AMPLIFIER GAIN, GAIN FLATNESS AND POWER MEASUREMENTS

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Ver 3.0

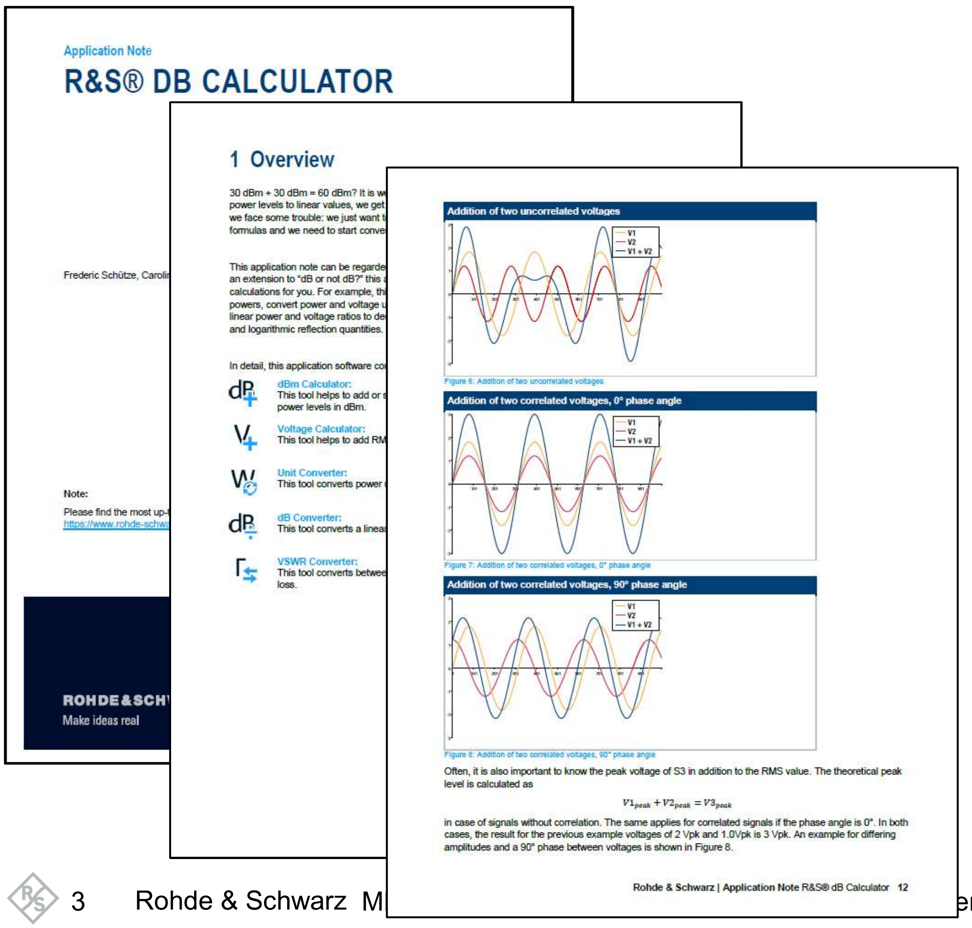
ROHDE&SCHWARZ

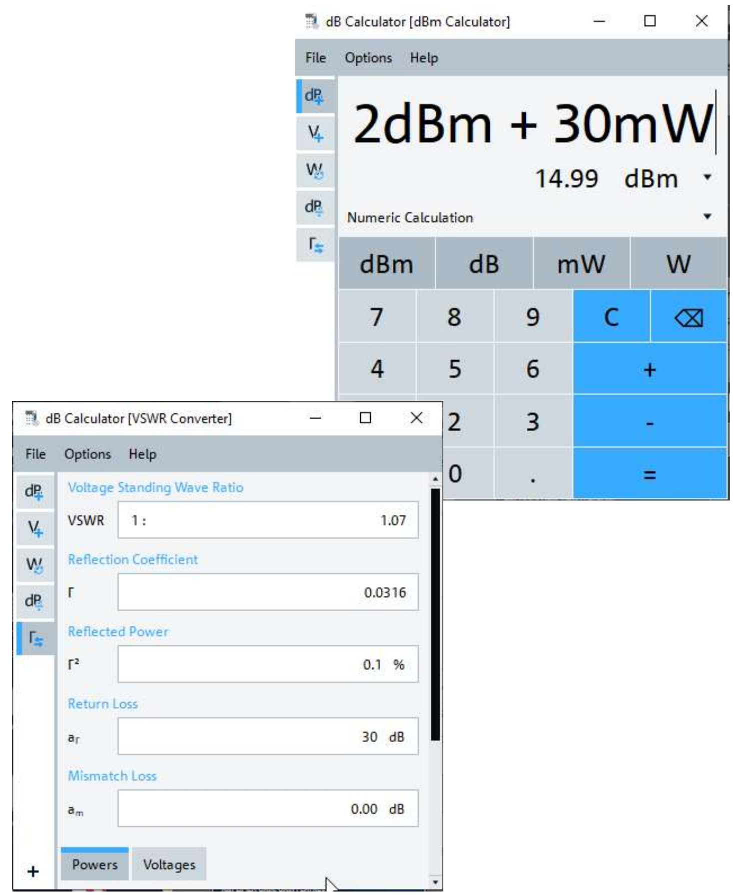
Make ideas real

AGENDA

- ► dB Basics: Calculator App (reference doc)
- ► "Constellation" of Amplifier Measurements
- ► Amplifier Types
- ► Critical Criteria
- ► Measurement Approaches (T&M Equipment)
- ► Measurement Details as a Function of Amplifier Type
- ► Tools to Improve Measurement Performance

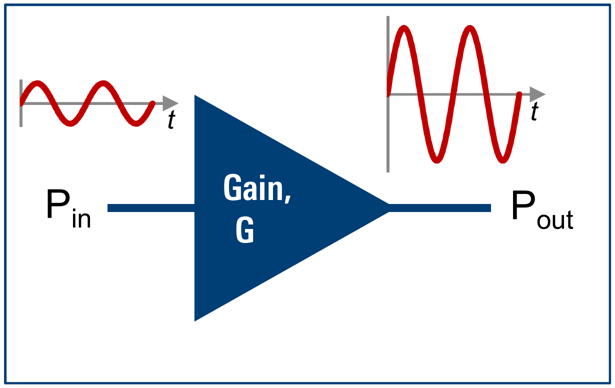
DB CALCULATOR APP





AMPLIFIER MEASUREMENTS – OVERVIEW

$$Gain, G = 10Log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$



AMPLIFIER MEASUREMENTS – OVERVIEW

- Gain
  - Small-signal, Large-signal (2-port S-parameters)
- Gain Flatness
- Gain Compression (AM to AM conversion)
  - 1 dB, 3 dB…
  - Amplitude and/or phase (AM to PM conversion)
- Intermodulation (IMD)
- Complex Impedance
  - a.k.a Return Loss, VSWR
  - “Hot” S22
- Spurious energy
- Harmonics
- Noise Figure
- Additive Noise

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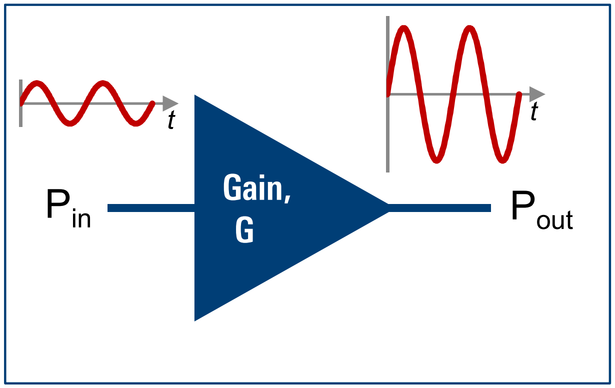
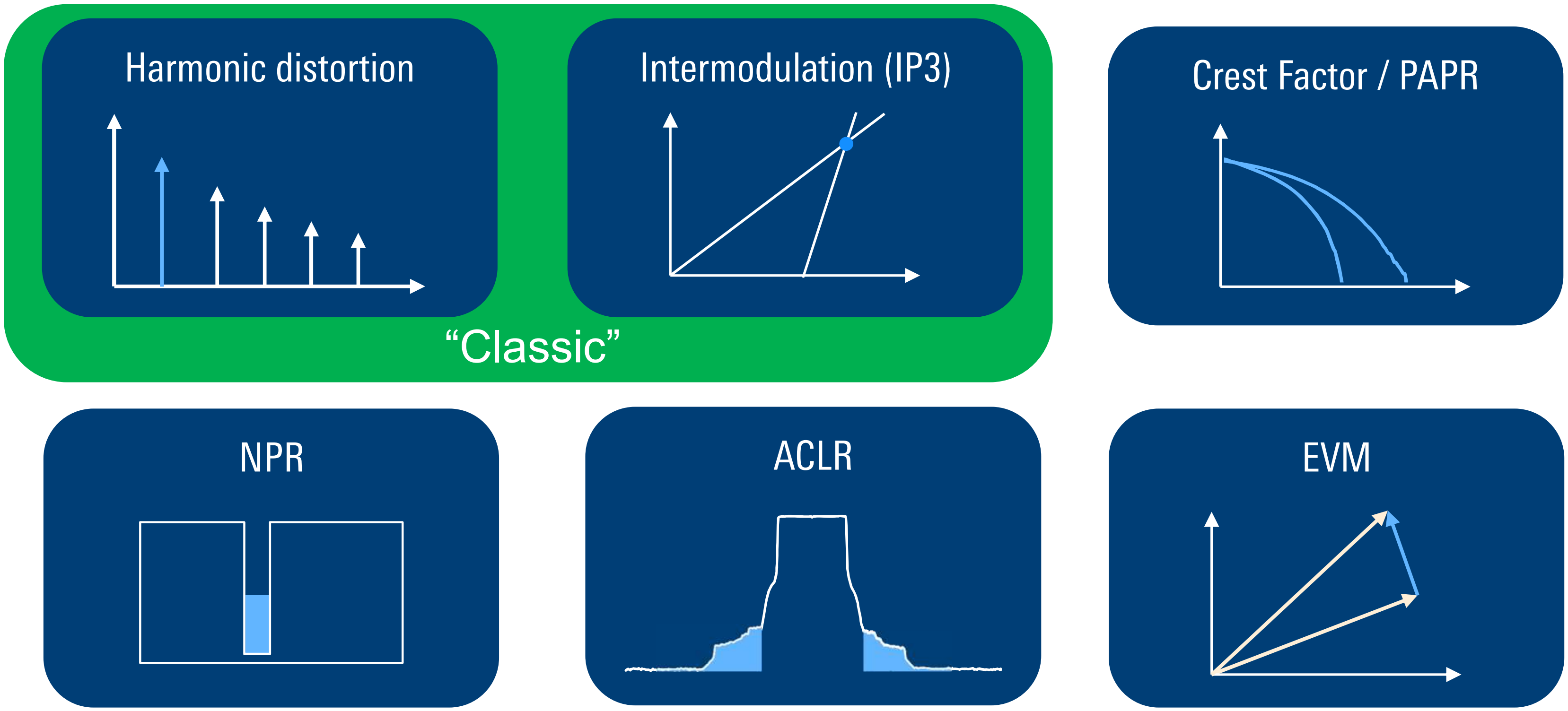


Common performance measurements for RF components: "Classic" (CW) to "Dynamic" (modulation-based) evolution



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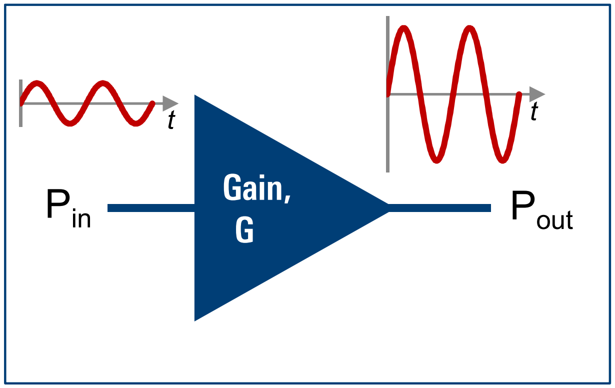
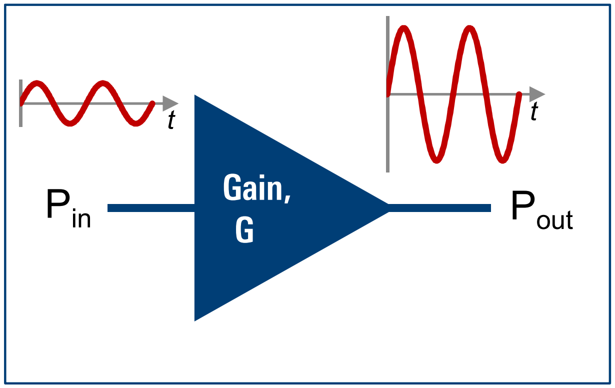


AMPLIFIER MEASUREMENTS – OVERVIEW

- Gain
  - Small-signal, Large-signal (2-port S-parameters)
- Gain Flatness

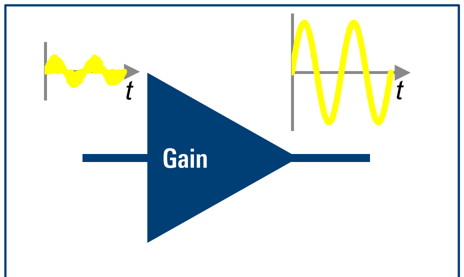
- How much gain?
- How much power?
- CW or Pulsed?

$$Gain, G = 10Log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$



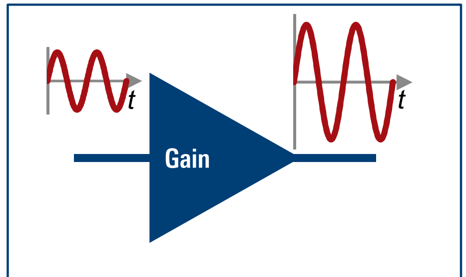
TYPES OF AMPLIFIER

Receivers



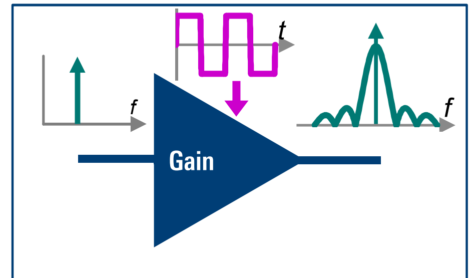
Low noise (noise figure)

General applications

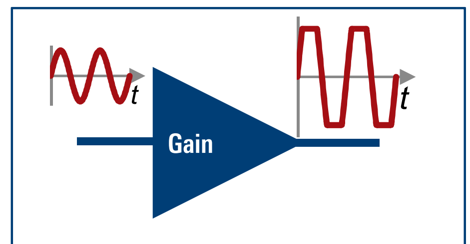


Small signal (linear)

Transmitters

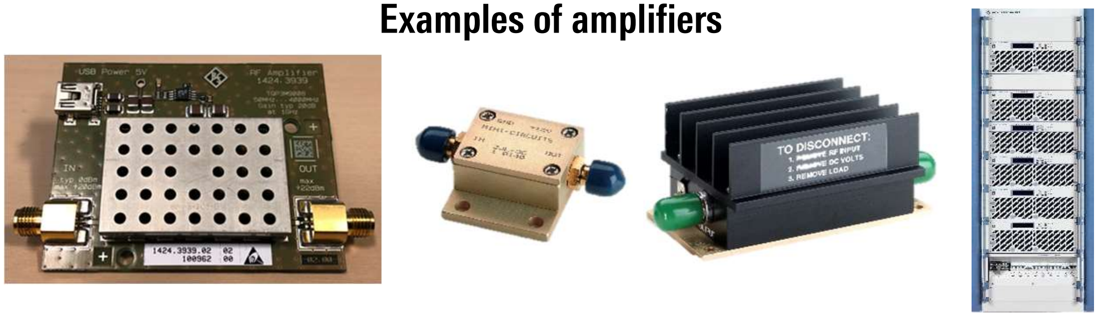


Pulsed



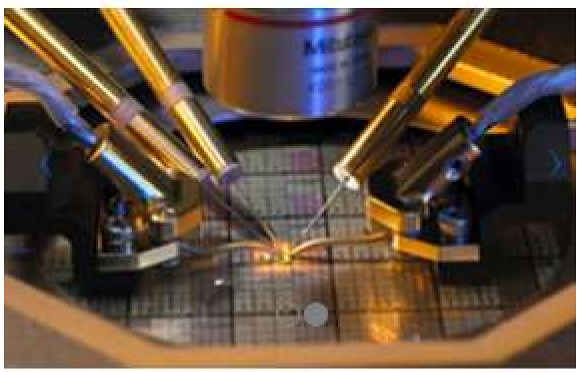
High power (non-linear)

Examples of amplifiers



AMPLIFIER MEASUREMENTS –
GAIN AND OUTPUT POWER: CRITICAL CRITERIA

- How much gain?
- How much power?
- CW or Pulsed?



GAIN MEASUREMENT APPROACHES: SIG GEN > POWER SENSOR

Advantages

- Simple configuration
- Some Sig Generators support freq sweeps w/ power sensor

Disadvantages

- Sensitive to Harmonics
- Poor Dynamic Range (~50 to 70 dB)
- Pulse Desense?
- Relatively slow
- Scalar only
- Requires calibration sweep
- Does not compensate for mismatch

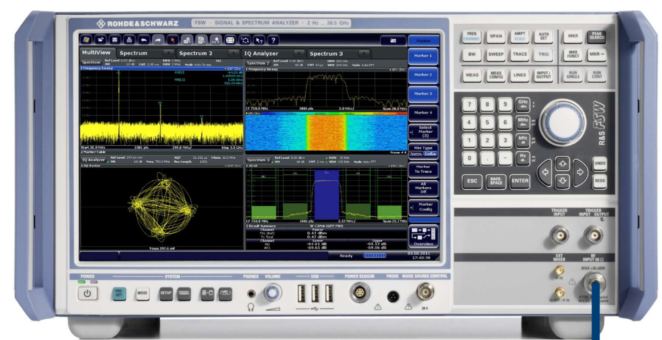
GAIN MEASUREMENT APPROACHES: SIG GEN > SPEC ANALYZER

Advantages

- ► Re-purpose available equipment
- ► Good Dynamic Range

Disadvantages

- ► Requires External Controller
- ► Relatively slow
- ► Scalar only
- ► Requires calibration sweep
- ► Does not compensate for mismatch
- ► SA msmt uncertainty?



SPECTRUM ANALYZER MEASUREMENT UNCERTAINTY

Level Error Calculation for Spectrum Analyzers

Application Note 1EF36_0E

Subject to change

09 January 1998, Josef Wolf

Products:

FSEA, FSEB, FSEM, FSEK

ROHDE&SCHWARZ

	A	B	C
1	**Error Calculation for FSE**		
2	**Inherent errors**	**specified error**	**standard uncertainty**
3	Absolute error 120 MHz[dB]	0.3	0.17
4	Frequency response[dB]	0.5	0.29
5	Input attenuator[dB]	0.3	0.17
6	If Gain[dB]	0.2	0.12
7	Log linearity[dB]	0.3	0.17
8	Bandwidth switching error [dB]	0.3	0.17
9	Bandwidth error [%]	10.00	0.26
10	combined variance		0.29
11	combined standard uncertainty		0.54
12	**rss error[dB] (95 % confidence level)**		**1.05**
13			
14	**Error due to source mismatch**		
15	VSWR of SA	1.5	
16	VSWR of DUT	2	0.42
17	combined variance		0.47
18	combined standard uncertainty		0.68
19	**error including source mismatch (95%)**		**1.34**

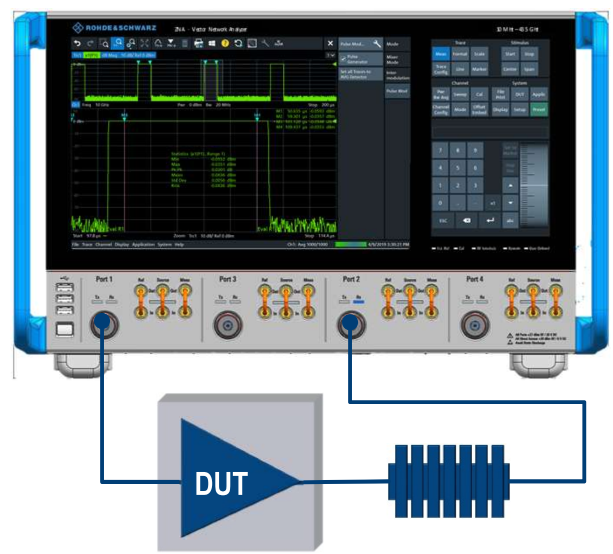
GAIN MEASUREMENT APPROACHES: VECTOR NETWORK ANALYZER

Advantages

- Excellent Dynamic Range
- Absolute power accuracy transferred from USB power sensor
- Calibration applied directly to the DUT connection plane
- Fast sweeps to characterize frequency response
- Power sweeps to characterize compression point Psat etc.
- Characterisation of all relevant S-Parameters (S11, S21, etc.)
  - Magnitude AND phase
- Deeper analysis of production quality using TDR techniques
- Mismatch correction

Disadvantages

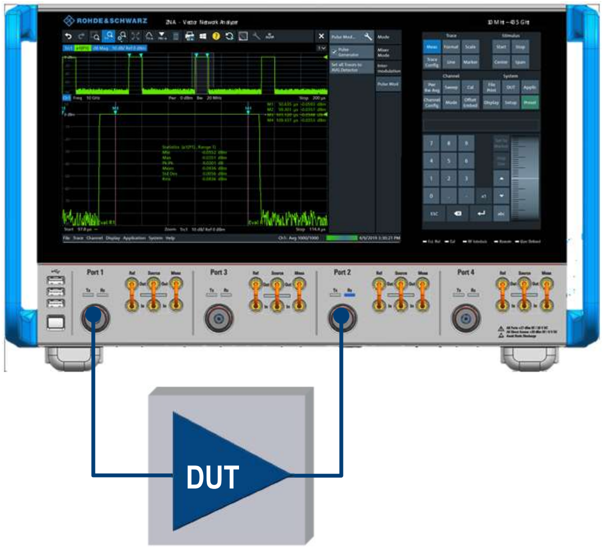
- More Expensive (generally) than scalar solution



MEASUREMENT DETAILS BASED ON AMPLIFIER TYPE

LNA, (Low Noise Amplifier), Small-Signal Amp, Instrumentation Amp

- ► Generally has low-power input requirement
- ► May have high-gain
- ► Simple setup: can usually connect directly to VNA ports



Considerations:

- ► Is input power range of VNA sufficient?
  - *How low can you go?*
- ► Ensure that input levels will not compress DUT
- ► Ensure output levels will not compress VNA receivers

MEASUREMENT DETAILS BASED ON AMPLIFIER TYPE

Considerations:

► Is input power range of VNA sufficient?

– *How low can you go?*

► Ensure that input levels will not compress DUT

► Ensure output levels will not compress VNA receivers

Parameter	Frequency range	Specification	Typical	Measured
Power range	without optional extended power range			
	R&S®ZNB4 and R&S®ZNB8			
	9 kHz to 100 MHz	–55 dBm to +10 dBm	up to +12 dBm	
	100 MHz to 2.5 GHz	–55 dBm to +13 dBm	up to +15 dBm	
	2.5 GHz to 7.5 GHz	–55 dBm to +10 dBm	up to +13 dBm	
	7.5 GHz to 8.5 GHz	–55 dBm to +8 dBm	up to +12 dBm	
	R&S®ZNB20			
	100 kHz to 10 GHz	–30 dBm to +12 dBm	up to +15 dBm	
	10 GHz to 20 GHz	–30 dBm to +10 dBm	up to +13 dBm	
	R&S®ZNB26 and R&S®ZNB43			
	100 kHz to 300 kHz	–30 dBm to +7 dBm	up to +10 dBm	
	300 kHz to 1 GHz	–30 dBm to +10 dBm	up to +12 dBm	
	1 GHz to 10 GHz	–30 dBm to +8 dBm	up to +10 dBm	
	10 GHz to 15 GHz	–30 dBm to +6 dBm	up to +8 dBm	
	15 GHz to 20 GHz	–30 dBm to +5 dBm	up to +7 dBm	
	20 GHz to 30 GHz	–30 dBm to 0 dBm	up to +4 dBm	
	30 GHz to 40 GHz	–30 dBm to –2 dBm	up to +2 dBm	
	R&S®ZNB43, 2.4 mm interface			
	40 GHz to 43.5 GHz	–30 dBm to –3 dBm	up to +2 dBm	
	R&S®ZNB43, 2.92 mm interface			
	40 GHz to 43.5 GHz			+2 dBm
Minimum power level	using optional extended power range (see Options)			
	R&S®ZNB4 and R&S®ZNB8			
	9 kHz to 8.5 GHz	–85 dBm		
	R&S®ZNB20 and R&S®ZNB26 and R&S®ZNB43			
	100 kHz to 40 GHz	–60 dBm		
	R&S®ZNB43, 2.4 mm interface			
	40 GHz to 43.5 GHz	–60 dBm		
	R&S®ZNB43, 2.92 mm interface			
	40 GHz to 43.5 GHz			

MEASUREMENT DETAILS BASED ON AMPLIFIER TYPE

Considerations:

- Is input power range of VNA sufficient?
  - *How low can you go?*
- Ensure that input levels will not compress DUT
- Ensure output levels will not compress VNA receivers

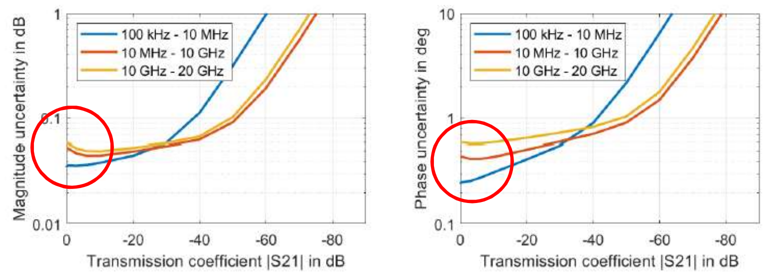
Transmission Measurements

Version 06.00, April 2022

Measurement accuracy of the R&S®ZNB20

This data is valid between +18 °C and +28 °C, provided the temperature has not varied by more than 1 °C since calibration. Validity of the data is conditional on the use of an R&S®ZN-Z235 calibration kit. This calibration kit is used to achieve the effective system data specified below. Frequency points, measurement bandwidth and sweep time have to be identical for measurement and calibration (no interpolation allowed).

Uncertainty of transmission measurements		Magnitude	Phase
100 kHz to 10 MHz	0 dB to –20 dB	0.04 dB	0.4°
	–20 dB to –40 dB	0.11 dB	0.9°
	–40 dB to –50 dB	0.32 dB	2.2°
	–50 dB to –60 dB	0.98 dB	6.5°
> 10 MHz to 10 GHz	0 dB to –20 dB	0.05 dB	0.5°
	–20 dB to –40 dB	0.06 dB	0.7°
	–40 dB to –50 dB	0.09 dB	0.9°
	–50 dB to –60 dB	0.19 dB	1.5°
> 10 GHz to 20 GHz	0 dB to –20 dB	0.05 dB	0.7°
	–20 dB to –40 dB	0.07 dB	0.8°
	–40 dB to –50 dB	0.10 dB	1.0°
	–50 dB to –60 dB	0.24 dB	1.8°
Specifications are based on a matched DUT, a measurement bandwidth of 10 Hz and a nominal source power of –10 dBm.			



Typical uncertainty of transmission magnitude and transmission phase measurements for the R&S®ZNB20 in the frequency range from 100 kHz to 20 GHz; analysis conditions: $S_{11} = S_{22} = 0$, cal. power: –10 dBm, meas. power: –10 dBm

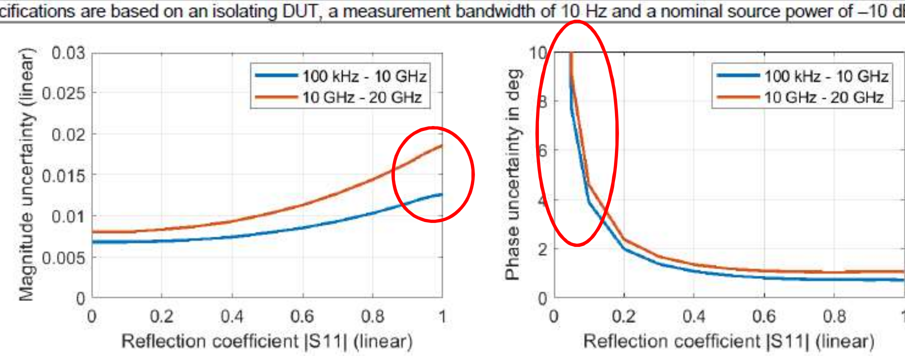
MEASUREMENT DETAILS BASED ON AMPLIFIER TYPE

Considerations:

- ► Is input power range of VNA sufficient?
  - – *How low can you go?*
- ► Ensure that input levels will not compress DUT
- ► Ensure output levels will not compress VNA receivers

Reflection Measurements (for completeness)

Uncertainty of reflection measurements	Logarithmic			Linear	
	Reflection level	Magnitude	Phase	Reflection range	Magnitude
100 kHz to 10 GHz	0 dB	0.1	0.7°	0 dB to –15 dB	0.013
	–15 dB	0.3	2.0°	–15 dB to –25 dB	0.007
	–25 dB	1.0	7.7°	–25 dB to –35 dB	0.007
> 10 GHz to 20 GHz	0 dB	0.2	1.1°	0 dB to –15 dB	0.019
	–15 dB	0.4	2.4°	–15 dB to –25 dB	0.008
	–25 dB	1.2	9.1°	–25 dB to –35 dB	0.008
Specifications are based on an isolating DUT, a measurement bandwidth of 10 Hz and a nominal source power of –10 dBm.					



Typical uncertainty of reflection magnitude and reflection phase measurements for the R&S®ZNB20 in the frequency range from 100 kHz to 20 GHz; analysis conditions: $S_{12} = S_{21} = 0$, cal. power: –10 dBm, meas. power: –10 dBm

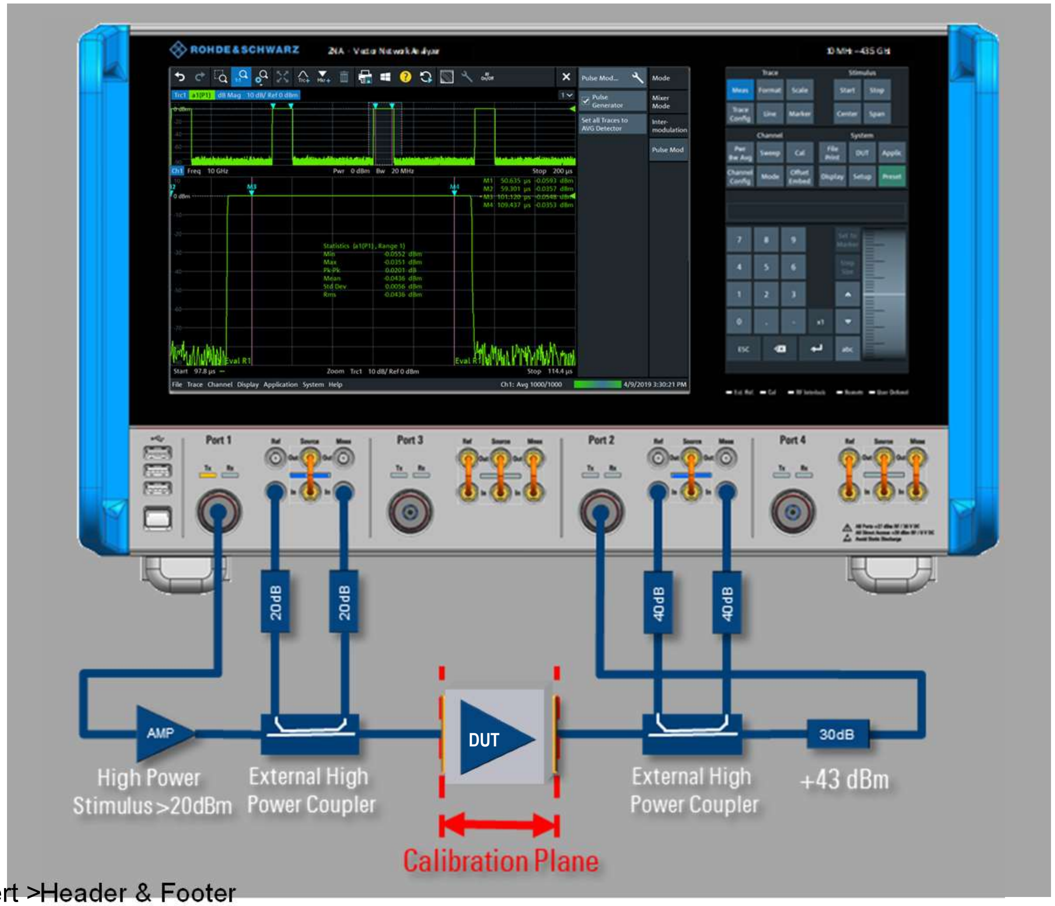
MEASUREMENT DETAILS BASED ON AMPLIFIER TYPE

High-Power Amplifier

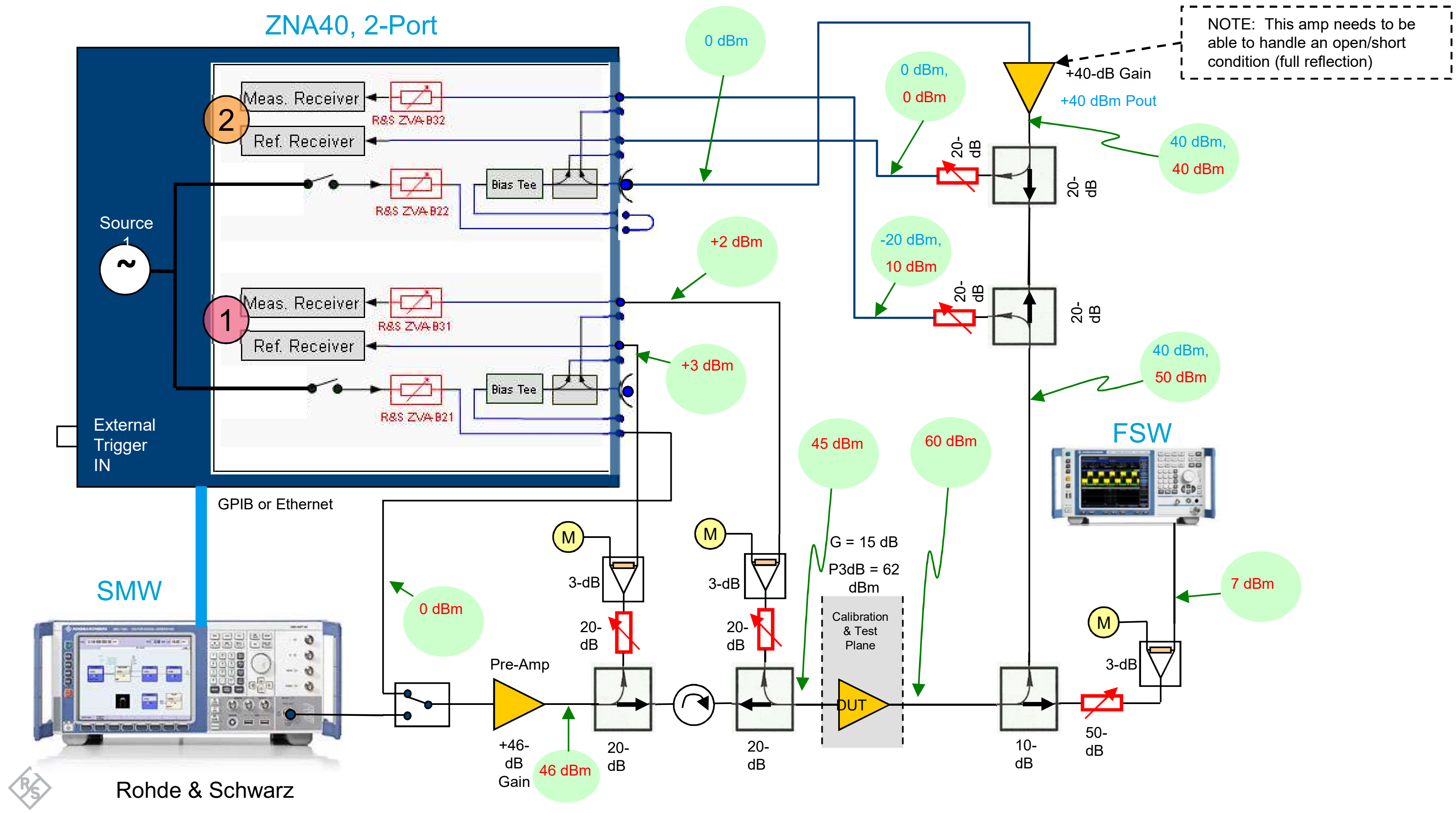
- ► Extremely Complex Setup may be required
  - – External high-power couplers
  - – External high-power attenuators

Considerations:

- ► Is Pre-amp required for driving the DUT
  - – Low-gain, high-power device
- ► Ensure that input levels will not compress DUT
- ► Ensure output levels will not compress VNA receivers

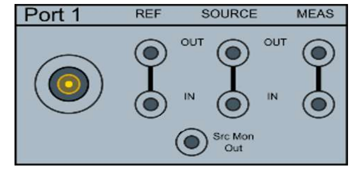


MAP OUT POWER LEVELS VIA SETUP BLOCK DIAGRAM

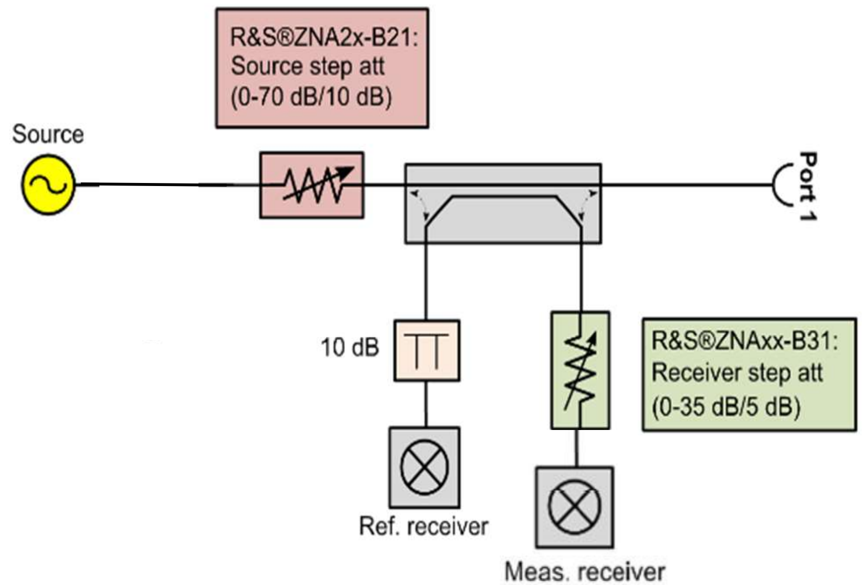


TOOLS TO IMPROVE AMPLIFIER MEASUREMENT PERFORMANCE

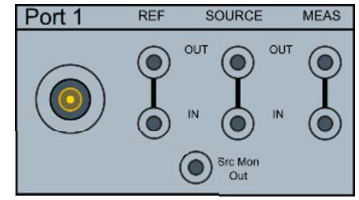
All Ports - Standard Configuration

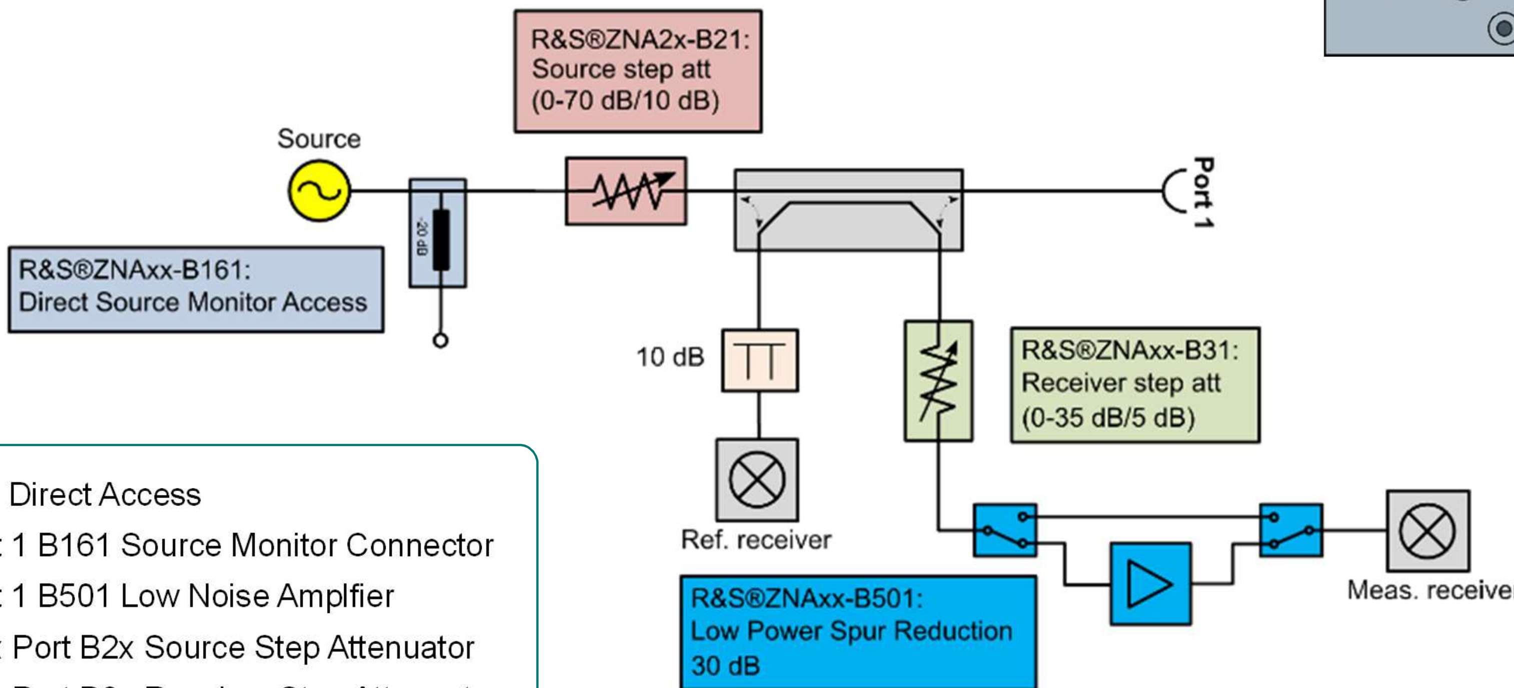


- **Standard Configuration**
  - Most common VNA set-up. This configuration can be used on all ports.
  - Shown with source and receiver attenuators
  - Useful in measuring both active and passive DUTs
- **Default Preset values:**
  - Port is set to -10 dBm
  - Receiver Step attenuator set to 10 dB
  - Source step attenuator set to 0 dB
  - IFBW 10 kHz
  - Phase Coherence – OFF
  - Defaults to 1 LO
- **Applications:**
  - S-Parameters
  - Wave quantities
  - Harmonics (with K4)
  - Noise Figure (with K30)
  - Amplifier measurements using the 100 dB power sweep range of the ZNA



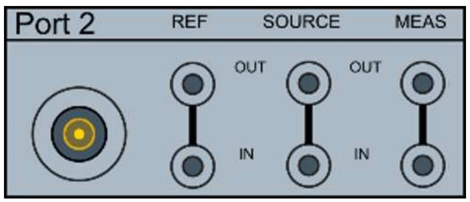
Port 1 Flexibility and Options

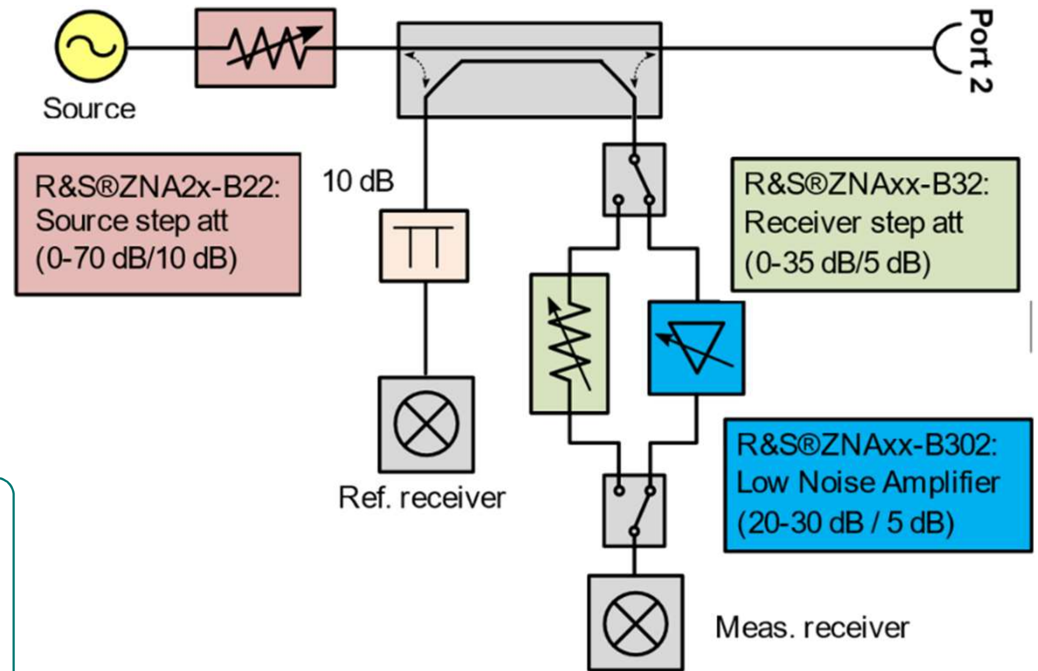




- B16 Direct Access
- Port 1 B161 Source Monitor Connector
- Port 1 B501 Low Noise Amplfier
- All x Port B2x Source Step Attenuator
- All x Port B3x Receiver Step Attenuator

Port 2 Flexibility and Options

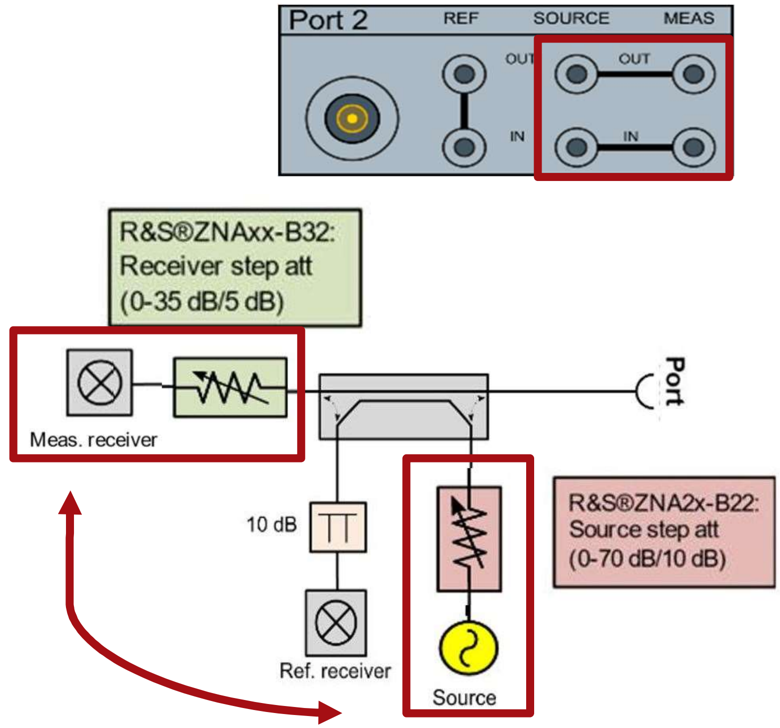




- B16 Direct Access
- Port x B3x Receiver Step Attenuator
- Port x B2x Source Step Attenuator
- Port 2 B302 LNA
  - 20, 25 or 30 dB of gain

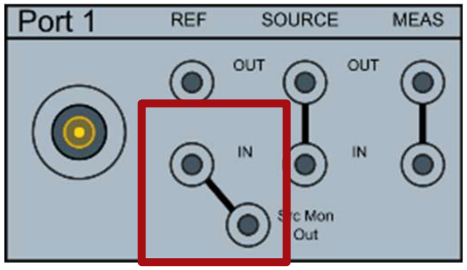
Options for any Port: Reverse the Port Coupler

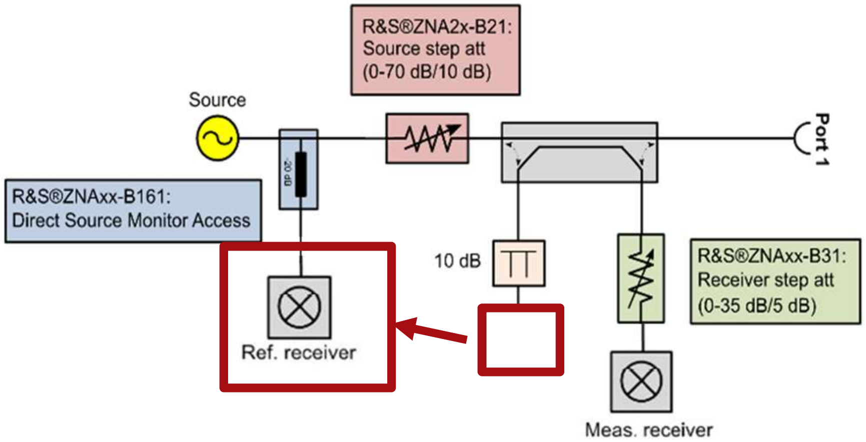
- **Reverse the Port coupler**
  - Improves measurement receiver sensitivity by 10 dB
  - Improves the measurement receiver Dynamic Range by 10 dB
  - Decreases the source output at port by 10 dB
  - Reduces the measurement receiver compression level by 10 dB
    - It is important to keep the receiver out of compression during calibration and measurement
- **Applications**:
  - Useful for Noise Figure measurements
    - Able to measure devices with lower “DUT gain + DUT NF” metric
  - High Dynamic Range measurements
    - Increase the DR of the ZNA by 10 dB at the expense of 10 dB decrease in output power
  - Simple full band solution that mitigates the < 500 MHz coupler roll of the measurement receiver.



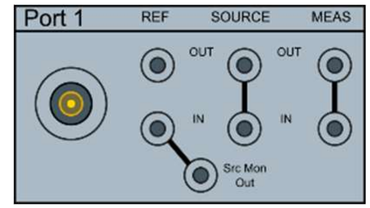
Options for Port 1: B161 Source Monitor Port
Options for Port 1 & 3: B163

- **B161 Source Monitor Port**
  - Moves the Reference receiver (a1,3) before the source attenuator
  - Done by moving the B16 loop on the reference receiver
  - Increases the reference SNR for high settings of Source attenuator
  - Avoids the coupler roll-off < 500 MHz of the reference receiver
- **Applications:**
  - Used for measuring high gain devices where the drive level must be kept low to keep the DUT out of compression
  - Since S11 (b1/a1) and S21 (b2/a1) both use the a1 reference receiver these S-Parameters will benefit from a high SNR on the a1 receiver.
  - B163 adds this to ports 1 and 3 on 4 Port ZNAs

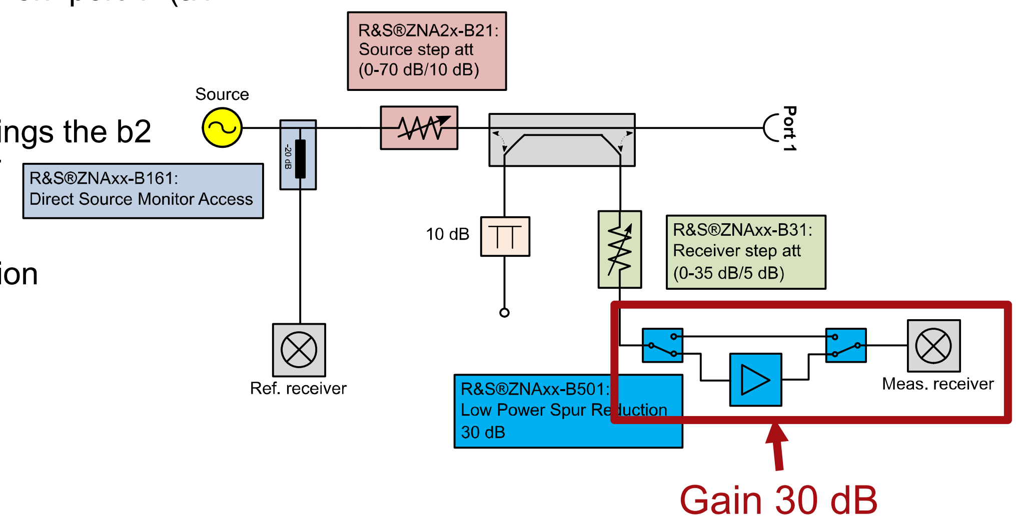




Options for Port 1: B501 Port 1 Amplifier

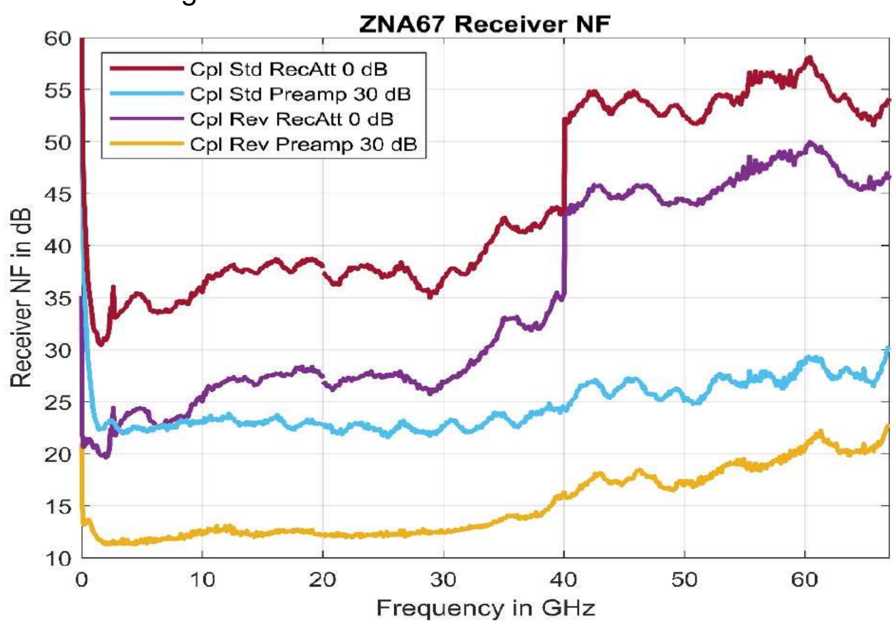


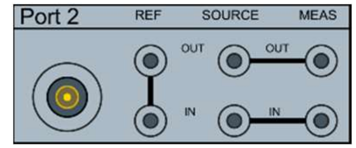
- **B501 Low Noise Amplifier**
  - Adds an amplifier to the Measurement receiver (b1)
  - Useful for measuring S11 of high gain devices with very low drive level
  - Often recommended with B161
  - Has the net effect of reducing the spurious output level on port 1 (a1 receiver LO leakage)
- **Applications**
  - Under low drive levels and high source attenuator settings the b2 receiver level reduced by the return loss from the DUT
  - Example on a high gain DUT with a 20 dB return loss:
    - DUT input level -60 dBm. To avoid DUT compression
    - Measurement receiver (b2) sees -80 dBm
    - S11 would be very noisy
  - Using B161 and B501 much netter SNR is achieves
  - Example using the same DUT
    - B501 Gain is 30 dB
    - b2 receiver sees -50 dBm
    - S11 SNR improved by 30 dB

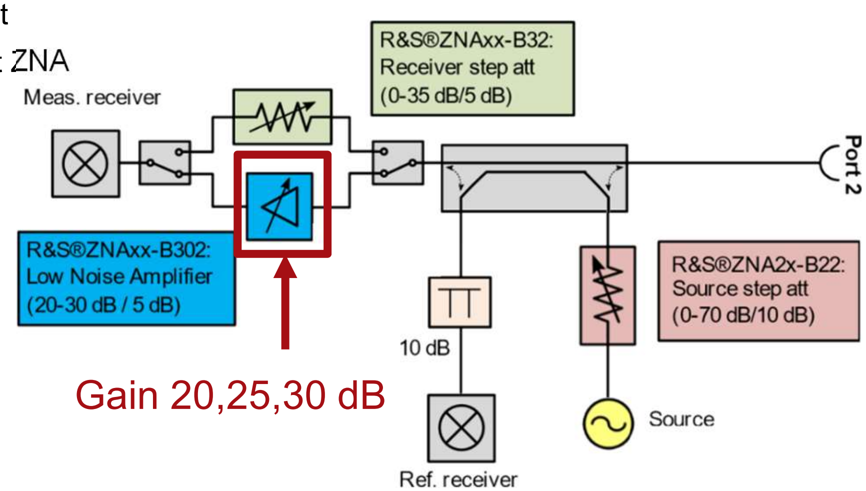


Options for Port 2: B302 Pre-amplifier

- **B302 pre-amplifier**
  - Improves b2 receiver sensitivity by up to 30 dB
    - Able to measure devices with lower “DUT gain + DUT NF” metric
  - Degrades b2 receiver compression point by up to 30 dB
    - Need to avoid compression during calibration and measurement
  - When used with a reversed coupler on port 2 it provides the lowest ZNA Noise Figure

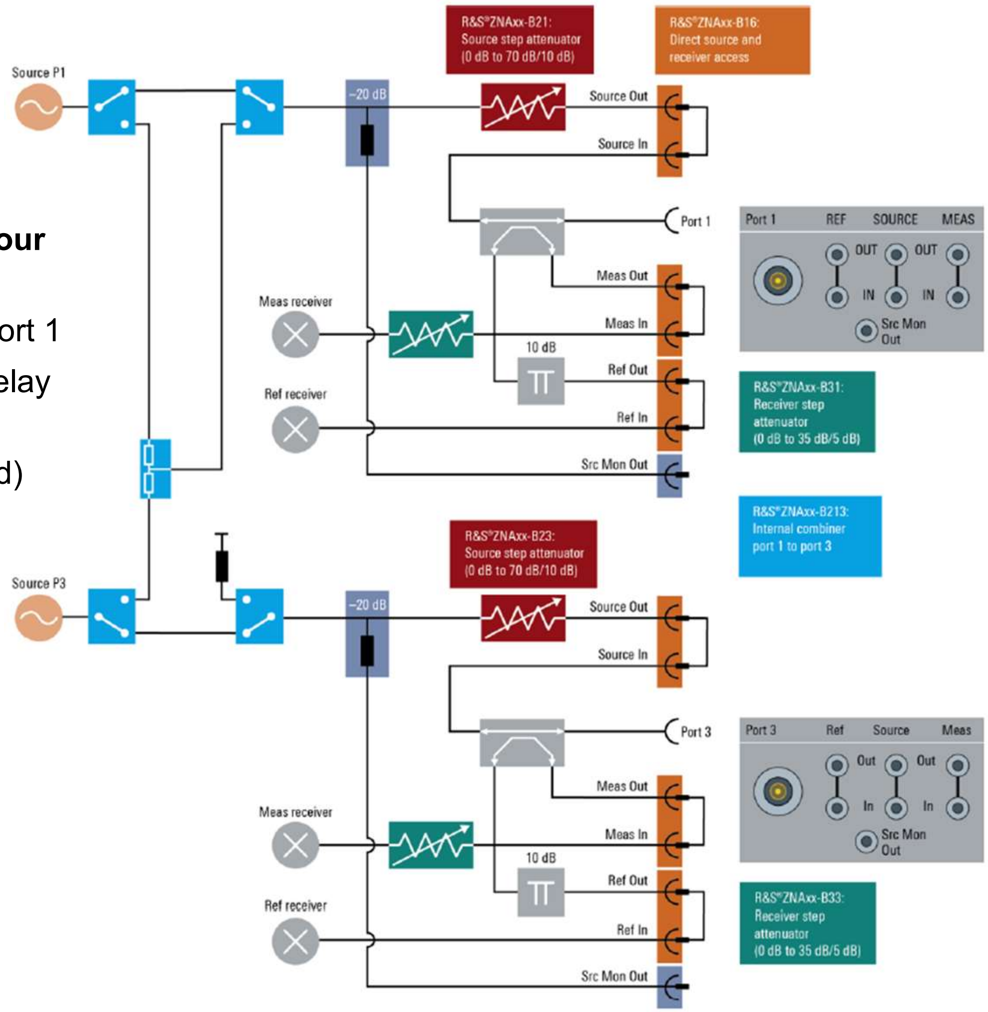






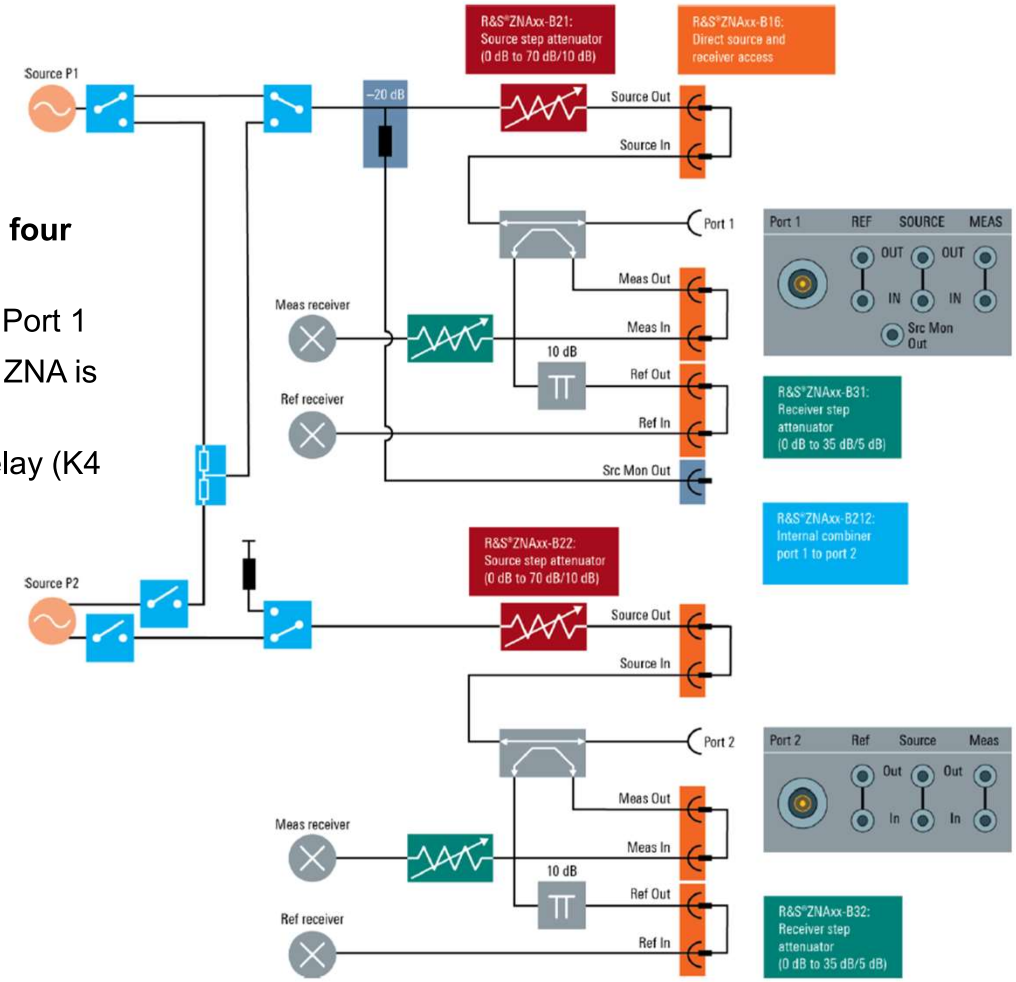
Internal Combiner
Four Port

- **B213 Combines ports 1 & 3 on a four port ZNA**
  - Allows Multi-tone stimulus from Port 1
  - Used for Embedded LO Group Delay (K4 and K9 needed)
  - Used to measure IMD (K4 needed)

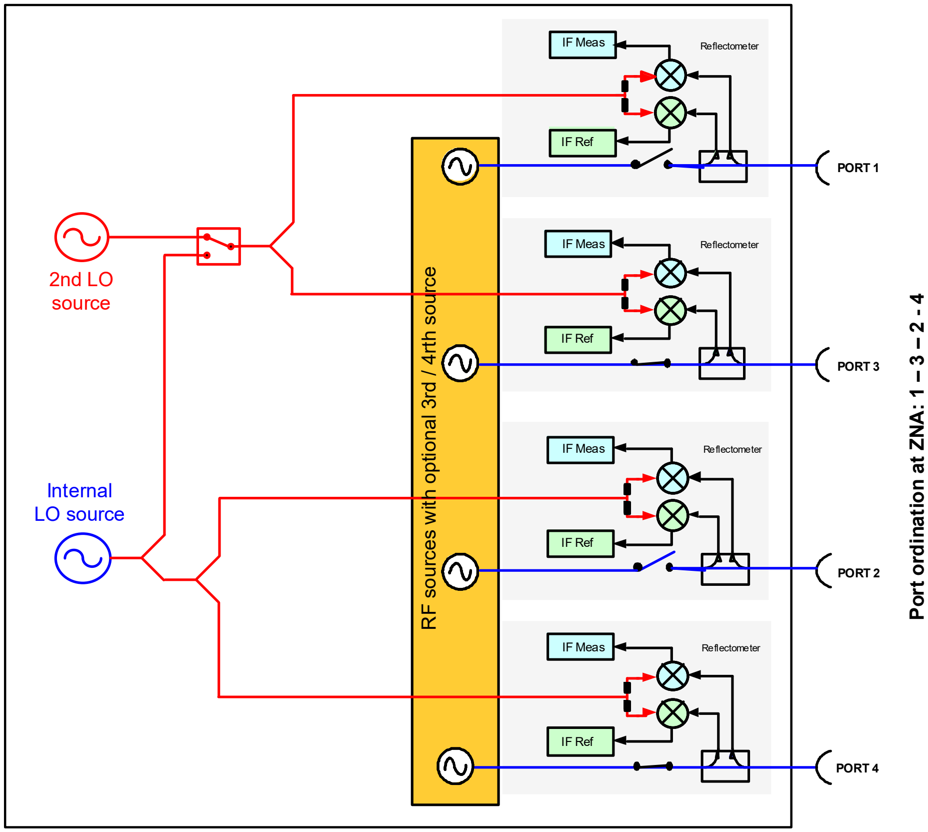


Internal Combiner
Two Port

- **B212 Combines ports 1 & 3 on a four port ZNA**
  - Allows Multi-tone stimulus from Port 1
  - Cost effective because a 4-port ZNA is no longer required to measure:
    - Embedded LO Group Delay (K4 and K9 needed)
    - IMD (K4 needed)



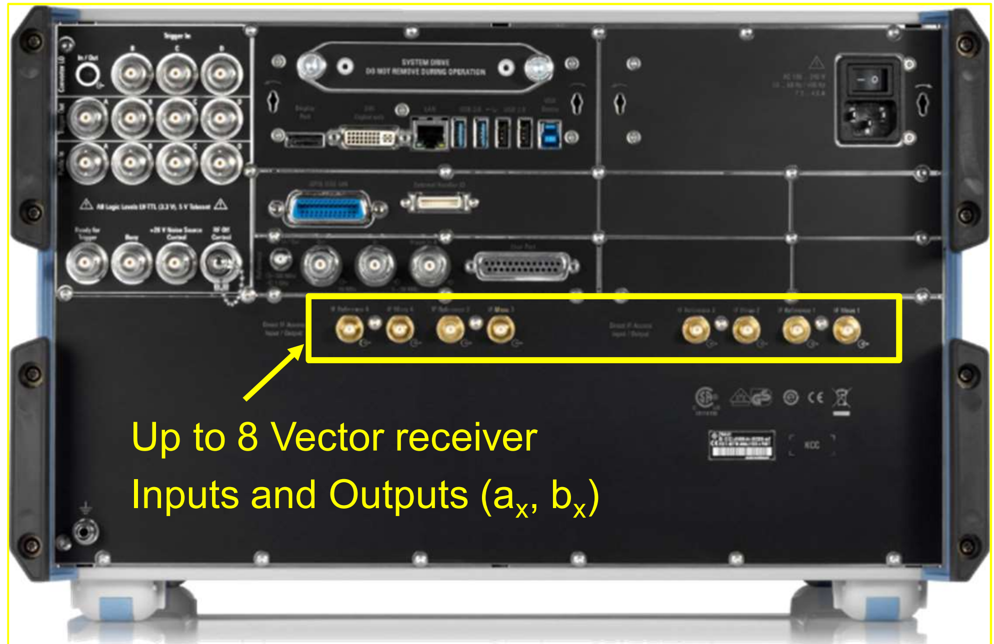
Two internal LOs and multiple Internal Sources



- **Two internal LO sources B5 (2 & 4 Port ZNAs)**
  - Measure two frequencies simultaneously
  - Fast mixer and converter measurements
  - Very low trace noise with frequency-converting measurements
- **Four port, Four source ZNA (B3 adds 3rd, 4th sources)**
  - Flexible-to-configure, compact test setups, e.g. for DUTs with two converter stages
  - Sources available with B16 direct source outputs
- **Two port, Two source ZNA (B52 adds 2nd source)**
  - Cost effective solution to a Four port system
  - Sources available with B16 direct source outputs

Direct IF Inputs and Outputs (B26)

- **Inputs:**
  - One for each channel (a_x, b_x) – Up to 8 inputs
  - Bypasses ZNA front end – Lower noise performance
  - Direct 125 MHz A/D converter input (50 Ω)
  - 100 kHz – 1 GHz input BW
  - Useful for external mmW heads IF out at 279 MHz
- **Outputs:**
  - IF output down converted from front panel RF inputs
  - For RF inputs ≤ 5 GHz IF output 100 kHz – 60 MHz
  - For RF inputs > 5 GHz IF output 100 kHz – 2 GHz



R&S®ZNA-B26 direct IF access

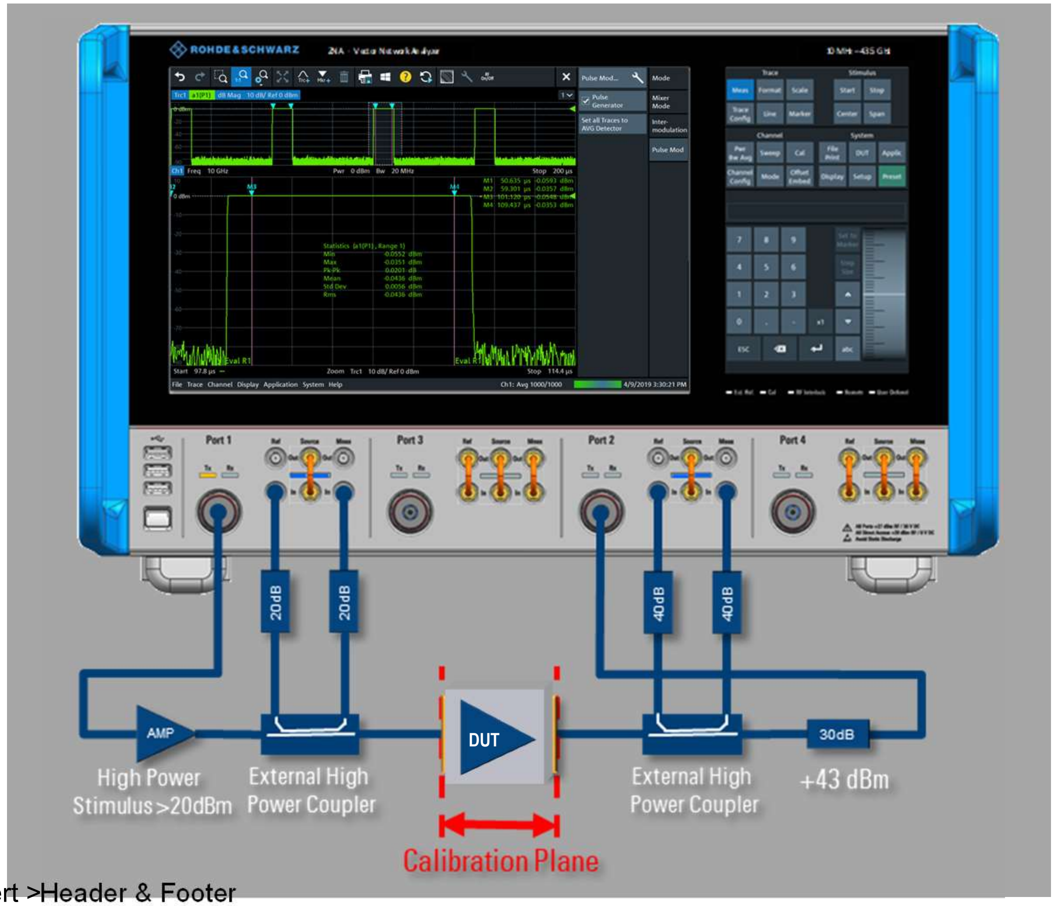
Connector type		SMA, female
Impedance		50 Ω (nom.)
Frequency range	input (ADC clock 125 MHz)	100 kHz to 1 GHz (nom.)
	output, RF ≤ 5 GHz	100 kHz to 60 MHz (nom.)
	output, RF > 5 GHz	100 kHz to 2 GHz (nom.)
Damage level		+20 dBm, 10 V DC

PULSED MEASUREMENTS: EVEN MORE CHALLENGING!

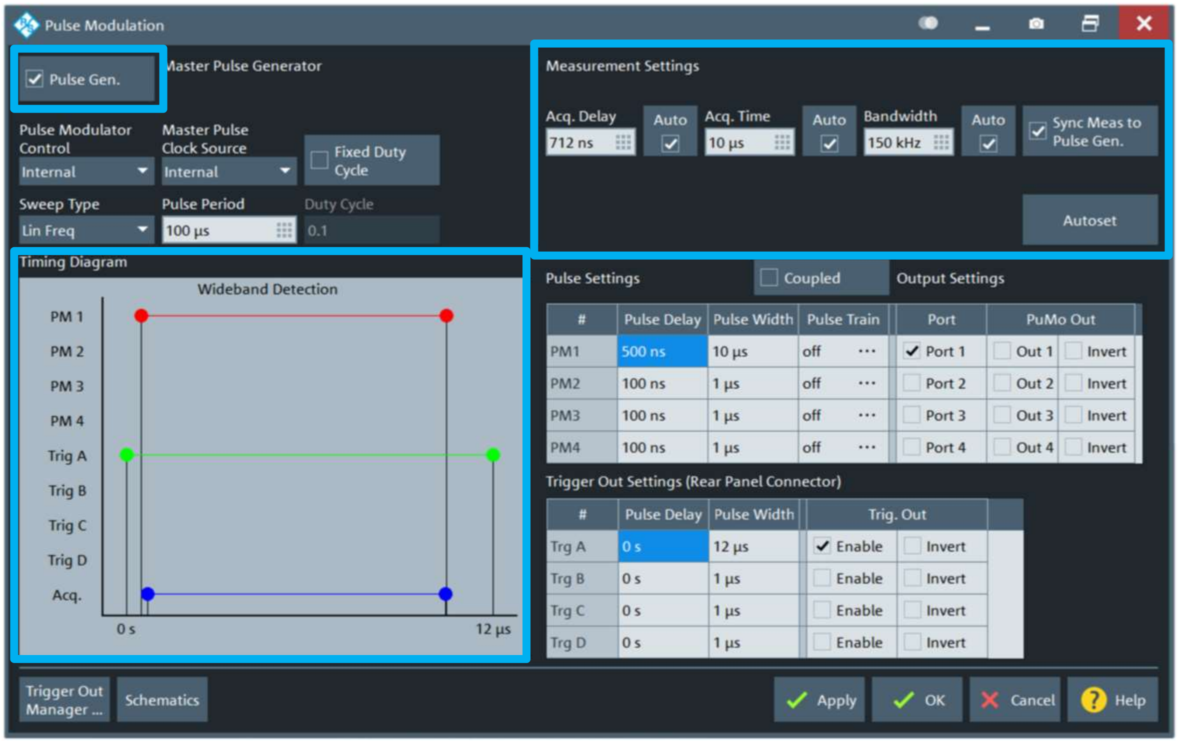
High-Power Amplifier

Considerations:

- ► If Pre-amp required for driving the DUT
  - – Preamps often have different output power (CW vs. Pulsed Operation)
  - – Complicates power calibration
- ► Power calibrate in CW mode, or is Pulsed mode required?
- ► Complicates power calibration
- ► Don't "let the smoke out" of your DUT/VNA/Power Sensor!



PULSE MODULATION SETUP DIALOG (ZNA)



All receiver settings are automatically configured with the "Autoset" button.

Measurement Trigger is automatically assigned to Master Pulse Clock source (int/ext).

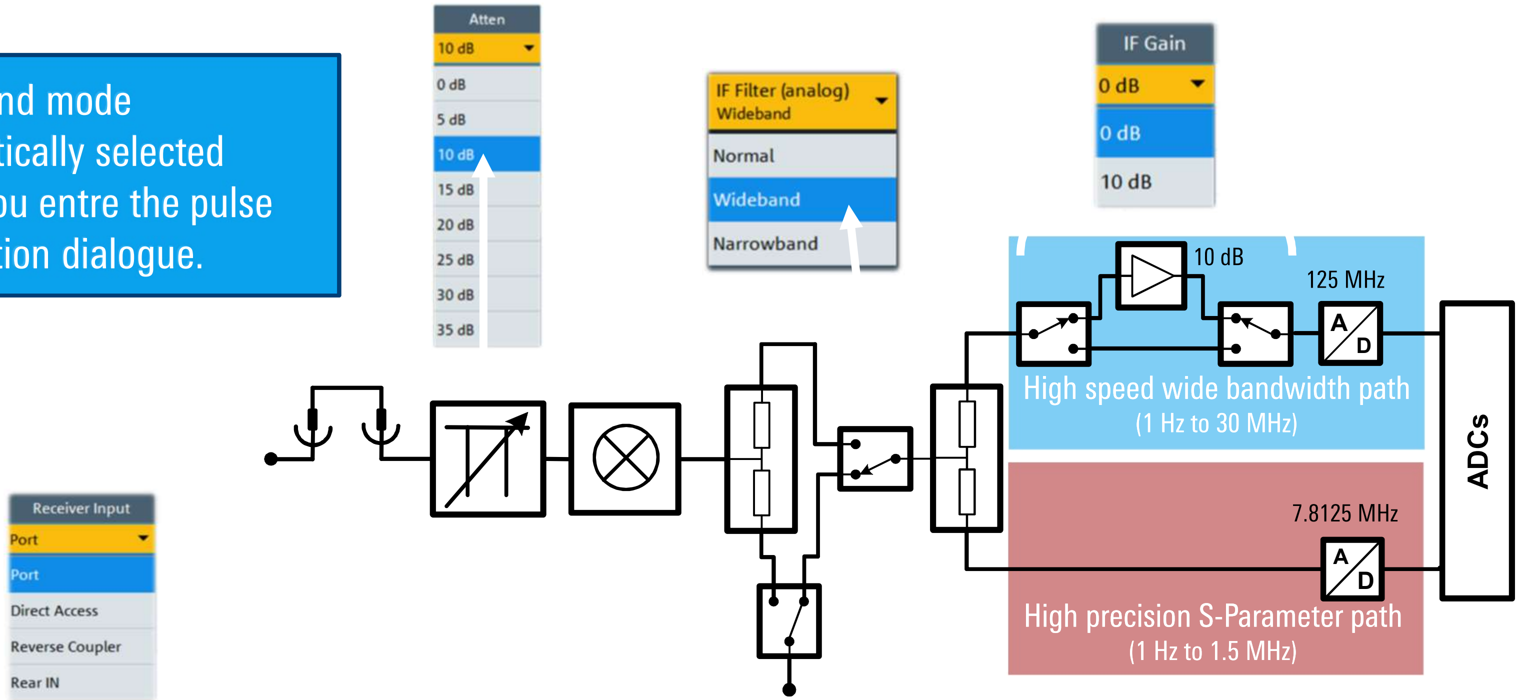
Toggling "Pulse Gen" switches between:

- Pulse modulators **on** with synchronous triggered measurement.
- Pulse modulators **off** with measurement set to free running.

All relevant events are shown in the timing diagram, incl acquisition time.

DEDICATED RECEIVER PATH FOR HIGHER PERFORMANCE AT WIDE BANDWIDTHS

Wideband mode automatically selected when you entre the pulse modulation dialogue.



Measurement receiver path shown

Available ZNA input frequency ranges