Challenges and Solutions of Advanced Automotive Radar Design and Test Lifecycle

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KEYSIGHT TECHNOLOGIES

Our Expectations Are Growing: The Car Industry

LAST 220+ YEARS (1770 – 1997)

Cugnot – Steam Powered

1770

Benz – Combustion

1885

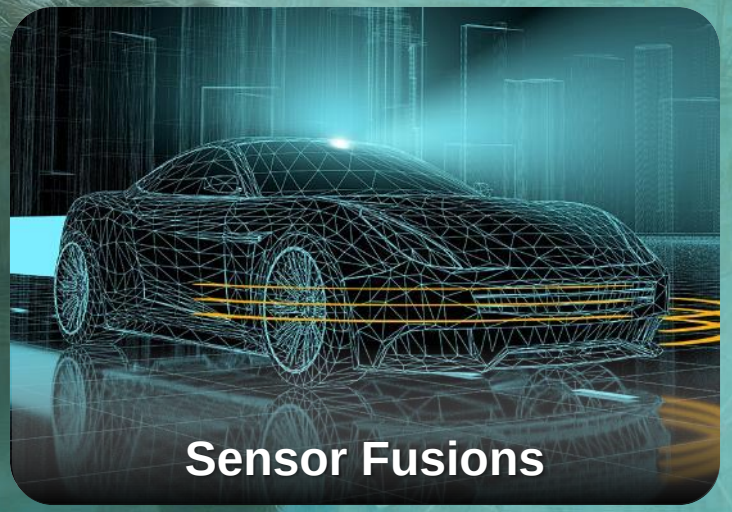
Toyota – Hybrid Electric

1997

Progress was electromechanical in the first 220+ Years

Pace of Innovation is Accelerating

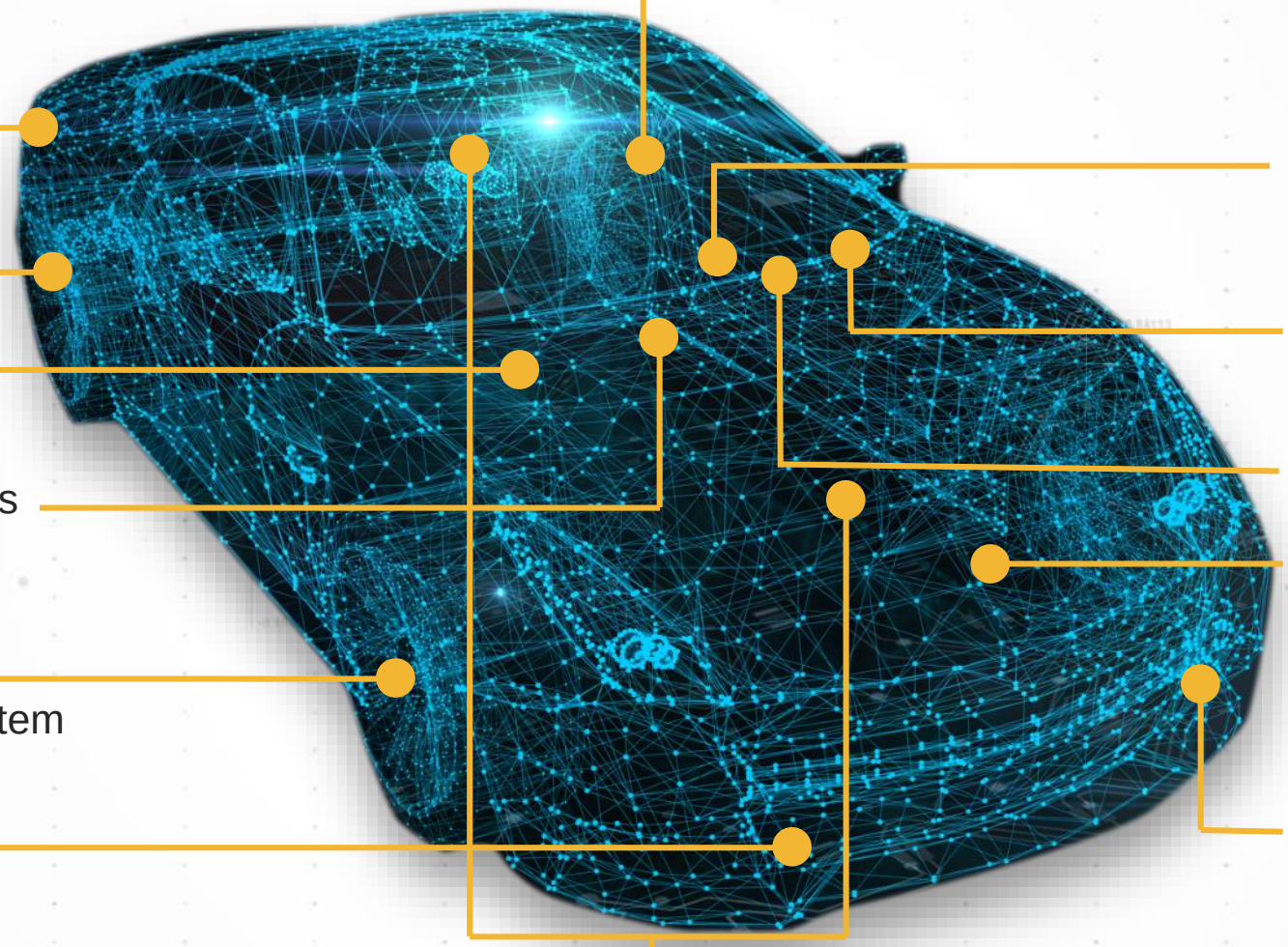
LAST 20+ YEARS



2004 → 2016 → 2020+

Innovation has completely **revolutionized** the industry

Innovations Through Multiple Technology Domains



Radar Collision Avoidance

Electronic Stability Control Module

Climate Control System

Infotainment/Navigation Modules (DVD, eCalls, Hands Free Telephony, GPS)

Anti brake Locking system
Tire Pressure Monitoring system

Emission Control Module

Power Steering Control
Rear-view camera
Backup sensors
Power Seat Control

Personnel Occupancy Detection Systems (PODS) for Air Bag systems

Remote Keyless Entry

Instrument Clusters

Fuel Injection Module
Power Train &
Engine Management
(MiL, SiL, HiL)

Adaptive Lightning Control

Hybrid Electric Vehicle
(HEV) / Electric Vehicle (EV)

Evolution of Sensors in Vehicles

Mechanical Designs Starting in 1976

- Basic electronics
- Mostly mechanical
- No connectivity

Assisted Driving Starting in 1997

- Electronic safety systems
- Integrated electronics
- Electric control units
- Infotainment

Autonomous Coming Next

- Sensor fusions
- Autonomous processing
- Auto-charging technologies
- Multi-connectivity

Technology Requirements Keep Advancing

MORE ELECTRONICS, MORE EFFICIENCY, MORE SENSORS

Electronics

- Better diagnostics
- Automotive Ethernet
- Infotainment

Batteries

- Longer range
- Higher densities
- More eco-friendly

Connectivity

- More information
- Better safety
- Easier navigation

Sensors

- Electro-mechanical
- Driver vision
- More autonomy

Automotive Radar Design and Test Lifecycle Webinar

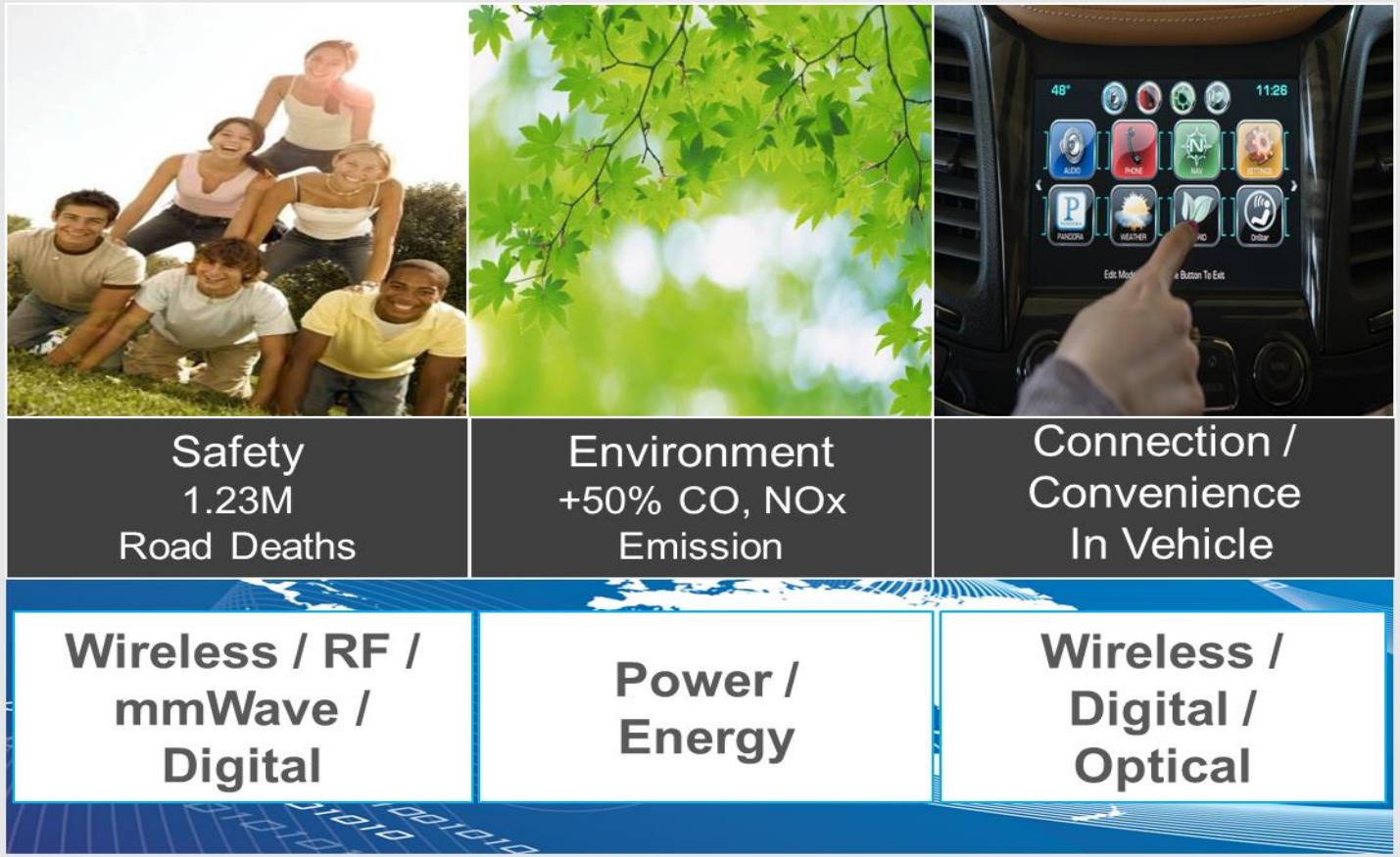
TOPICS

Automotive Radar Review

Enabling Technologies

Design & Test Challenges / Solutions

Automotive Market & Innovation Drivers



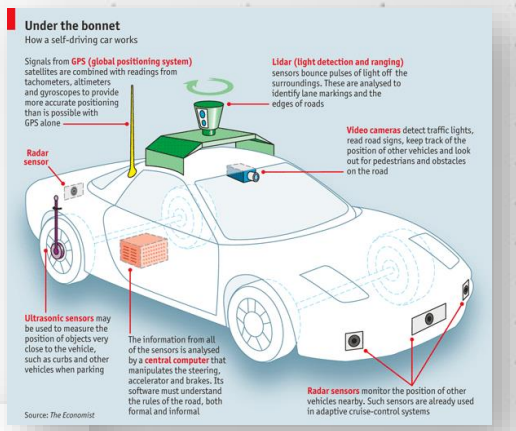
Autonomous Driving & e-Mobility

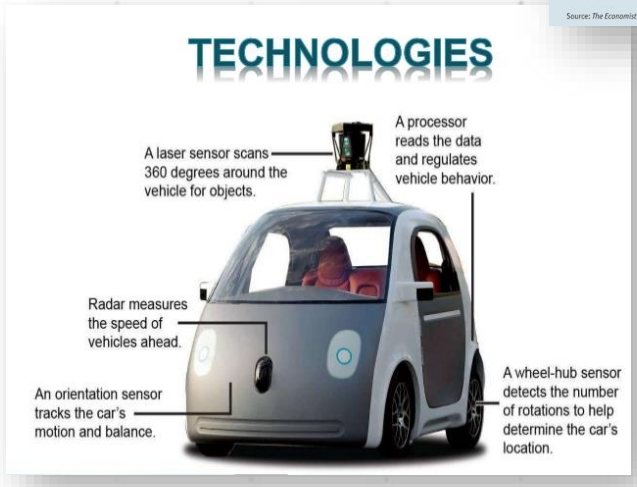
Data Source: WHO, US EPA

Autonomous Driving System

ENABLING TECHNOLOGIES

- Sensors
  - Radar
  - LIDAR
  - Camera
- Wireless connections
  - 2/3/4G and coming 5G
  - 802.11p DSRC
- Automotive Ethernet
  - BroadR-Reach, 100 / 1000 BASE-T
- Navigation systems
- Processors
- Artificial Intelligence
- High Definition Mapping
- More





Autonomous Driving System

SENSORS

	RADAR	Camera	LIDAR
Used for	• Detection - distance (range) and motion (velocity, angle) by radio waveforms	• Recognition, classification by images	• 360° 3D view by laser / light
Applications	• Adaptive Cruise Control, Automatic Emergency Braking Systems, Blind Spot Detection, Parking Assistance	• Traffic Sign Recognition, Land Keep Systems, Parking Assistance, Blind spot detection, ACC, AEBS	• Emergency Brake Assist for Pedestrian, Crash Imminent Braking, Mapping
Advantages	• Working in all environmental conditions • Light weight • Longer detection distance than LIDAR	• Lower cost • Smaller sensor size • High resolution • Color recognition • Imaging processing	• High accuracy • High resolution • Intelligent signal processing with large amount of captured data
Limitations	• Limited information of detected obstacles • Lower resolution than LIDAR	• Various performance in some environments (e.g. weather, lighting)	• (still) expensive sensor • (still) big sensor size • Expensive and complicated signal/data management • Affected by weather

Automotive Radar trend and test requirement

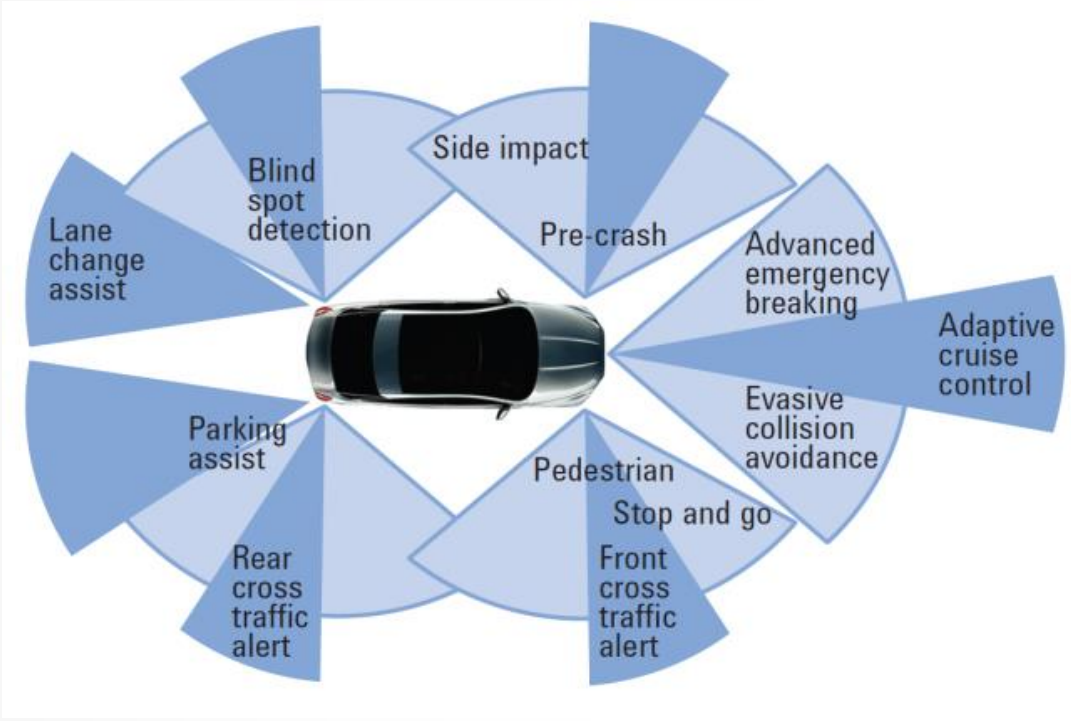
Automotive Radar

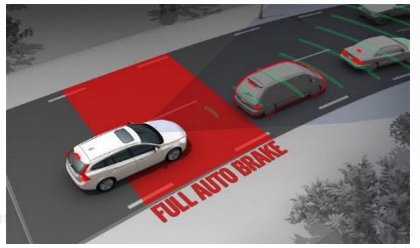
ENABLING TECHNOLOGIES & TEST CHALLENGES

Technologies	Applications	Challenges
Higher frequency	24GHz, **77GHz, 79GHz**, 122GHz	Generate and characterize accurate mmWave signals
Wider Modulation Bandwidth	100MHz, 500MHz, **1GHz, 2GHz, 4GHz**, and beyond	Generate and analysis accurate wideband signals
Complex Pulse Modulation and Phase noise	**FMCW**, Pulse	Analyse modulation qualities and characterize phase noise
Power control	e.g. ETSI conformance specification, EN 302 264 for 79GHz	Validate both wanted power levels and unwanted emissions
In-Vehicle Ethernet	**BroadR-Reach** Optical buses	Verify protocol decode/trigger, eye-diagram mask testing, and physical layer compliance

Automotive Radar

APPLICATION EXAMPLES

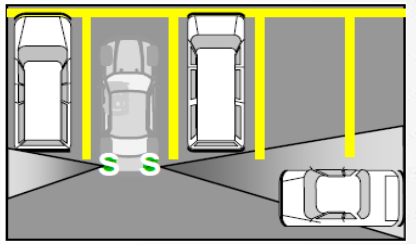




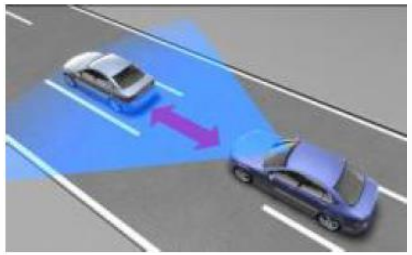
Auto Emergency Braking / Pre-tensioning Seatbelts

Blind Spot Monitoring

Lane Change Assist



Real Collision Protection



Adaptive Cruise Control

Stop & Go Cruise Control

Making Roads Safer with 360 Degree Vision!

Making Autonomous Driving Possible!

Automotive Radar

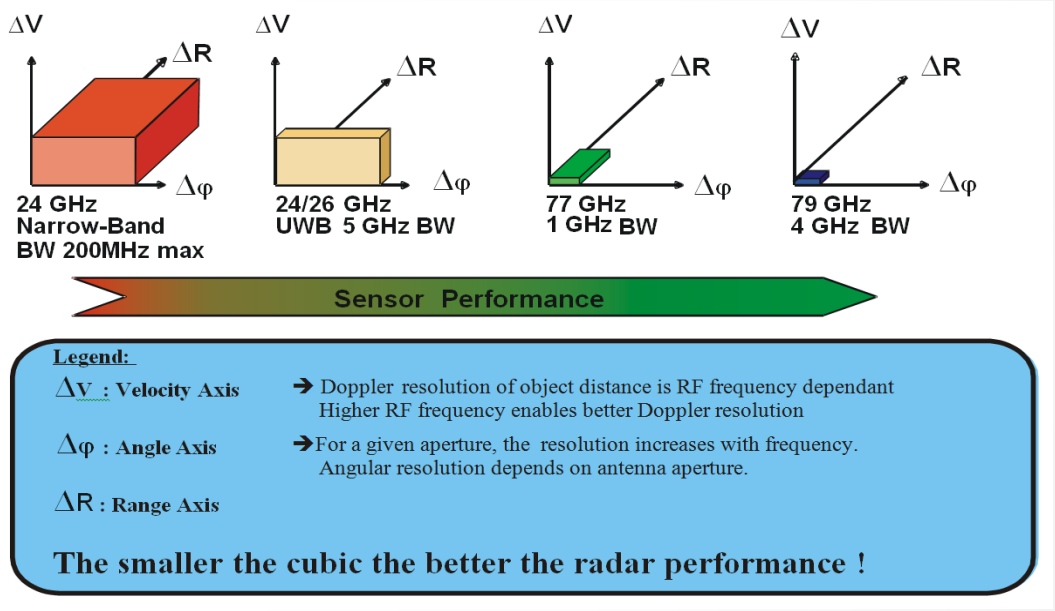
MAJOR TECHNOLOGIES

- High Frequency and wide bandwidth millimeter wave (24, 77, and 79GHz)
- Modulation (FMCW)
- Antenna
- Automotive Ethernet / Serial Buses (BroadR-Reach, 100 BASE-T, CAN/CAN FD)
- Power Control (ETSI conformance specification, EN 302 264 for 79GHz)
- More

Automotive Radar Major Technologies

HIGH FREQUENCY & WIDE BANDWIDTH MILLIMETER WAVE (77/79 GHZ)

- Benefits
  - Better spatial angular (smaller wavelength), velocity (doppler), and range resolution
  - Higher range (up to 300 meter)
  - Smaller and lighter sensor
  - Rapid signal attenuation (better for interference), improved interference mitigation
  - Higher attenuation per km → higher spectrum re-use (sharing) scheme on the busy road
  - Better power efficiency (less emission power → lower possibility of interference issue)



Source: CEPT Report 37

Fig.1 Comparison of sensor performance showing key parameters Angular resolution, Range resolution, Doppler resolution

Automotive Radar Major Technologies

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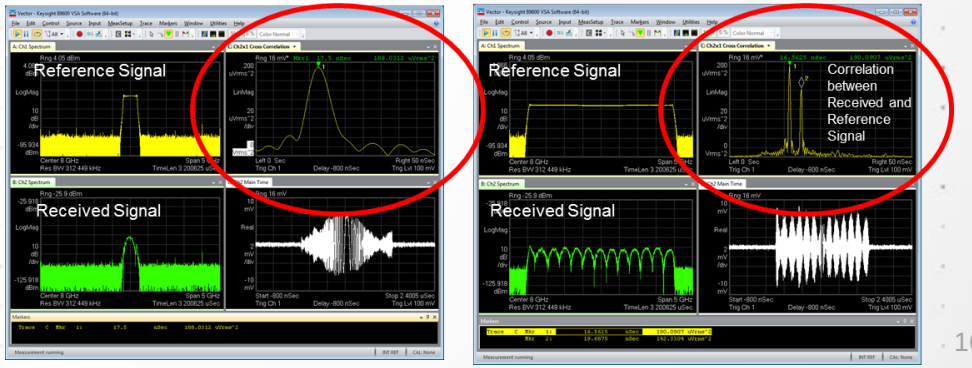
- Challenges
  - Higher propagation loss
  - Phase noise, IQ and frequency response errors degrade
  - Repeatability
  - More noise to impact on EVM
  - Complex test set up
  - Generate and characterize accurate wide bandwidth millimeter wave signals



Automotive Radar Major Technologies

MODULATION (FMCW)

- Benefits
  - Avoid high peak-to-average power ratio (PAPR) in transmission
  - Simplifies the design process for antennas and RF components (narrow-band IF processing)
  - Good performance with simplified RF components → small size, light weight, and low cost.
  - Improved noise floor
  - Interference tolerance
  - Reduced RF intermodulation
  - Simpler / easier waveform to generate (compared to very narrow, high power pulsed)
  - Constant high average power, without requiring high peak powers, managed close-in blind-range issues (always transmitting and receiving)

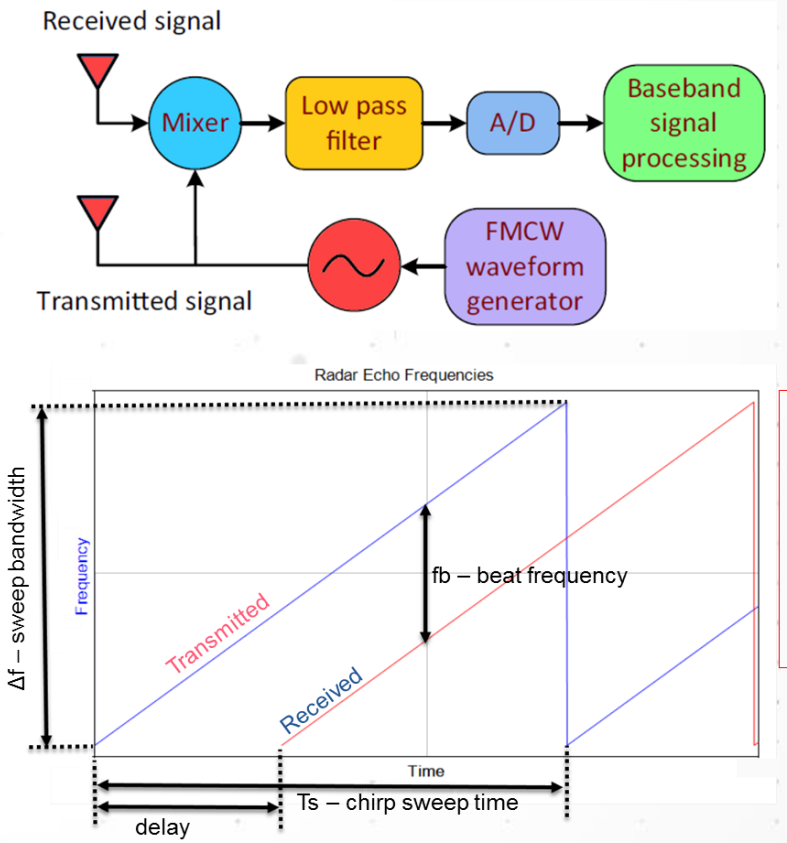


Fig.4 FMCW diagram and frequency detection

Automotive Radar Major Technologies

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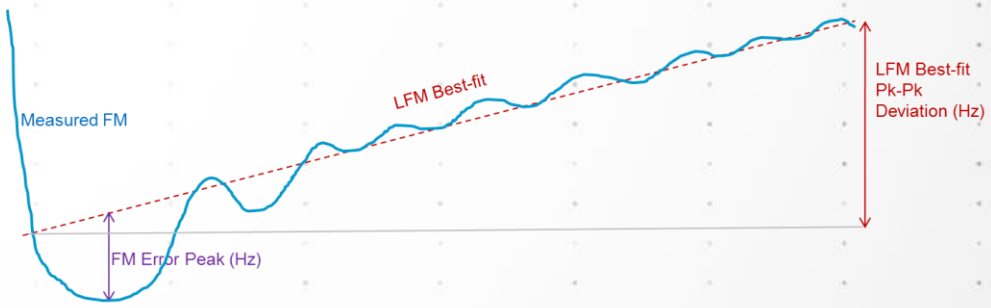
  - Constant high average power, without requiring high peak powers, managed close-in blind-range issues (always transmitting and receiving)

- Challenges
  - FM Linearity modulation quality
  - Phase Noise and AM Noise of transmitter
  - RF leakage from Tx to Rx
  - Dealing with clutter from multiple undesirable reflections between sensor and targets
  - Dealing with interference from other radar sensor band users
  - Thermal Power Challenges

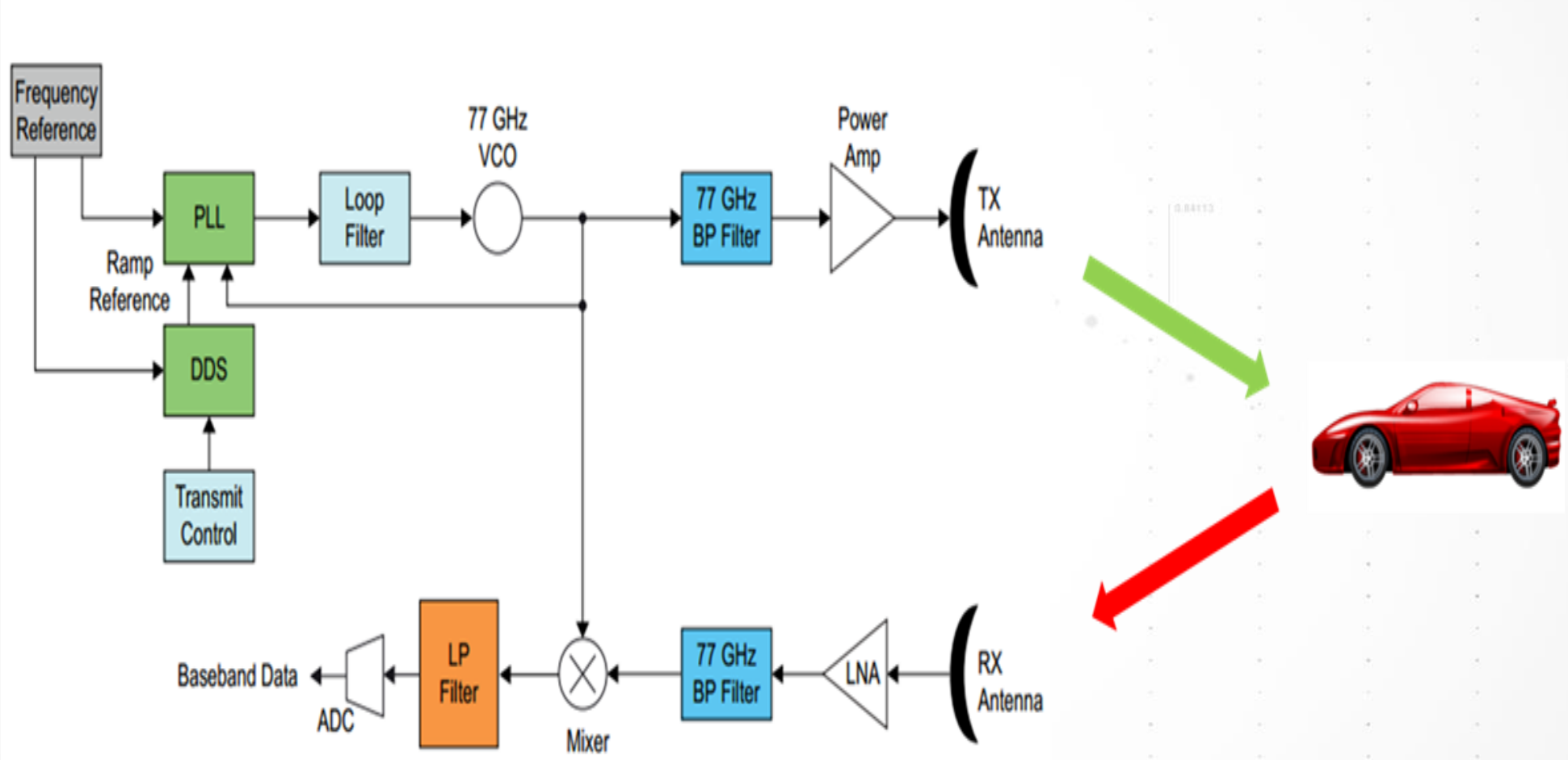


FM Error Peak (Hz) = max(Measured FM – LFM Best-fit)

INL Best-fit (%) = [FM Error Peak (Hz) / LFM Best-fit Pk-Pk Deviation (Hz)] * 100

Automotive Radar Development

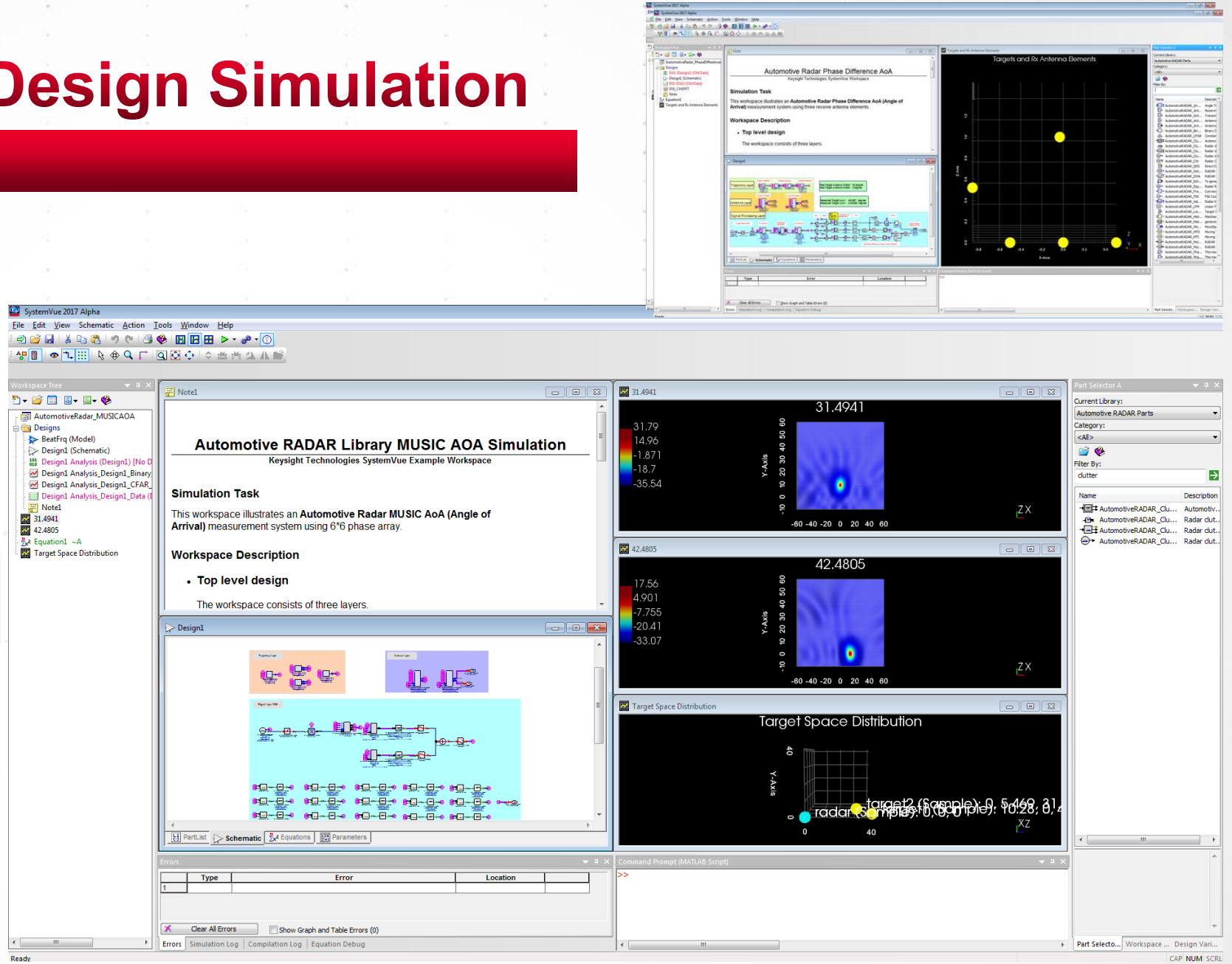
MILLIMETER WAVE TEST SET UP EXAMPLE



Automotive Radar Design Simulation

MUSIC AOA SIMULATION

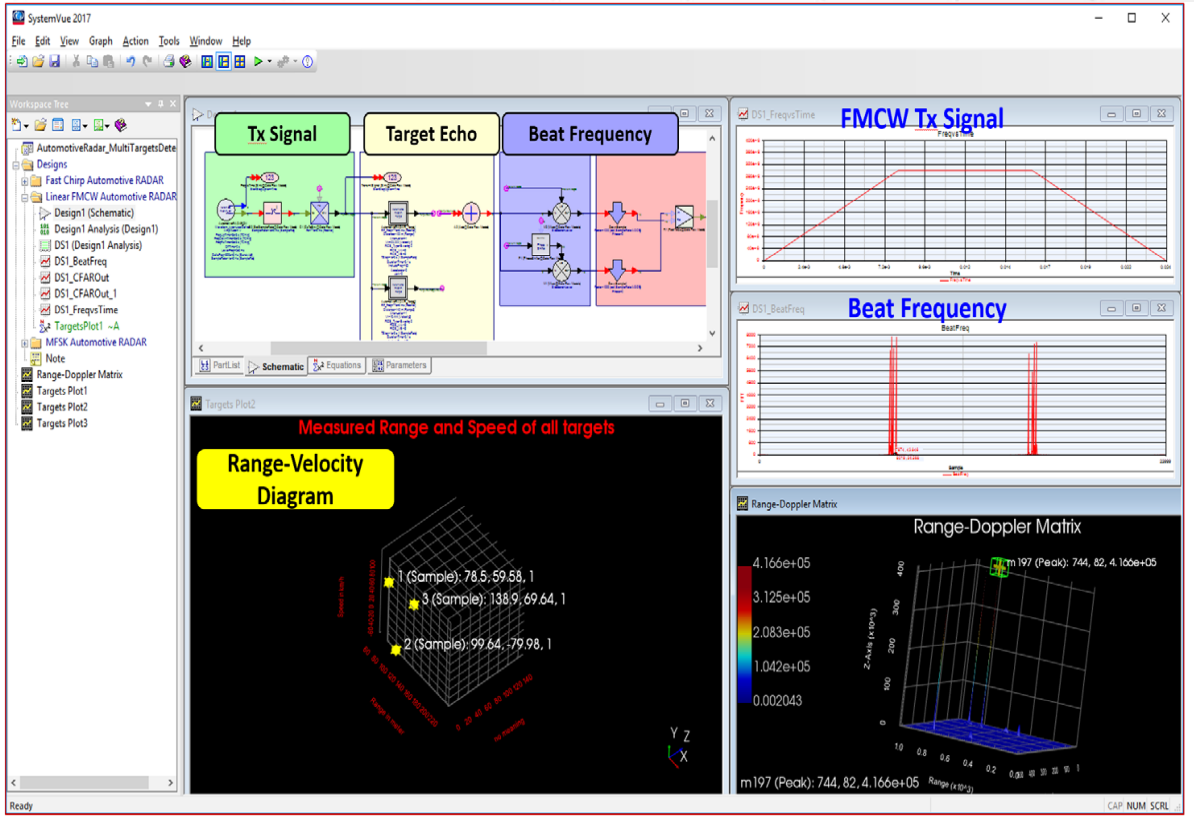
- MUSIC AoA
  - Multiple Signal Classification, algorithm used for frequency estimation and emitter location
  - High resolution digital beamforming method with sensor array is required
  - Estimated by investigating the phase difference by a time delay



Automotive Radar Design Simulation

LINEAR FMCW MULTI-TARGET DETECTION

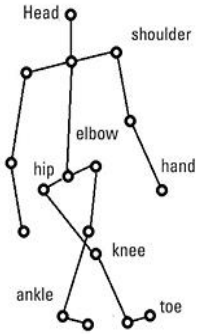
- Using single tone of linear FMCW signal with up-chirp and down-chirp with echo and beat frequency of every targets, users can simulate the multi target detection and show them in range-velocity diagram.
- Showing three targets detected and shown in range-velocity diagram

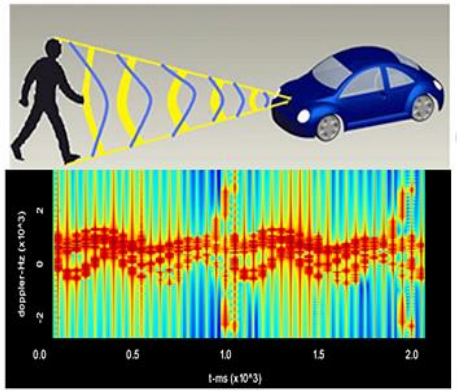


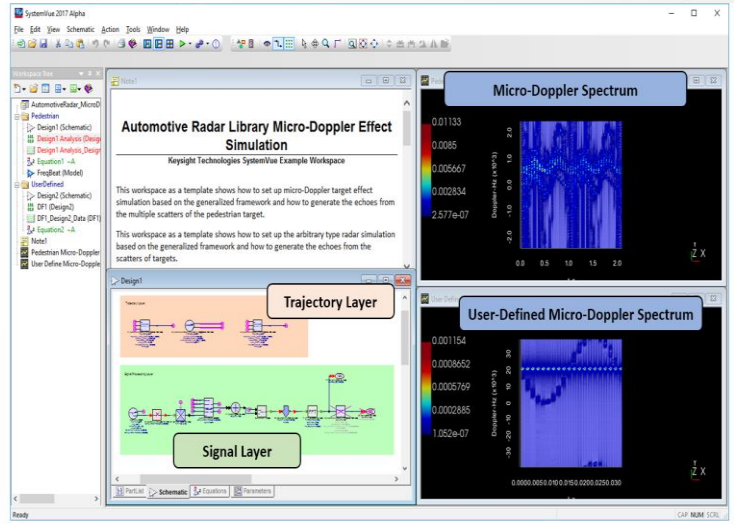
Automotive Radar Design Simulation

MICRO-DOPPLER

- Using the micro-Doppler spectrum distribution to distinguish the targets from pedestrian or vehicle
- Pedestrian target has more sub parts like arm, leg, head, neck, and torso with different instantaneous velocity
- The arms and legs move periodically in walking; the Doppler spectrum is changing periodically in time
- A common scenario model with
  - Pre-defined walking passenger
  - Pre-defined running passenger
  - Pre-defined moving car
  - Custom scenario with customized trajectory



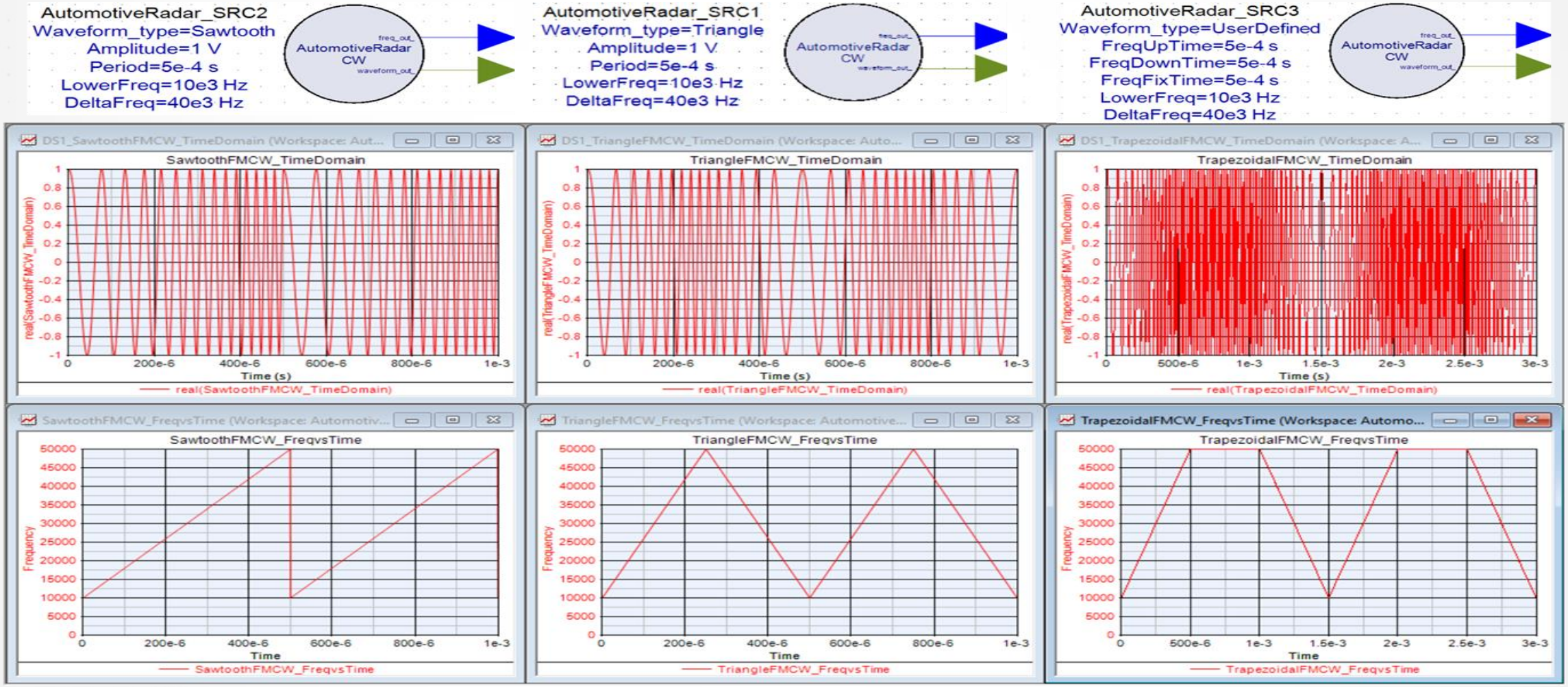




- 10+ scatters for a walking passenger
- Accurate modeling for moving trajectory for each scatter
- Reference radar data processing to identify micro-Doppler signature of the walking passenger

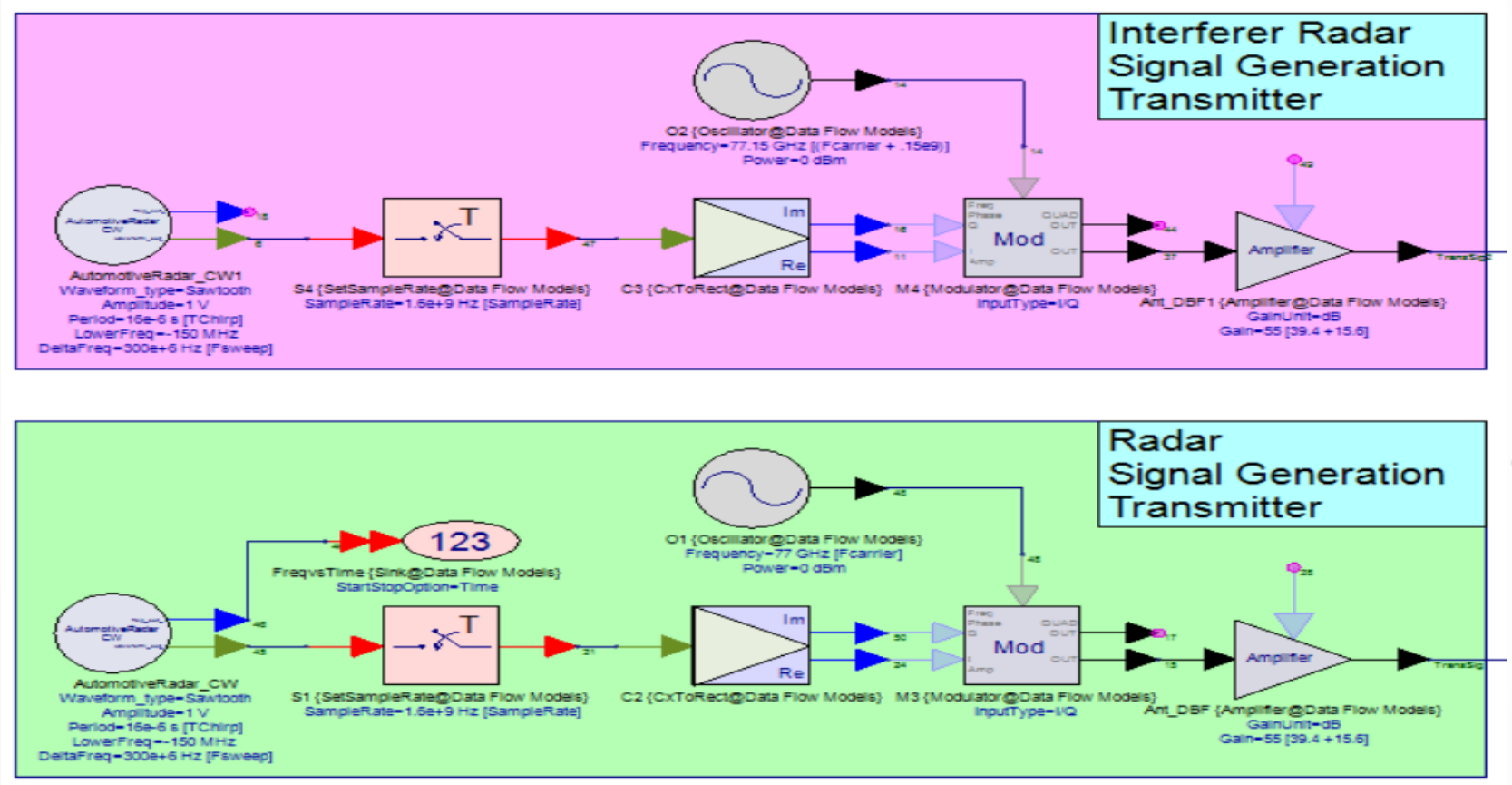
Automotive Radar Simulation

FLEXIBLE AUTOMOTIVE RADAR SIGNAL GENERATION WITH SYSTEMVUE



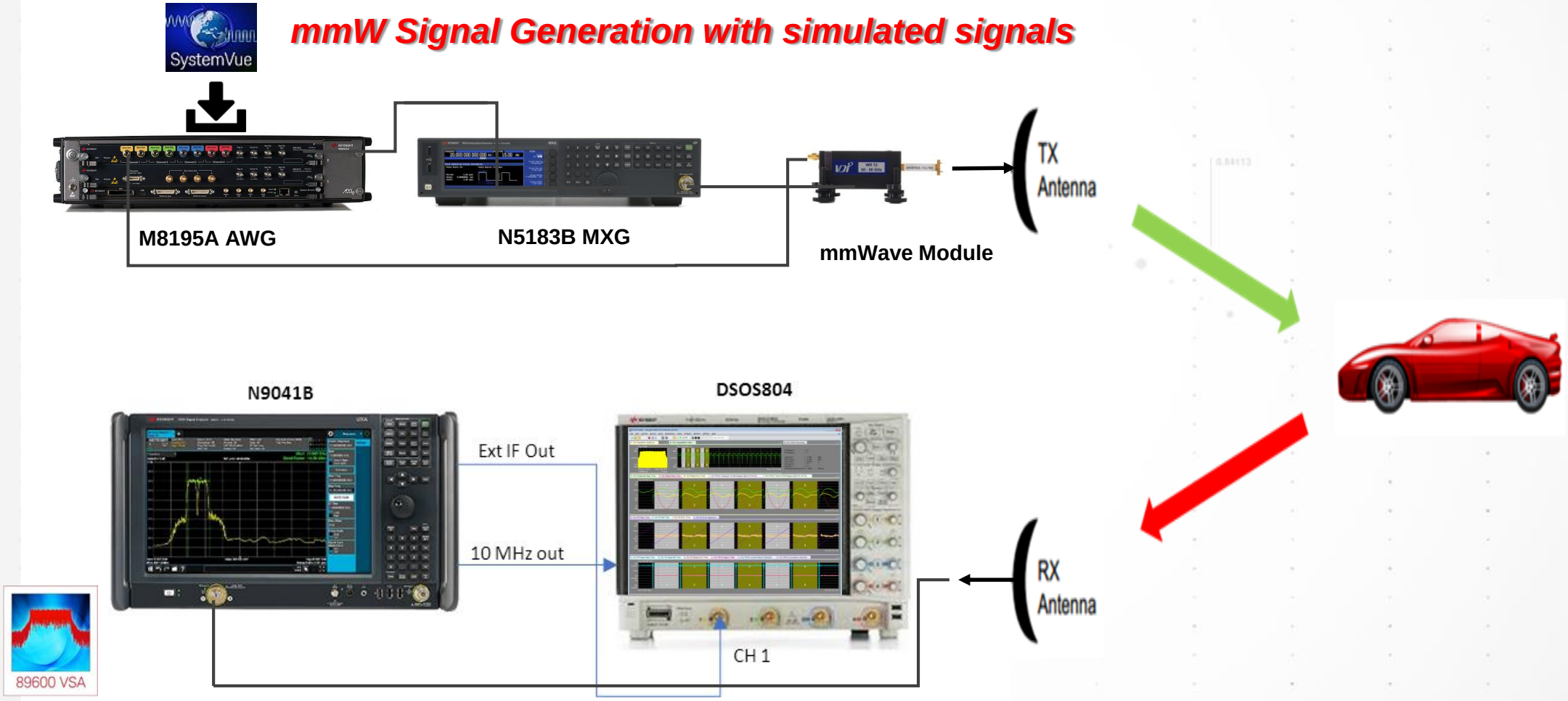
Automotive Radar Simulation

AUTOMOTIVE FAST CHIRP SIGNAL GENERATION & TRANSMISSION



Automotive Radar Development

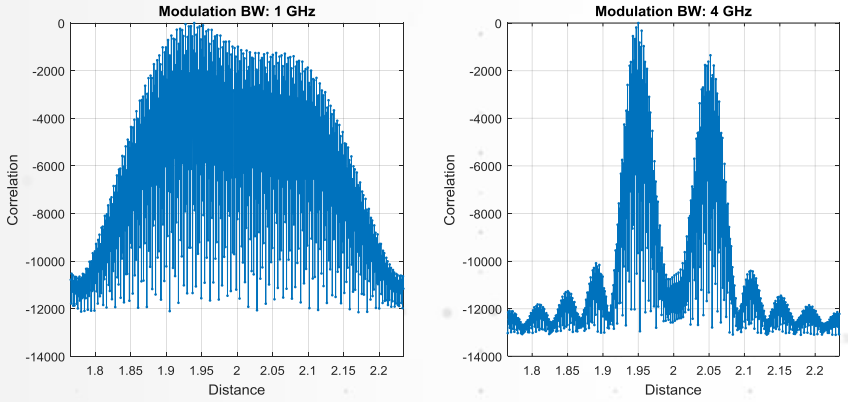
MILLIMETER WAVE TEST SET UP EXAMPLE

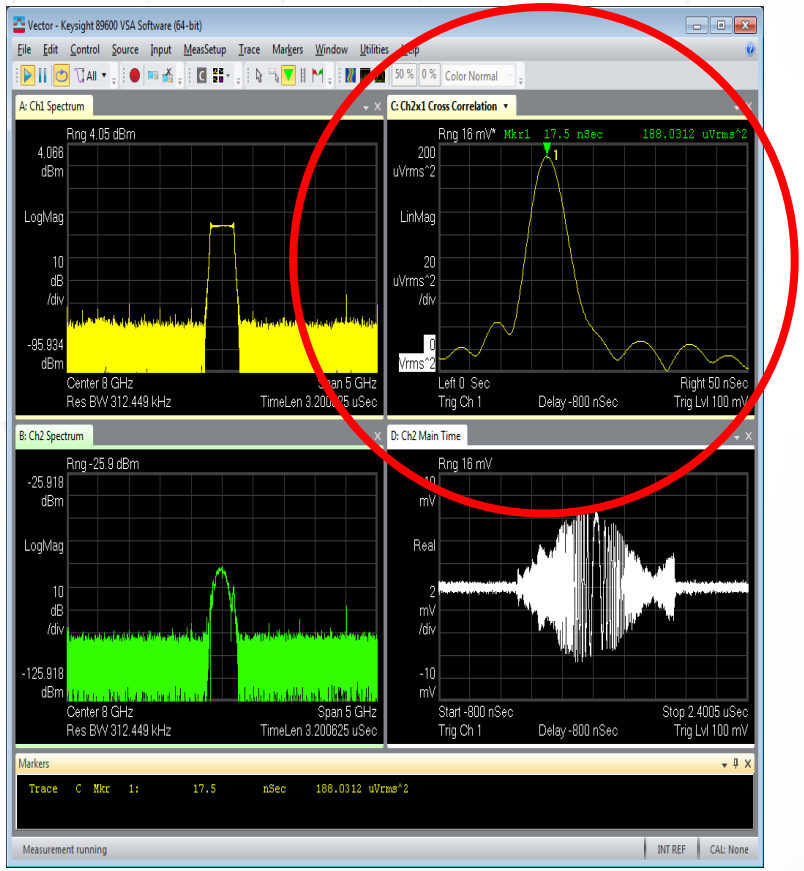


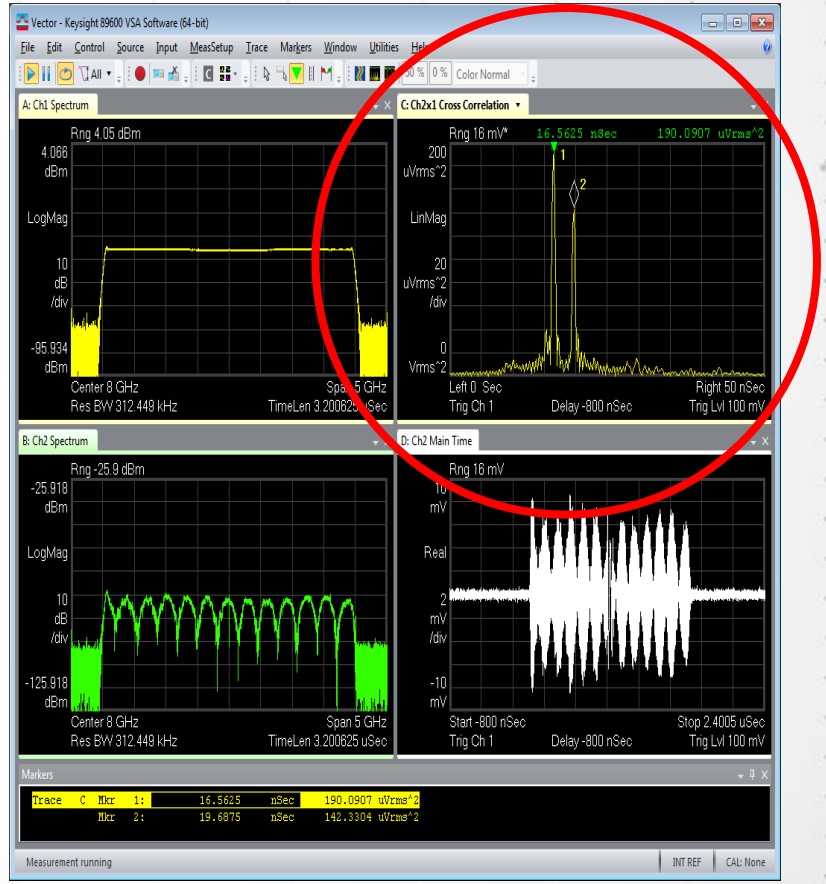
Automotive Radar Development

SIMULATION AND TEST RESULTS

- Two objects, 10 cm apart, FMCW, 1 GHz and 4 GHz modulation bandwidths
- Simulation result (left) and Measurement result (right)







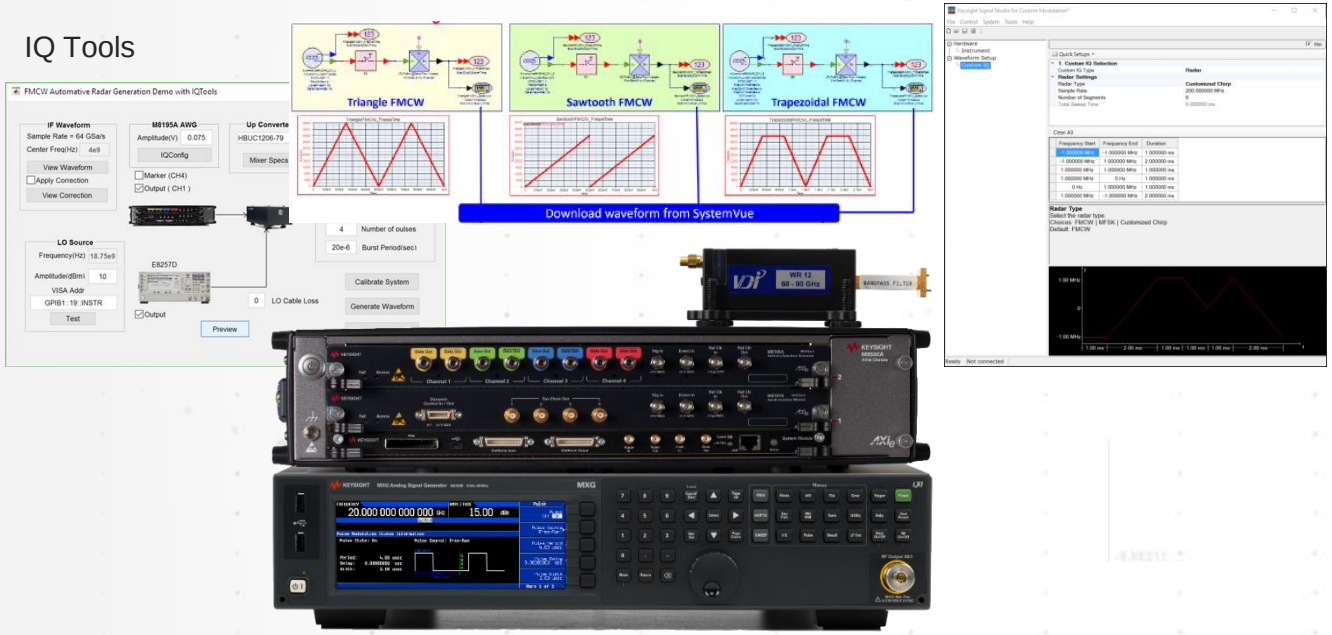
Automotive Radar Development

FLEXIBLE AND COMPLEX MODULATION SIGNAL GENERATION

IQ Tools

W1908 SystemVue Auto Radar Library

N7608C Signal Studio



Key Features

- Download Radar FMCW signals from either: SystemVue, *IQ Tools, Signal Studio, or others*
- Generate ideal reference signals (replace Tx LO / VCO)
- Generate interferer, clutter, jamming test signals (Rx Test)

Parameters	E8740A-070 Performance SG
Frequency Range	DC to 25GHz, 60GHz to 90GHz
Signal Bandwidth for IF/RF	IF/RF up to 25GHz
3dB Bandwidth for mmW	5GHz for FMCW @ 79GHz Fc (with correction)
Pout1dB	-14.6dBm@76GHz -13.5dBm@79GHz
Amplitude flatness (at SMA connector,* compensated for sin(x)/x)	±2 dB (typ), fout= DC to 10 GHz +2 dB, -3 dB (typ), fout = 10 to 25 GHz (typ)
Amplitude resolution	200uV (nom)
DAC resolution	8Bit
AWG Sample rate	13.44 GSa/s to 65GSa/s
Sample Memory (Internal / extended)	1 MSa / 16GSa
Frequency Switching time	505us / 38ps (opt FSW)
MIMO and beam forming	Expandable to 16 synchronized channels
mmW Modulation signals	FM, PM, FMCW, pulse sequence, MFSK, custom OFDM,……

*Measured at Data Out.

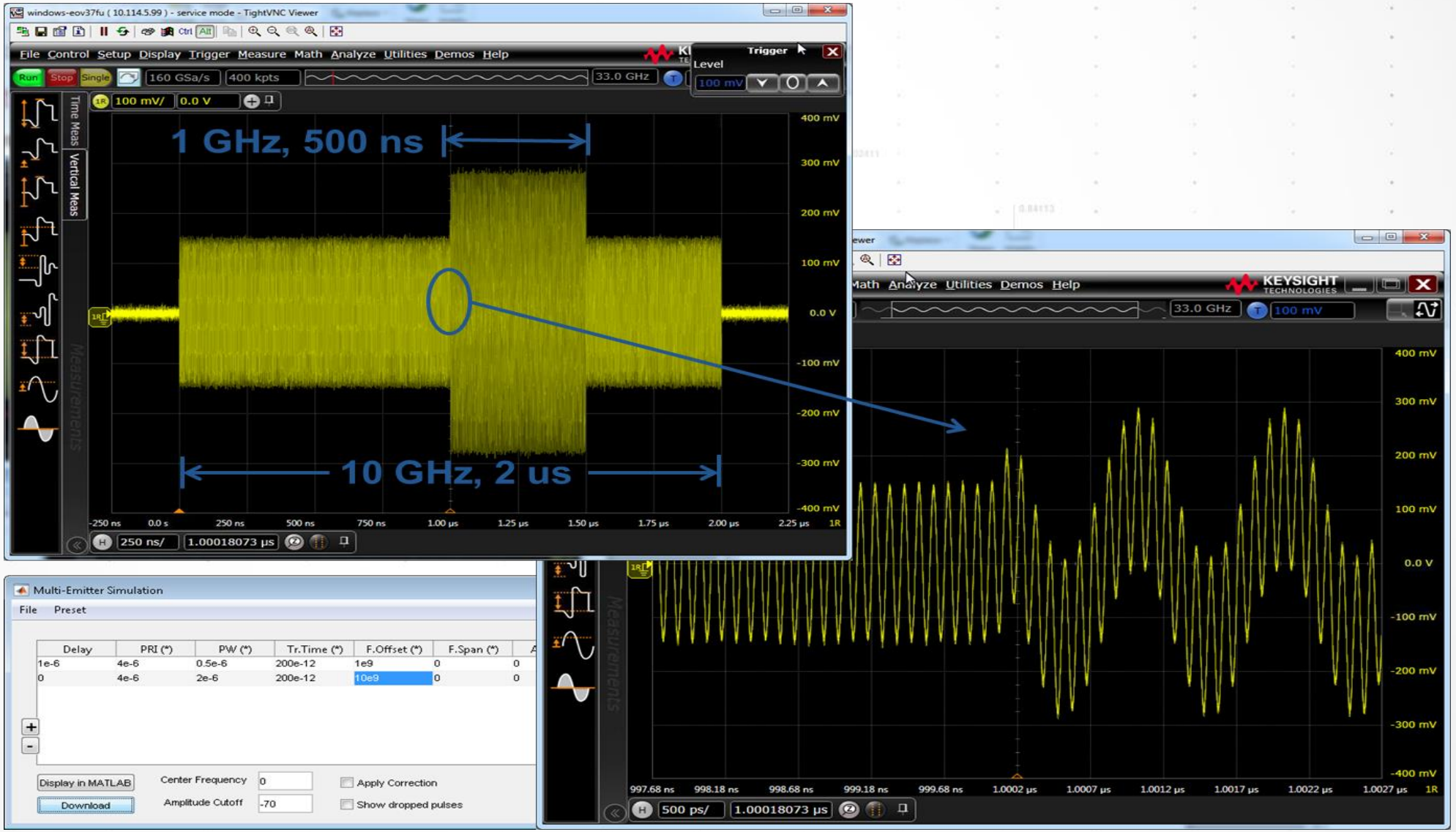
Automotive Radar Development

BENEFITS OF HIGH-SPEED ARBITRARY WAVEFORM GENERATOR

High Speed AWG functionality	Benefit for Radar Testing
Extremely **wide modulation bandwidth** (e.g. DC to 32 GHz)	**Discern targets** that are close together **Finer resolution** of a given object
Instantaneous **frequency hopping** **Overlapping pulses** at different frequencies	**Realistic simulation** of multiple emitters that are transmitting simultaneously
Phase-coherent, **multi-emitter, multi-channel** pulse generation	**Economical setup** to for testing multi-channel radar receivers (e.g. DOA)
Repeatable phase from pulse-to-pulse and channel-to-channel, perfect frequency ramps	**Repeatable** test results
Flexible modulation formats	Develop new modulation schemes that are more **tolerant to interference**
No **images** or **carrier feedthrough.** **Flat magnitude- and phase response** (after calibration)	Testing your device and not the instrument!

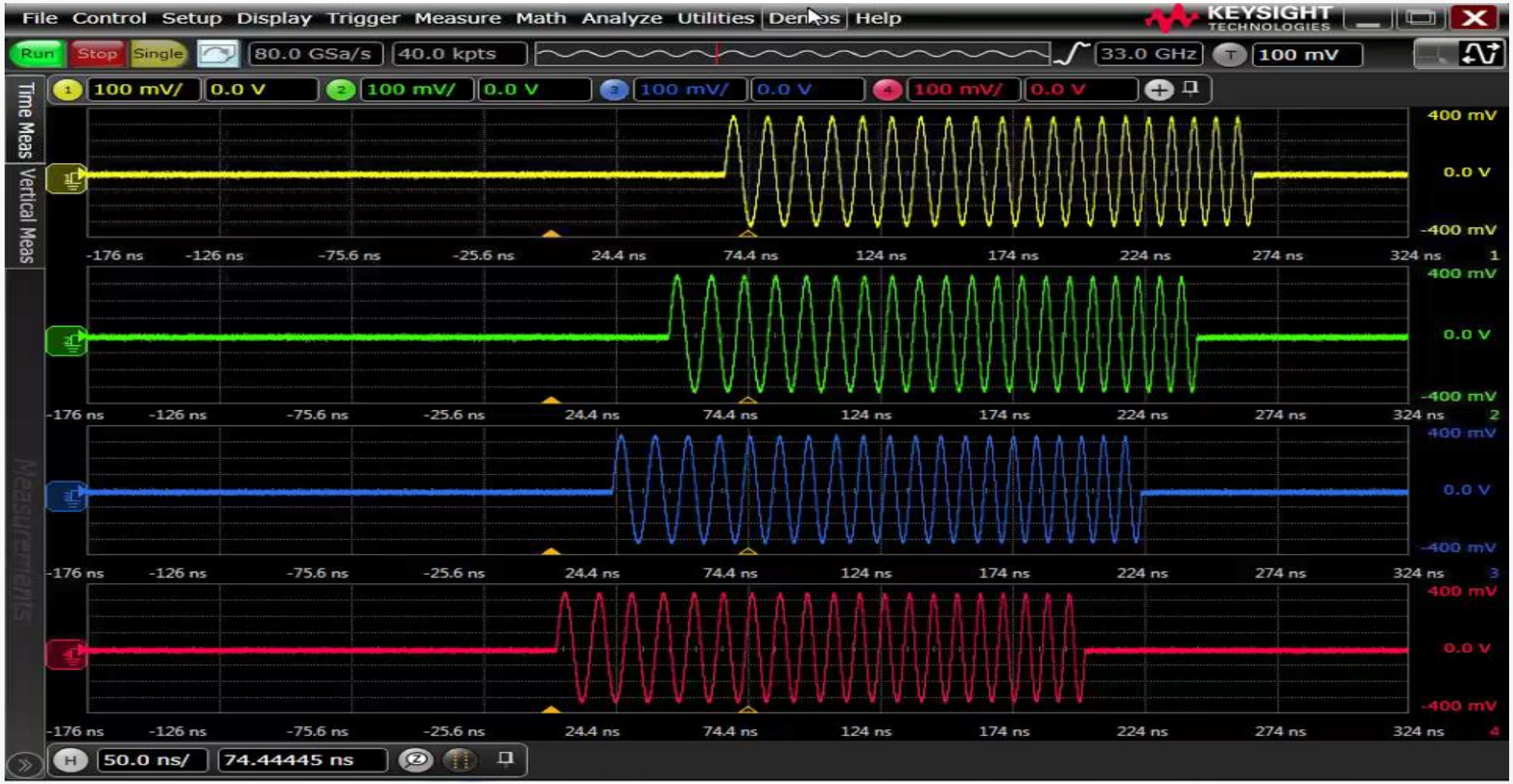
Automotive Radar Development

OVERLAPPING PULSES AT DIFFERENT FREQUENCIES



Automotive Radar Development

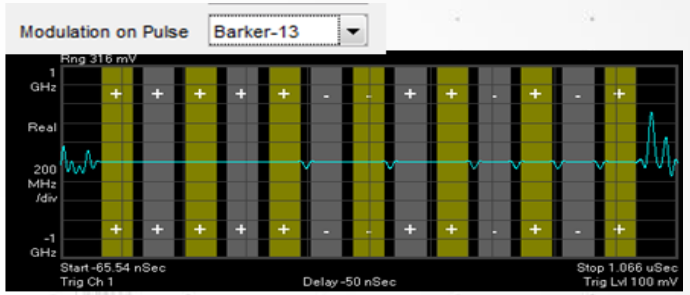
SYNCHRONIZED MULTI-CHANNEL PULSE GENERATION

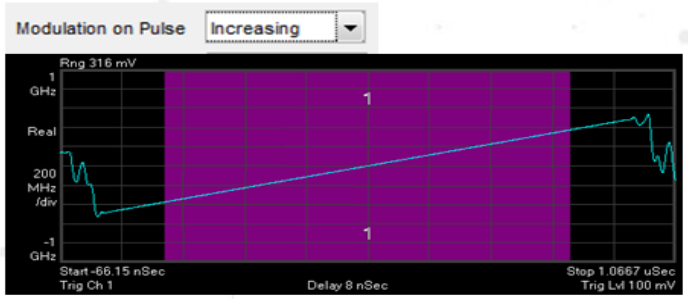


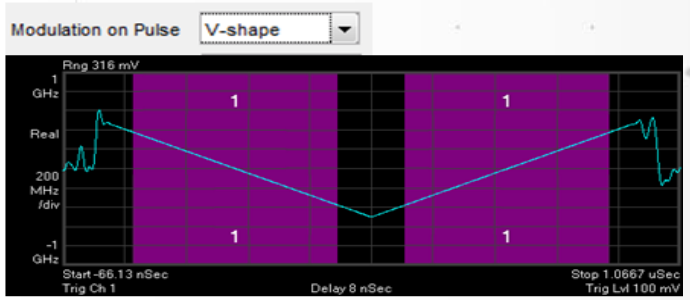
Automotive Radar Development

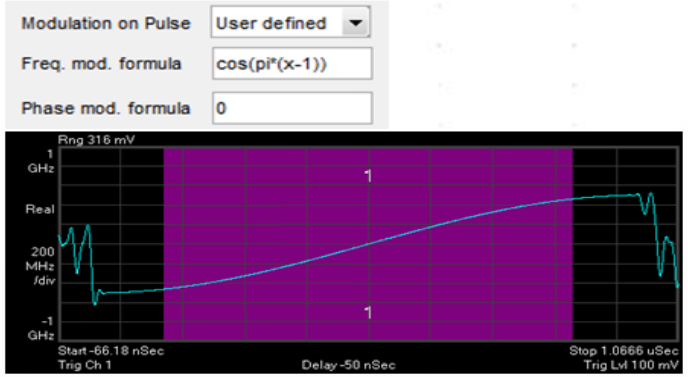
FLEXIBLE MODULATION FORMATS

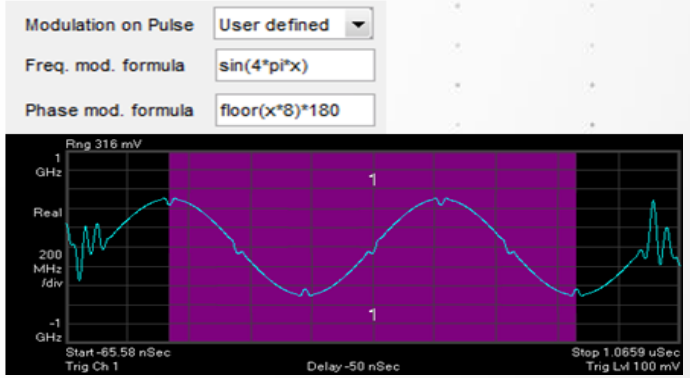
- Any mathematical expression can be used to describe the modulation on the pulse including CW, FMCW, LFM chirp, Barker, non-linear chirp, user-defined frequency- and phase modulation











Automotive Radar Development

INDUSTRY'S MOST POWERFUL AUTOMOTIVE RADAR SIGNAL ANALYSIS

E8740A-060 Performance SA

Key Features

With N9041B UXA

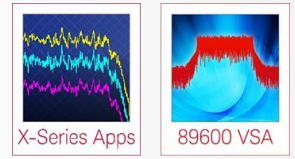
- Continuous Freq sweep 3Hz~ 110GHz
- 5GHz BW (with external oscilloscope)
- Up to 1GHz internal BW with adding opt H1G
- -150dBm/Hz DANL up to 110 GHz
- Dual input rugged 2.4mm and 1mm connector
- 50M RBW with adding opt H1G and opt RBE
- RF Power, Harmonic and spurious, Spectrum Emissions, OBW, Frequency Stability
- Phase Noise with N9068C
- Noise Figure with N9069C and opt P50 at input port 1 (up to 50GHz)

With DSOS804A Scope and VSA s/w

- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV) 4x better resolution than RTO 8 bit ADC
- Analog/Digital I/Q input

Key Measurements

- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality



1st 3 Hz - **110 GHz** Continuous sweeps

1st **5 GHz BW** (with external oscilloscope)

1st Up to **1 GHz internal** BW

1st **-150 dBm/Hz** DANL up to 110 GHz

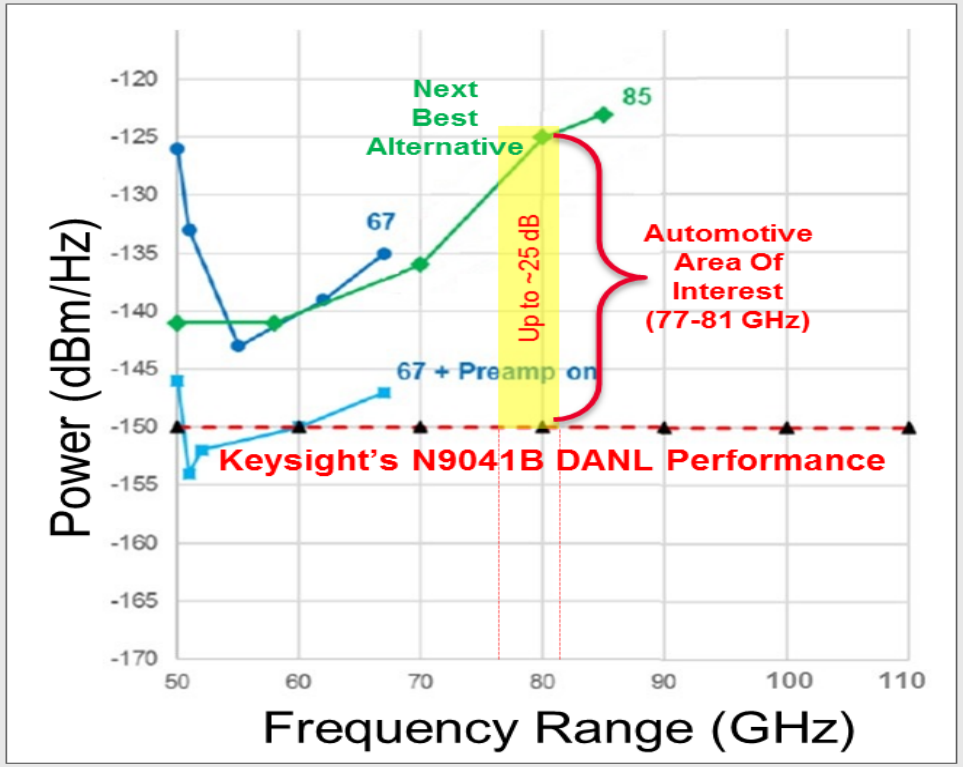
1st Dual input **rugged 2.4 mm** and 1 mm connector

Automotive Radar Development

NEXT BEST ALTERNATIVE FOR DANL AND DYNAMIC RANGE

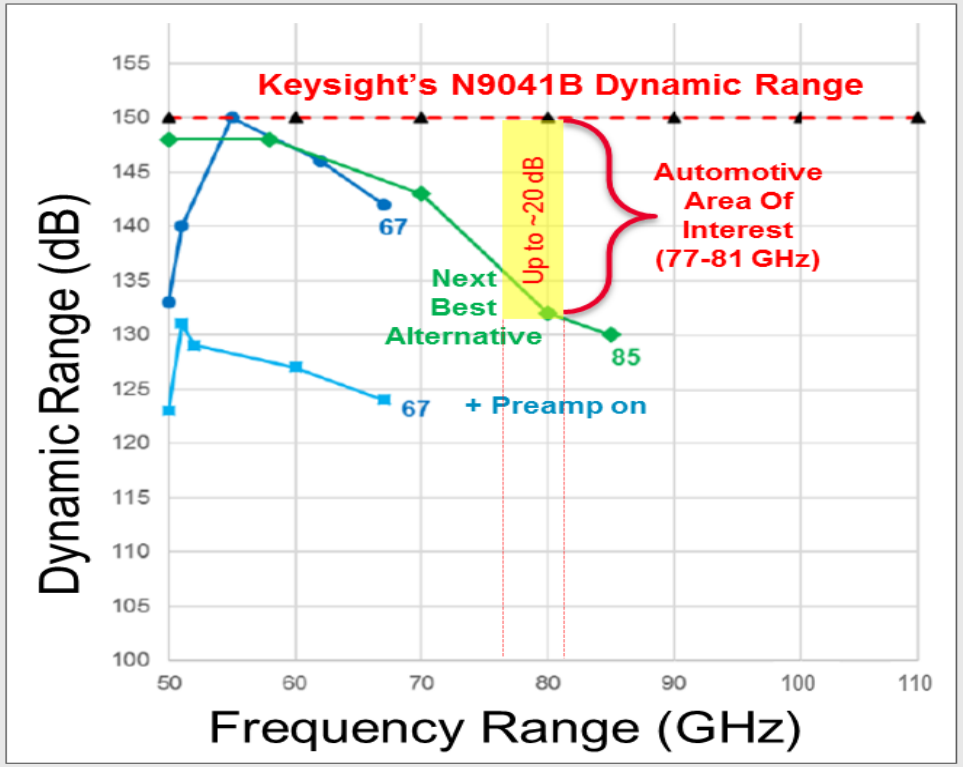
Displayed Average Noise Level (DANL)

Up to ~25 dB better than next best alternative



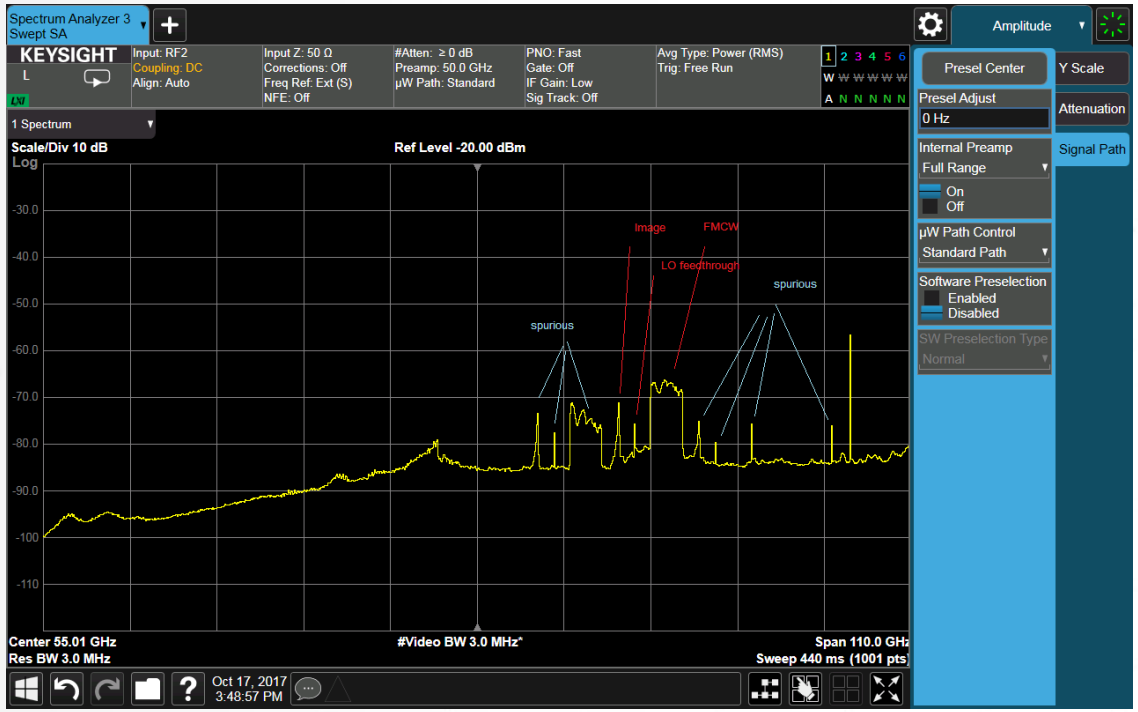
P1 dB to DANL Dynamic Range

Up to ~20 dB better than next best alternative

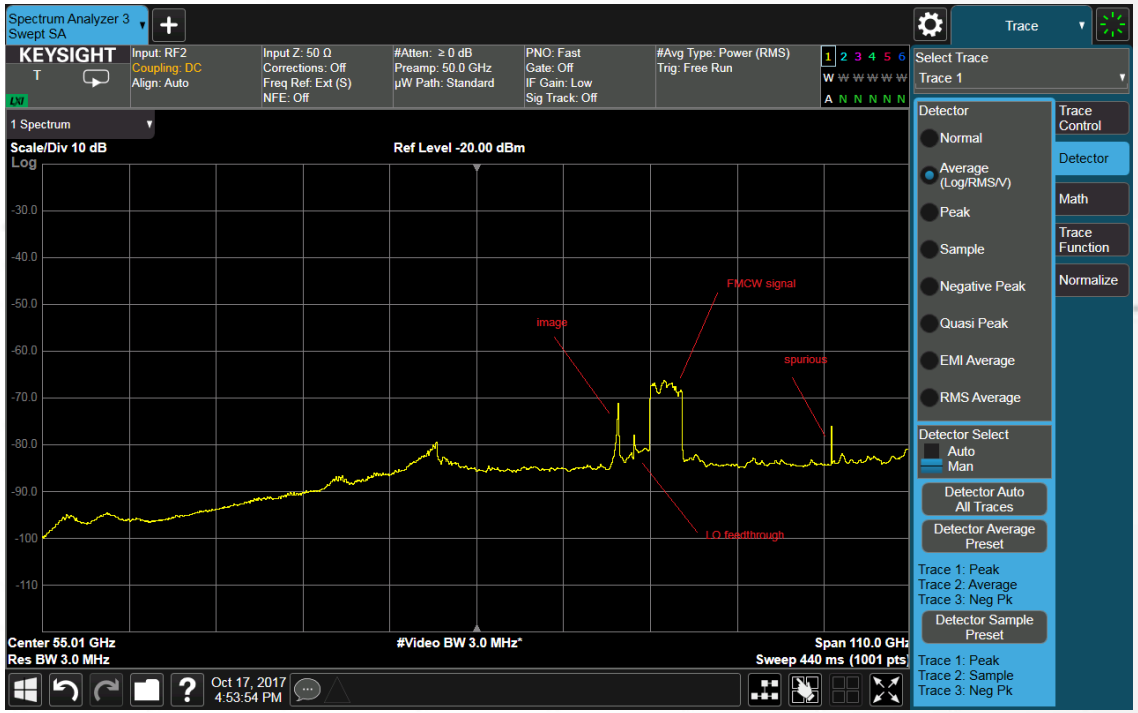


Automotive Radar Development

EFFECT OF SOFTWARE PRE-SELECTOR



FMCW spectrum without software pre-selector



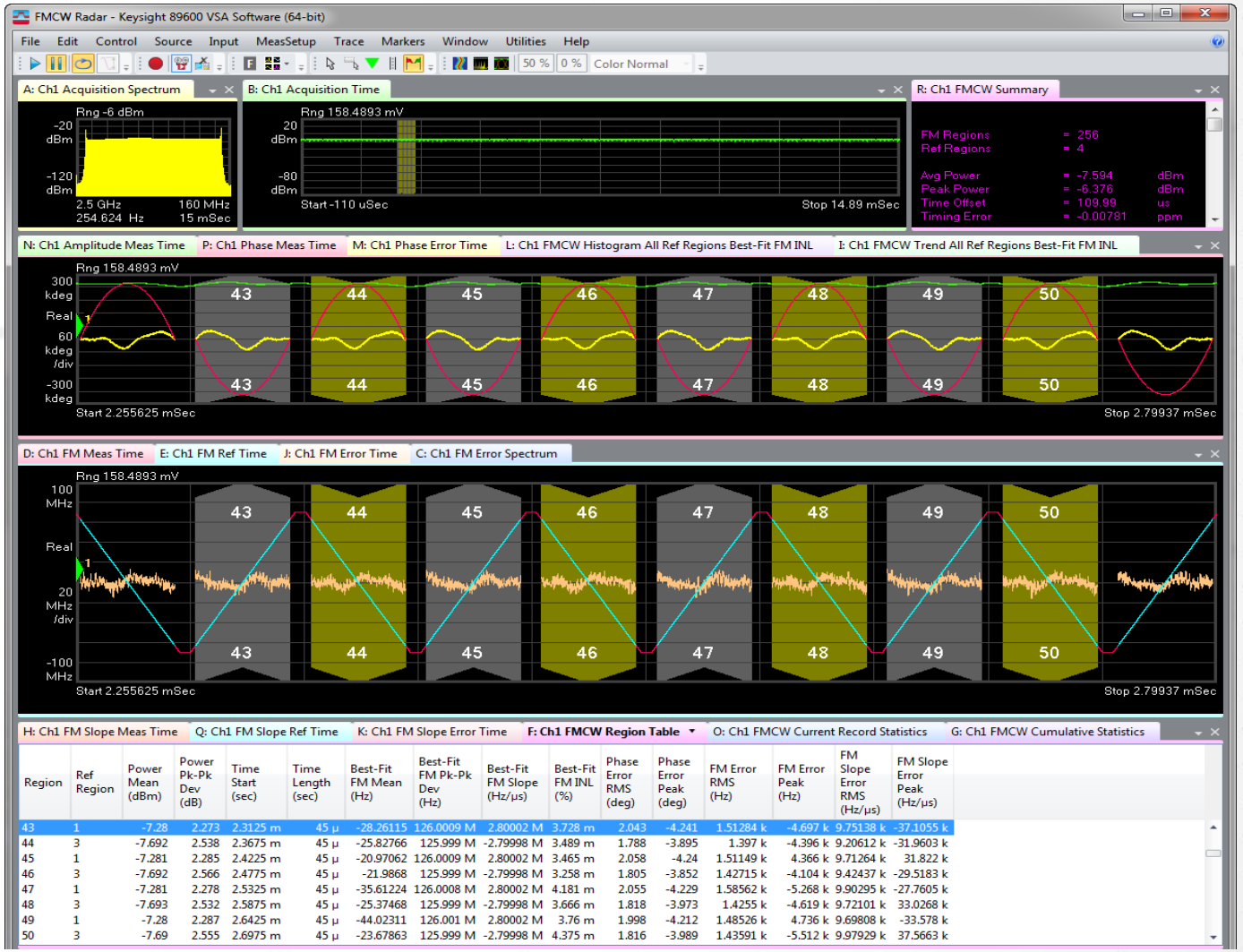
Observed FMCW signal and spectrum with software pre-selector ON

Automotive Radar Development

FLEXIBLE FMCW SIGNAL ANALYSIS IN SPECTRUM & TIME DOMAINS

89600 VSA Key Features:

- **Automatically synchronize** to **FMCW radar signals** comprised of multi-chirp linear FM modulation patterns.
- Synchronized **Amplitude** & **Phase**
- Synchronized **Frequency (FM)** Modulation
- FMCW Region Tabular metrics
  - **Power** and **Time**
  - **Best-Fit FM**
  - **Phase Error**
  - **FM Error**
  - **FM Slope Error**



Region	Ref Region	Power Mean (dBm)	Power Pk-Pk Dev (dB)	Time Start (sec)	Time Length (sec)	Best-Fit FM Mean (Hz)	Best-Fit FM Pk-Pk Dev (Hz)	Best-Fit FM Slope (Hz/µs)	Best-Fit FM INL (%)	Phase Error RMS (deg)	Phase Error Peak (deg)	FM Error RMS (Hz)	FM Error Peak (Hz)	FM Slope Error RMS (Hz/µs)	FM Slope Error Peak (Hz/µs)
43	1	-7.28	2.273	2.3125 m	45 µ	-28.26115	126.0009 M	2.80002 M	3.728 m	2.043	-4.241	1.51284 k	-4.697 k	9.75138 k	-37.1055 k
44	3	-7.692	2.538	2.3675 m	45 µ	-25.82766	125.999 M	-2.79998 M	3.489 m	1.788	-3.895	1.397 k	-4.396 k	9.20612 k	-31.9603 k
45	1	-7.281	2.285	2.4225 m	45 µ	-20.97062	126.0009 M	2.80002 M	3.465 m	2.058	-4.24	1.51149 k	4.366 k	9.71264 k	31.822 k
46	3	-7.692	2.566	2.4775 m	45 µ	-21.9868	125.999 M	-2.79998 M	3.258 m	1.805	-3.852	1.42715 k	-4.104 k	9.42437 k	-29.5183 k
47	1	-7.281	2.278	2.5325 m	45 µ	-35.61224	126.0008 M	2.80002 M	4.181 m	2.055	-4.229	1.58562 k	-5.268 k	9.90295 k	-27.7605 k
48	3	-7.693	2.532	2.5875 m	45 µ	-25.37468	125.999 M	-2.79998 M	3.666 m	1.818	-3.973	1.4255 k	-4.619 k	9.72101 k	33.0268 k
49	1	-7.28	2.287	2.6425 m	45 µ	-44.02311	126.001 M	2.80002 M	3.76 m	1.998	-4.212	1.48526 k	4.736 k	9.69808 k	-33.578 k
50	3	-7.69	2.555	2.6975 m	45 µ	-23.67863	125.999 M	-2.79998 M	4.375 m	1.816	-3.989	1.43591 k	-5.512 k	9.97929 k	37.5663 k

E8740A Automotive Radar Signal Analysis and Generation Solution

>5GHZ BW & UP TO 110GHZ SIGNAL ANALYSIS AND GENERATION

Introducing E8740A Automotive Radar Solution

INDUSTRY'S UNIQUE >5GHZ UP TO 110GHZ SIGNAL ANALYSIS AND FLEXIBLE SIGNAL GENERATION

Signal Analysis Solution

E8740A-010
Radar RF SA
Leading cost effective Auto Radar RF test tool

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- FMCW RF analysis

E8740A-020,030
Basic, Basic Plus SA
Optimum choice for Auto radar signal quality test

- 60 GHz to 90 GHz,
- 2.5 GHz BW, >5GHz BW (Basic +) for FMCW Quality analysis

E8740A-040,050
Advanced, Advanced Plus SA
Benchmark for demanding applications

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- 2.5 GHz BW , >5GHz BW (Advanced +) for FMCW Quality analysis

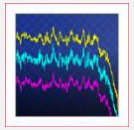
E8740A-060
Performance SA
Wide-open performance

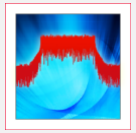
- 3 Hz to 110 GHz
- >5 GHz BW for FMCW Quality analysis
- DANL-171dBm/Hz@1GHz, -150dBm/Hz up to 110GHz
- 2.4 mm, 1 mm input

X-Series applications
Ready-to-use RF measurements

89600 VSA software
Comprehensive demodulation & vector signal analysis

FMCW Radar Analysis Assistant
E8742A-001 Easy U/I for Downconverter set up and FMCW analysis (VSA utility)





Signal Generation Solution

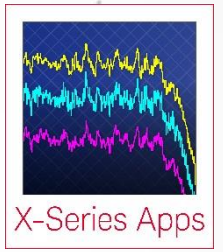
E8740A-070
Performance SG
Wide-open performance

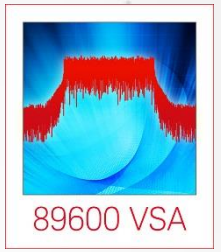
- 60 GHz to 90 GHz
- >5 GHz 3dB BW
- FM, PM, FMCW, pulse sequence, MFSK, customer OFDM
- Linear FMCW Multi-Targets Detection, Automotive radar 3D Scan with systemVue

SystemVue
W1908 Auto radar library measurements
Signal Studio
N7608C Pulse/FCM/FMCW/MFSK signal creation
FMCW Radar Generation Assistant
E8742A-002 Easy U/I for Upconverter set up, FMCW/FCM signal creation and wideband calibration (IQTools utility)

The New N9041B UXA Signal Analyzer, 110 GHz

"SEE THE WHOLE PICTURE" TO 110 GHZ





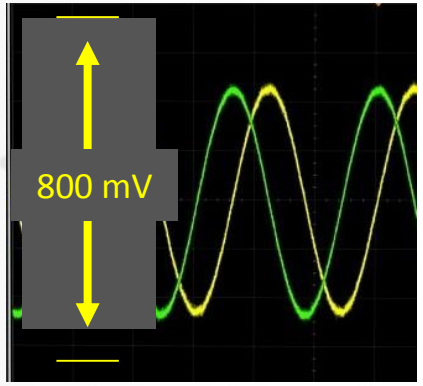
- 1st — 3 Hz - **110 GHz** Continuous sweeps
- 1st — **5 GHz BW** (with external oscilloscope)
- 1st — Up to **1 GHz internal** BW
- 1st — **-150 dBm/Hz** DANL up to 110 GHz
- 1st — Dual input **rugged 2.4 mm** and 1 mm connector

Infiniium S-Series

THE NEW STANDARD FOR SUPERIOR MEASUREMENTS

- Industry's Best Signal Integrity
  - 10-Bit ADC
    4X More Resolution vs 8-Bit Scopes

65 nm CMOS ADC with
130 nm Bi-CMOS buffer IC



Traditional Scope
- 8 bits of vertical resolution
- 2^8 = 256 Q levels

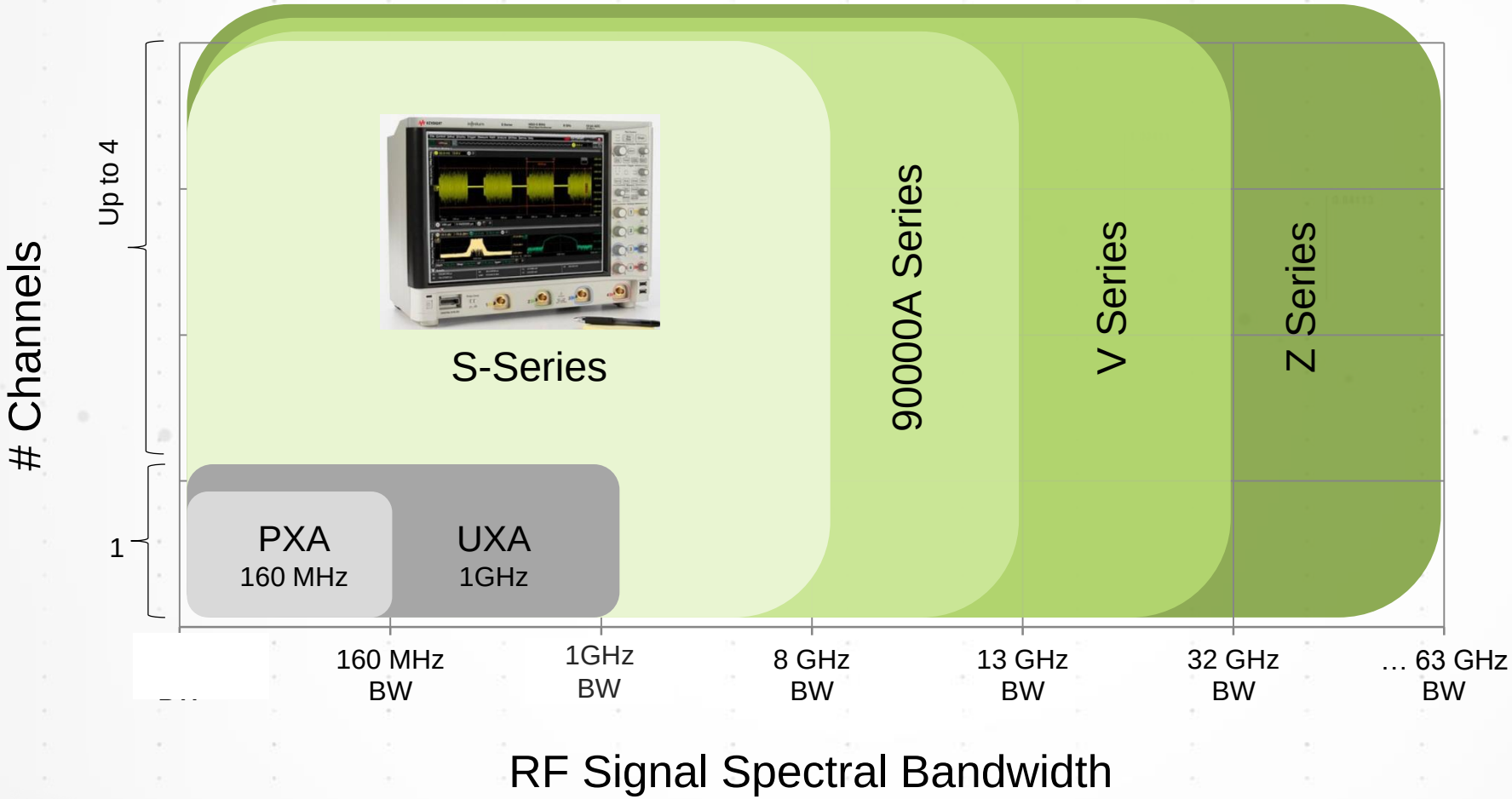
3.125 mV

S Series ADC
- 10 bits of vertical resolution
- 2^{10} =1024 Q levels

0.781 mV

Minimum resolution
@ 800 mV full screen

S-Series for RF Measurements

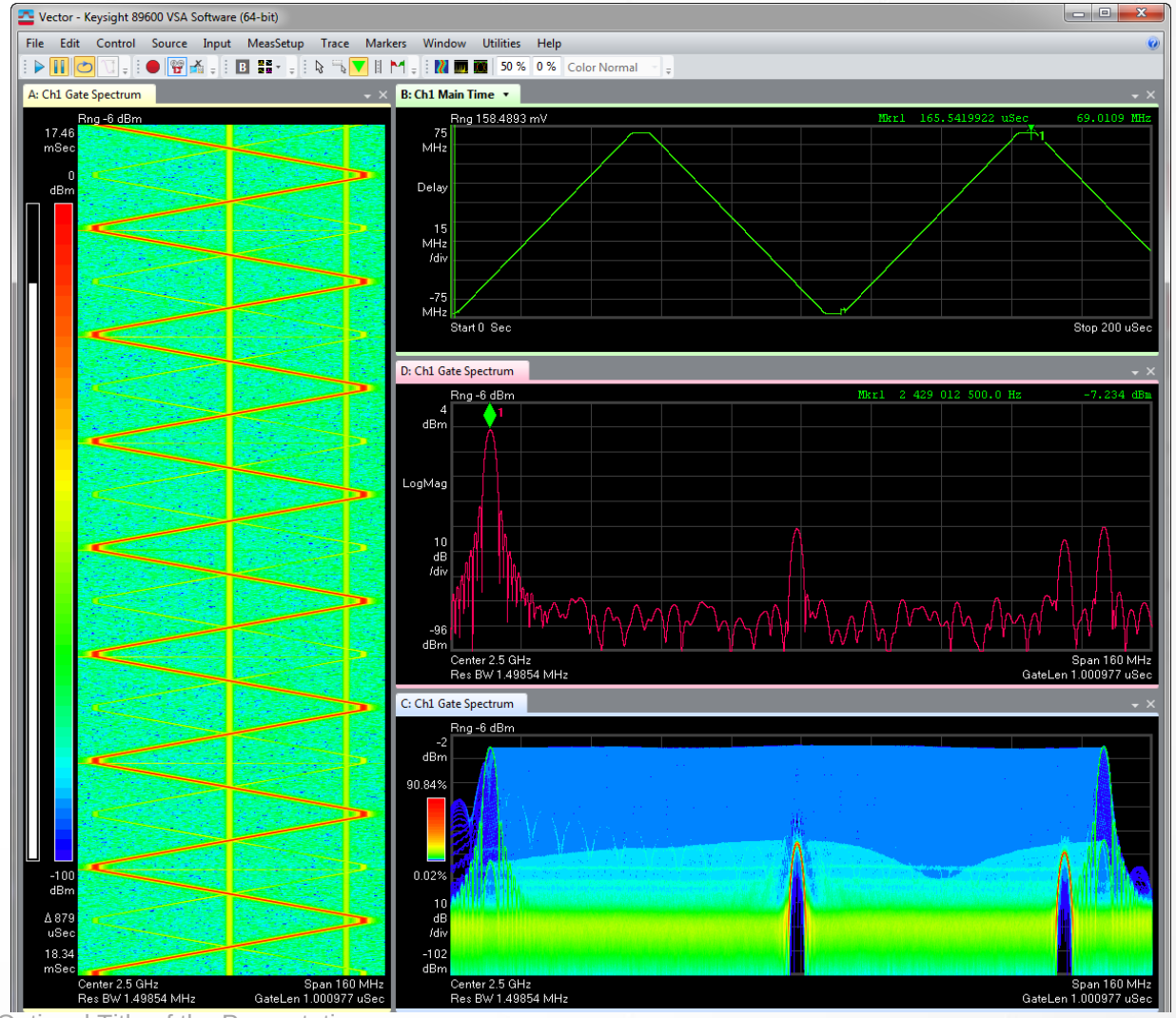


Automotive Radar – Signal Analysis - Modulation

89601B VSA OPTION BHP - FMCW RADAR ANALYSIS

Key Features:

- Supports over 40 Keysight measurement platforms including
  - X-Series Signal Analyzers
  - Infiniium Oscilloscopes
  - Modular digitizers
- Solution is **bandwidth scalable**
- Signal **Record / Playback** support
- Visualize dynamic signal time and frequency characteristics using displays :
  - **RF Spectrum**
  - **Spectrogram**
  - **Persistence**
  - **Cumulative History**



For more information: www.keysight.com/find/89601B and 89601B Opt BHP - FMCW Radar Analysis

FMCW Analysis in Spectrum & Time Domains

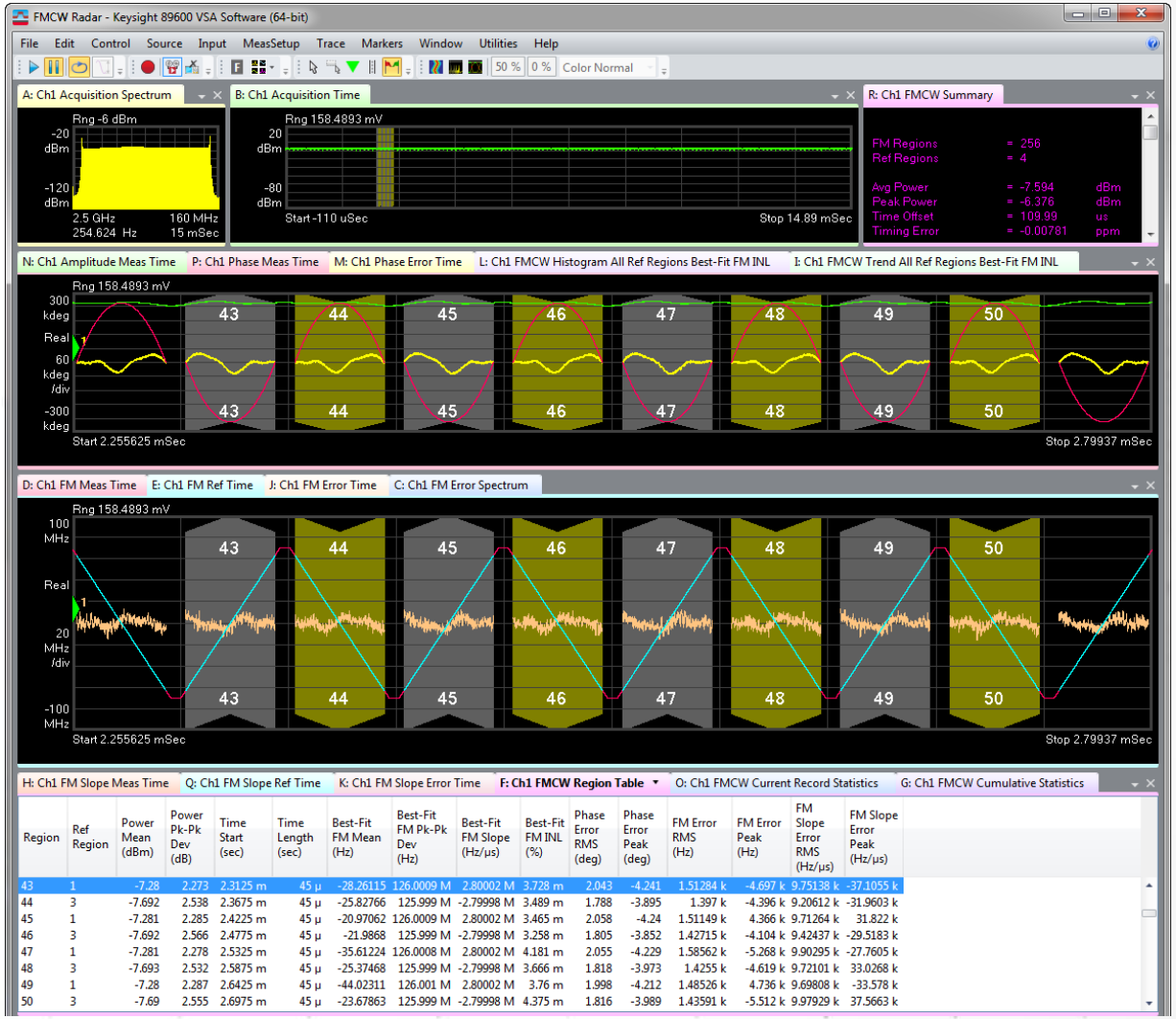
Key Features:

- **Automatically synchronize** to **FMCW radar signals** comprised of multi-chirp linear FM modulation patterns.

- Synchronized **Amplitude** & **Phase** ➔

- Synchronized **Frequency (FM)** Modulation ➔

- FMCW Region Tabular metrics ➔
  - **Power** and **Time**
  - **Best-Fit FM**
  - **Phase Error**
  - **FM Error**
  - **FM Slope Error**



Region	Ref Region	Power Mean (dBm)	Power Pk-Pk Dev (dB)	Time Start (sec)	Time Length (sec)	Best-Fit FM Mean (Hz)	Best-Fit FM Pk-Pk Dev (Hz)	Best-Fit FM Slope (Hz/µs)	Best-Fit FM INL (%)	Phase Error RMS (deg)	Phase Error Peak (deg)	FM Error RMS (Hz)	FM Error Peak (Hz)	FM Slope Error RMS (Hz/µs)	FM Slope Error Peak (Hz/µs)
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49	1	-7.28	2.287	2.6425 m	45 µ	-44.02311	126.001 M	2.80002 M	3.76 m	1.998	-4.212	1.48526 k	4.736 k	9.69808 k	-33.578 k
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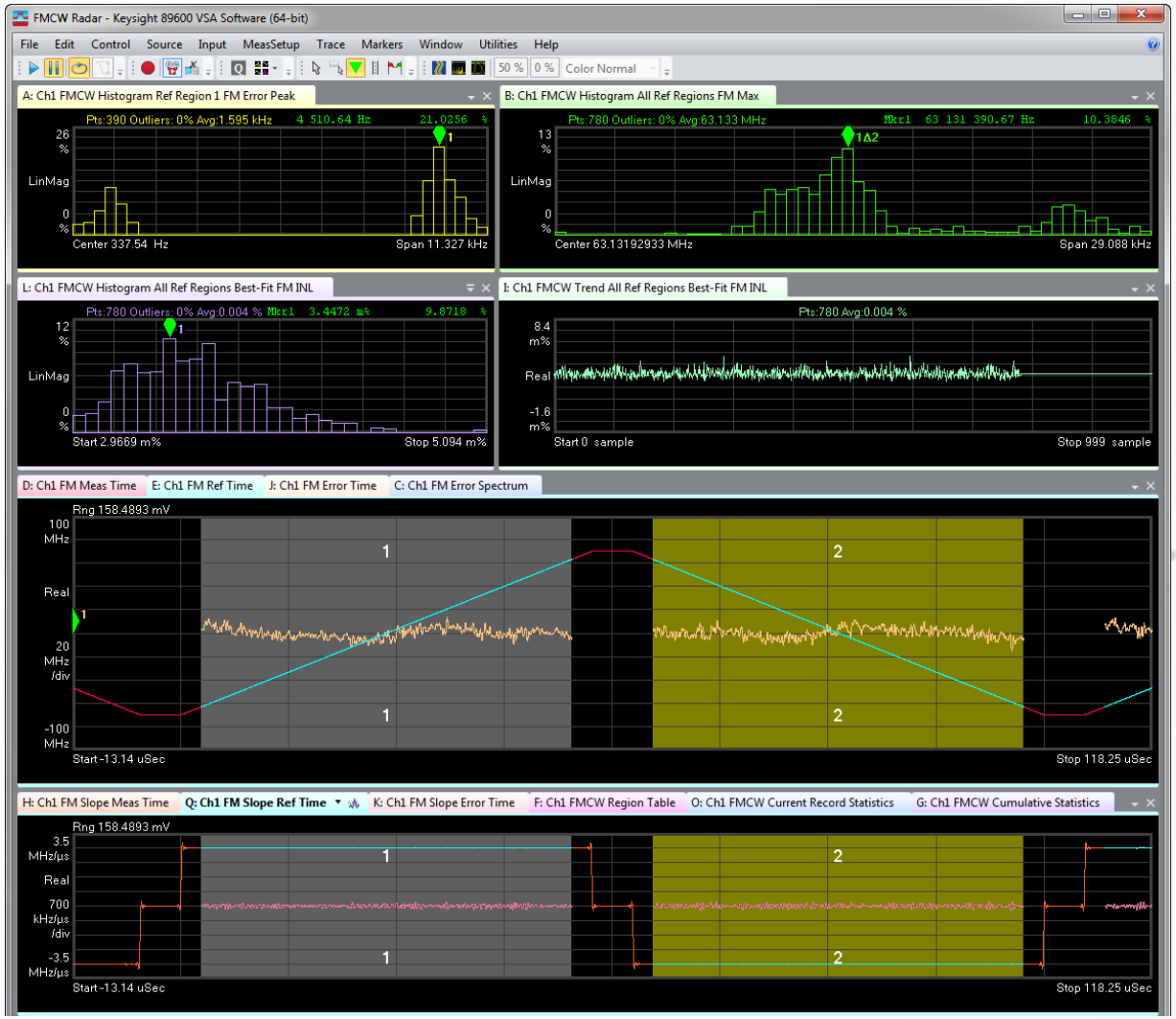
FMCW Analysis Statistics

Key Features:

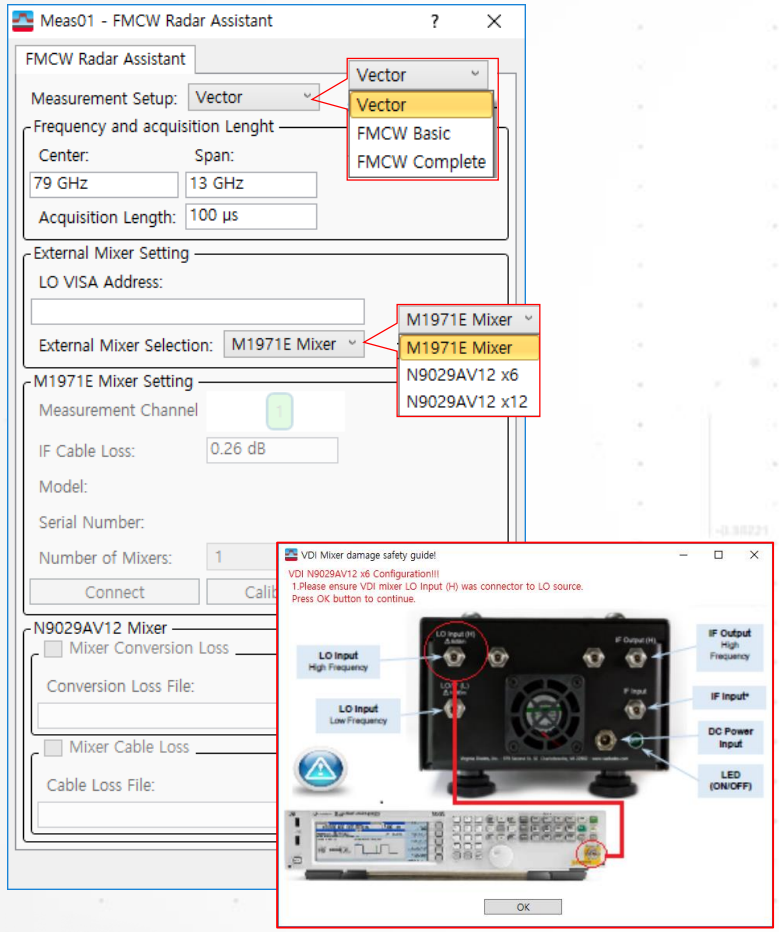
- View statistical performance data for all supported result metrics using
  - **Histograms** ➔
  - **Trend Lines** ➔
- Select specific modulation regions to analyse in detail using time synchronized trace overlays : ➔
  - **FM Measured** (red)
  - **FM Reference** (blue)
  - **FM Error** (yellow)
- Similarly examine chirp rates: ➔
  - **FM Slope Measured**
  - **FM Slope Reference**
  - **FM Slope Error**



FMCW Assistant Utility

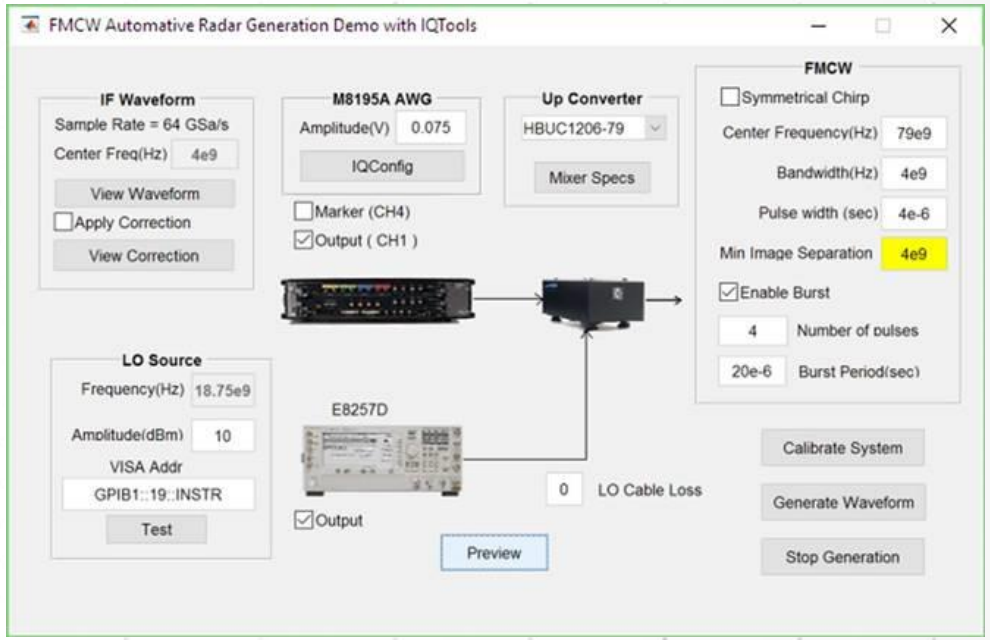
E8742A-001 FMCW Radar Analysis Assistant

Easy U/I for Downconverter set up and FMCW analysis (VSA utility)



E8742A-002 FMCW Radar Generation Assistant

Easy U/I for Upconverter set up, FMCW/FCM signal creation and wideband calibration (IQTools utility)



Automotive Radar Signal Analysis

E8740A-060 PERFORMANCE SA

Key Features

With N9041B UXA

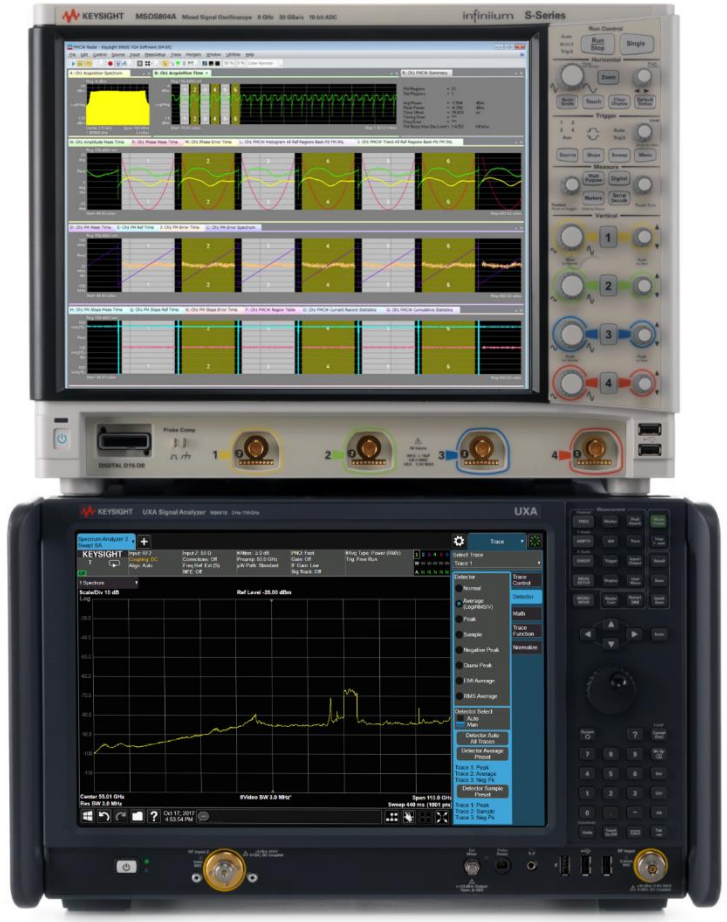
- Continuous Freq sweep 3Hz~ 110GHz
- 5GHz BW (with external oscilloscope)
- Up to 1GHz internal BW with adding opt H1G
- -150dBm/Hz DANL up to 110 GHz
- Dual input rugged 2.4mm and 1mm connector
- 50M RBW with adding opt H1G and opt RBE
- RF Power, Harmonic and spurious, Spectrum Emissions, OBW, Frequency Stability
- Phase Noise with N9068C
- Noise Figure with N9069C and opt P50 at input port 1 (up to 50GHz)

With DSOS804A Scope and VSA s/w

- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV) 4x better resolution than RTO 8 bit ADC
- Analog/Digital I/Q input

Key Measurements

- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality



Automotive Radar Signal Analysis

E8740A-050 ADVANCED PLUS SA

Key Features

With N9020B MXA and N9029AV12

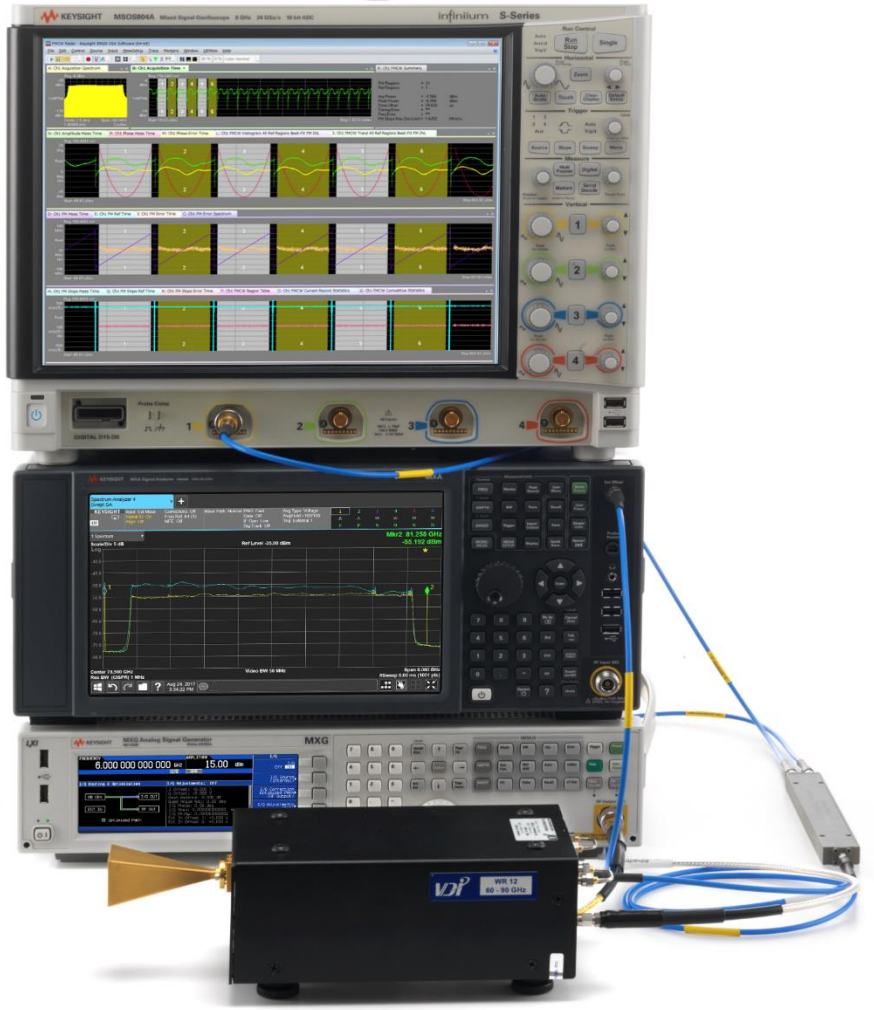
- 24GHz radar test with opt CR3 for 410MHz BW (with external oscilloscope)
- 77GHz and 79GHz radar test for >5GHz BW
- Freq trigger mask triggering with N9067C pulse application and VSA s/w with opt B85~B1X, FT1/FT2
- 50M RBW with opt B85,B1A and B1X and opt RBE

With DSOS604A Scope and VSA s/w

- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV) 4x better resolution than RTO 8 bit ADC
- Analog/Digital I/Q input
- Modulation Quality, FMCW analysis with VSA opt BHP, Linearity ,……

Key Measurements

- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality



Automotive Radar Signal Analysis

E8740A-040 ADVANCED SA

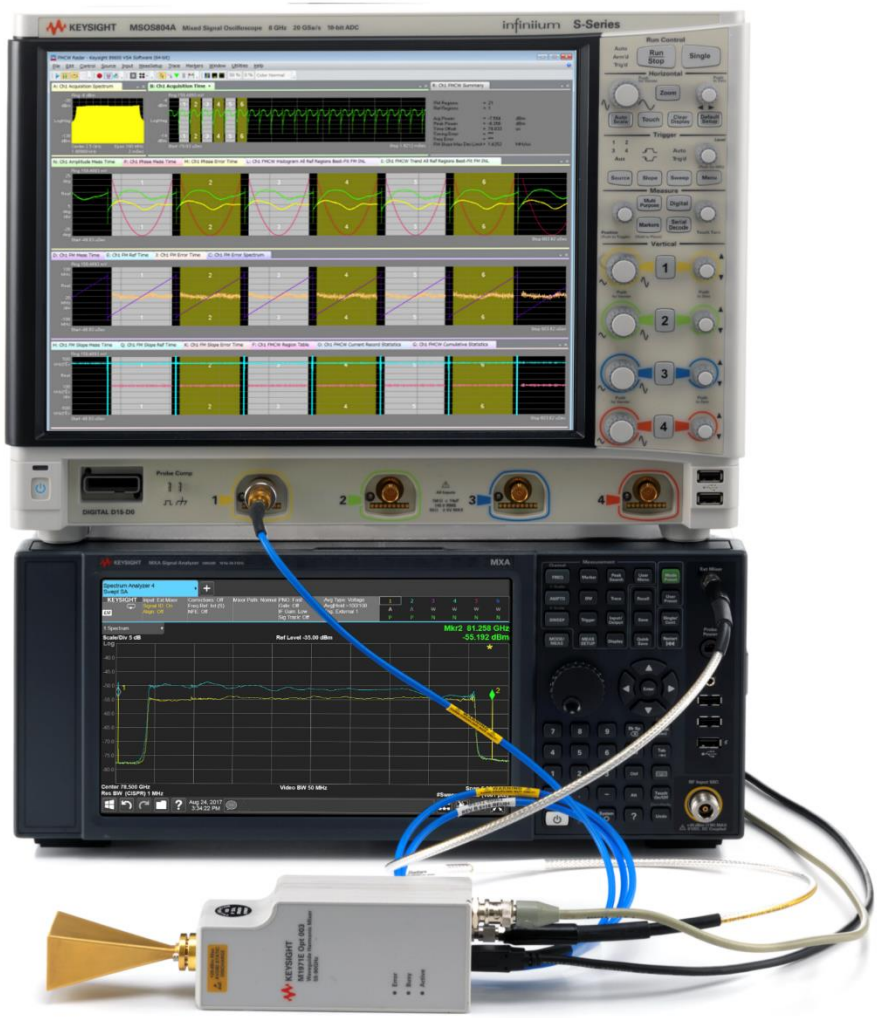
Key Features

With N9020B MXA and M1971E

- 24GHz radar test with opt CR3 for 410MHz BW (with external oscilloscope)
- 77GHz and 79GHz radar test for 2.5GHz BW
- Freq trigger mask triggering with N9067C pulse application and VSA s/w with opt B85~B1X, FT1/FT2
- 50M RBW with opt B85,B1A and B1X and opt RBE

With DSOS604A Scope and VSA s/w

- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV) 4x better resolution than RTO 8 bit ADC
- Analog/Digital I/Q input
- Modulation Quality, FMCW analysis with VSA opt BHP, Linearity ,……



Key Measurements

- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality

Automotive Radar Signal Analysis

E8740A-030 BASIC PLUS SA

Key Features

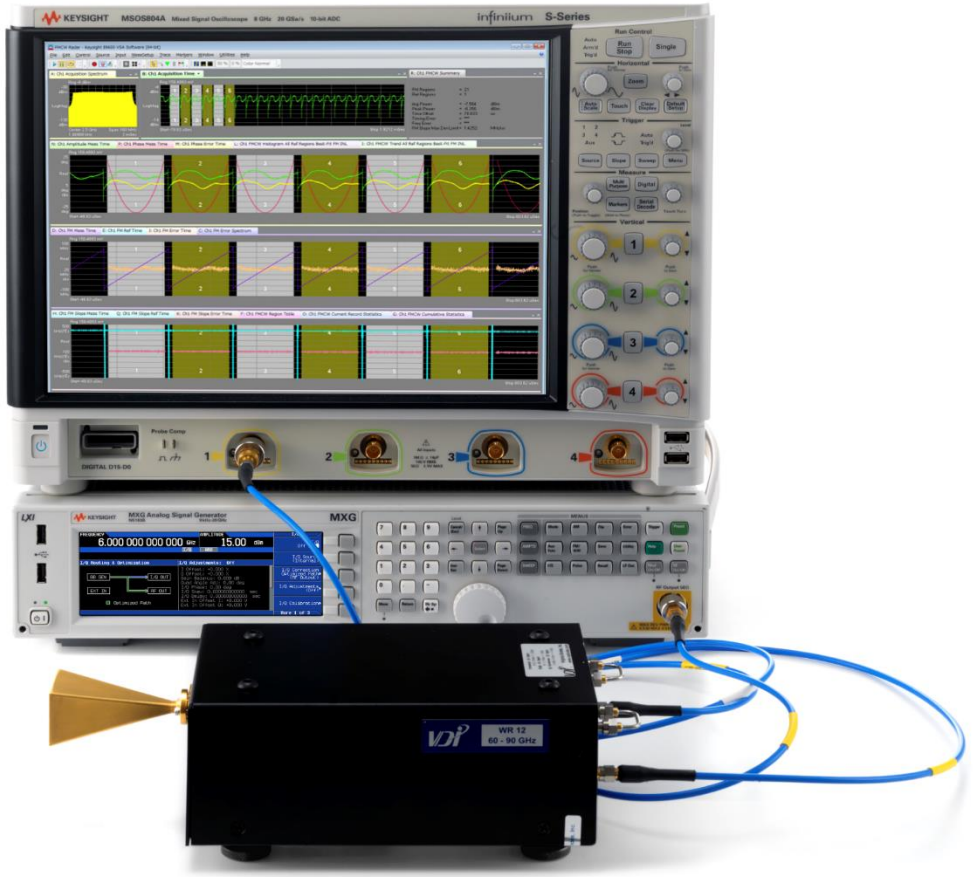
- Lower Cost and Simpler Setup
- A simple user interface to provide confidence in measurement

With DSOS604A and N9029AV12

- Continuous Freq sweep 60~90GHz with N9029AV12
- >5GHz BW thru AUX port of M1971E
- -135dBm/Hz DANL@E-band with N9029AV12
- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV)
  4x better resolution than RTO 8 bit ADC
- RF Power, Harmonic and spurious, Spectrum Emissions, OBW
- Phase Noise
- Analog/Digital I/Q input
- Modulation Quality, FMCW analysis with VSA opt BHP, Linearity ,……

Key Measurements

- RF Power
- Spectrum Emissions
- Phase Noise
- Frequency Stability
- Modulation Quality



Automotive Radar Signal Analysis

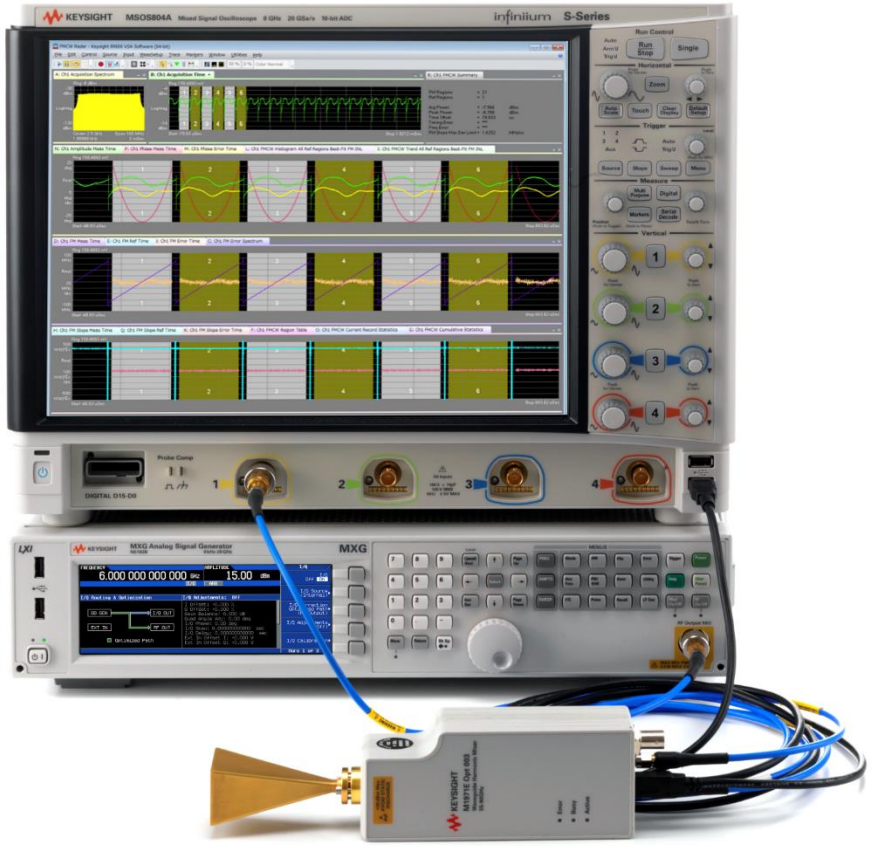
E8740A-020 BASIC SA

Key Features

- Lower Cost and Simpler Setup
- Expand to simultaneous 2 channel analysis with 2 M1971E mixers at same frequency
- A simple user interface to provide confidence in measurement

With DSOS604A and M1971E

- Continuous Freq sweep 60~90GHz with M1971E
- 2.5GHz BW thru AUX port of M1971E
- -139dBm/Hz DANL@E-band with M1971E dual conversion mode
- 10 Bit ADC up to 8GHz bandwidth with minimum resolution : 0.781 mV) 4x better resolution than RTO 8 bit ADC
- RF Power, Harmonic and spurious, Spectrum Emissions, OBW
- Phase Noise
- Analog/Digital I/Q input
- Modulation Quality, FMCW analysis with VSA opt BHP, Linearity ,……



Key Measurements

- RF Power
- Frequency Stability
- Modulation Quality

Automotive Radar Signal Analysis

E8740A-010 RADAR RF SA

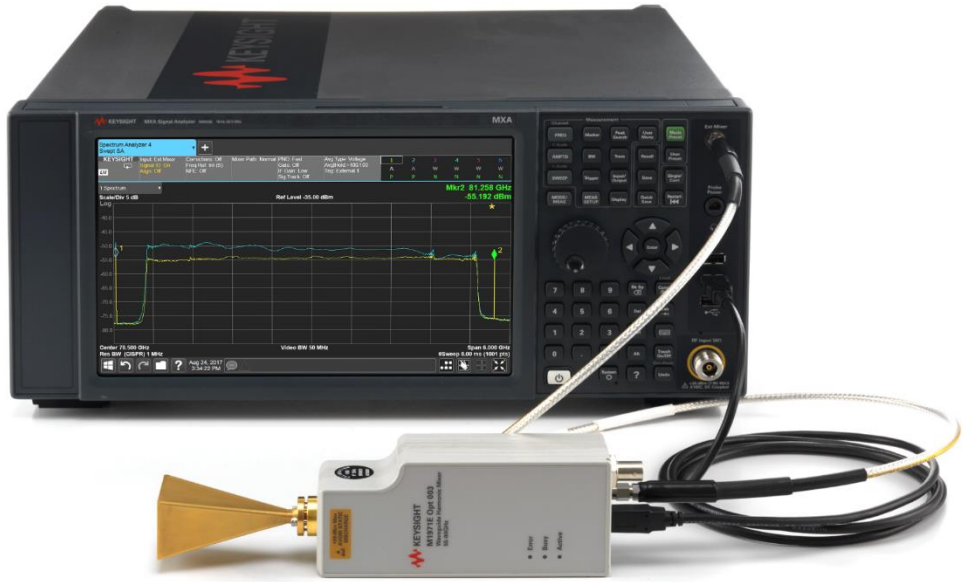
Key Features

With N9020B MXA and M1971E

- Continuous Freq sweep 3Hz~ 26.5GHz, 60~90GHz with M1971E
- 85MHz internal BW with opt B85 (upgradable to 160MHz with B1X)
- Phase noise@1GHz(10kHz offset) -114dBc/Hz
- -166dBm/Hz DANL@1GHz, -139dBm/Hz DANL@E-band with M1971E
- 50M RBW with opt B85,B1A and B1X and opt RBE
- RF Power, Harmonic and spurious, Spectrum Emissions, OBW, Frequency Stability
- Phase Noise with N9068C
- Noise Figure with N9069C and opt P50

Key Measurements

- RF Power
- Spectrum Emissions (up to 26.5GHz)



Signal Analysis Solution Spec comparison

AUTOMOTIVE RADAR SIGNAL ANALYSIS

	RADAR RF	BASIC	BASIC +	ADVANCED	ADVANCED +	PERFORMANCE
Optimal for Radar Application	RF test. In-band RF measurements for transmitter systems.	RF test(FFT) and FMCW signal Quality. In-band measurements for transmitter systems.	RF test(FFT) and FMCW signal Quality In-band measurements for transmitter systems.	RF test and FMCW signal Quality In-band measurements for transmitter systems.	RF test and FMCW signal Quality In-band measurements for transmitter systems.	RF test and FMCW signal Quality In-band measurements & Out-of-band measurements SEM, ACLR
Frequency Range	3Hz ~ 26.5GHz, 60GHz ~ 90GHz	~6GHz, 60GHz ~ 90GHz	~6GHz, 60GHz ~ 90GHz	3Hz ~ 26.5GHz, 60GHz ~ 90GHz	3Hz ~ 26.5GHz, 60GHz ~ 90GHz	3Hz~ 110GHz
Analysis BW	-	2.5 GHz(3dB BW) using M1971E AUX path mode with Scope	3.5 GHz(3dB BW) *Measurement bandwidth can be extended to 5 GHz with correction.	2.5 GHz(3dB BW) using M1971E AUX path mode with Scope	3.5 GHz(3dB BW) *Measurement bandwidth can be extended to 5 GHz with correction.	1GHz(Integrated) > 5 GHz (w Scope)
DANL/Noise Floor	-165 dBm/Hz at 1 GHz -139 dBm/Hz at 77 GHz, typical	(Noise Floor) -126 dBm/Hz at 76~81 GHz (using M1971E AUX path mode with DSO scope)	(Noise Floor) -135 dBm/Hz at 76~81 GHz	N9020B (DANL) -166 dBm / Hz at 1 GHz -139 dBm/Hz at 76 GHz DSOS604A (Noise floor) -126 dBm/Hz at 76~81 GHz	N9020B (DANL) -166 dBm/Hz at 1 GHz -140 dBm/Hz at 76 GHz DSOS604A (Noise Floor) -135 dBm/Hz at 76 GHz	DANL -174 dBm 20 MHz~3.6 GHz (Preamp On with Opt NF2), -149 dBm 55 GHz to 70 GHz -144 dBm 70 GHz to 82 GHz

Flexible connectivity of 89600 VSA

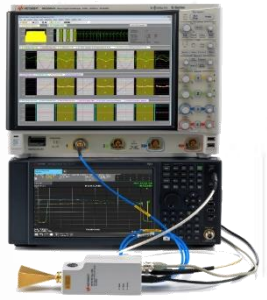
89600 VSA

CHOOSE WITH TEST CONDITIONS OF FREQUENCY & BANDWIDTH

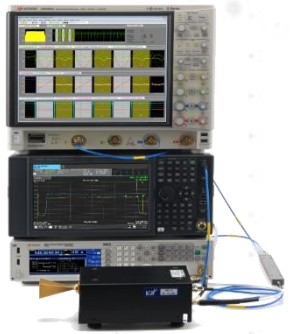
Frequency

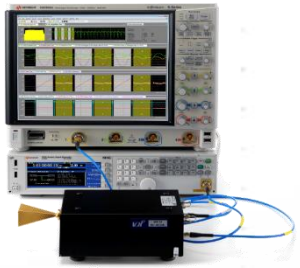
110G

26.5G



UXA N9041B





2.5G

M1971E Smart Mixer

>5G

N9029AV12 mmWave Freq Extender

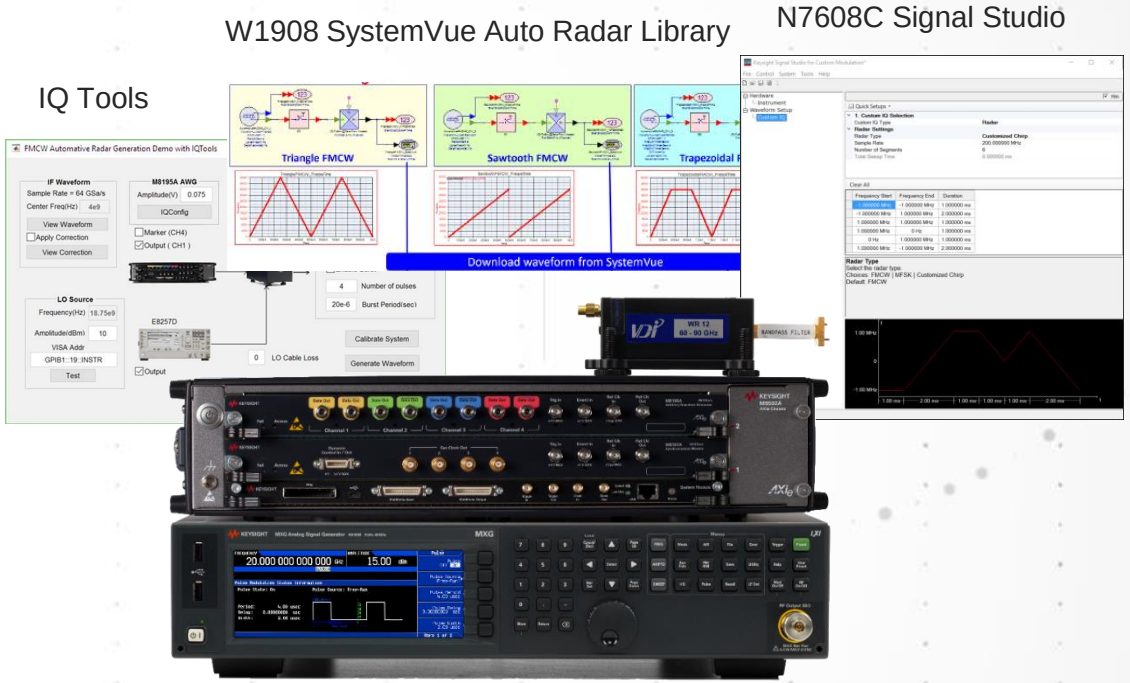
Bandwidth

Automotive Radar Signal Generation

FLEXIBLE AND COMPLEX MODULATION SIGNAL GENERATION

Parameters	E8740A-070 Performance SG
Frequency Range	DC to 25GHz, 60GHz to 90GHz
Signal Bandwidth for IF/RF	IF/RF up to 25GHz
3dB Bandwidth for mmW	5GHz for FMCW @ 79GHz Fc (with correction)
Pout1dB	-14.6dBm@76GHz -13.5dBm@79GHz
Amplitude flatness (at SMA connector,* compensated for sin(x)/x)	±2 dB (typ), fout= DC to 10 GHz +2 dB, -3 dB (typ), fout = 10 to 25 GHz (typ)
Amplitude resolution	200uV (nom)
DAC resolution	8Bit
AWG Sample rate	13.44 GSa/s to 65GSa/s
Sample Memory (Internal / extended)	1 MSa / 16GSa
Frequency Switching time	505us / 38ps (opt FSW)
MIMO and beam forming	Expandable to 16 synchronized channels
mmW Modulation signals	FM, PM, FMCW, pulse sequence, MFSK, custom OFDM,……

*Measured at Data Out.



Key Features

- Download Radar FMCW signals from either: ***IQ Tools, Signal Studio***, ***SystemVue***, *or other*
- Generate ideal reference signals (replace Tx LO/VCO)
- Generate interferer, clutter, jamming test signals (Rx Test)

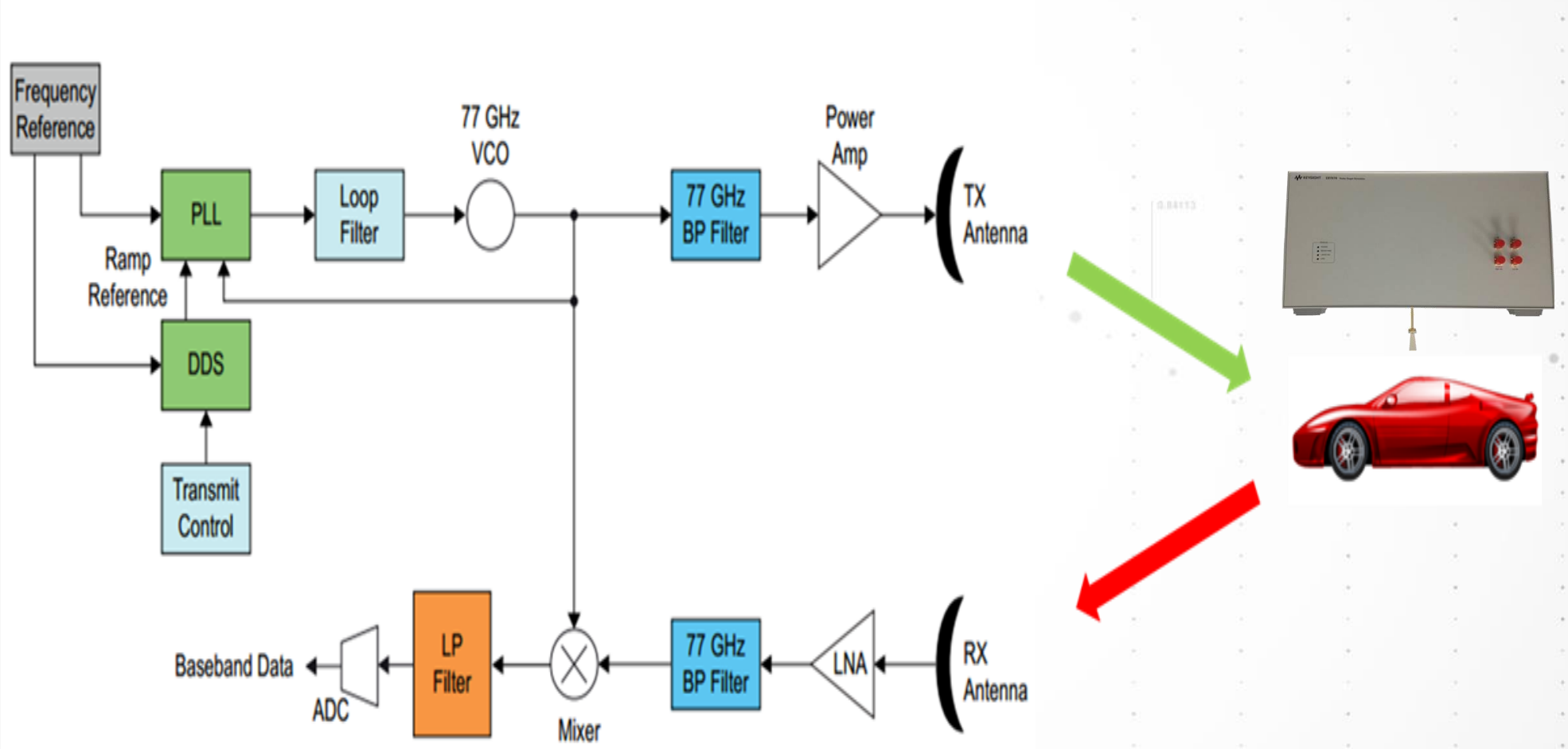
Summary

E8740A AUTOMOTIVE SIGNAL ANALYSIS AND GENERATION SOLUTION

- Industry's unique >5GHz bandwidth up to 110GHz Automotive radar signal analysis and flexible radar signal generation solutions for full frequency range and bandwidth testing of 24, 77, 79Ghz and upcoming automotive radar.
- The UXA X-Series signal analyzer, which covers 3 Hz to 110 GHz in a continuous sweep. You can test 79 GHz radar signals for compliance with ETSI spurious specs using a single instrument:
  - Internally, the UXA has a maximum analysis bandwidth of 1 GHz. To achieve a 5 GHz analysis bandwidth, simply connect an external oscilloscope to the IF input.
  - Great sensitivity and dynamic range ensure better SNR: DANL is –150 dBm up to 110 GHz.
  - The Keysight 89600 VSA software enables detailed analysis of modulation characteristics with maximum analysis bandwidth of 4 GHz.
- The M8195A high-speed arbitrary waveform generator (AWG) can produce signals with wide modulation bandwidth (> 4 GHz) with flexible modulation formats.
- The Keysight SystemVue Automotive Radar Library (W1908) enables you to easily generate a variety of FMCW waveforms and scenarios using the M8195A AWG
  - Easy interoperation with the 89600 VSA software ensures consistency throughout the design process

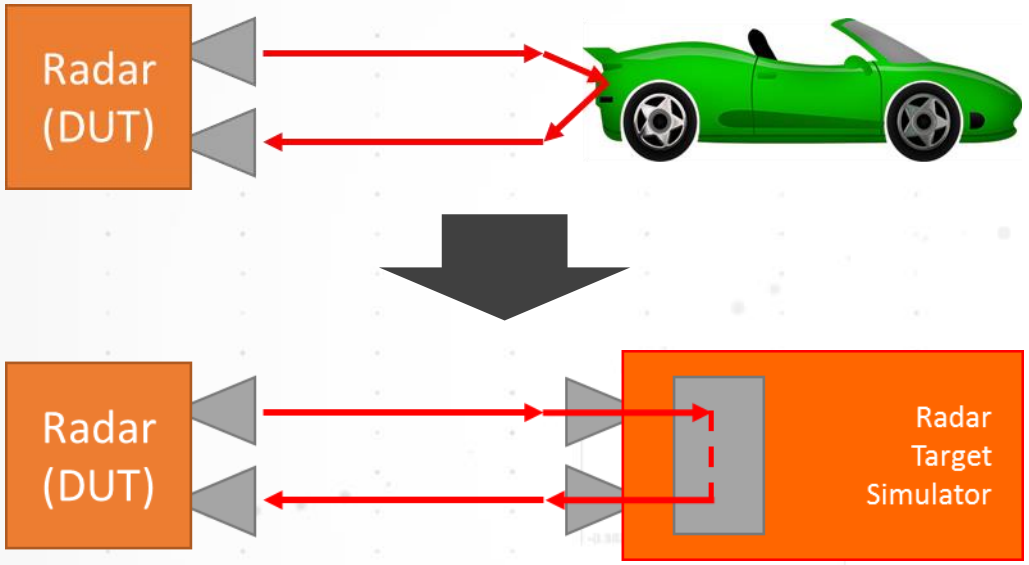
Automotive Radar Manufacturing

SOLUTION



Automotive Radar Manufacturing

RADAR TARGET SIMULATOR (RTS) BASIC FUNCTIONALITY



1 meter min. physical distance

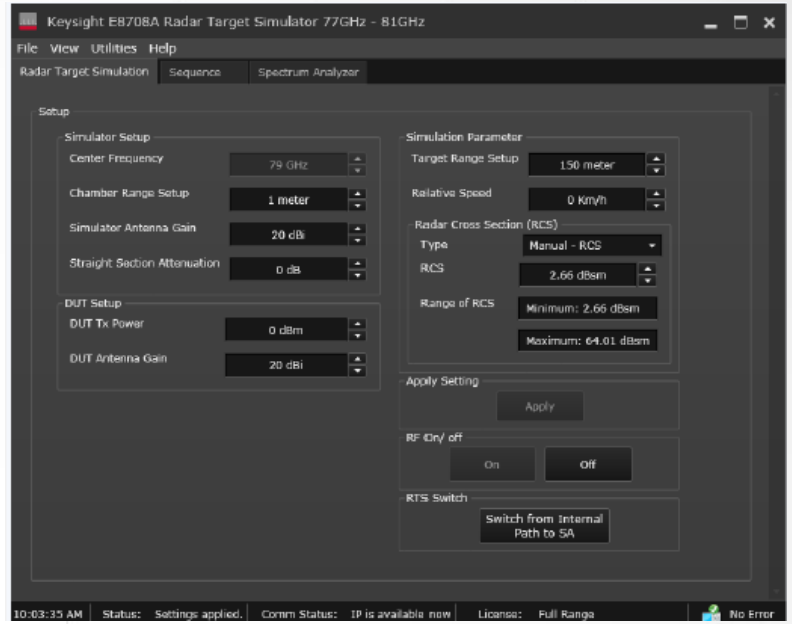
Basic Functionality

1) Radar DUT signal is received
2) Signal is manipulated in the Radar Target Simulator
3) Signal is then re-transmitted back to the Radar DUT

Radar Target Simulator will apply…	to simulate…
Time delay	Range (Distance)
Doppler Frequency Shift	Radial Velocity (Speed)
Attenuation	Radar Cross Section (Object Size)

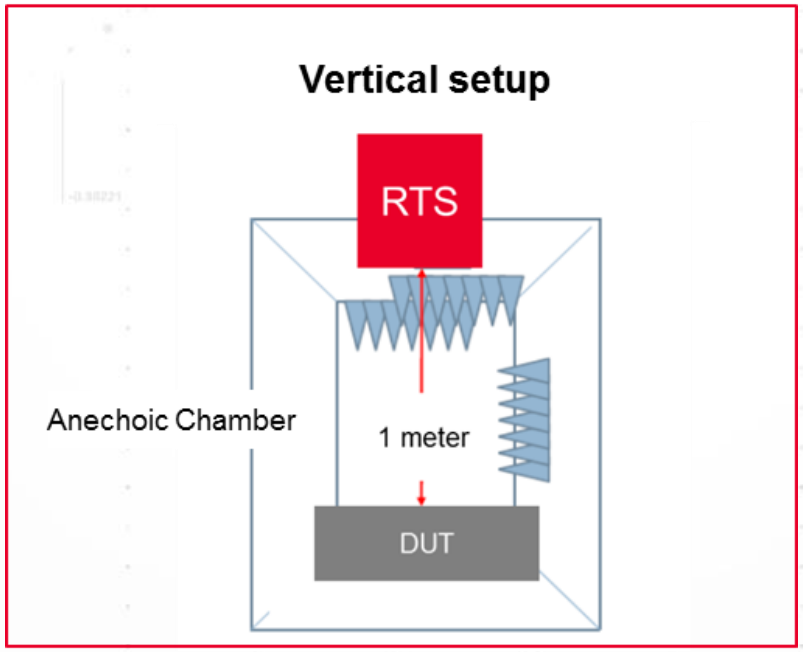
Automotive Radar Manufacturing

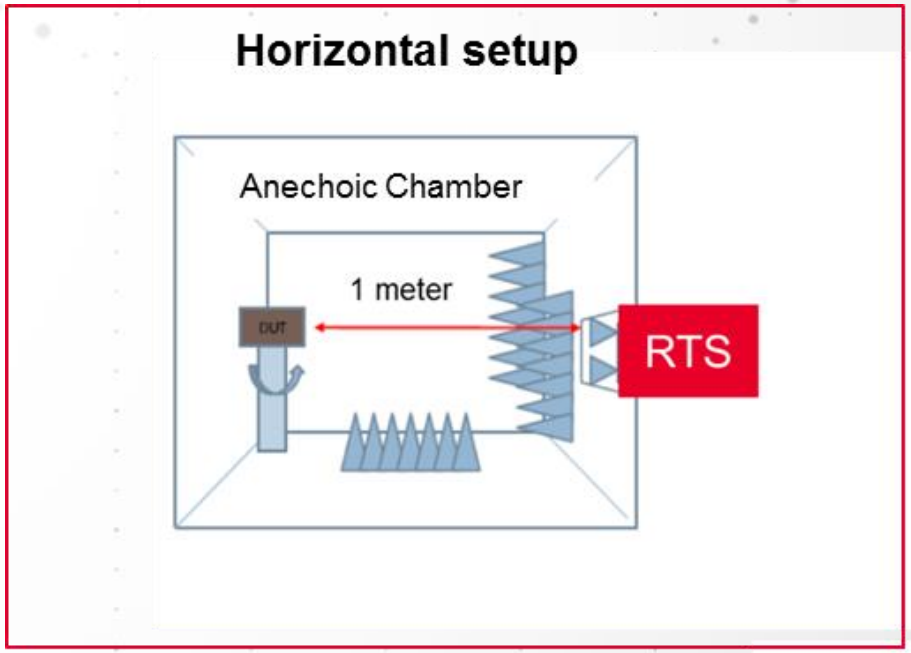
RADAR TARGET SIMULATOR (RTS) OVERVIEW



Manufacturing Test concept and Capabilities

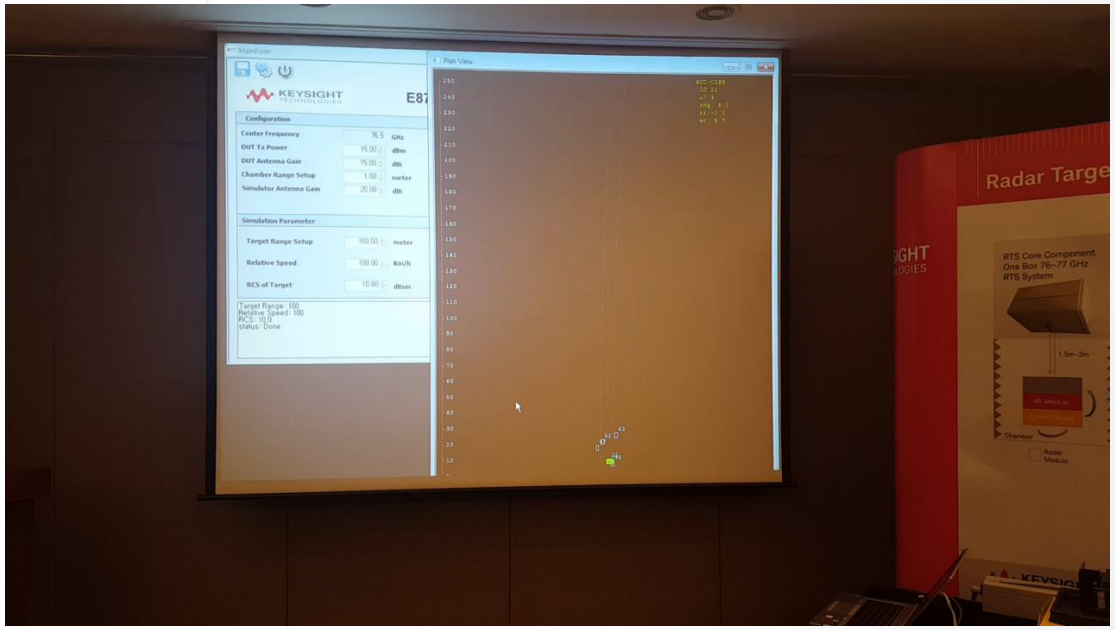
- Frequency Band : 76GHz -81GHz
- Bandwidth 5GHz
- Single Target
- Range 4m to 300m
- RCS Range 63.5 dB attenuation at 1 GHz BW
- Speed 0 to +/- 360Km





Automotive Radar Manufacturing

RADAR TARGET SIMULATOR (RTS) BENEFITS



Automotive Radar Manufacturing

RADAR TARGET SIMULATOR (RTS) BENEFITS

E8708A
Radar Target Simulator

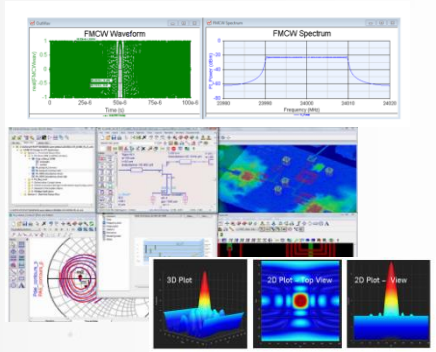
Key Product Specifications and Features

Frequency Range	76 – 81 GHz
Transmit and Receive horn	Single and Dual Horns antenna options
Radar Signal Occupied Bandwidth	4 GHz
Min Target Distance	1m + Physical target distance
Simulated Range	4 to 300m with 1m step
Doppler shift range	+/- 360km/h with 1km/h resolution
Transmit/Receive Gain Control (object target size)	63.5 dB with 0.5dB step
Dimension (H x W x D)	222.25 x 425.6 x 574 (mm)

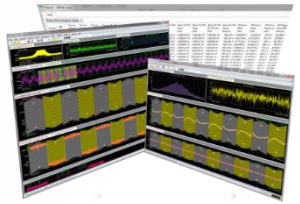
- Wide simulated range coverage with ***minimum distance starting from 4m***
- ***4GHz*** Bandwidth support wide range of module without the need of changing center frequency
- ***Scalable*** for both Manufacturing and R&D test
  - Basic – Fixed range simulation (ie 75m & 150m)
  - Comprehensive – Full range, RCS, Doppler & DUT Transmit Power
- ***Reliable***, ***accurate*** and ***repeatable*** performance
- ***Ease of use GUI*** and ***API*** where all parameters controllable in ***C++ & C# programming environment***
- Designed, manufactured and ***supported by single company Keysight Technologies***
- ***World wide support***, calibration and warranty
  - Default 3 years factory warranty
  - Optional upgrade with onsite calibration, onsite spare and 7x24 support packages
- CE and Safety certified

Keysight Automotive Radar Solutions

OVER WHOLE DESIGN AND TEST LIFECYCLE



W1908 SystemVue Simulation SW



89600 VSA SW with FMCW option

PXI Modular VSA/VSG/Digitizer /Network Analyzer

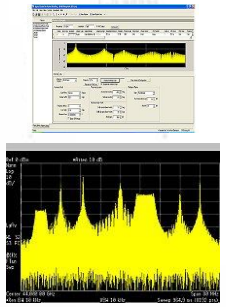
E8740A-060 Performance SA

E-Band Power Sensor and Meter

Architecture / Design | **Development** | Validation & Mfg.

E8740A-070 Performance SG

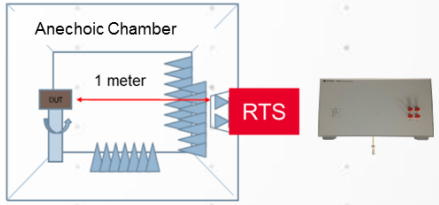
E8267D PSG Vector Signal Generator



Signal Studio for Pulse Building

Signal Source Analyzer

PNA Network Analyzers Banded mmW Solution



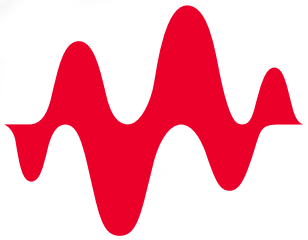
Radar Target Simulator (RTS)

From Design Simulation, Wide Bandwidth mmWave Signal Generation & Analysis, Precise Power and Component Measurements to Manufacturing Tests

Automotive Radar Design and Test Lifecycle

SUMMARY

- Advanced automotive radar with millimeter frequency and wide bandwidth are now an indispensable part of Advanced Driver Assistance Systems (ADAS) and autonomous driving vehicles
- Growing demand of advanced technologies, such as 79GHz frequency with 4GHz modulation bandwidth and micro-Doppler to detect and protect pedestrians, has led to new design and test challenges
- Keysight Automotive Radar solutions from early design simulation through Research & Development (R&D) and manufacturing to solve current and future automotive radar design and test challenges



KEYSIGHT
TECHNOLOGIES

Thank you!