Optimizing EVM Measurement

Optimizing EVM

- This presentation is targeted for:
  - Engineers making (challenging) EVM measurement for various applications
  - Mainly using vector signal generator (VSG) and vector signal analyzer (VSA)

- You should walk away with:
  - Mechanism of the EVM bathtub curve
  - Internal architecture of the VSG and VSA
  - Best practices to optimize test equipment to make EVM measurement
  - Different options to characterize EVM

Agenda

1 EVM and Bathtub Curve Fundamentals

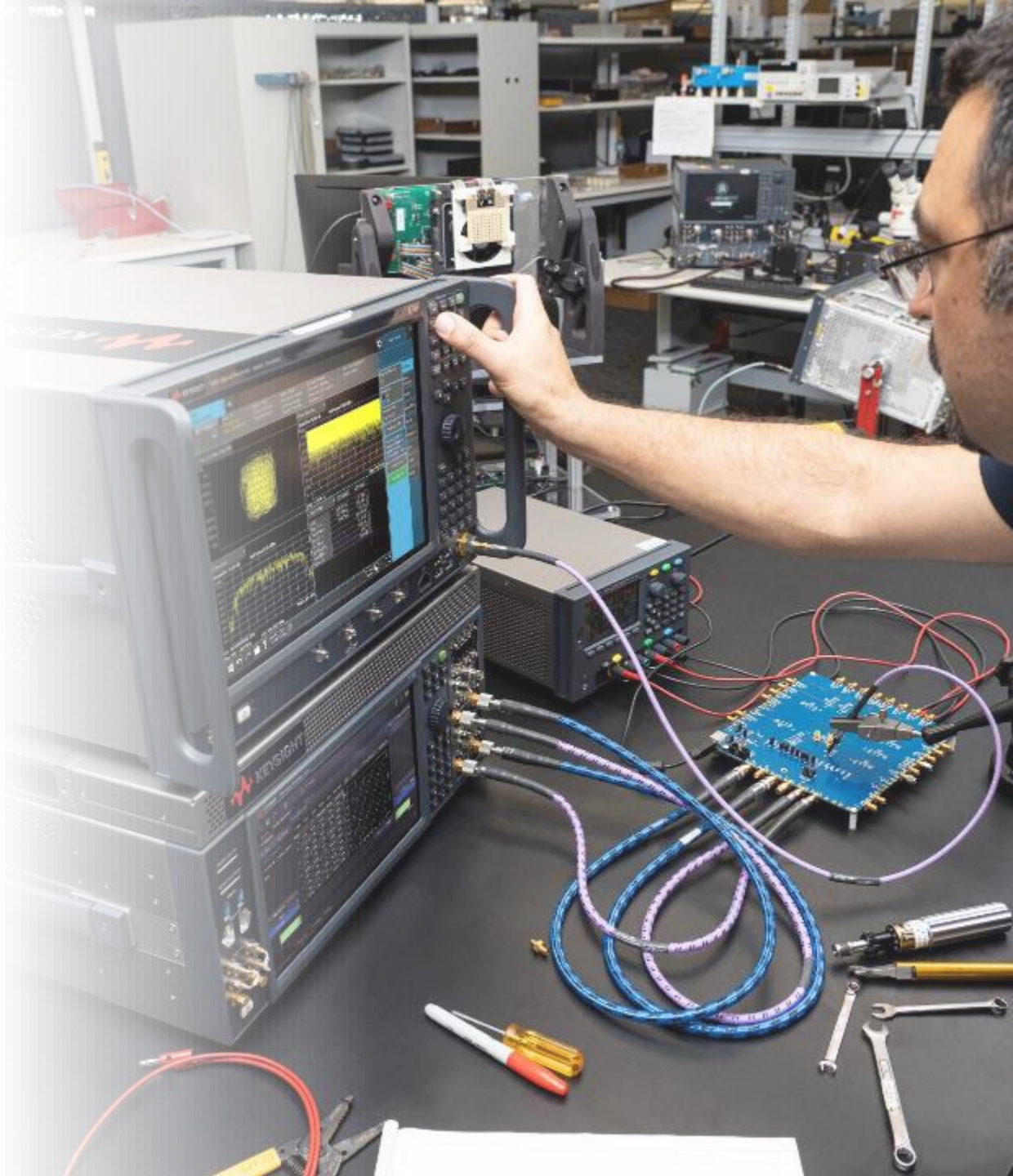
2 Optimizing Receiver

3 Optimizing Source

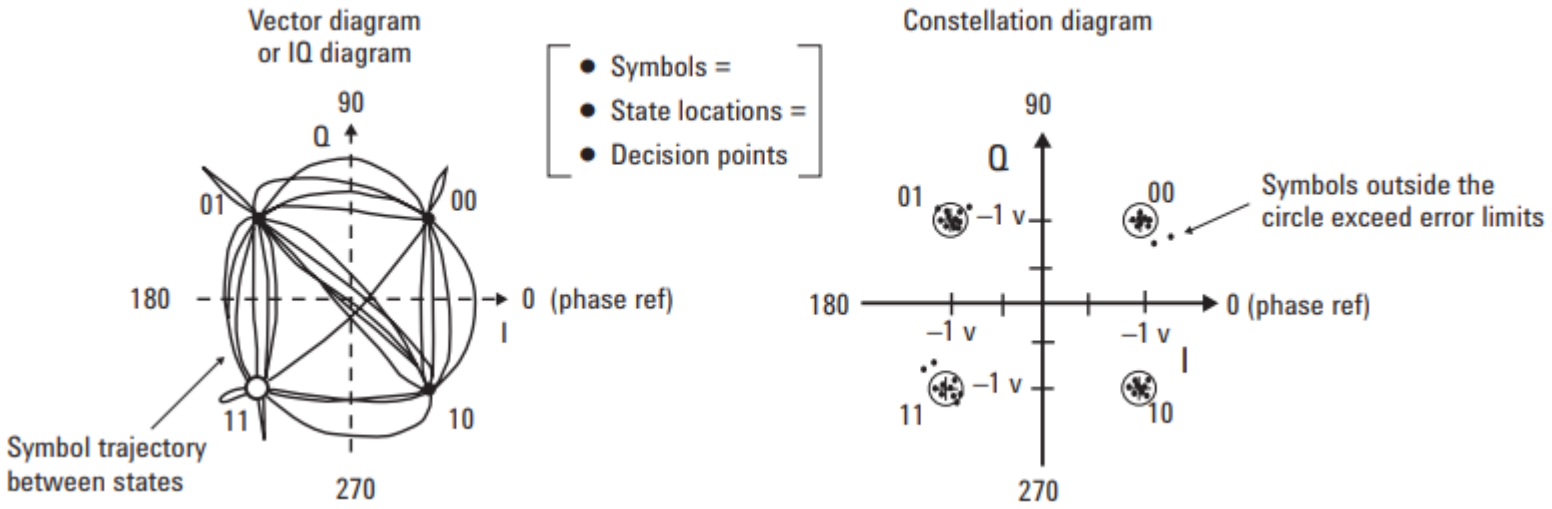
4 Measurement Example

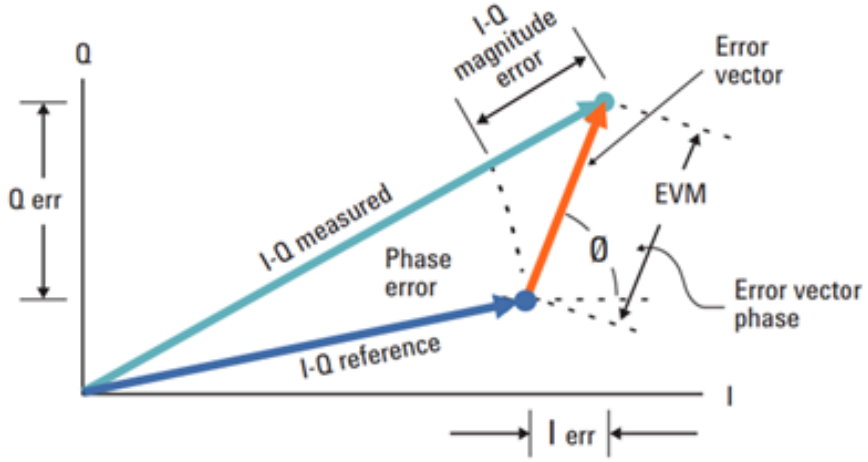
5 Keysight Wideband Measurement Solution

EVM and Bathtub Curve Fundamentals



EVM: Error Vector Magnitude





$$EVM\,[n] = \sqrt{I\,err[n]^2 + Q\,err[n]^2}$$

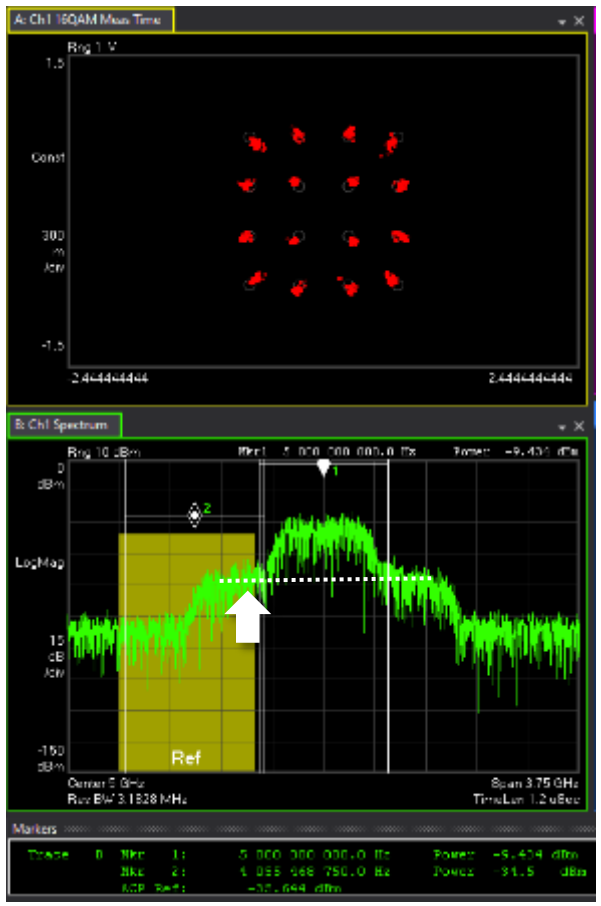
where [n] = measurement at the symbol time

I err = I ref - I meas

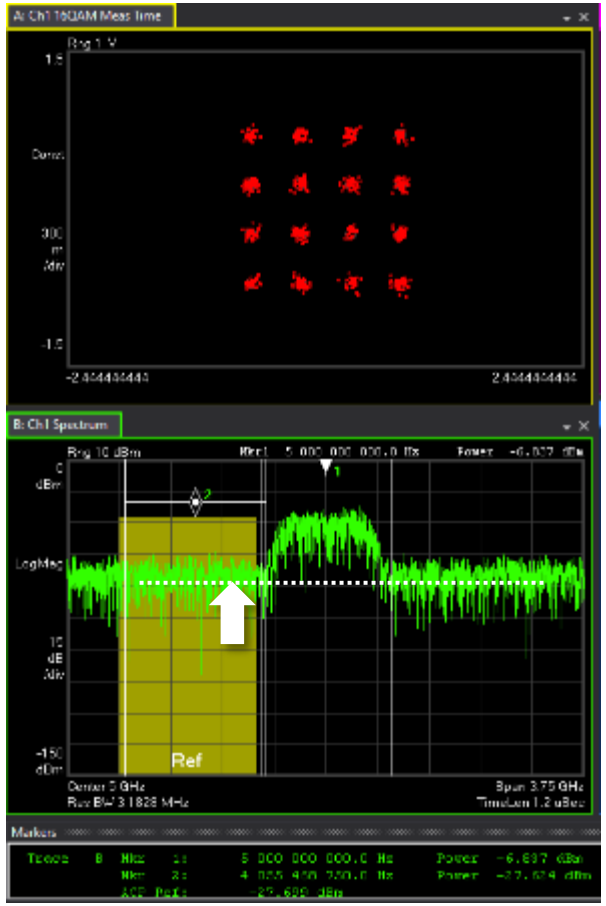
Q err = Q ref - Q meas

Source: AN 5990-7451 Vector Signal Analysis Basics

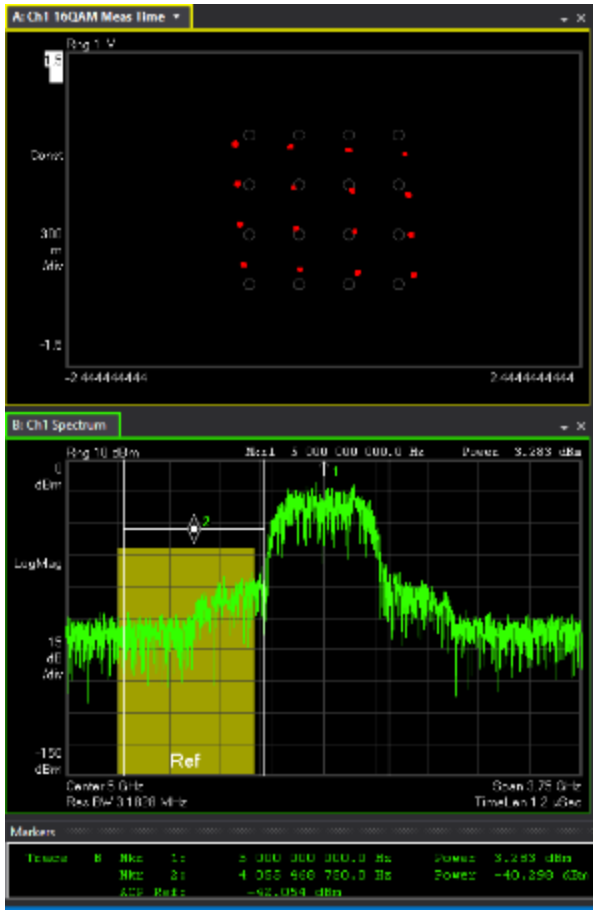
EVM Impairments Implication



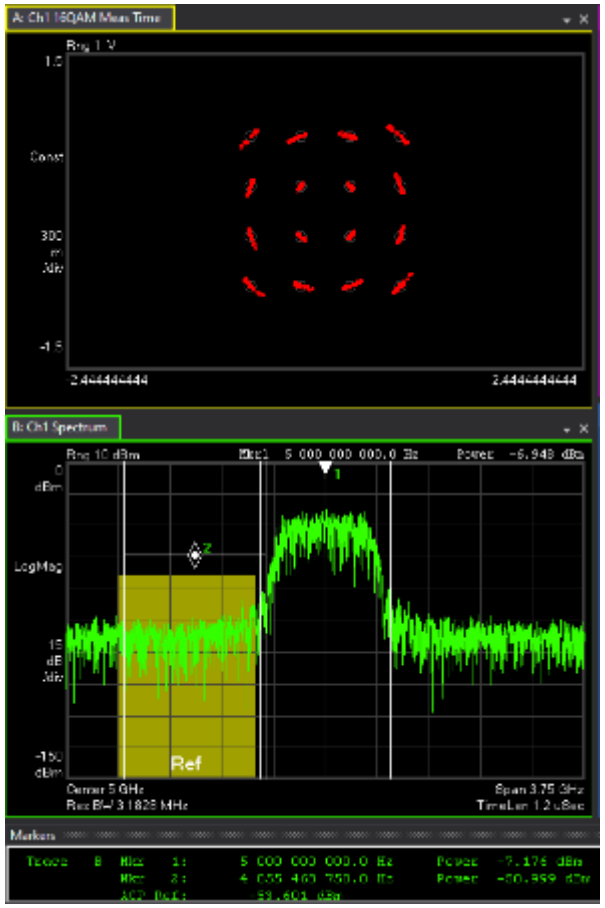
Distortion



White Noise



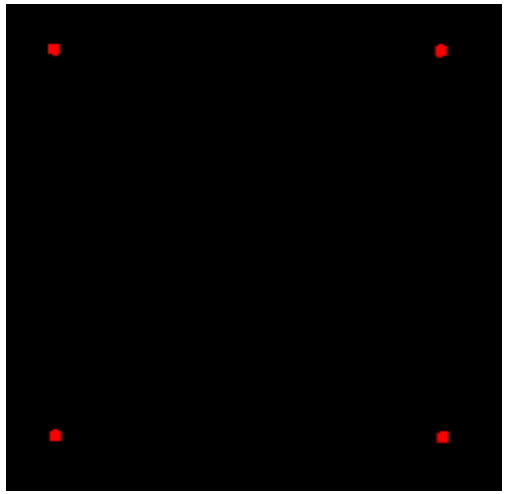
IQ imbalance



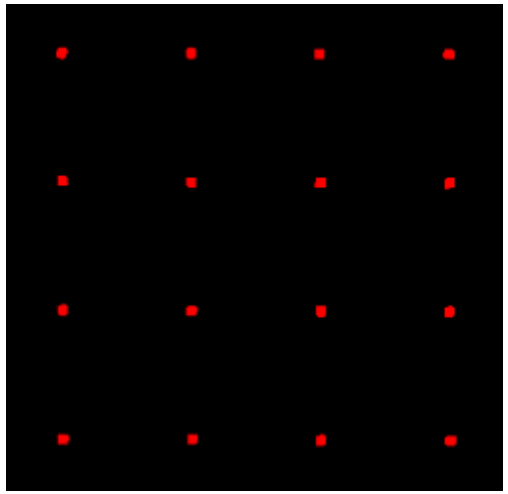
Phase noise

Illustrations created with Keysight PathWave SystemVue Design (SystemVue) and VSA

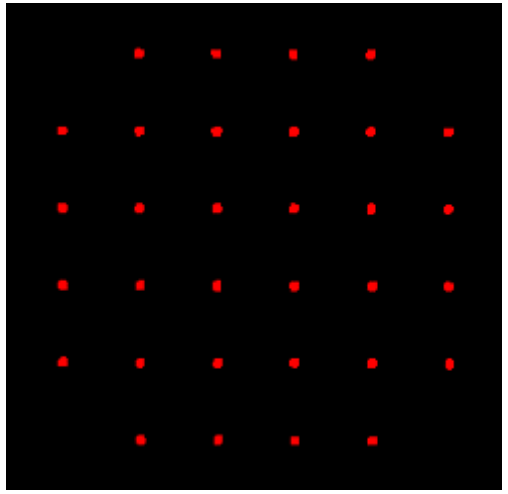
QAM Order



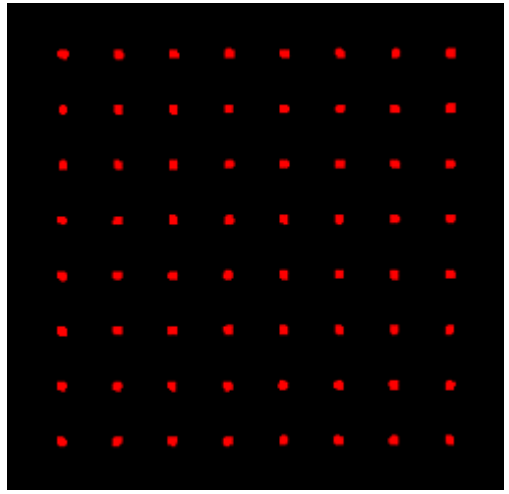
QPSK



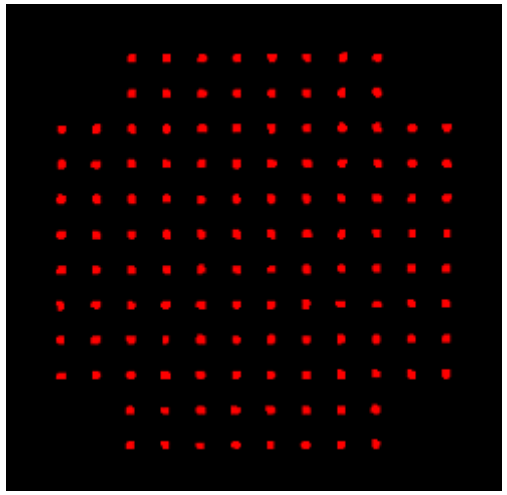
16QAM



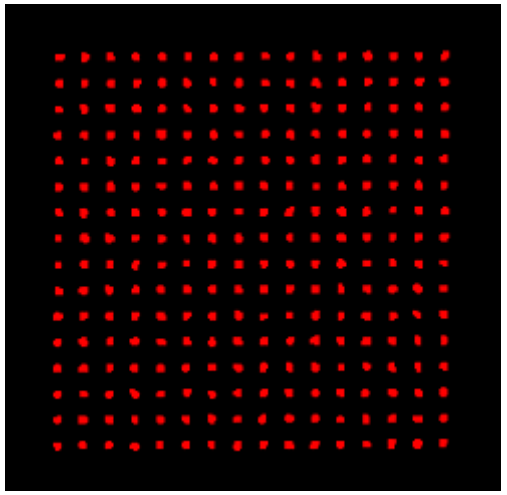
32QAM



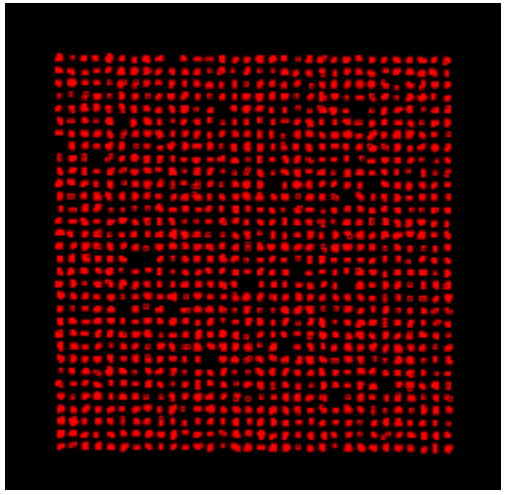
64QAM



128QAM



256QAM

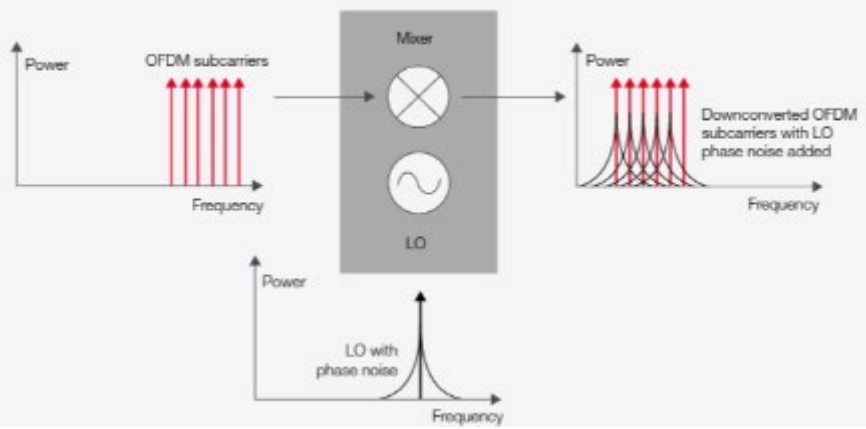


1024QAM

Illustrations created with Keysight PathWave SystemVue Design (SystemVue) and VSA

Industry Trend & Challenge

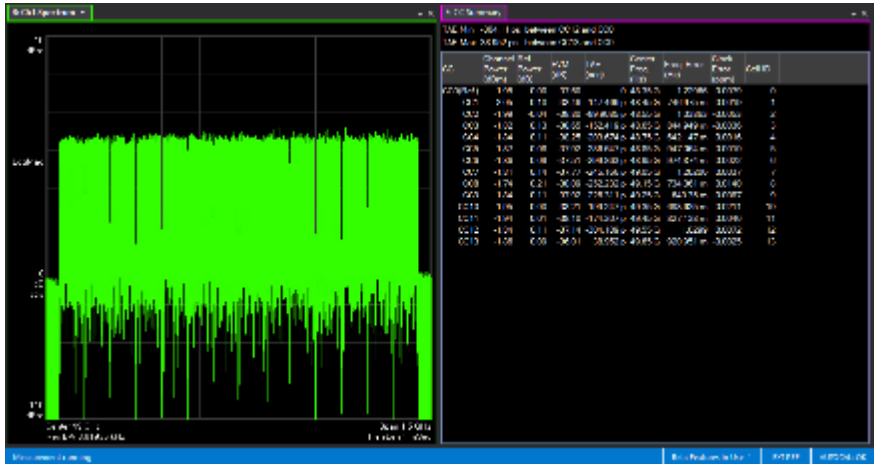
OFDM



Source: Three Best Practices for Optimizing EVM Measurements for Wideband Signals

- High peak-to-average signal
- Requires linear system

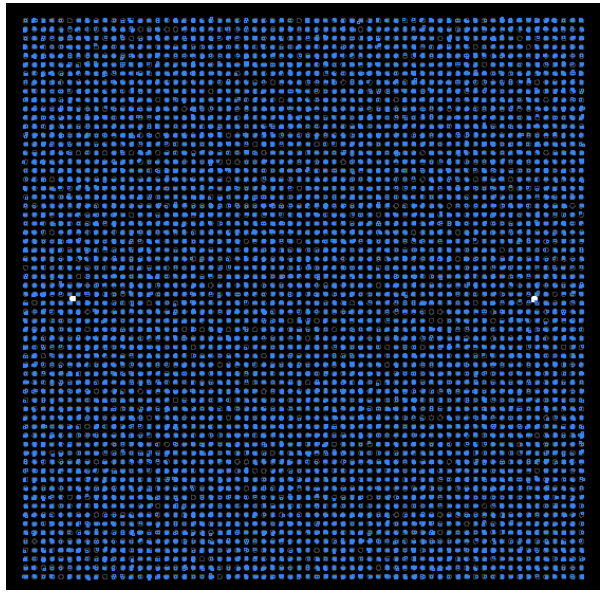
High carrier frequency & Wide bandwidth



Ex): 5GNR 14cc x 100MHz at 49GHz carrier frequency Demodulation analysis for each cc

- Dynamic range narrows as frequency goes up
- Frequency response (flatness)

Higher Order QAM



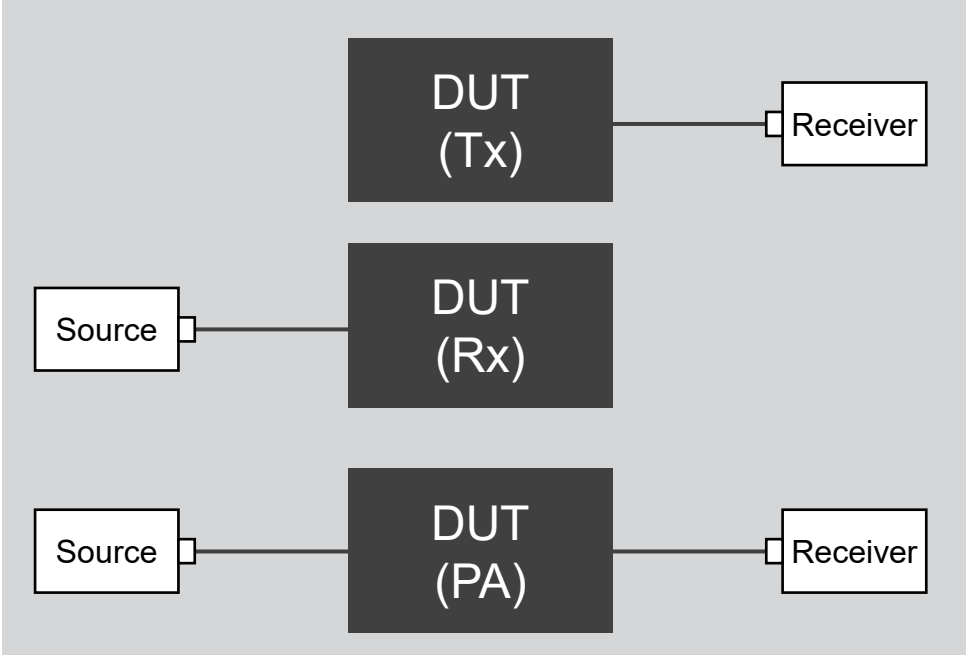
Ex): 802.11be 4096QAM

- Each symbol are close together, more chance of error in symbol
- Tighter EVM requirement

EVM Bathtub Curve

- Form of measurement to describe EVM power dependency for given waveform and frequency
- Tx test, Rx test, PA test
- Test equipment needs to be lower EVM than target EVM measurement
  (Typically, 6dB lower EVM is recommended)

- Loop Back configuration is often used to make sure the test equipment EVM.



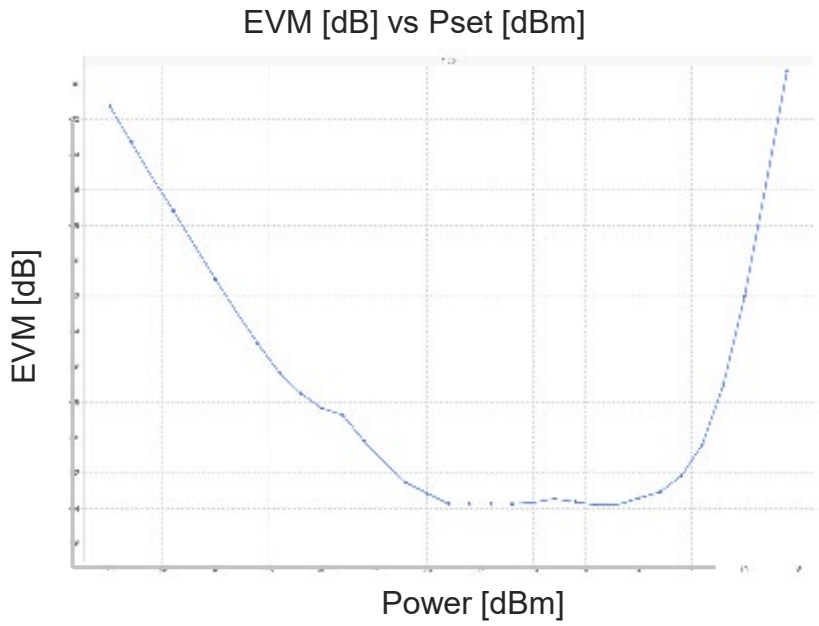
Actual DUT measurement

Loop-back EVM measurement

EVM Loop-Back Bathtub Curve

- SG and SA connected just with cable
  - Today's modern demodulation scheme compensates linear response (adaptive equalizer)
  - IQ impairments: small enough for high-end models
  - Phase noise: small enough for high-end models
  - Signal-to-noise ratio (SNR) and nonlinearity of source-receiver: Remaining factor that determines EVM
- Loop-back: Shows SNR and nonlinearity performance of source-receiver chain

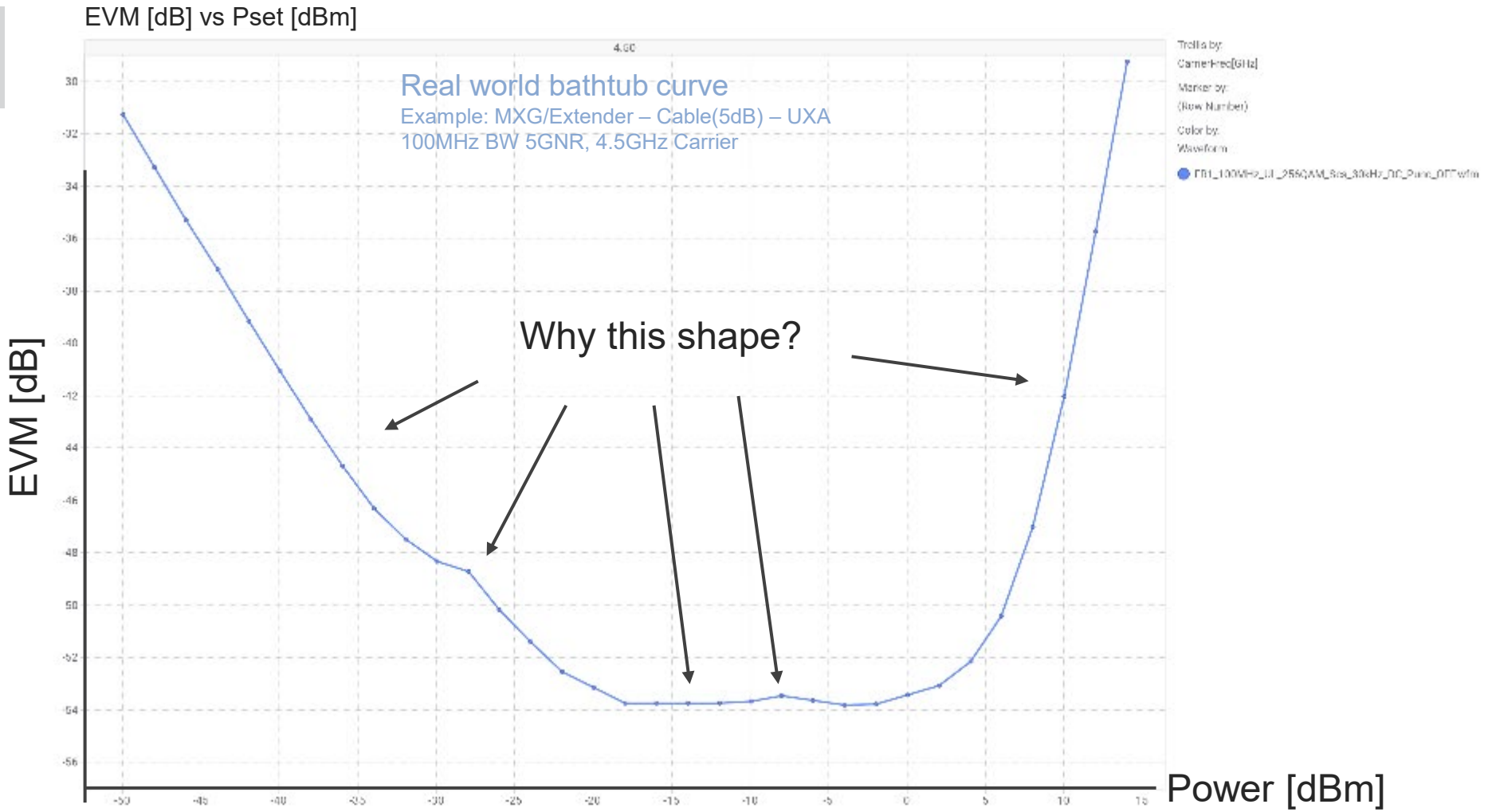
Keysight N9042B – M9484C loop-back connection



EVM Loop-Back Bathtub Curve

SRC-RCV chain

Actual measurement result

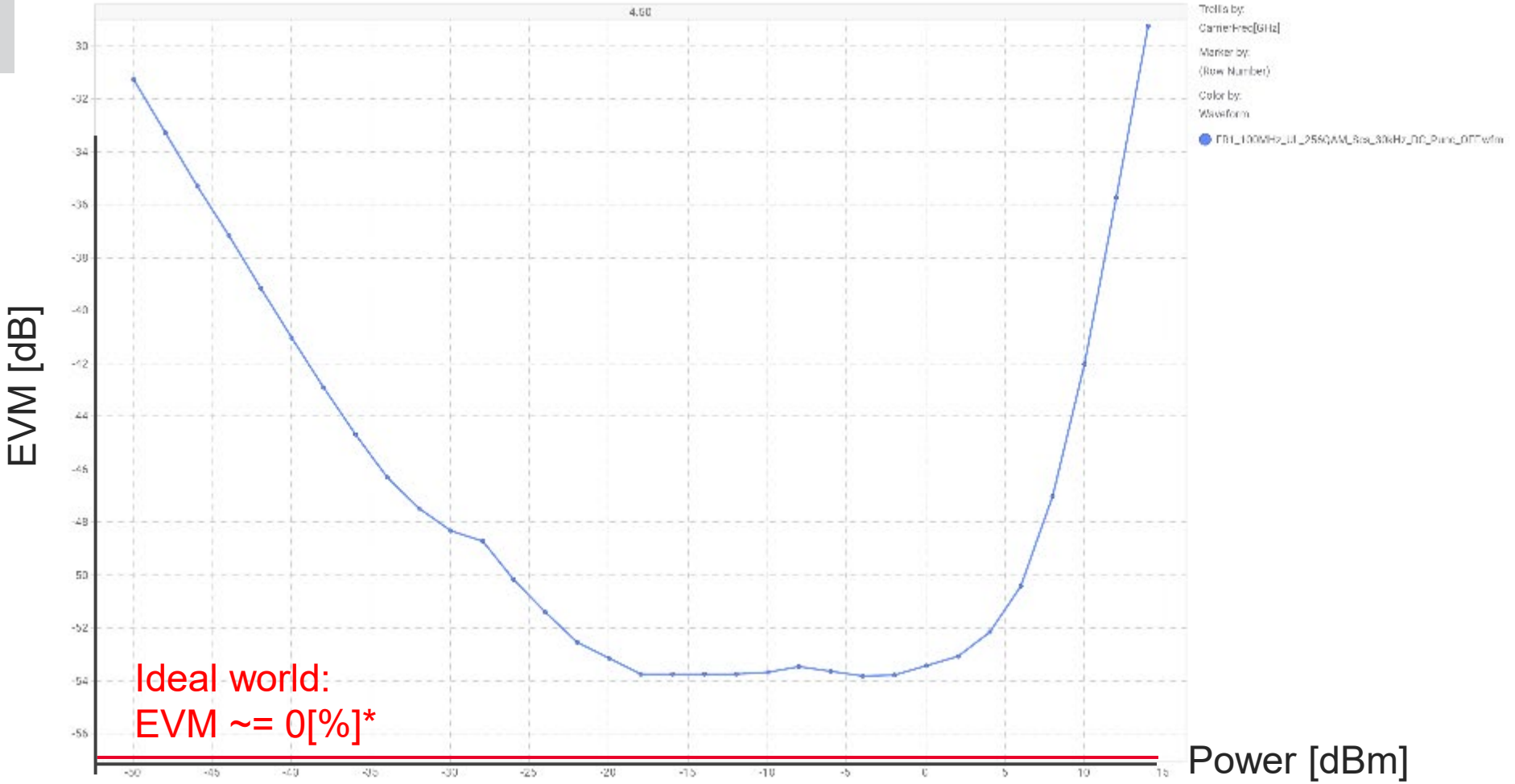


EVM Loop-Back Bathtub Curve

SRC-RCV chain

Ideal world (No noise, no distortion, no IQ impairments)

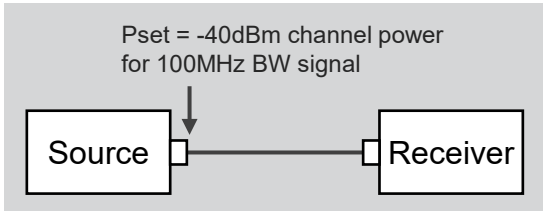
EVM [dB] vs Pset [dBm]

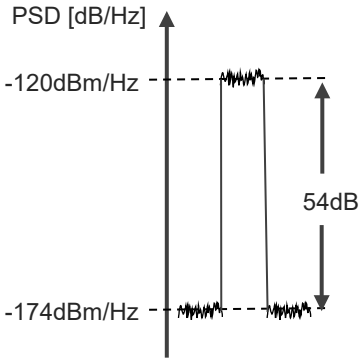


*Due to inter-symbol interference, EVM can't be 0% in OFDM. Also, baseband filter for ACPR improvement impacts the EVM performance

EVM Loop-Back Bathtub Curve

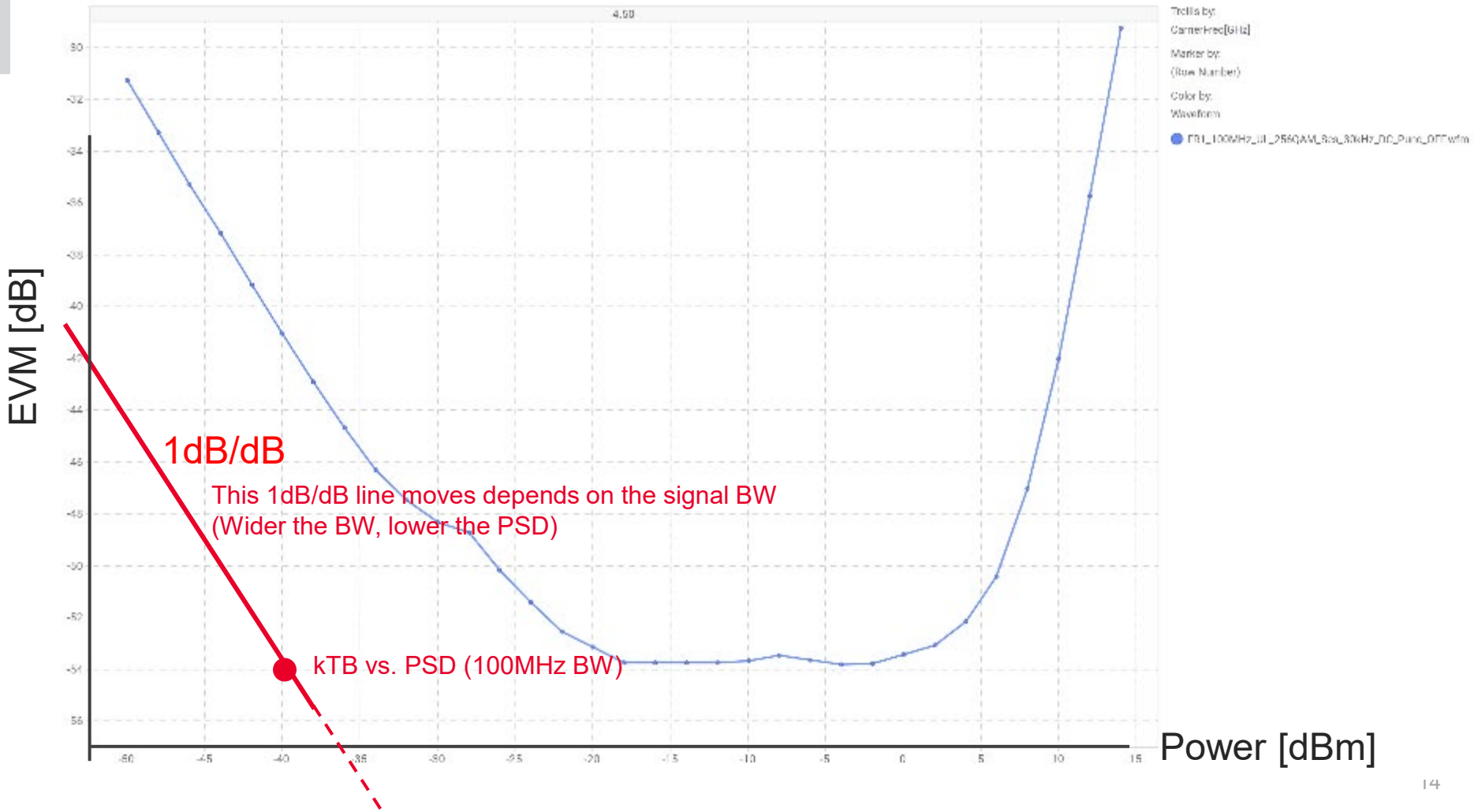
SRC-RCV chain





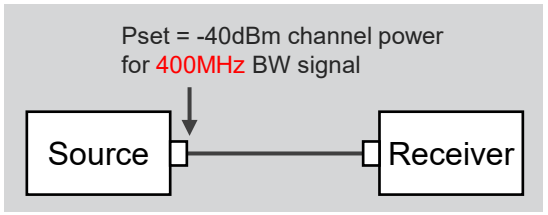
+ Thermal Noise (Room temp)

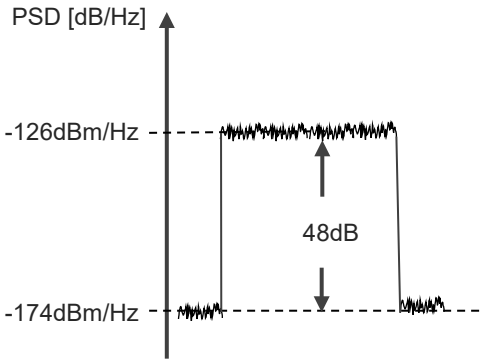
EVM [dB] vs Pset [dBm]



EVM Loop-Back Bathtub Curve

SRC-RCV chain





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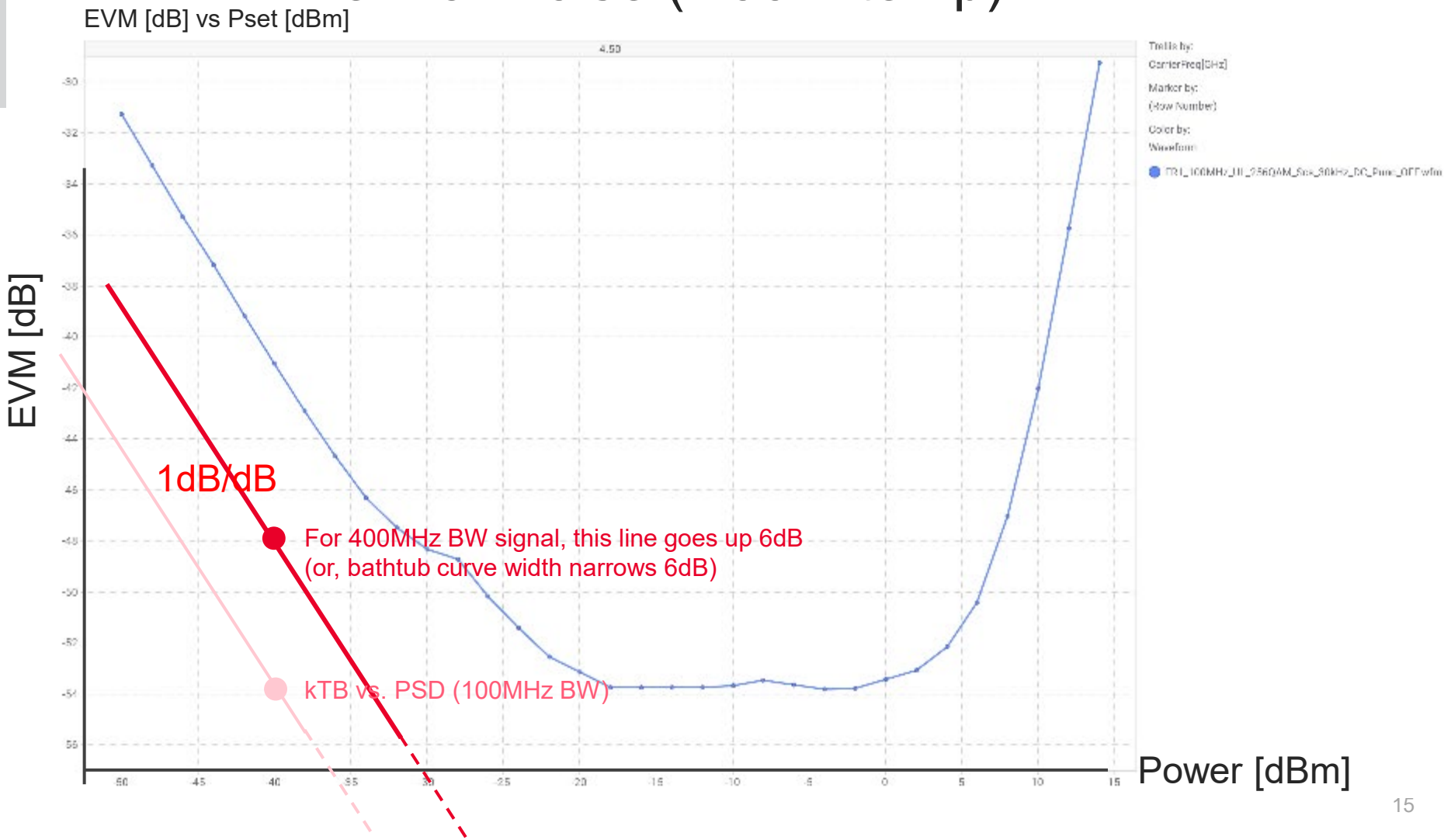
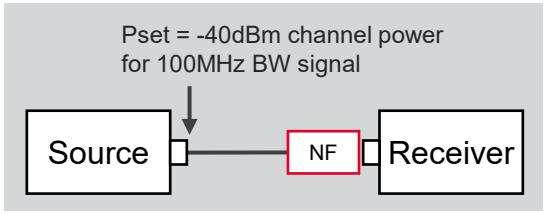


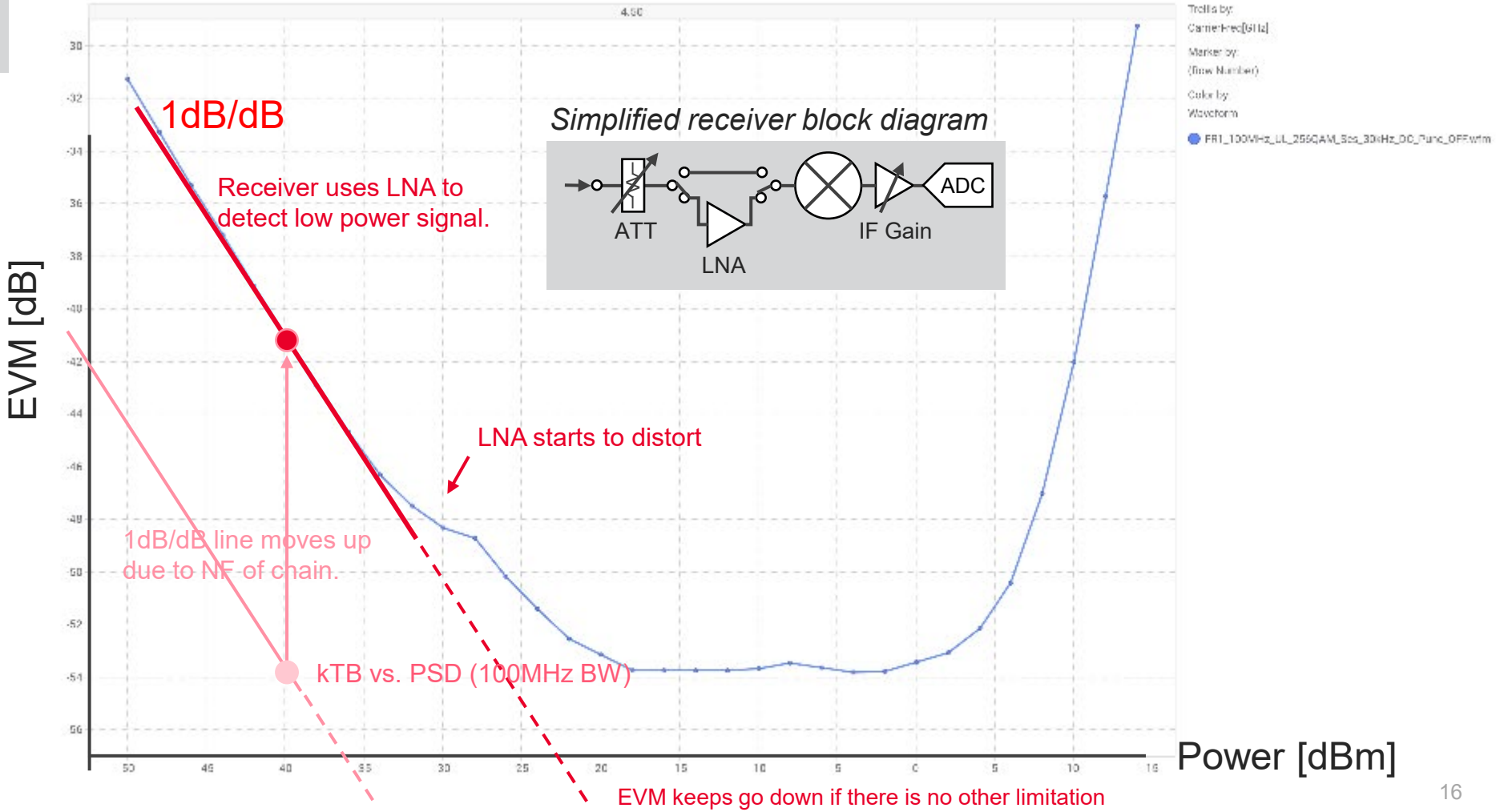
EVM Loop-Back Bathtub Curve

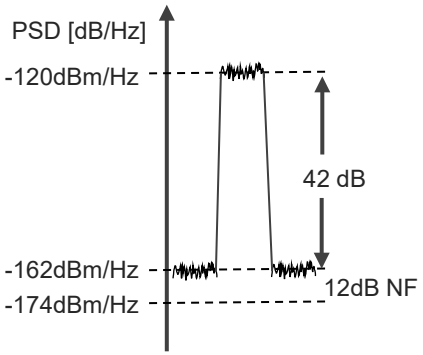
SRC-RCV chain



+ Noise Figure of Receiver

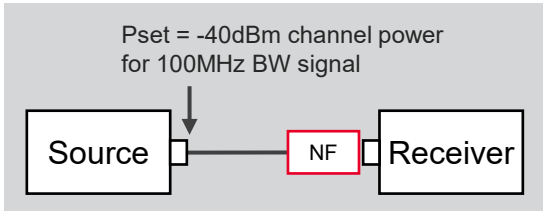
EVM [dB] vs Pset [dBm]





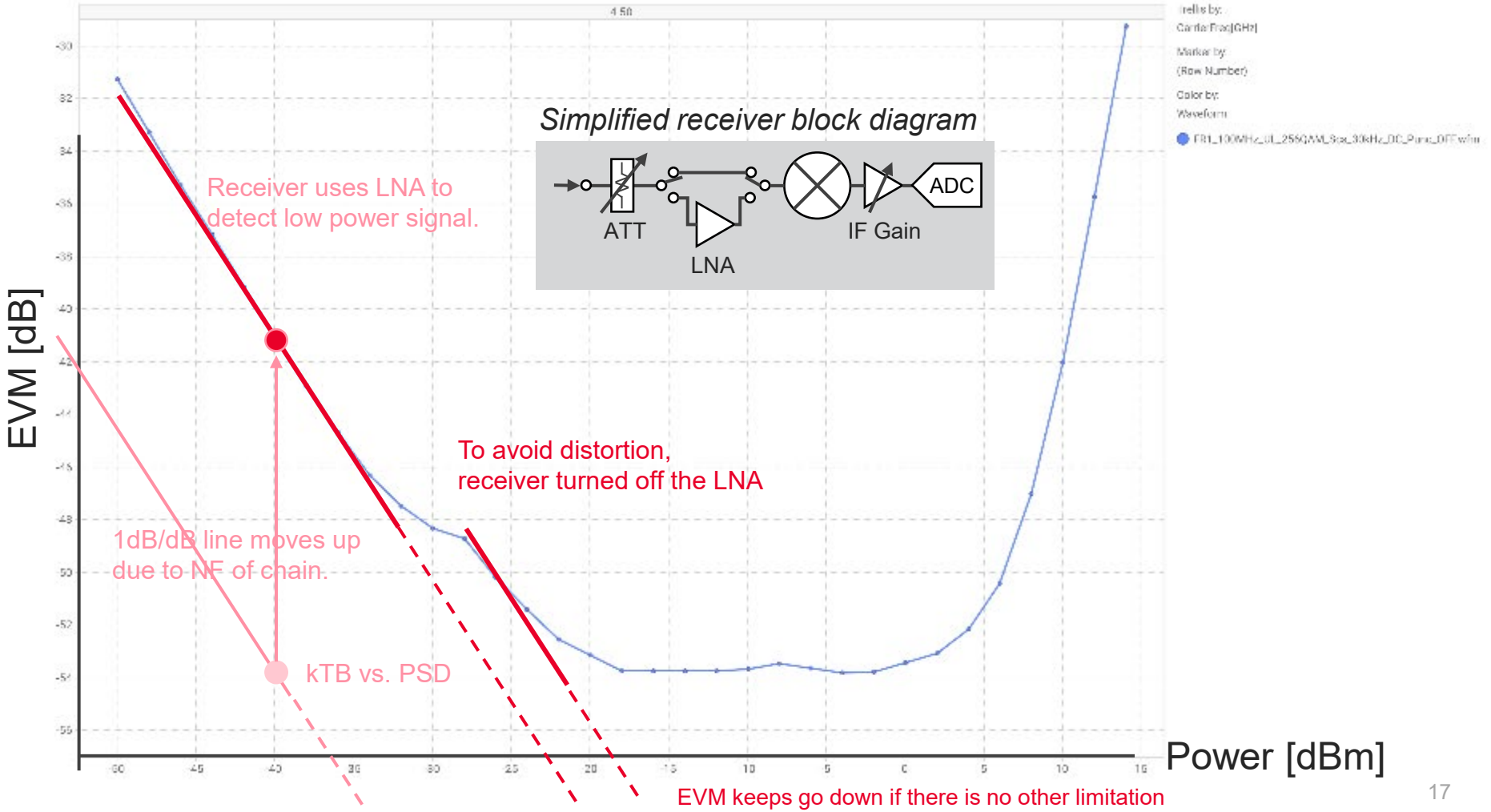
EVM Loop-Back Bathtub Curve

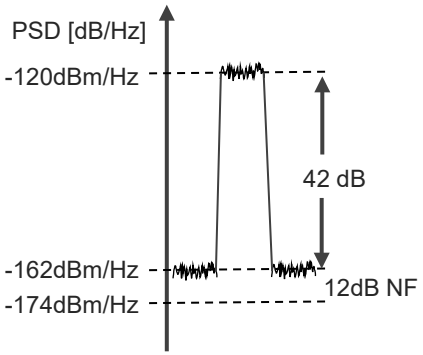
SRC-RCV chain



+ Noise Figure of Receiver

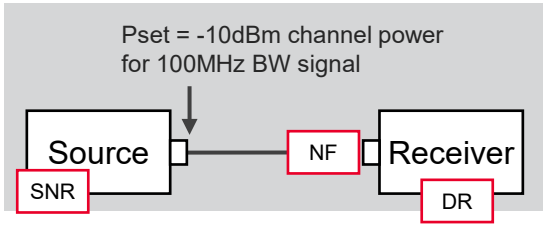
EVM [dB] vs Pset [dBm]

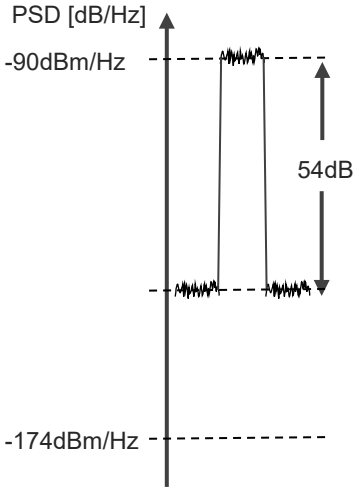




EVM Loop-Back Bathtub Curve

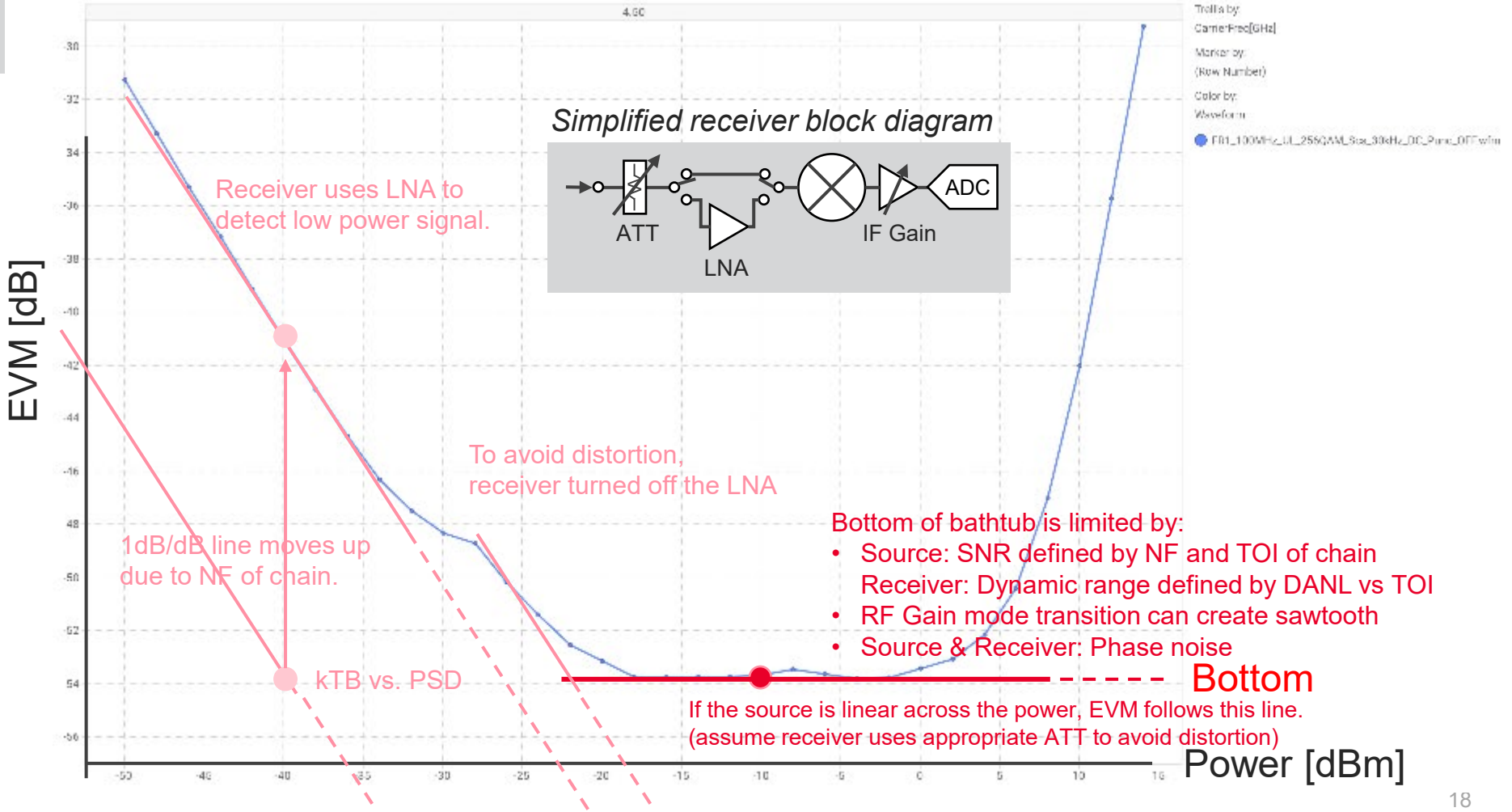
SRC-RCV chain





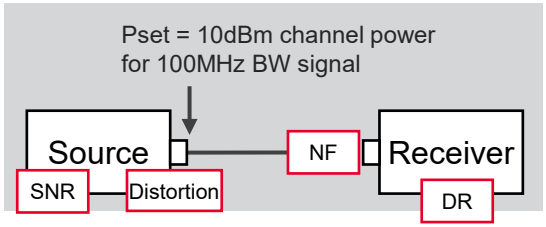
+ SNR of source and receiver, Phase Noise

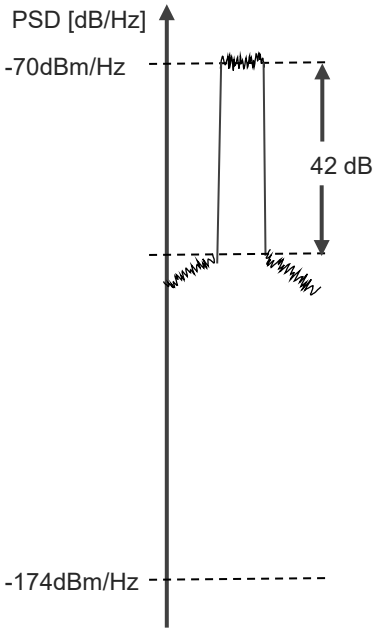
EVM [dB] vs Pset [dBm]



EVM Loop-Back Bathtub Curve

SRC-RCV chain

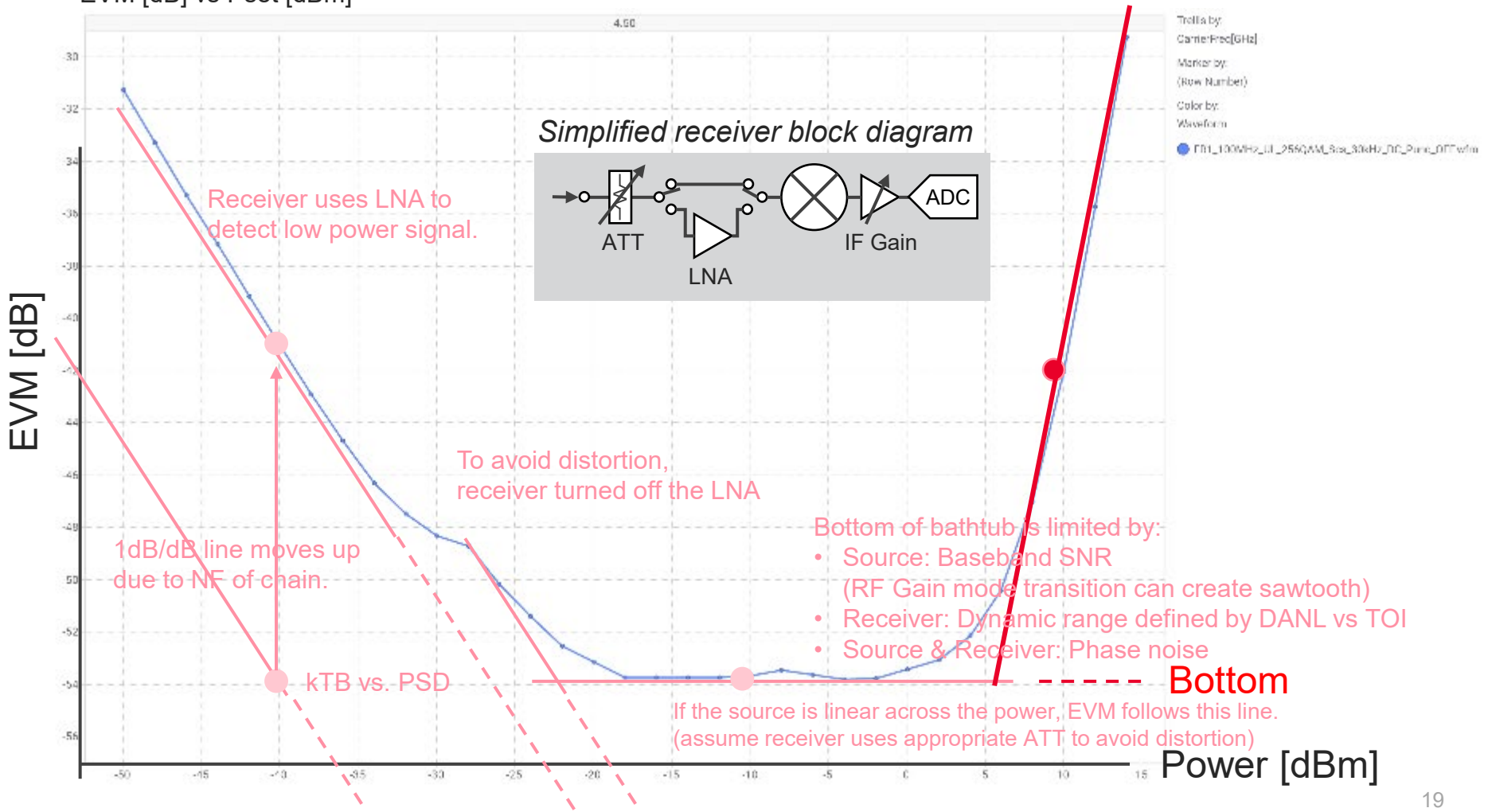




+ Source distortion

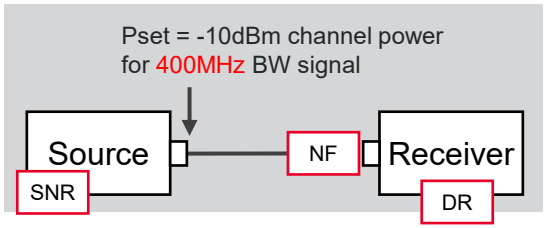
Distortion of source

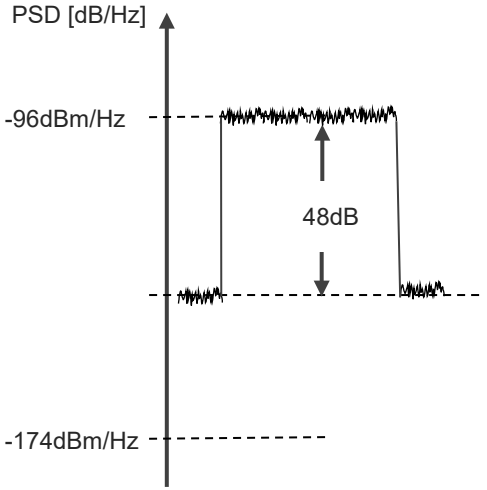
EVM [dB] vs Pset [dBm]



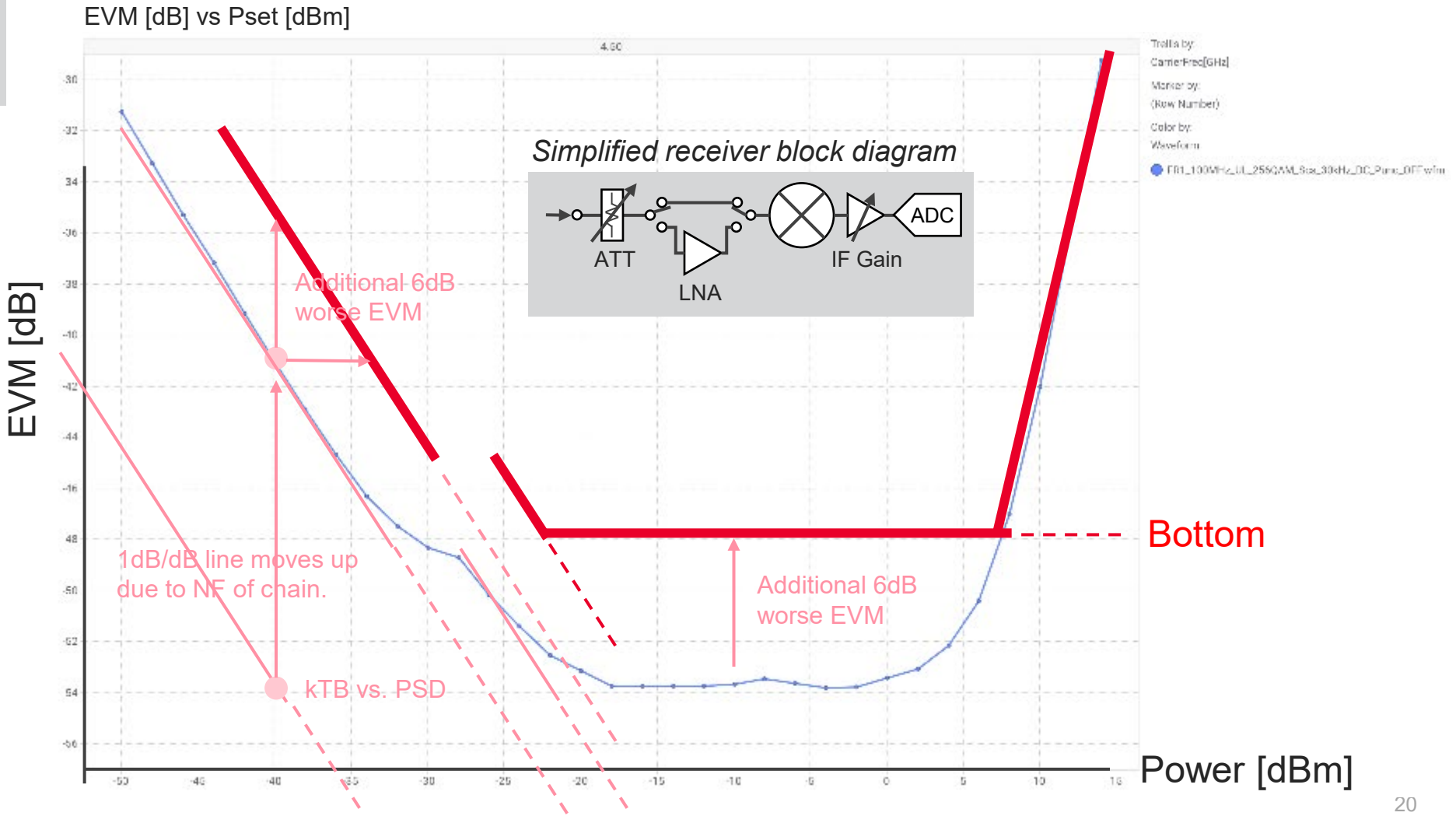
EVM Loop-Back Bathtub Curve

SRC-RCV chain





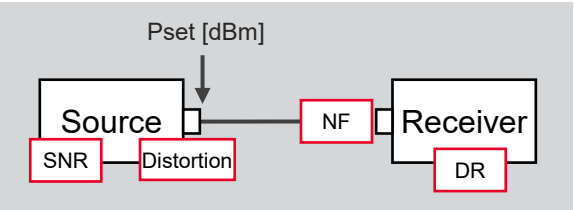
+ SNR of source and receiver, Phase Noise



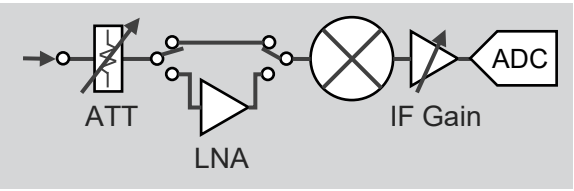
Receiver Optimization

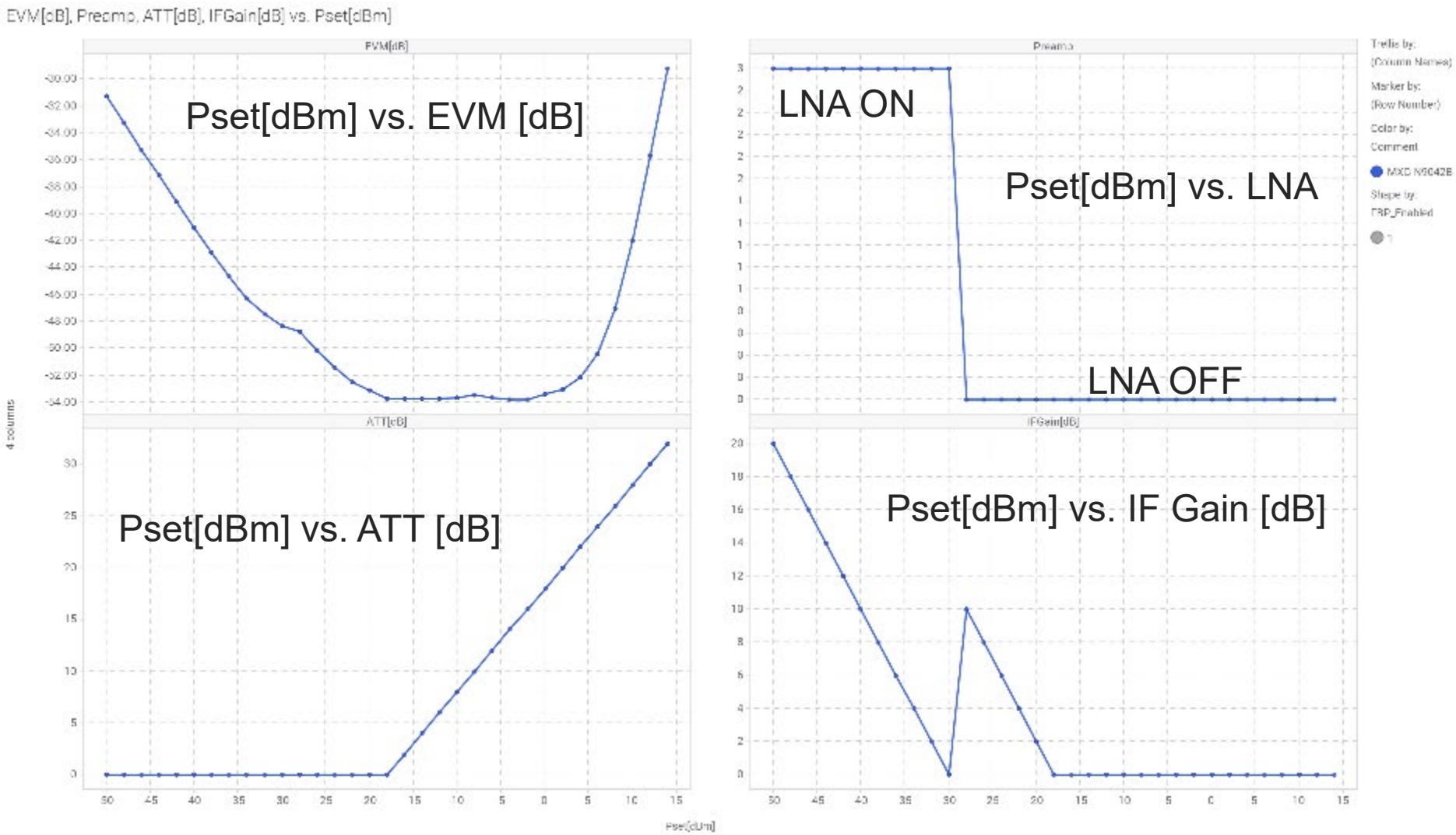
Receiver Optimization

SRC-RCV chain in real-world



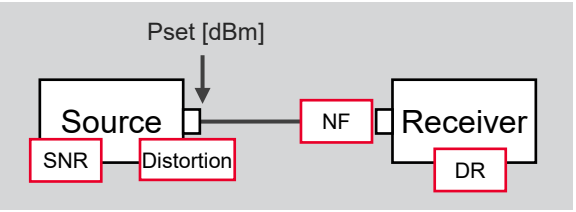
Simplified receiver block diagram



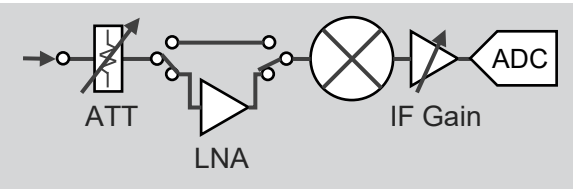


Receiver Optimization (Low Power)

SRC-RCV chain in real-world

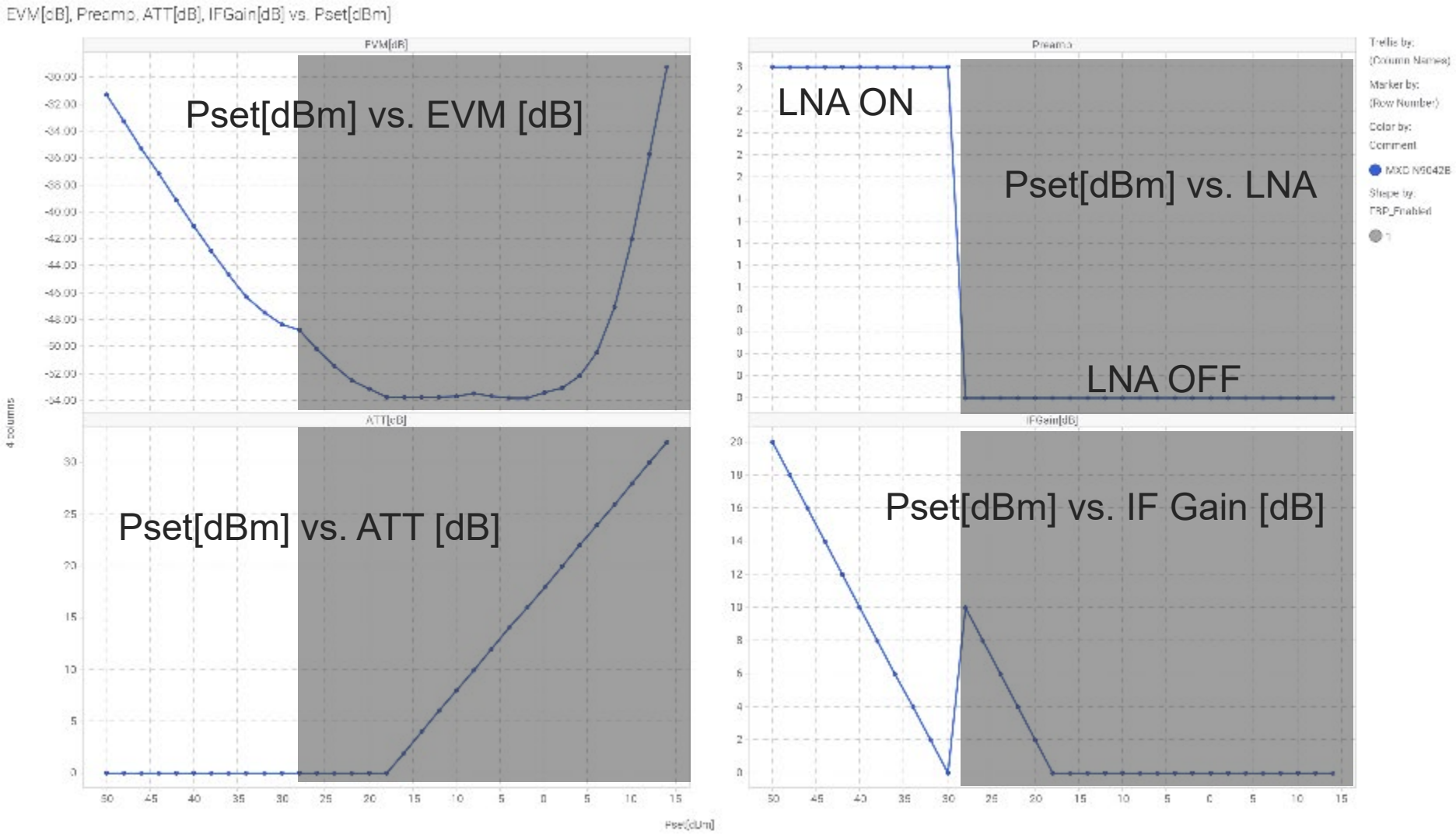


Simplified receiver block diagram



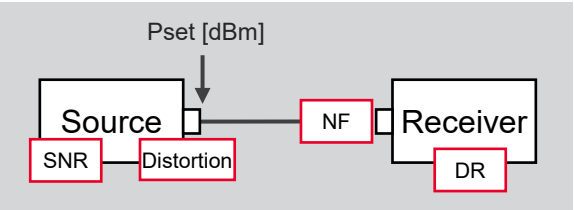
- LNA ON
- No ATT
- As Pset increment, IFGain decrement (Avoid IF chain distortion)

  Continue this until LNA starts to show distortion.

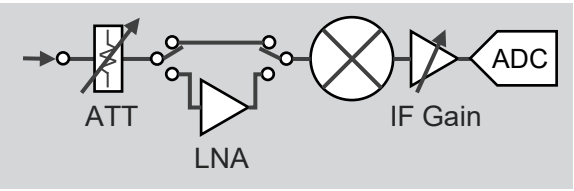


Receiver Optimization (Mid Power Transition)

SRC-RCV chain in real-world

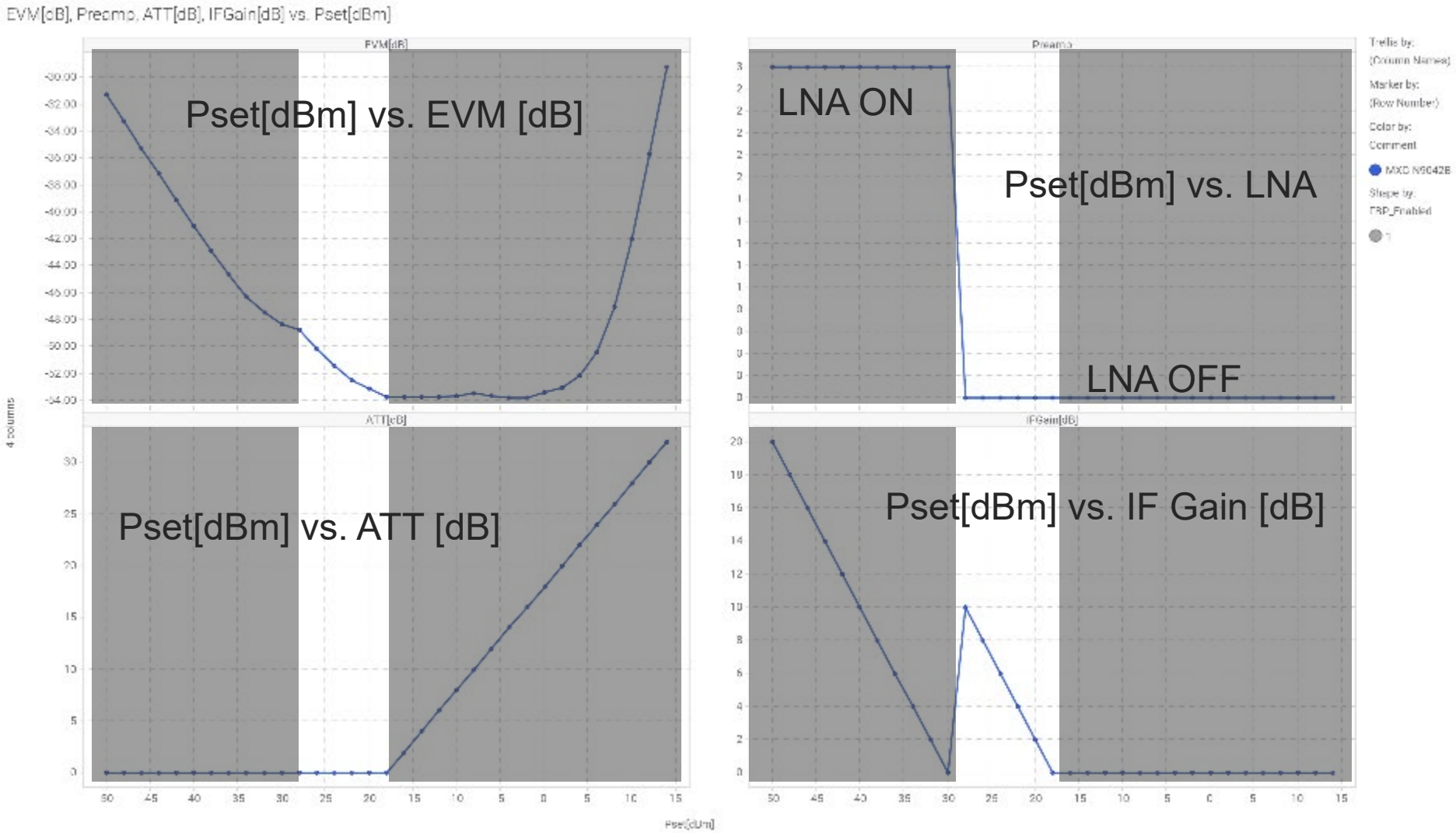


Simplified receiver block diagram



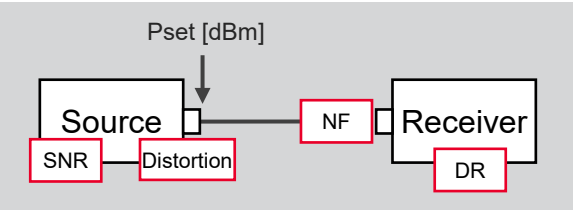
- LNA OFF
- No ATT
- As Pset increment, IFGain decrement (Avoid IF chain distortion)

  Continue this until EVM hits bottom (RF front chain starts to show distortion)

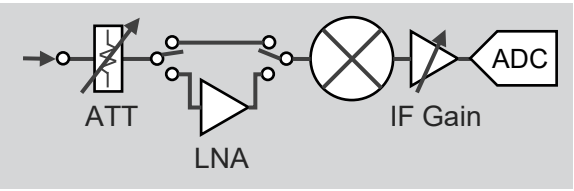


Receiver Optimization (Mid-High Power)

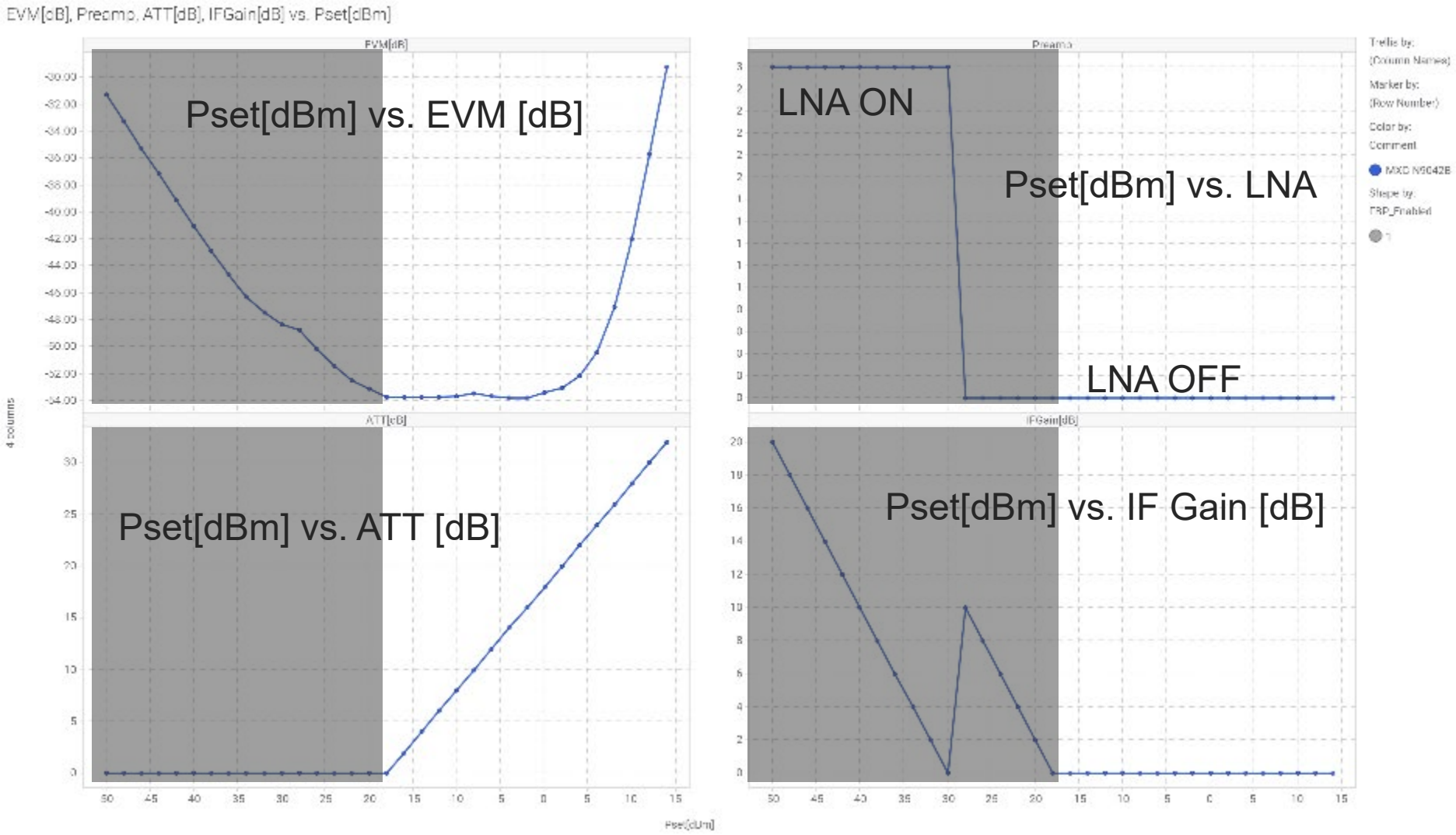
SRC-RCV chain in real-world



Simplified receiver block diagram



- LNA OFF
- IFGain: no change
- As Pset increments, increment ATT (maintain power level that hits mixer)

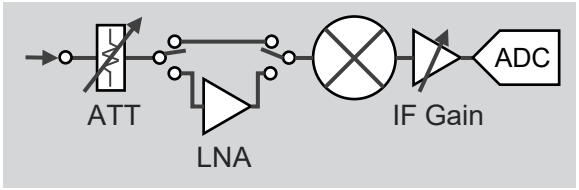


Automatic Receiver Optimization (Optimize EVM function)

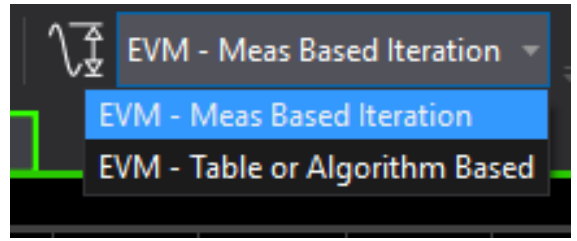
- Table or algorithm (Normal method)
  - Evaluates power, then chose value from given look-up table or algorithm
  - Speed: Fast
  - Performance: Reasonably good, but will never be perfect (table or algorithm are designed for nominal unit and nominal waveform)

- Iterative
  - Performs table/algorithm first, then iteratively measures EVM with slightly different receiver configuration to find optimum setting
  - Speed: Slow
  - Performance: Best. Finds best possible performance of hardware

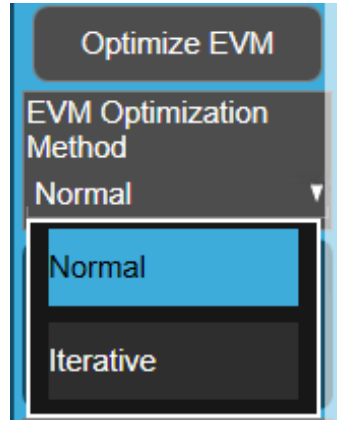
Simplified receiver block diagram



Keysight VSA



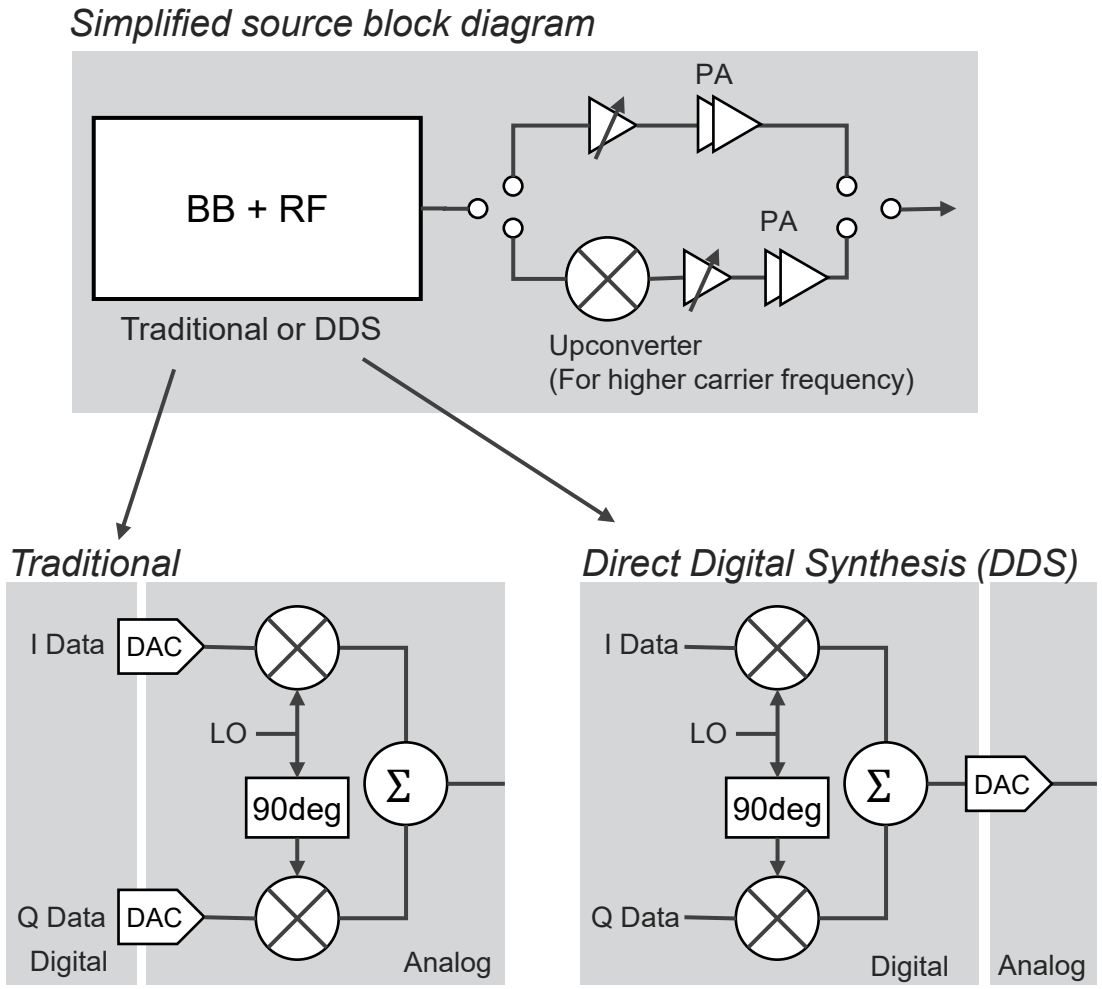
Keysight XSA



Source Optimization

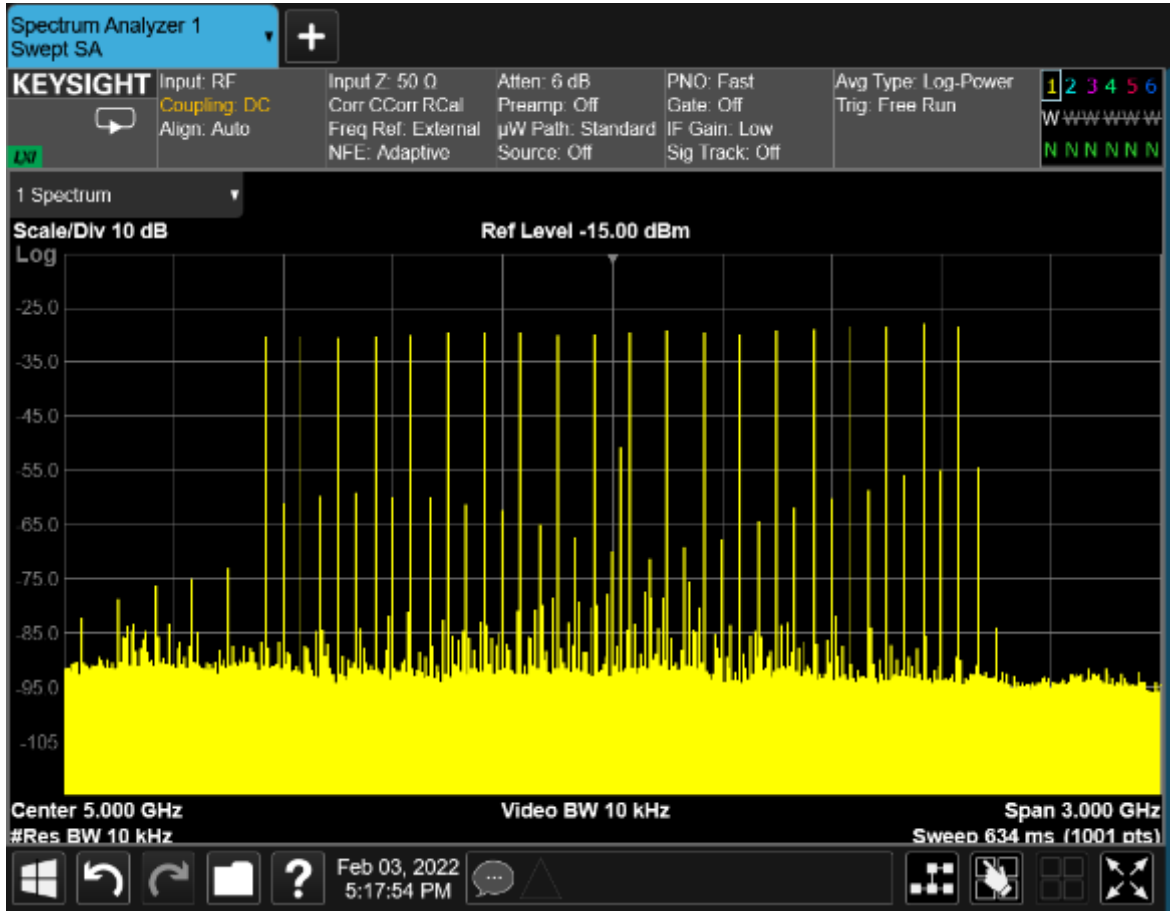
Signal Generator

- Signal generator is expected to generate RF signal for given waveform, carrier frequency, and power at test port
- Latest signal generator tends to adopt DDS, which overcomes IQ impairments challenges
- Factory calibration provides best performing internal configuration (each unit knows best possible hardware configuration for given waveform, frequency, and power) – No need for user to tweak knobs
- Last stage PA tends to distort when the high-power signal is generated

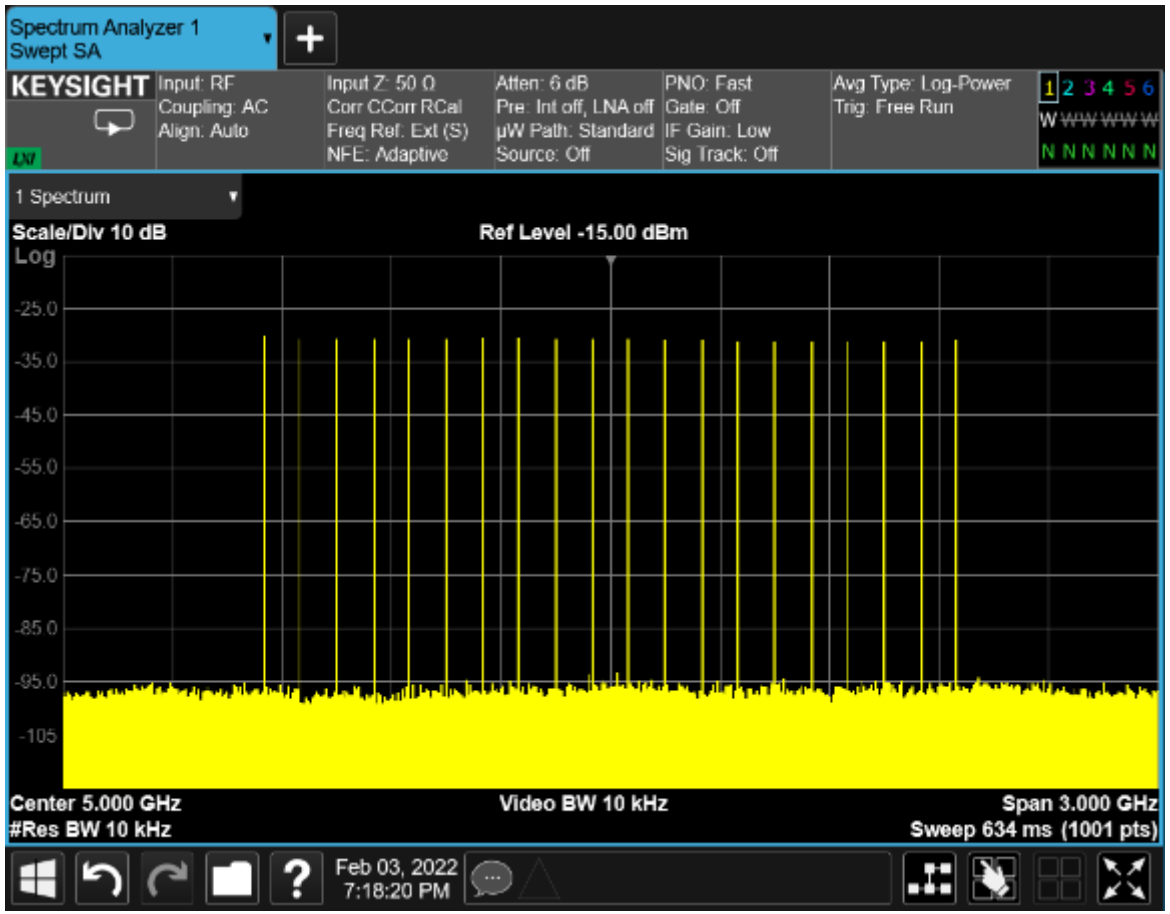


Traditional Baseband Generator & DDS

*Traditional**



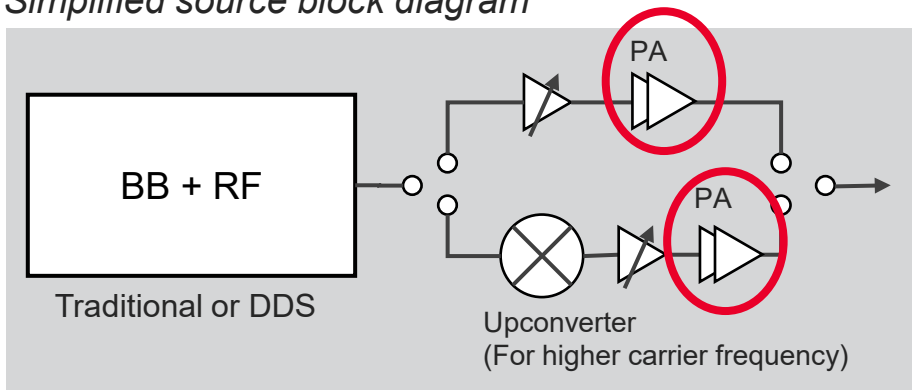
Direct Digital Synthesis



** Unwanted spectrum shown is extreme result when no Analog imperilments calibration is done. Typically, signal generator has its own calibration algorithm to knock down those spectrum.*

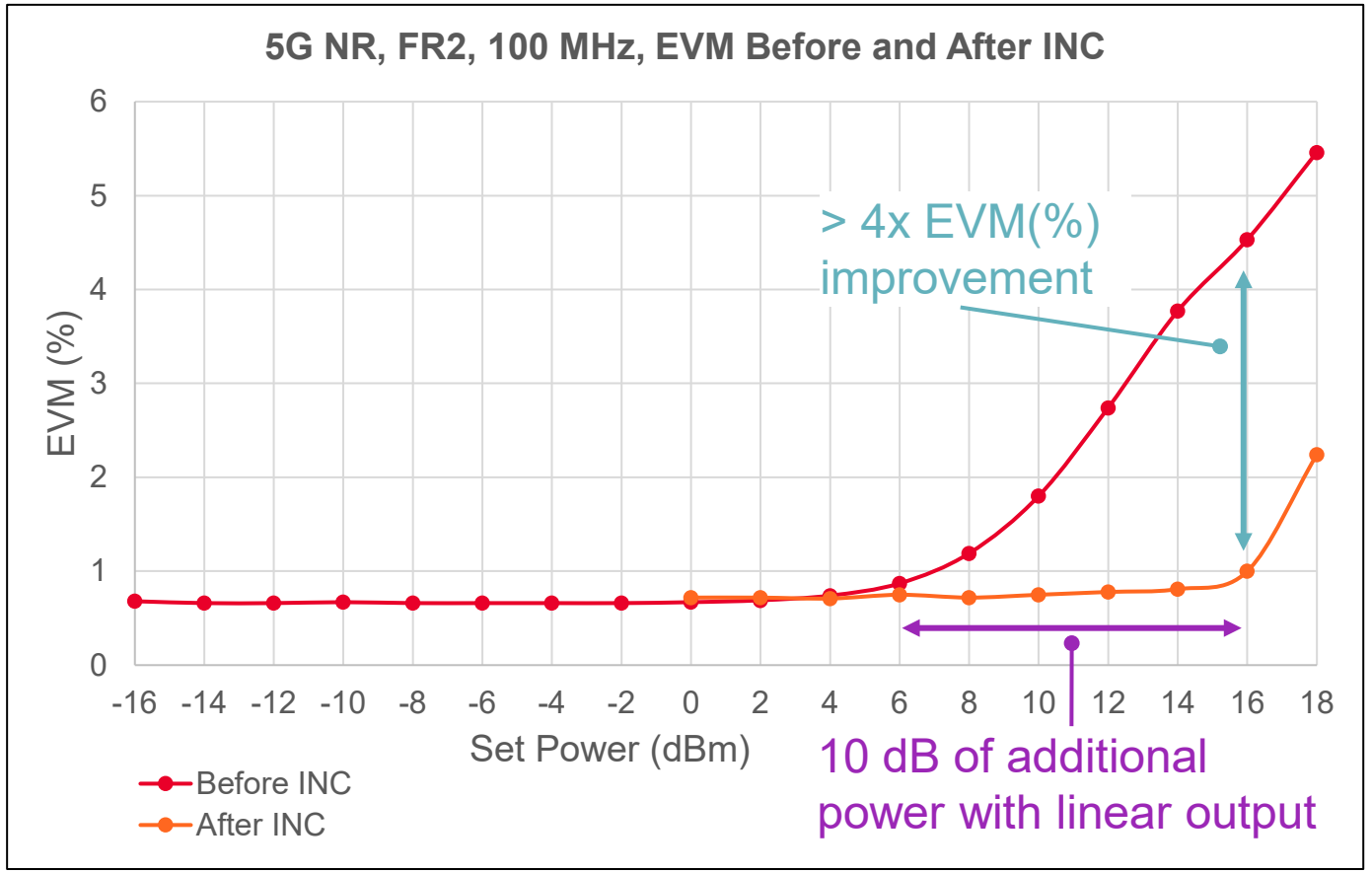
Instrument Nonlinear Correction (INC)

Simplified source block diagram



INC: Extends the usable power range of signal generator

- Digital pre-distortion (DPD) based correction
- Compensates for nonlinearities at high power levels



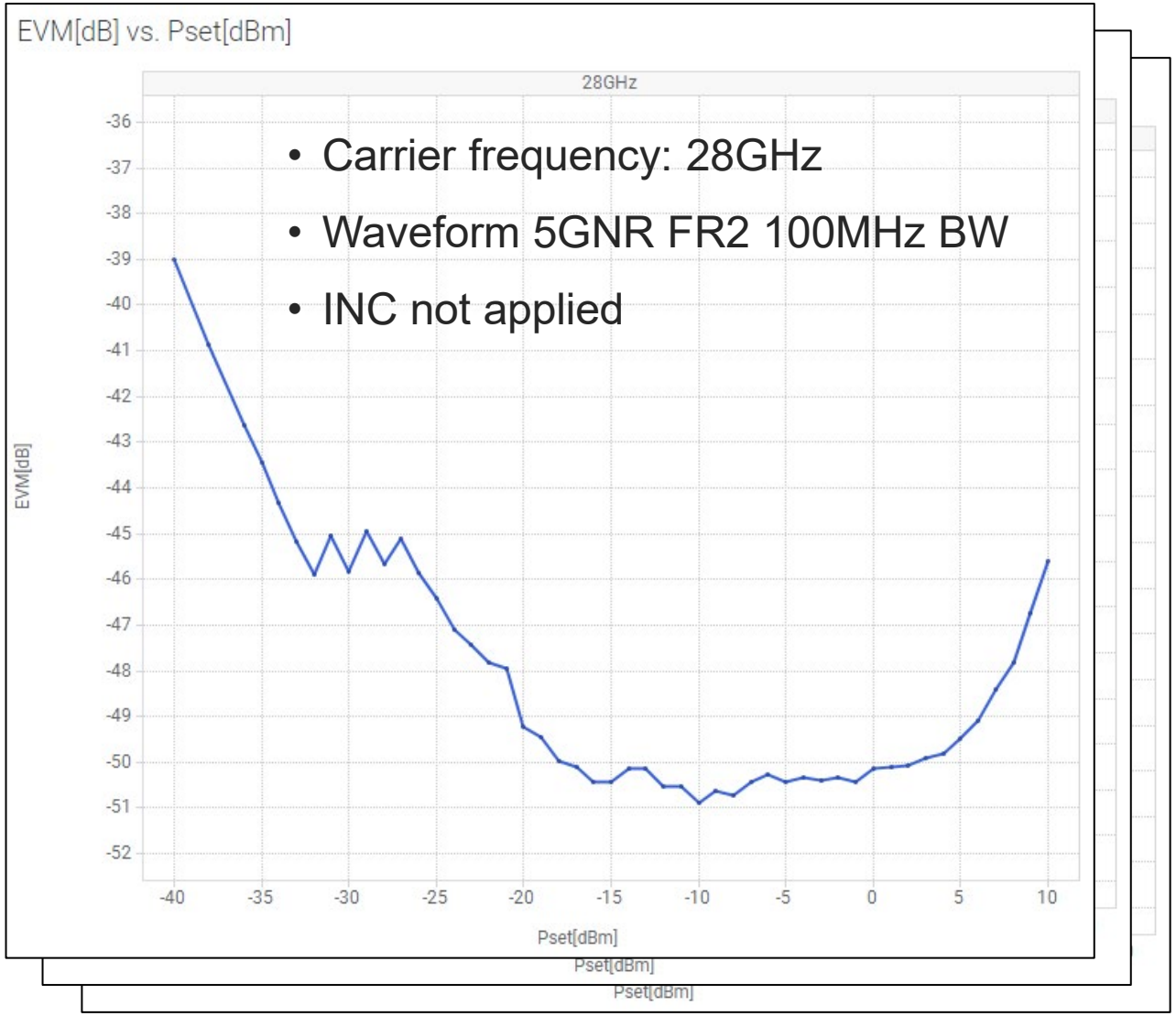
Source: Keysight M9484C. Receiver: Keysight N9042B

EVM Measurement Examples

EVM Loop-Back Bathtub Curve Example

Keysight M9484C – N9042B loop-back connection

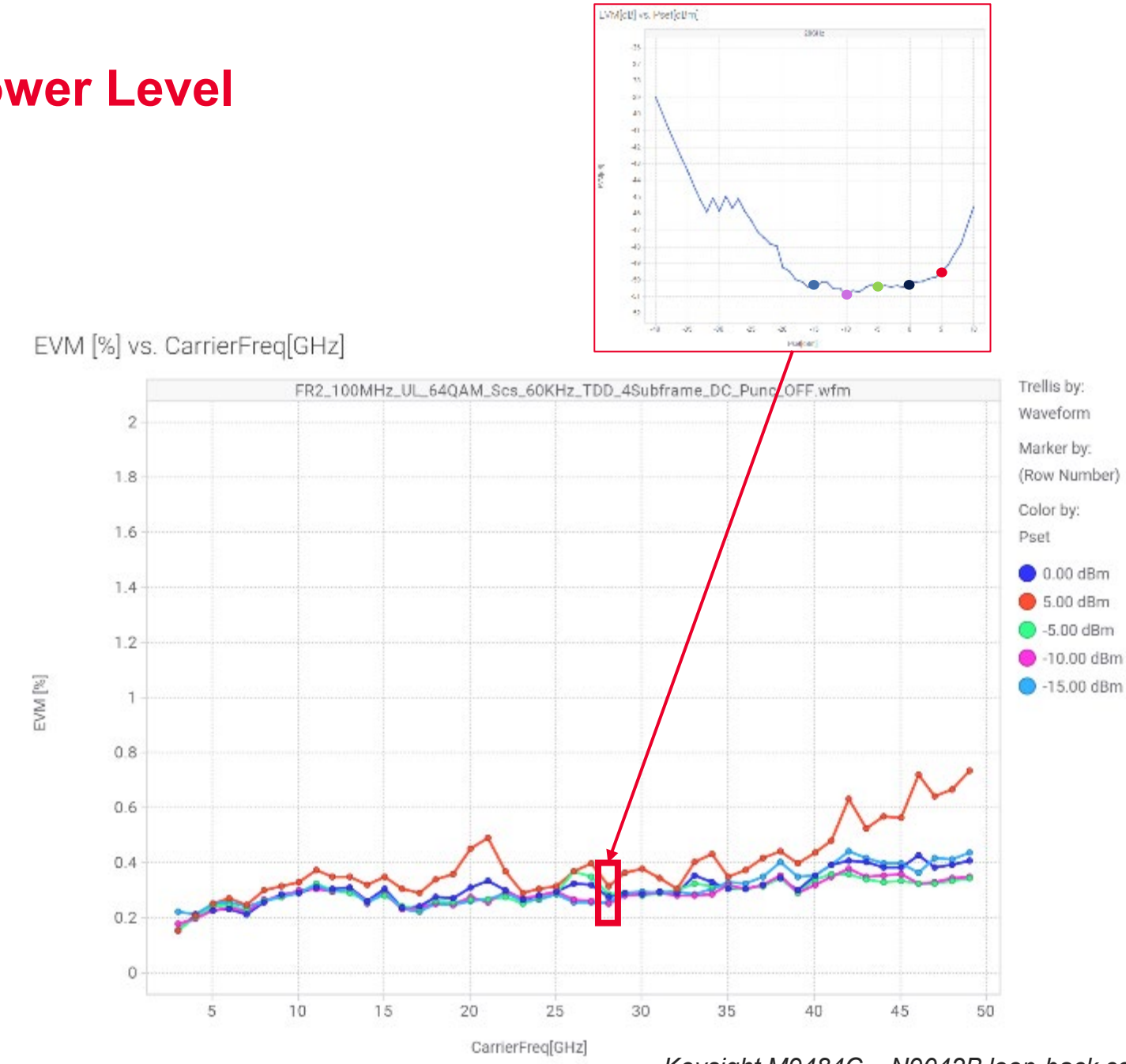
- Simply connect source and receiver with cable
- Multi-dimension measurements
  (Waveform & Frequency)



...

EVM vs. Frequency for Power Level

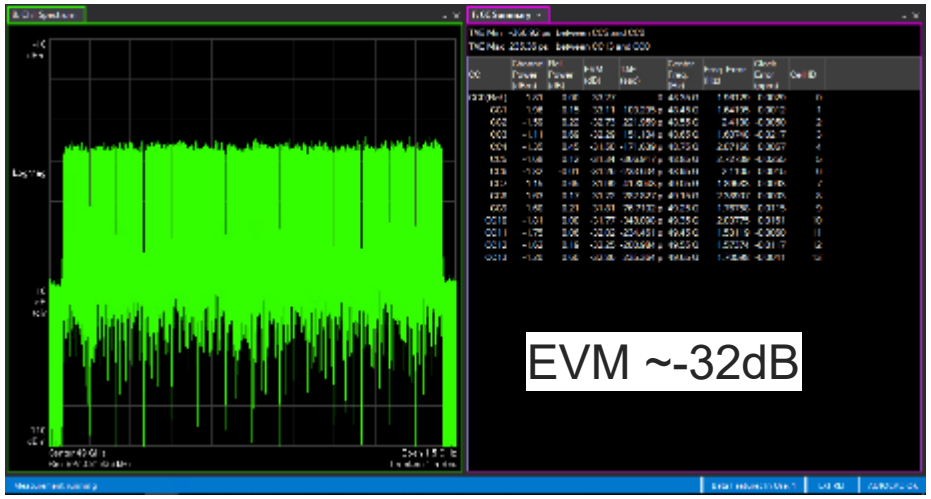
- Another representation of bath-tub curve
- Used to show source distortion performance over carrier frequency
- Typically, distortion get worse in higher frequency
- INC not applied

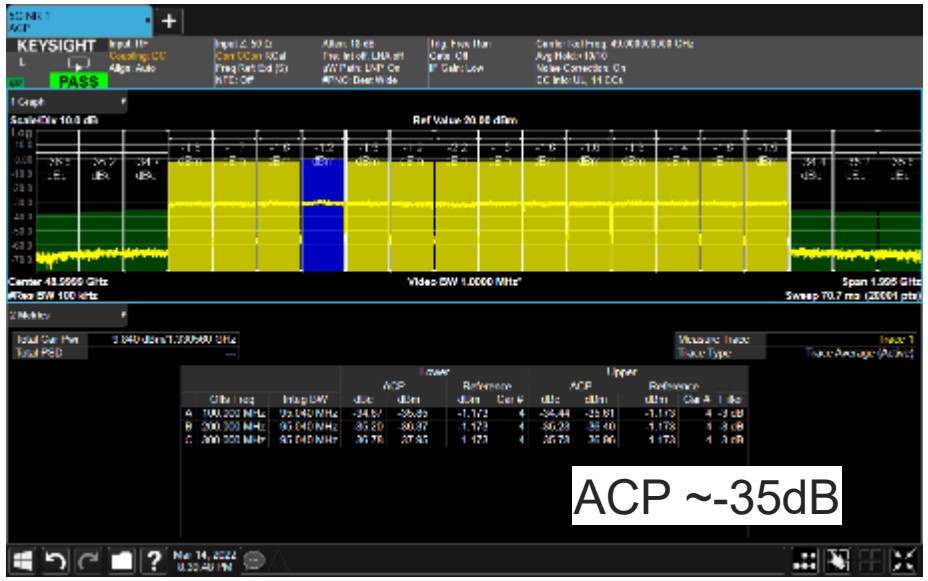


Keysight M9484C – N9042B loop-back connection

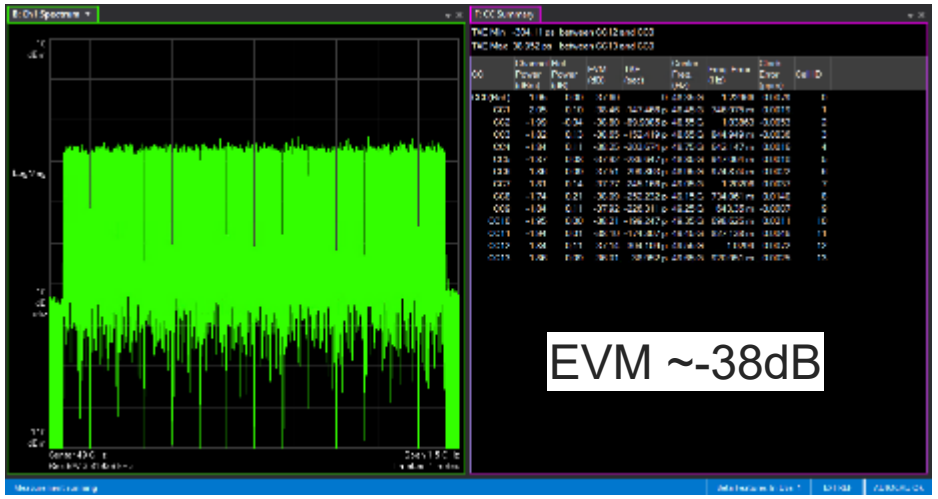
Fc = 49GHz, Pset = 10dBm, 14cc (1.4GHz BW waveform)

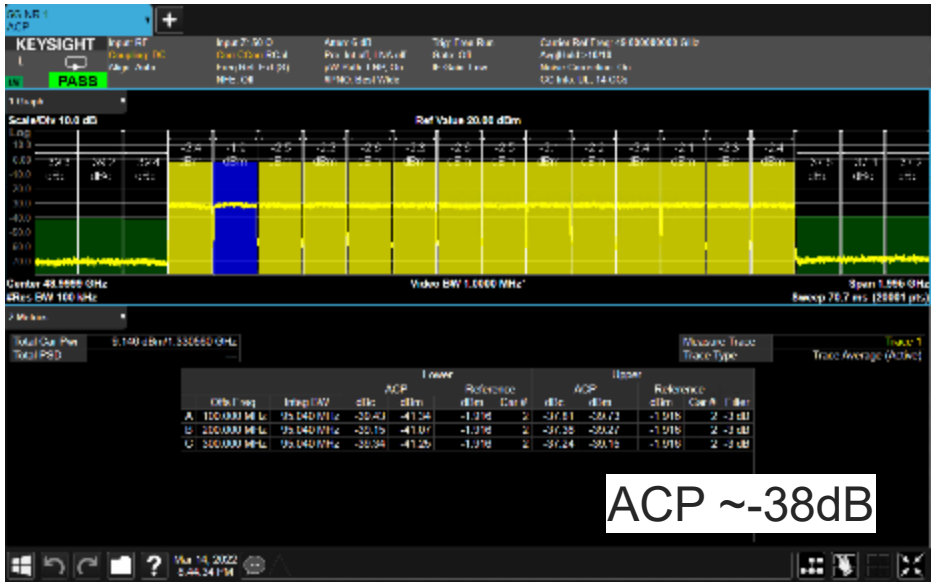
Default performance





After INC (linearize VXG front-end)





Keysight M9484C – N9042B loop-back connection

Keysight Wideband Measurement Solution

Keysight Wideband Measurement Solutions

Signal Analyzer or Wideband Digitizer

Captures wideband signal in **time domain** as **single shot wideband event**

Benefits

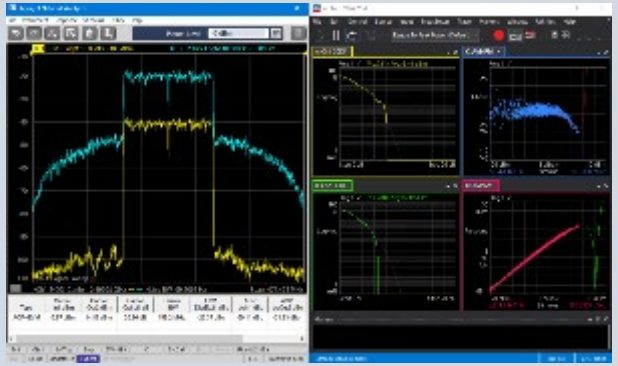
- Captures time-domain dynamic attributes
- Fully compliant with standard algorithms (ex: 3GPP, IEEE, etc.)
- Advanced signal analysis and scope features

Considerations

- Includes contribution of DUT and input signal
- Analysis BW limited by the intrinsic BW of the analyzer

VNA (MOD; Modulation Distortion)

Captures wideband stimulus and response in **frequency domain** with **multiple acquisition**



Benefits

- Vector correction and wide dynamic range allows precise evaluation of small distortion (ex: ACP / EVM / NPR)
- Analysis BW limited only by the signal generator
- Advanced component analysis features

Considerations

- Stational response analysis with repetitive waveform
- Measurement limited by waveform length (<1ms)

Keysight Signal Analyzer and Wideband Digitizer

Signal Analyzer

Box SA (ex. UXA)

- **Wide frequency range** up to 110 GHz
- **Wide BW** up to 4GHz with integrated ADC.
- **In-band and Out-of-band** measurement
- **Signal Conditioning** with preselection and outstanding sensitivity for general purpose measurement of small signals
- **Even wider BW with optional** external scope or digitizer

Transceiver (VXT)

- **Integrated RF source** for transceiver
- **Scalability** by modular platform. optimized for manufacturing and DVT, up to 8x8 MIMO
- **Extend to mmWave** with remote heads

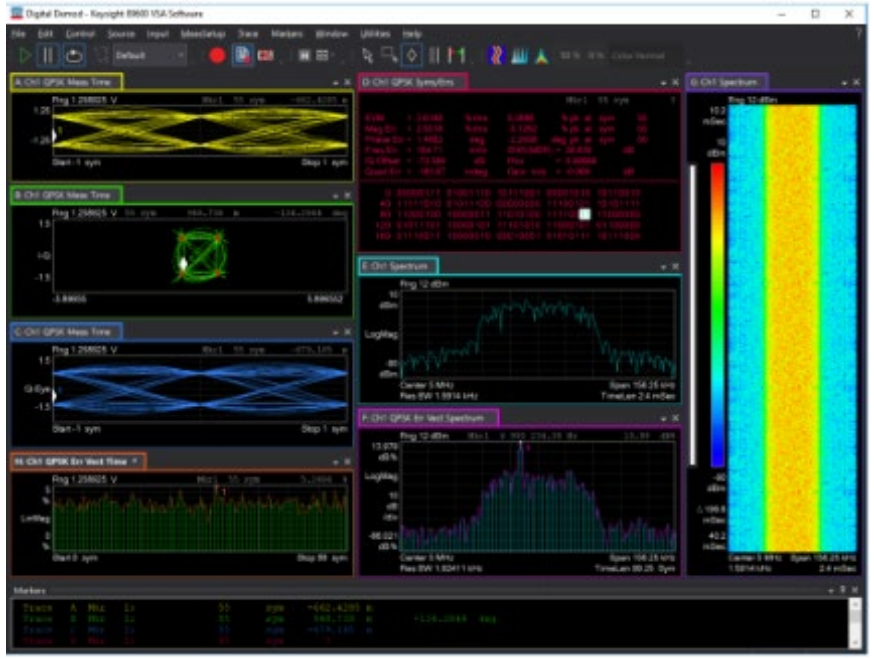
Wideband Digitizer

Scope (ex. UXR)

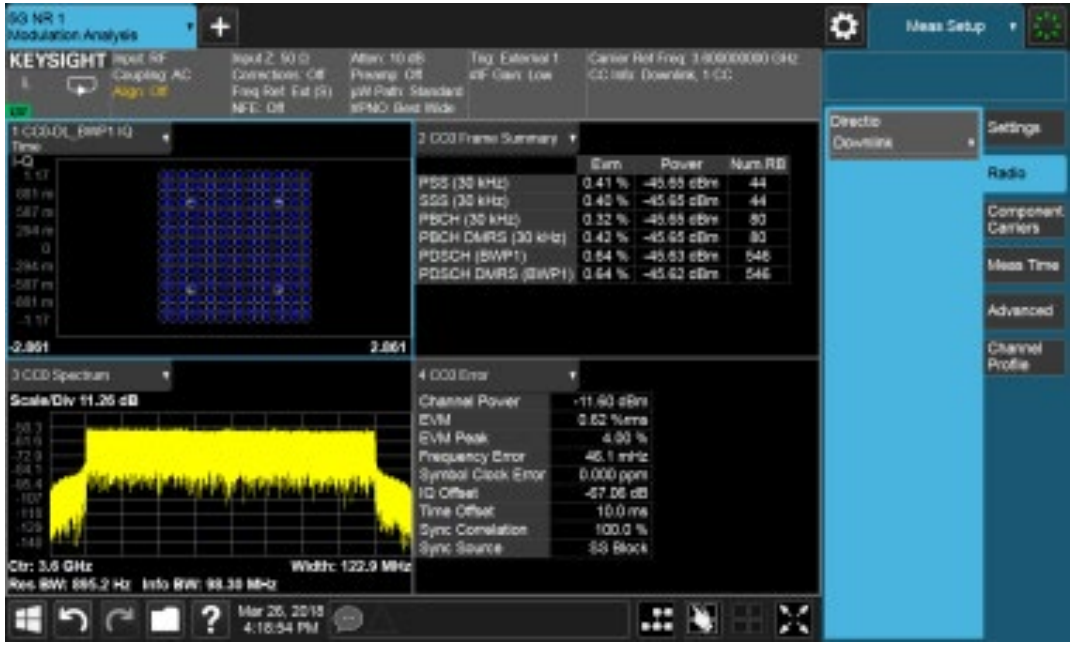
Digitizer

- **Extremely wide bandwidth** up to 110 GHz
- **In-band measurements** (in addition to EVM, BBIQ/front haul and time domain are available)
- **Muti-channel (Up to 4 channels)** for advanced applications (MIMO, cross correlation, delta EVM, angle of arrival)

Keysight Signal Analysis Software Solutions

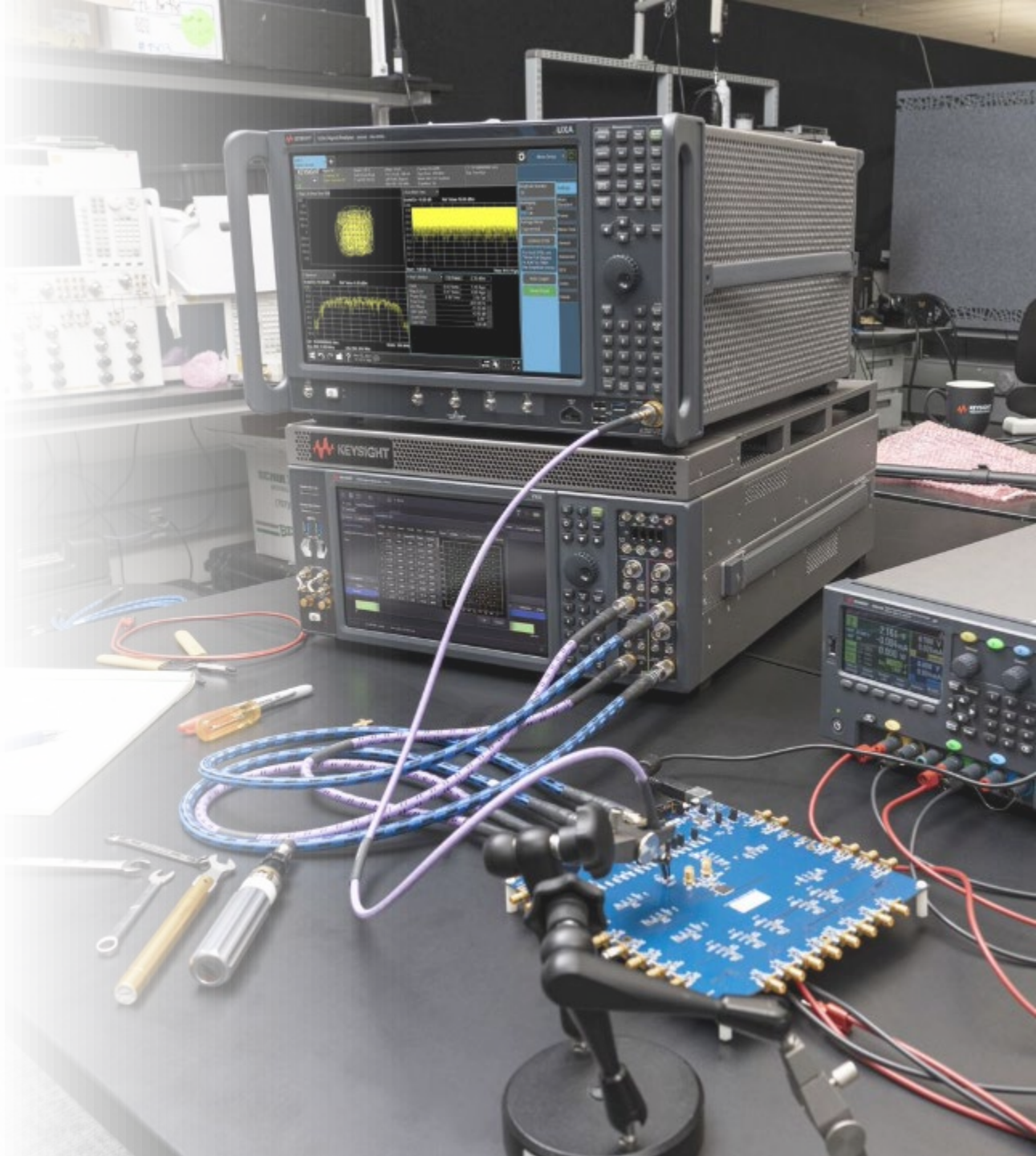


PathWave 89600 Vector Signal Analysis:
Explore every facet of a signal and optimize your designs. Measure a broad range of signals, and gain greater insight in frequency, time and modulation domains.
Available on Signal Analyzers, Transceivers, Digitizers, Scopes, and VNAs



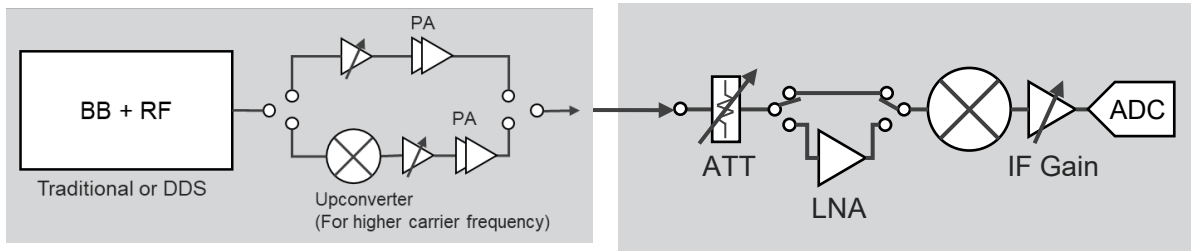
PathWave X-Series Measurement Applications:
Proven and ready-to-use measurements for signal analysis that let you see and understand the performance of your devices and designs.
Available Signal Analyzers and Transceivers.

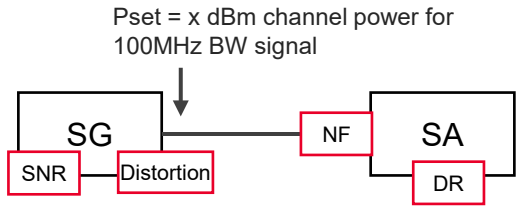
Summary

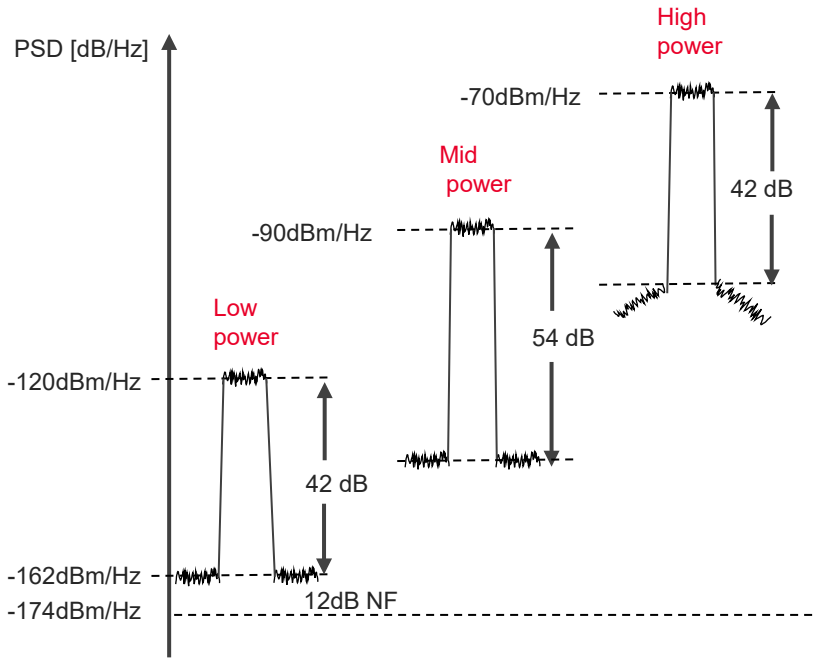


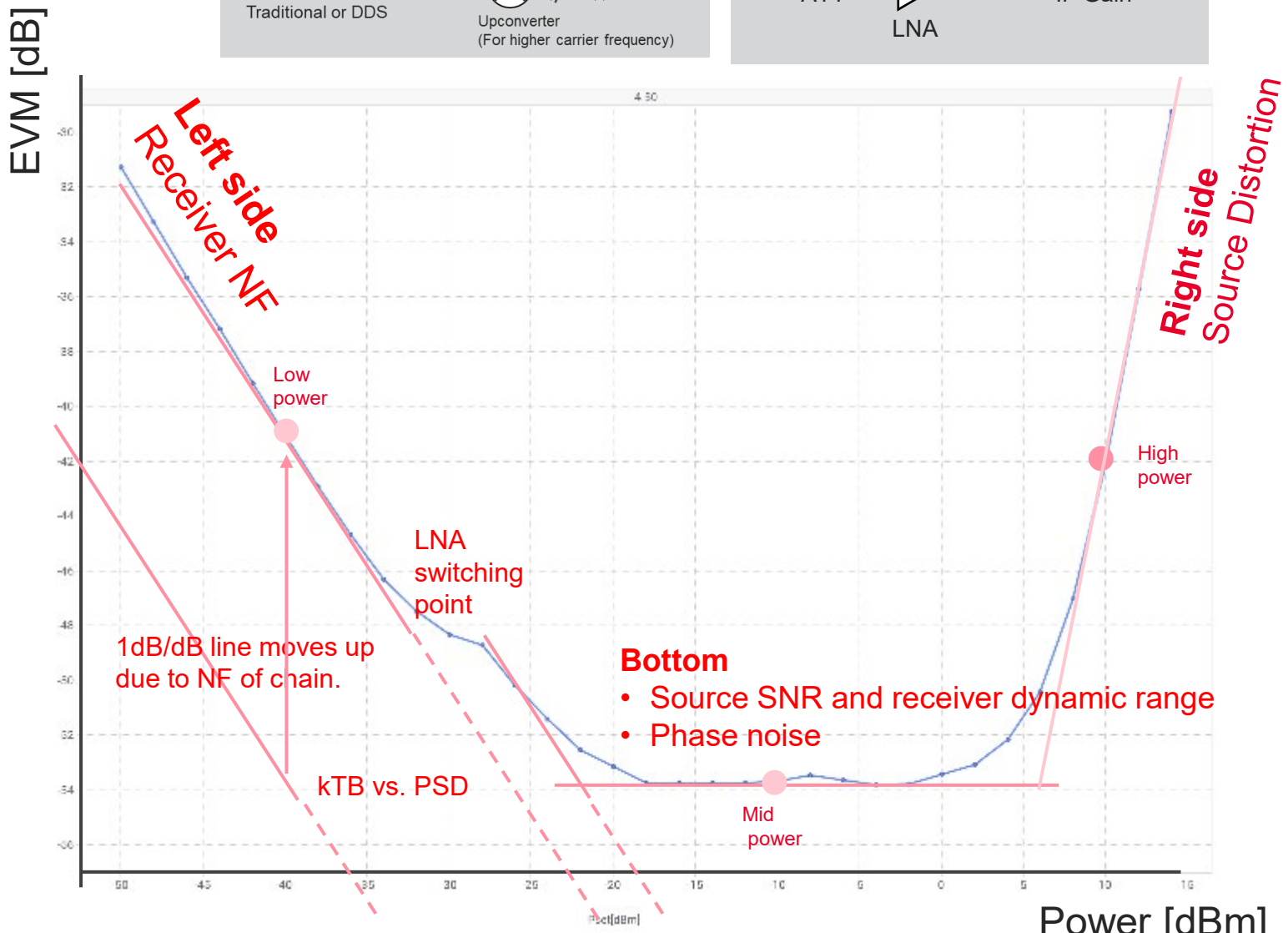
EVM Loop-back Bathtub Curve

Simplified source and receiver block diagram









Key Takeaway

- EVM Loop-back measurement on high-end test equipment is representation of SNR and distortion of entire RF chain
- Appropriate internal hardware control is needed to maximize the performance
- Latest test equipment has sophisticated features to optimize internal hardware
  - Optimize EVM (Table/Algorithm and Iterative)
  - Instrument Nonlinear Correction
- Multiple measurement choices for modulated signal analysis

Thank you

Q&A