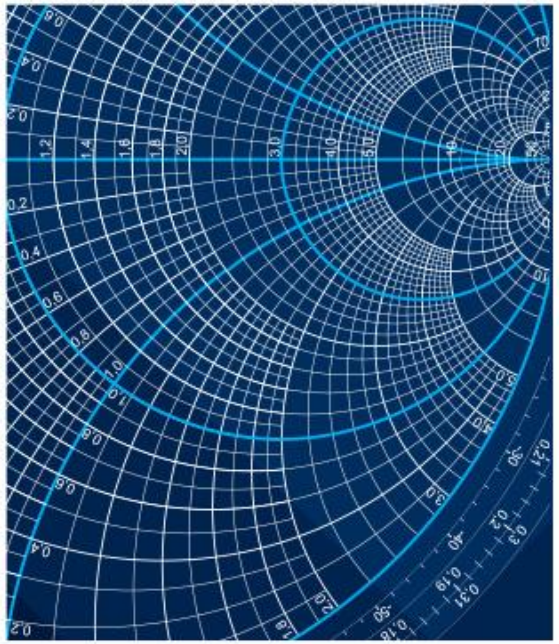


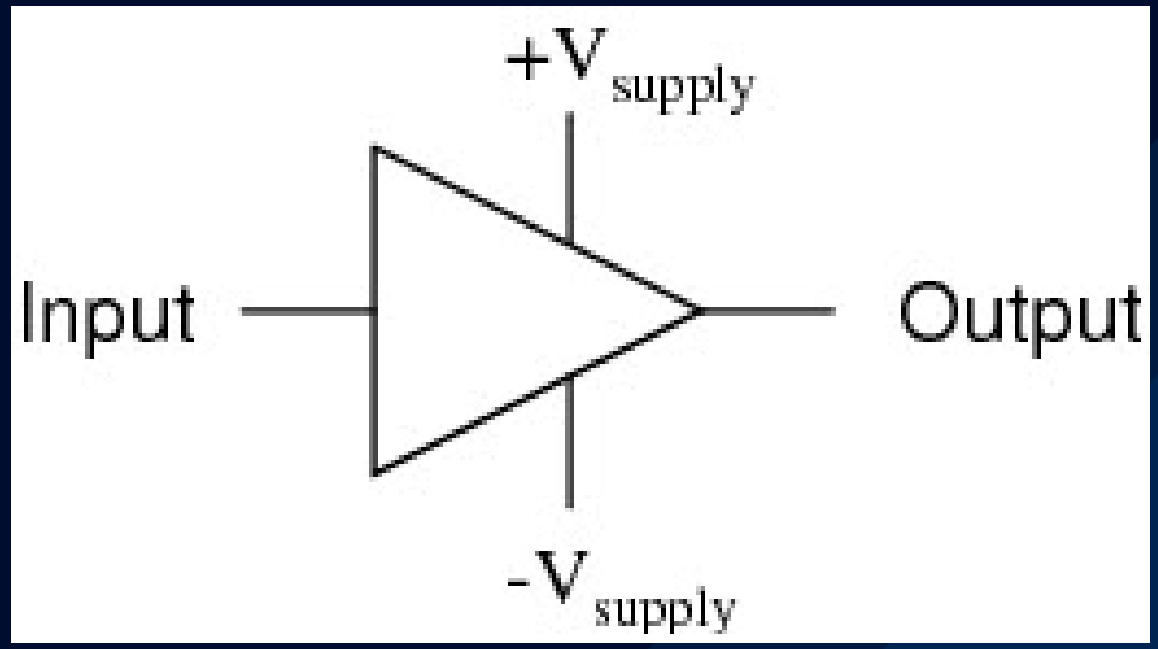
Measurement Techniques

Design Verification & Evaluation

EVERYTHING TEST

Instrument Selection & Optimization

RF TEST:
Amplifier Test Fundamentals



Martin C Lim, Application Engineer

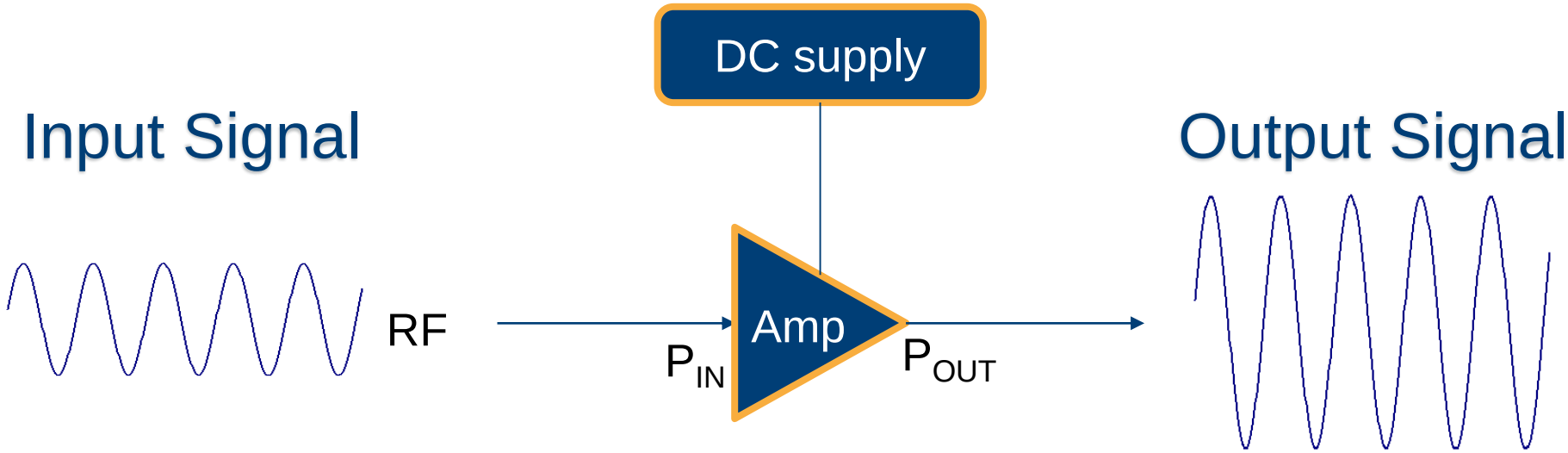
ROHDE&SCHWARZ

Make ideas real

Contents

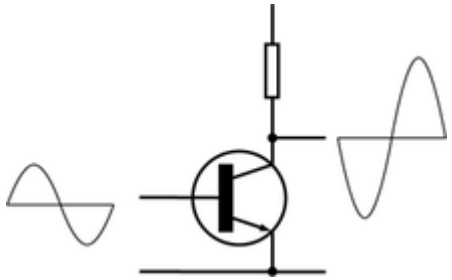
What is an amplifier

- An **amplifier** is an electronic device that can increase the power of a signal
  - Signal: a time-varying voltage or current.
- It is a two-port electronic circuit.
- Electric power from a power supply to increase the amplitude of a signal applied to its input terminals, producing a proportionally greater amplitude signal at its output
- An active device the takes an input signal and outputs a signal that is a copy of the input signal, but having a increased amplitude

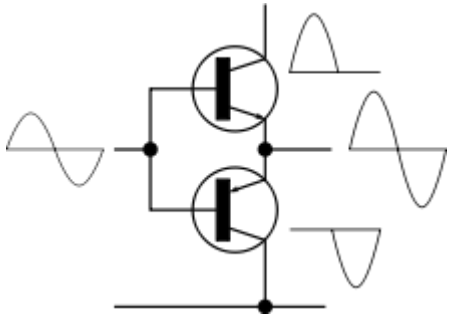


https://en.wikipedia.org/wiki/Amplifier

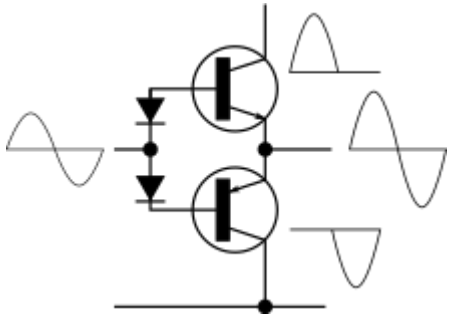
Amplifier Types



- Several types of RF amplifiers
  - Broadband; Gain Block; Log; Variable Gain; Low Noise; Linear; DC Coupled;

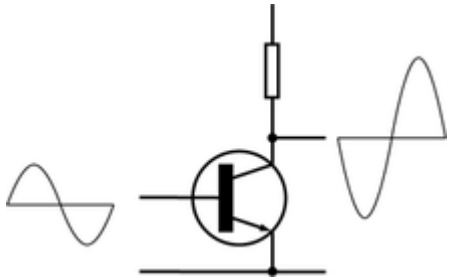


- Fixed Amplifier Parameters:
  - Amplifier Class
  - Gain
  - Frequency Range
  - Output power



- ‘Smart’ amplifier varies parameters

Amplifier Types



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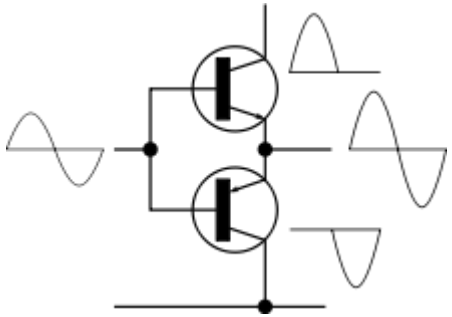

- Fixed Amplifier Parameters:
  - Amplifier Class
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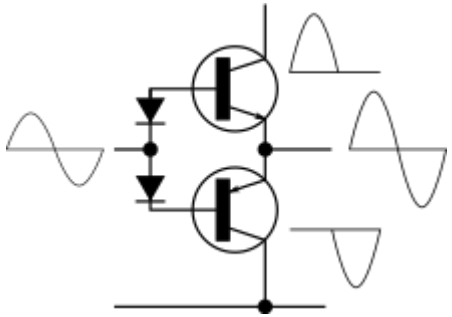
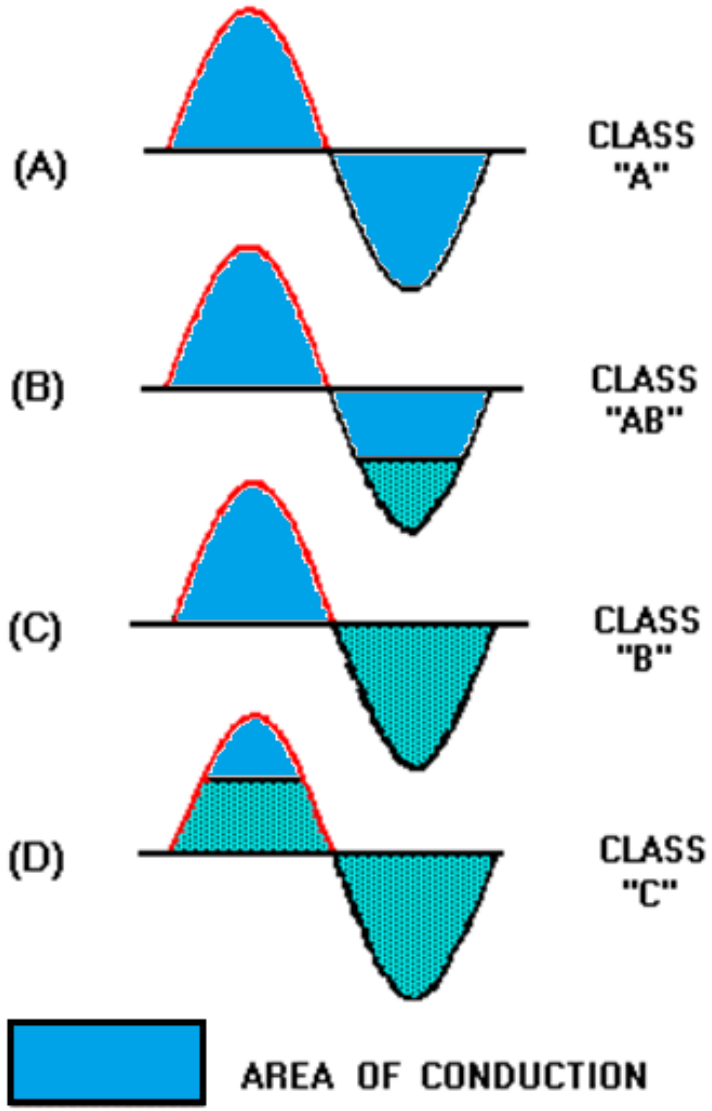
  - Output power



- ‘Smart’ amplifier varies parameters

Power Amplifier Class

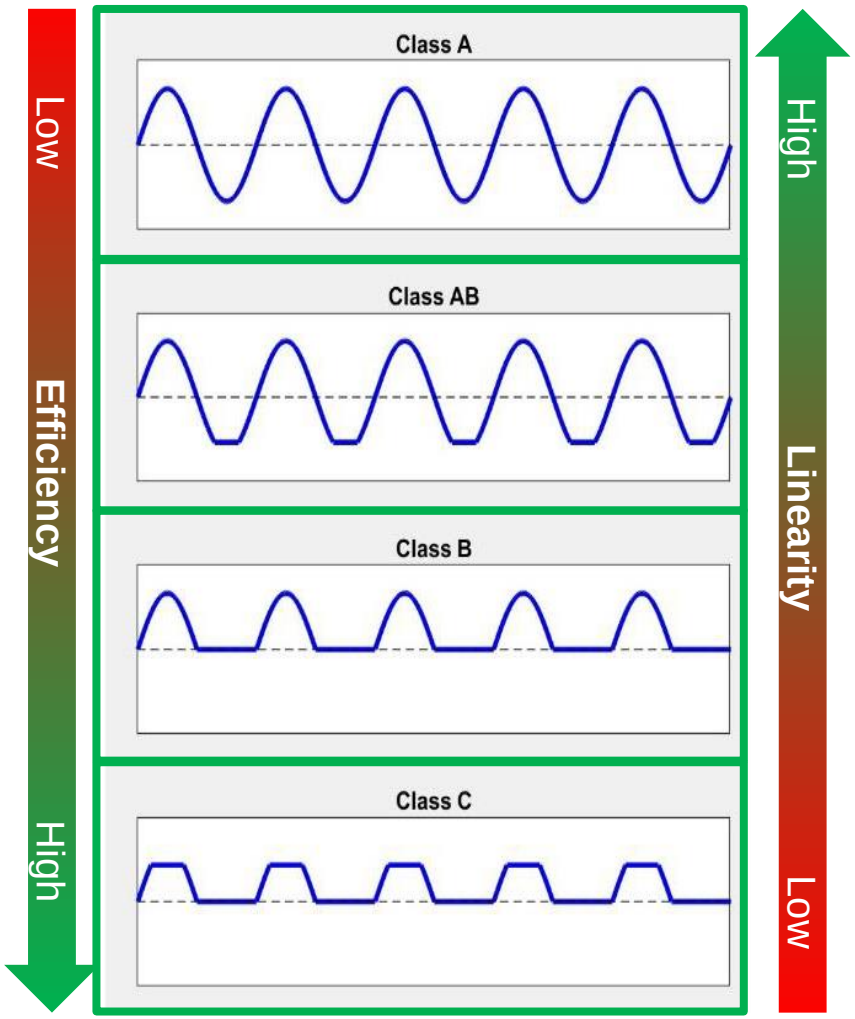


Conduction Angle

- Performance is a function of the amplifier class
- Defined by % time it is conducting power
- Conduction angle↕ = linearity ↑ efficiency ↓

	Conduction Angle
Class A	360°
Class B	180°
Class AB	180° to 360°
Class C	<180°

Power Amplifier Class



Conduction Angle

- Performance is a function of the amplifier class
- Defined by % time it is conducting power
- Conduction angle↕ = linearity ↑ efficiency ↓

	Efficiency	Linearity
Class A	50%	High
Class B	78%	Low
Class AB	50% - 78%	Mid
Class C	80%	Low

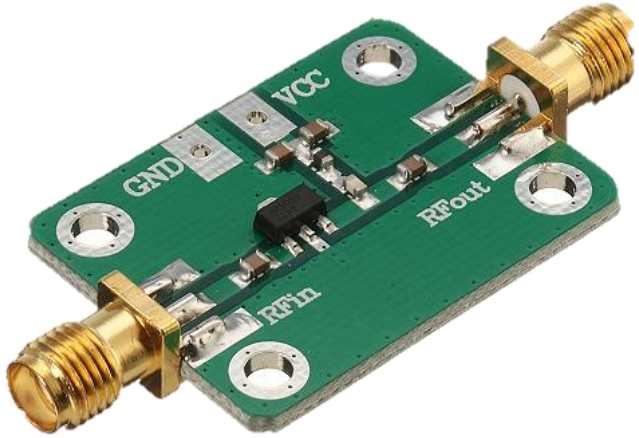
Low Noise Amplifier (LNA)

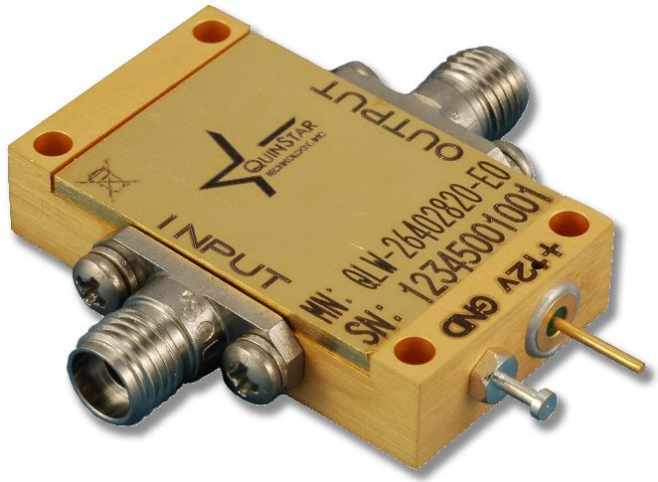
Characteristics

- Part of Receiver
- Low Noise: NF < 2
- Lower input power
- Operation Type: Class A

Common LNA Tests

- Gain
- Intermodulation Distortion (IMD)
- Noise Power Ratio
- Noise Figure





Power Amplifier (PA)

Characteristics

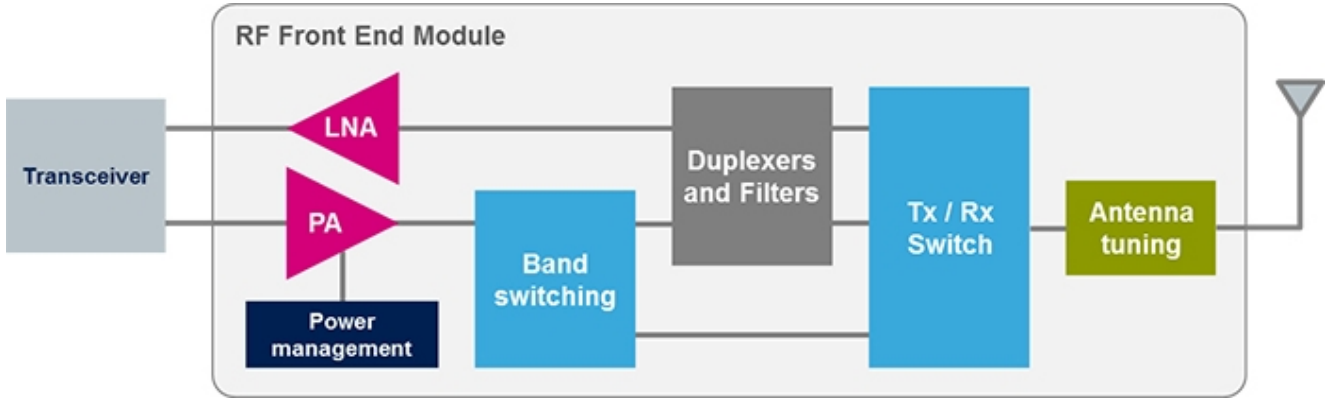
- Part of Transmitter
- High output power (Heatsink)
- Operation Class Varies

Common PA Tests

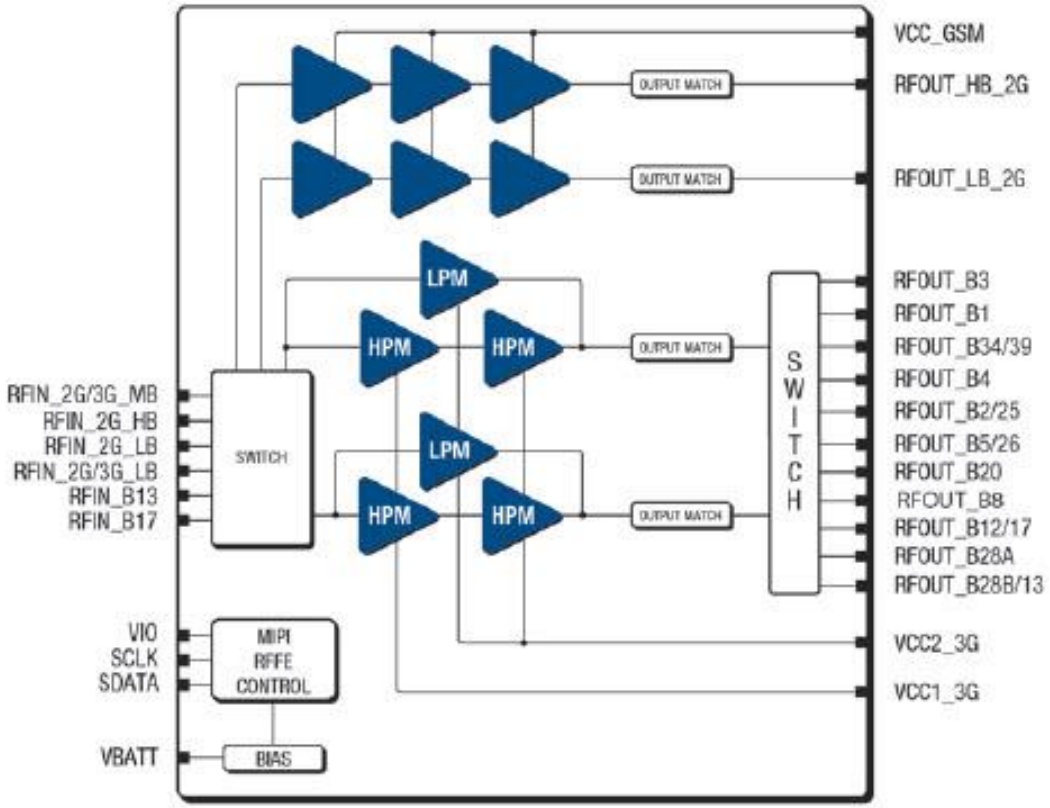
- Gain (Compression)
- ACLR
- Input/Output Match
- Power Efficiency
- Distortion (AM/AM, AM/PM)
- Load Pull
- Noise Power Ratio

RF Front-End Module

- Integrated Rx & Tx
- Several Components
  - LNA
  - PA
  - Filters
  - Switches
  - Antenna Tuner

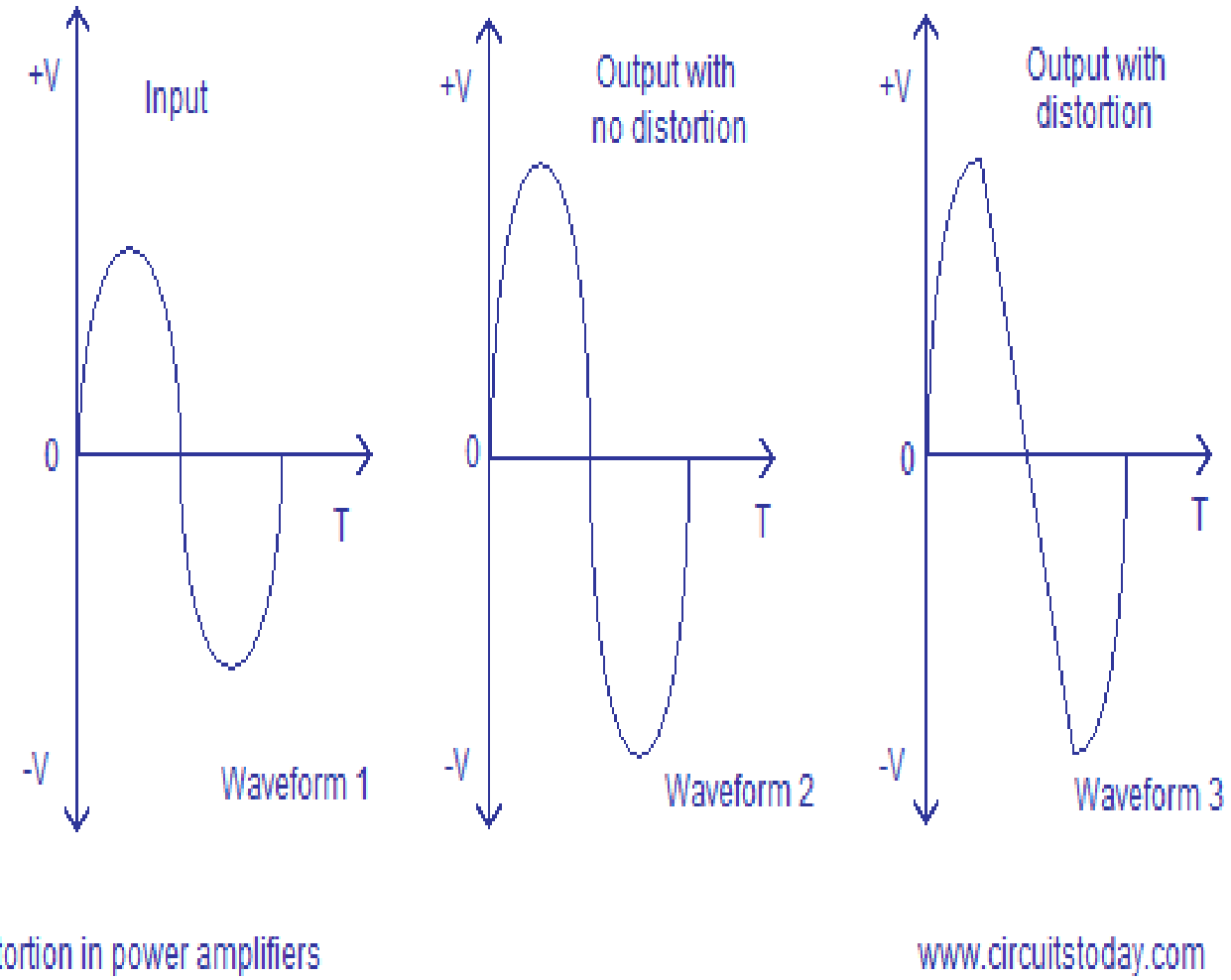


Source: https://www.st.com/



Source: https://www.skyworksinc.com/Products/Amplifiers/SKYA21055

Why do we test?



Distortion in power amplifiers

www.circuitstoday.com

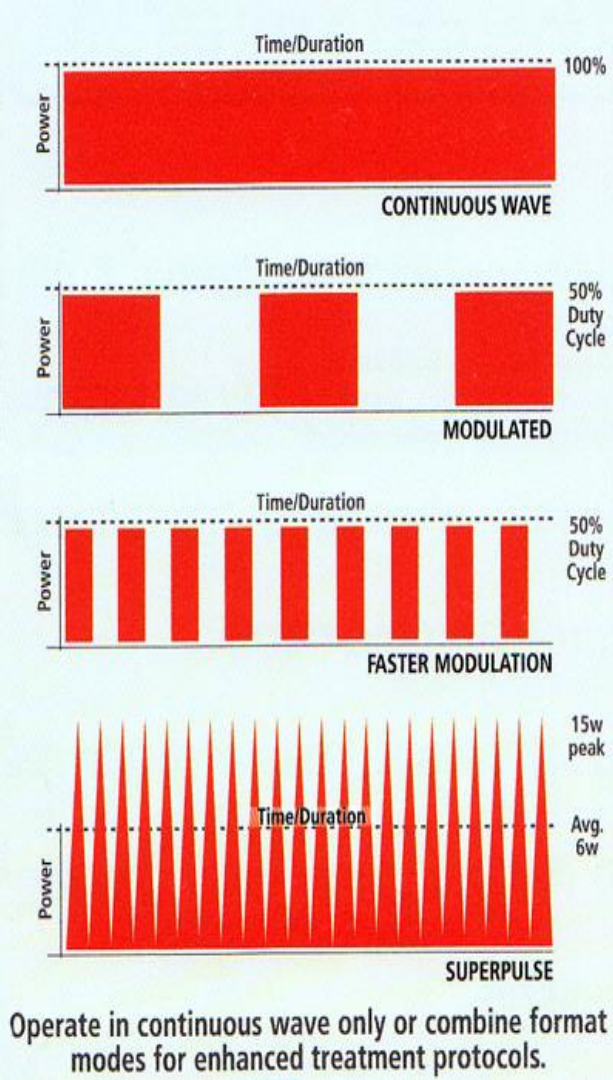
Verify Performance

- Does measurement match spec?
- Does part match simulation?
- Does part meet application?

Identify Distortion

- Measure signal quality
  - Gain Compression
  - Spectral Regrowth
    - ACLR; IMD; Harmonics
  - AM & PM Distortion
- Provide insight to correct issue

How do we test?



Continuous Signals

- Unmodulated
  - Continuous Wave (CW) sweep
    - Start/Stop Frequency Start Stop Step
    - Amplitude
  - Multi-Carrier CW
    - Several CW signals generated across a frequency range
- Modulated Signals
  - Real-world representation for amplifier testing,
  - Uncovers dynamic effects of amplifiers behaviors with real-signals

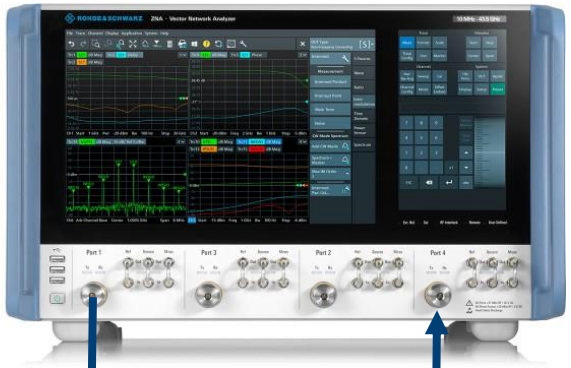
Non Continuous (Pulsed) Signal

  - Application specific amplifiers (i.e. Radar)
  - High power device

Example Test Setup

- Typically done using a VNA or Signal Generator + Spectrum Analyzer combination

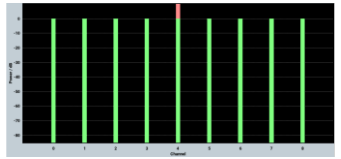
VNA



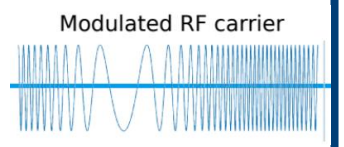
Single CW Swept through frequency range

Signal Generator + Spectrum Analyzer

or



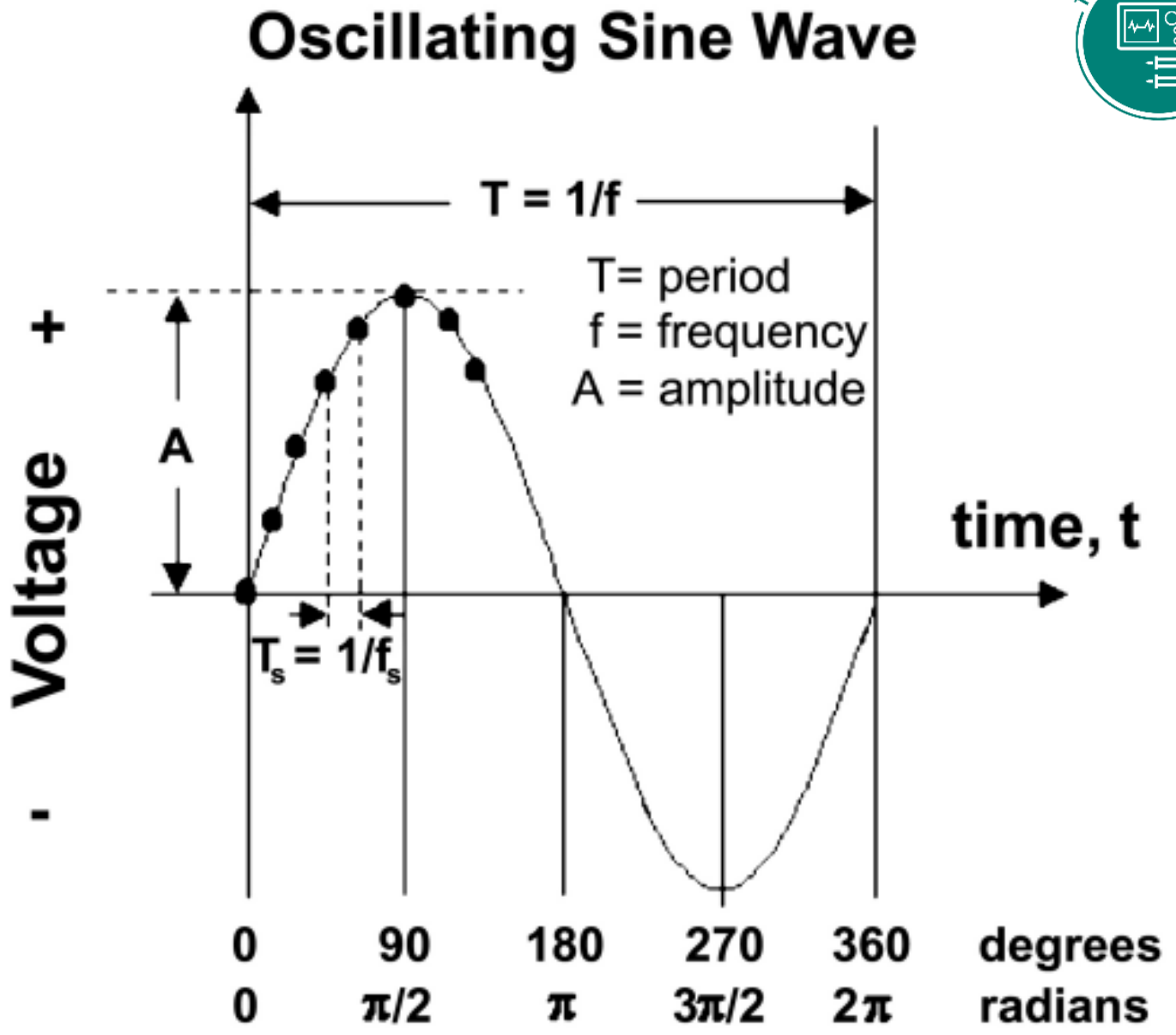
or



Single CW Swept through frequency range

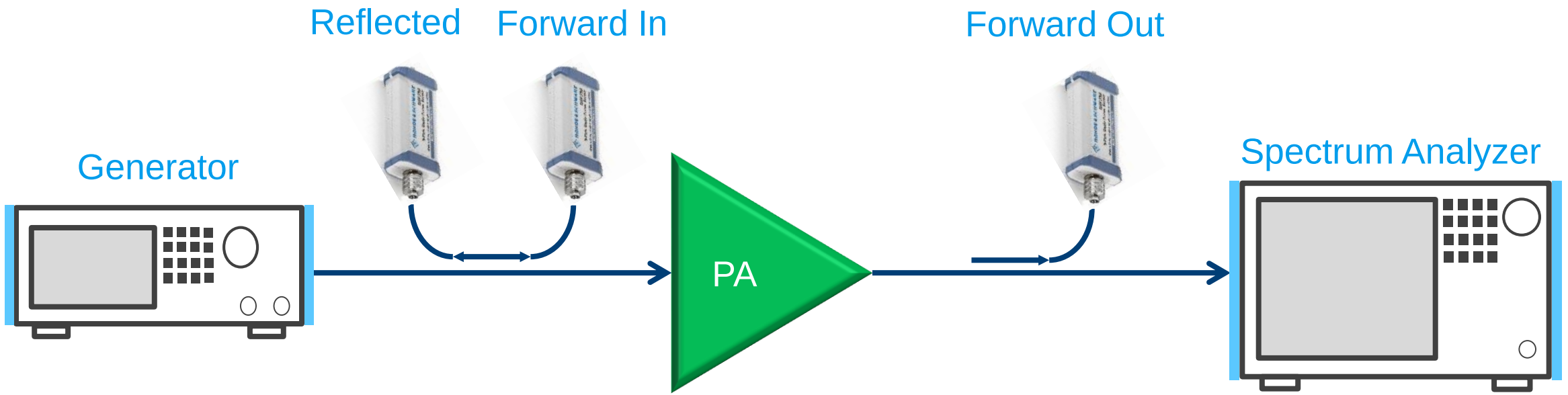
Multi-Carrier CW

Contents

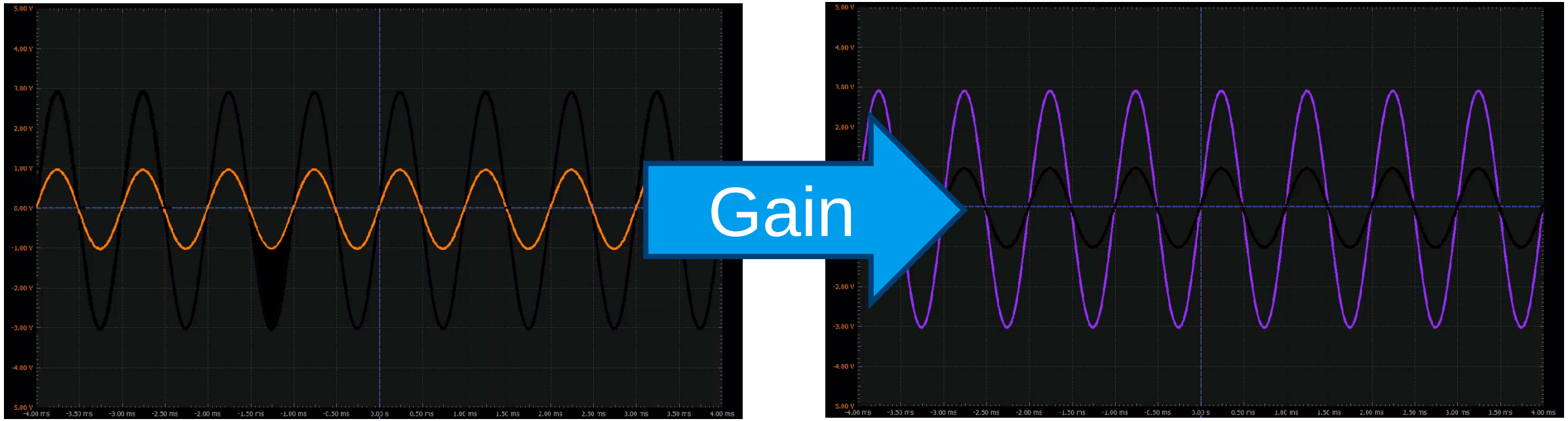


Typical CW Setup

- Power meters offer highest accuracy
- NRP series is recognized in the industry as fast and accurate



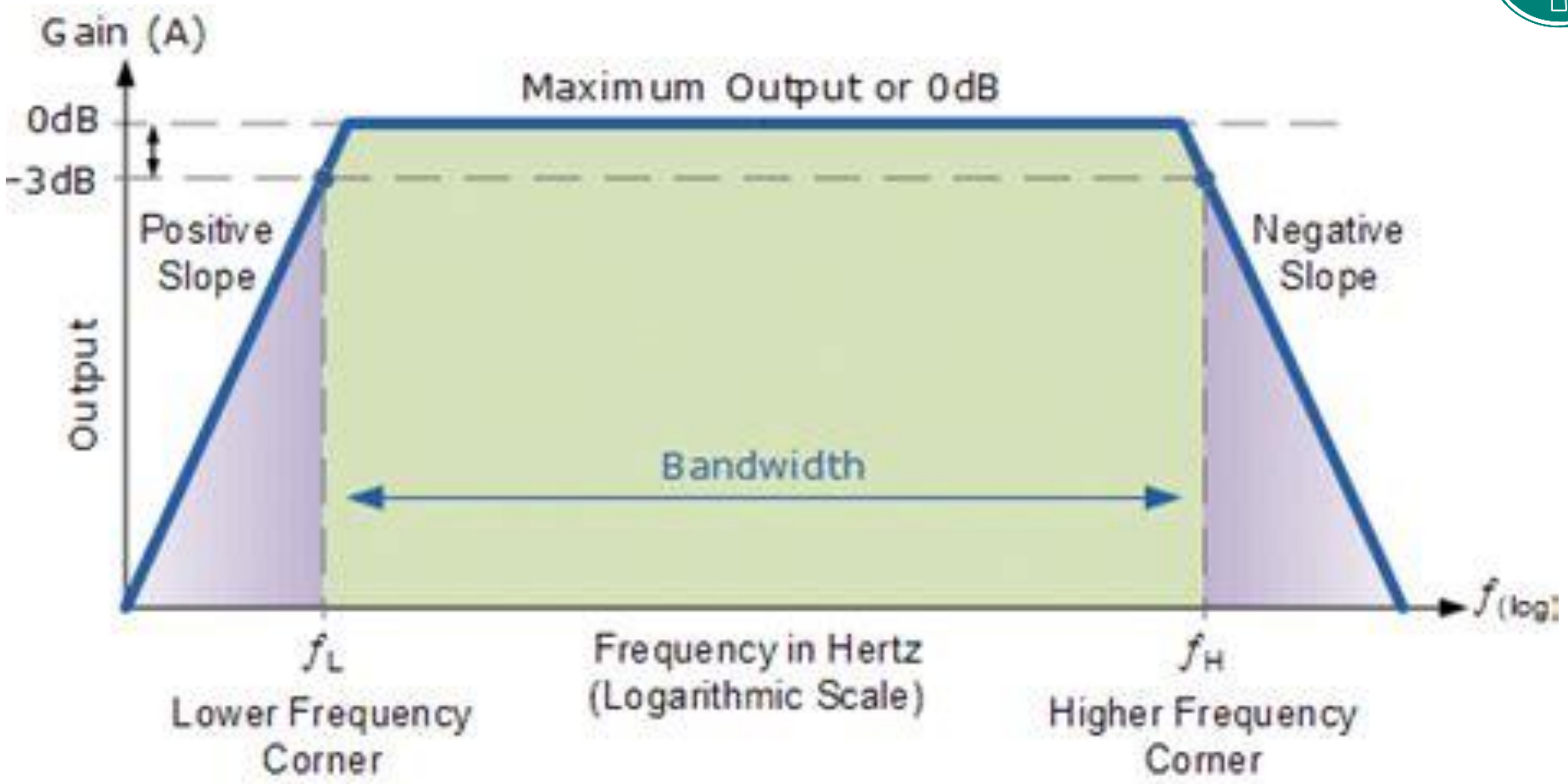
Gain



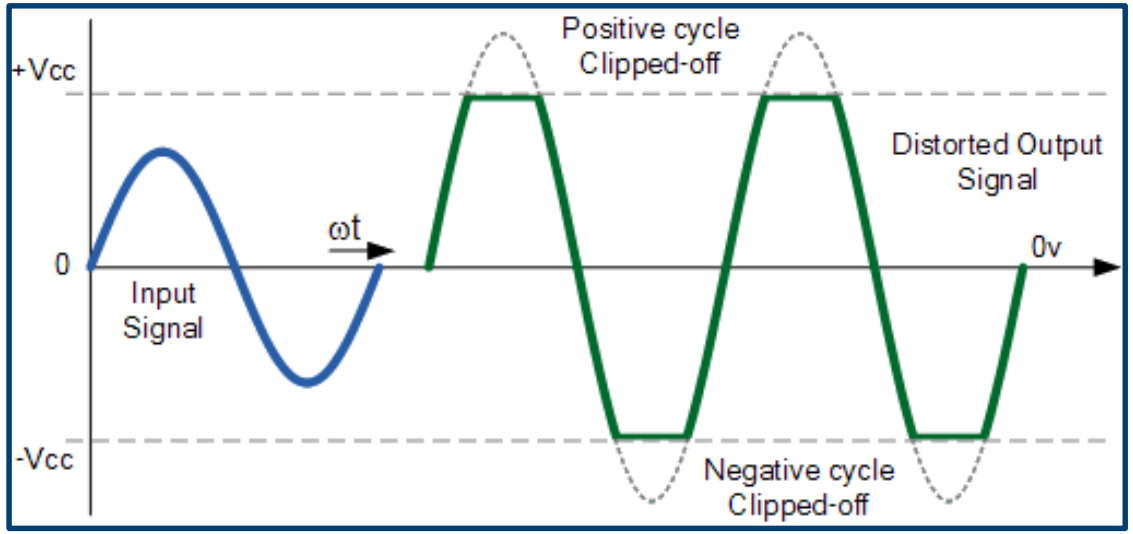
Amplifiers: Increase Amplitude/Power

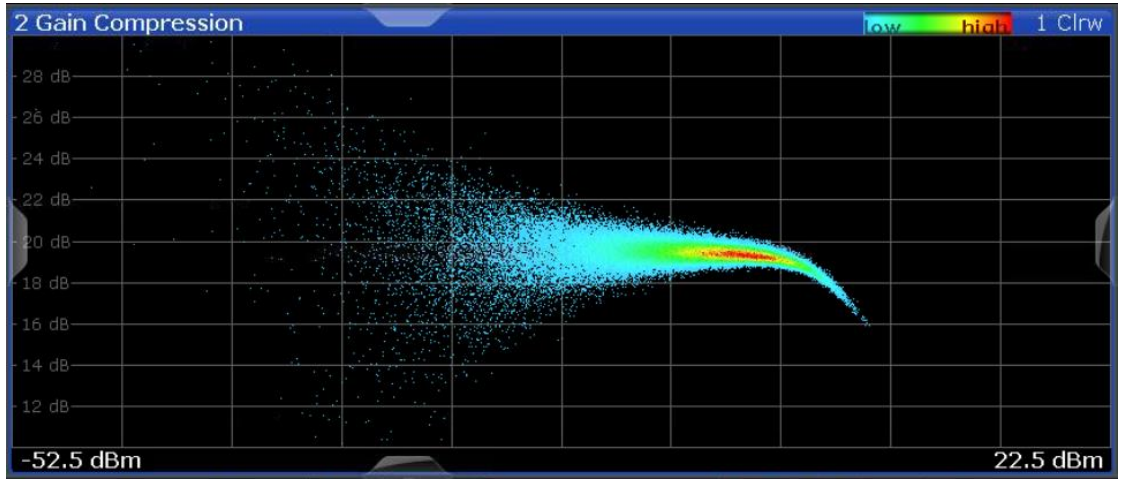
Gain = Output Power – Input Power

Frequency response



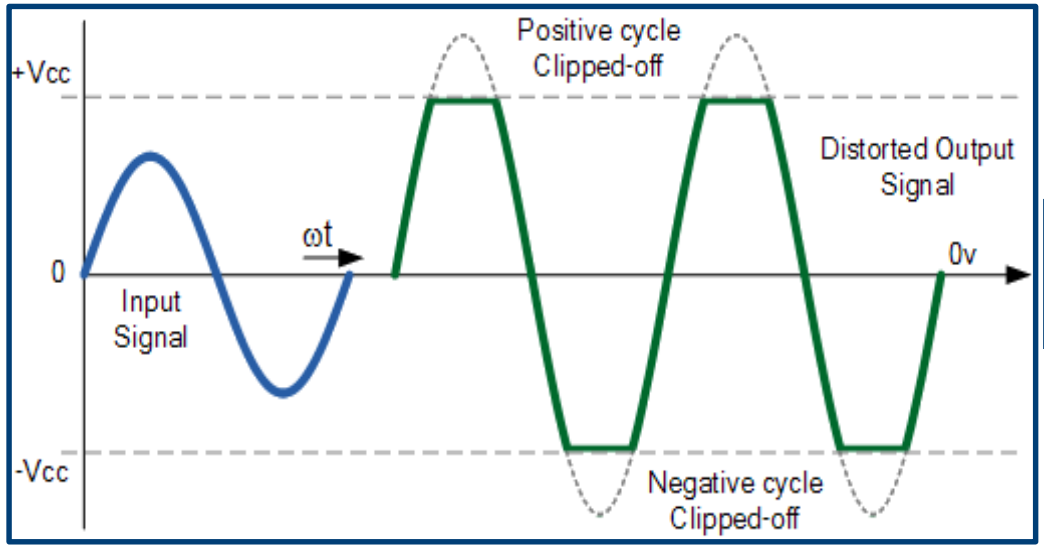
Gain Compression, P1dB

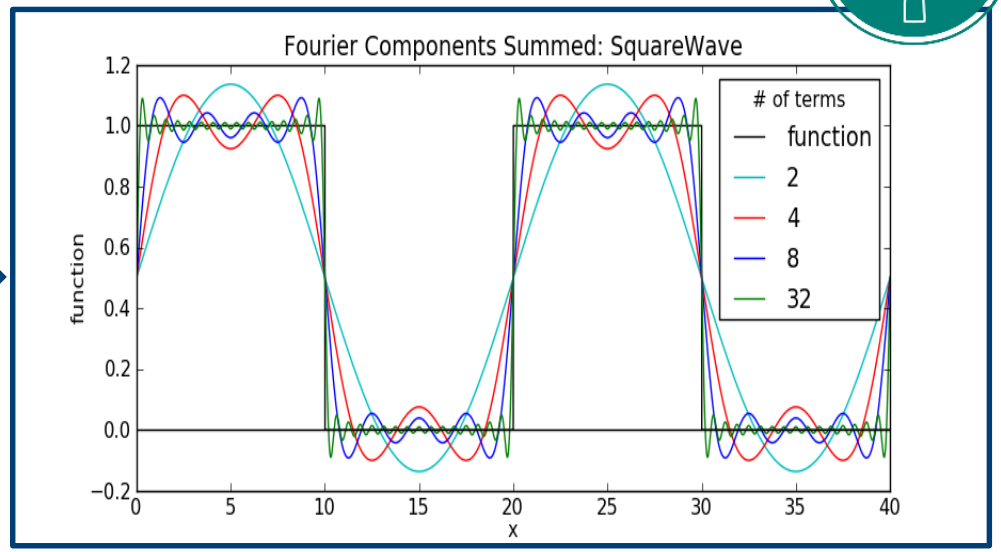




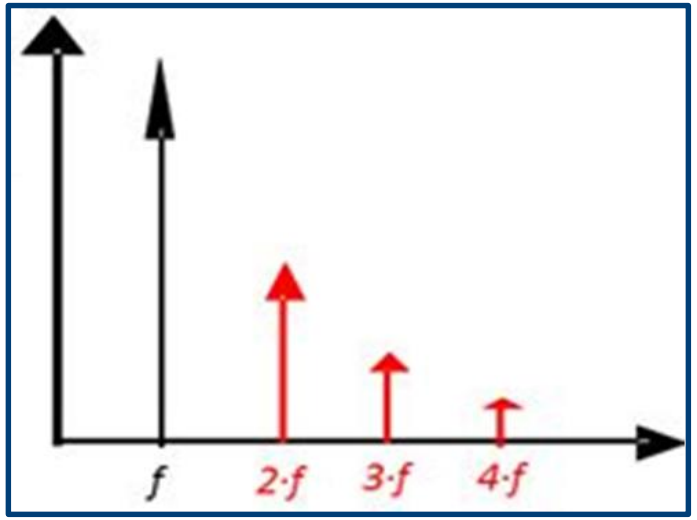
- DC (Source) Power is limited
- Eventually we reach the limit
  - Output Pwr Fixed
  - Input Power ↑
  - Gain = Out / In
  - Gain ↓
- P1dB: 1dB deviation from linear gain

Harmonics

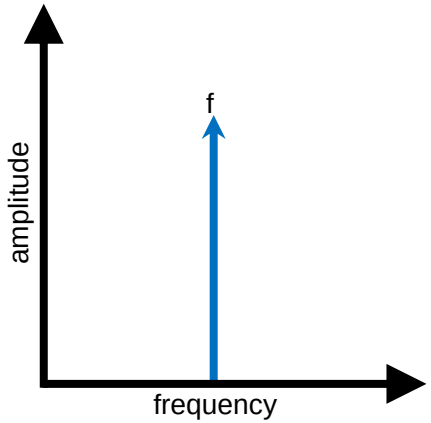


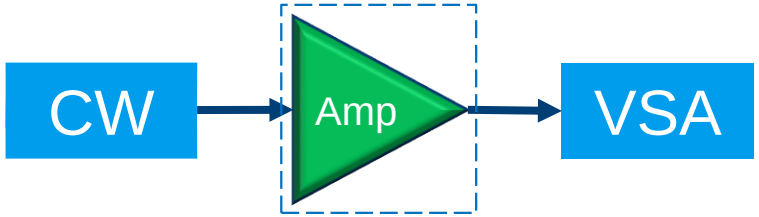


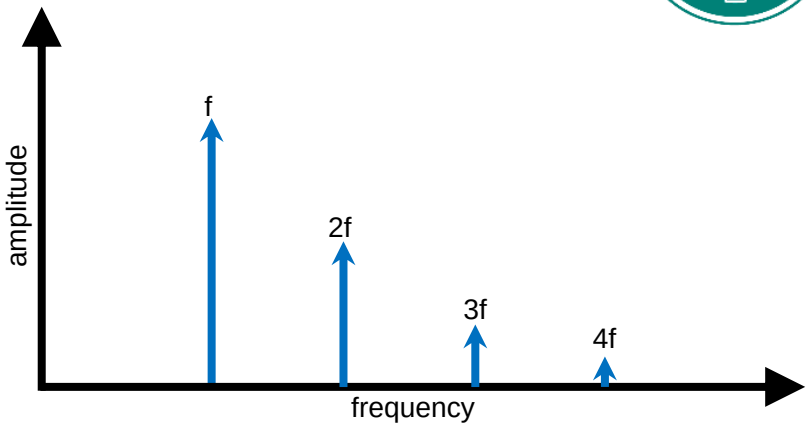
- Clipped Signal: Sine Wave → Square Wave
  - Sine Wave → No harmonics
  - Square Wave → ∞ Odd Harmonics



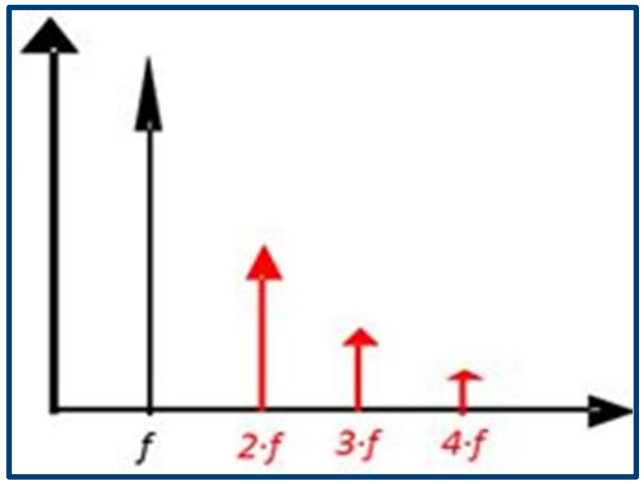
Harmonics

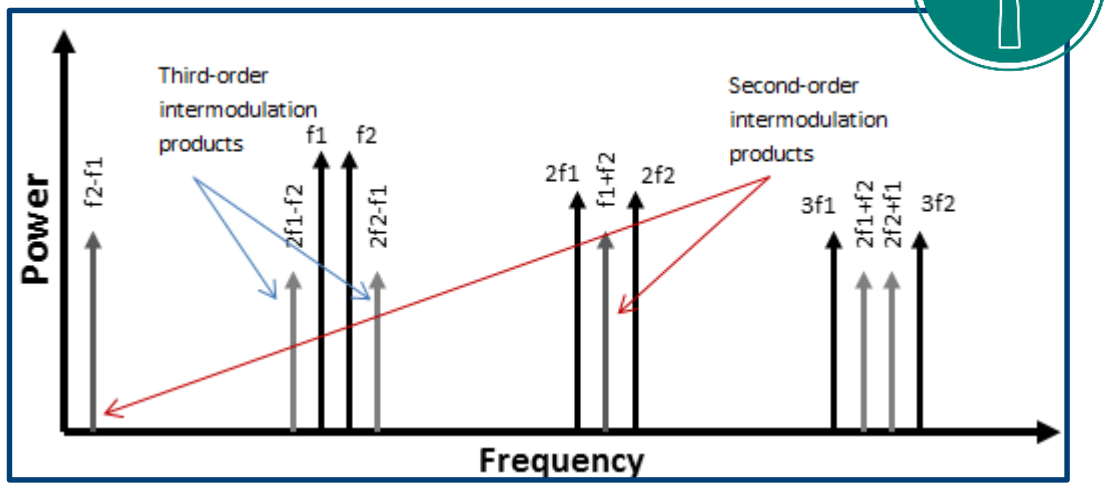

f
amplitude
frequency


CW
Amp
VSA


f
2f
3f
4f
amplitude
frequency

Intermodulation Products: IMD; IP2; IP3





Signals:

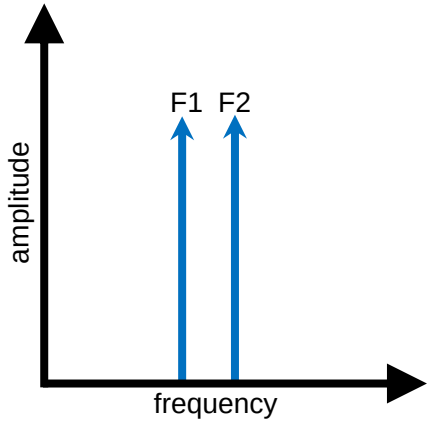
- Fundamental
- Harmonics
- Internal LO(s)

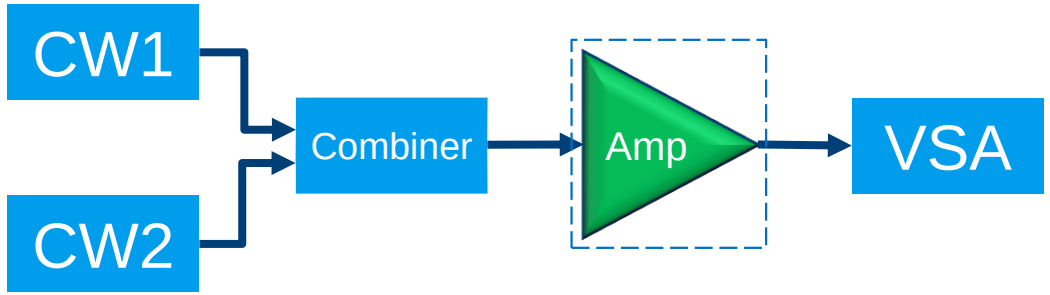
These signals can mix

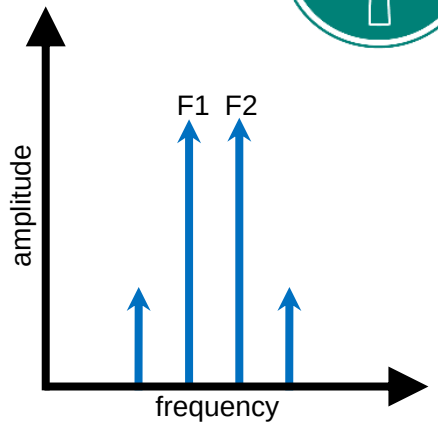
Intermodulation Products:

- IP2:
  - LO + Fundamental
  - Harmonic
- IP3:
  - Harmonic + LO
  - Harmonic + Fundamental

Intermodulation Products: IMD; IP2; IP3



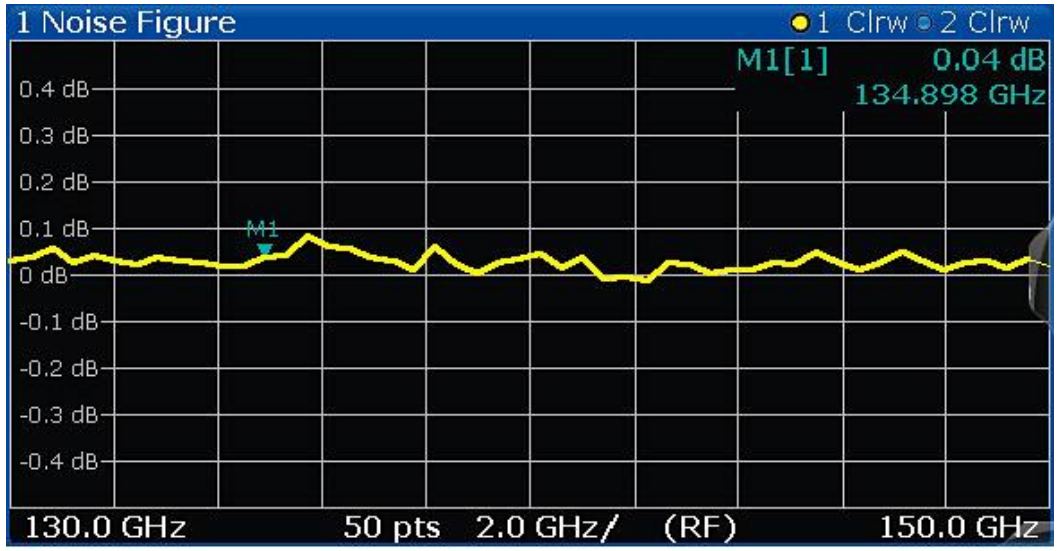


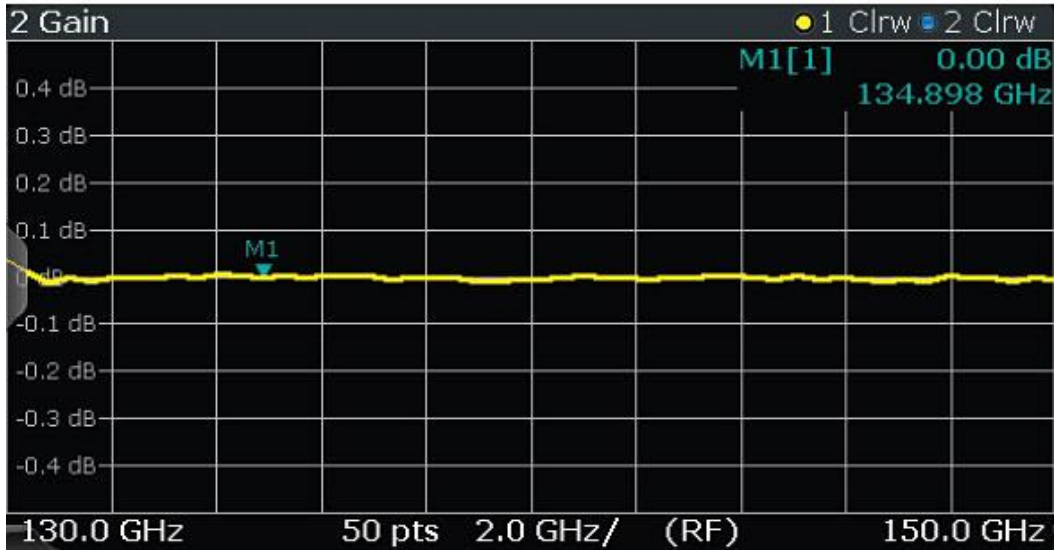


Intermodulation Products:

- IP2:
  - LO + Fundamental
  - Harmonic
- IP3:
  - Harmonic + LO
  - Harmonic + Fundamental

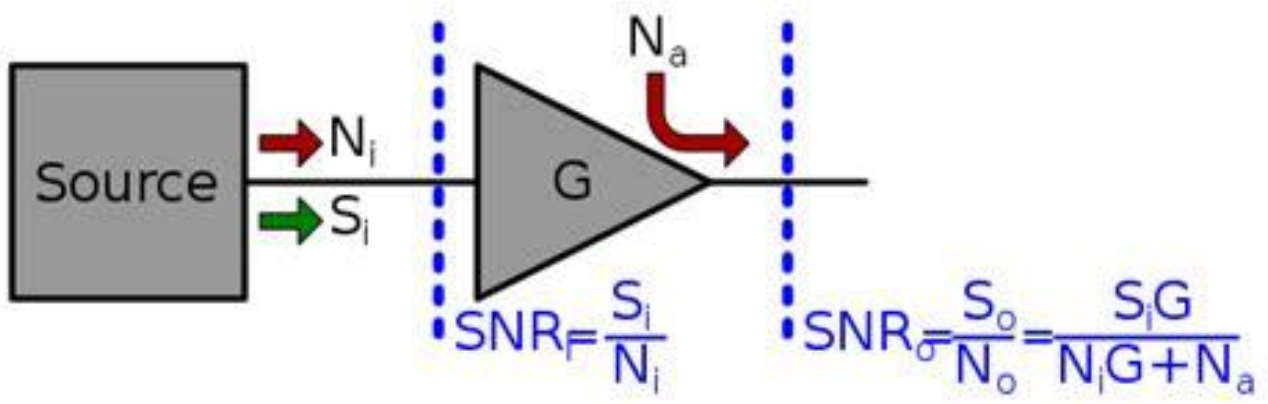
Noise Figure (LNA)



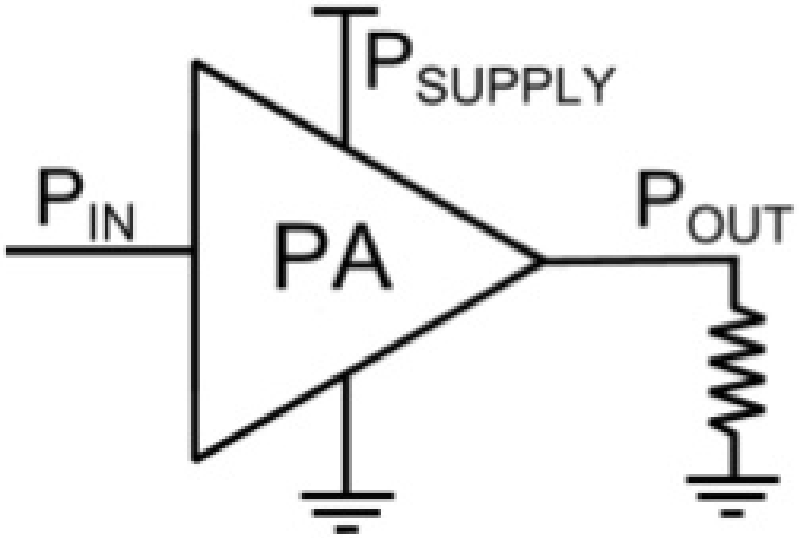


Noise Figure

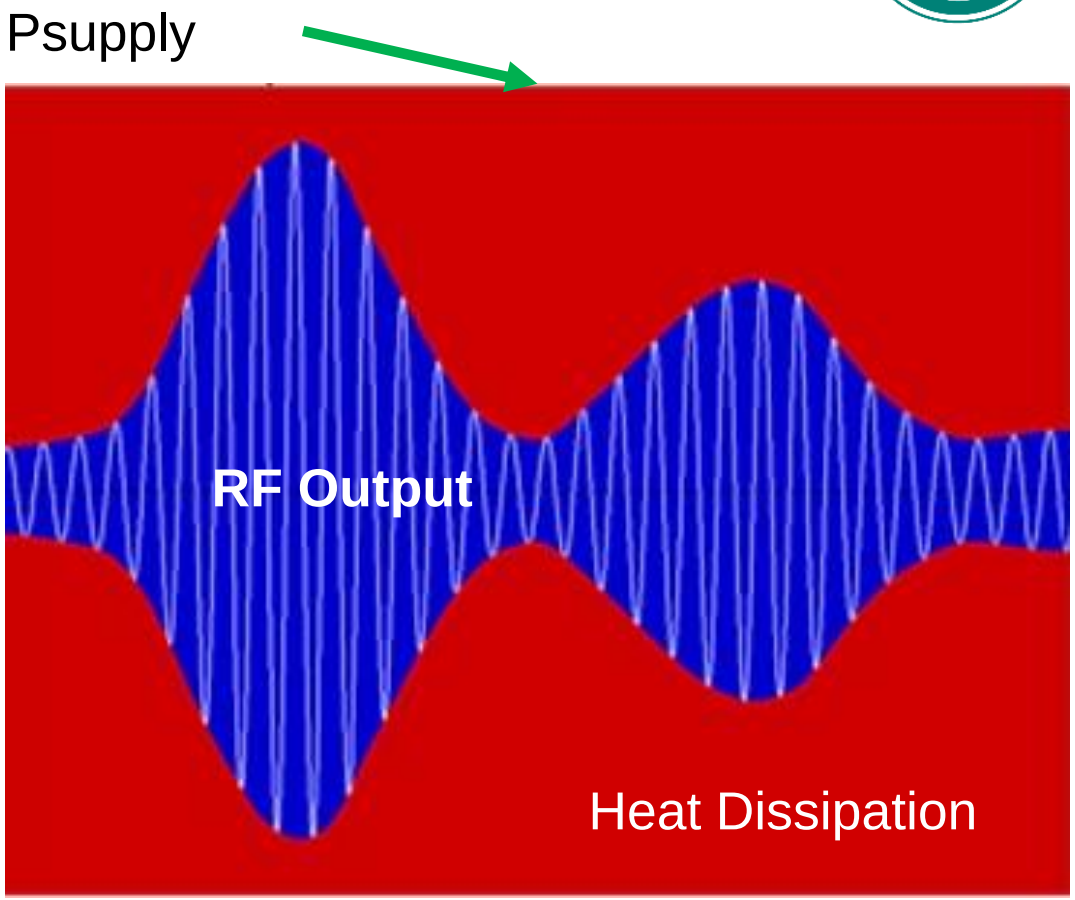
- Active components increase noise floor
- How much does this amplifier add?



Power Added Efficiency (PAE)

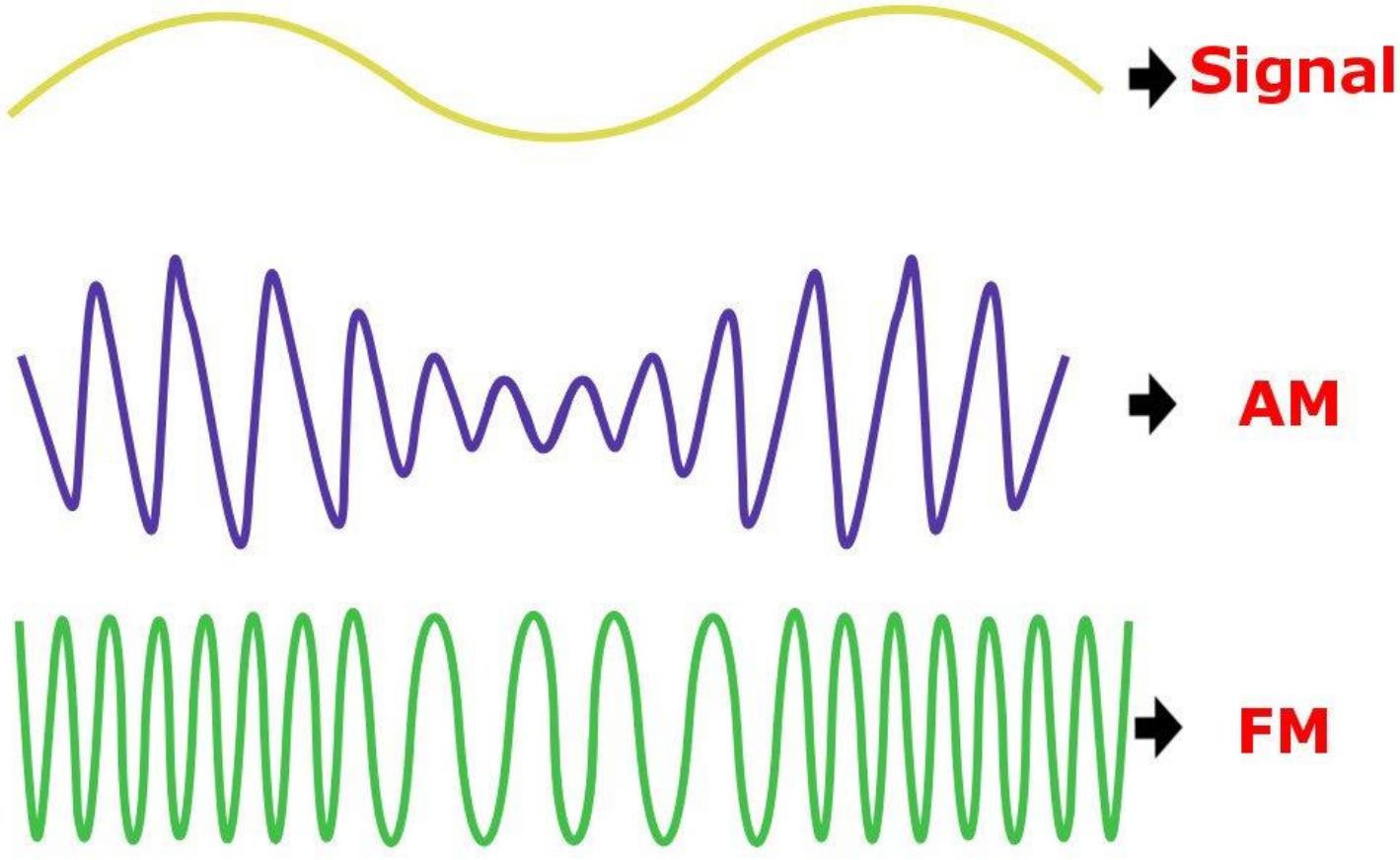


$$PAE = \frac{P_{out} - Pin}{V_{supply} * Isu_{pply}} = \frac{RF_{gain}}{P_{supply}}$$



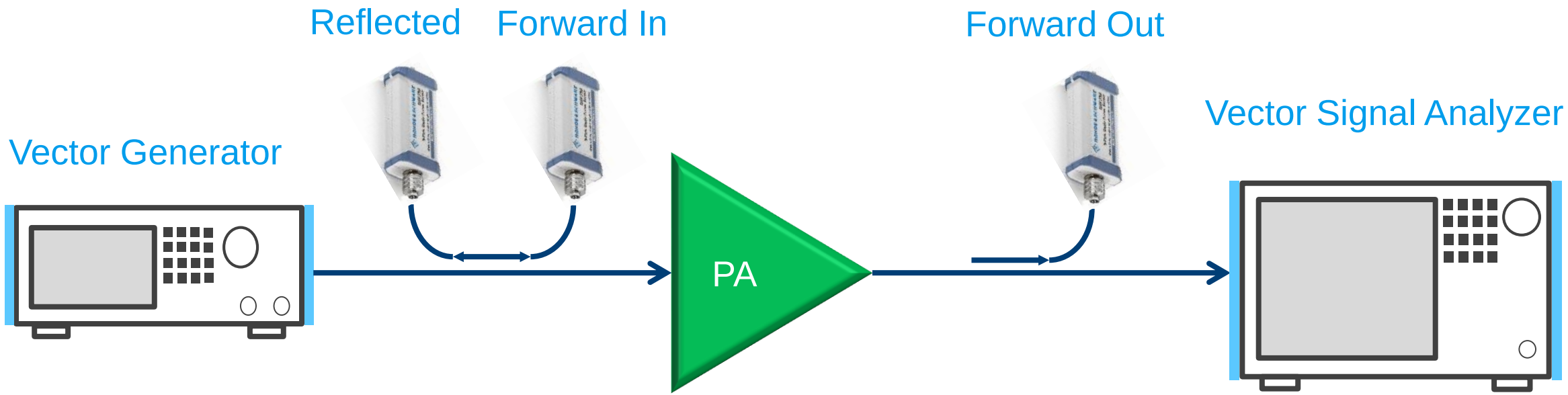
Contents

Modulation

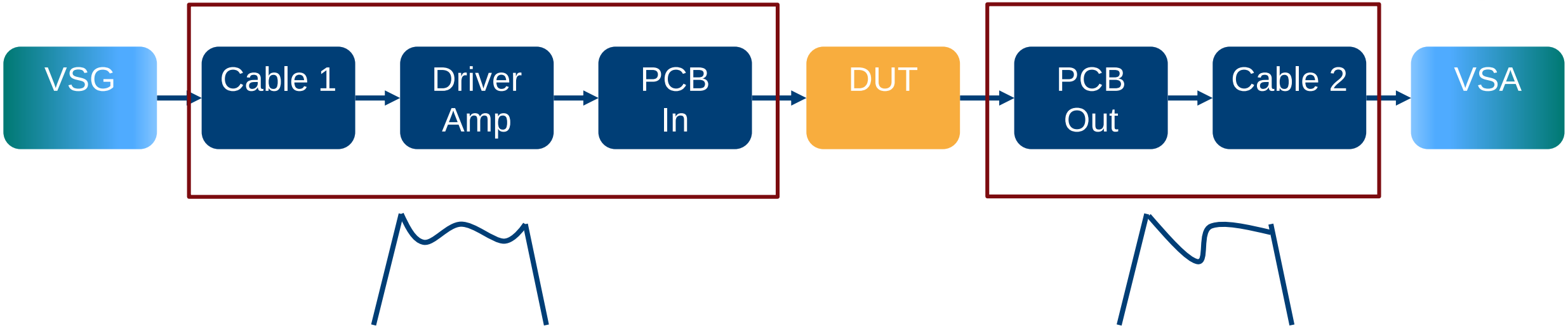


Typical Modulated Setup

- Power meters offer highest accuracy
- NRP series is recognized in the industry as fast and accurate



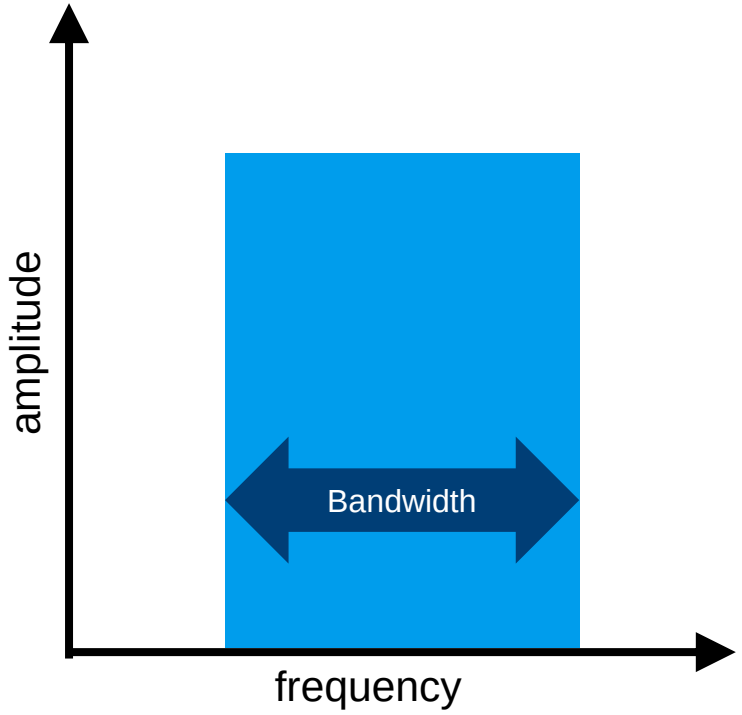
Test Setup Correction



Frequency Response (magnitude and phase vs. frequency)

- Interconnections (cable; filters; probes; and amplifiers) are not flat
- Instrument flatness is not what DUT sees**.**

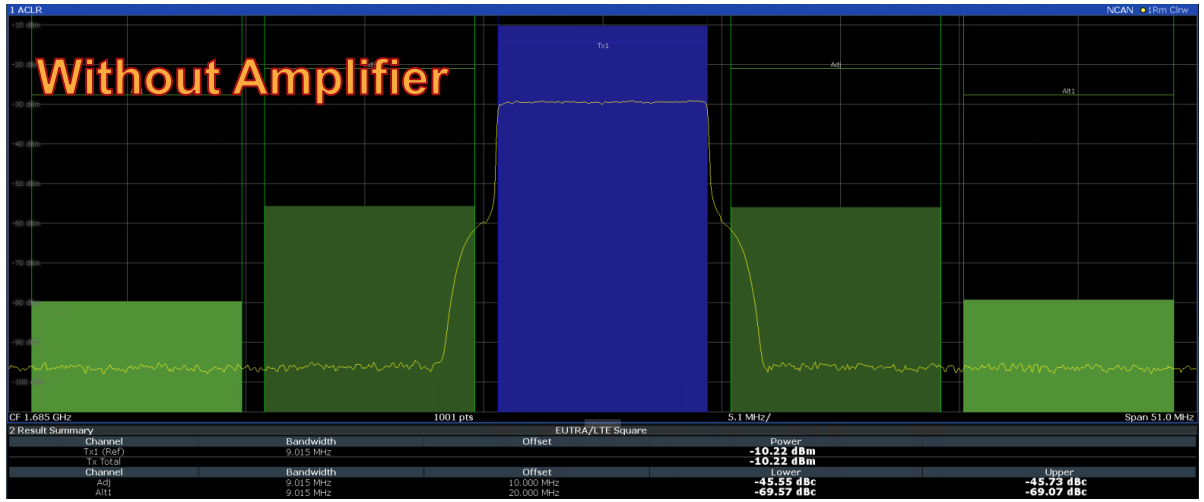
Channel Power

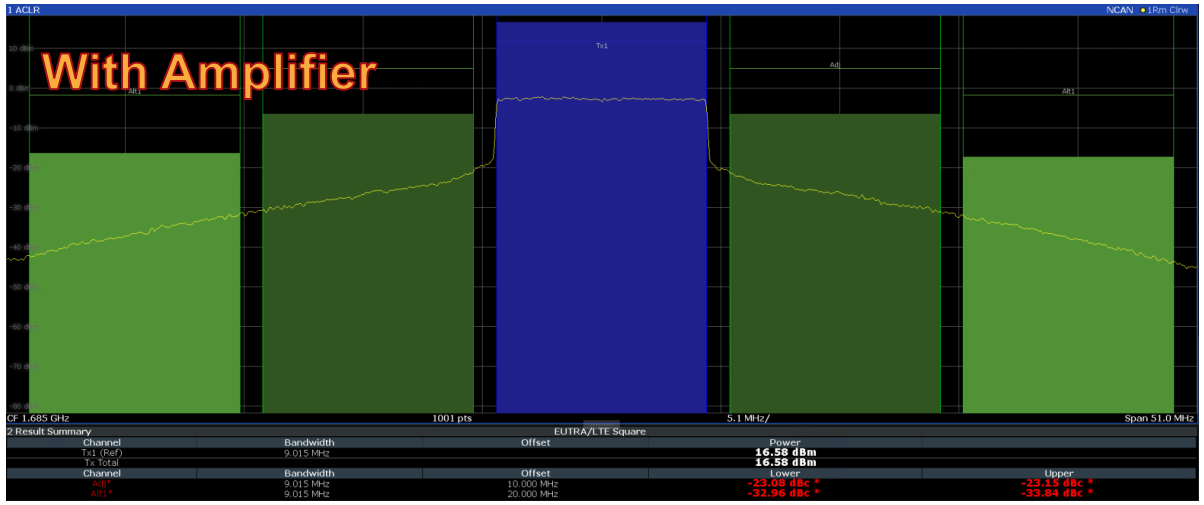


$$P_{ch} = \frac{\sum_{f=Freq\ Start}^{Freq\ Stop} 10^{\frac{FFT\ Bin(f)}{10}}}{Window\ Bandwidth}$$

- How much power are we transmitting?
- Gain
  - Output - Input

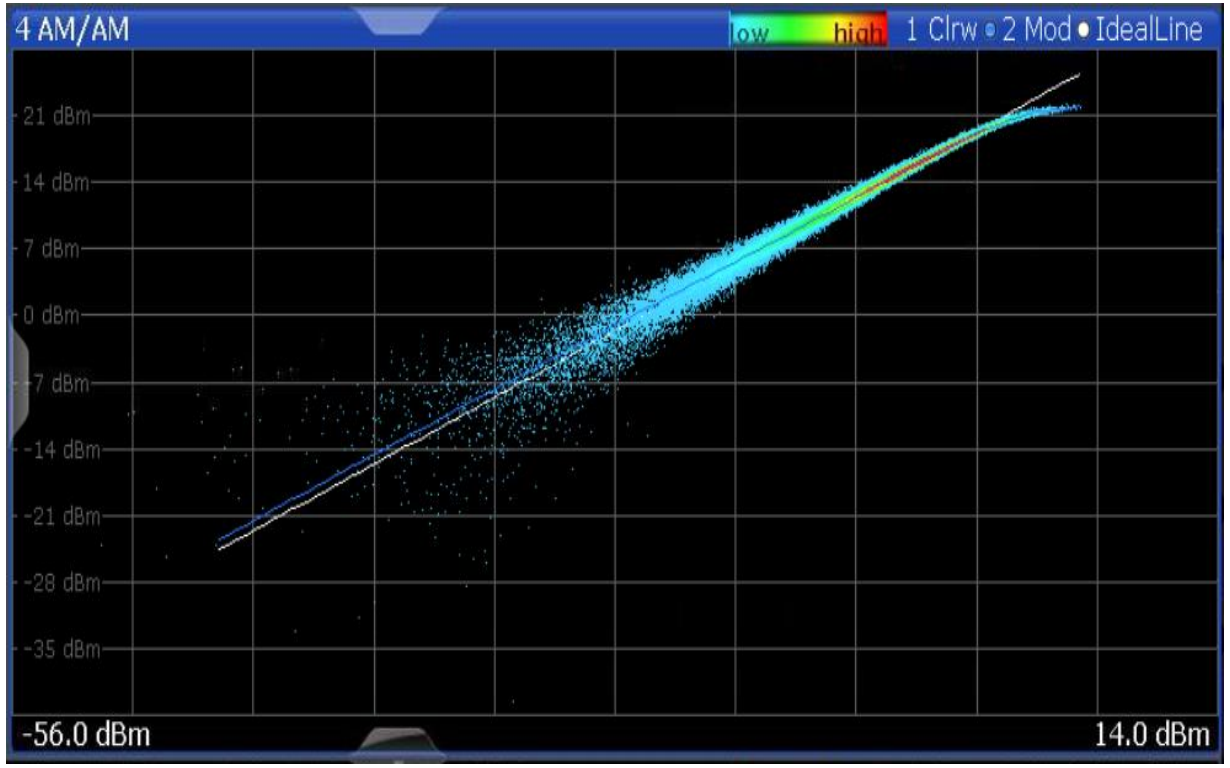
Adjacent Channel Leakage Ratio, ACLR

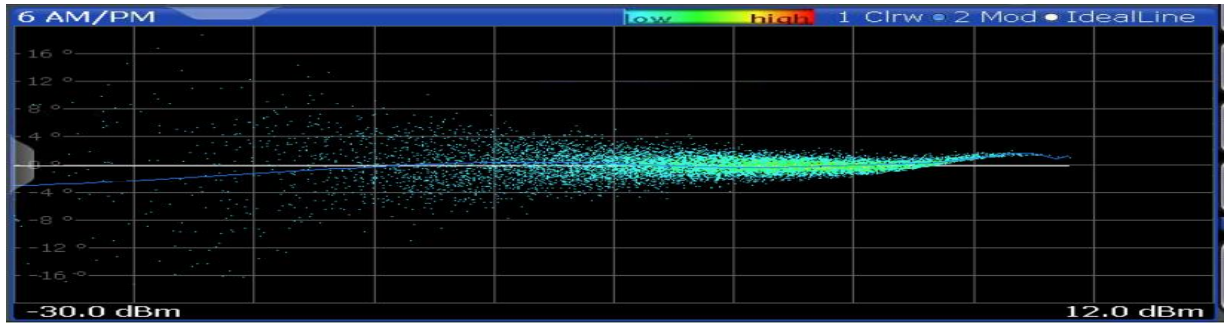




- ACLR measurements determine the channel power and adjacent channel power
- Amplifiers can cause spectral regrowth to occur in adjacent channels resulting in more power
  - Important to characterize how much power an amplifier contributes to adjacent channels

AM/AM AM/PM



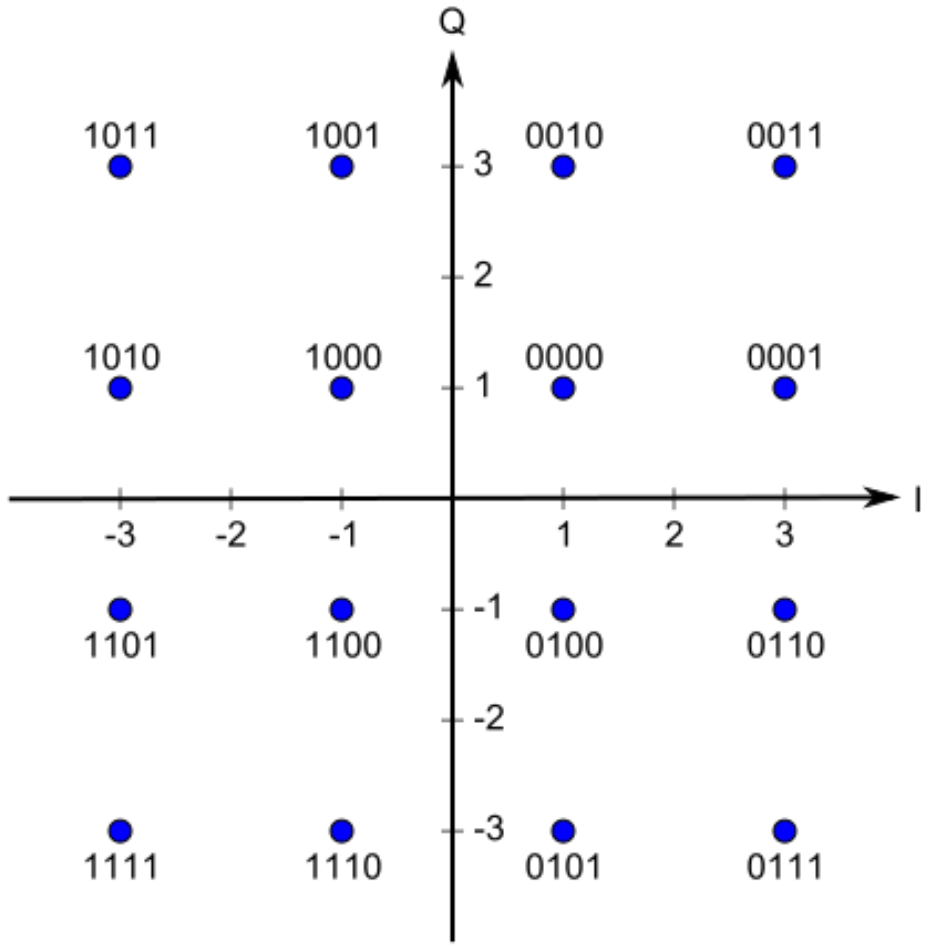


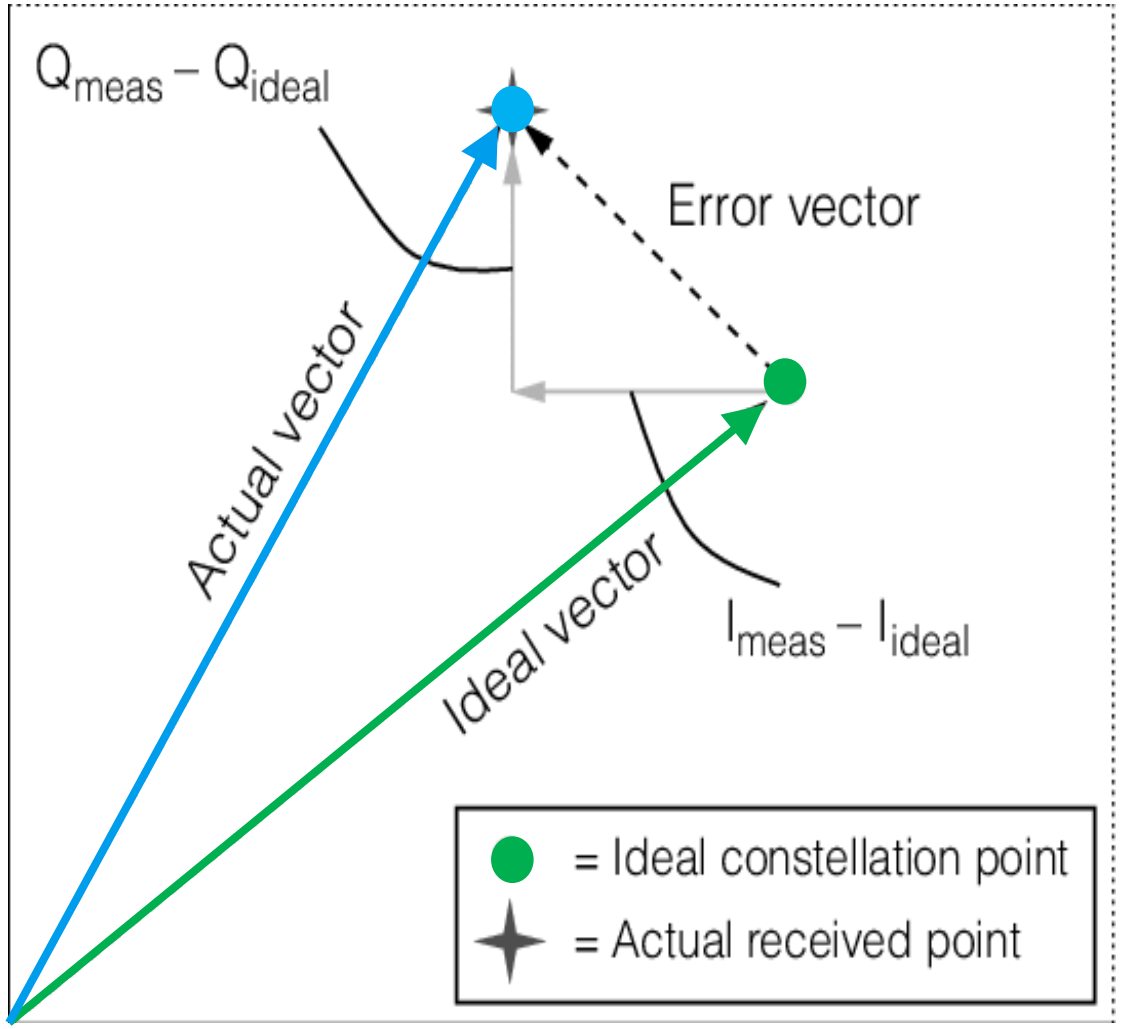
AM/AM & AM/PM

- Plots
  - X-Axis: Input power
  - Y-Axis:
    - Output Power
    - Output Phase

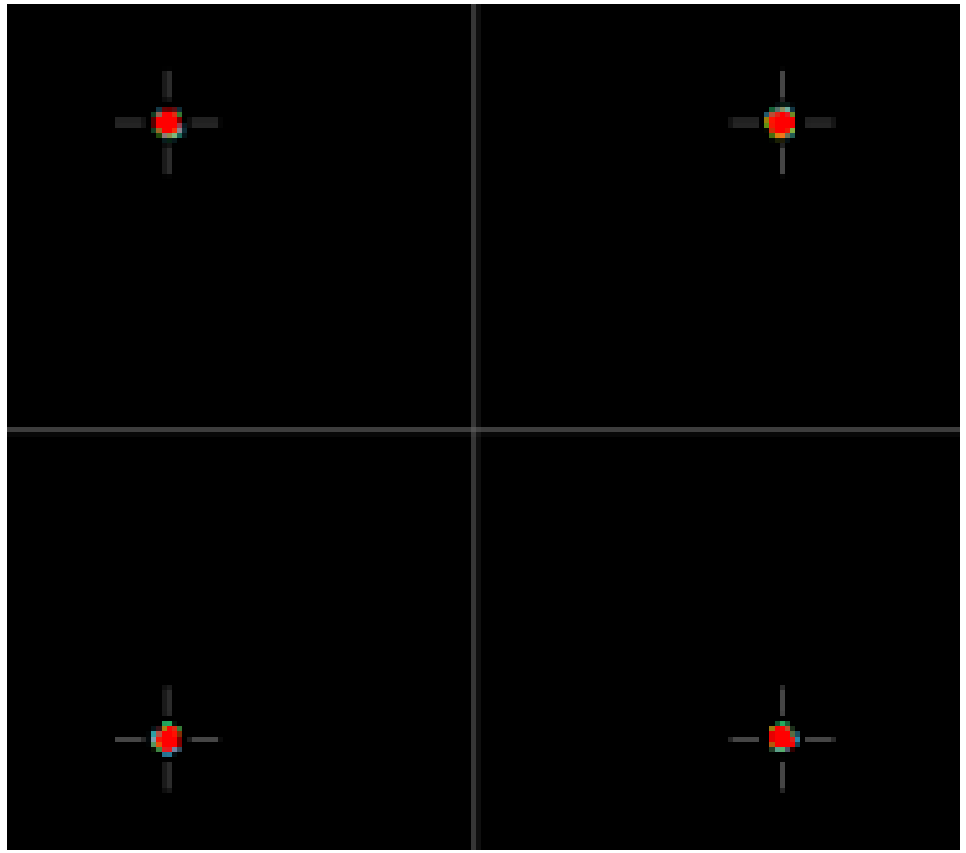
- How my output distorted?
  - Compression
  - Memory Effect

Error Vector Magnitude

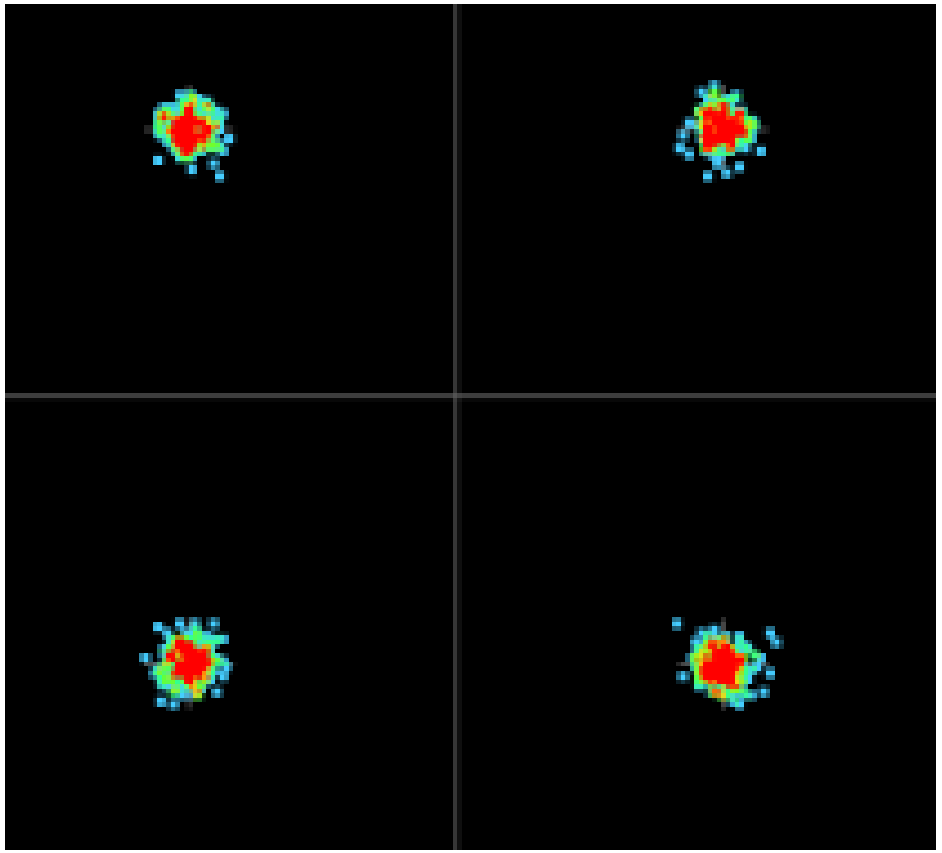




Error Vector Magnitude vs Constallation



QPSK Constellation
EVM: 1% (-40 dB)



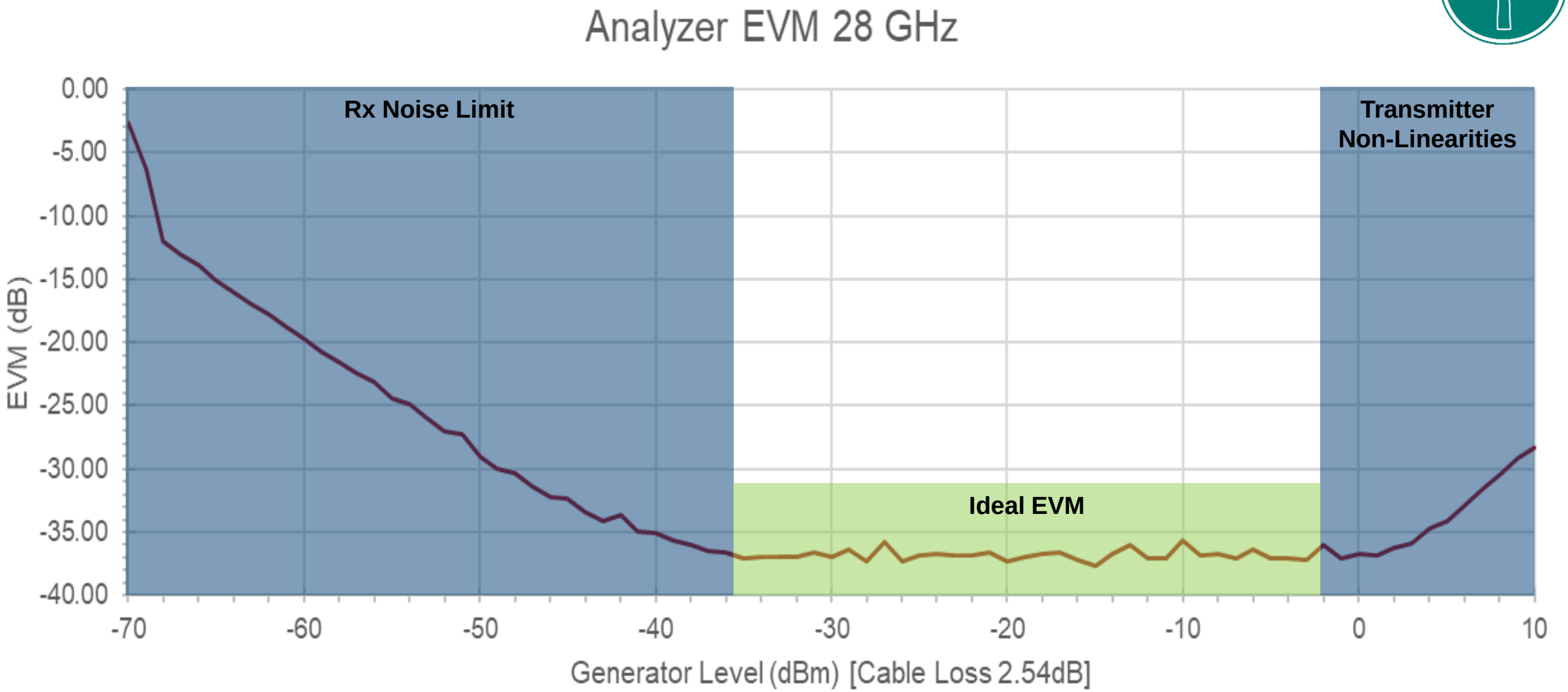
QPSK Constellation
EVM: 5.5% (-25 dB)

Error Vector Magnitude

EVM Includes

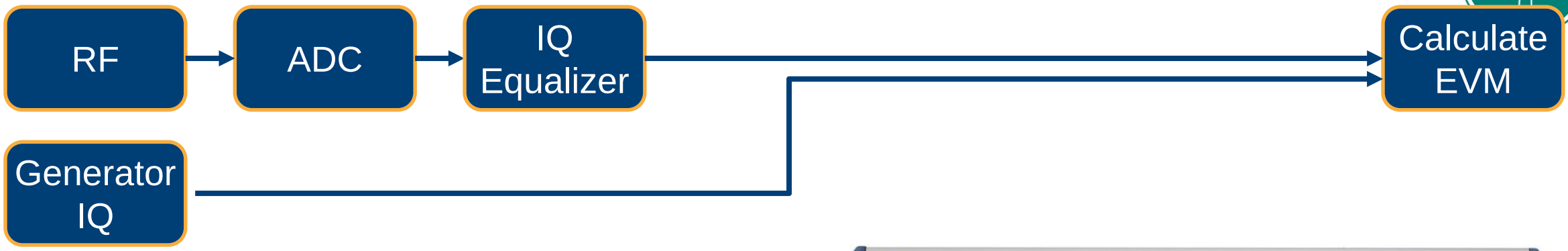
- ▶ Phase Error
- ▶ Amplitude Error
- ▶ IQ Imbalance
- ▶ Time Skew
- ▶ Gain Imbalance

“Bathtub Curves”



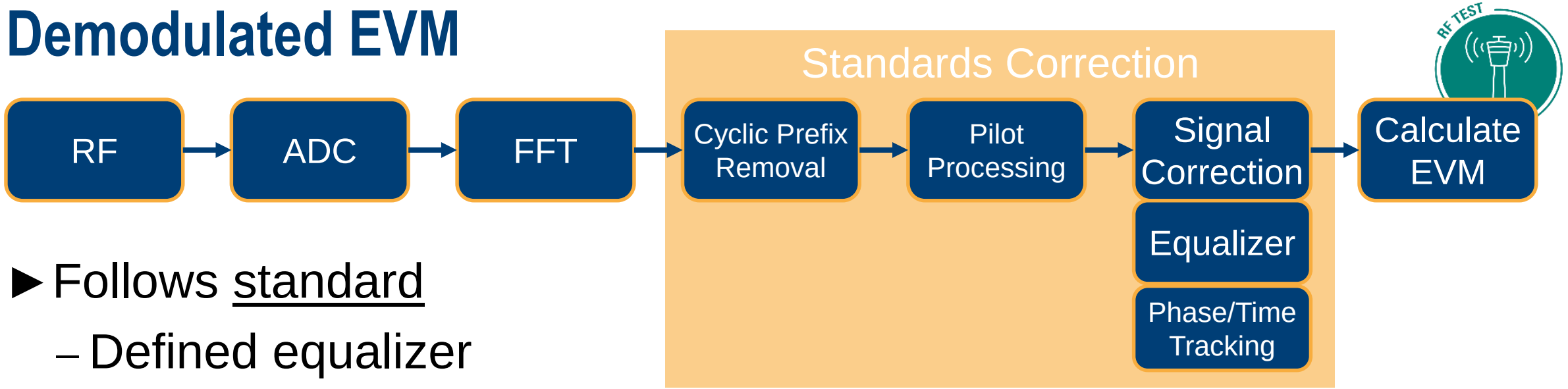
Two EVM?

RMS EVM



- ►Signal is down converted
- ►Equalizer can be applied
- ►Time based signal is analyzed
- ►RMS EVM = Rx IQ – Tx IQ

Demodulated EVM



- Follows standard
  - Defined equalizer
  - Defined tracking
  - Defined data/packet sized
- Industry accepted
  - Data can be compared internally
  - Data can be compared externally

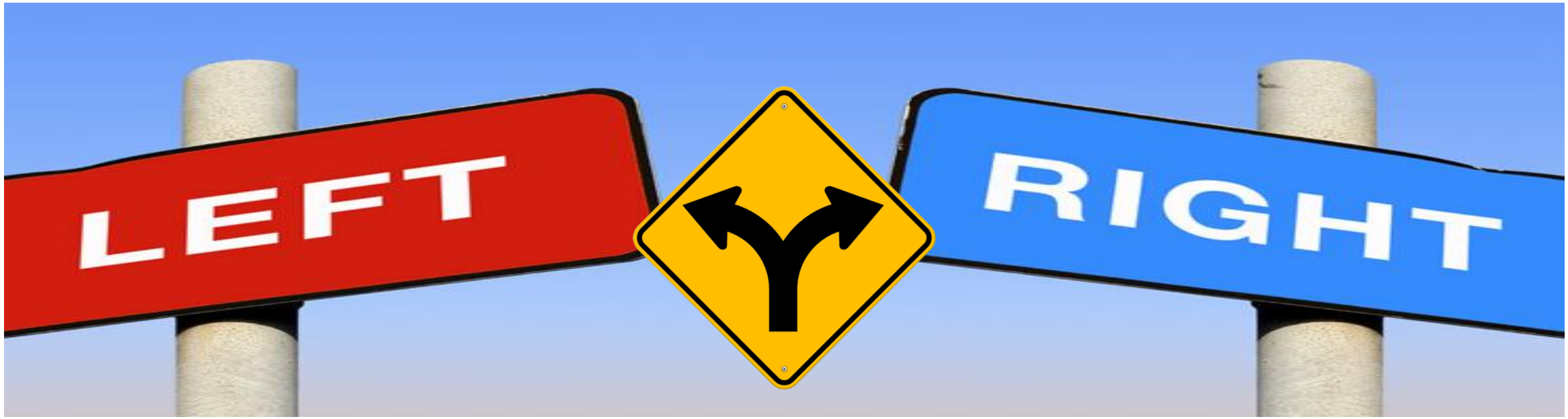
Which One do we use?

RMS EVM

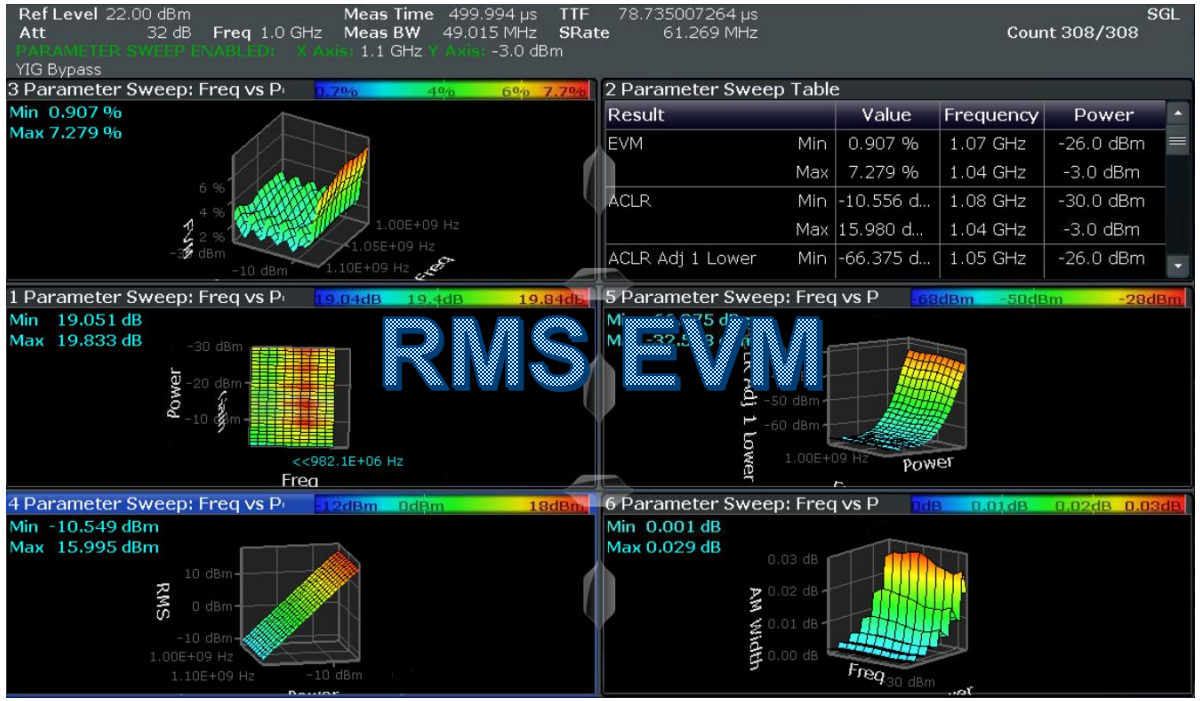
- Fast measurement
- Trends in with Demod EVM
- Ensures worse case EVM.

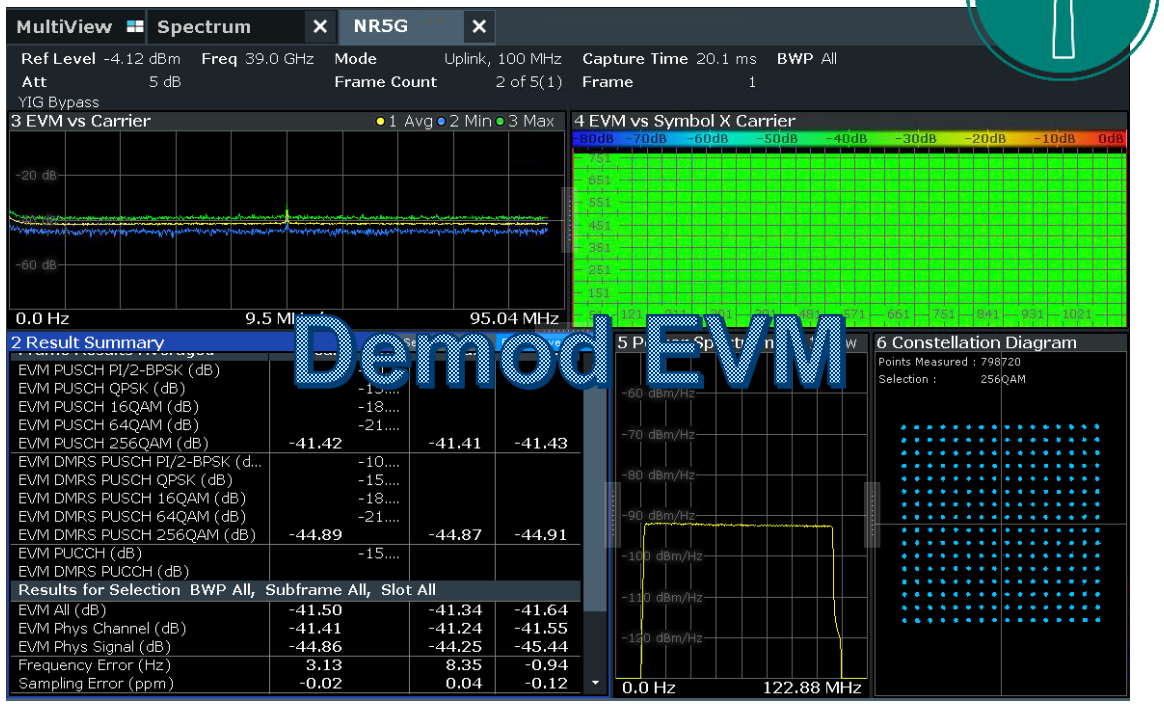
Demod EVM

- Standards Compliant
- Data can be compared to spec
- Data can be correlated externally
- Does not need original baseband IQ



Smart Approach





- Sweep parameters RMS EVM
  - Collect lots of data
  - Understand where issues are
  - Collect corner condition data
- Get a picture of your DUT

- Characterize Protocol EVM
- Understand what real performance is
- Collect data for external exchange.

SUMMARY / Q&A

Amplifiers:

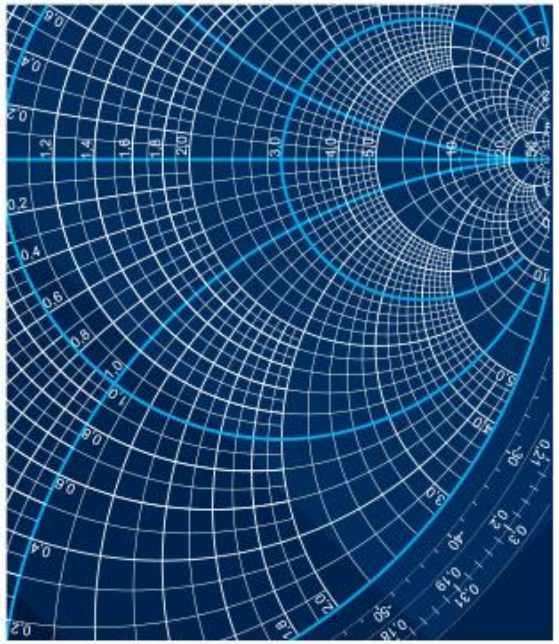
- Low Noise Amplifier
- Power Amplifier
- Front End Module

CW Tests

- Gain
- Frequency response
- Harmonics
- Intermodulation Distortion
- Noise figure
- PAE

Modulated Tests

- Channel Power
- Adj Channel Leakage Ratio
- EVM



Measurement Techniques

Design Verification & Evaluation

EVERYTHING TEST

Instrument Selection & Optimization