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.01-20 GHz Small Form Factor Multiport Network Analyzer Design Accelerators

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RFPD Design Accelerator Background

ENABLING MMWAVE DESIGNS

RadioThorium
from Richardson RFPD

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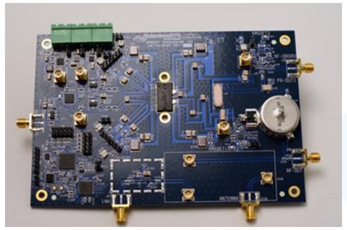
RF & Wireless   Energy & Power   Internet of Things

- Serving the RF and Microwave community since 1947
- Providing best-in-class access to technology and design support
- Wholly own subsidiary of Arrow Electronics

Design "Accelerators"



- System level platforms include leading edge technology from RFPD component suppliers
- Personalized RF Front Ends
- 0.03-6GHz SoM (System-on-Module) SDRs
- *NEW* - Frequency Converters

RadioThorium

- 24-44 GHz and 6-26 GHz Frequency Converters
- Designed for high performance
- Available exclusively from RFPD
- 2 products in family, additional designs planned for 2023

Design Goals

MAKING MMWAVE DESIGN SIMPLE

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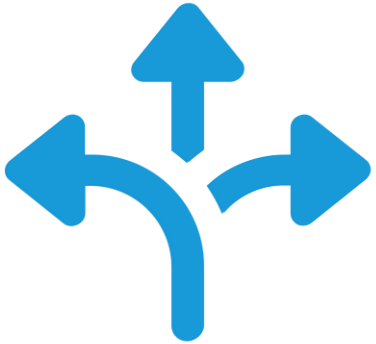
Ease-of-Use

Flexibility



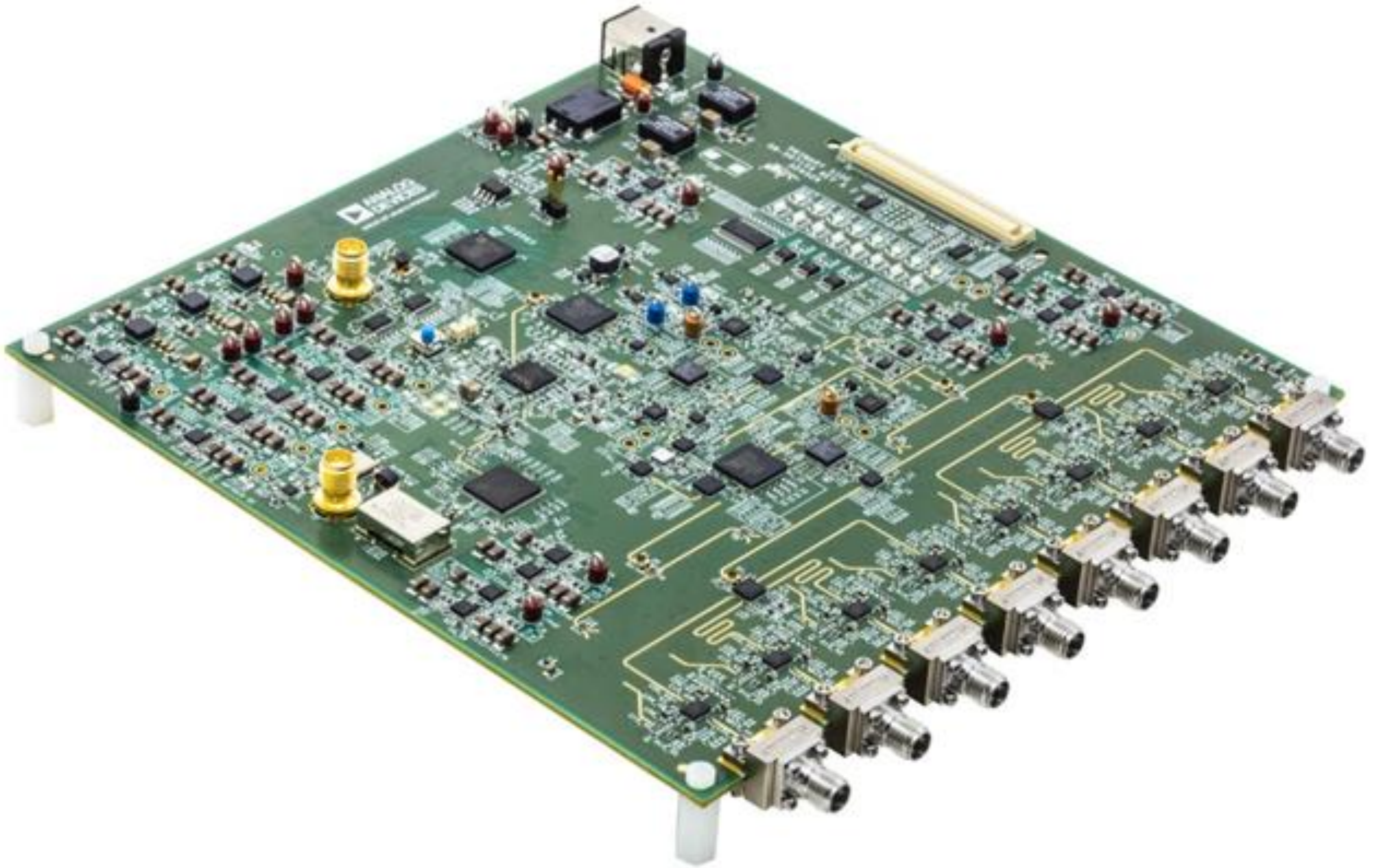
Customizable

Availability

Time-to-Market

8-Port Vector Network Analyzer-Reference Design
AD-FMCVNA8-EBZ

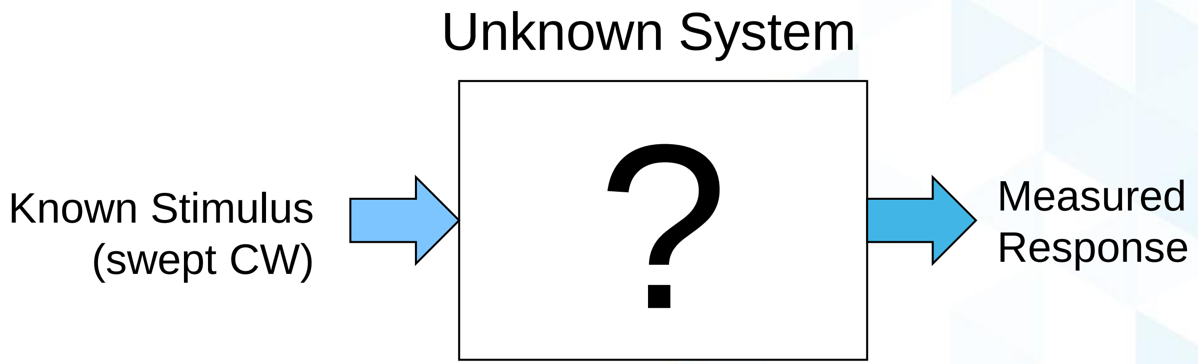
- 8-Ports
- .01-20 GHz
- Very Small
- Low Power
- Purchasable by EOY
- Design Files Available
- Customizable by 3rd Party



Vector Network Analysis Concepts

What is (RF) Vector Network Analysis?

- Technique for System Identification:
  - Determine “what is inside the box”
  - Apply a stimulus, measure the response
  - Usually CW, swept over (wide) frequency range



- Measures Scattering Parameters
  - Suitable for (very) high frequencies
  - Provide a lot of information (gain/loss for different loads, bandwidth, stability, ...)
  - Enable signature (image recognition) – based measurements

VNA Measurements

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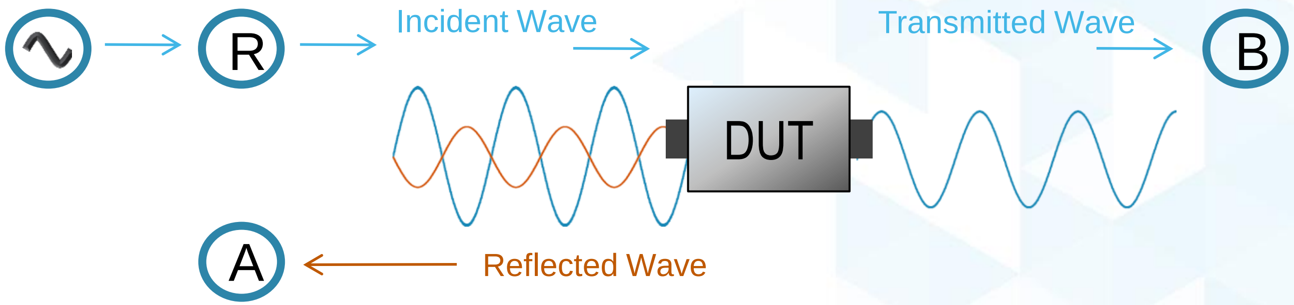
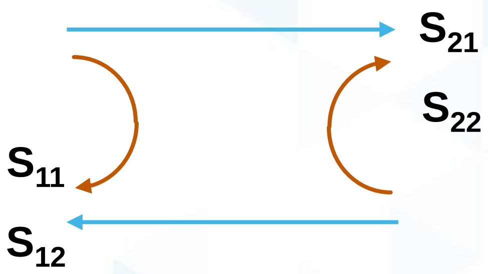
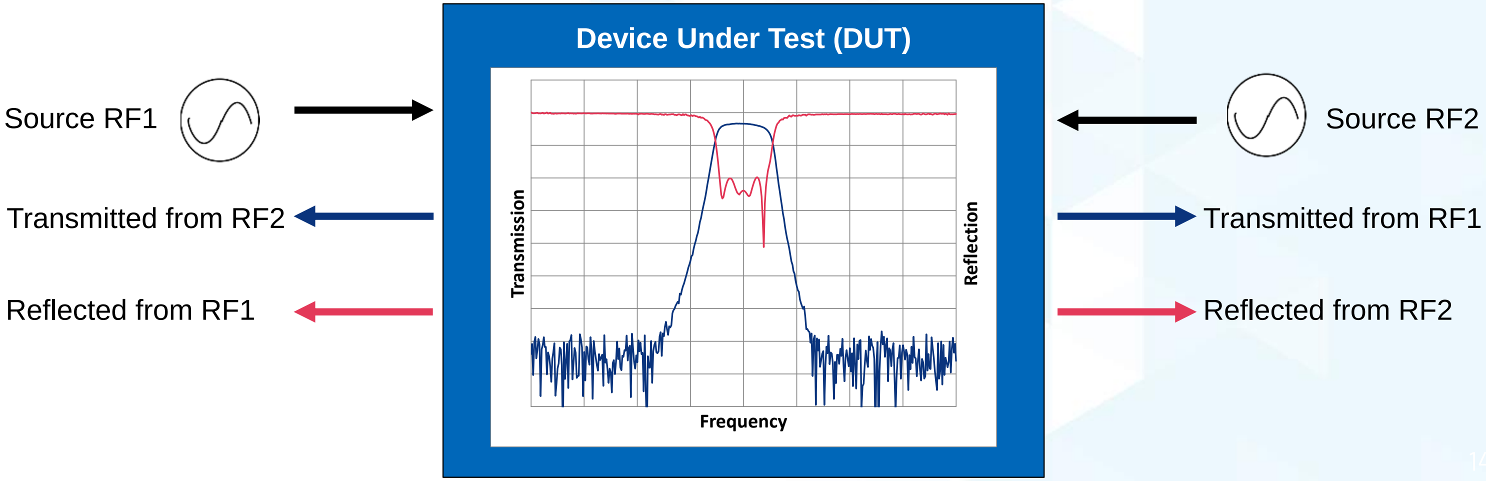


S-Parameters for a Two Port Device





<u>Reflection (A/R)</u>
Return Loss
Impedance
Reflection Coefficient
VSWR
S-Parameters

<u>Transmission (B/R)</u>
Insertion Loss (or Gain)
Transmission Coefficient
Group Delay
Phase
S-Parameters

Vector Network Analyzer – Concept

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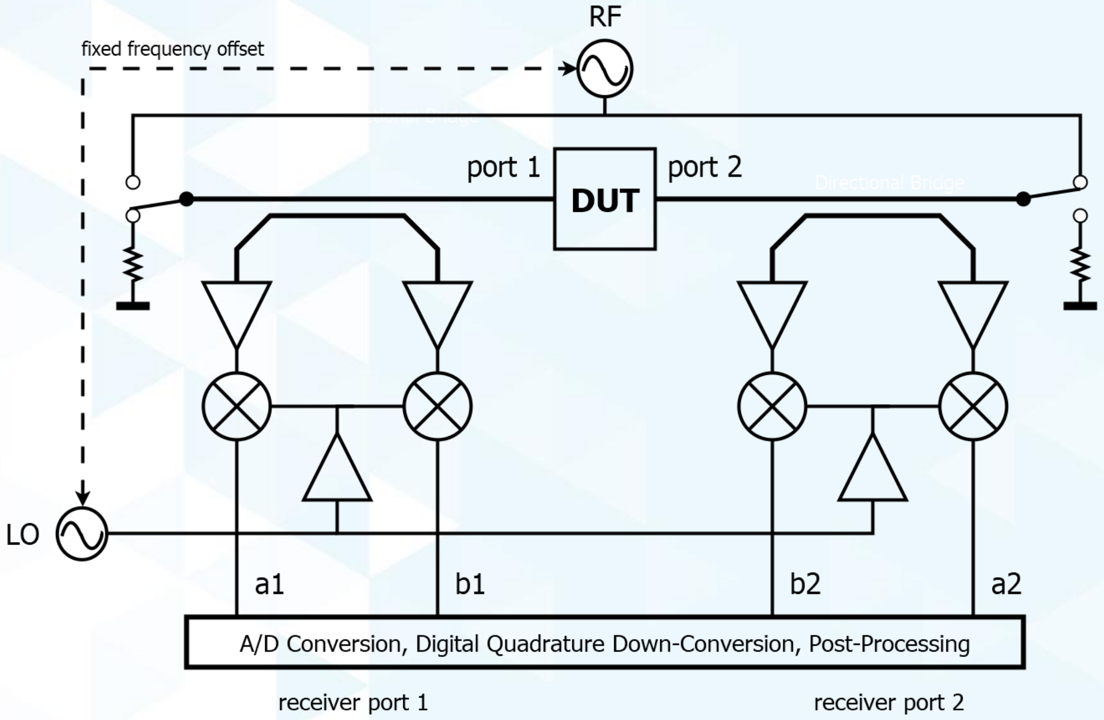
- **Key Components:**
  - **RF signal source:**
    - Drive DUT
    - Sweep over full measurement frequency range
  - **Switch:**
    - Connect RF source to selected port
    - Terminate the other port(s)
  - **Directional Couplers:**
    - Separate waves traveling in forward/reverse direction
    - Individual measurement of a1, a2 and b1, b2
  - **Mixers:**
    - Down Conversion to fixed IF frequency
  - **LO source:**
    - Drive mixer LO interface
    - Track RF source at fixed frequency offset
  - **Post Processing:**
    - A/D Conversion
    - Digital I/Q Demodulation: 'a' and 'b' magnitude & phase
    - Calculation (raw) S-parameters & Error correction
    - Representation



One Possible Block-Diagram of a 2-port Vector Network Analyzer

(there are many variants)

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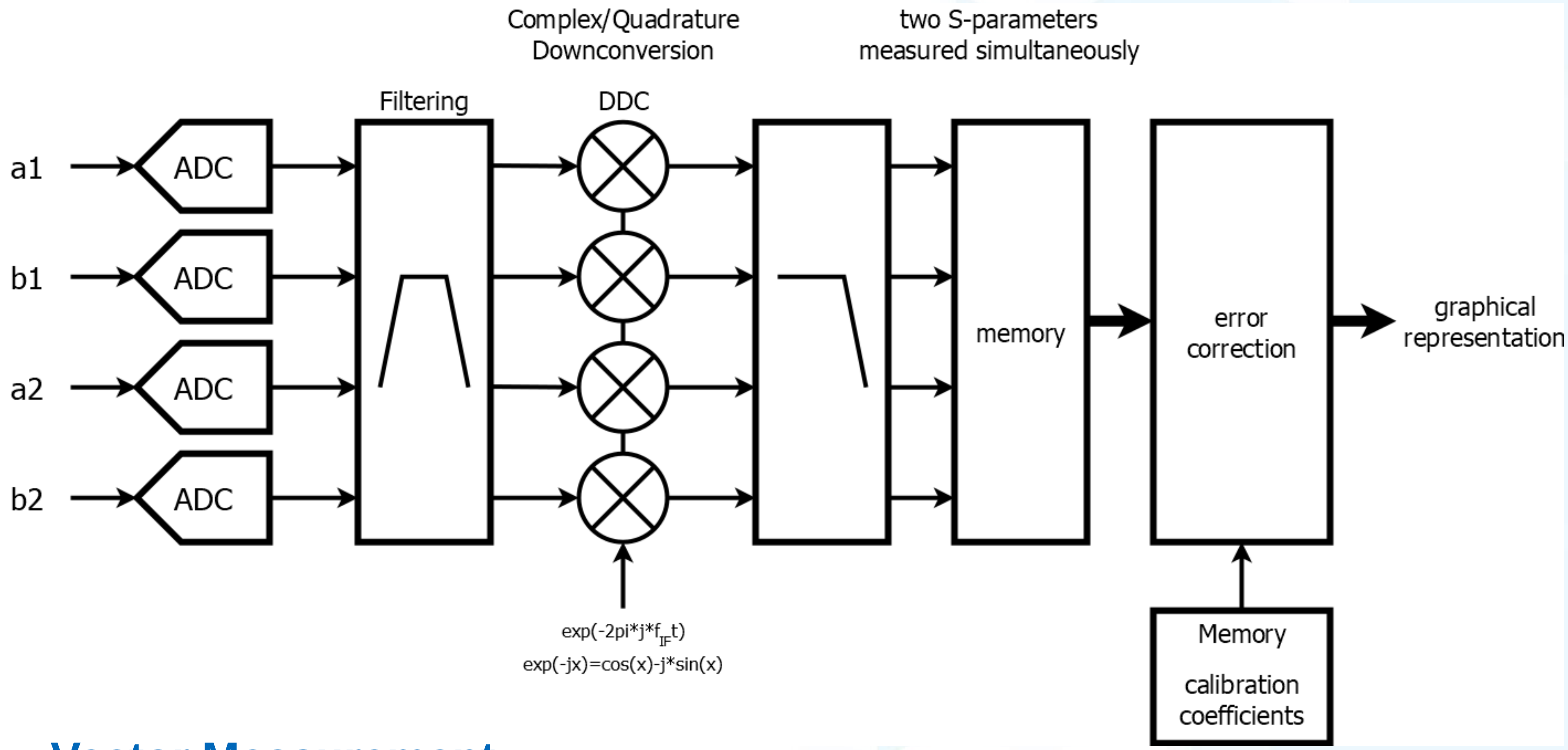
Post-Processing



- **Vector Measurement:**
  - Complex values
  - Magnitude & Phase
  - Real & Imaginary ("Cartesian")

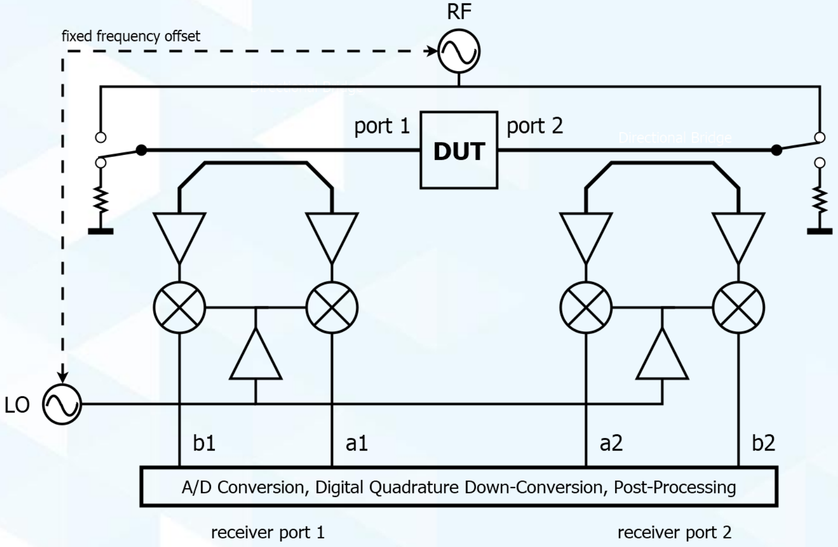
Vector Network Analyzer – Calibration

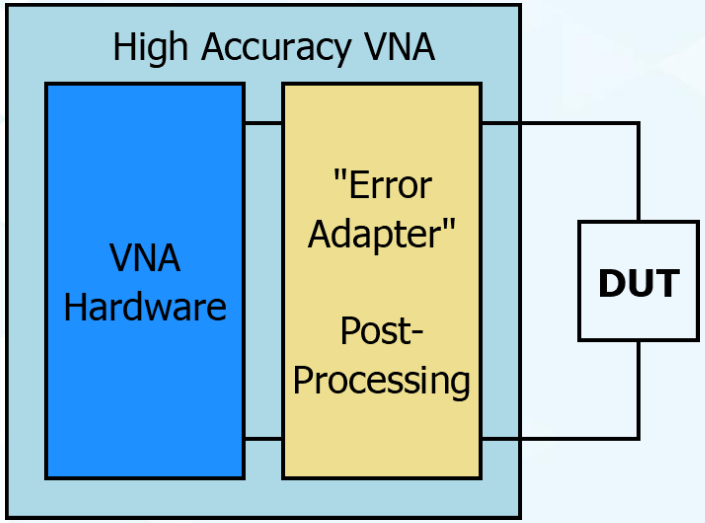
Hardware Introduces Measurement Errors:

- Frequency dependent response
- Insertion loss of filters and couplers
- Finite coupler directivity
- Cross-talk between channels
- Gain mismatch between channels
- Imperfect isolation in switches

Correction of Systematic (Repeatable) Errors:

- Measure accurately known DUT's (calibration standards)
- Use in algorithms to calculate "Error Adapter" coefficients
- Apply error correction to DUT measurements
- Many different error correction algorithms are available, using different standards. E.g.
  - Short-Open-Load-Thru (SOLT),
  - Thru-Reflect-Line (TRL), ...





Wide-Band Small Form Factor VNA - Challenges

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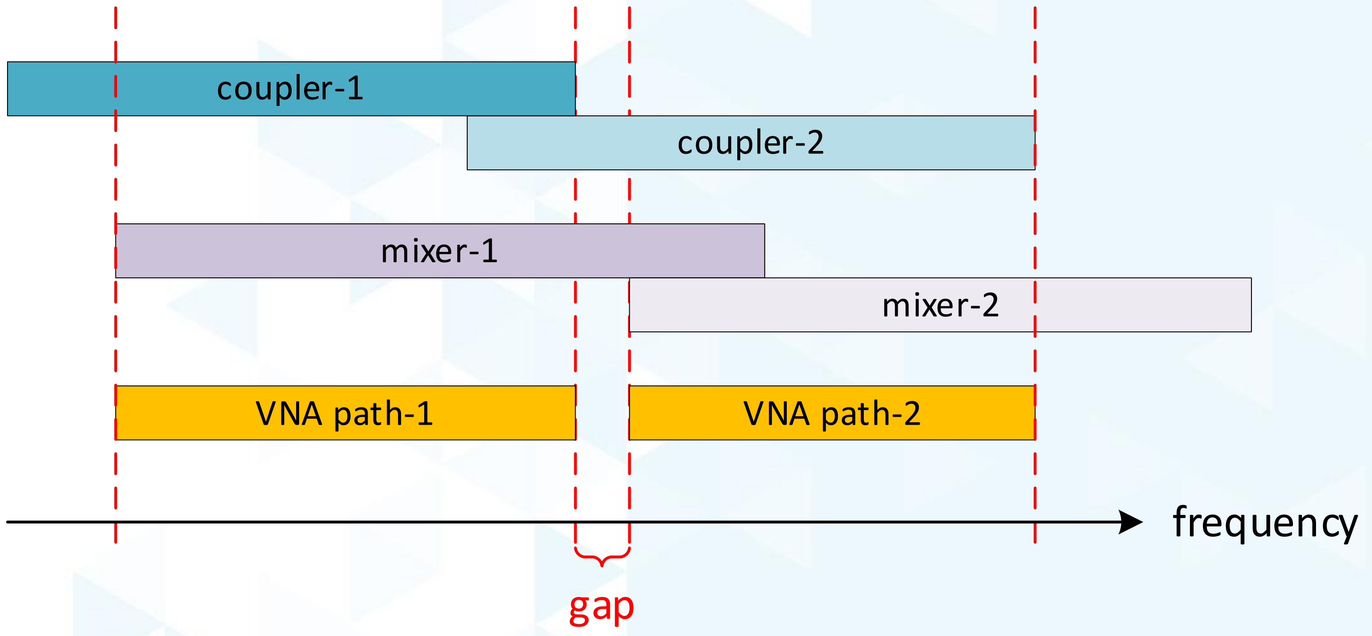
Limited Bandwidth Components

- multiple signal paths to cover range
- Non-matching frequency ranges
- Possibly gaps in VNA frequency range
- 2 ports is often not enough - need 4, 8 or more ports ...



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Wide-Band Small Form Factor VNA - Challenges

Frequency Source Complexity

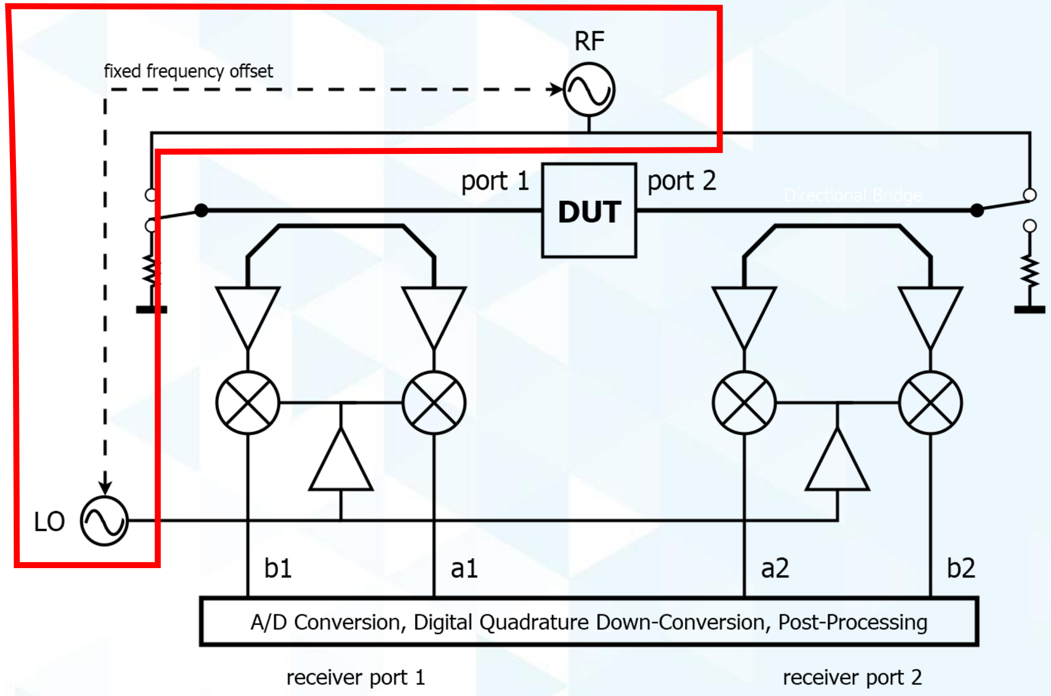
- Need to arrive at fixed IF = RF – LO

- IF needs to be 'low', i.e. few MHz
  - suitable for amps, ADC, ...

- RF and LO both need to sweep over wide range from MHz to GHz ...

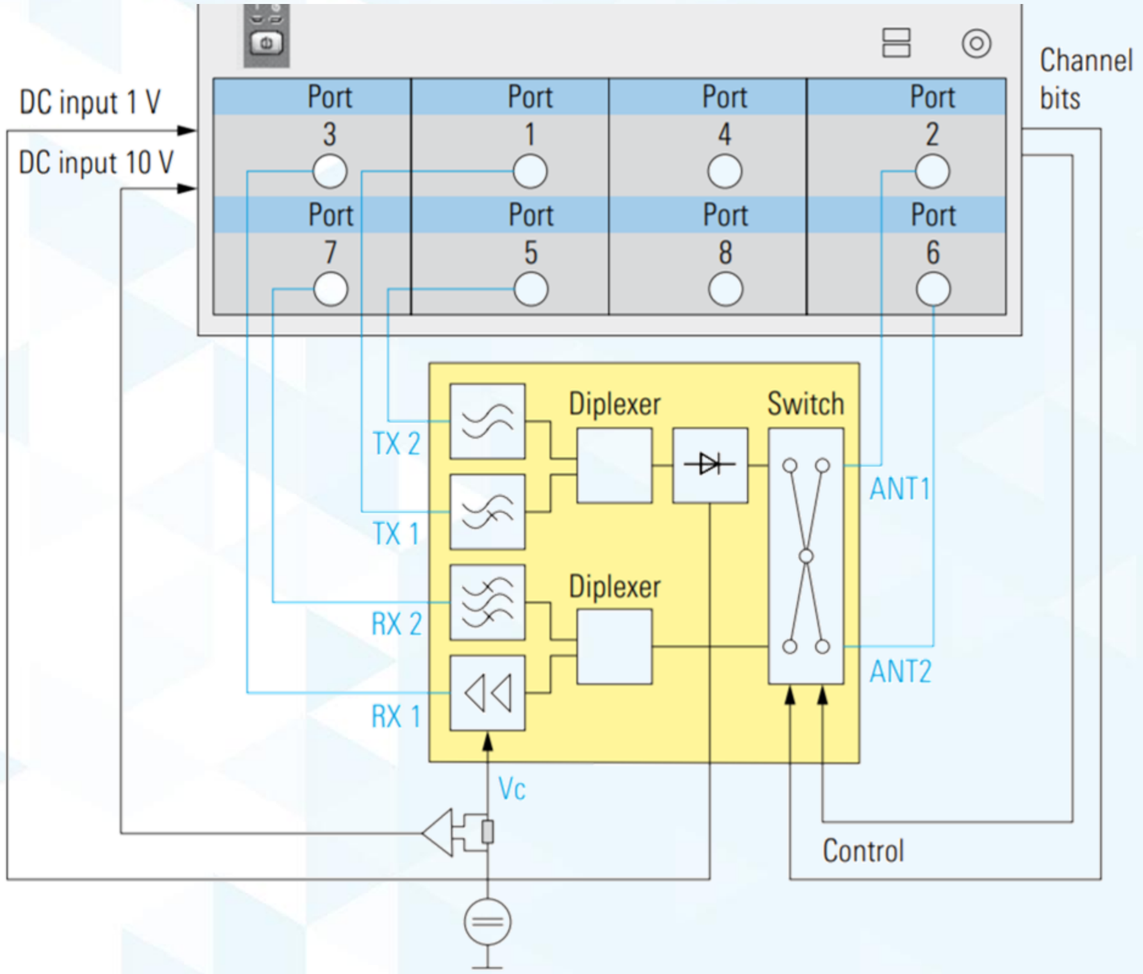
  not easy to do accurately

- Need either
  - 2 separate PLLs', or
  - PLL and single side-band mixer (typically narrow-band)



Multi-port VNA Requirements

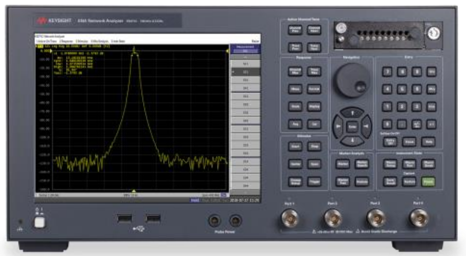
- Today's modern integrated devices and modules have more than 2 ports.
- These modules call for increasingly complex tests in production, and these tests have to be performed in shorter and shorter periods of time.
- In the example shown opposite, 8 ports measures:
  - Transmission and isolation parameters between the RF ports of an antenna switching module.
    - The TX→Ant paths and the RX→Ant paths are measured simultaneously by using test port groups, thus reducing measurement time by nearly half without any loss of performance.
  - One DC input measures the current drain of the low-noise amplifier versus frequency and level.
  - One DC input determines the detector characteristic versus frequency and level.
  - To select the paths required for the measurement, the switch of the DUT is controlled by "channel bits". These are digital signals that are brought out at the rear panel and are synchronous to the active measurement channel



Typical antenna switching module

2-Port 20 GHz Vector Network Analyzers

High Performance
>$60K



Low Cost
>$14K

Small Size
>$33K

Portable
>$39K

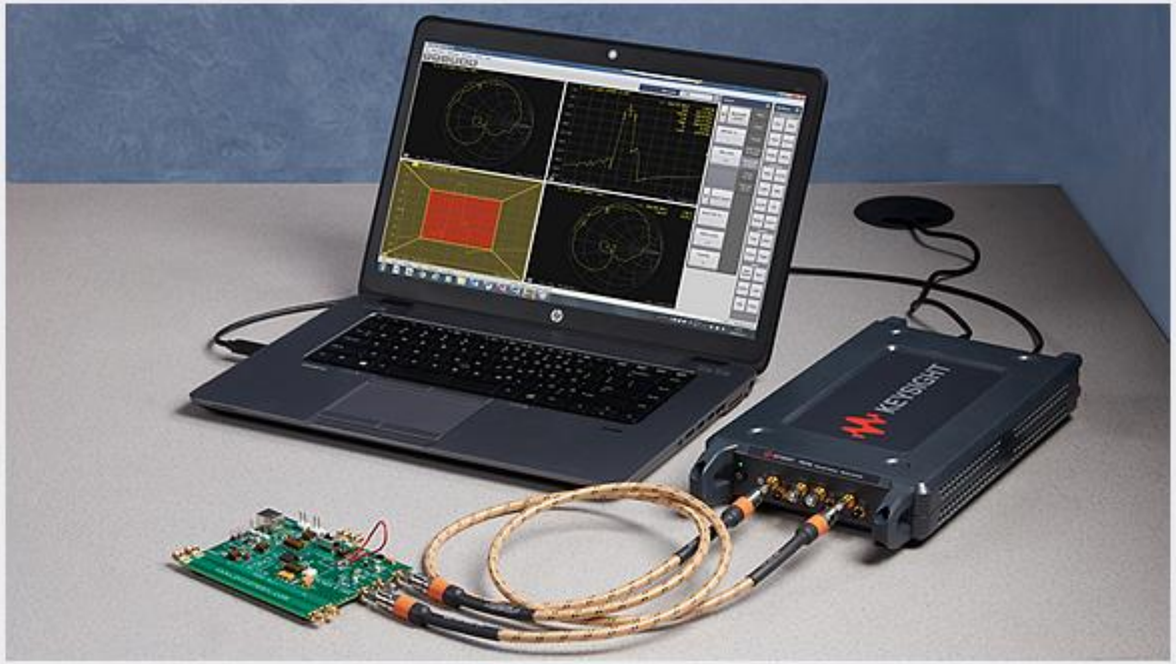
PXI
>$50K

USB
>$33K

Small FF VNA Market

- Either very low frequency, low performance
- Usually limited (2) number of ports
- Or high performance and VERY expensive
- Not small & cheap enough for many applications

$50 – 100k (?)



Maximum Frequency:	14 GHz	20 GHz	26.5 GHz
Number of Built-In Ports:	2 ports	2 ports	2 ports
Dynamic Range:	115 dB	115 dB	115 dB
Output Power:	7 dBm	7 dBm	7 dBm
Trace Noise:	0.003 dBrms	0.003 dBrms	0.003 dBrms
Starting from	US$ 18,935	US$ 27,612	US$ 36,755

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8 Port Vector Network Reference Design

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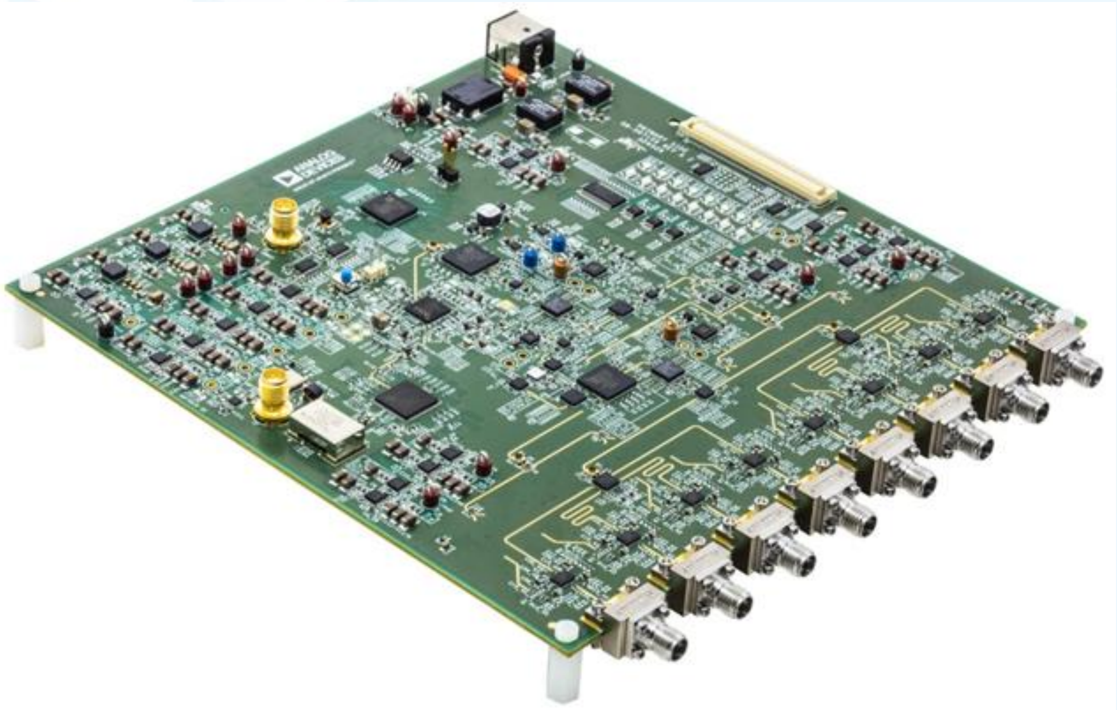
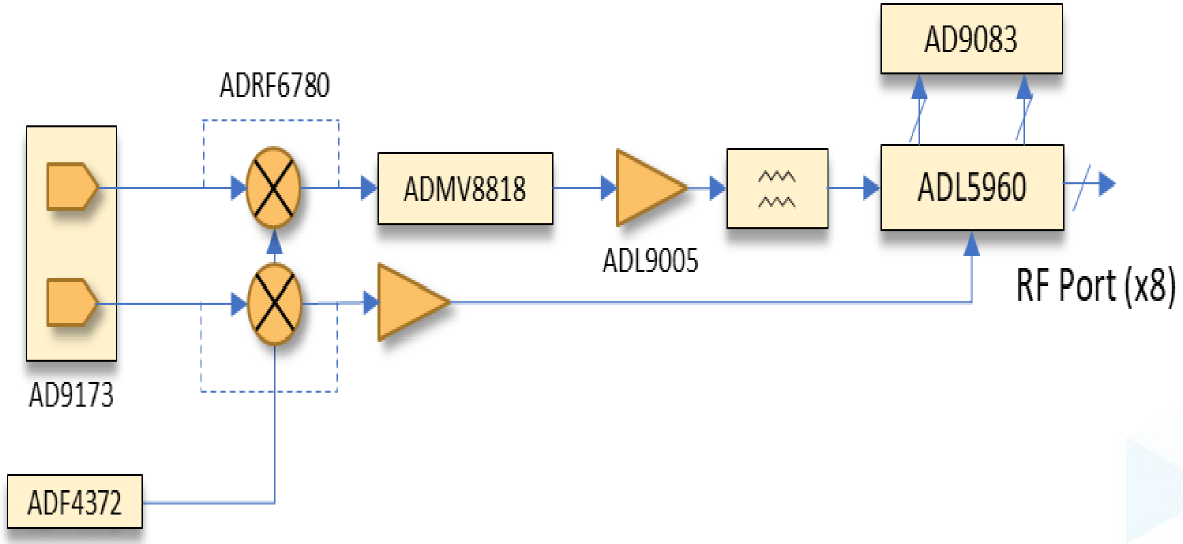
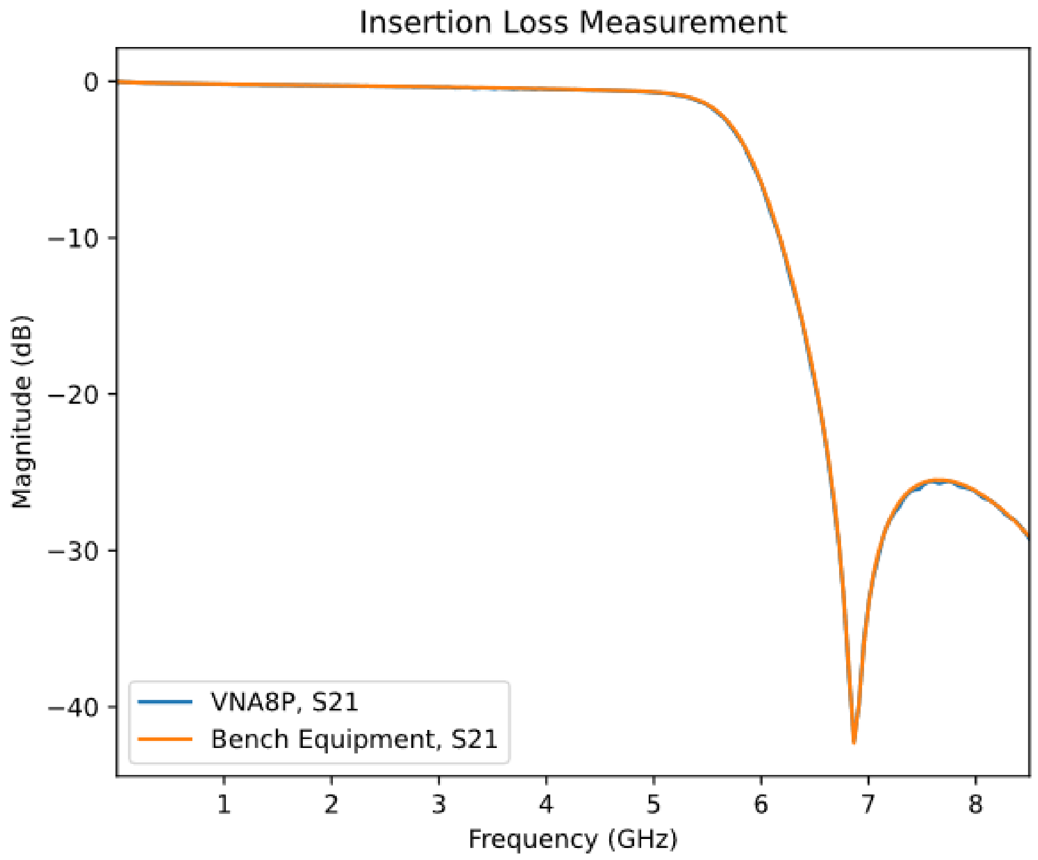
- Vector network analysis is emerging into newer applications like production test, system health monitoring & material defect analysis
- Compact 8-port vector network analyzer solution
- Wideband support from 10MHz to 20GHz
- -60dBm to +10dBm output power
- Fast Frequency tuning
- Simplified RF clocking using single swept source



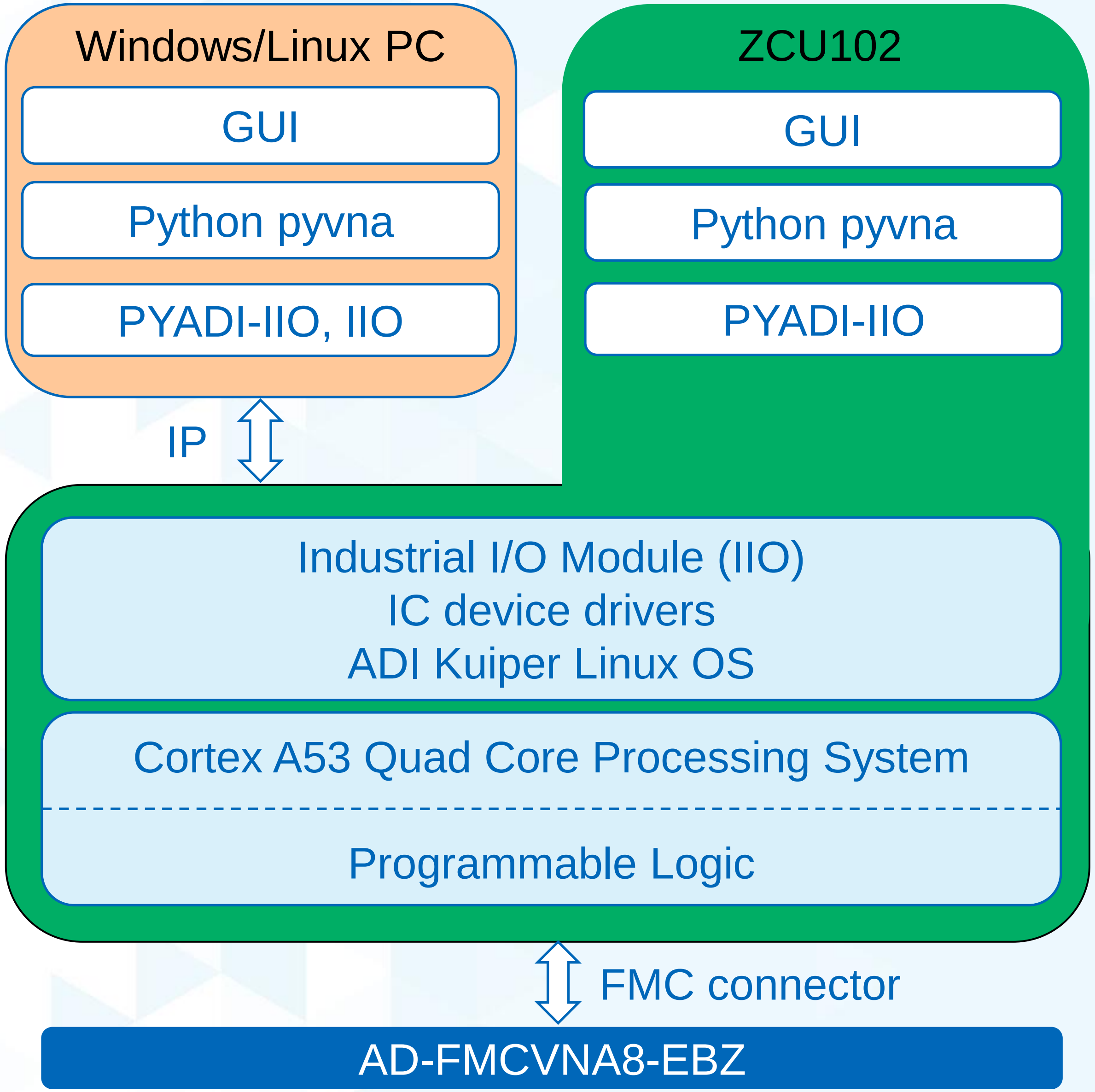
Representative Block Diagram





Firmware & Software Stack

- Flexible Hardware Setup
  - All software can run on ZCU
  - Run from PC connected over IP (or USB)
- Flexible Software
  - Run through GUI
  - Use Python scripts
  - Create your own scripts/code
  - Measurements using additional external hardware (USD/IP/GPIB)
- Build your own Linux Kernel
- Create your own Firmware



ADL5960
10MHz to 20GHz
Integrated Vector-Network Analyzer Front -End

Ed Woytaszek
Product Line Manager

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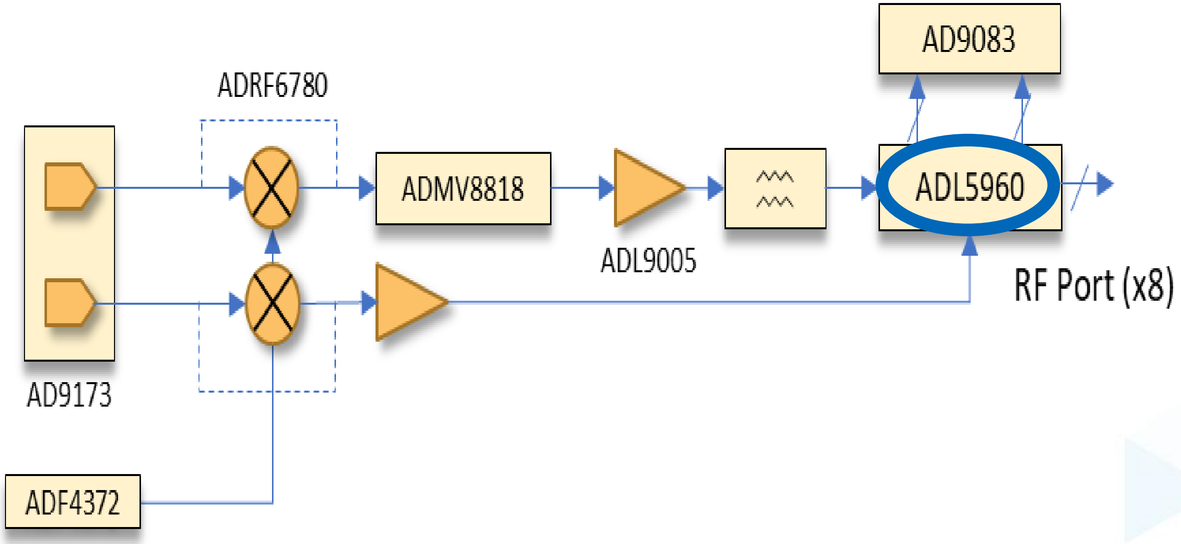
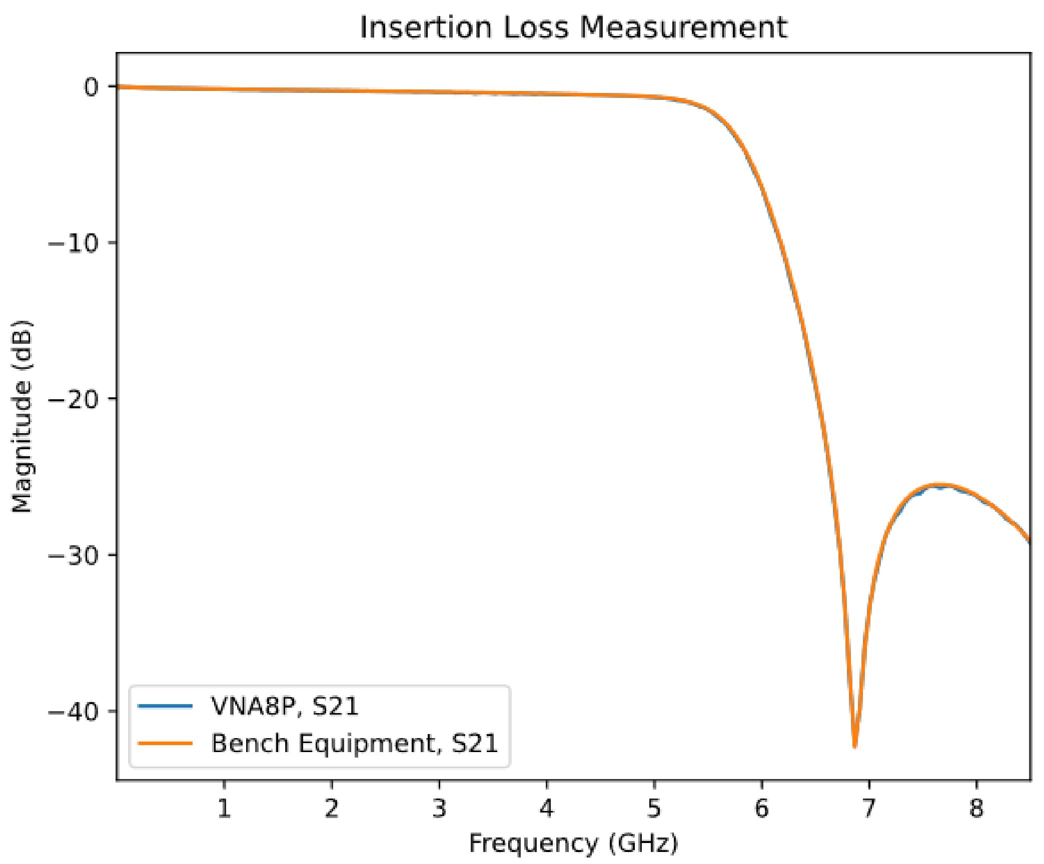
Representative Block Diagram





ADL5960: Integrated Vector-Network Analyzer Front-End

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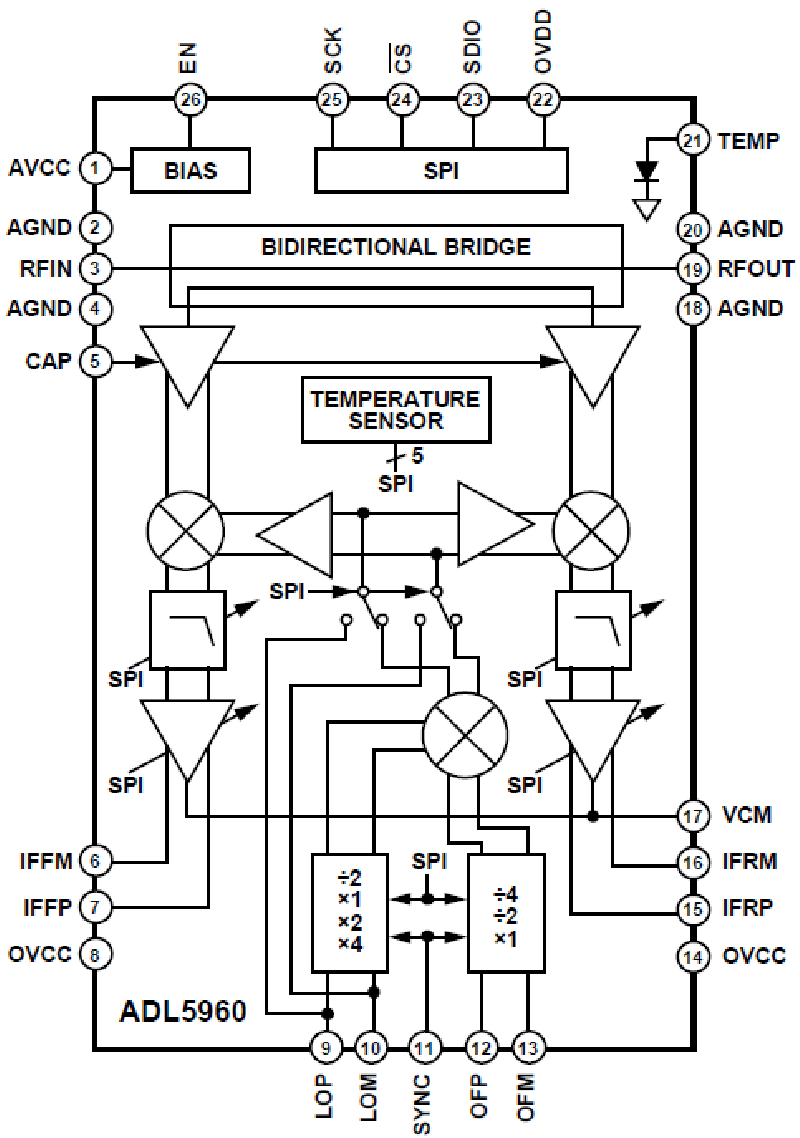
Benefits

- Enables dramatic size and complexity reduction of VNA solutions
  - Broad bandwidth, monolithic solution
    - Other solutions require multiple signal paths to cover same BW
      - Discrete solution dual down-converter
      - Offset LO generation
      - Multiple directional couplers to cover frequency range
  - Footprint is 5x to 10x smaller than discrete solutions
    - Very Small Size: 3x4mm LGA-26
- Provides very good performance in an extremely small footprint enabling new applications for VNAs:
  - ATE
    - Multiple VNA ports grouped in a smaller tester head
  - Industrial Sensors
    - Moisture
    - Mass
    - Density
    - Composition measurements in production lines
    - Agriculture
  - Automotive
    - Exhaust filters
    - Plasma ignition systems



ADL5960: Integrated Vector-Network Analyzer Front-End

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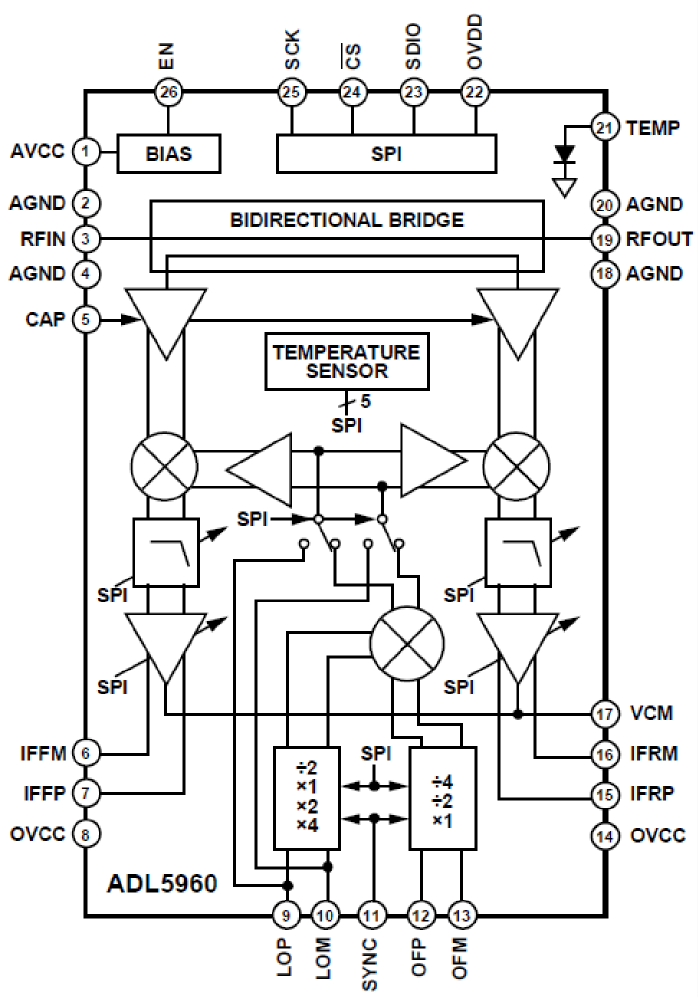
Features

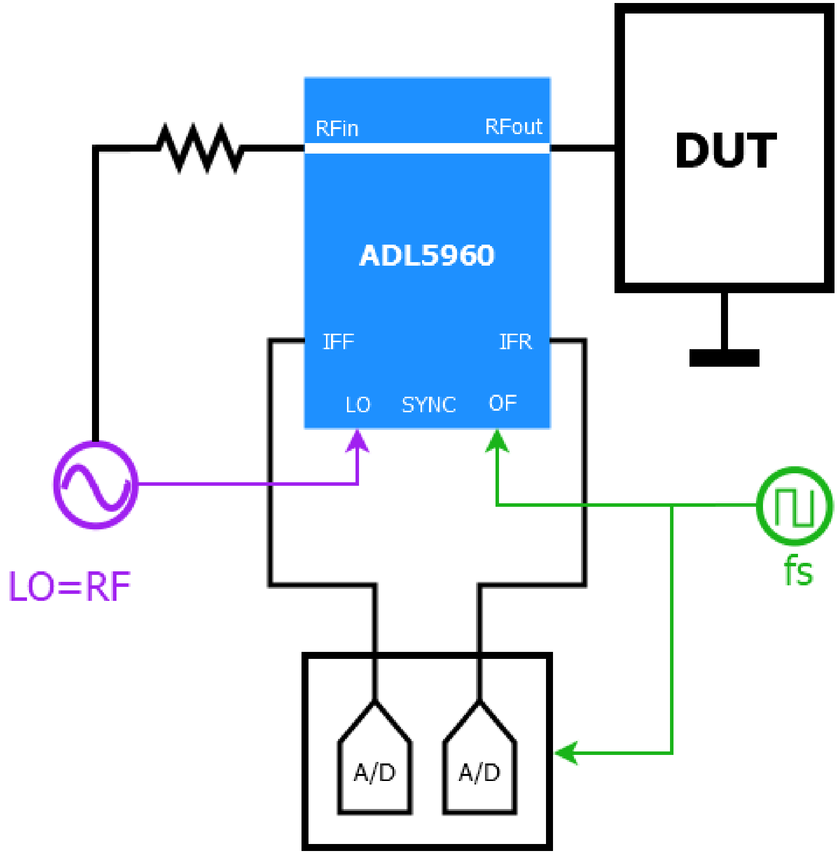
- **Integrated Wide-Band Bi-Directional Bridge:**
  - High Directivity >15dB up to 15GHz
  - 50Ohm, DC coupled single-ended RFin to RFout
  - Max. 100mA DC through current for DUT biasing
- **IF Signal Path:**
  - Wide-Band, High-Sensitivity Mixers
  - IF Amplifiers with Individually Programmable Gain
  - Analog Adjustable Output Common-Mode Voltage
  - Programmable IF Bandwidth 1MHz – 100MHz
- **Multi-Configuration LO Chain:**
  - LO multipliers & dividers: to operate from 6GHz LO
  - Optional built-in frequency offset mixer enables zero-offset frequency sweeps (RF=LO)
  - Offset frequency divider: sync to ADC clock (fs/4)
  - Asynchronous divider/multiplier sync
- **3x4mm LGA-26**
  - 0.5mm pitch RFin and RFout to adjacent GND pins
  - 0.4mm pitch between other pins
- **Low-Power Shutdown**
- **SPI Readable 5-Bit Temperature Sensor**

Parameter	Unit		
RF Frequency Range	Hz	10M – 20G	
LO Frequency Range	Hz	10M – 20G	
IF Frequency Range	Hz	100k – 100M	
Input Power Range (>1MHz)	dBm	-50 to +30	
Bi-Directional Bridge (RFin, RFout)		**1GHz**	**20GHz**
Insertion Loss	dB	1	1.9
Return Loss (S11, S22)	dB	>12	>12
Directivity	dB	27	10
Input IP3 RFin to RFout	dBm	71	
Maximum DC Current	mA	100	
Transfer RF to IFF, IFR		**1GHz**	**20GHz**
Noise Figure	dB	50	56
Input P1dB	dBm	28	
Conversion gain (6dB steps)	dB	-16 to +90	
Max. Diff. Output Voltage Swing	Vpp	8	
Output Common-Mode Voltage	V	1.0 – 4.0	
Power Supply			
Supply Voltage (AVCC, OVCC)	V	4.75 – 5.25	
SPI Supply Voltage (OVDD)	V	1.2 – 3.6	
Supply Current (1xLO mode)	mA	110	
Package, size	mm	LGA-26, 3x4	



One-Port Measurement Configuration

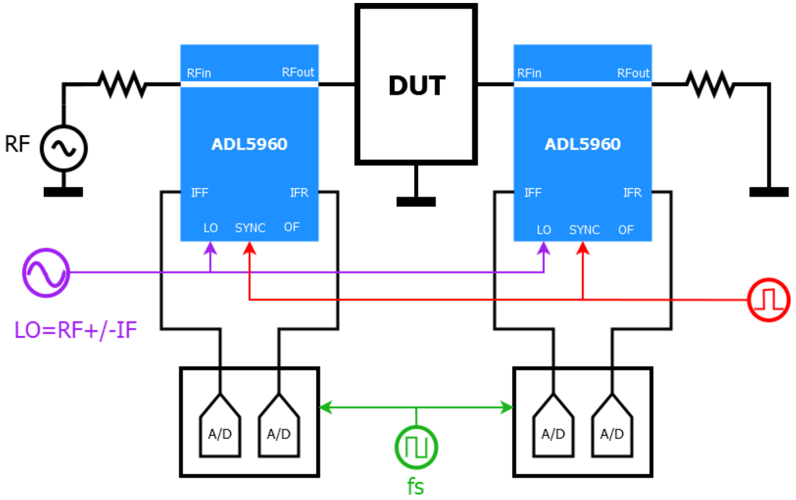
- Setup:
  - 1xADL5960
  - Dual-Channel ADC
  - 1x Swept RF source
  - 1x clock source (shared with ADC)



BYPASS Mode vs OFFSET Mode

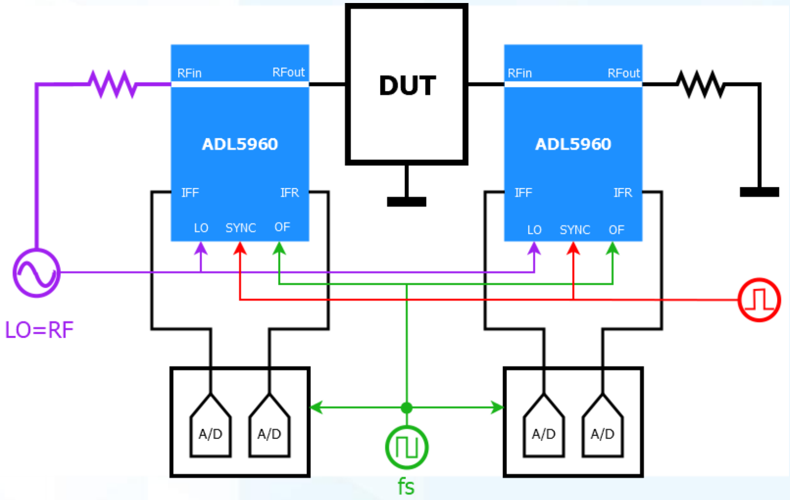
BYPASS Mode

- LO frequency swept at fixed offset vs RF
- Can use LO divider/multipliers
- Typically requires 2 PLL’s
- More complex frequency source design
- Higher system cost
- Highest performance mode

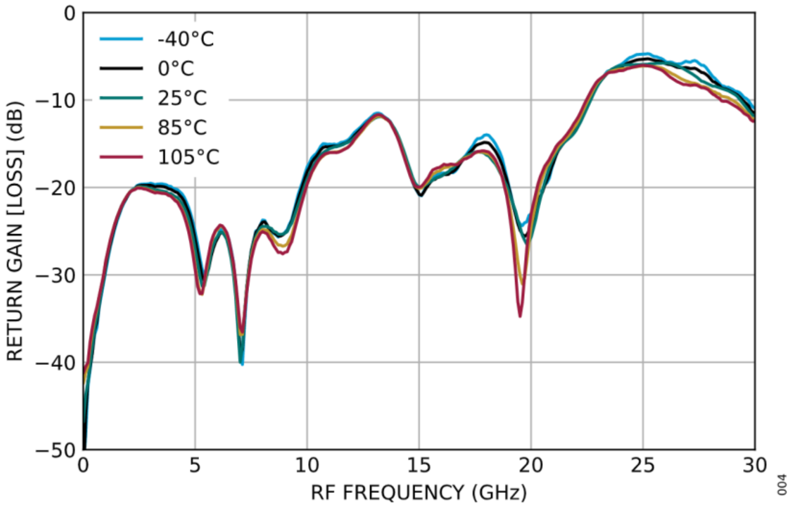


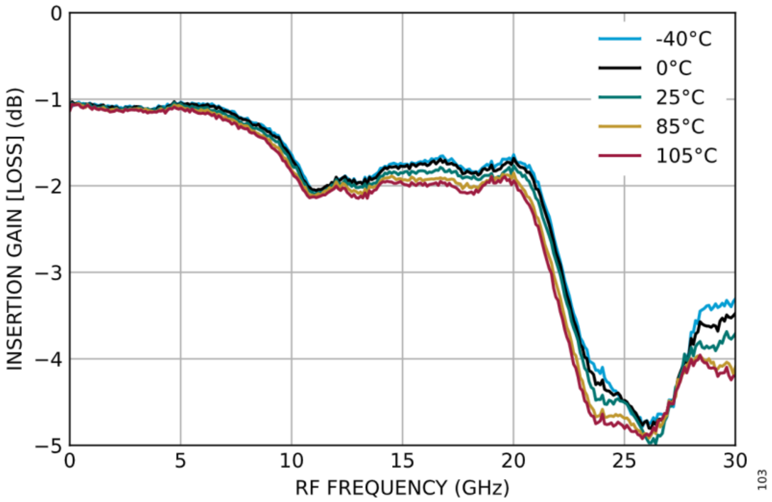
OFFSET Mode

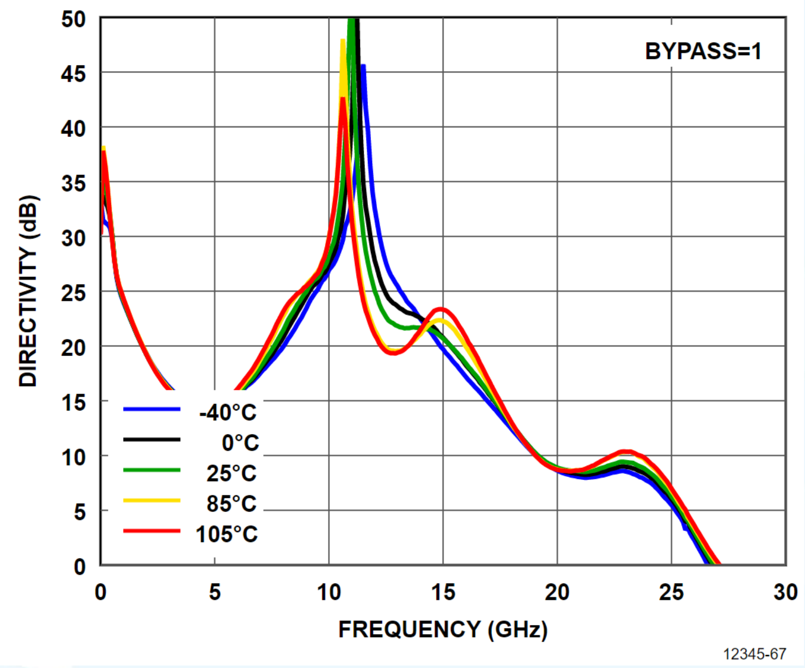
- LO and RF generated by same source (PLL)
- IF output frequency set through OF interface
- OF divide by 4 centers IF in 1st Nyquist ADC
- Greatly simplified frequency source design
- Simplified board design
- Performance tradeoff



Return Loss, Insertion Loss & Directivity Measurements

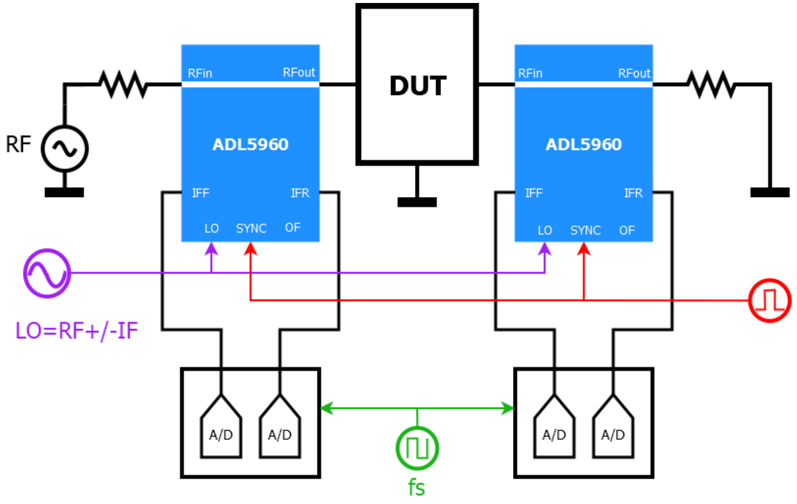


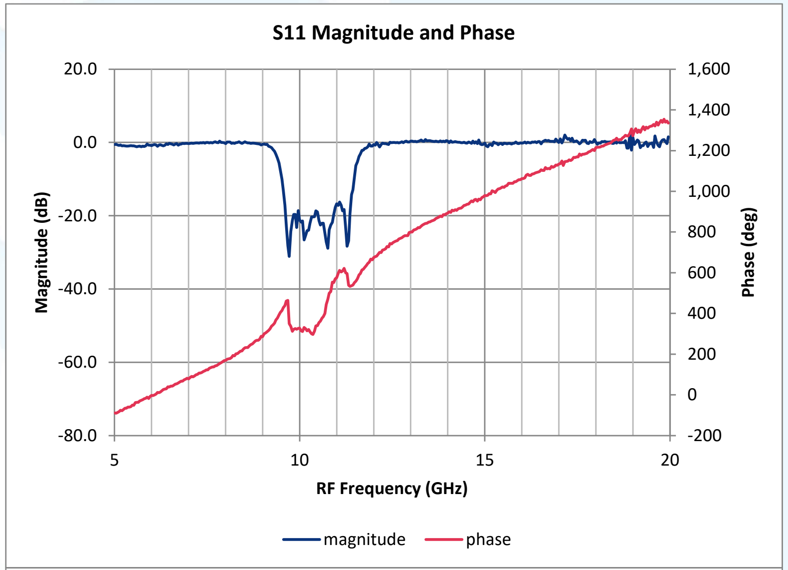


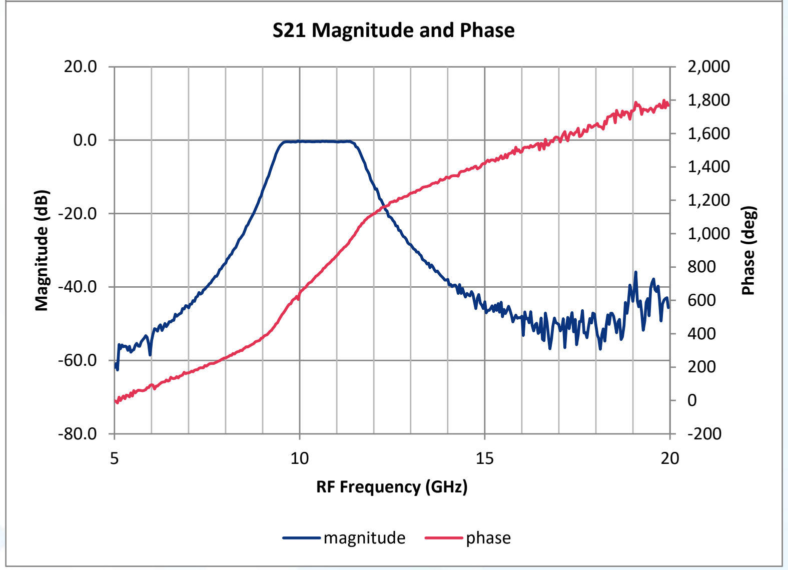


Two port Measurement with SOLT Calibration

- Setup:
  - 2xADL5960, syncronized to same LO
  - 4-channel 8-bit oscilloscope measuring ADL5960 outputs (fwd/rev of both IC's)
  - Response at IF (2.5MHz) calculated through fft on 8-bit scope time-capture

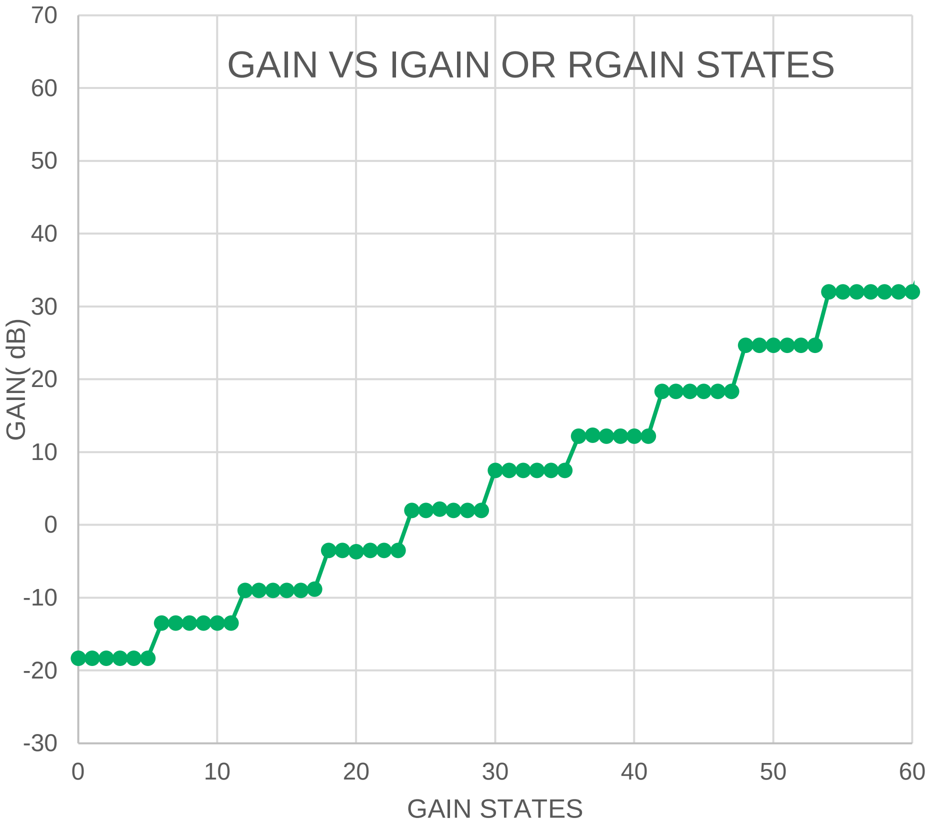






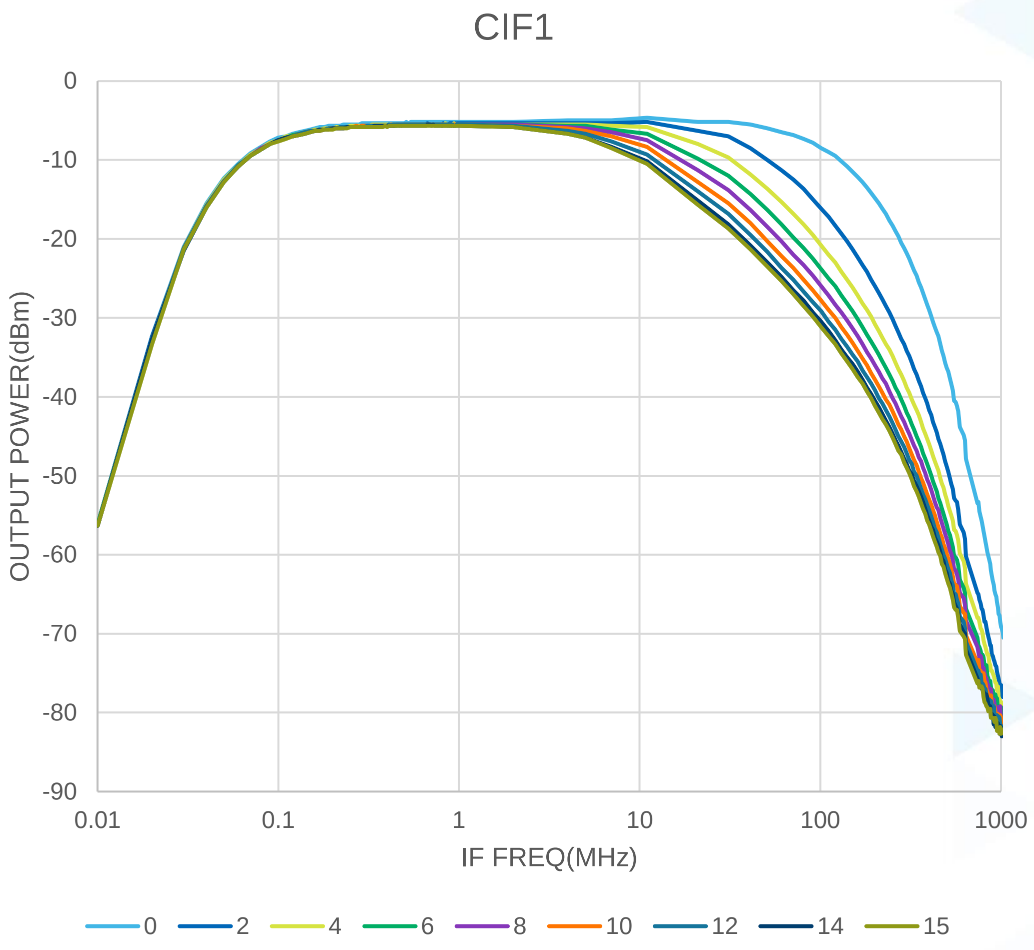
RF to IF Conversion Gain

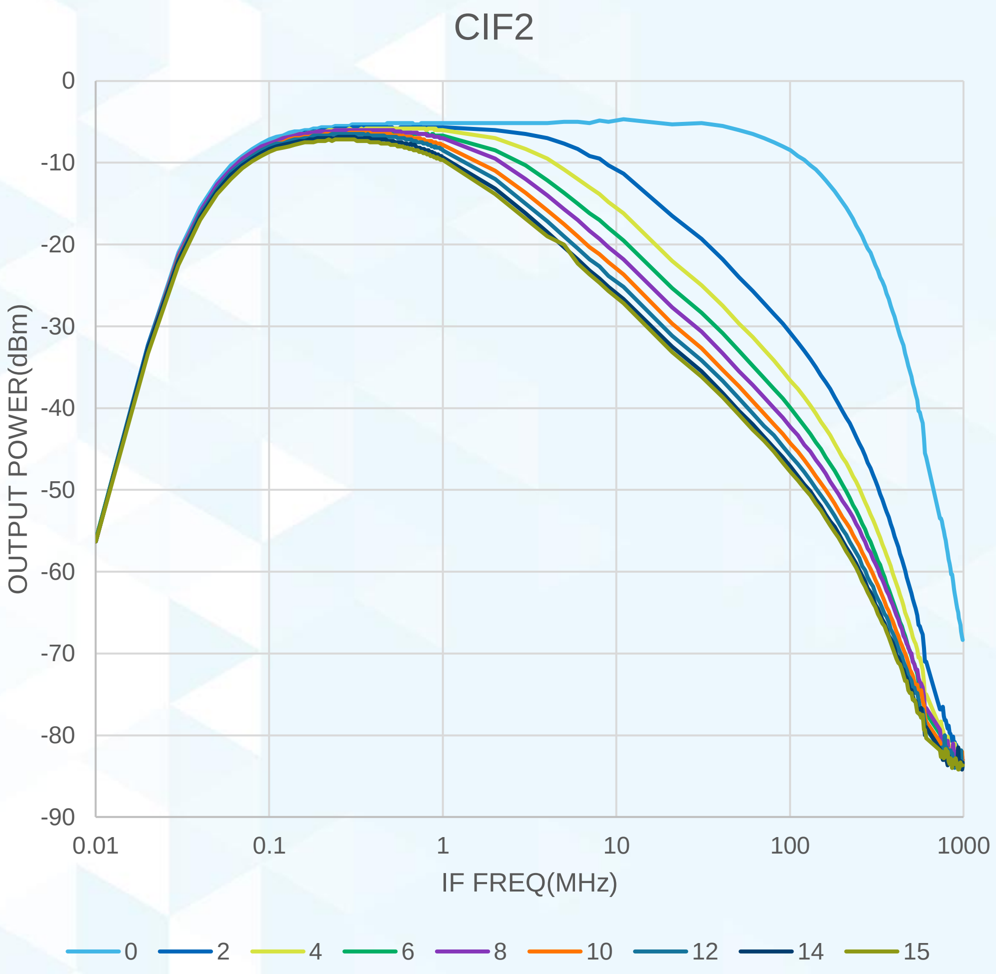
Gain vs SPI gain setting



Gain vs Frequency (lowest gain setting)

IF bandwidth vs SPI Register Settings





ADL5960 Clocking Schemes

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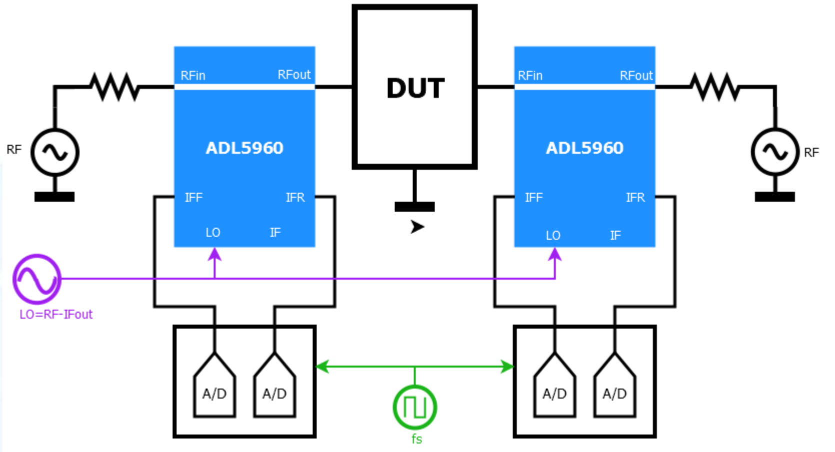
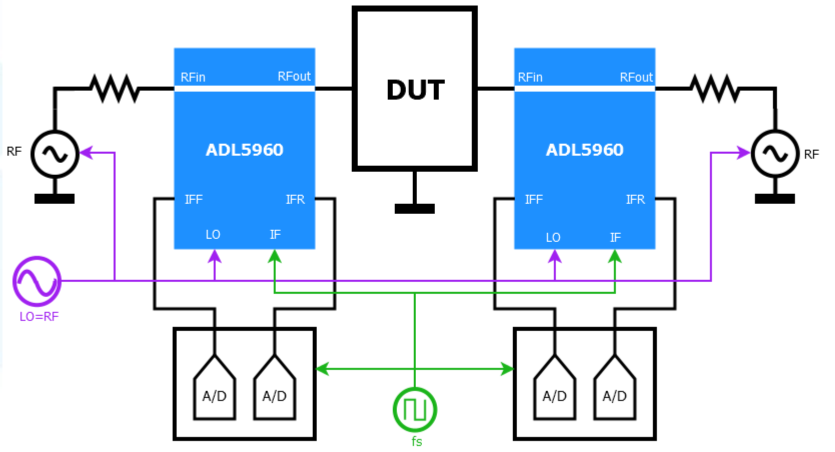
Offset Frequency Sweep Mode

- LO swept at an offset vs RF, equal to IF output frequency
- LO modes –frequency applied to internal mixer LO:
  - ÷2: LO/2
  - 1x: LO – LO input frequency directly applied to mixers
  - 2x: 2LO
  - 4x: 4LO – can cover up to 20GHz with 6GHz synthesizer
- IF offset mixer disabled



Zero-Offset Frequency Sweep Mode

- LO and RF swept at the same frequency
  - Divider and multiplier modes still available
- IF offset mixer sets output IF frequency:
  - ÷2: offset frequency divided by 2
  - ÷4: offset frequency divided by 4
- Applying fs to offset mixer, use of ÷4 mode puts output IF in center of A/D first Nyquist zone (fs/4).



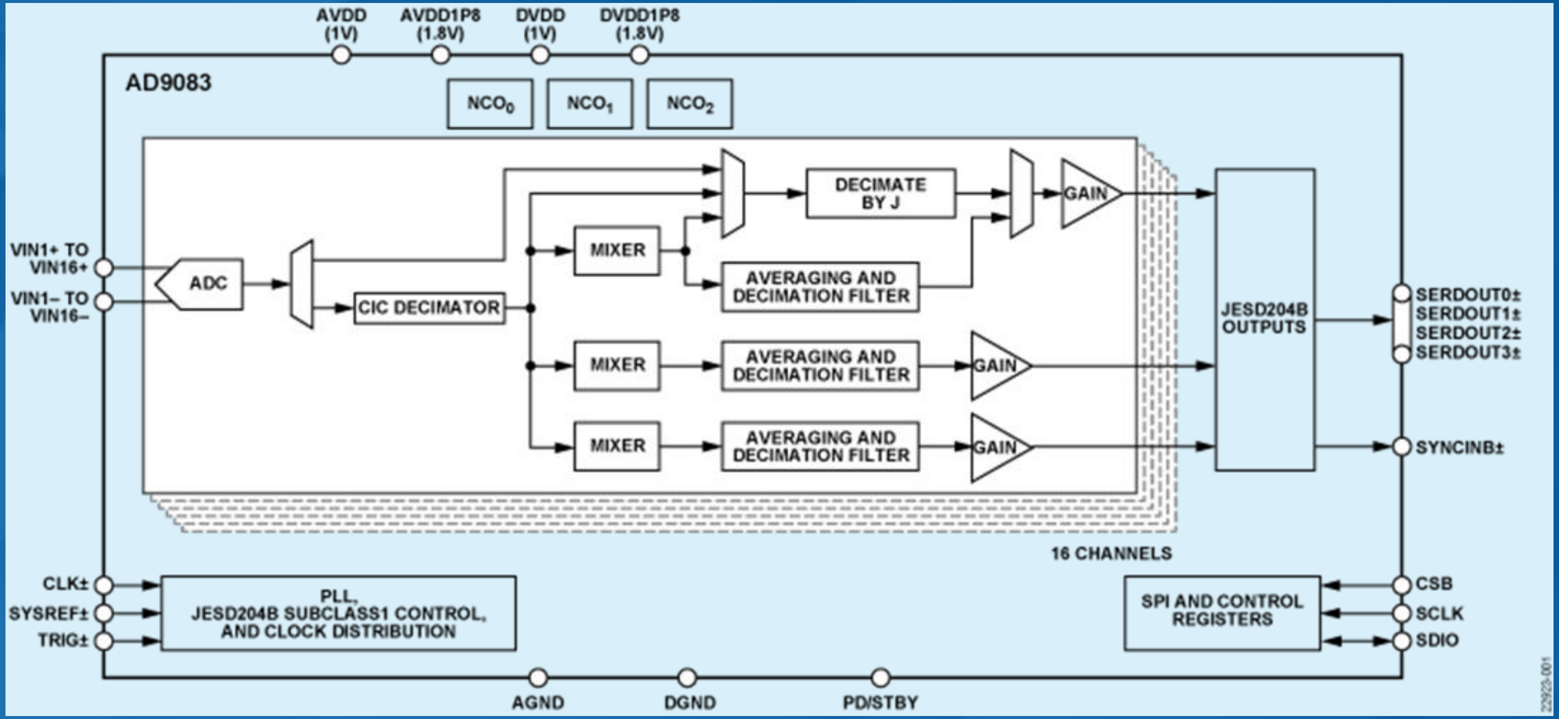
Summary

- The ADL5960 is a Vector Network Analyzer Front-end on a Chip
  - Single device for 1-port measurement of incident and reflected signals
  - Broad Frequency Range: 10MHz-20GHz
  - Multiple ADL5960 devices can be combined to form a multi-port VNA

- Applications
  - Beyond Test and Measurement: Materials Analysis, Built-in Test, Industrial Process Control, Sensors...
  - Many applications need smaller size (3mm x 4mm LGA), lower cost per channel

- ADI can provide a complete, very small size, wide-band, lower cost VNA solution
  - All RF & analog signal path functions
  - Power management

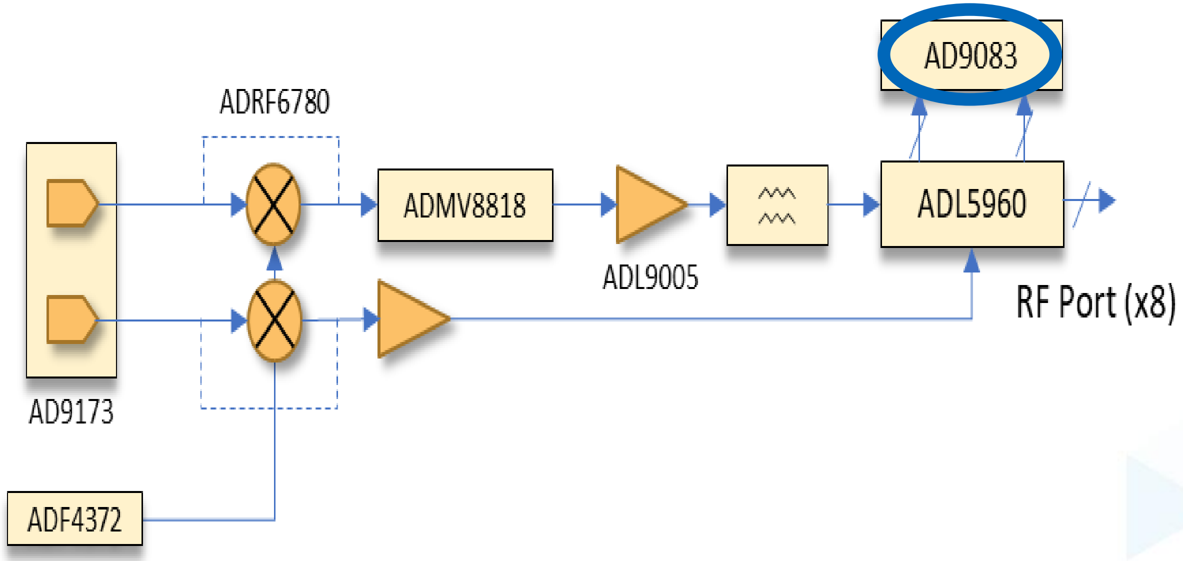
- Reference Design AD-FMCVNA8-EBZ
  - 8-port VNA FMC card for Xilinx ZCU102

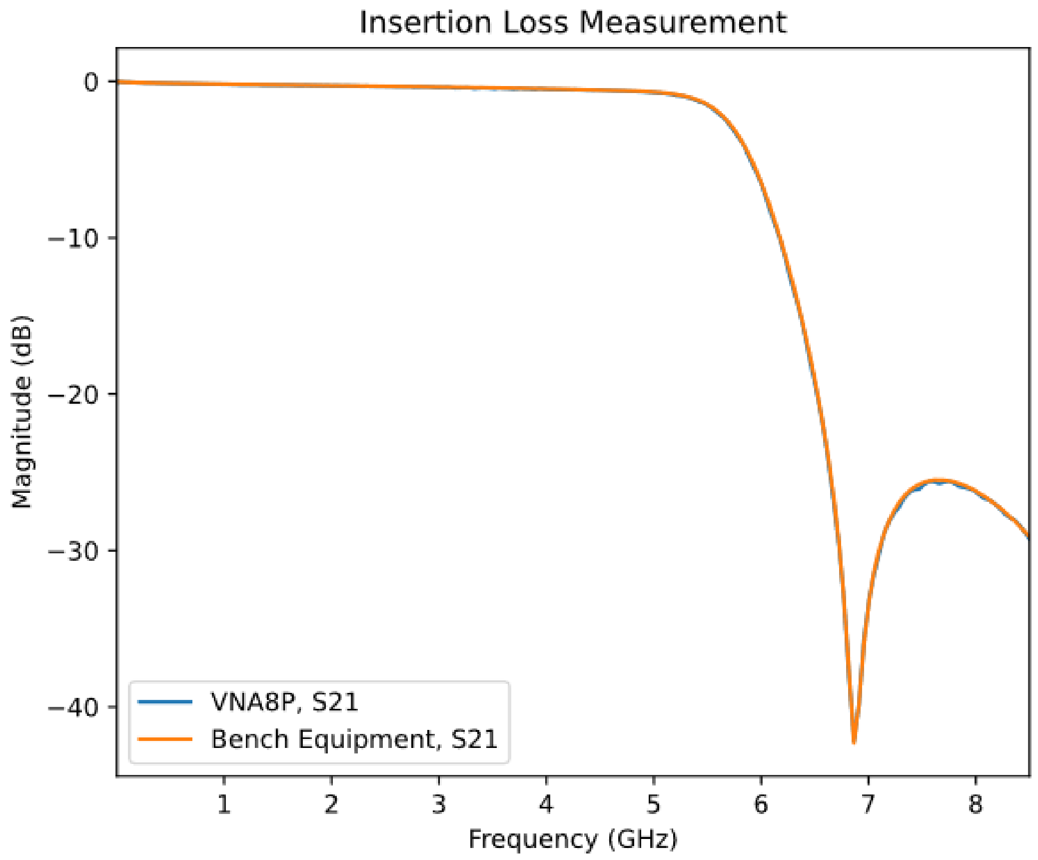


Multi-channel ADCs for Network Analyzers

JON HALL, STRATEGIC MARKETING MANAGER (JON.HALL@ANALOG.COM)

Representative Block Diagram





Wide Selection of Multi-channel high speed ADCs

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High Speed A/D Converters >10 MSPS

Choose Parameters | All | Reset Table | Maximize Filters | Sort by Newest | Save to myAnalog | Download to Excel | Share

Compare

Filter Parts

17 parts

Part Number	Analog.com Inventory	Converter Primary Function	Channels	Resolution bits	Sample Rate max | SPS
		OR / AND 5 Values Selected	4 - 16	12 - 14	125M - 2G
AD9671	Check Distributor Inventory	High Speed ADC	8	14	125M
AD9675	1	High Speed ADC	8	14	125M
AD9681	2	High Speed ADC	8	14	125M
AD9674	Check Distributor Inventory	High Speed ADC	8	14	125M
AD9670	16	High Speed ADC	8	14	125M
LTM9012		Signal Chain uModule Receiver	4	14	125M
AD9253-125	22	High Speed ADC	4	14	125M
AD9633-125	7	High Speed ADC	4	12	125M
LTM9011-14	11	Signal Chain uModule Receiver	8	14	125M
LTC2175-12	6	High Speed ADC	4	12	125M
LTC2175-14	Check Distributor Inventory	High Speed ADC	4	14	125M
AD9239-170	Check Distributor Inventory	High Speed ADC	4	12	170M
AD9239-210	Check Distributor Inventory	High Speed ADC	4	12	210M
AD9239-250	Check Distributor Inventory	High Speed ADC	4	12	250M
AD9694	Check Distributor Inventory	High Speed ADC	4	14	500M
AD6684	1	IF/RF Receiver	4	14	500M
AD9083	9	High Speed ADC	16	14	2G

- Instantaneous bandwidths of 65MHz and higher
- Quads, Octals and 16-channel
  - Each ADC core running at clock rate
- Stand alone ADC functions or integrated signal chain modules
- Serial LVDS or JESD204B
- Most are pipeline ADC architectures

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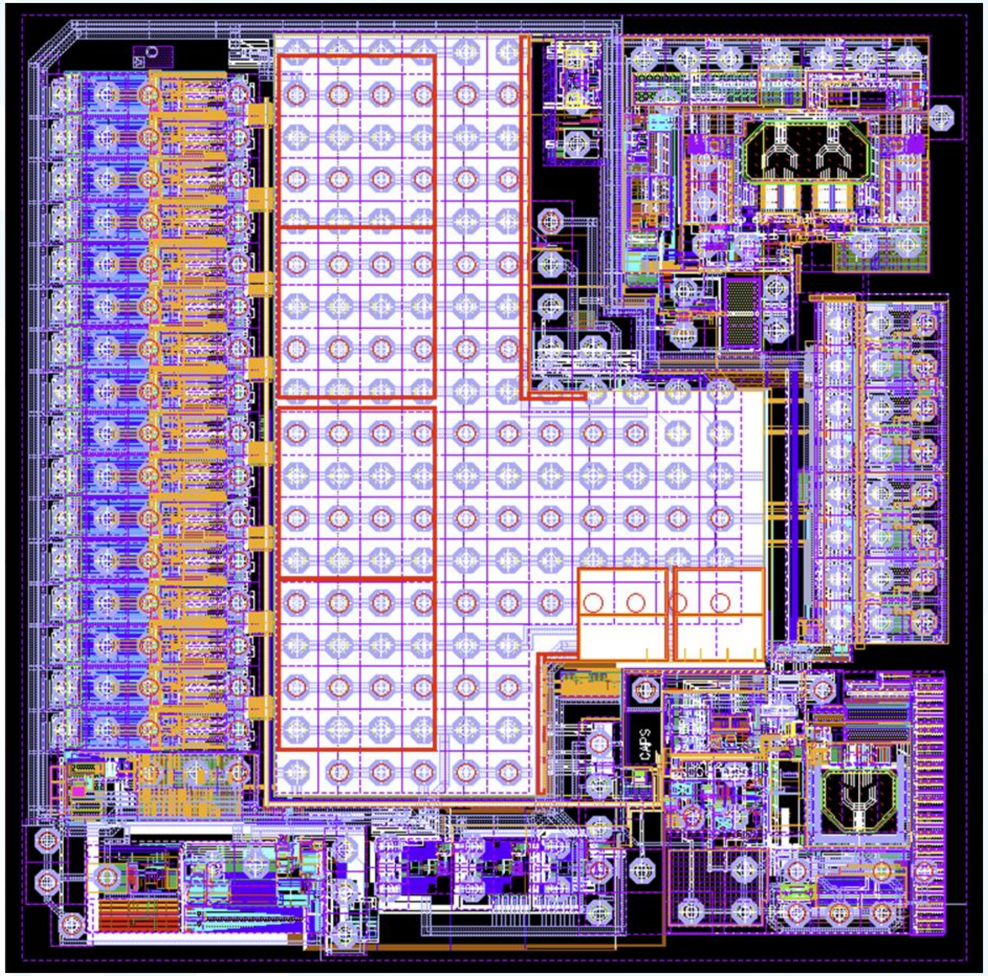
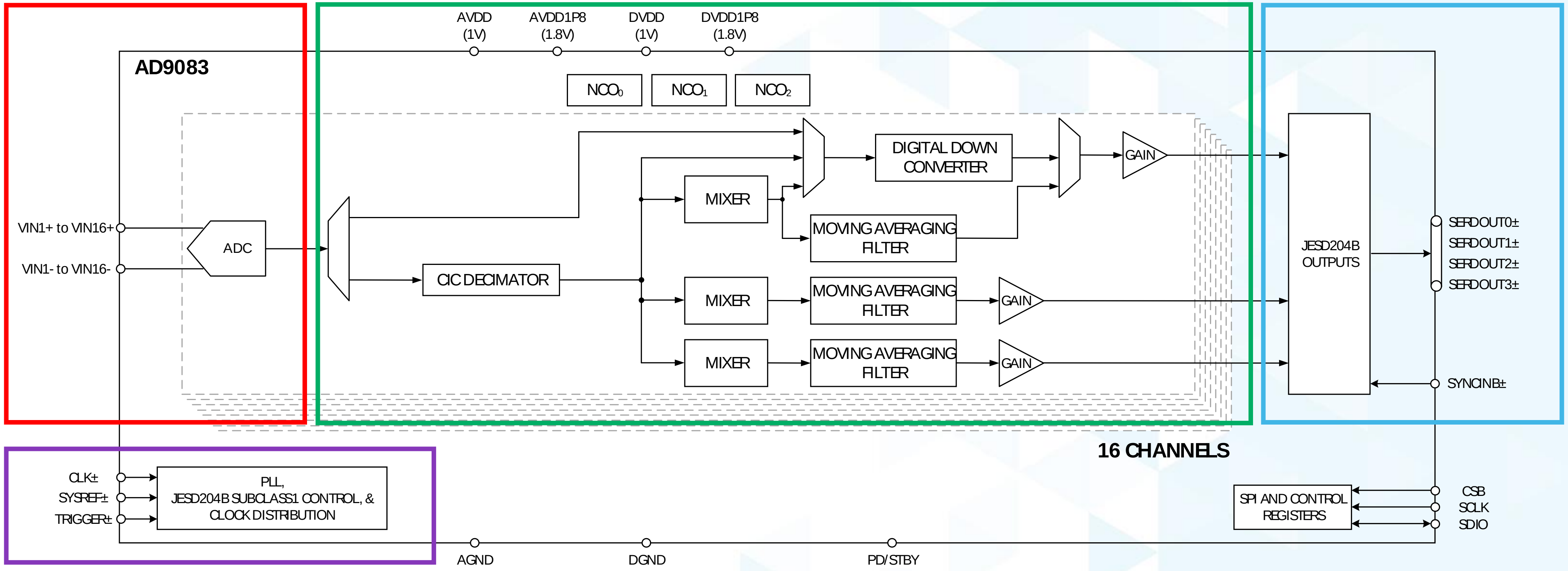
16-Channel, 125 MHz Bandwidth, JESD204B ADC

The AD9083 is a 16 channel, 125MHz bandwidth continuous-time ΣΔ Analog to Digital Converter designed for low power and small package size.

- Sample rate up to 2Gsps
- Flexible Input range
- 90dB channel cross talk
- 90mW per channel at 2Gsps
- -145 dBFS/Hz NSD at 2Gsps
- On–Chip DSP consisting of decimation and programmable DDC
  - SNR of 82dBFS in 15.6MHz channel
  - SFDR of 80dBc in 15.6MHz channel
- JESD204B up to 16 Gbps per lane



AD9083 Block Diagram



16 Channel, reconfigurable, variable-rate, 1st-order CT ΣΔ ADC

- Analog full-scale input: 0.5-2.0Vdpp

On-Chip PLL

- for ADC and SERDES Clock generation & Multi-Chip Sync

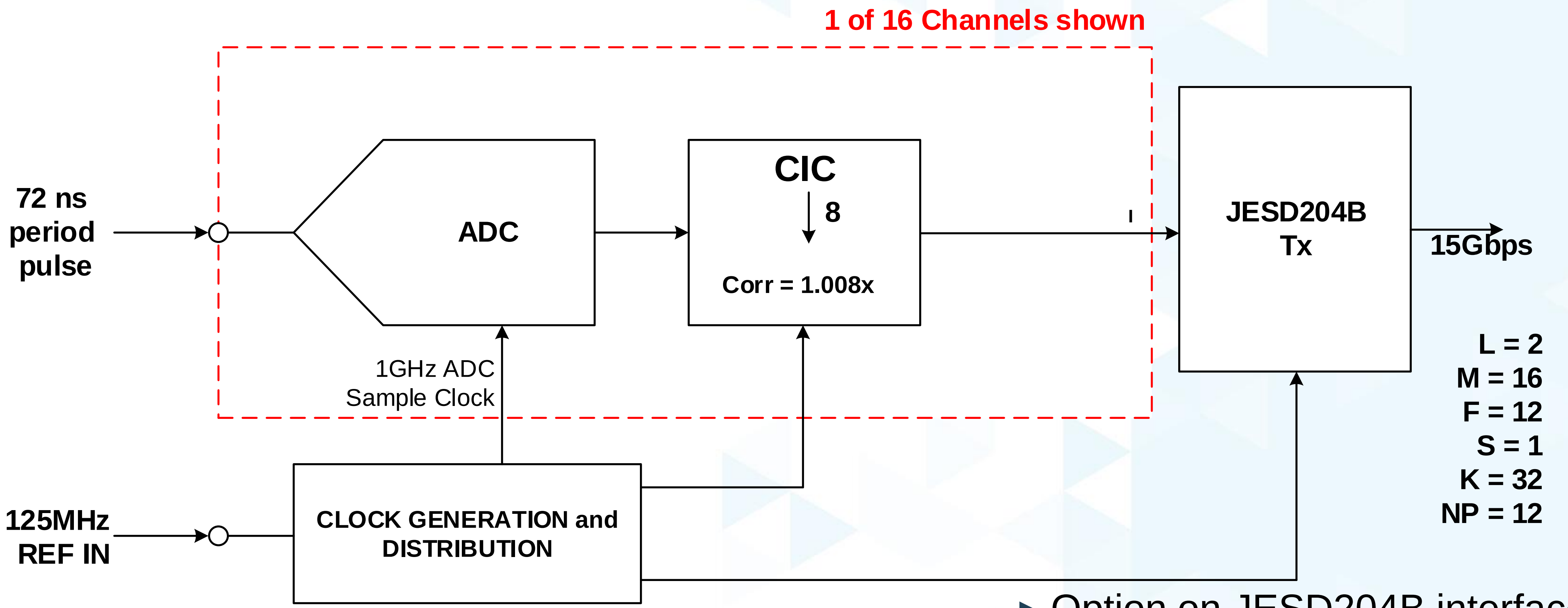
On-Chip Digital Signal Processing

- CIC Decimator per channel
- Digital Down Converter per channel
- 3 Moving Averaging Filters per channel
- 3 NCO's per chip

Configurable JESD204B+ Interface

- 4 Lanes up to 16Gbps
- 2 lanes at 12.5Gbps often sufficient

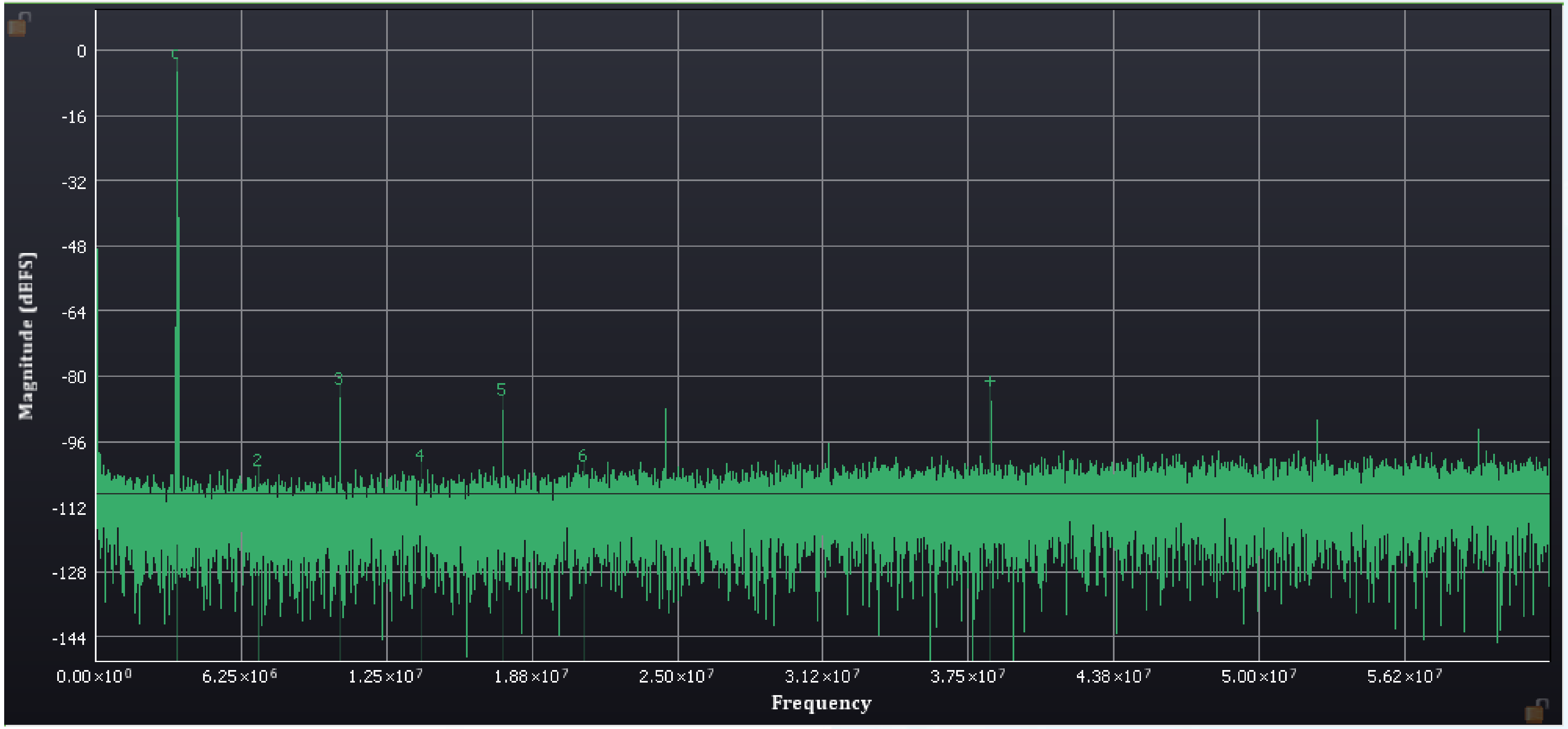
AD9083 Use Case : 16-Channel Precision Time Domain (Full BW) Time Domain



- Option on JESD204B interface
  - L = 3 at 10Gbps/lane
  - L = 4 at 7.5Gbps/lane

Single-Tone FFT with 3.494 MHz input.

Spec	Value
Fund Mag	-2 dBFS
Fund Freq	3.494 MHz
2^{nd} Harm.	-100 dBc
3^{rd} Harm.	-80 dBc
SFDR	80 dB
SNR	61.6 dB
NSD L = 3	-141.62 dBFS/Hz



DOMAIN	Voltage (V)	Current (A)	Power (W)
AVDD1	1	0.208	0.208
DVDD1	1	0.288	0.288
AVDD1p8	1.8	0.066	0.1188
DVDD1p8	1.8	0.041	0.0738
			0.6886

~43mW / Channel

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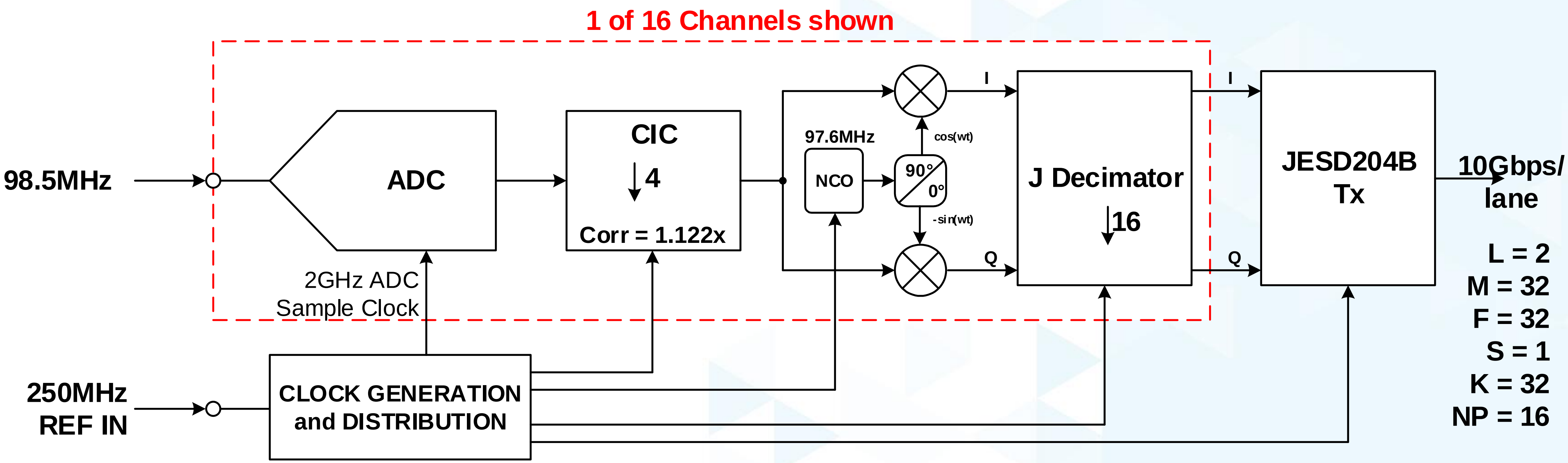
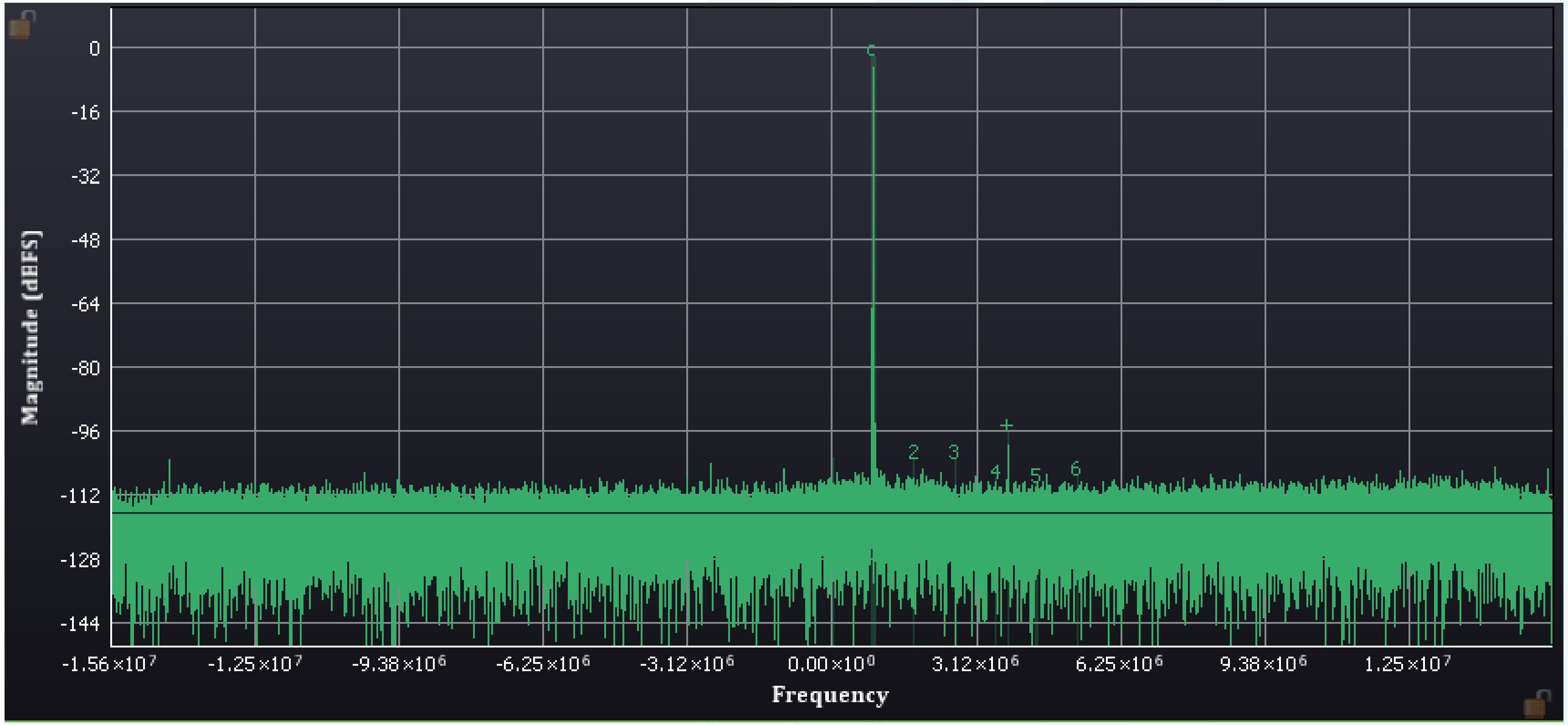
AD9083 Use Case : 16-Channel IF Rx Frequency Domain



Single-Tone FFT with 98.5MHz input. Normal Mode NCO = 97.7MHz

Spec	Value
Fund Mag	-2 dBFS
Fund Freq	0.89 MHz
SNR	66.3 dB
SFDR	94 dB
NSD	-143.3 dBFS/Hz



Power Consumption

DOMAIN	Voltage (V)	Current (A)	Power (W)
AVDD1	1	0.386	0.386
DVDD1	1	0.548	0.548
AVDD1p8	1.8	0.097	0.1746
DVDD1p8	1.8	0.041	0.0738
			1.1824

~74mW / Channel

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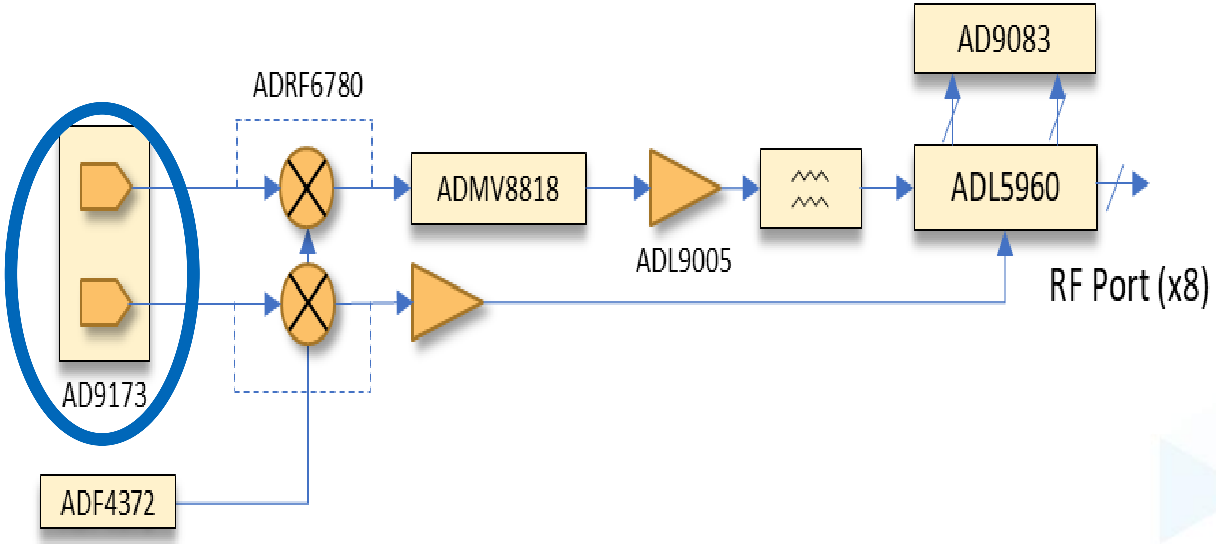
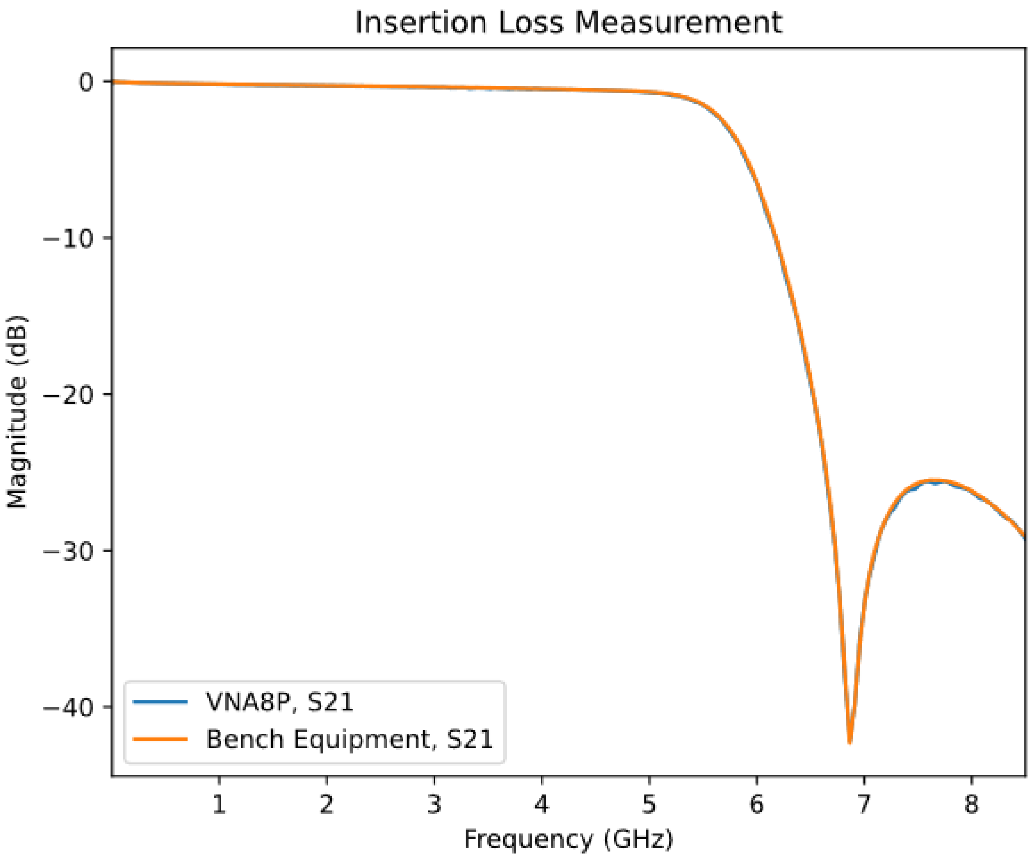
Representative Block Diagram

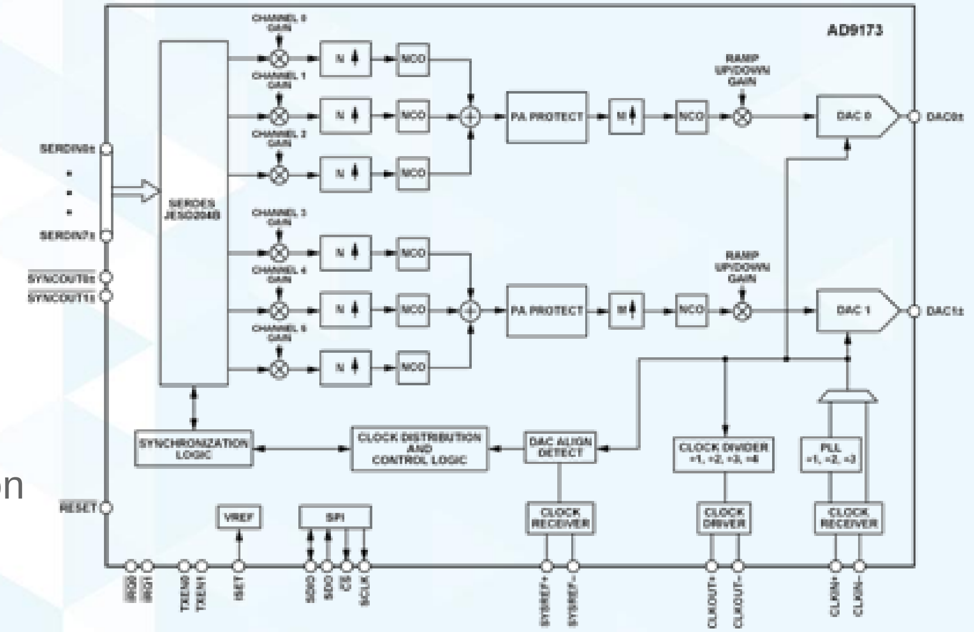




ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

AD9173 - Dual, 16-Bit, 12.6 GSPS RF DAC with Channelizers

- •Supports multiband wireless applications
- •3 bypassable, complex data input channels per RF DAC
- •1.54 GSPS maximum complex input data rate per input channel
- •1 independent NCO per input channel
- •Proprietary, low spurious and distortion design
- •2-tone IMD = −83 dBc at 1.8 GHz, −7 dBFS/tone RF output
- •SFDR < −80 dBc at 1.8 GHz, −7 dBFS RF output
- •Flexible 8-lane, 15.4 Gbps JESD204B interface
- •Supports single-band and multiband use cases
- •Supports 12-bit high density mode for increased data throughput
- •Multiple chip synchronization
- •Supports JESD204B Subclass 1
- •Selectable interpolation filter for a complete set of input data rates
- •1×, 2×, 3×, 4×, 6×, and 8× configurable data channel interpolation
- •1×, 2×, 4×, 6×, 8×, and 12× configurable final interpolation
- •Final 48-bit NCO at the DAC rate to support frequency synthesis up to 6 GHz
- •Transmit enable function allows extra power saving and downstream circuitry protection
- •High performance, low noise PLL clock multiplier
- •Supports 12.6 GSPS DAC update rate
- •Observation ADC clock driver with selectable divide ratios
- •Low power
- •2.55 W at 12 GSPS, dual channel mode
- •10 mm × 10 mm, 144-ball BGA_ED with metal enhanced thermal lid, 0.80 mm pitch



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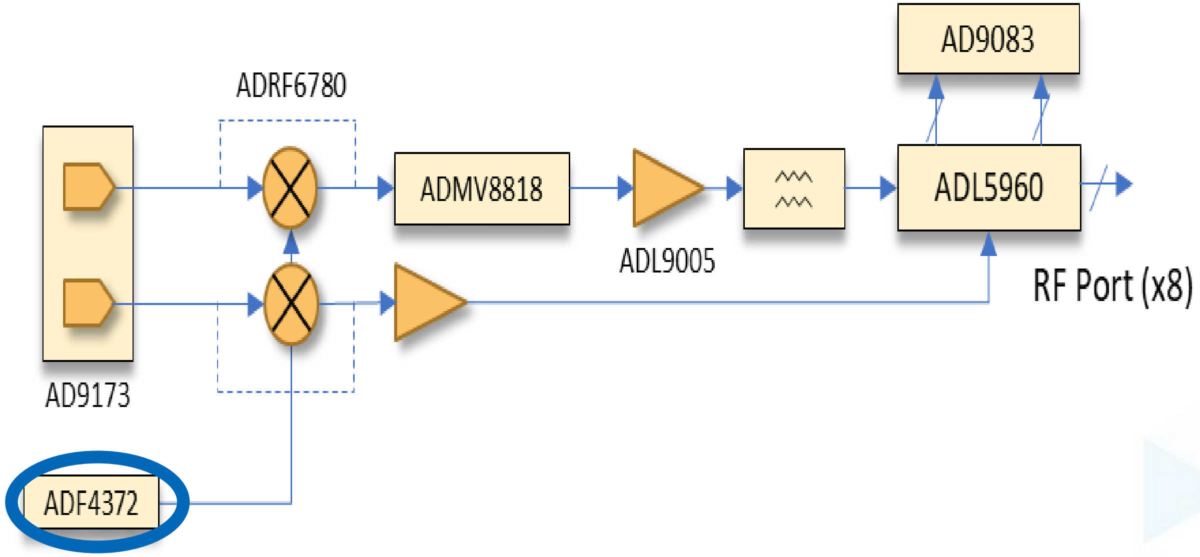
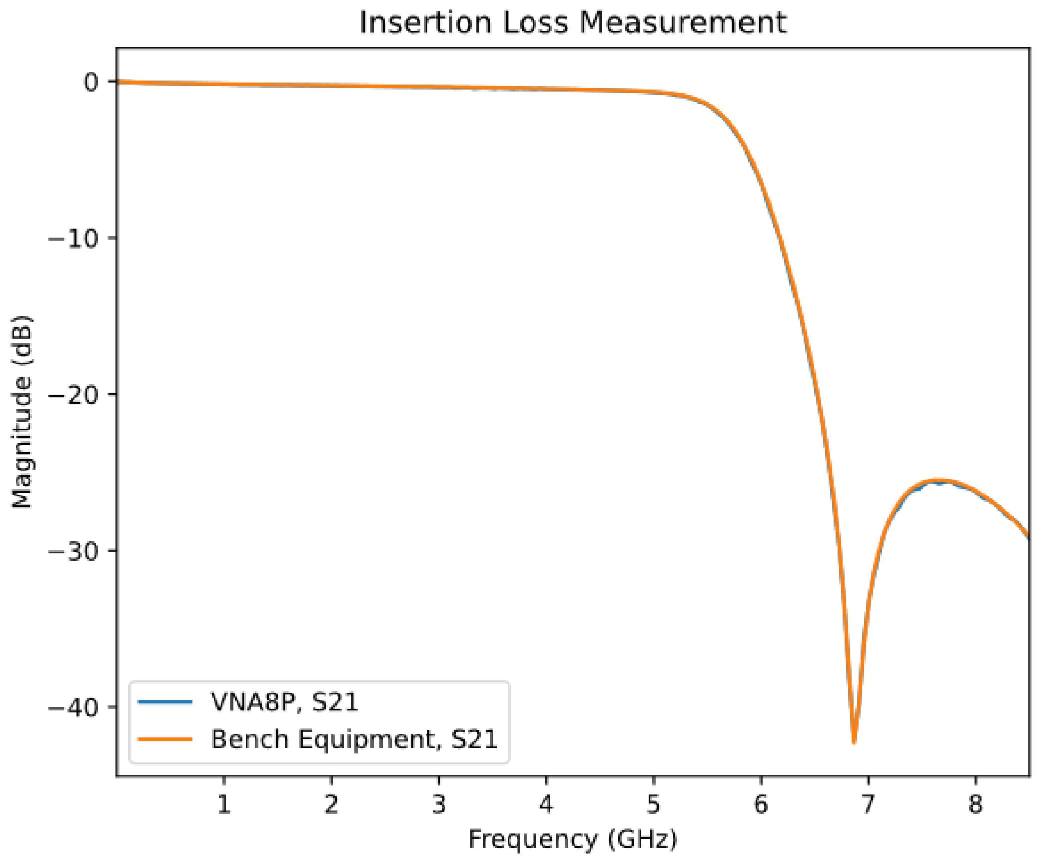
Representative Block Diagram

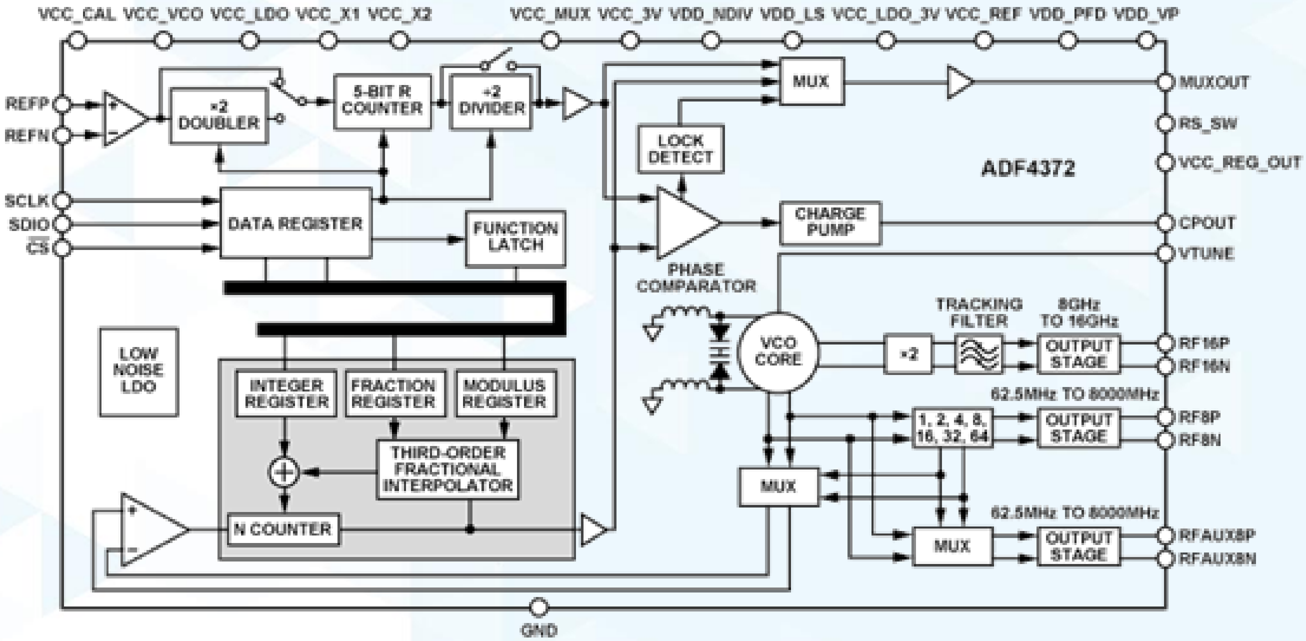




ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

ADF4372 - Microwave Wideband Synthesizer with Integrated VCO

- •RF output frequency range: 62.5-16,000 MHz
- •Fractional-N synthesizer and integer-N synthesizer
- •High resolution 39-bit fractional modulus
- •Typical spurious fPFD: −90 dBc
- •Integrated rms jitter: 38 fs (1 kHz to 100 MHz)
- •Normalized phase noise floor: −234 dBc/Hz
- •fPFD operation to 250 MHz
- •Reference input frequency operation to 600 MHz
- •Programmable divide by 1, 2, 4, 8, 16, 32, or 64 output
- •62.5 MHz to 8,000 MHz output at RF8x and RFAUX8x
- •8,000 MHz to 16,000 MHz output at RF16x
- •Lock time approximately 3 ms with automatic calibration
- •Lock time <30 μs with autocalibration bypassed, typical
- •Analog and digital power supplies: 3.3 V typical
- •VCO supply voltage: 3.3 V and 5 V
- •RF output mute function
- •7mm × 7mm, 48-terminal LGA package



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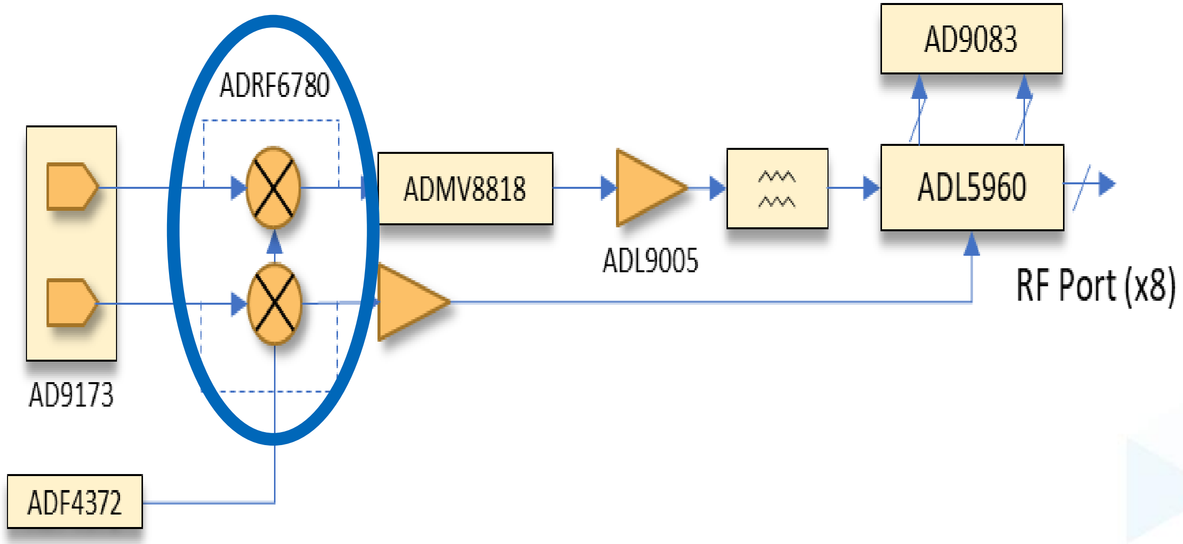
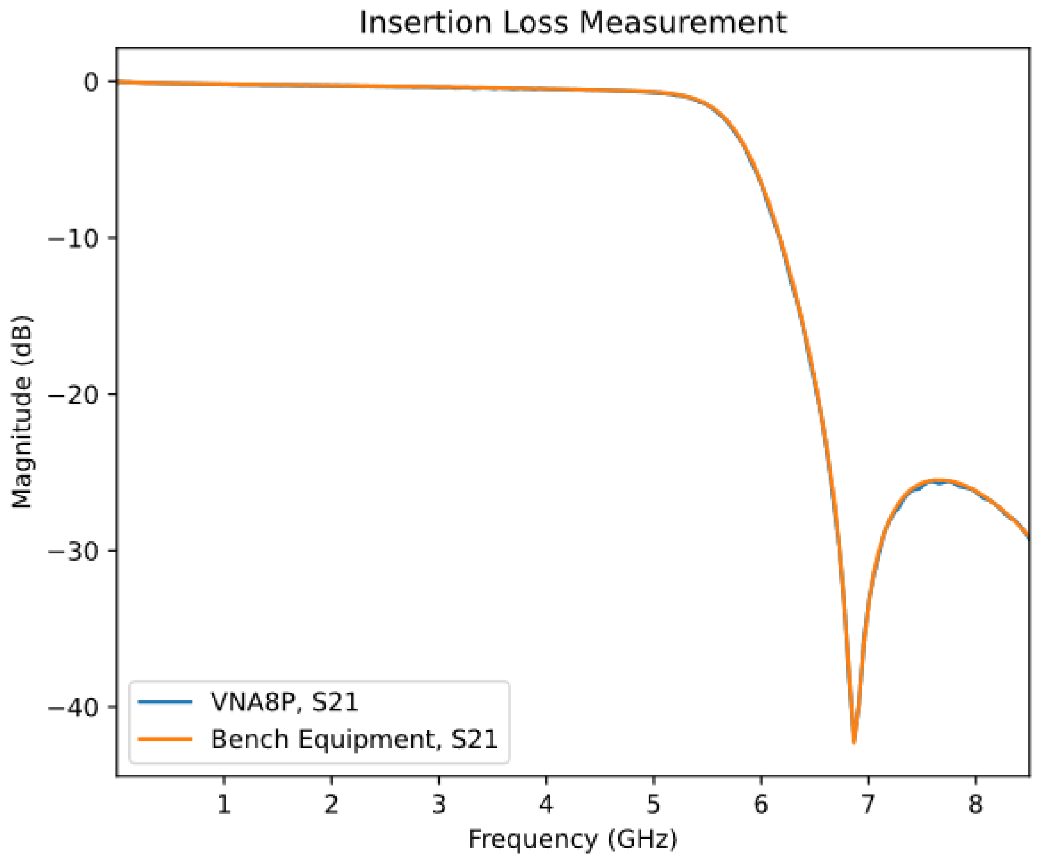
Representative Block Diagram

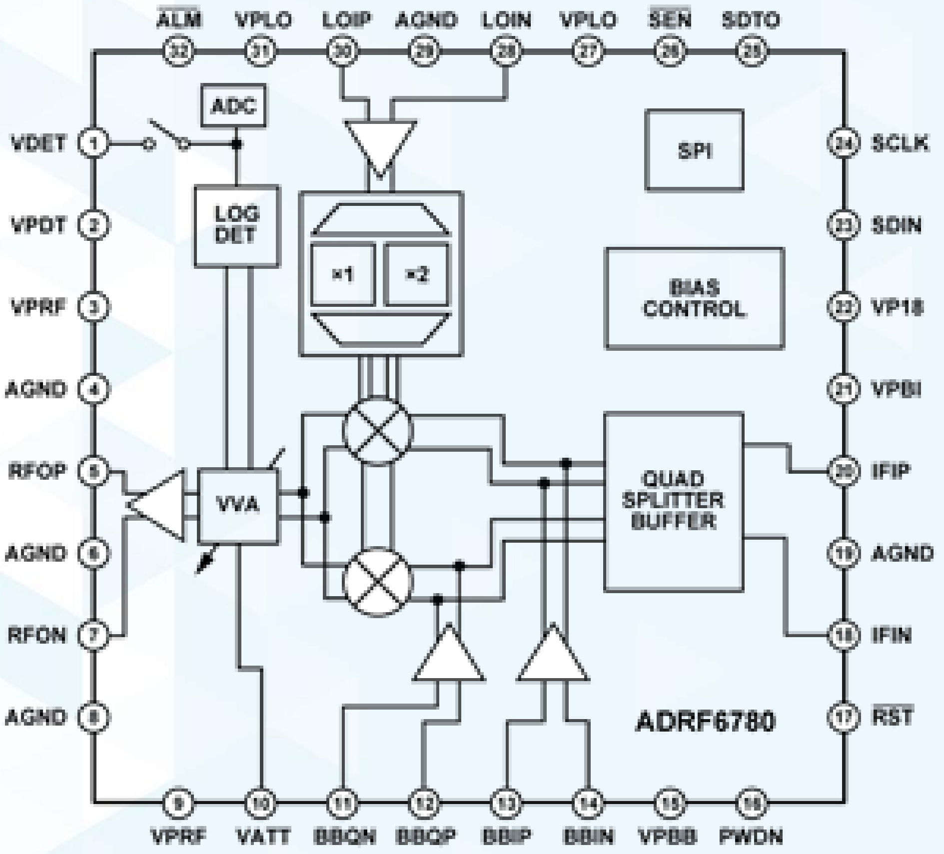




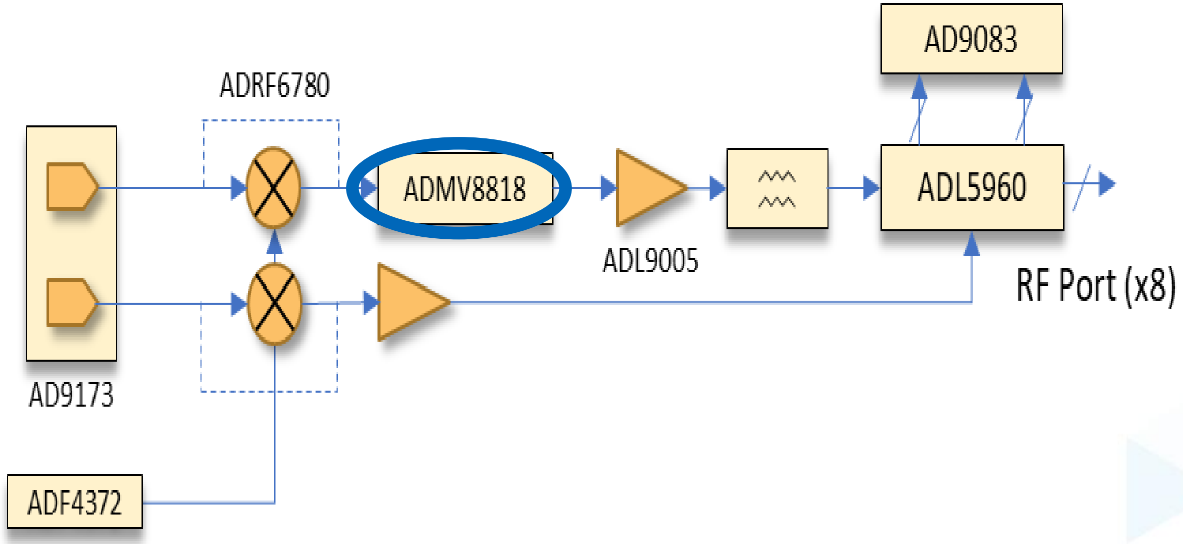
ADRF6780 - 5.9 - 23.6 GHz, Wideband, Microwave Upconverter

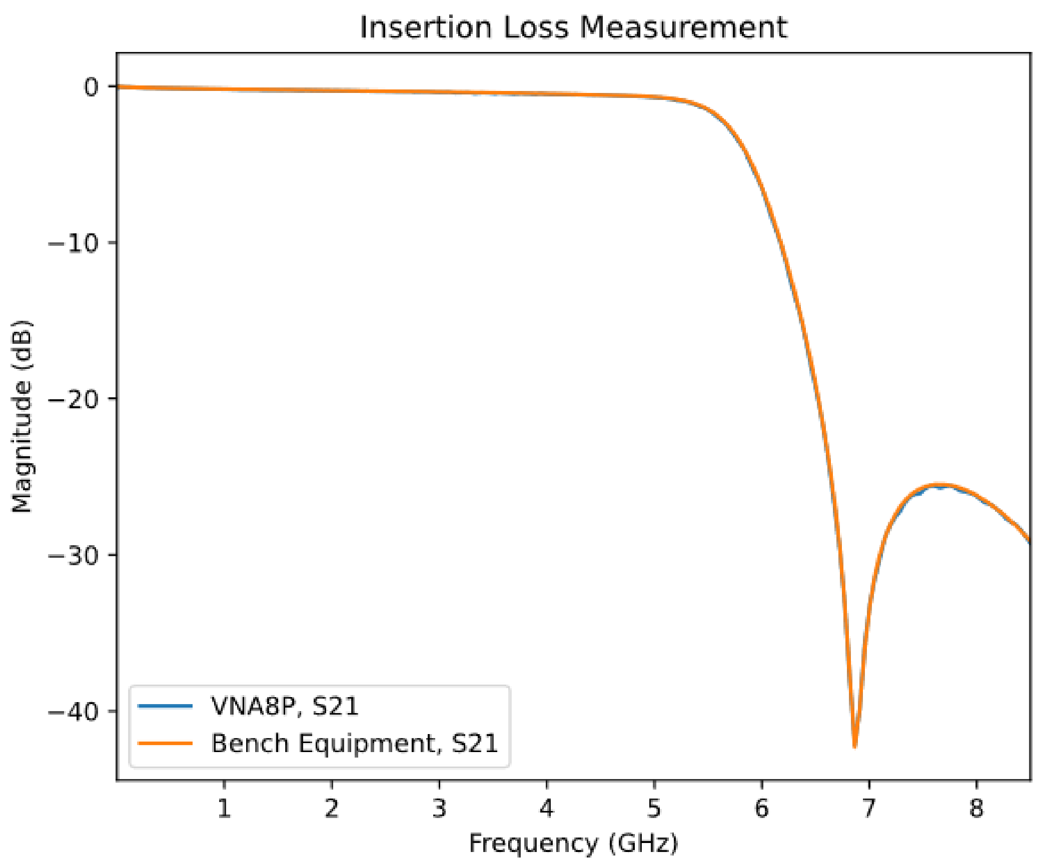
ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

- Frequency Range: 5.9 - 23.6 GHz
- Two upconversion modes
    - Direct conversion from baseband I/Q to RF
    - Single sideband upconversion from real IF
- LO input range: 5.4 -14 GHz
- LO doubler up to 28 GHz
- Matched 100 Ω balanced RF output, LO input, and IF input
- High impedance baseband inputs
- Sideband suppression and carrier feedthrough optimization
- Variable attenuator and power detector for Tx power control
- Programmable via 4-wire SPI interface
- 32-lead, 5 mm × 5 mm LFCSP



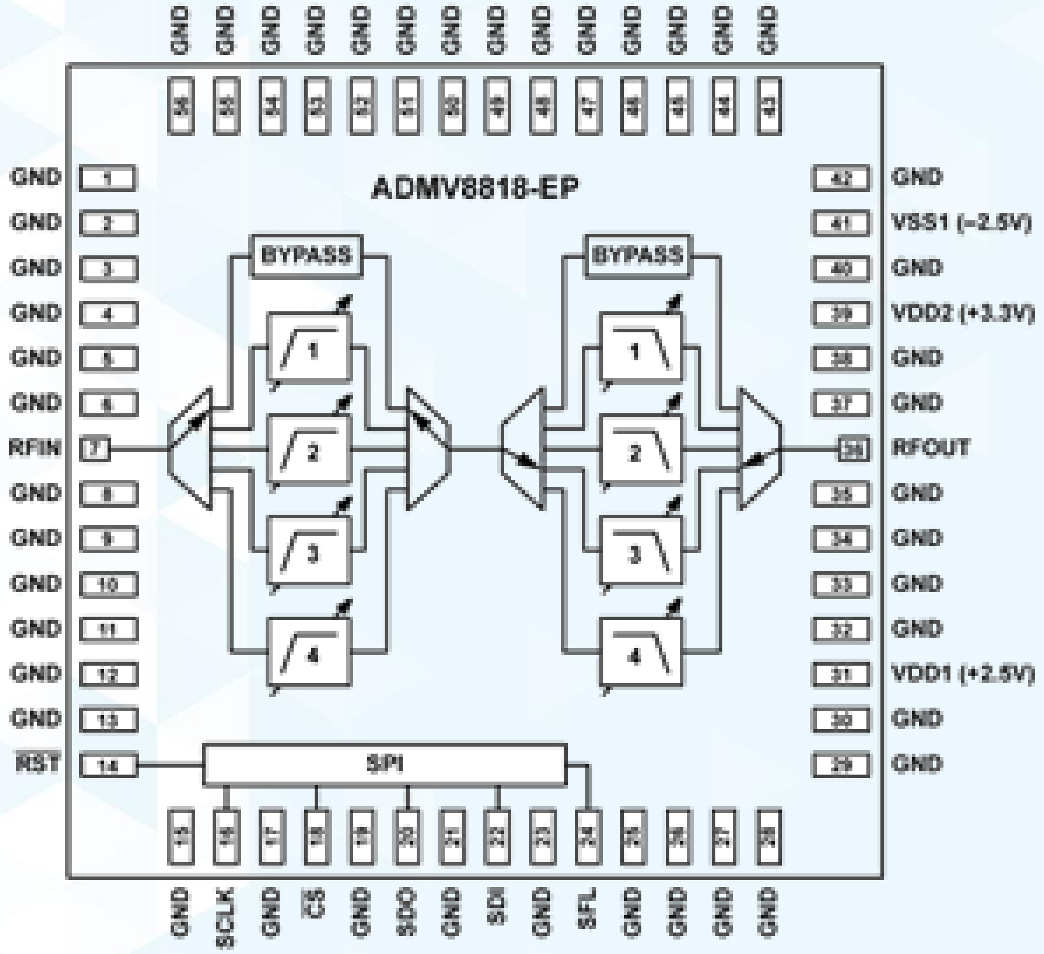
Representative Block Diagram



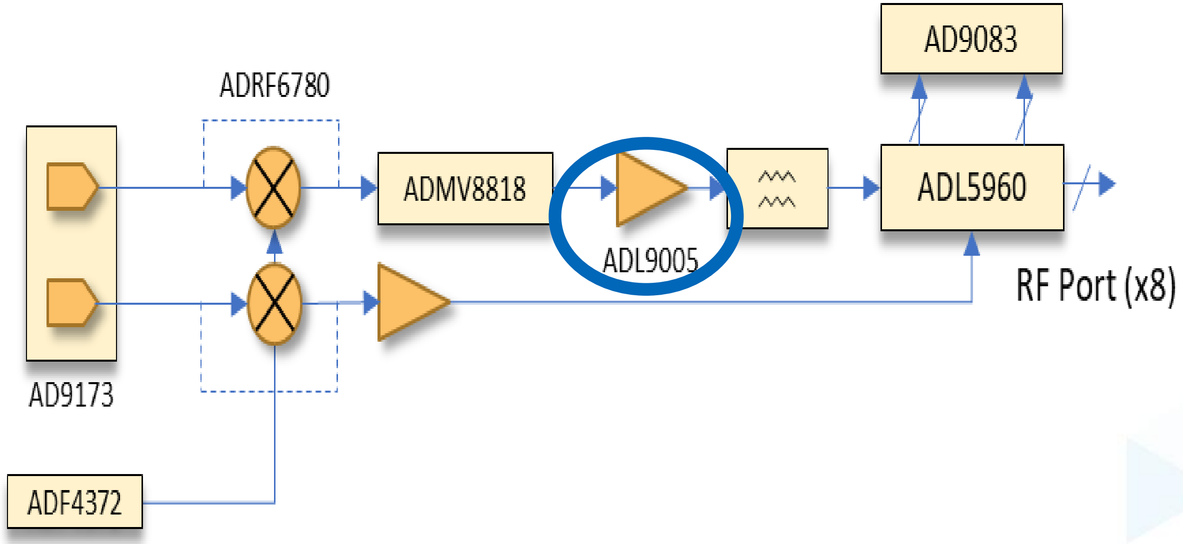


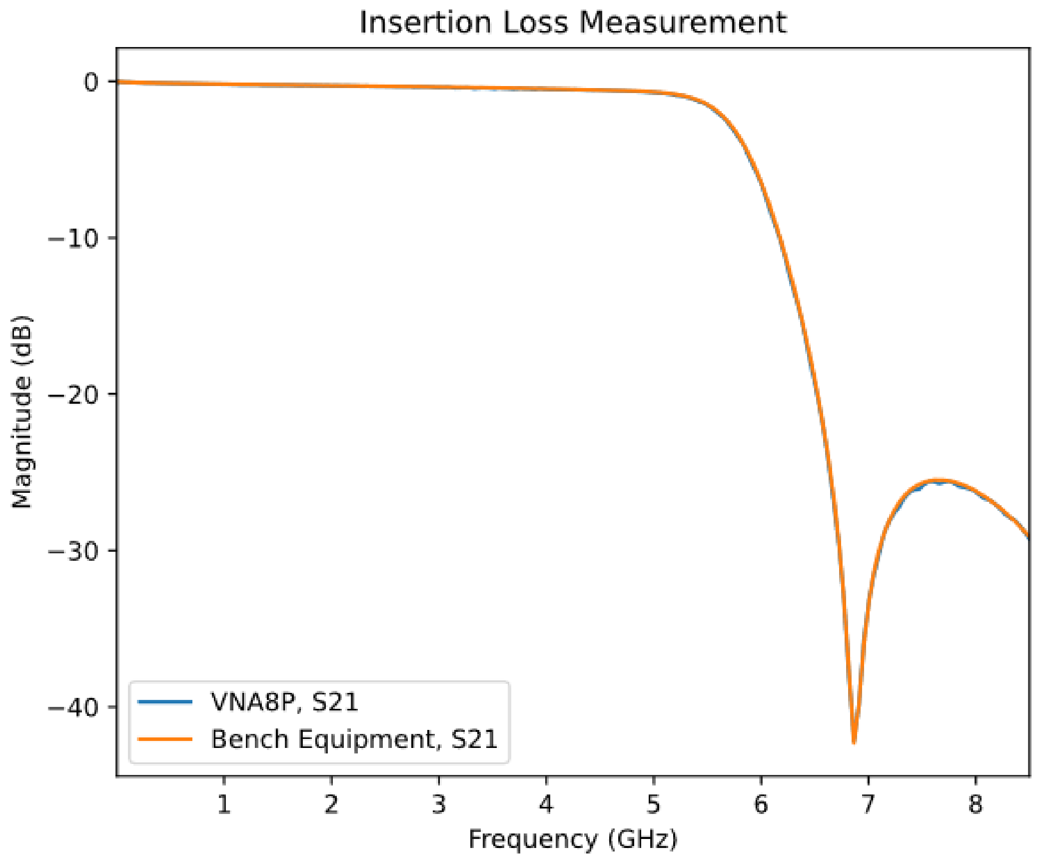
ADMV8818 - 2 GHz to 18 GHz, Digitally Tunable, High-Pass and Low-Pass Filter

•Digitally tunable, multioctave, high-pass and low-pass tuning
•Independent 3 dB frequency control for up to 4 GHz of bandwidth
•Typical insertion loss: 9 dB
•Optimal wideband rejection: 35 dB
•Up to 4 GHz of bandwidth
•Digital logic control: 4 bits each filter
•Single chip replacement for discrete filter banks
•Compact 9 mm × 9 mm, 56-terminal LGA package



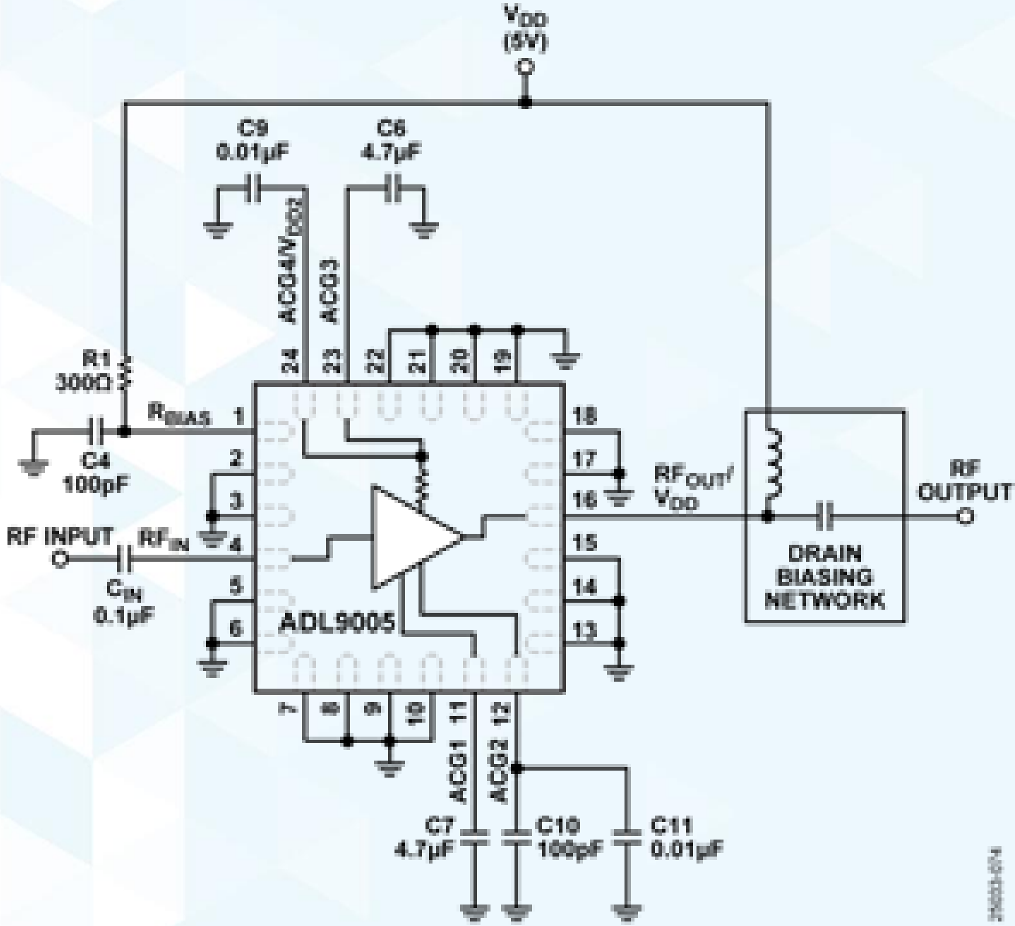
Representative Block Diagram





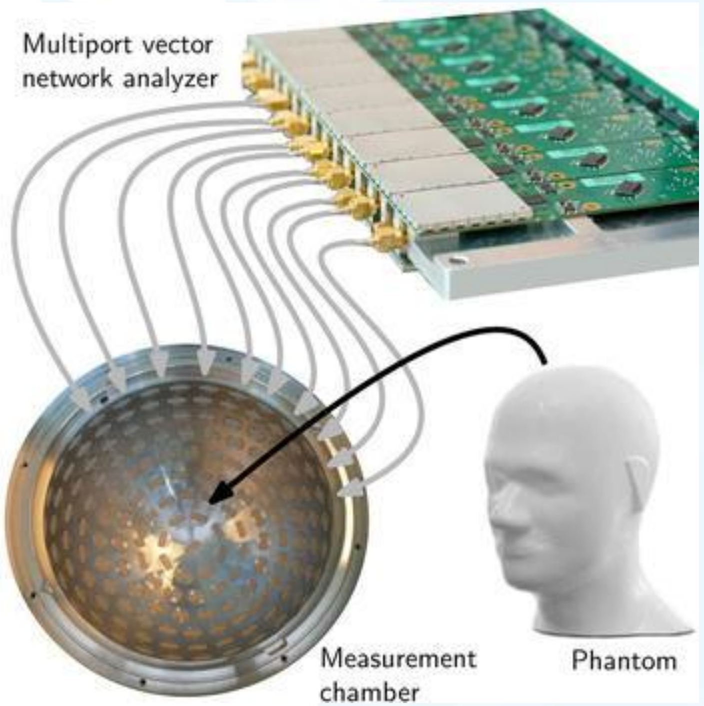
ADL9005 - 0.01 - 26.5 GHz, Low Noise Amplifier, Single Positive Supply,

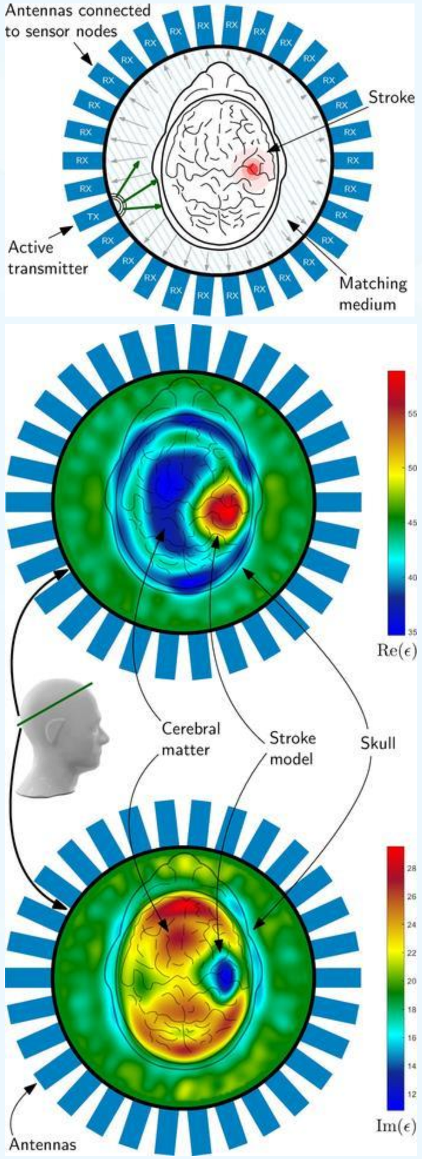
- Single positive supply
- Low noise figure: 2.5 dB (0.01 - 14 GHz
- High gain: 17.5 dB (0.01 - 14 GHz)
- OP1dB: 13.5 dBm (0.01 - 20 GHz)
- High OIP3: 26 dBm (0.01 - 14 GHz)
- RoHS-compliant, 4 mm × 4 mm, 24-lead LFCSP



Multi-port VNA for Medical Devices

- Medical imaging is of great importance for patients and medical professionals
- Multiport vector network analyzer system uses electromagnetic tomography (EMT) as an alternative imaging technique to larger magnetic resonance imaging or computed tomography imaging
- A chamber with 64 antennas which are connected to a measurement system used for stroke detection
- Can be used (sort of) as multi-channel SDR





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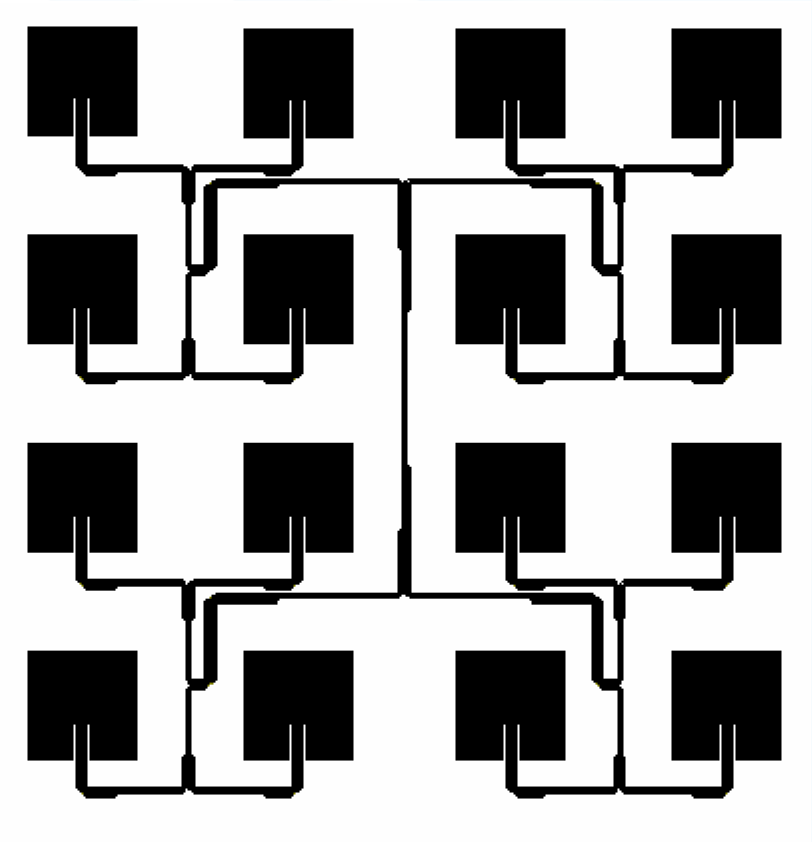
Phase Array Antenna Boards

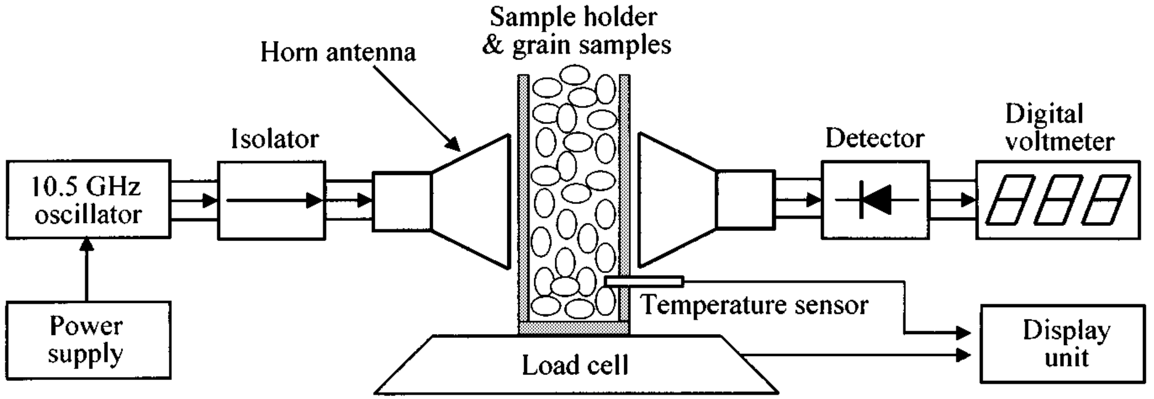
- Multiple patch antennas on the same substrate (see image) called microstrip antennas, can be used to make high gain array antennas, and phased arrays in which the beam can be electronically steered.
- Exciting a patch will affect the impedance (and performance) of the nearest neighbors – and array can not be tested/characterized one element at a time, they all need to be looked at simultaneously.
- Typically look at S11



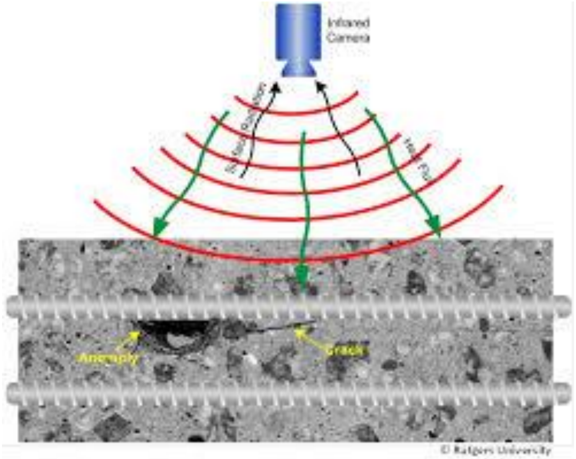
Indirect Measurement Applications

Signature-Based Measurements

Moisture Level Measurements



Defect Detection in Concrete



“Black Powder” Levels in (Gas) Pipes

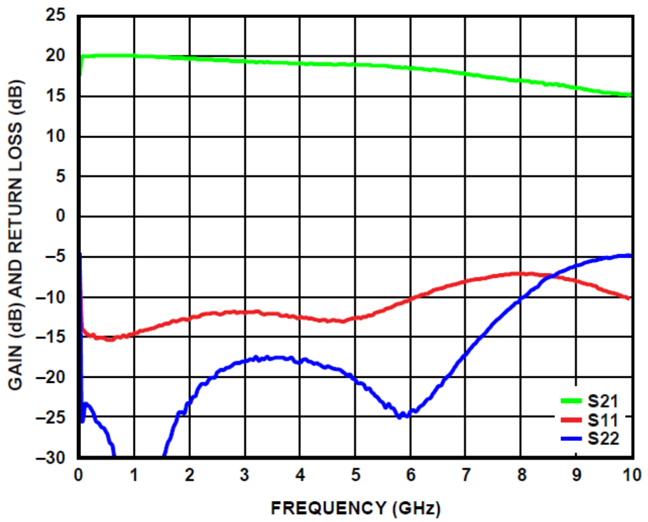
ADL5960: Application Examples

Applications	Benefits
▶ Automated Test Equipment	▶ More advanced continuity measurements for RF IC's. Can not only test if package pin is connected, but also by how many bond wires (inductance). ▶ More complete test coverage (gain, reflection, ...)
▶ Materials Analysis: measure a wide range of material characteristics: ▶ Humidity levels ▶ Pollution levels in filters, pipes, etc. ▶ Thickness measurements ▶ Weight (e.g. medicines) ▶ Temperature (e.g. PCB temperatures in battery packs) ▶ Pressure (e.g. break pressure/force in cars) ▶ ... any other attribute that correlates with transmission/reflection coefficients.	▶ Supports wide range of new sensors based on electromagnetic transmission/reflection measurements ▶ Quantity of interest correlates to S-parameters ▶ Contactless; no wear and tear ▶ Non-intrusive, non-destructive (opposed to e.g. chemical/mechanical testing). ▶ Continuous measurement ▶ Easily complemented with comprehensive post-processing.
▶ Maintenance/System Health Monitoring	▶ Integrity of cables and connectors – modular systems ▶ Detection of unauthorized cable taps

Network Analysis – Use Cases

Direct Measurement

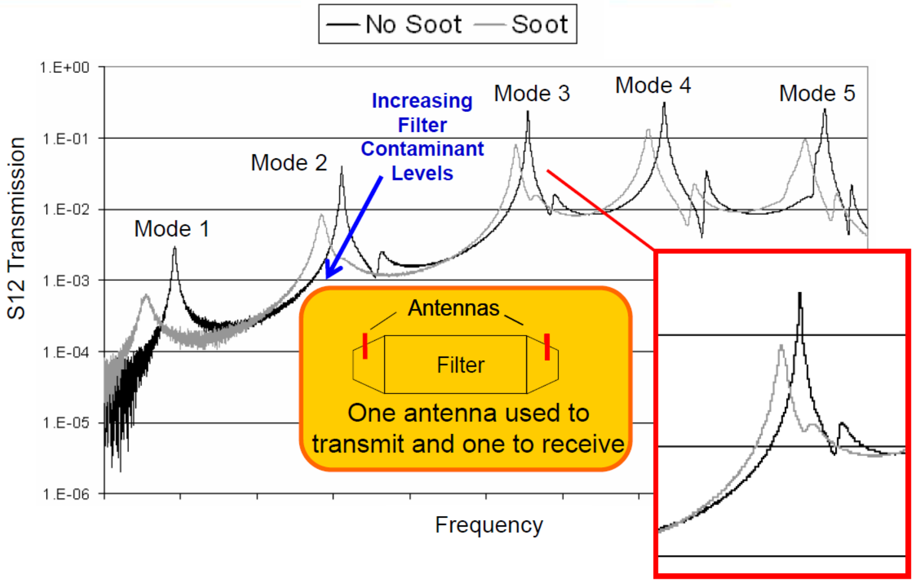
- Measure S-parameters (no secondary property)
- Characterization of electronic circuits/systems
  - Filter characteristics
  - Amplifiers
  - Switches & Attenuators
  - Mixers
  - ....



Amplifier
Gain & Return Loss

Indirect Measurements

- Use S-parameters to measure "Something Else"
- Often signature based measurement
- Example: Soot Filter
  - Resonance frequency shifts with soot level
  - Quality factor reduced by soot



Visit ADI Booth 1335 For Demo

Thank you

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