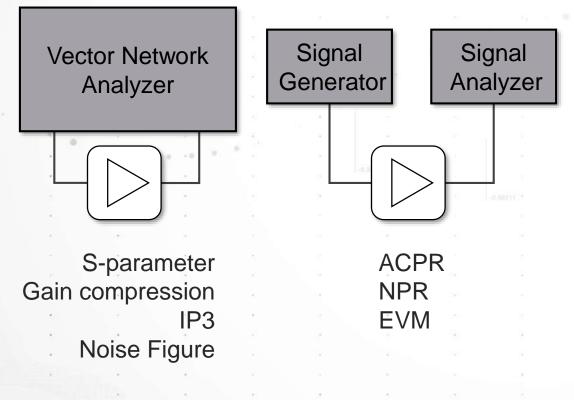


Breakthroughs in Wideband Millimeter-Wave Power Amplifier Test

R&D Software Engineer, Aerospace, Defense, and Government Solutions Group Augustine Stav

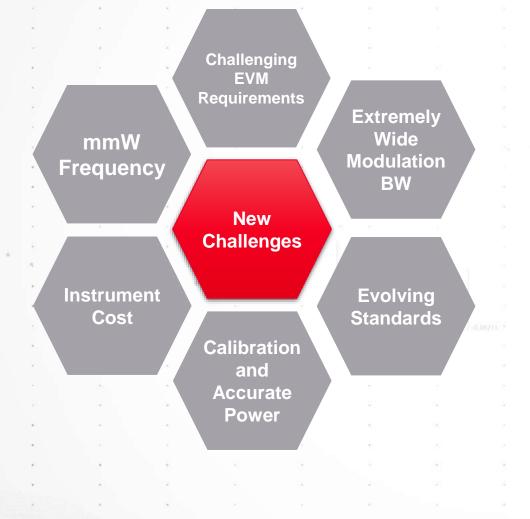
Industry Common Practice

"I need two sets of instrumentation to characterize my power amplifier..."





Overcoming New Challenges







Intro: Target Device / Measurement Challenge Keysight Solution Underlying Technology Measurement Example Summary

Target Device: PA with a Wideband Signal

Any amplifier which operates under modulated signal conditions is a target device for this solution. Power amplifiers in 5G FR2 front end are a "sweet spot" application.

Requirements

- Operate at extremely wide bandwidths at mmW frequencies
- Good power efficiency for higher power density with power/heat management
- OFDM operation scheme requires linear output signal for better signal quality

Key challenges for designers

- Linear amplification at high power, with high efficiency in any operating conditions
- Integration into beamformer component

Key measurement for design verification

- Linearity evaluation with wide bandwidth at mmW frequencies
- Figures of merit: EVM, ACPR



Device Example: PA in 5G FR2 System

https://www.qorvo.com/products/p/QPF4001

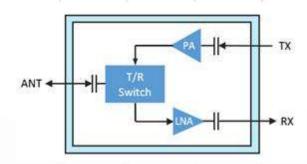
QONOO

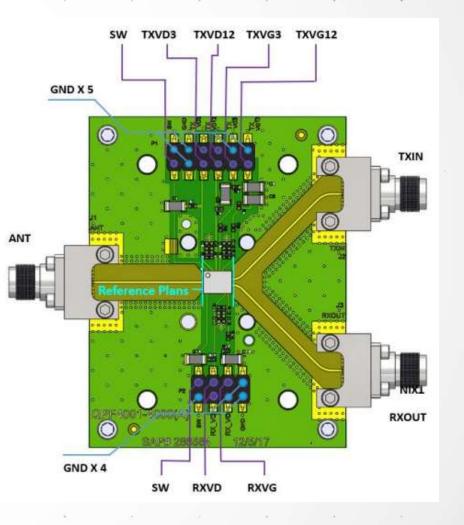
Product Description

The QPF4001 is a multi-function Gallium Nitride MMIC front - end module targeted for 28 GHz phased array 5G base stations and terminals. Fabricated on Qorvo's 0.15um GaN on SiC process, the device combines a low noise high linearity LNA, a low insertion-loss high - isolation TR switch, and a high - gain high - efficiency multi-stage PA.

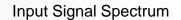
The QPF4001 operates from 26 GHz to 30 GHz. The receive path (LNA + TR SW) is designed to provide 17 dB of gain and a typical noise figure of 3.5dB. The transmit path (PA + SW) provides 27 dB of small signal gain with high linearity of 35 dBc ACPR and low EVM of 3% at 23 dBm average output power, while supporting peak power of 1 - Watt.

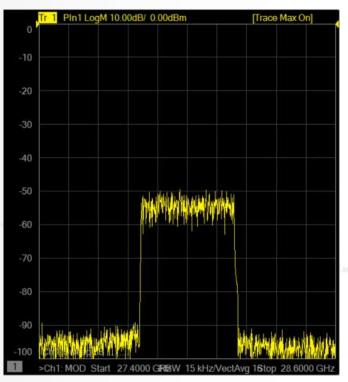


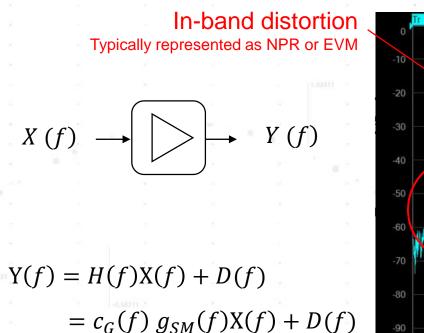




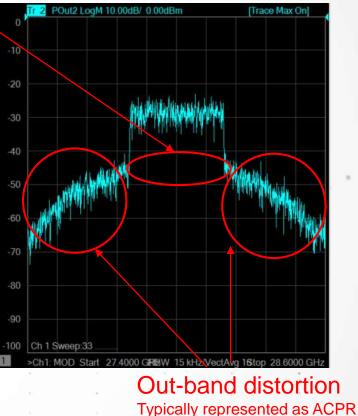
Linearity Evaluation Under Modulated Conditions Nonlinear Distortion Model







Output Signal Spectrum

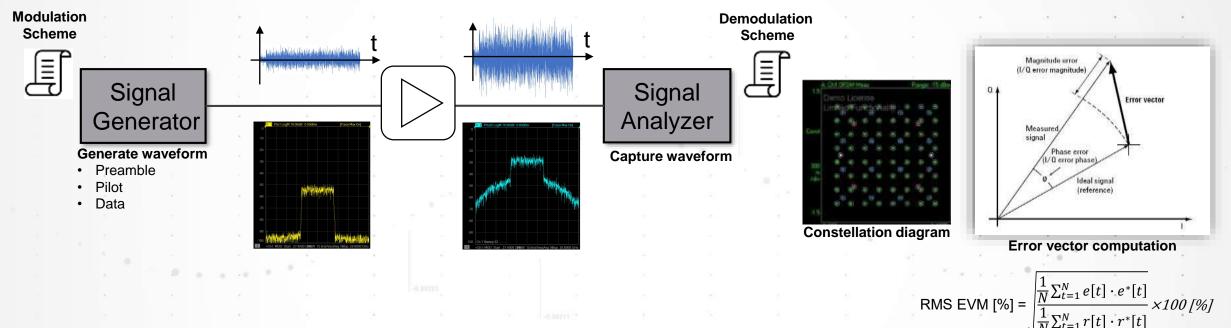


- Nonlinear distortion performance is traditionally measured with signal generator and signal analyzer
- EVM is commonly used as the figure of merit to show performance of in-band distortion



Traditional EVM Measurements

Challenges of component testing with wideband modulated signals



- Residual EVM (EVM of test system) is close to EVM of DUT
 - Source: Imperfections in generated signal directly affect measured EVM
 - Receiver: Capturing wideband signal also captures wideband noise. S/N ratio degrades as bandwidth increases.

Signal fidelity

- Lossy cable and mismatch in high frequency. Actual signal applied to DUT is different from ideal.
- Test system optimization for specific power level to minimize nonlinearity of receiver while optimizing S/N ratio

Intro: Target Device / Measurement Challenge Keysight Solution Underlying Technology Measurement Example Summary

Modulation Distortion App on PNA-X with SG

Modulated source such as:



Modulation Distortion app on PNA-X

- Software option of PNA-X that characterizes distortion of the device under modulated stimulus conditions
- Simple & easy setup. Measurement setup fully integrated in PNA-X
- Leverages state of the art calibration for the best accuracy
- Single connection for existing VNA measurements and new feature which delivers ACPR, EVM and NPR.
- Lowest residual EVM system in the market



Key Contributions to PA Industry

- Overcome wideband measurement challenges
 - Low residual EVM due to wider system dynamic range (lower noise floor)
 - Signal fidelity at the DUT input easily achieved by PNA calibration techniques
 - Easy calibration for "vector corrected" EVM measurements
- Measurement reproducibility
 - Obtain consistent measurement results, supported by PNA calibration techniques
- Faster measurement speed
 - "Test time is reduced by a factor of 10 in my DVT test scenario"
- Design flow improvement with simulation
 - Same computation engine as PNA-X to simulate nonlinear behavior in ADS will be available
- Leverages PNA-X hardware to make analysis under modulated conditions
 - PNA-X: De facto standard
 - Single connection, multiple measurement



Underlying Technology

Compact Test Signal

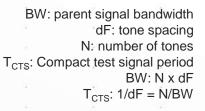
Modulation Distortion "compacts" the stimulus waveform to make measurements faster.

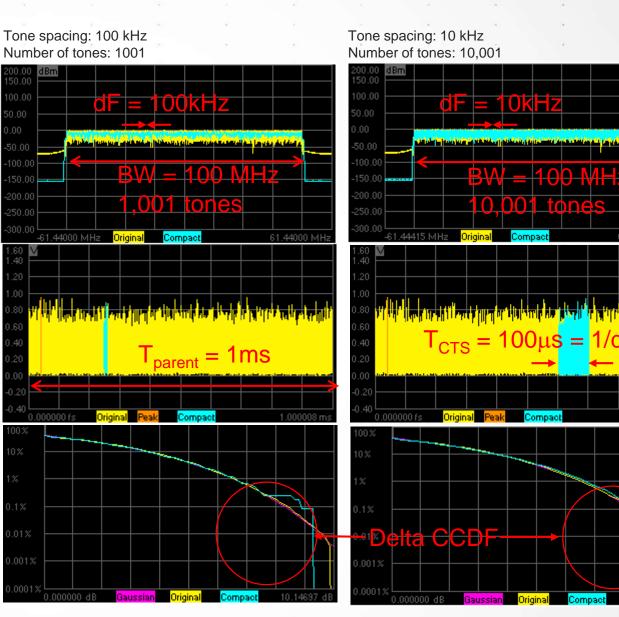
"Parent waveform" e.g. 5G NR 100MHz BW signal

"Compact Test Signal"

Slice of waveform that represents same

- Frequency signature
- Statistical distribution (CCDF)





• A finer tone spacing results in a longer period for the compact test signal

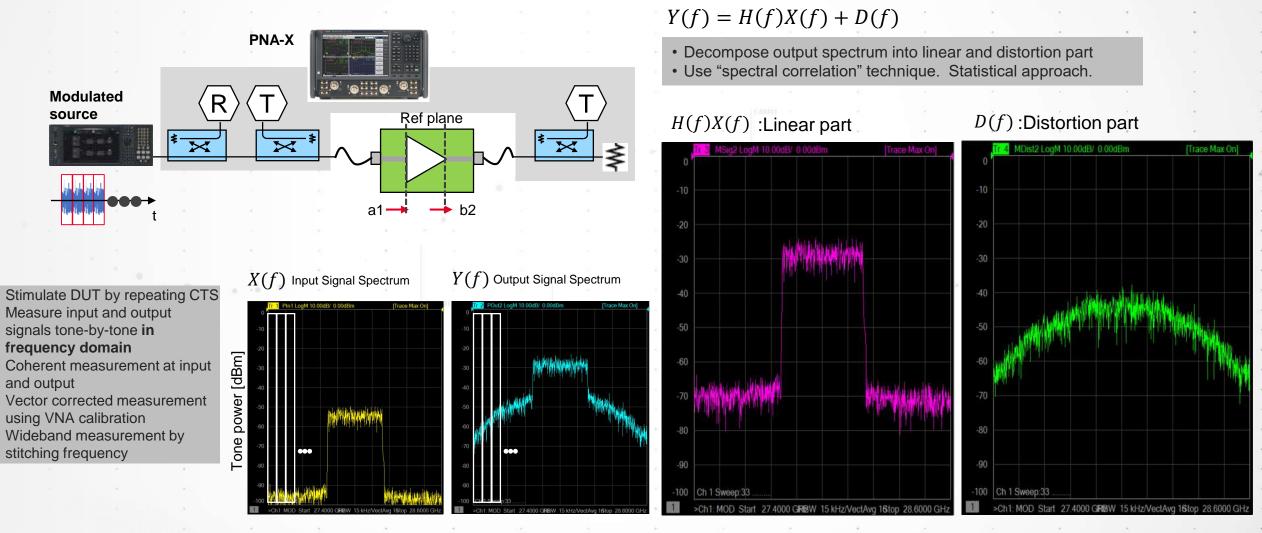
A longer period results in more accurate CCDF



12

Underlying Technology

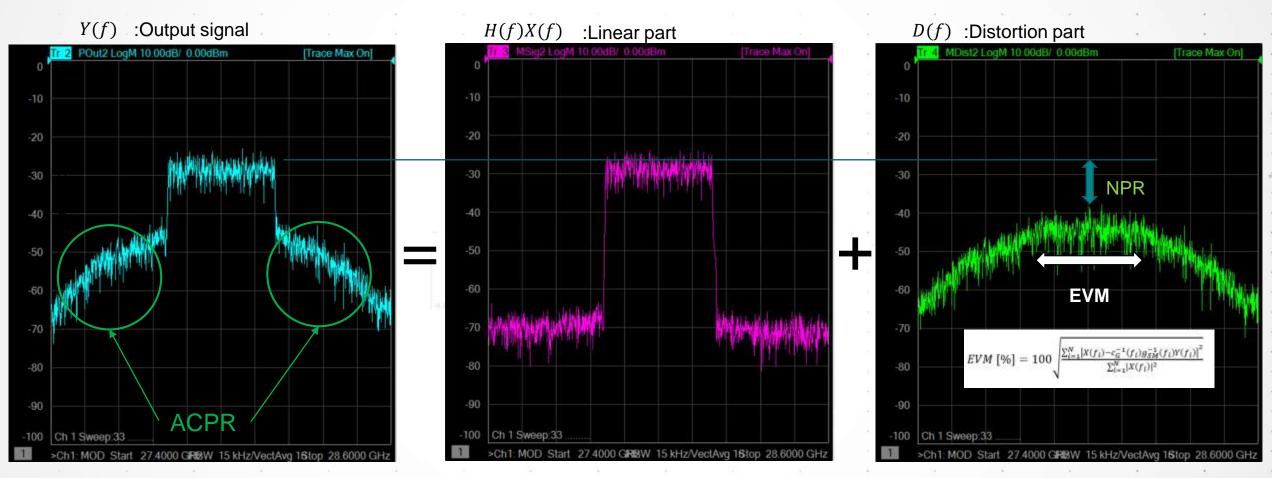
Multitone measurement and signal decomposition





Underlying Technology

Computing figures of merit



• EVM computed in time domain or frequency domain are mathematically equivalent (Parseval's theorem)



Correlation Study - Setup

Traditional SA/SG setup

Signal Generation



Waveform for traditional EVM

- Preamble •
- Pilot
- Data

Signal Analysis



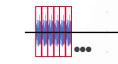
"Compact" the

waveform

Modulation Distortion setup

Signal Generation





"Compact waveform" Represents the same characteristics

as original waveform

- Frequency signature
- Statistical distribution

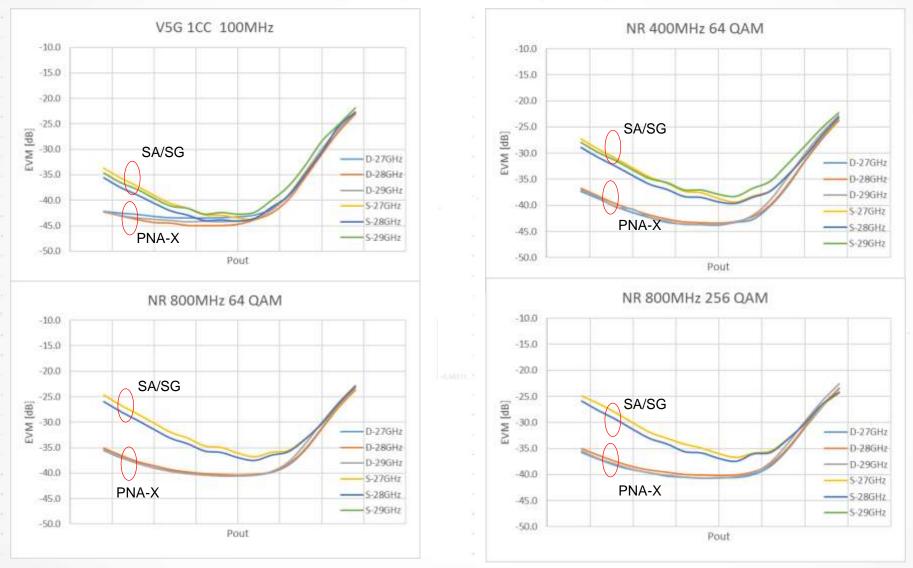
Stimulus response analysis **PNA-X** with MD option





Correlation Study - Results

DUT: Keysight 50GHz amplifier, 12 dB Gain





٠

SA/SG and PNA-X results correlate when the device is operating under nonlinear conditions

• PNA-X shows lower residual EVM which shows the Pout where the DUT starts nonlinear behavior

Technique Comparison for Measuring EVM for Amplifiers

89600 VSA and X-Apps

Measures all contributors to EVM

Keysight signal analyzers, oscilloscopes, PXI VSAs



Benefits

- Standards compliant algorithms (ex: 3GPP, IEEE, etc.)
- Flexible views to view EVM vs. time, frequency, subcarrier, power...and many more
- Constellation diagram view

Considerations

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

Modulation Distortion App

Isolates the distortion and additive noise contributions

PNA-X

Benefits

EVM

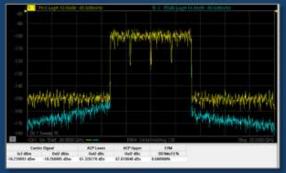
= distortion +

noise +

phase noise +

IQ imbalance +

input signal



- Removes contribution of phase noise, imbalance and signal inputs
- Very wide measurements bandwidth limited only by the signal generator
 - High dynamic range and low EVM noise floor

Considerations

- Requires repetitive waveform
- No constellation diagram



Intro: Target Device / Measurement Challenge Keysight Solution Underlying Technology Measurement Example Summary

PNA-X Measurement Class "Modulation Distortion"

- PNA-X firmware has the Modulation Distortion app which has everything required for the measurement
 - Creates stimulus
 - Controls external generator Calibrates the measurement system
 - Makes measurement

Measurement Class :	Channel 1								
Determines the types	of measurements	available on a	channel.						
General		Converters							
◯ Standard		⊖ Gain Com	pression Conv	erters					
◯ Gain Compression		◯ IM Spectr	um Converters	5					
○ Differential I/Q		○ Swept IM	D Converters						
◯ IM Spectrum		O Noise Fig	ure Converters	5					
○ Swept IMD		O Scalar Mixer/Converter + Phas							
Modulation Distort	ion	○ Vector Mi	xer/Converter						
 ○ Noise Figure Cold ○ Spectrum Analyze 									
Spectrum Analyzer Show setup dialog Confirm changes New Channe		ОК	Cancel	Help					

Sle Instrument Response Stimulu	a cally Help							
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							RF Power	Leveling & Offsets
				N. 1			5N	
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	Modulation Type Come	act -					-32.60	
	Original Signal	ALC: .			Optimize Signal		-	
		Instrument/Desktop/Samid	GNR 25	BOAM 120kt	Enable Optimizer Setup	61	Start Power	
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Lood File	Number tr	Samples 1228800			Calculated Result	100	Stop Power	1
Enable Modulation	Tone Space Waveform						-0.88	
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CP+EVM -21.76 dBm 100.1 MH	Number of Files	5			Calculated Sample Rate 122/847 MPtz Measurement Time 1.4 s			
					Filename 50NR_2500AM_125NHz_503	2.100M.		
	The signal was recalled	1						
	Calculate Se	nvo	D	efaults	OK Cancel	Help		

Setup Channel (Sweep and RF Path Setup)

Sweep RF Path	Nodulate Measure		Source DUT		Carrier Power /	Modulate Measure	0dBm DUT -5.0		Receiver	*
Carrier Frequency SA Center v SA Span v	28.00000000 GHz + 28.00000000 GHz + 1.200000000 GHz +	Carrier Power At		•	Nominal Src Amp	DUT Input Port 1 ~	Nominal DUT Gain 0.00 dB	DUT Output Port 2 ~	Rcvr Atten 0 dB	
Sweep Details										
Sweep Details		ОКС	ancel Apply	Help	BASIC advanced		ОК	Cancel	Apply	Help
	- <u>.</u>	ОКС	Apply	Help	BASIC advanced		ОК	Cancel	Apply	Help
ASIC advanced		ОК Са	Apply	Help	BASIC advanced	· · · ·	OK	Cancel	Apply	Help
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SIC advanced		<u>ОК</u> Са 	ancel Apply	Help	BASIC advanced		OK	Cancel	Apply	

Setup Channel (Modulate Setup)

	Setup : Channel 1				
weep RF Path	Modulate Measure				4
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	Load File	Create	Edit	Properties	
	ion	Create Source Cal	Edit	Properties	
Enable Modulat Enable Source Enable Pulse	ion		Edit	Properties	
☑ Enable Source	ion	Source Cal	Edit	Properties	Help
☑ Enable Source	ion	Source Cal Pulse Setup			
Enable Source	ion Correction	Source Cal Pulse Setup OK	Cancel	Apply	

KEYSIGHT TECHNOLOGIES

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	Sample Ra Number of Tone Space	f Samples	491.520 4915200 100.000			Frequency Tolerance Calculat	1.00 %ed Result
	Waveform		10.0000	ms		40.00	
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The calcula		plete; ready t	o save. Recall.		faults	Measurement Time Filename 5GNR_256Q/ OK	1.7 s AM_120kHz_SC Cancel

Original signal file can be:

- .wfm file (created by Keysight Signal Studio software)
- .csv file created by any tool



Setup.

I 120kHz SCS 400M.

Help

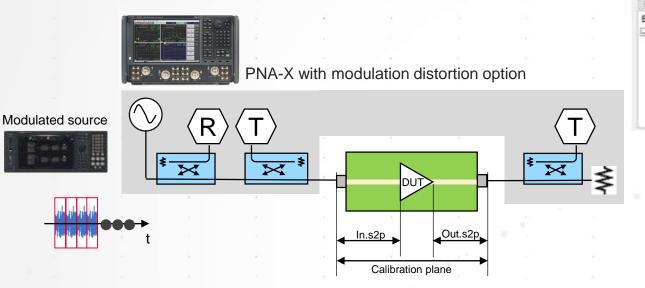
Setup Channel (Measure Setup)

TECHNOLOGIES

Modulation Distort	ion Setup : Channe	KI					×	Modulation Dis	cortion Setup	: Channel 1					×
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	noi Lim						2	Band	Meas Type	Carrier Offset	Carrier IBW	ACPLo Offset	ACPLo	ACPUp Offset	ACPU
								Band 1	ACP+EVM	0. MHz	400. MHz	-400. MHz	400. MHz	400. MHz	400. MHz
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ACPUp	400.000000 MHz	\$ 400.00	00000 MHz		oH	z									
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System Calibration (1)

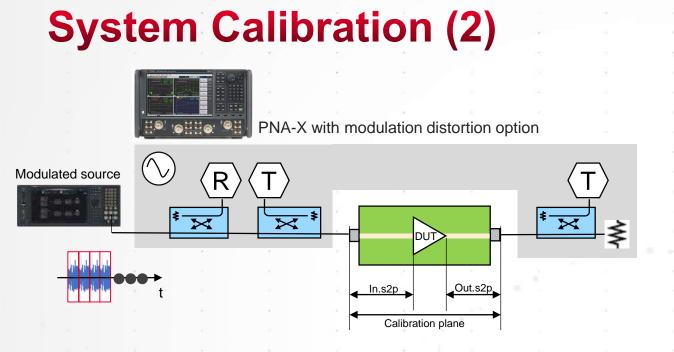


Use PNA-X "CalAll" to establish S-parameter calibration plane at DUT

- Conventional calibration method directly leveraged for modulation distortion measurement
- Fixture simulation feature available to move reference plane up to DUT
- Mismatch of the input port can be removed

Internet Class Cal Porta Chart Port 3 Address Port 4 Address Port 3 Port 3 Port 4 Address	ted Cha	nnel	5.											
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	nel Me	asu	rement	Class	i	Cal P					1	14		
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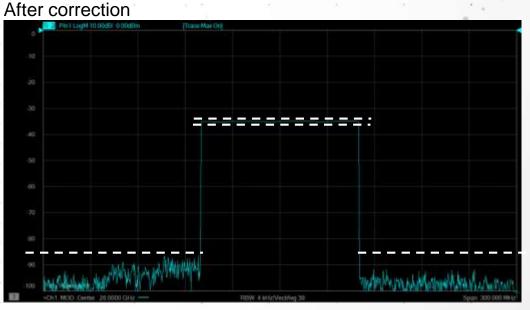


Use vector calibrated receivers to correct stimulus at DUT plane

- Correct channel power
- Correct IQ data to have flat input signal at reference plane
- Suppress ACPR of the signal at reference plane

Before correction





Measurement condition: 100MHz Flat tone, 400MSa

- 24

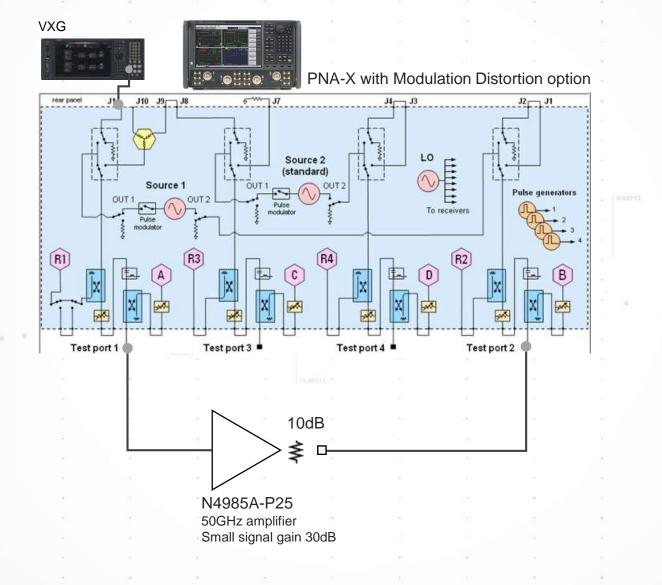
Measurement Examples

- 1. 5G NR 4 x 200MHz (4CC)
- 2. 2GHz BW flat tone Gaussian signal





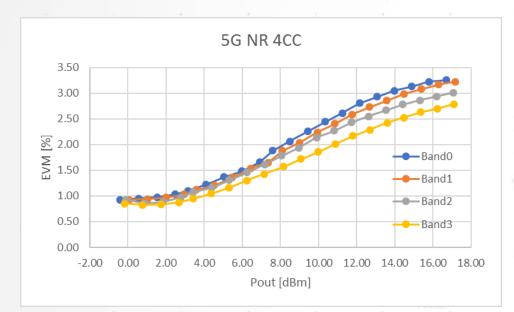
Measurement Example 1: 200MHz 4CC Measurement





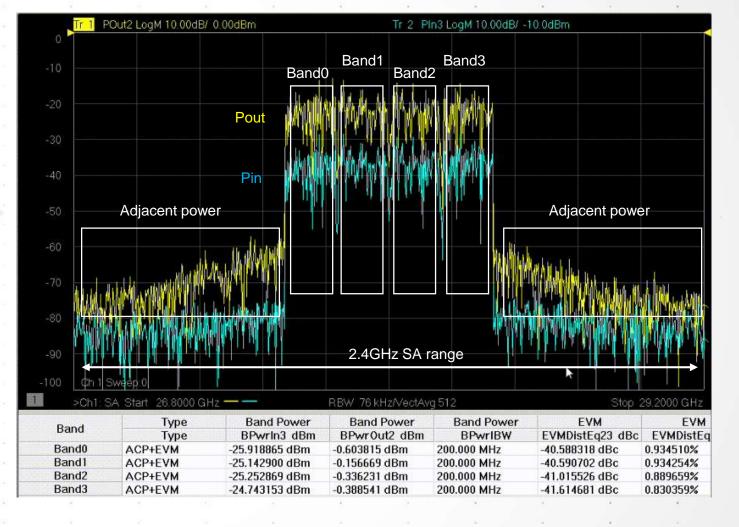
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Measurement Example 1: 200MHz 4CC Measurement



1.8 sec for each power point

- EVM measurement for all bands
- Adjacent power measurement





Measurement Example 2: 2GHz Flat Tone Gaussian Signal

reate Modulation						×	POUG	LogM 10 00dB/ 0 0	0dBm			Tr 2 Pin1	LogM 10 D0dB/	1 00dBm		
Addutation Type Flat Signal Signal Span Tone Specing Number of Tones Peak-to-Avg Carrier Offset Phase Type Random Phase Seed DAC Scaling	Desired Pr 2.000000000 GHz 100.00000000 kHz 2	a myVXG iority Calculated 2.00216 GHz 2.00617 MHz 999 8.495 dB 0.000000 Hz	OF I N C		se v 1.00 % ated Result	etup	0 -10 -20 -30 -40 -50 -50 -70 -80 -90					z signal E Iz SA rar	3W,			Manananan
The signal was recalle	4		Fi	ilename	Flat2GBW	.mdx	100 Ch 1, Swg	Start 25 0000 GHz	ALAN DA L		RBW 77 M	tz/VectAvg 772		WWW LAW, ALL	Juli	top 31.0000 (
				- and -	100		Type Carrier In1 dBm	Carrier Out2 dBm	Carrier IBW	ACP Loin1 dBc	ACP LoOut2 dBc	ACP Upin1 dBc	ACP UpOut2 dBc	EVM DistEq21 %		
Calculate S	ave Recall	Defaults		OK	Cancel	Help	ACP+EVM -20.45 dBr	10.21 dBm	2.002 GHz	-29.91 dBc	-29.21 dBc	-26.94 dBc	-26.73 dBc	1.90%		
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		÷		9		100	Tr 5 Ch 1 IntTrag	Swp BW+77.24	C EcRe	1 5.02 s SicCa*	(Seri	ALCONTRACTOR				
		4		5	4		3	21		2	22	4				-
							DUT: N4985A-	25, Gain =	30dB		× .					

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Intro: Target Device / Measurement Challenge Keysight Solution Underlying Technology Measurement Example Summary

Software Product Information

- Software models for PNA-X
 - Supported only for PNA-X B model
 - No other software options required to make Modulation Distortion measurements
 - Options for each frequency range

Model number and description

S930700B Modulation Distortion up to 8.5 GHz
S930701B Modulation Distortion up to 13.5 GHz
S930702B Modulation Distortion up to 26.5 GHz
S930704B Modulation Distortion up to 43.5 GHz
S930705B Modulation Distortion up to 50 GHz
S930707B Modulation Distortion up to 67 GHz

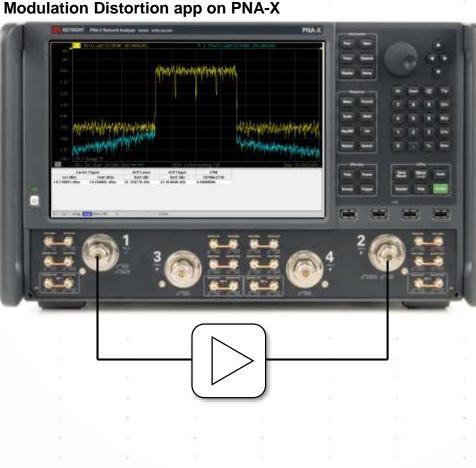
- Supported SG:
 - VXG (M9383B/84B)
 - M9383A
 - PSG + M8190A
 - PSG
 - MXG



Modulation Distortion App on PNA-X with SG

Modulated source such as:





- Software option of PNA-X that characterizes distortion of the device under modulated stimulus conditions
- Simple & easy setup. Measurement setup fully integrated in PNA-X
- Leverages state of the art calibration for the best accuracy
- Single connection for existing VNA measurements and new feature which delivers ACPR, EVM and NPR.
- Lowest residual EVM system in the market



