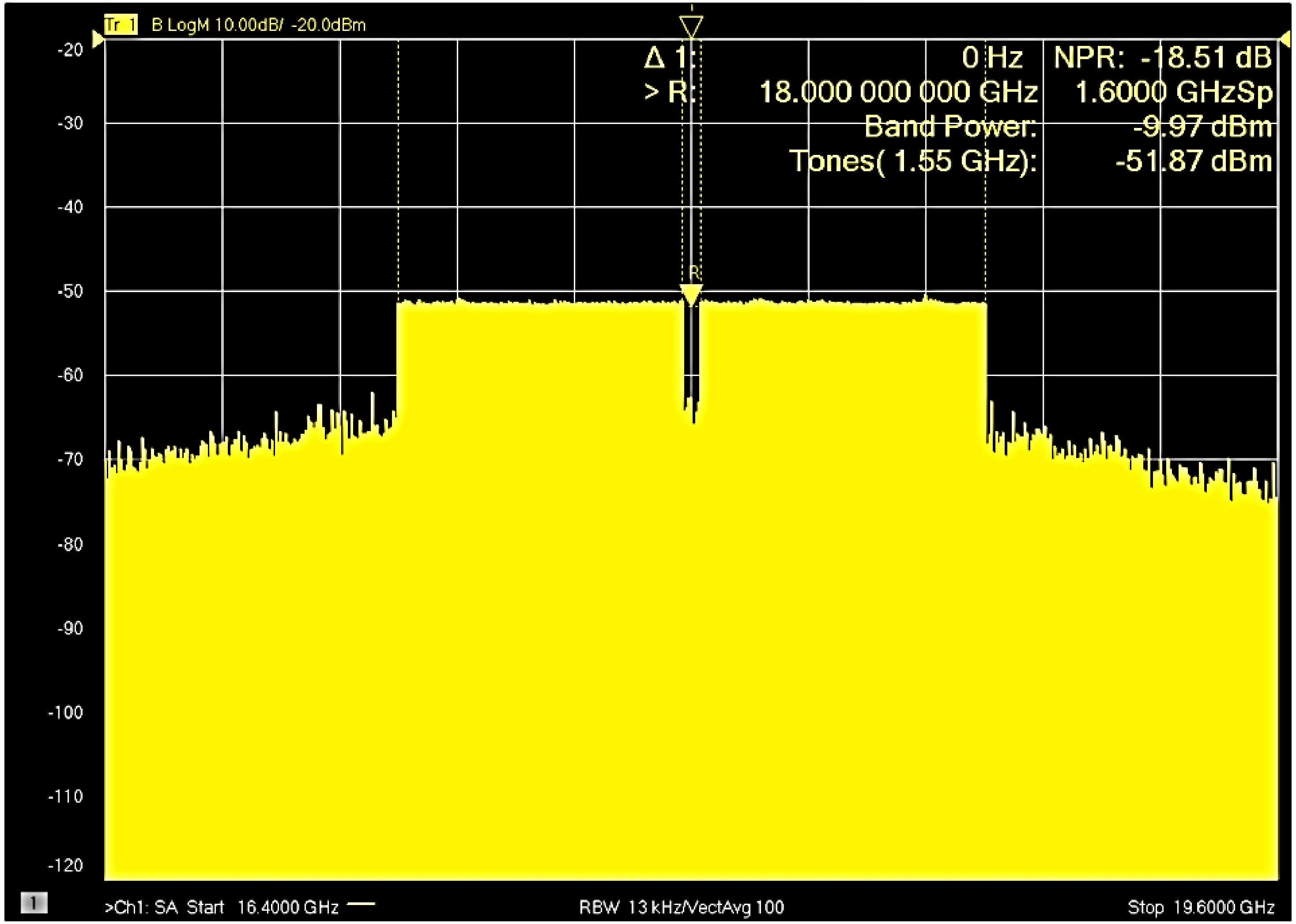


Flatten The Signal

SIGNAL PERFECTION

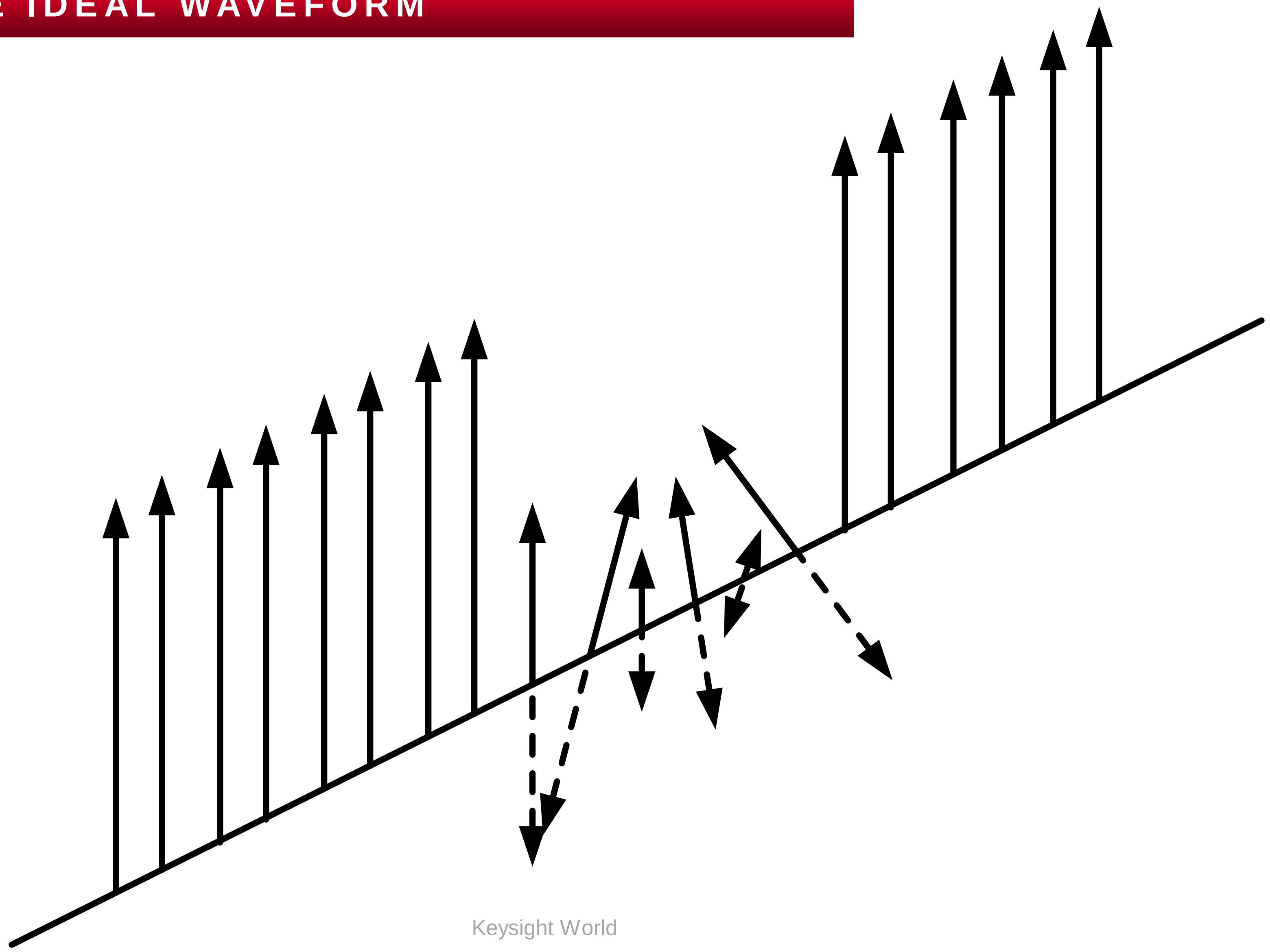
- The first step has two parts:
  - Measure the Offset in Power
  - Measure the Flatness

- Correct both, to obtain the perfect signals (in amplitude), at the perfect level (in power).
- But how to correct for distortion?



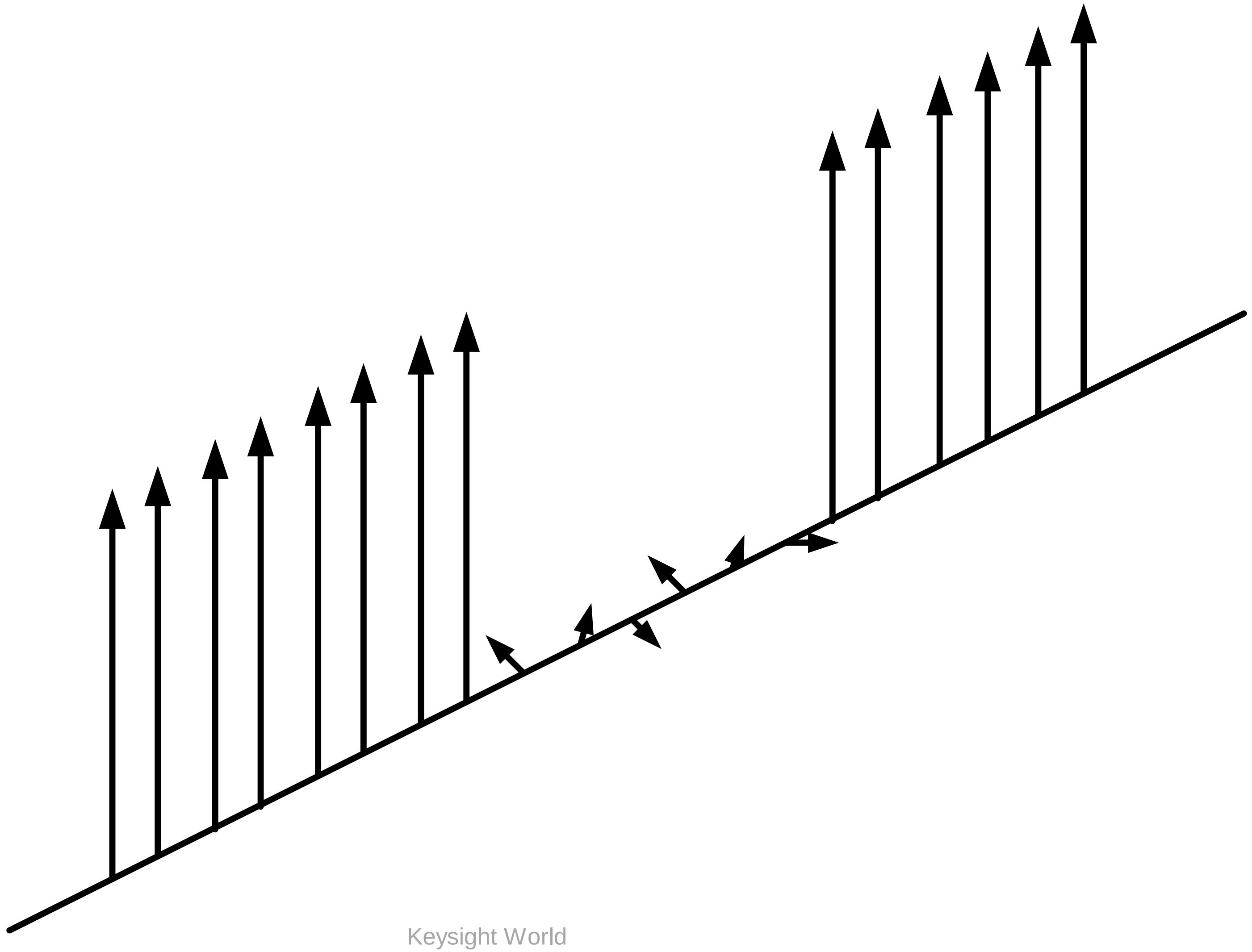
Compute The Phase That Best Cancels The Tones

ADD THAT TO THE IDEAL WAVEFORM



Now We See The Residual Notch Tones Are Much Smaller

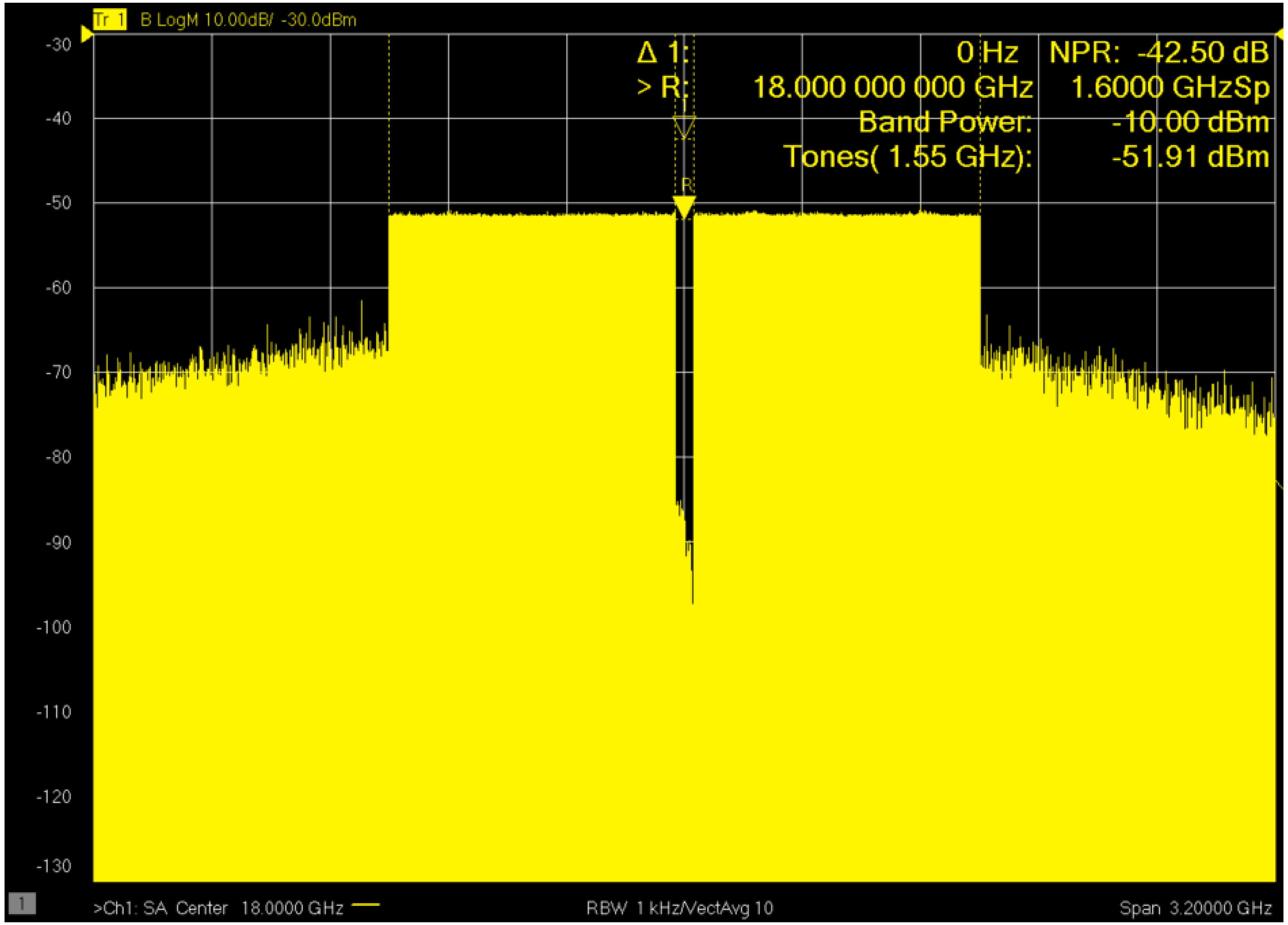
ABOUT 10-15 dB IMPROVEMENT ON EACH CYCLE



After Correction

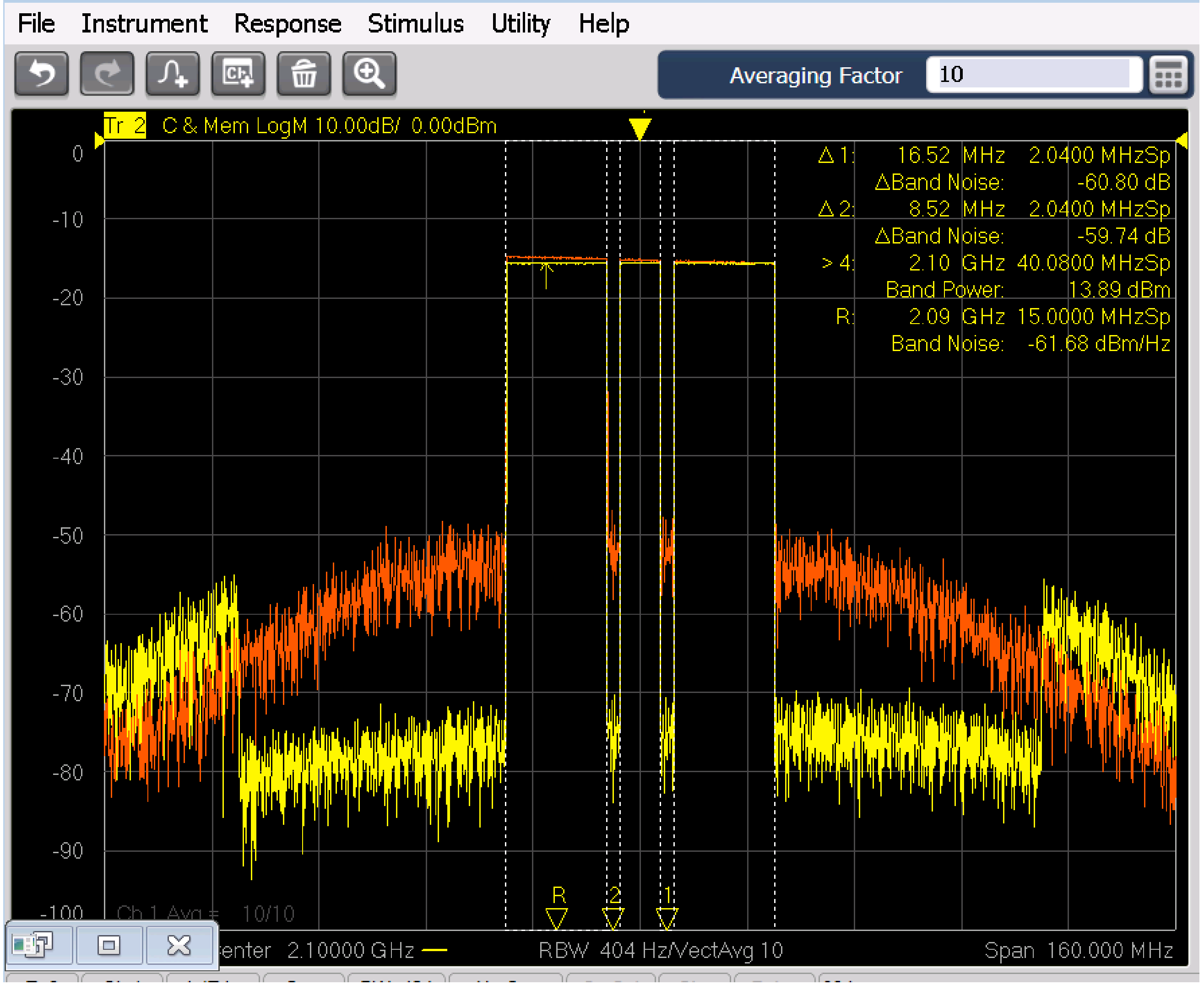
SIGNAL PERFECTION

- A two-step process corrects for signal flatness AND distortion
- Flatness improvement from 5 dB pk-pk to 0.2 pk-pk
- Distortion improvement of more than 20 dBc (from -18 dBc to -42 dBc)
- Other examples show >30 dBc improvement
- Note out-of-band distortion remains (the AWG bandwidth is not wide enough to clean up ACP)



Multi-Notch Example, Including Out-of-band Cancellation

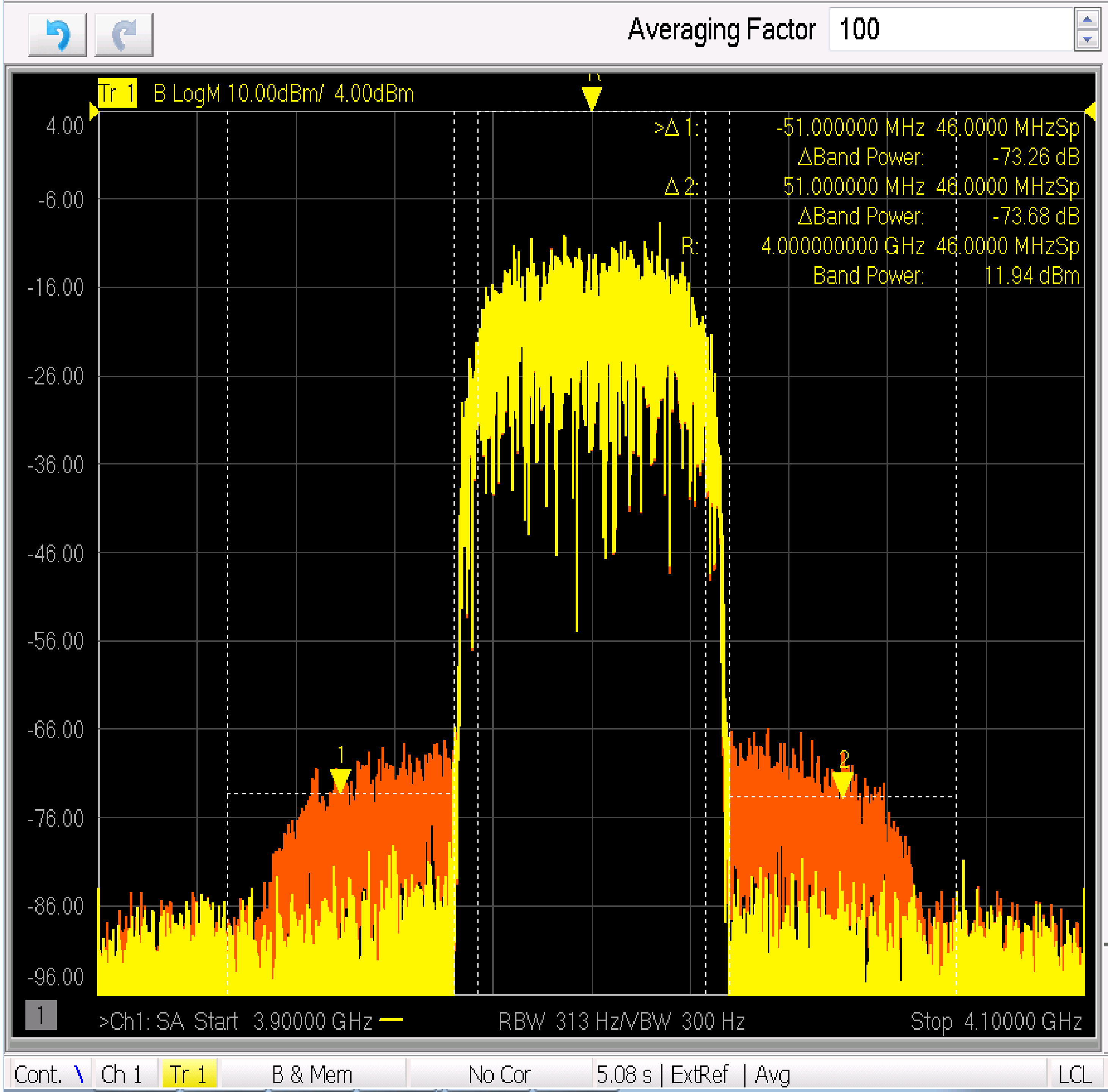
THIS PROVIDES A METHOD TO EMULATED MULTI-CARRIER SIGNALS



ACPR on QAM signal

DRAMATIC IMPROVEMENT

- Here is an example of a 40 Msym/s 16 QAM from an MXG, 3000 symbols
- Red is as generated
- Yellow is after correction
- Improvement from -58 dBc ACPR to -73 dBc ACPR
- This is an MXG at +12 dBm output… It never looked so good!

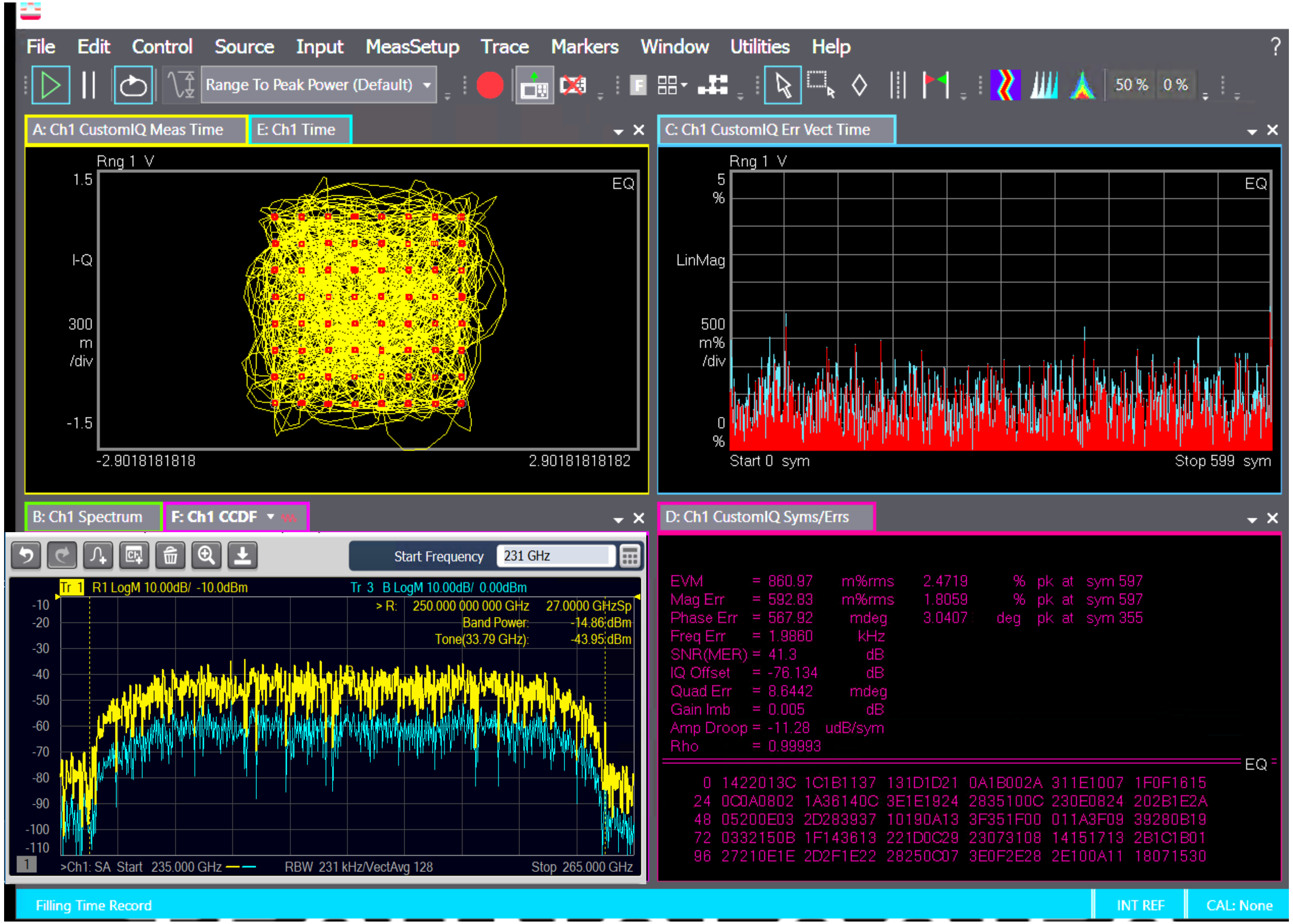


Extension to 6G Applications: 220-330 GHZ

USING VECTOR COMPONENT ANALYZER (VCA)

250 GHz Center Freq, 20 Gsymb/sec, 64 QAM

Clock-Locked Performance 0.86% EVM



KEYSIGHT TECHNOLOGIES

Summary

VNA BASED MODULATED MEASUREMENTS

- VNAs can have a Spectrum Analyzer mode, which has the ability to measure precisely modulated signals when the signals are stationary, or repetitive
- VNA calibration methods can be applied in the spectrum analyzer measurements
- Knowing the period of a modulated signal allows coherent measurements
- Coherency allows improvements in signal-to-noise through Vector Averaging
- Coherency also allows wide-band acquisitions with a narrow-band VNA receiver
  - Wideband acquisitions can be sent to VSA software for further analysis
- Coherency also includes using common clocks to remove phase noise effects
  - This is especially important at 6G frequencies
- Given repetitive signals, with precise measurements, the signal quality can be improved.