Bringing 5G to Space: Wideband & Modulated Test for SatCom Converters

Joel Dunsmore, Keysight Fellow

June 2020

Bringing 5G to Space:

PRESENTATION OUTLINE

- How 5G and Space Communications are Converging
  - Technology Overlaps
  - What’s the Same, and What’s Different
- Key Building Blocks
  - Wideband, High-Order Modulation
  - Flexible Frequency Conversion
  - Use of Phased-Array or Electronically Steerable Antennas
- Focus on Converter Test
  - Measuring Frequency Flexible Converters
  - Measuring under Modulation Drive
    - Gain/Phase/Group Delay
    - EVM and NPR

How 5G and Space Communications are Converging

- Technologies, Frequencies, Test Methods

How 5G and Space Communications are Converging

FREQUENCIES

- 5G FR2 Bands: (https://en.wikipedia.org/wiki/5G_NR_frequency_bands)

Frequency Range 2 [edit]

Band	ƒ (GHz)	Common name	Subset of band	Uplink / Downlink[B 1] (GHz)	Channel bandwidths[5] (MHz)
n257	28	LMDS		26.50 – 29.50	50, 100, 200, 400
n258	26	K-band		24.25 – 27.50	50, 100, 200, 400
n260	39	Ka-band		37.00 – 40.00	50, 100, 200, 400
n261	28	Ka-band	n257	27.50 – 28.35	50, 100, 200, 400
Band	ƒ (GHz)	Common name	Subset of band	Uplink / Downlink[B 1] (GHz)	Channel bandwidths[5] (MHz)

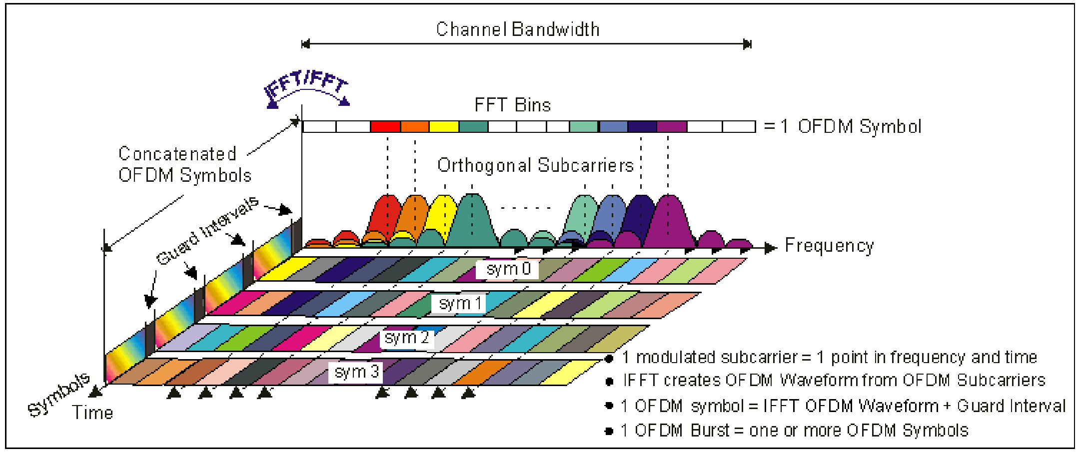
- SpaceX Starlink Bands: (https://arc.aiaa.org/doi/10.2514/6.2019-0768)

Characteristic	Uplink	Downlink
Frequency (GHz)	14.0 -14.5 27.5 - 29.1 29.5 - 30.0 47.2 - 52.4	10.7 - 12.7 17.8 - 18.6 18.8 - 19.3 37.5 - 42.5
Modulation Type	BPSK, QAM	OQPSK, QAM

How 5G and Space Communications are Converging

HIGH ORDER MODULATION FORMAT

- 5G FR2 Bands: OFDM: Multi-channel Orthogonal Frequency Domain Multiplexing



Frequency-Time Representative of an OFDM signal

- Sat Com Modulation: Complex, Multi-channel (e.g. DVB-S2)

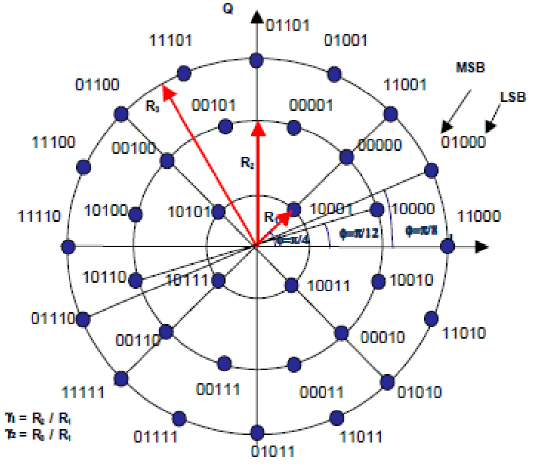


Figure 12: 32APSK signal constellation

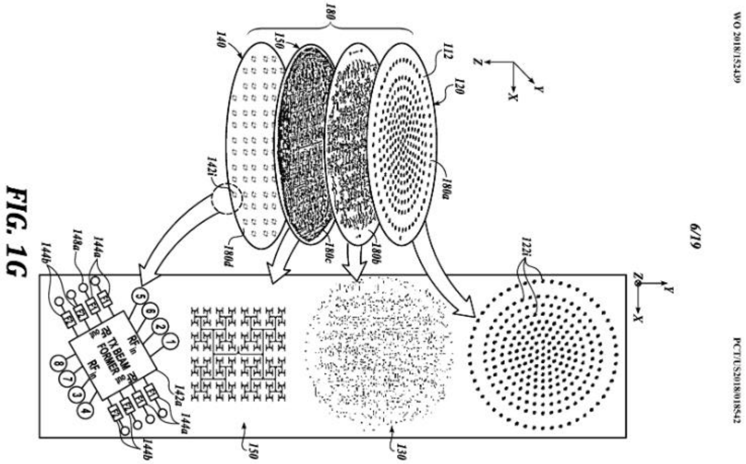
http://rfmw.em.keysight.com/wireless/helpfiles/89600B/WebHelp/Subsystems/wlan-ofdm/content/ofdm_basicprinciplesoverview.htm
https://edadocs.software.keysight.com/display/sv201007/DVBS2+Baseband+Verification+Library+Print+View

How 5G and Space Communications are Converging

BEAM FORMING ANTENNA

- 5G FR2 Bands:

- Sat Com Phase Array



Focus On Frequency Converters

- Test Methods, Signal Drives

Frequency Converter Test

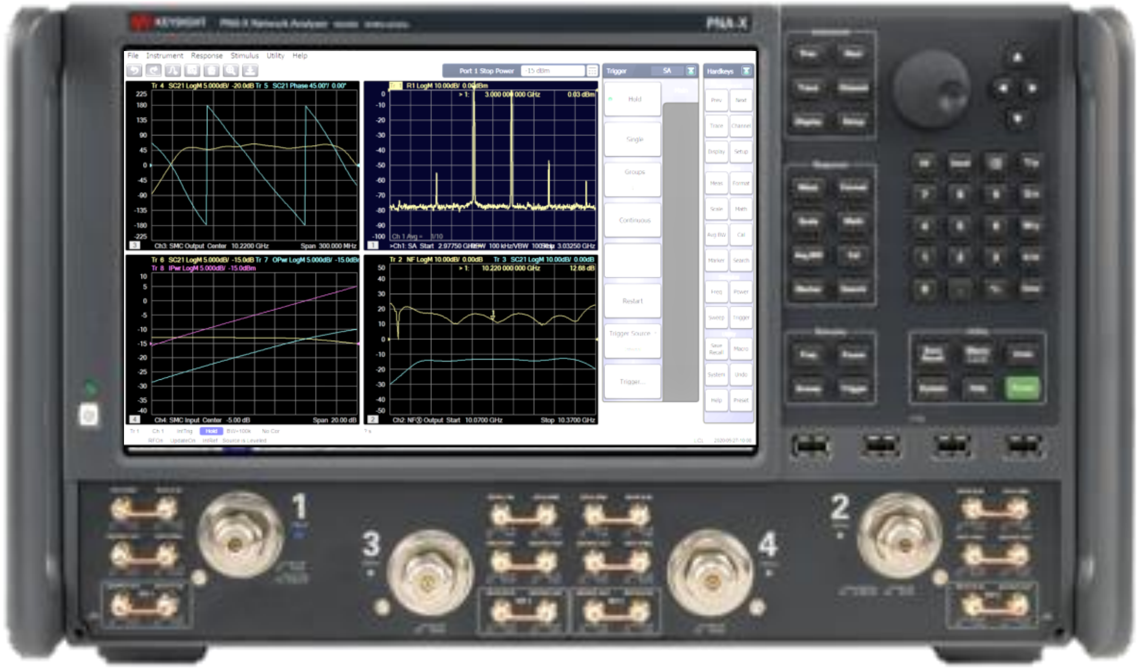
KEY MEASUREMENT AND CHARACTERISTICS

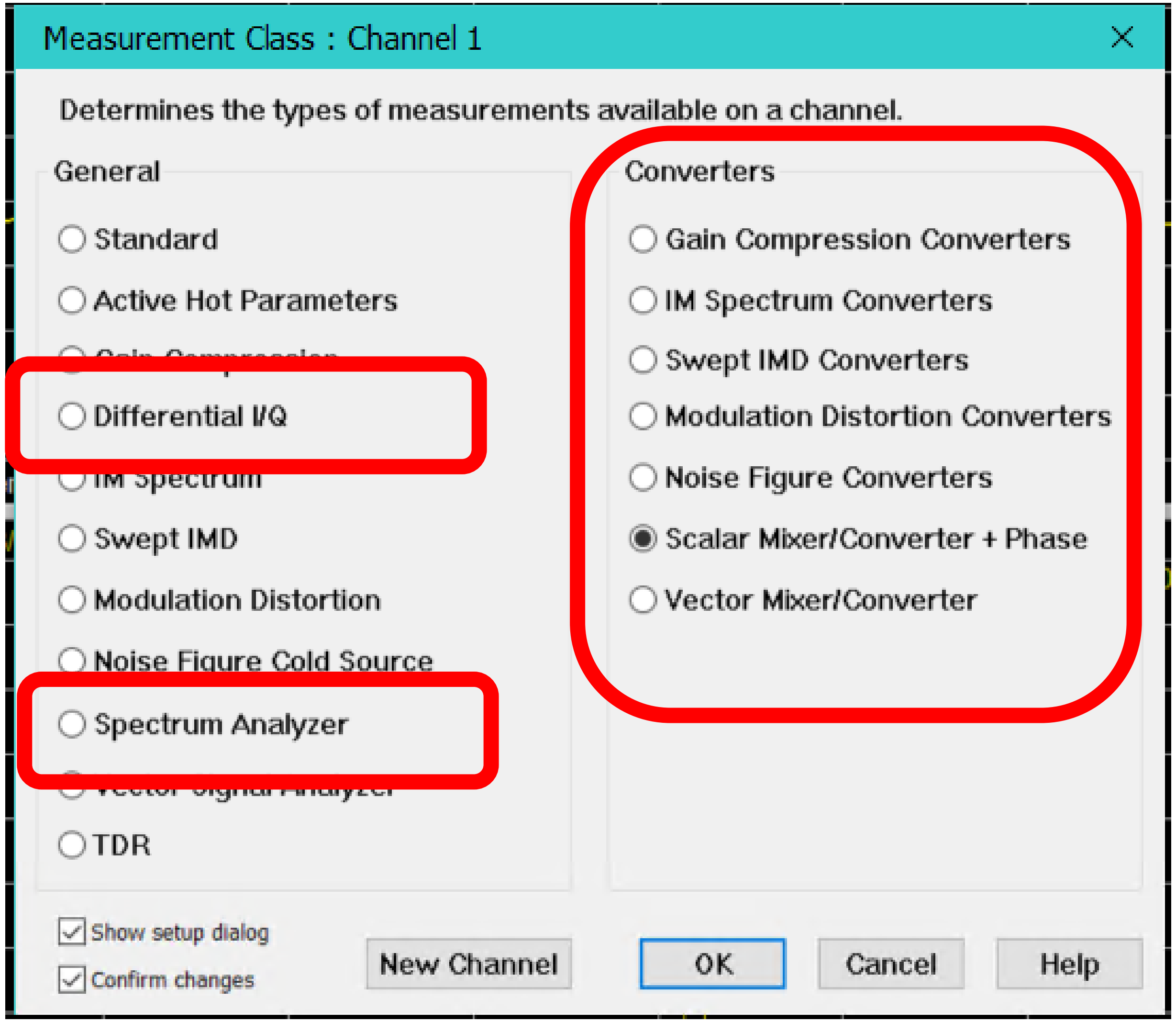
- Gain/Phase/Group Delay vs. Frequency
  - Using Swept CW Signals
  - NEW: Low-Phase Noise VNA Signal Source
  - NEW: Using Modulated Signals
- Compression Vs. Frequency
  - Modulated vs. Not Modulated
- Spurious Test
  - Close in Carrier Spurious
  - Higher Order Mixing Products
- Distortion Characteristics
  - Under CW Drive: Two-Tone Intermodulation Distortion
  - Under Modulated Drive

    Error-Vector Magnitude (EVM)
    Adjacent Channel Power
    Noise Power Ratio (NPR)

Frequency Converter Test with PNA-X

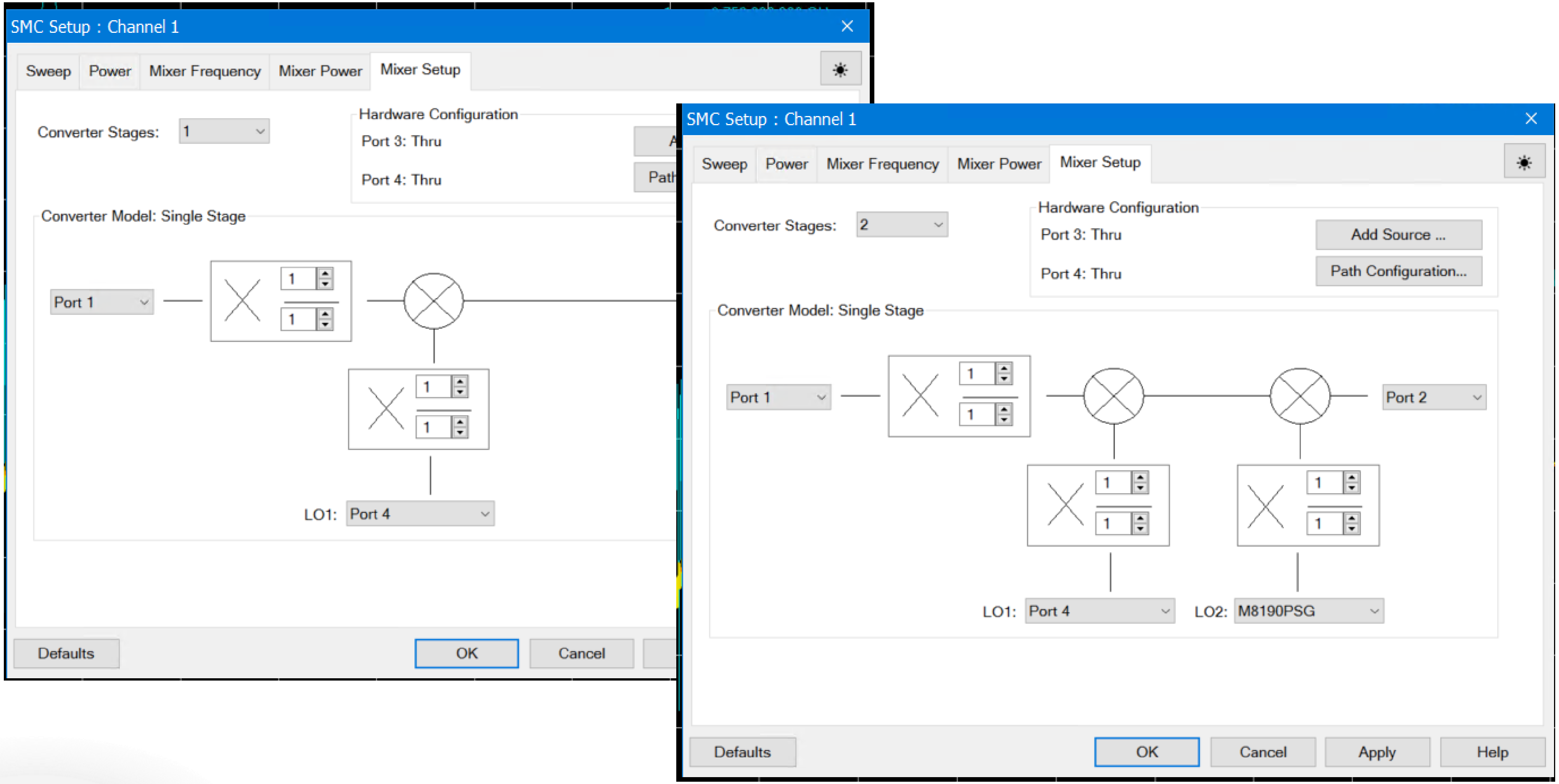
PNA-X MEASUREMENT CLASSES FOR CONVERTERS





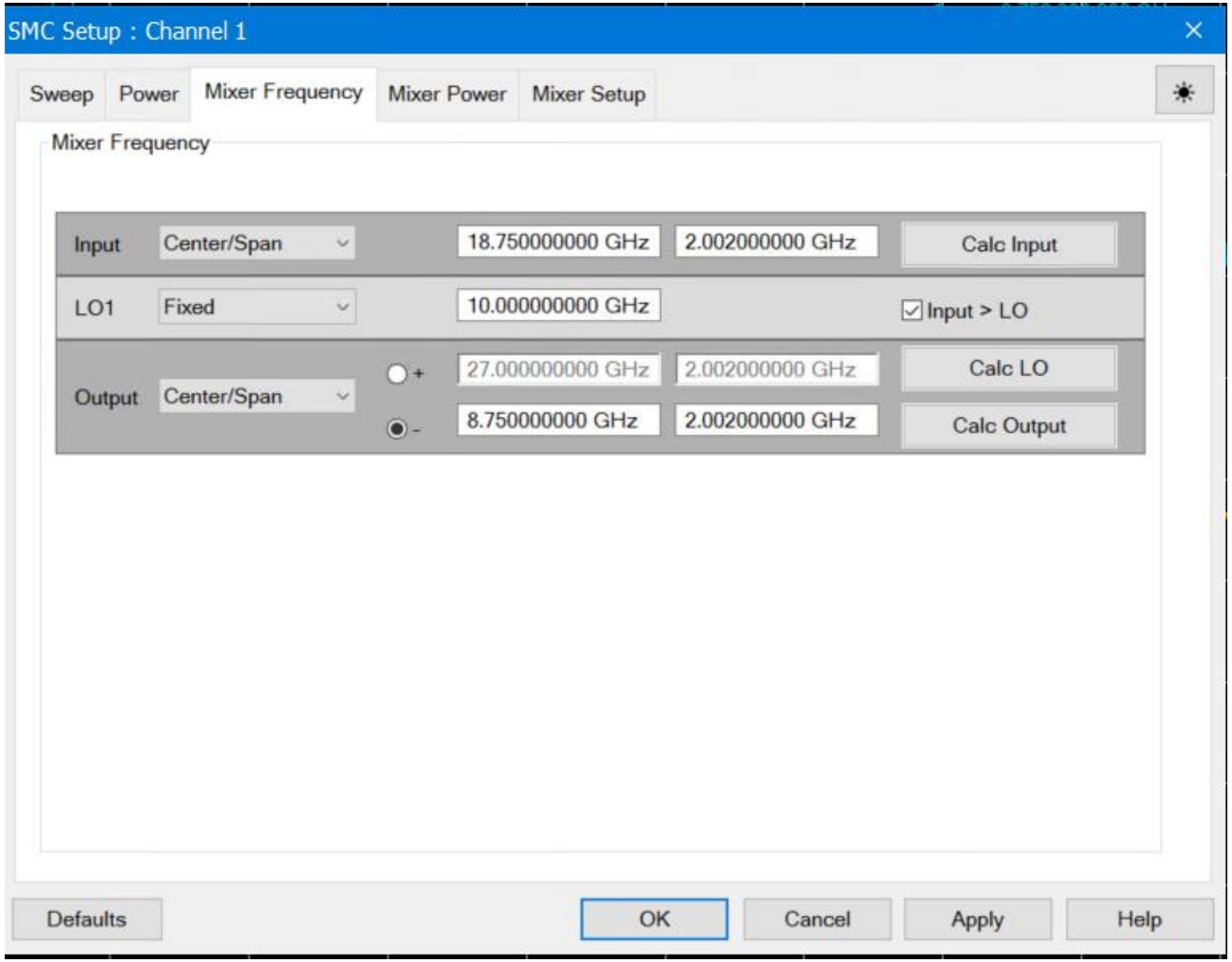
Frequency Converter Characterization

DEFINE THE MIXER CONFIGURATION (1 OR 2 LO)



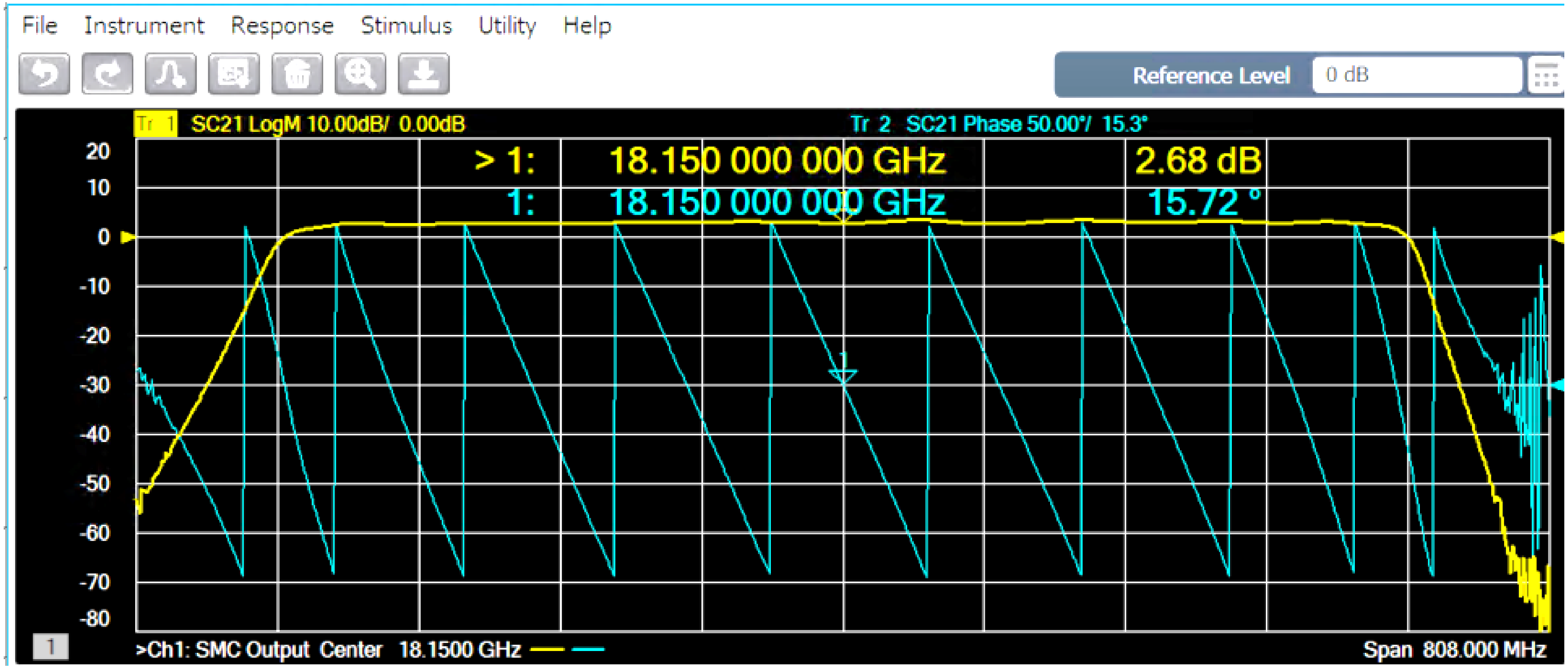
Frequency Converter Characterization

DEFINE THE FREQUENCY PLAN: INPUT, LO, OUTPUT



Frequency Converter Characterization

GAIN AND PHASE, SWEPT CW, FULLY CALIBRATED

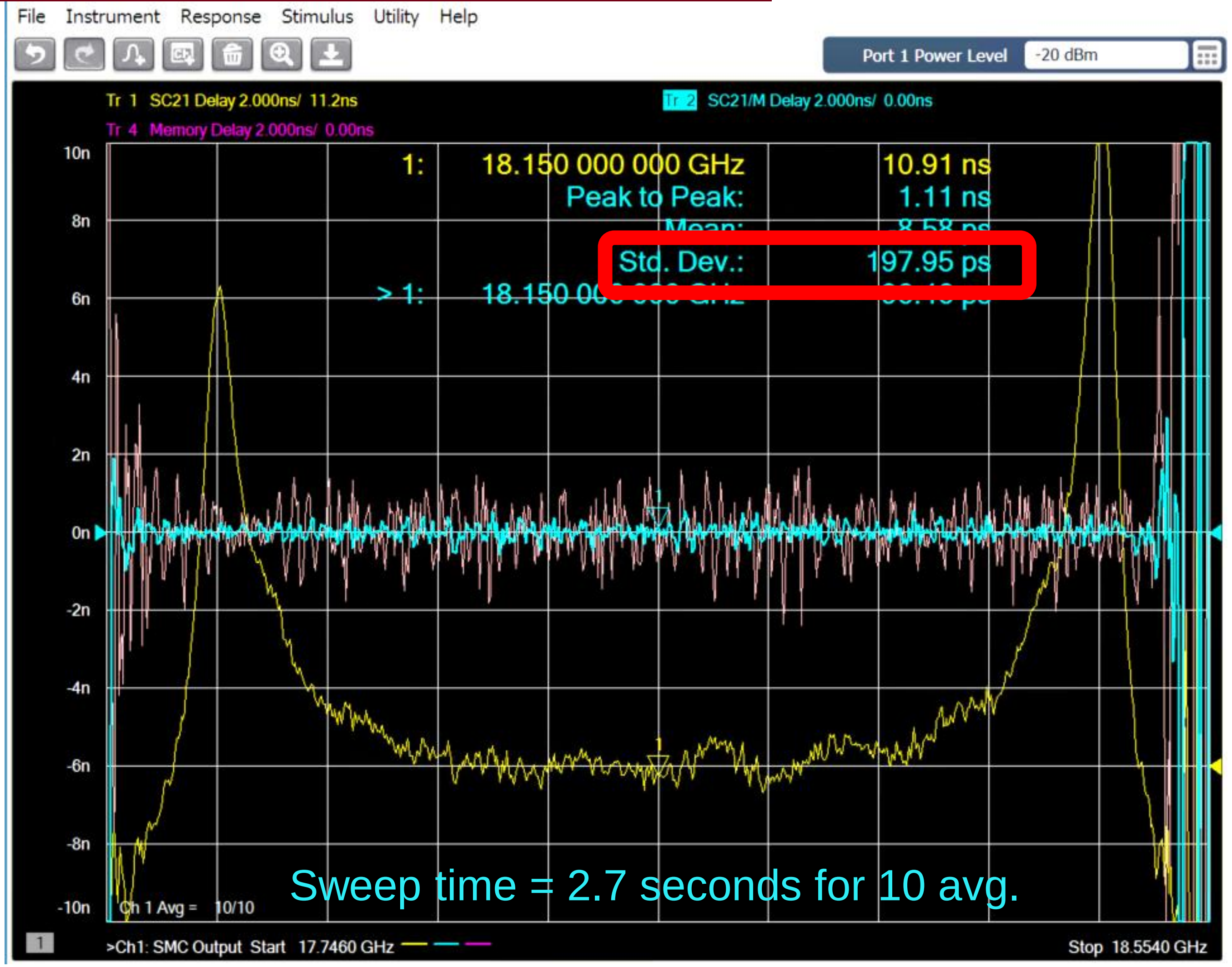


Frequency Converter Characterization

GROUP DELAY – YELLOW (NORMALIZED, BLUE)

The yellow trace shows the absolute group delay of the converter. The blue trace is a normalized version, which shows the standard deviation noise of ~200 ps, after 10 averages. The lighter trace behind shows noise with no averaging.

This noise is principally due to the phase noise of the source and LO in the PNA, and can only be lowered with sweep averaging; until now.



N522xB/4xB PNA/PNA-X signal source enhancement

EVOLVING ACTIVE COMPONENT MEASUREMENT SOLUTIONS

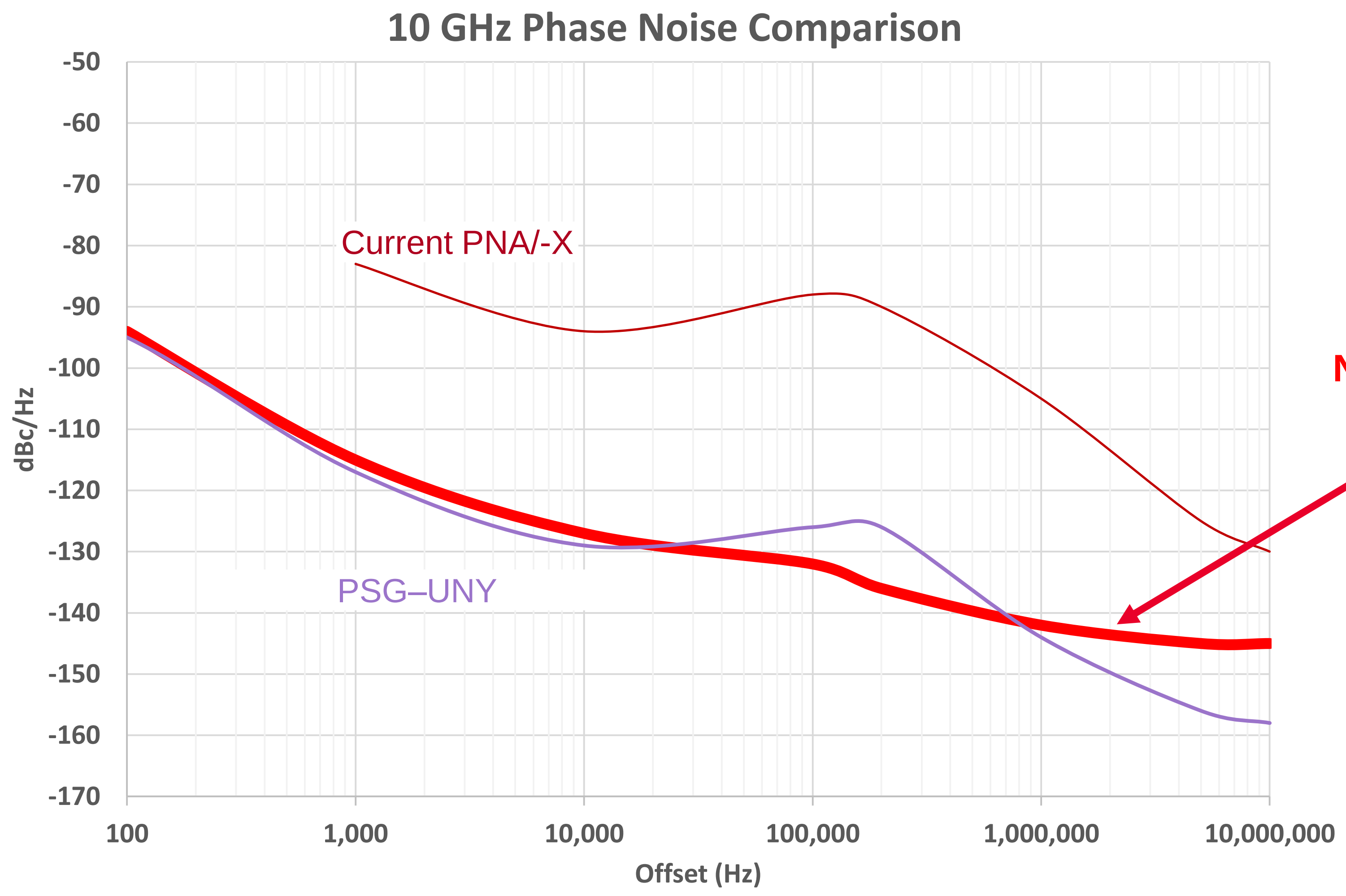
- **New DDS (direct digital synthesizers) source improving:**
  - phase noise by 30 dB
  - measurement performance of apps: SMC+phase, differential-IQ, modulation distortion, NVNA, iTMSA
  - dynamic range in sub-THz bands by 30 dB
- High-performance analog-SigGen-class low phase noise (Option UNY, Enhanced low-phase noise)
- 3rd RF source up to 13.5 GHz on 4-port PNA-X

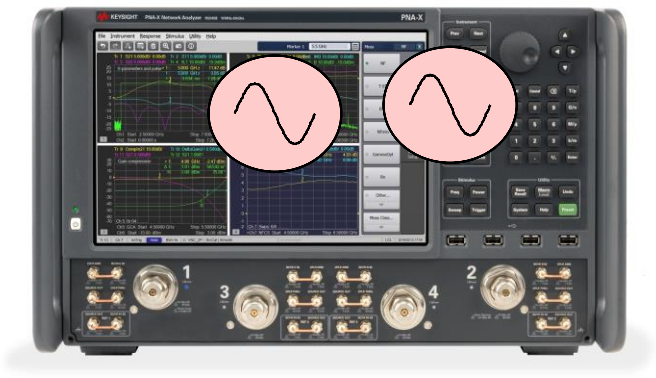
High-performance analog SigGen class phase noise

Optional 3rd RF Source

New DDS Source – best-in-class phase noise

CHALLENGES MET – NO NEED FOR HIGH-PERFORMANCE SIG GEN





New PNA/PNA-X Option UNY

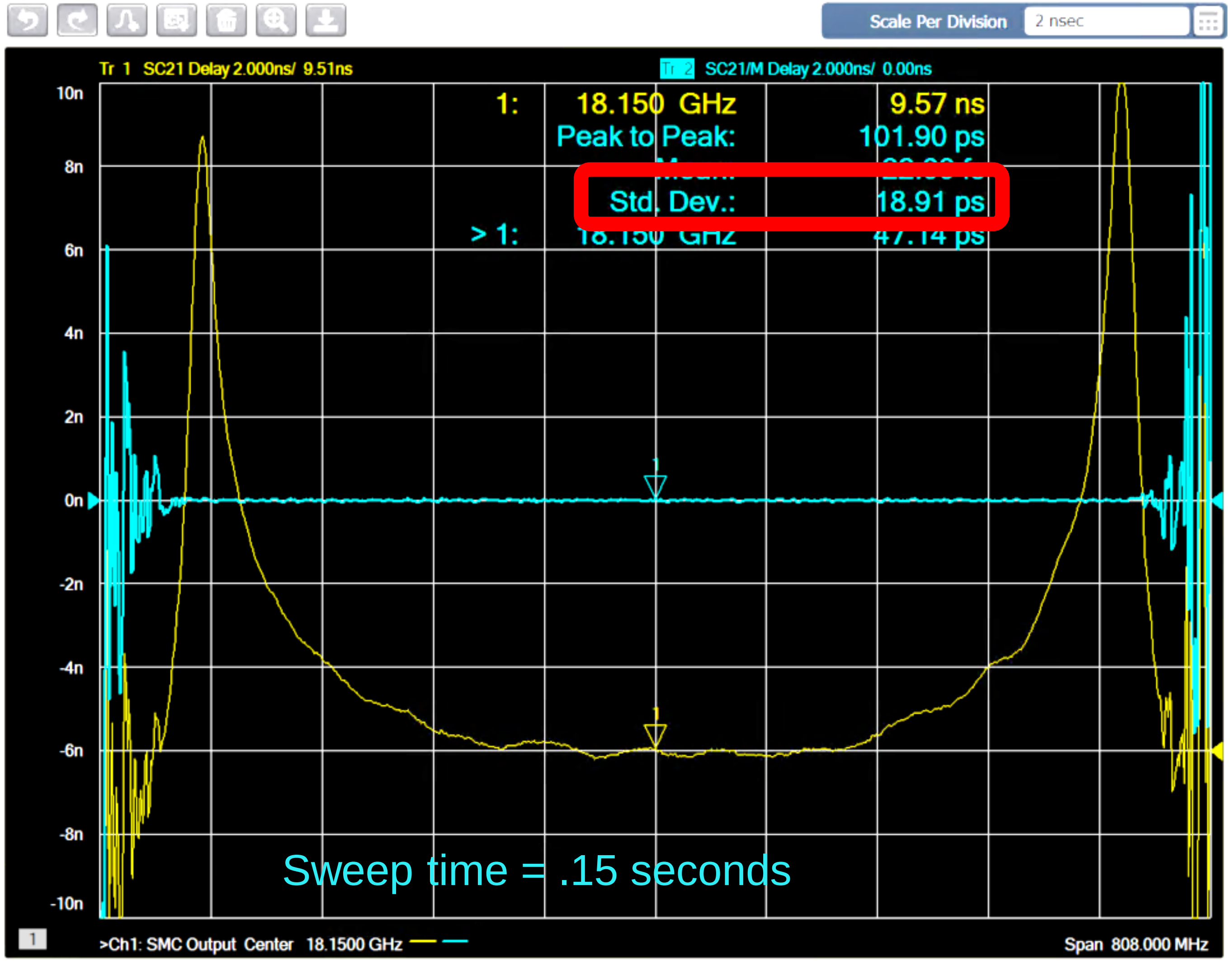
- Eliminates the need of external high-performance analog signal generators for the use of LO or where low-phase noise is needed.

Frequency Converter Characterization

GROUP DELAY – YELLOW (NORMALIZED, BLUE)

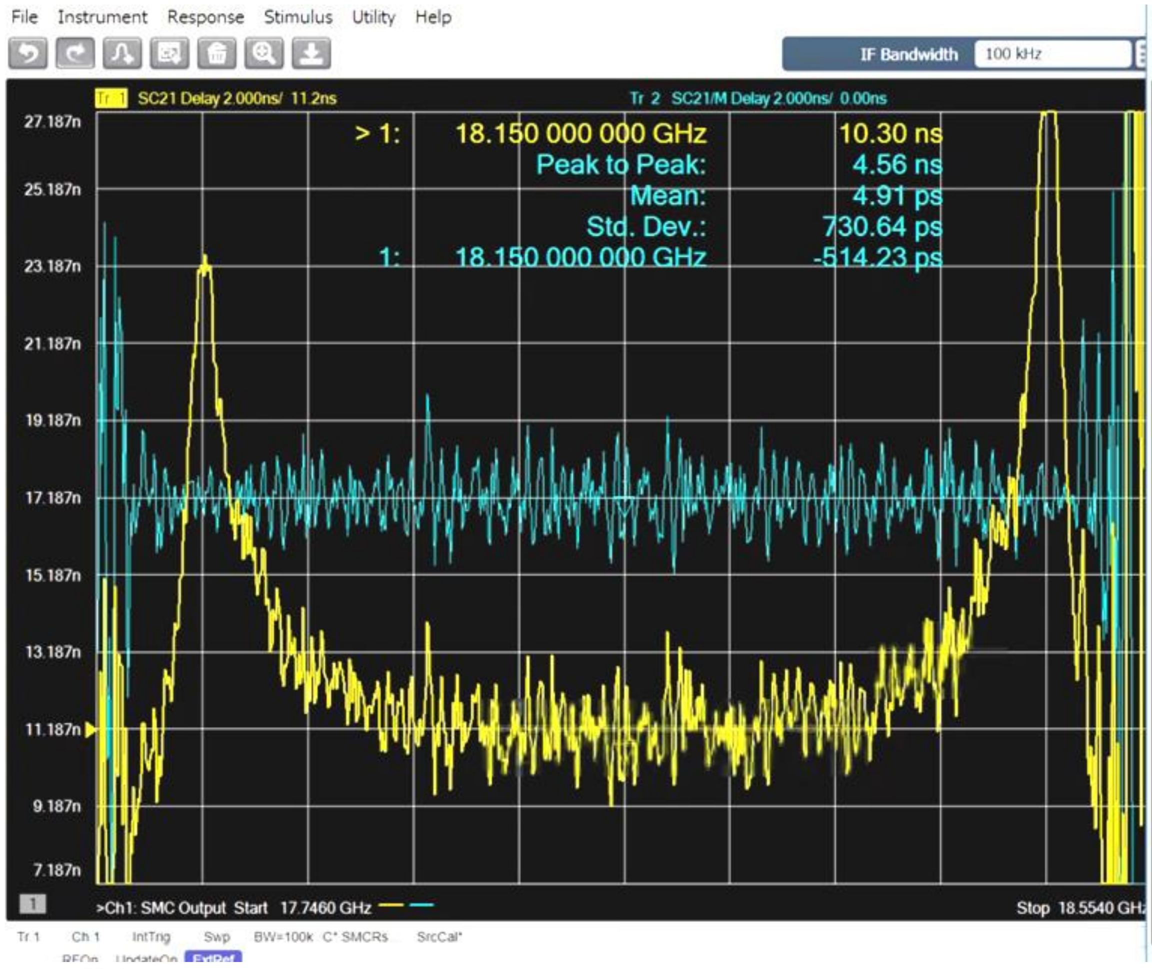
The new, low phase-noise synthesizer is also much faster. Lower noise means we don't need to have any averaging.

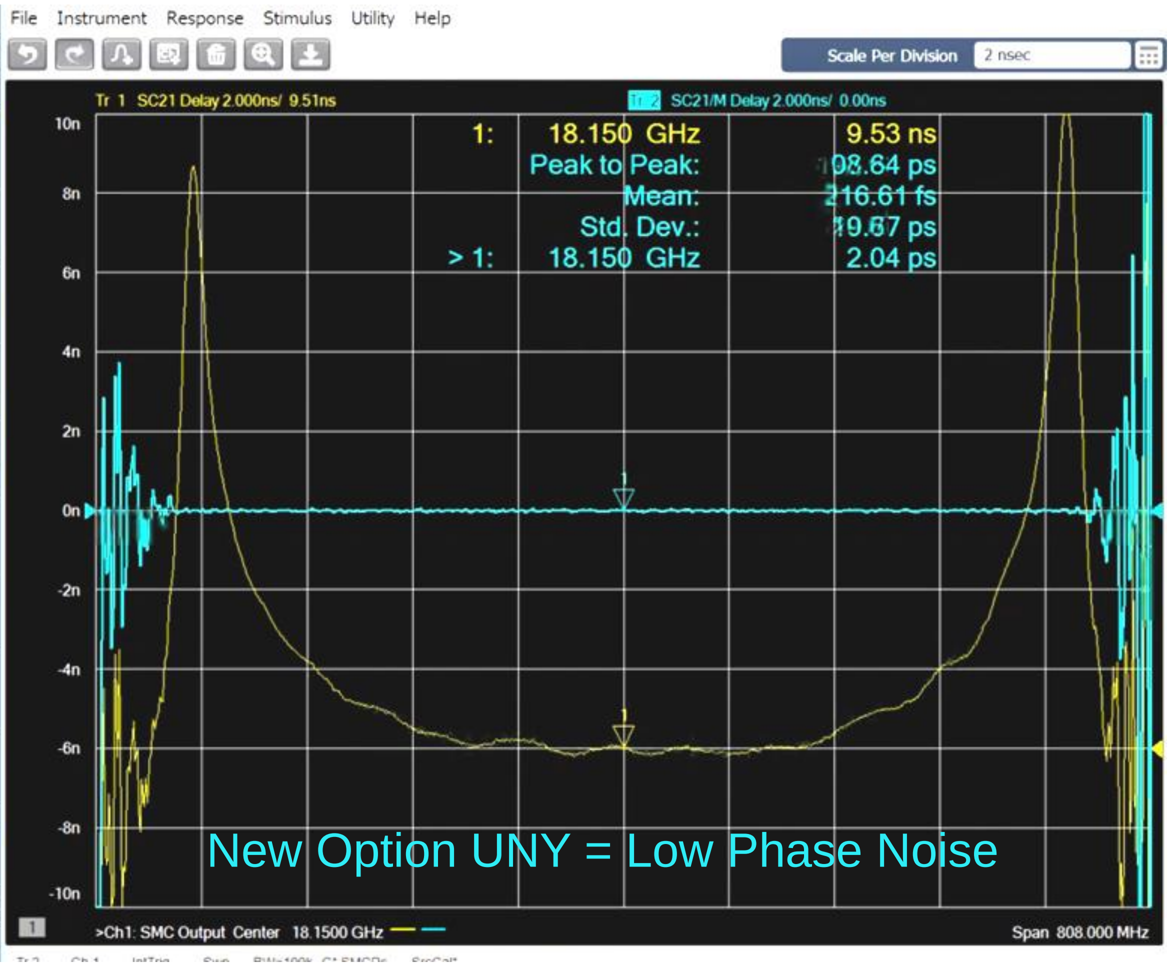
Here we show 10 times lower deviation in the delay trace, at a speed that is 18 time faster! With no averaging at all.



Low Phase Noise Option: 35 TIMES less noise in delay

EXACT SAME SETTINGS (SWEEP IS 72% FASTER)



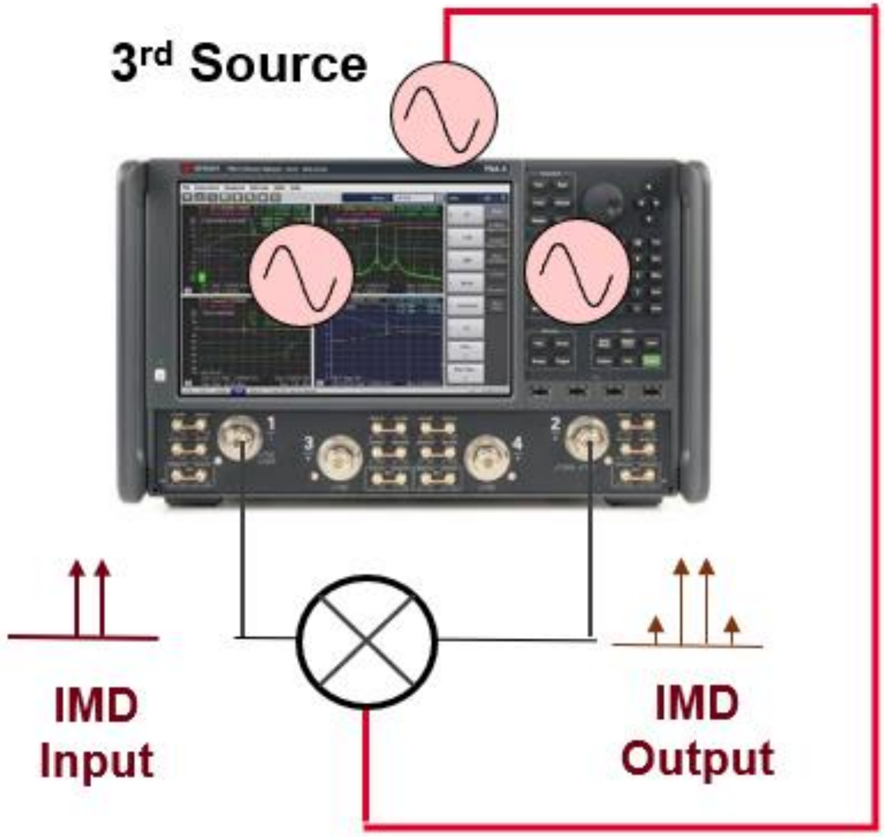


Please run the recording

More Sources

CHALLENGES MET – SYSTEM SIMPLIFICATION

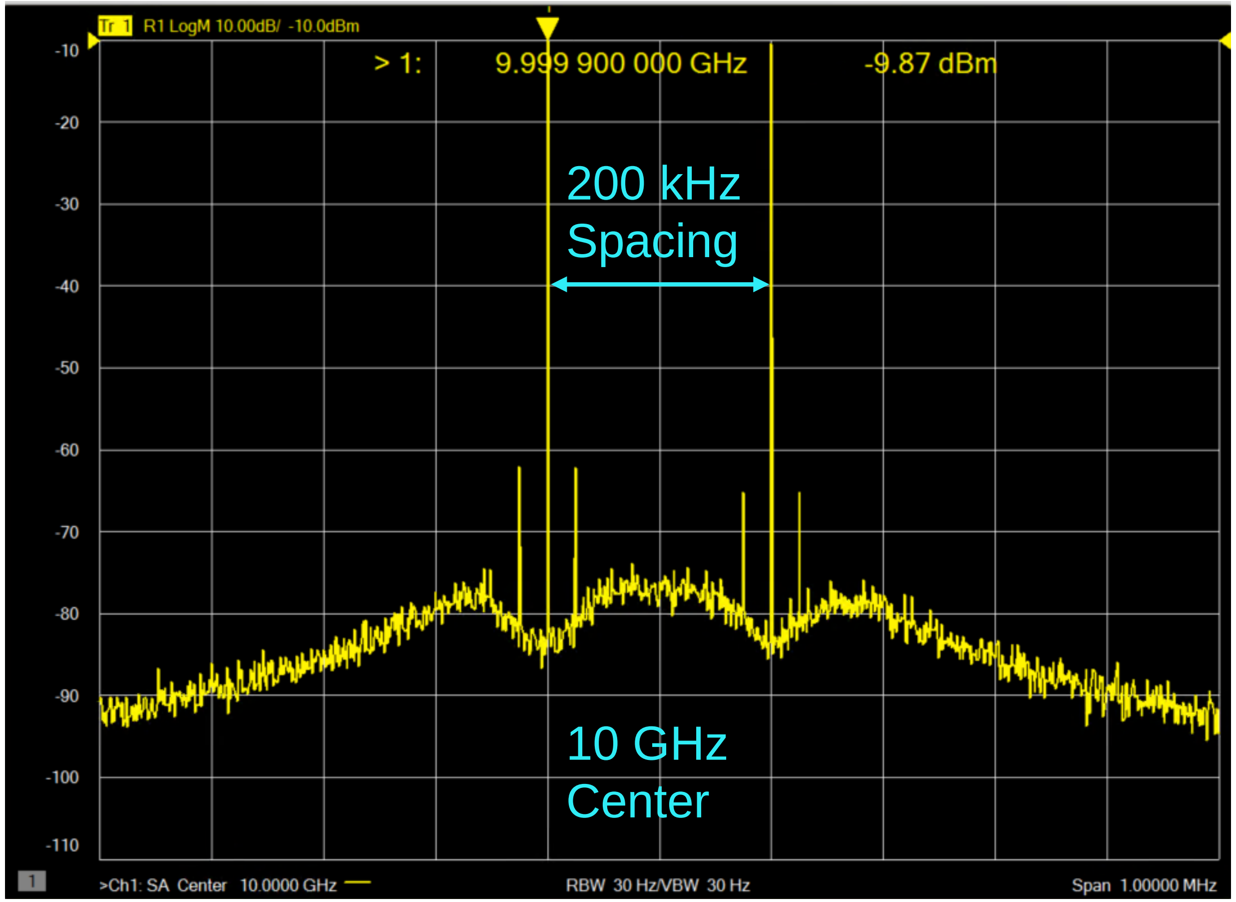
- Complex measurements require multiple instruments, *but the 3rd source* ***eliminates the need for an external signal generator*** for mixer IMD measurements
- Three high-performance analog signal generators
- Can be used as an independent signal generator.

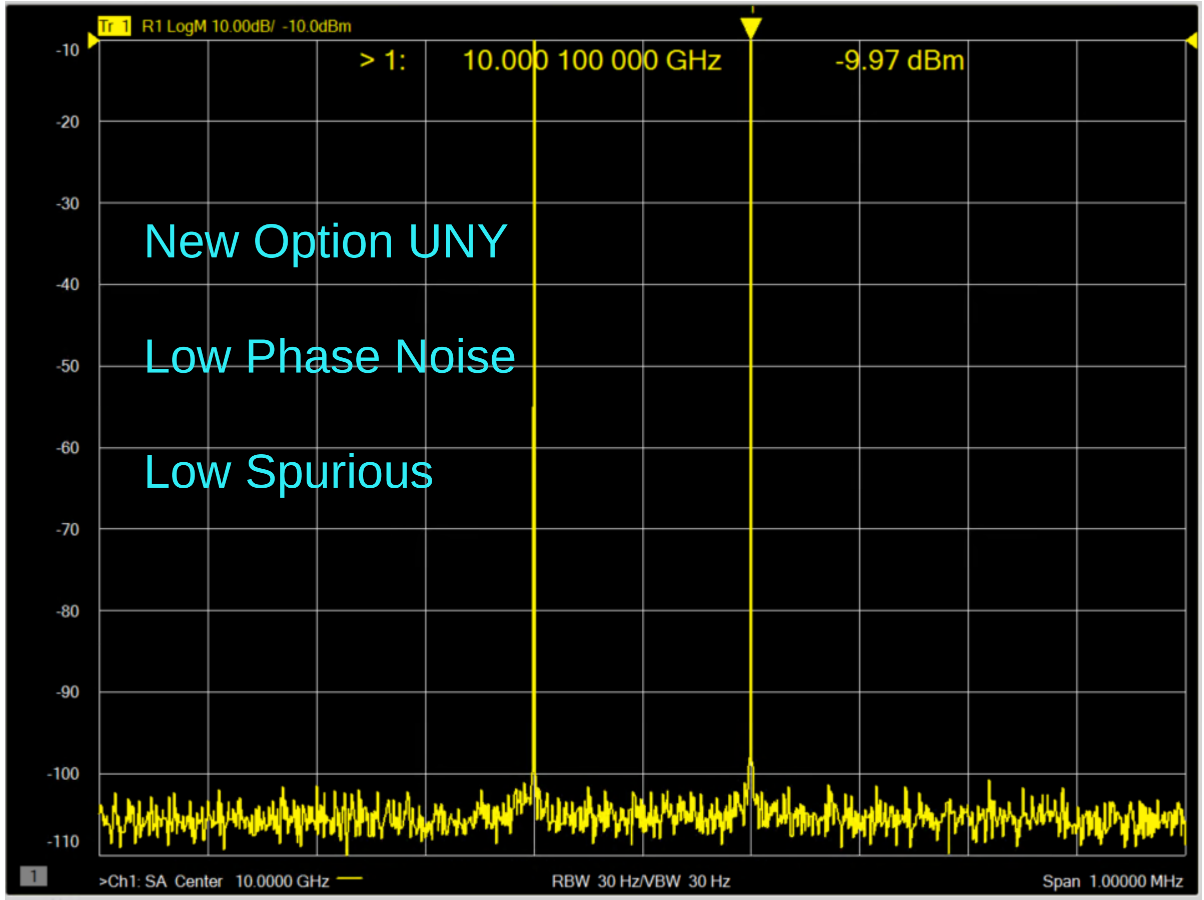


Note: The 3rd source is available only with 4-port PNA-X.

Two Tone Measurements

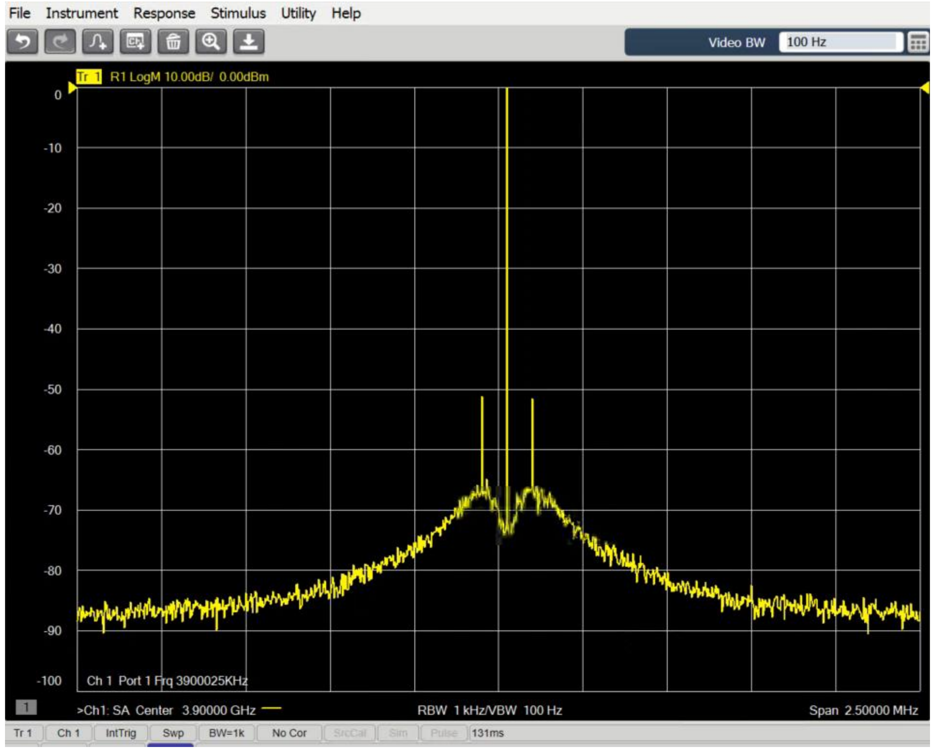
NEW: UNY OPTION. LOW PHASE NOISE, LOW SPUR





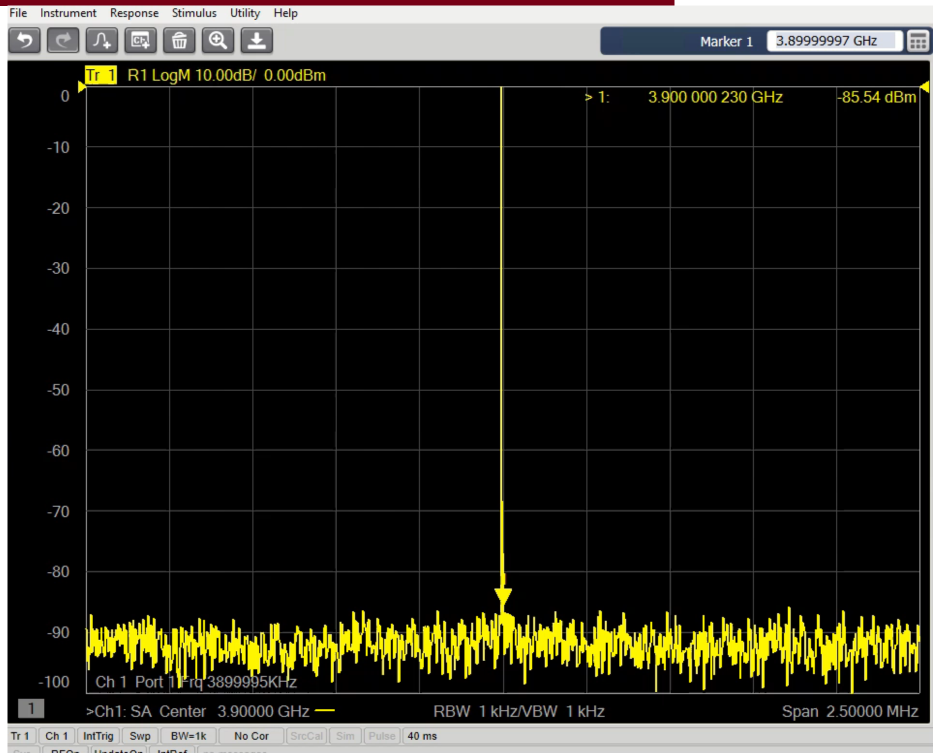
New DDS Souce - Clean source signal

CHALLENGES MET - CURRENT PNA SOURCE VS NEW DDS PNA SOURCE



Please run the recording
Current PNA

1 kHz RBW phase noise is limiting close-in spur dynamic range



Please run the recording
Enhanced PNA with new DDS synthesizers

There are almost no close-in spurs in the DDS source, typically better than -95 dBc. The phase noise does not limit the dynamic range.

KEYSIGHT TECHNOLOGIES

Focus On Frequency Converters

- Noise Power Ratio

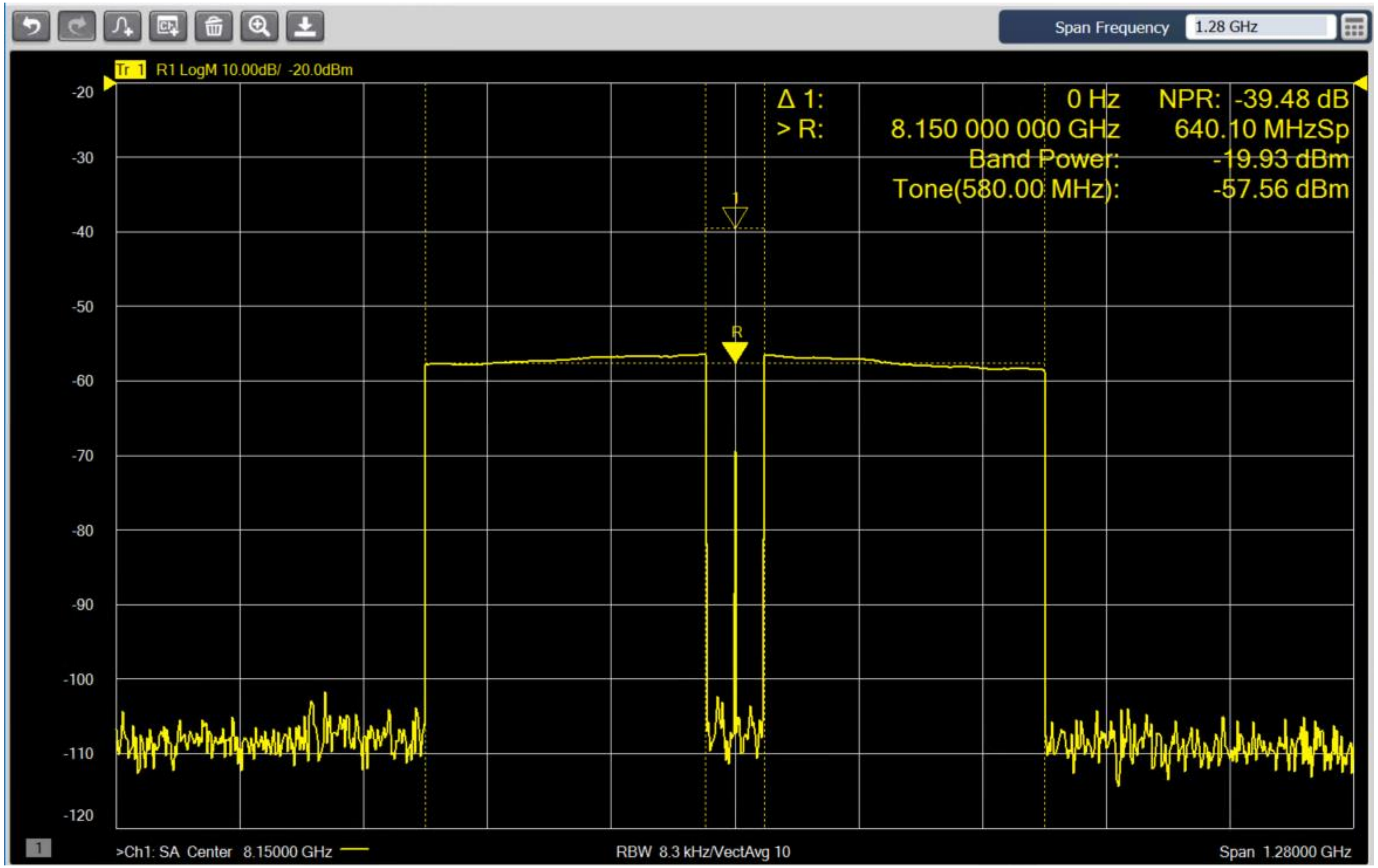
Noise Power Ratio: A noise signal with a notch

UNCORRECTED, 1.5 DB P-P, -39 DBC NPR

Noise Power Ratio creates a signal that matches Additive White Gaussian Noise (AWGN).

In the past, a noise source and notch filter were used, but today it is created using an Arbitrary Waveform Generator. The generator is set to create a multitone signal, with specified notch, using constant amplitude, random phase multitone input.

AWGN signals have a perfectly flat spectrum. Here we see a ripple due to loss and mismatch.

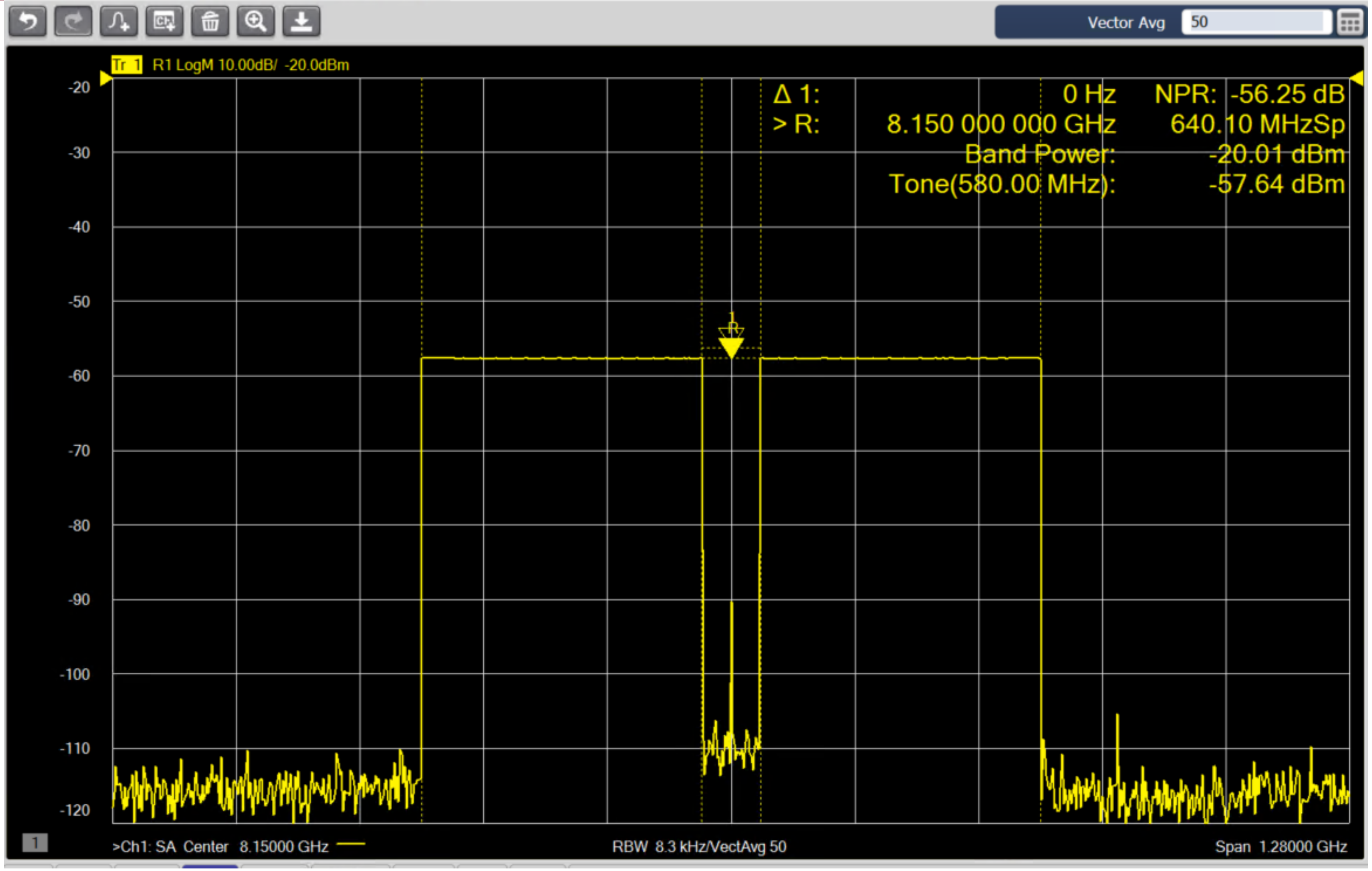


Noise Power Ratio: Linear and Non-Linear Correction

CORRECTED SOURCE: 0.1 P-P FLATNESS, -55 DBC NPC

Flatness and Distortion Correction improve the NPR input signal.

NPR is improved by about 18 dB and out of band ACPR is better by 10 dB. The p-p signal flatness is now less than 0.1 dB.

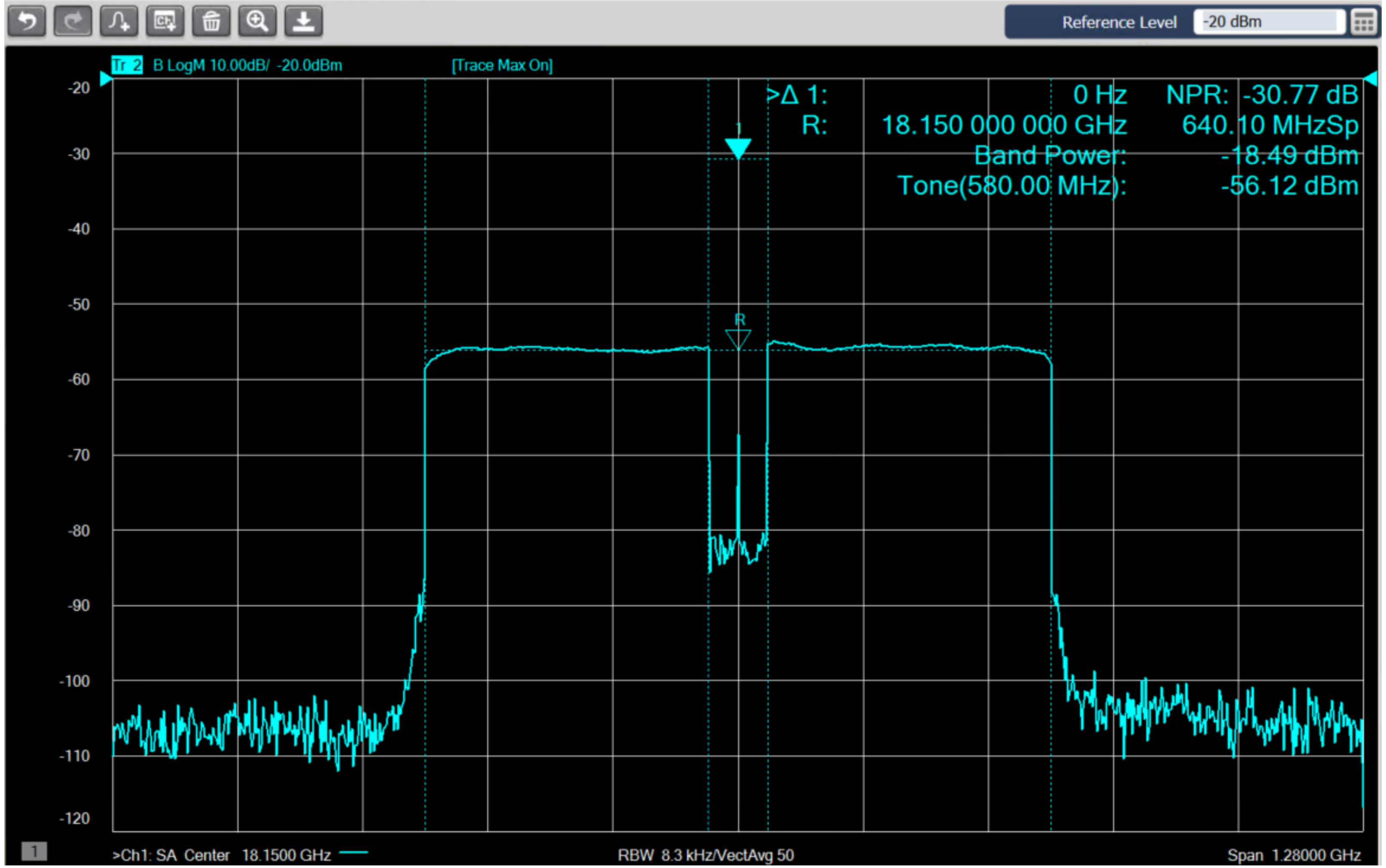


Noise Power Ratio: Output Response

30 DBC NPR

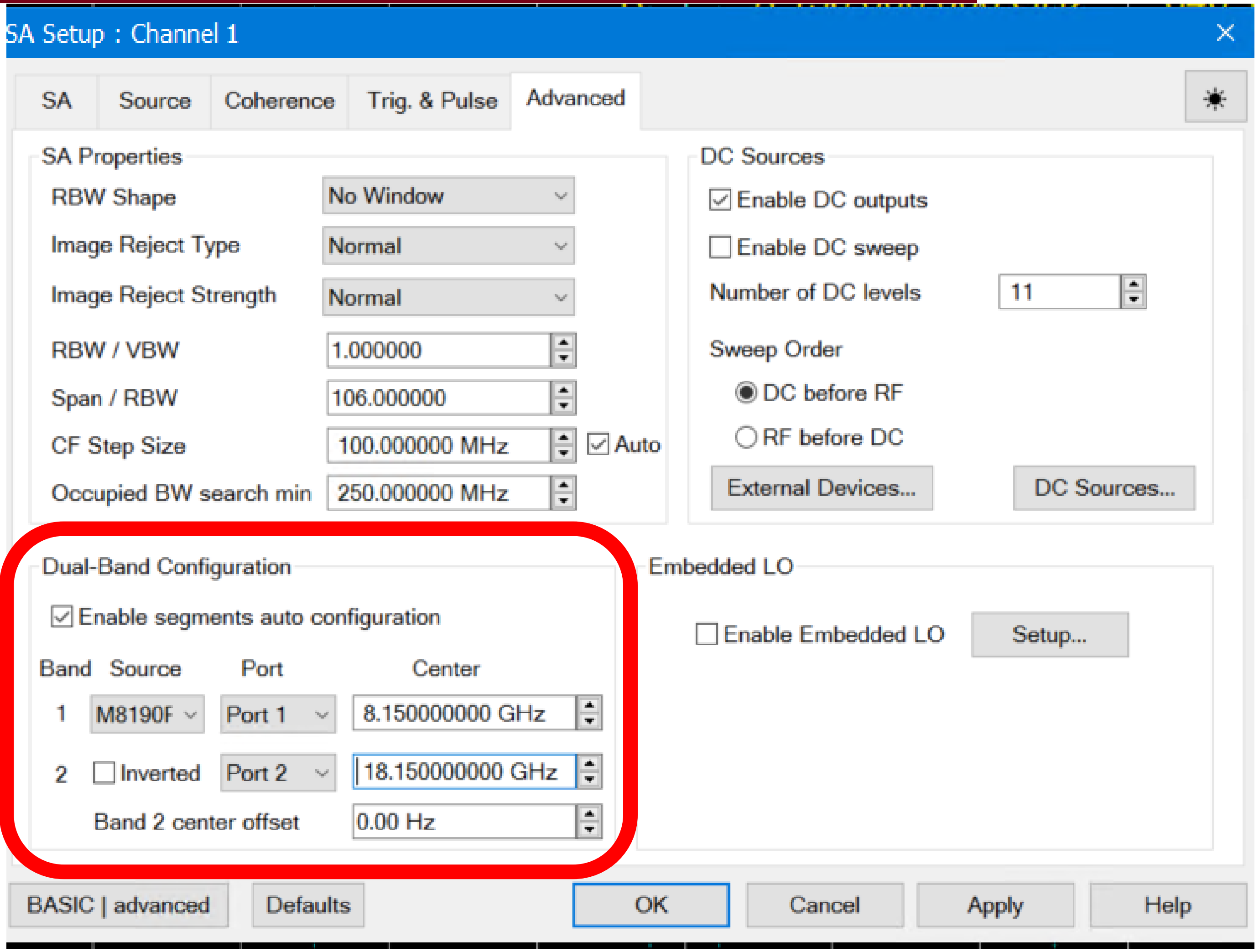
Here is the output response of the frequency converter.

Because it is strongly filtered after the amplifier stage, the ACPR we would expect (near the level of the NPR) does not appear at the output. Thus ACPR cannot be used for a measure of distortion. NPR is clearly seen and we see a 20 dB degradation in distortion for this frequency converter.



SA Segments allow viewing Input and Output

ONLY ON PNA-X



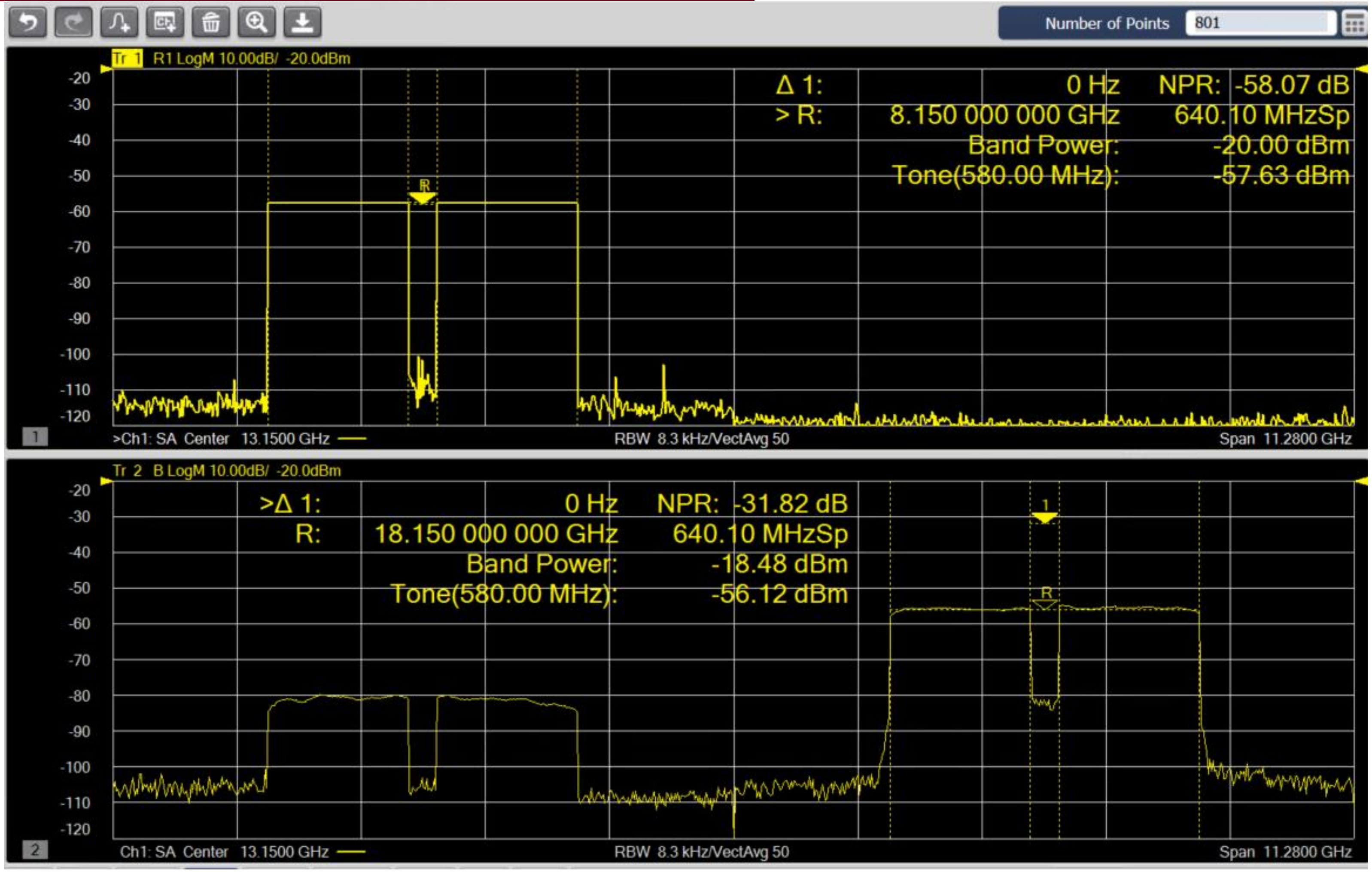
Noise Power Ratio: Dual Output Response

32 DBC NPR

Here we see a dual segment response. The upper trace shows the input signal.

The lower traces shows the output signal. The segments are each 1.3 GHz wide, and 10 GHz apart, but we see the segments concatenated on the display for easier viewing.

The RF feedthrough of the mixer is seen in the lower trace, left side, and the main output is in the lower trace, right side.

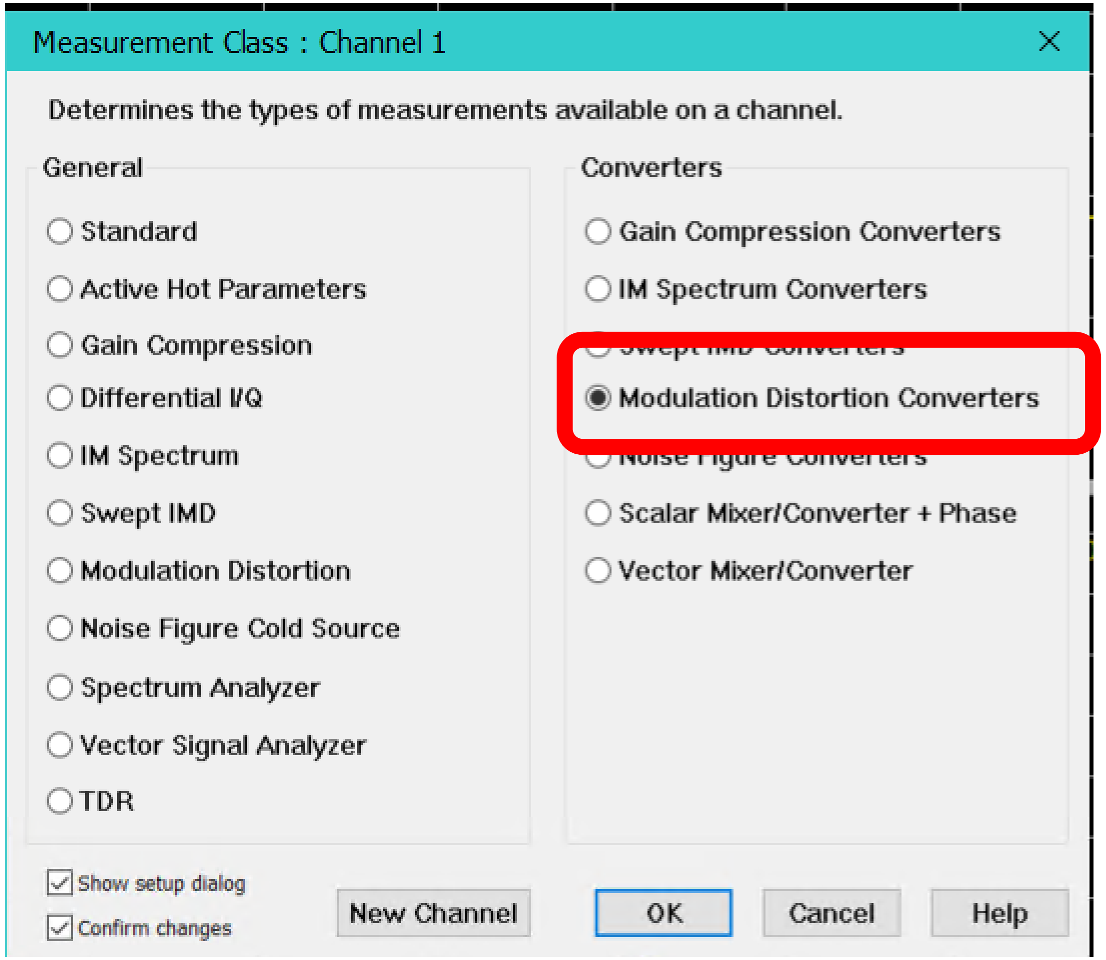


Focus On Frequency Converters

- Modulated Measurements, Gain/Phase/Delay and EVM

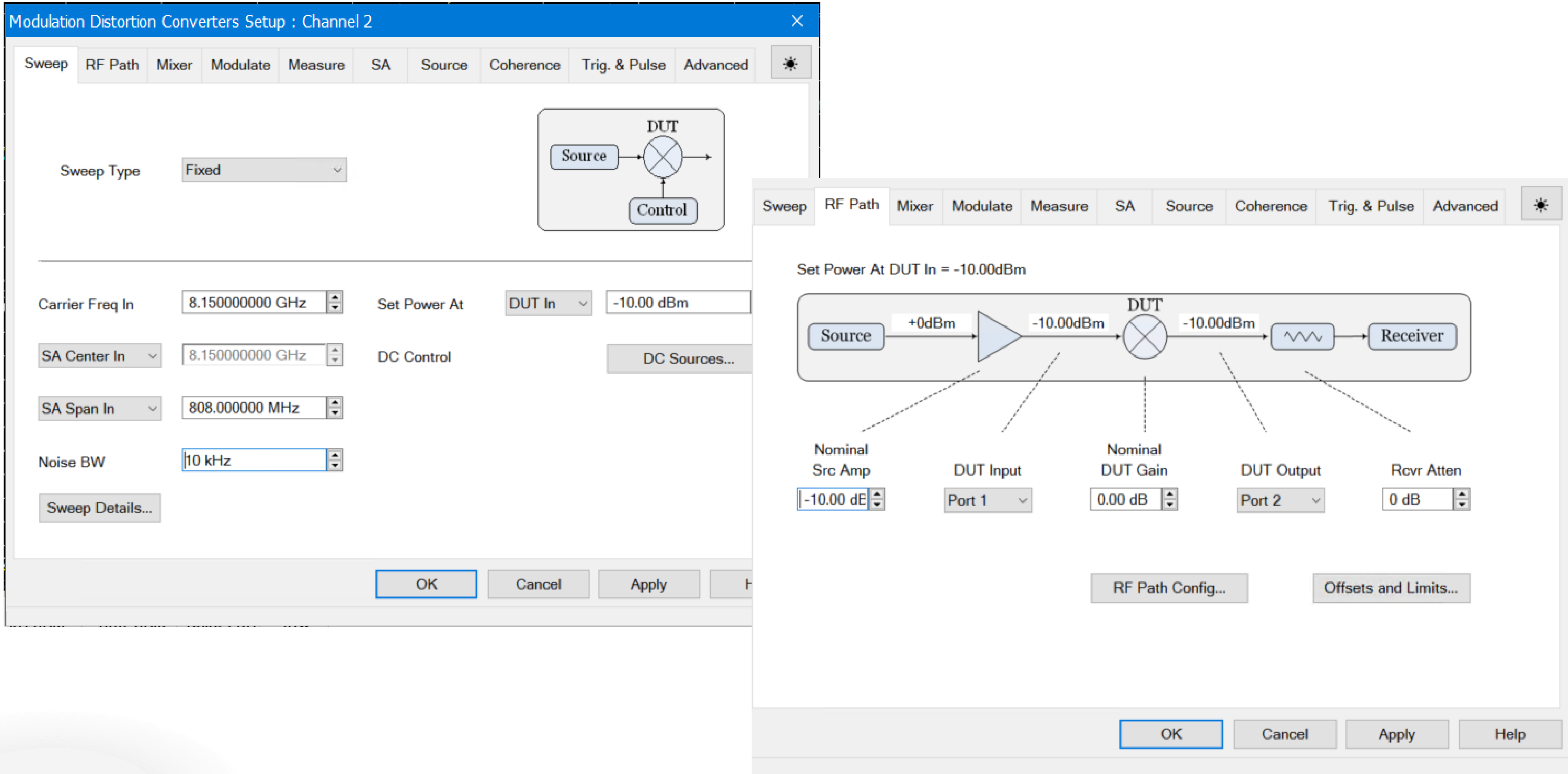
Frequency Converter Characterization

MODULATION/DISTORTION ALLOWS MODULATED INPUT ON CONVERTERS



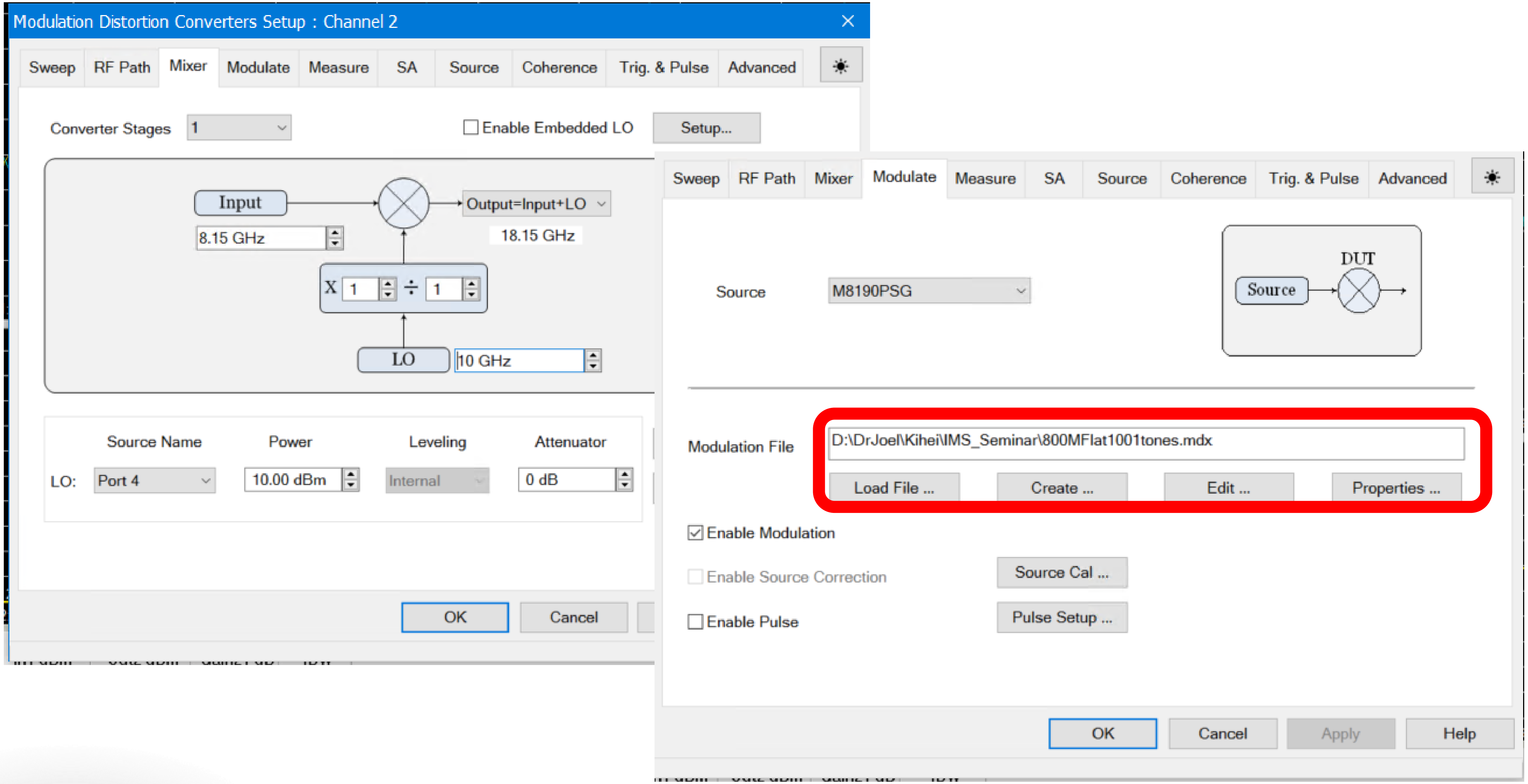
Frequency Converter using ModX

SETUP THE DRIVE SIGNAL AND DEFINE THE SIGNAL PATH



Frequency Converter using ModX

YOU CAN SELECT A MODULATION FILE, OR CREATE A NEW ONE



Frequency Converter using ModX

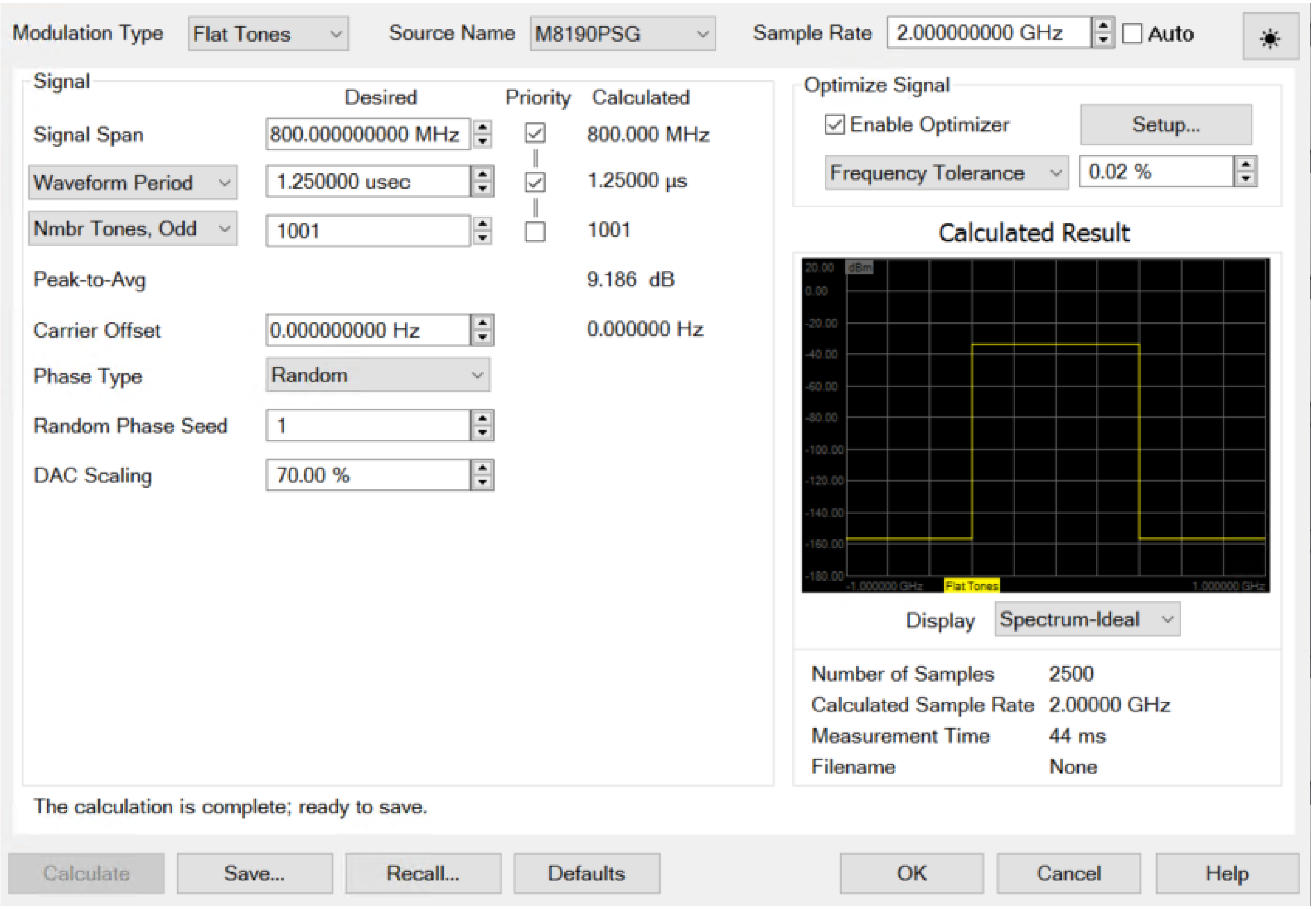
HERE WE CREATE AN 800 MHZ ADDITIVE-WHITE-GAUSIAN NOISE SIGNAL

An Additive White Gaussian Noise Signal (AWGN) has a Uniform Amplitude Spectrum with Random Phase.

Setting the waveform period makes this have an underlying multitone characteristic

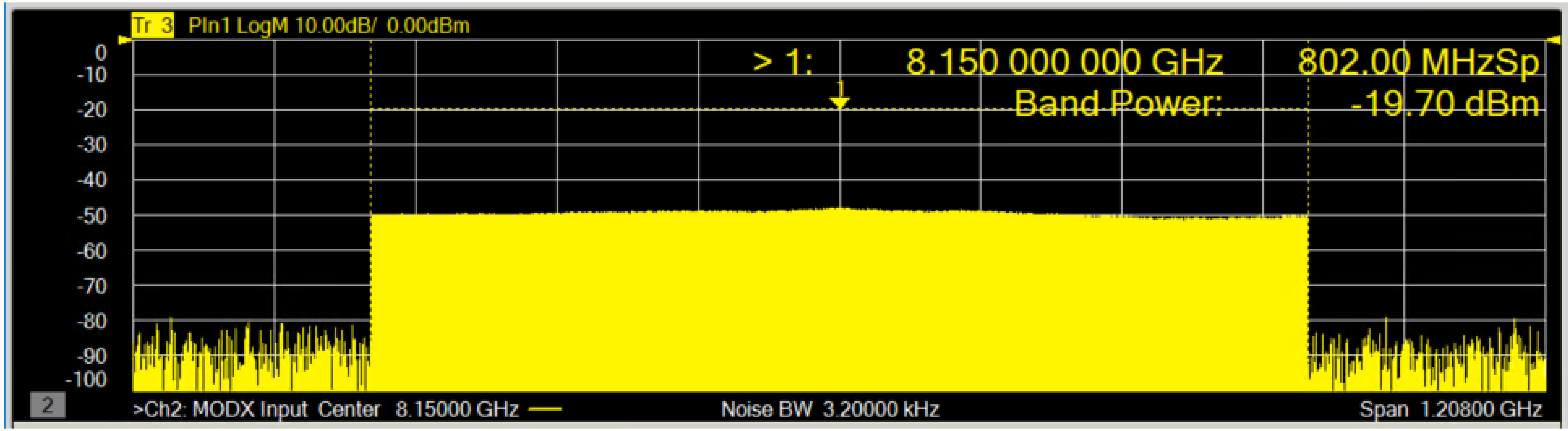
Setting the phase to Random makes this a AWGN signal.

Changing the Random Phase Seed can change the peak-to –average ratio.



Frequency Converter using ModX

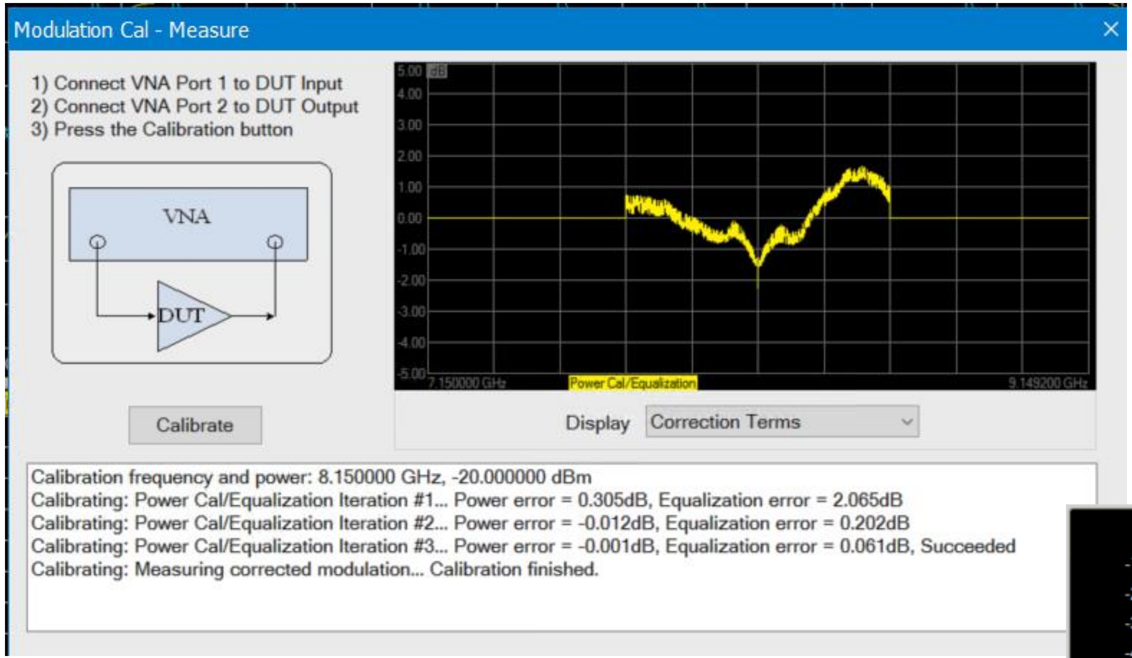
HERE WE CREATE AN 800 MHZ ADDITIVE-WHITE-GAUSSIAN NOISE SIGNAL

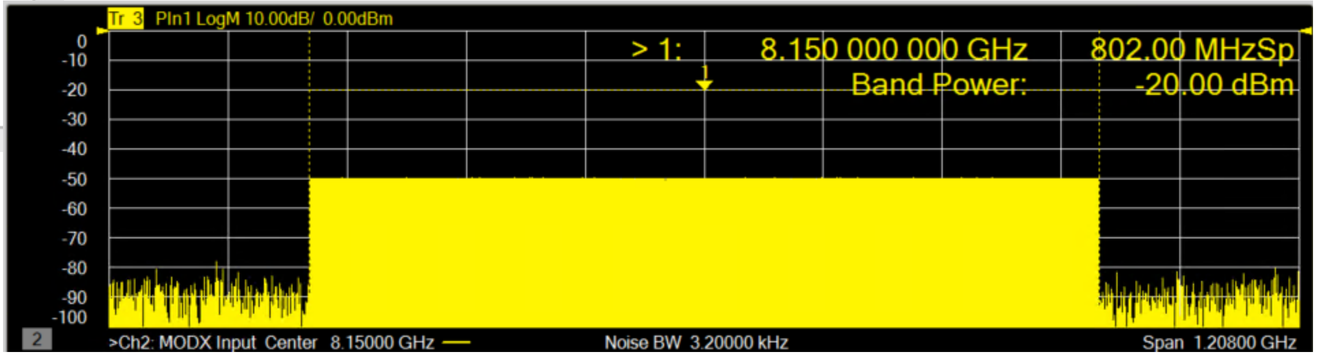


Here we see the drive signal consisting of 1001 tones. It should have flat response, but due to cables, connectors and mismatch, the power flatness has about 2 dB p-p error. We have a special modulation correction method to perfect the signal.

Frequency Converter using ModX

SOURCE MODULATION CORRECTION MAKES A PERFECT SIGNAL



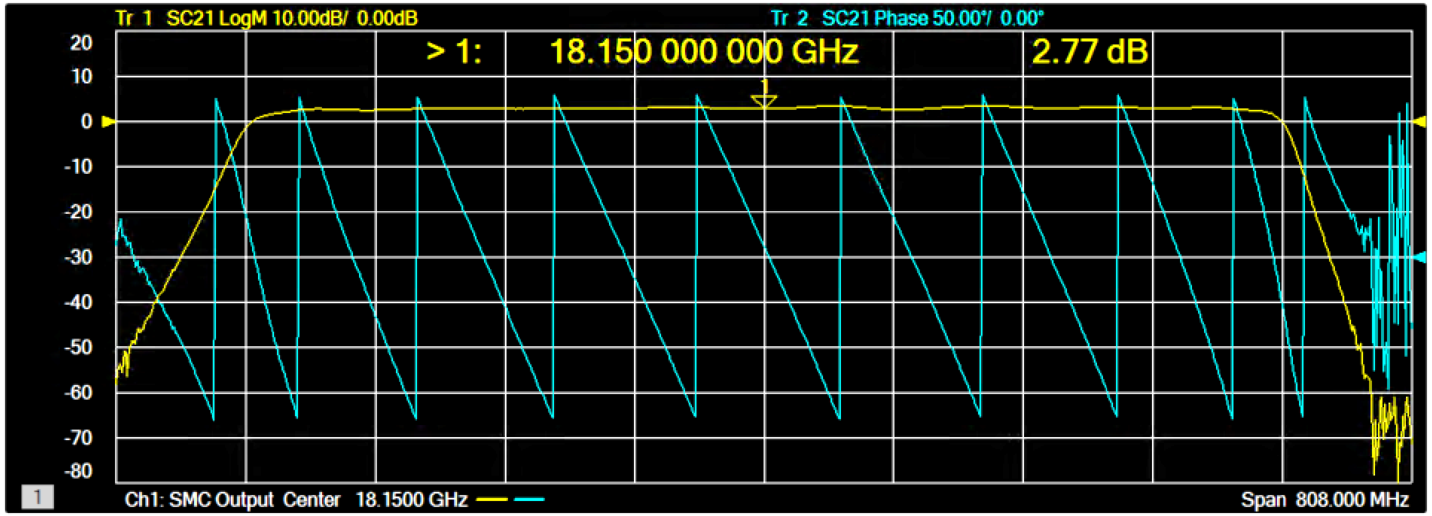


After correction, the flatness error is less than 0.1 dB p-p; the power level is exactly correct

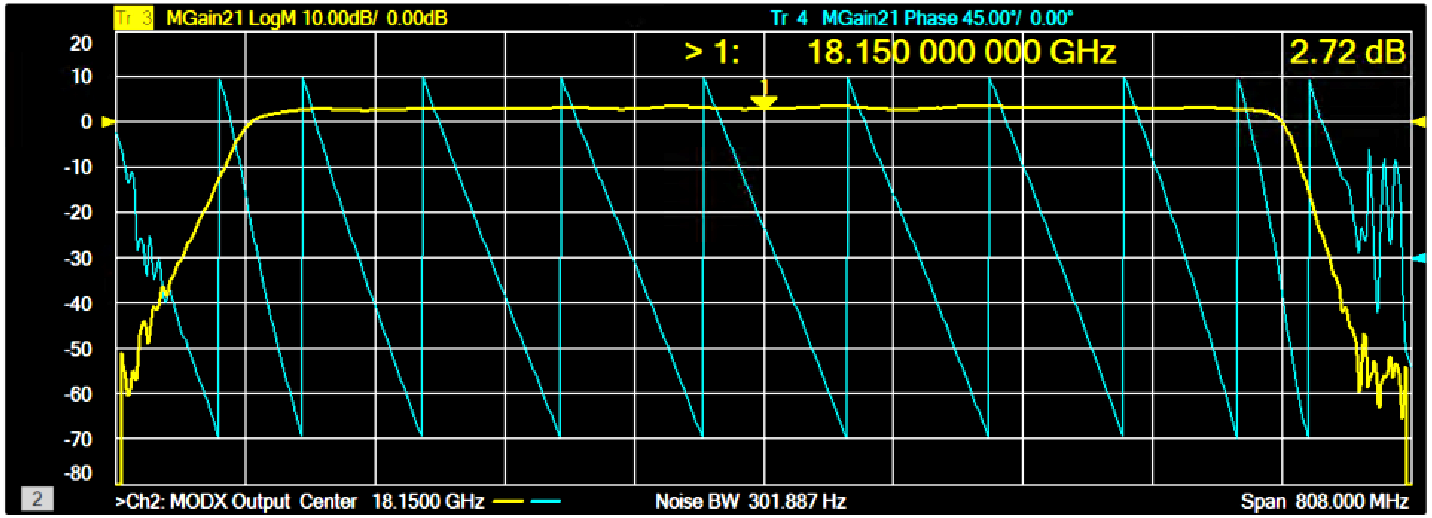
Frequency Converter using ModX

THE MODULATION WAVEFORM IS MEASURED AT INPUT AND OUTPUT

This upper plot shows traditional swept CW frequency gain and phase.



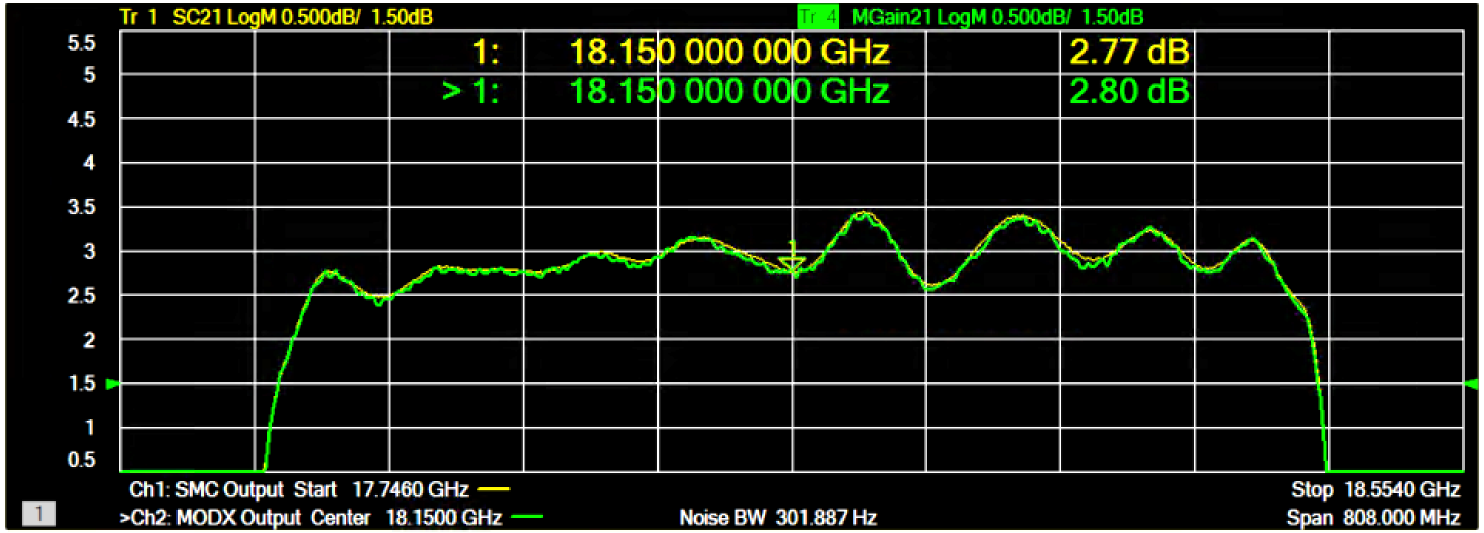
This lower plot shows the gain and phase under low-power modulated drive. The results are nearly identical.



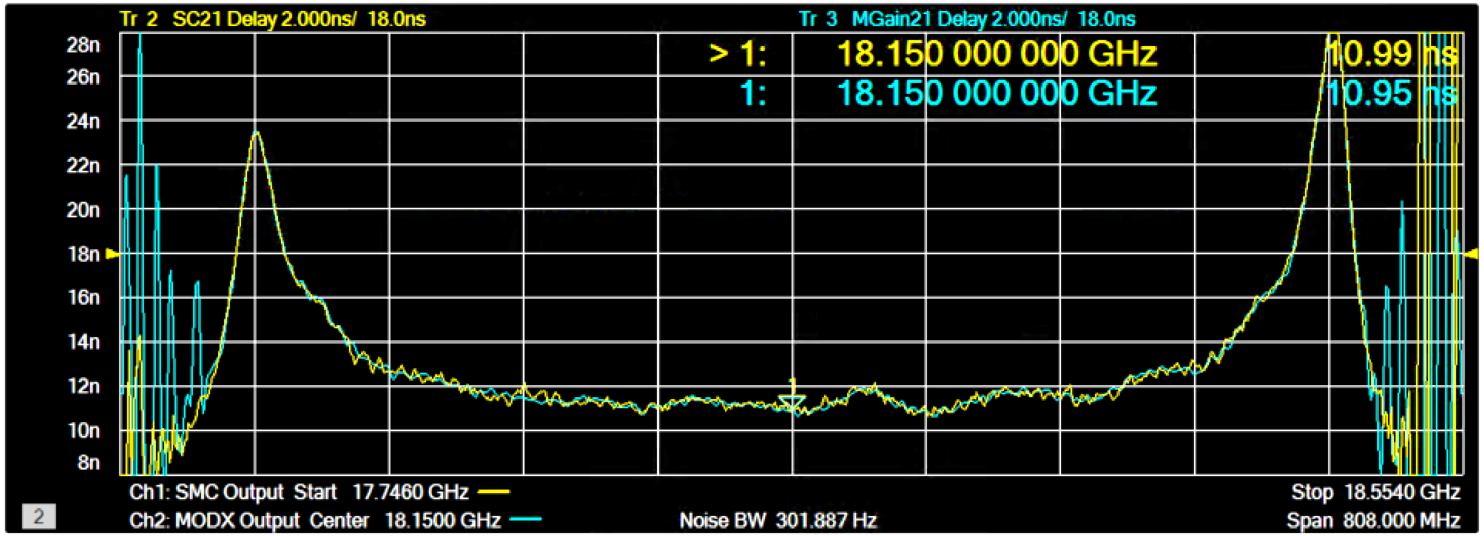
Frequency Converter using ModX

GAIN, PHASE, AND GROUP DELAY CAN BE MEASURED USING MODULATION

This upper plot compares gain at 0.5 dB per division. Almost perfect agreement between Swept CW and Wideband modulated signal



This lower plot shows the group delay response. For the first time a VNA can show group delay of a converter, driven with a wideband modulated signal



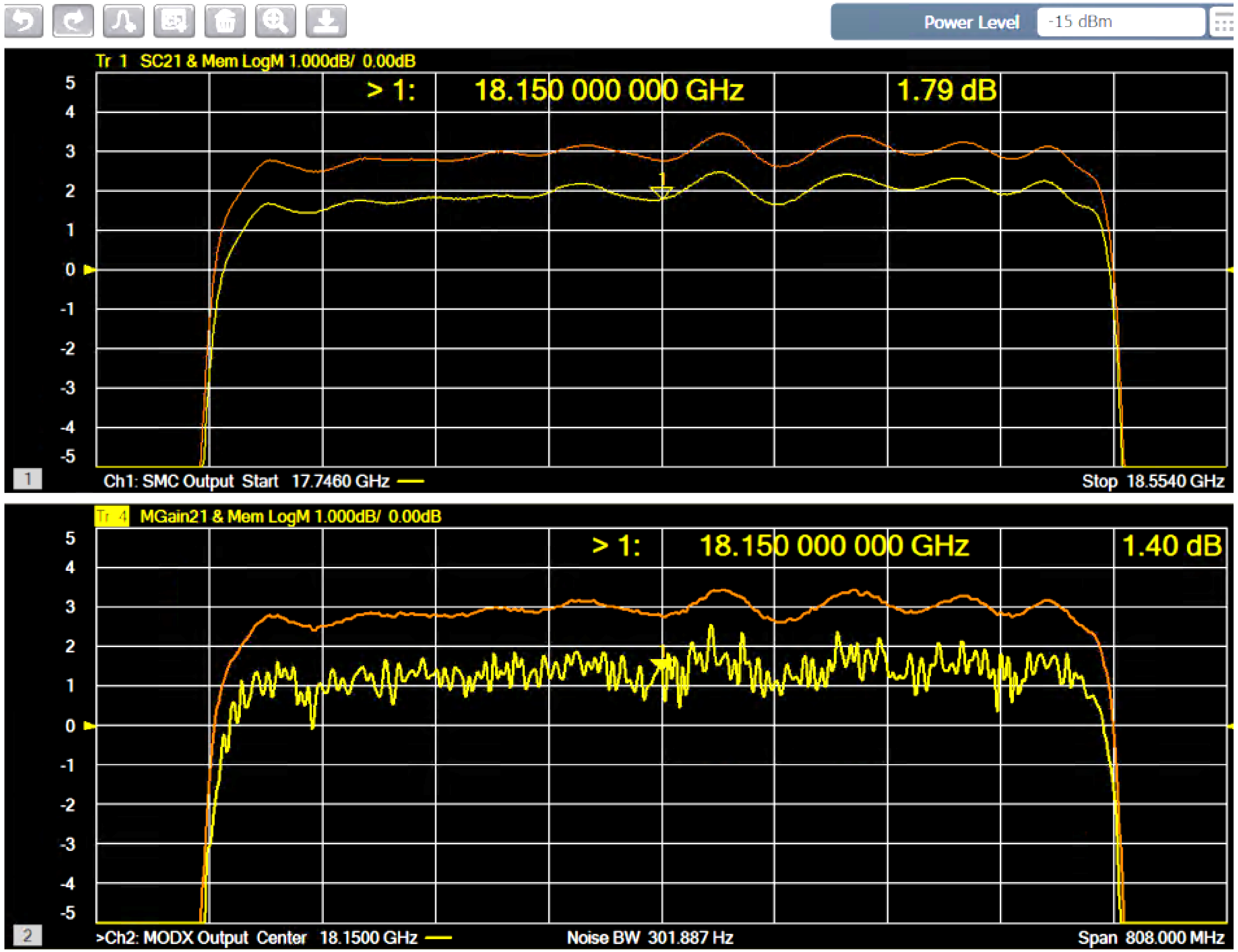
Frequency Converter using ModX

GAIN COMPRESSION SHOWS A BIG DIFFERENCE FOR MODULATED DRIVE

This upper plot shows -15 dBm drive in Swept CW traces, with 1 dB compression.

This upper plot shows -15 dBm drive for Modulated Signal. The compression is greater, and there is big variation on the signal.

The modulation signal has 9 dB peak-to-avg signal, so 6 dB higher peaks than CW, meaning more compression

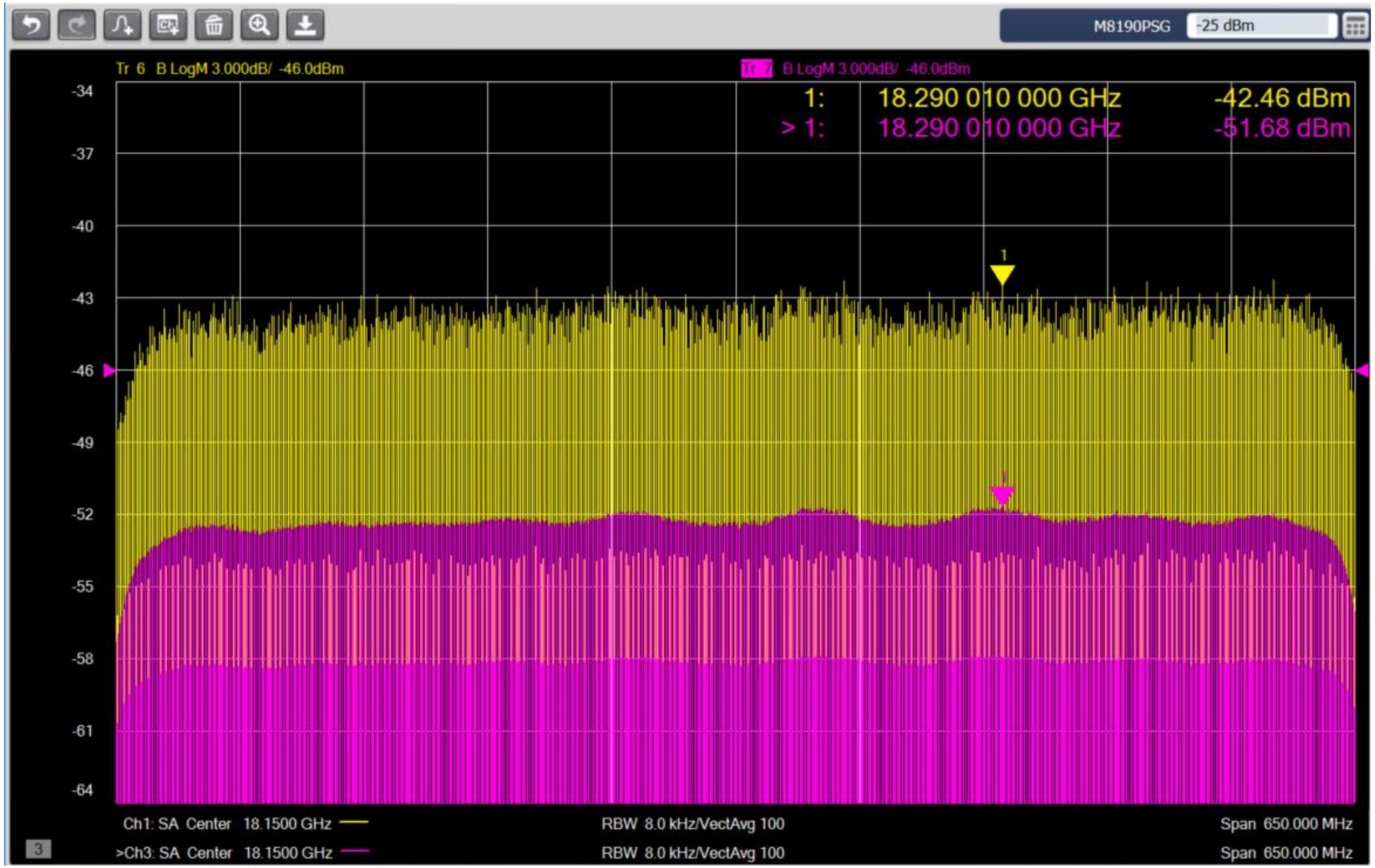


Frequency Converter measured in SA Mode

LOW POWER (PURPLE), HIGH POWER (YELLOW)

This upper plot shows -15 dBm Modulated Signal Drive. To top of the yellow traces shows a lot of deviation due to intermodulation of the underlying multitone signal

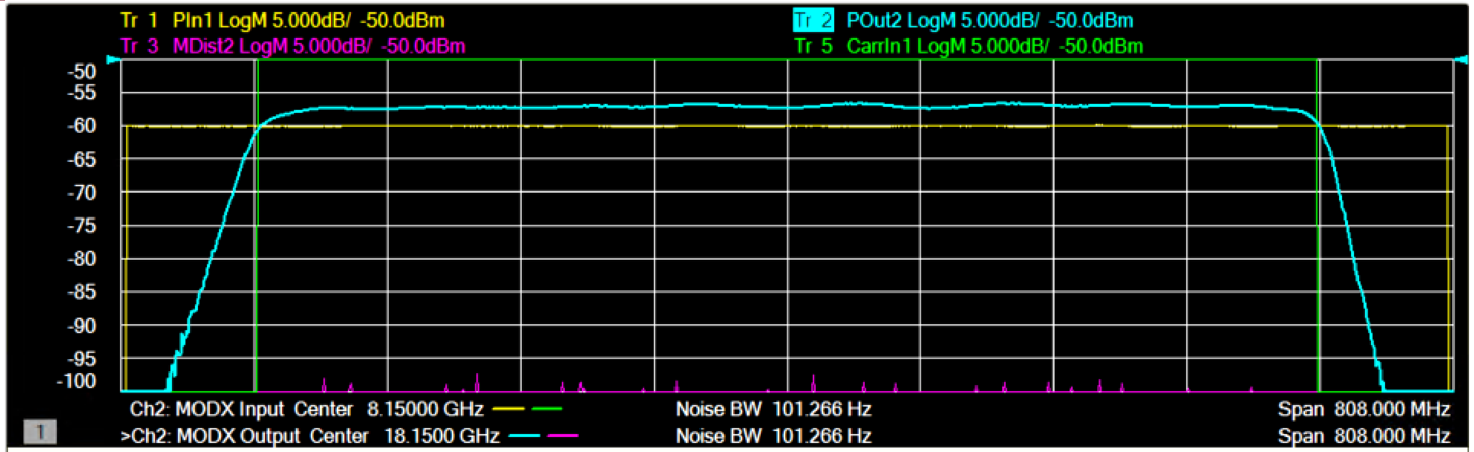
This lower plot shows the output with -25 dBm signal drive. The tops of the multitone spectrum are smooth and variation is due to the filter in the converter.



Frequency Converter using ModX

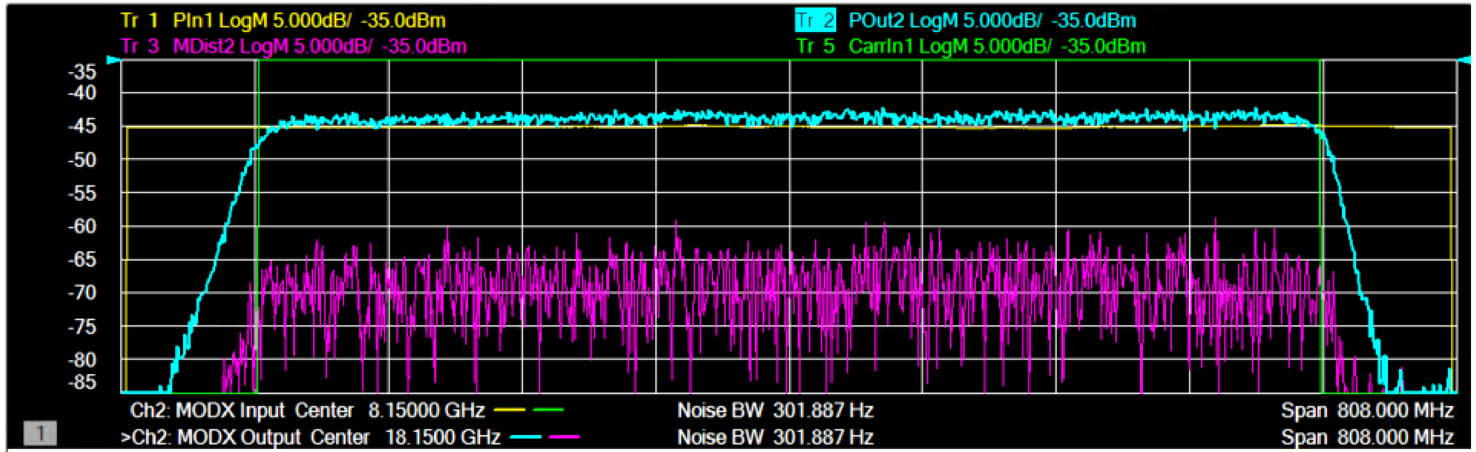
MODX CAN SHOW DISTORTION DIRECTLY, AS WELL AS COMPUTE EVM

This upper plot shows -30 dBm Modulated Signal Drive. The purple trace (almost off the screen) shows minimal distortion. The EVM of this converter is only 0.4% across the 640 MHz Signal BW.



Type	Carrier In1 dBm	Carrier Out2 dBm	Carrier Gain21 dB	Carrier IBW	EVM DistEq21 dBc	EVM DistEq21 %
EVM	-30.96 dBm	-28.15 dBm	2.81 dB	642.4 MHz	-47.54 dBc	0.42%

This lower plot shows -15 dBm signal drive. The distortion is clearly visible in the purple trace. The blue trace is output power, and the “fuzziness” on top is due to distortion. Here the EVM is computed at 6.87%



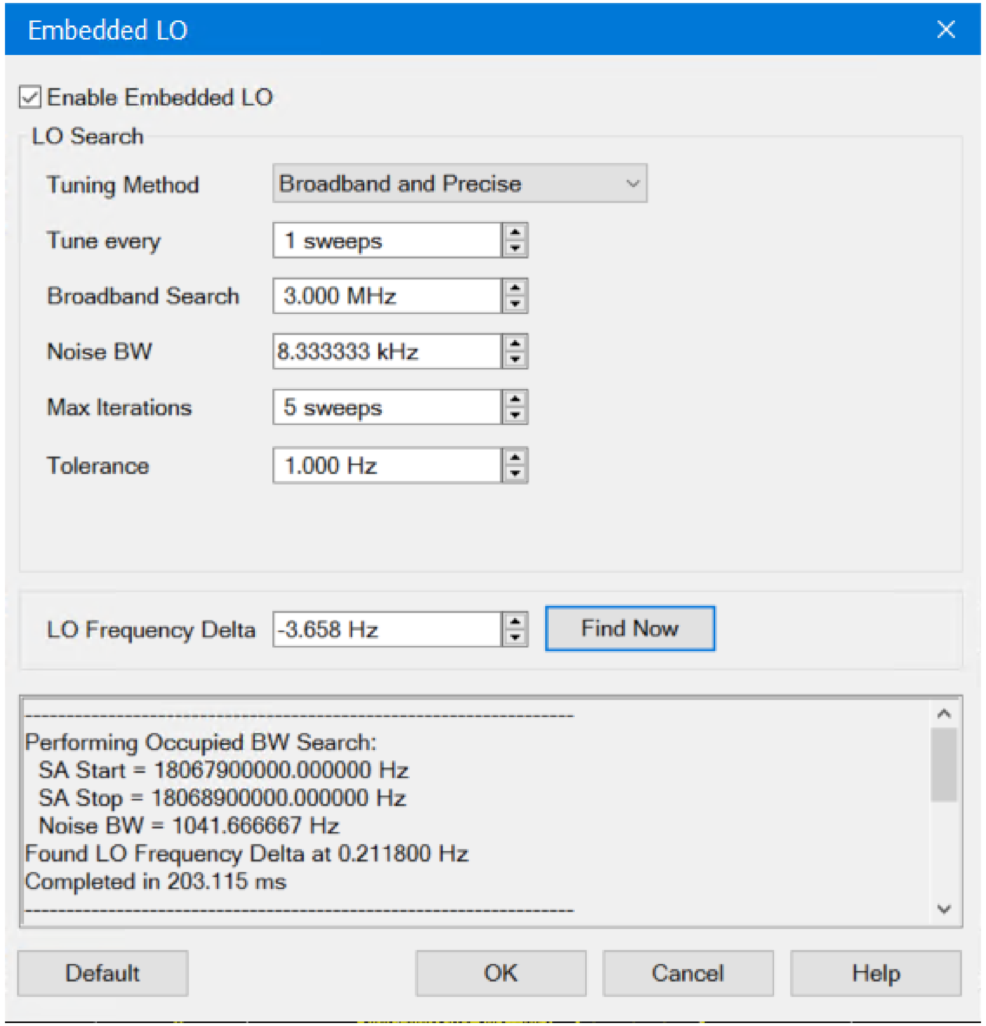
Type	Carrier In1 dBm	Carrier Out2 dBm	Carrier Gain21 dB	Carrier IBW	EVM DistEq21 dBc	EVM DistEq21 %
EVM	-16.01 dBm	-14.75 dBm	1.26 dB	642.4 MHz	-23.26 dBc	6.87%

Embedded LO

SATCOM CONVERTERS WITH BUILT-IN OSCILLATORS

All the test methods presented are supported by option 084:

Automatic detection of frequency for a converter with an embedded LO



Summary

PNA-X TEST METHODS FOR FREQUENCY CONVERTERS

- PNA-X is recognized as the premier instrument for SatCom and 5G converter test
- New DDS synthesizer hardware greatly improves the system performance in many areas
  - Faster Measurements
  - Much lower residual noise
  - No detectible close-in spurs
  - Narrow-spaced IMD
- New Software Application capabilities apply to wideband modulated signal test
  - Fully corrected NPR Measurements
  - Gain/Phase/Group Delay, with precise results, when driven with wideband modulated signals
  - Distortion of the Frequency Converter under test can be determined
  - Precision EVM measurements on modulated signals through converters are now available
- All Test Methods support converters with Embedded LO

KEYSIGHT
WORLD 2020

P.S. All the Details Are Available in Joel's book

NEW, SECOND EDITION, AVAILABLE JULY 2020