The Consideration of Unexpected Issue and Verification Method for Multiple Sensors in Autonomous Driving Technology

Product Planner for Automotive R&D Solution and
Standard Committee / Keysight Technologies USA
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Agenda

- Autonomous Driving enabling technologies and the timeline Guess
- Introducing sensors for autonomous driving technology
  - Pros and cons for each sensor
  - Sensor Fusion
- Challenges of Sensor fusion technology
- A method for estimating and verifying issues
- Interference and interoperability Issues.
  - Automotive V2X and DSRC
  - Automotive Radar and OFDM 5G BH
- Consideration of new Radar Technology and its Challenges
  - Automotive FMCW and Coded Radar
  - New Ant and division technologies

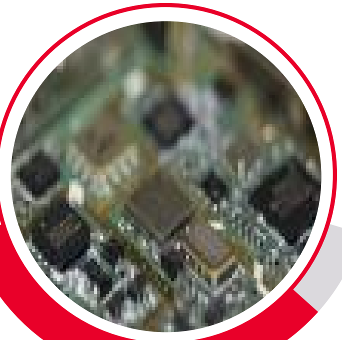
Key Technologies for Autonomous Vehicles

INNOVATIONS FOR ALL ADVANCED DRIVER SYSTEMS

Sensors (Advance Driver Assistance Systems)
- Short and long-range Radar
- Lidar
- Camera Systems

In-Vehicle Network
- CAN/LIN/SENT/MOST
- Automotive Ethernet
- MIPI A-PHY

Wireless Connectivity
- Cellular (4G / 5G + eCall)
- GNSS
- V2X (DSRC / ITS-G5 & C-V2X)

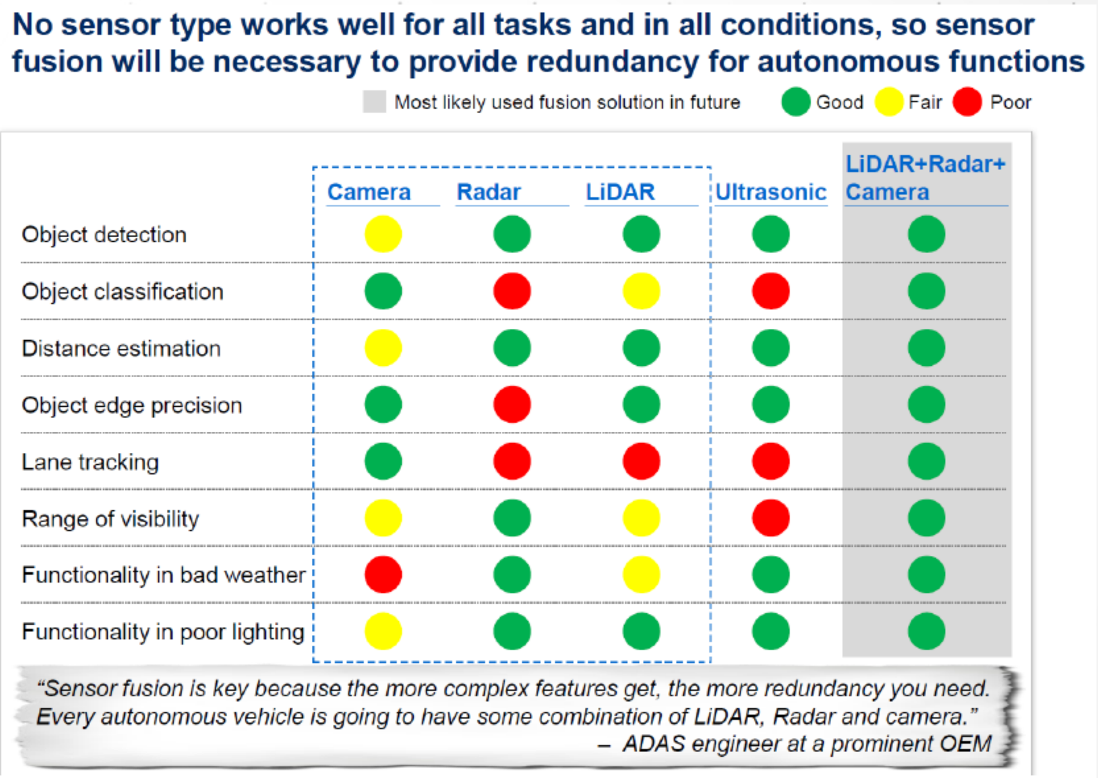


System Integration
- Sensor Fusion
- AI system training for decision making

Sensor Fusion Key to ADAS and AD

INTRODUCING SENSOR FUSION FOR AUTONOMOUS DRIVING TECHNOLOGY

- Individual Sensor
  - Different sensors good for different functions and environment
  - Fully-distributed system
  - Radar! vs Lidar! vs Camera! Redundancy needed
- Sensor Fusion – more than just the sum of its parts!
  - Better and safer decisions than independent systems could do
    - Radar and front camera
    - Ultrasonic and rear camera
  - Various condition for better decision (A and B, A or B, if A then B,….)
  - Centralized processing architecture


No sensor type works well for all tasks and in all conditions, so sensor fusion will be necessary to provide redundancy for autonomous functions

Most likely used fusion solution in future · Good · Fair · Poor

	Camera	Radar	LiDAR	Ultrasonic	LiDAR+Radar+ Camera
Object detection	Fair	Good	Good	Good	Good
Object classification	Good	Poor	Fair	Poor	Good
Distance estimation	Fair	Good	Good	Good	Good
Object edge precision	Good	Poor	Good	Good	Good
Lane tracking	Good	Poor	Poor	Poor	Good
Range of visibility	Fair	Good	Fair	Poor	Good
Functionality in bad weather	Poor	Good	Fair	Good	Good
Functionality in poor lighting	Fair	Good	Good	Good	Good

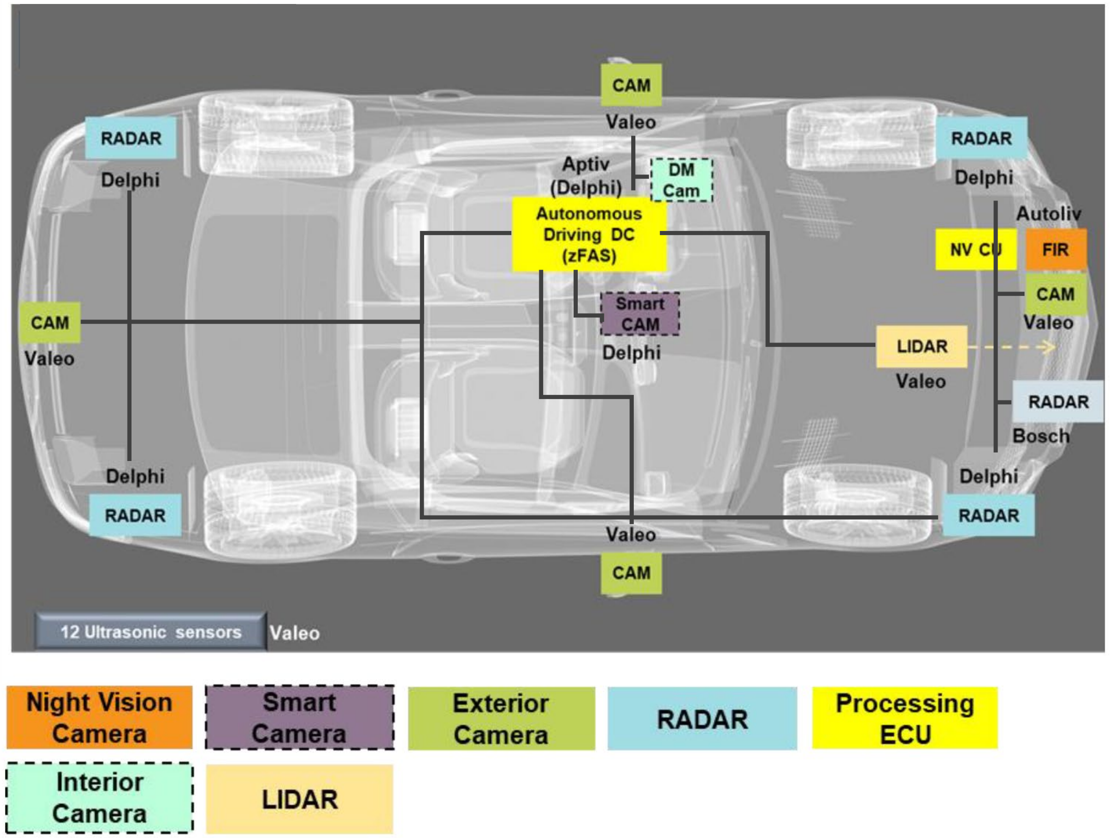
"Sensor fusion is key because the more complex features get, the more redundancy you need. Every autonomous vehicle is going to have some combination of LiDAR, Radar and camera."
– ADAS engineer at a prominent OEM

Source: WCP 2016

AD System architecture

L2/L3 IN 2018 AND L4/L5 IN MODEL YEAR 202X

Example: [redacted] model year 2019 ("zFAS" module from Aptiv)



Notes: *L3 is only in Germany because of regulations and legislation restrictions elsewhere.
Source: IHS Markit

Typical system content from L1 to L5

ADAS module	Units for L1	Units for L2	Units for L3	Units for L4	Units for L5
Ultrasonic sensors	0-12**	12	12	12	12
Long-range radar	1	1	1	1-2	1-4
Short/Mid-range radar	0-2	2-4	2-4	2-6	4-8
Exterior camera	2	5	6-10	12	8-15
Interior camera	0	0-1	1-3	2-4	3-6
FIR sensor and night vision CU	0-1	0-1	0-1	0-1	0-1
Long-range LiDAR	0	0	1	1	0-2*
Short-range LiDAR	0	0-2*	0-2*	0-4*	0-4*
IMU	0	0	0	0-1	0-1
GNSS	0	0	0	0-1	0-1
Park ECU	1	1	0	0	0
SV Park ECU	0-1	1	0	0	0
ADAS domain controller	0	0-1	0-1	0	0
Autonomous driving DC	0	0	1	1-2	2

Source: IHS Markit

Source: 2019 IHS report

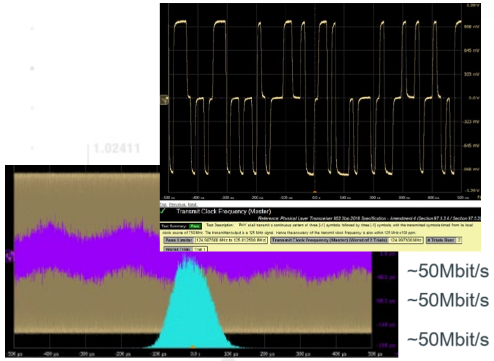
Consideration of Sensor Fusion Issue

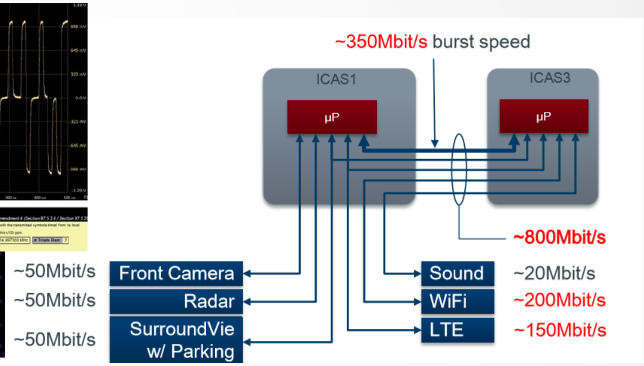
(Challenges and verification)

Sensor Fusion Challenges

CHALLENGES

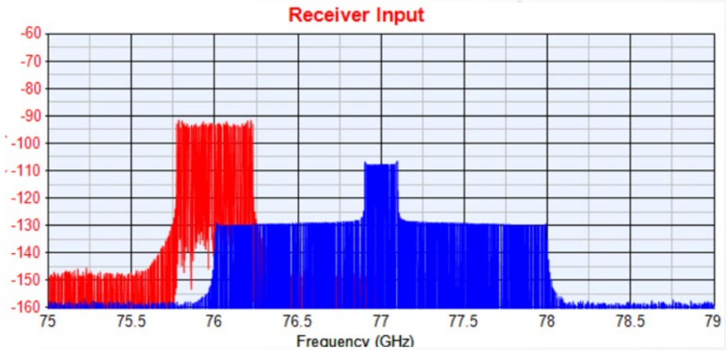
- Centralized processing : High speed network for wide-bandwidth communication is needed
  - EMI issue
  - Automotive Ethernet Compliance Test
    - Transmit Jitter, distortion, return loss, PSD, Droop Tests, and,…..
  - Protocol verification on IP based networking in the vehicle



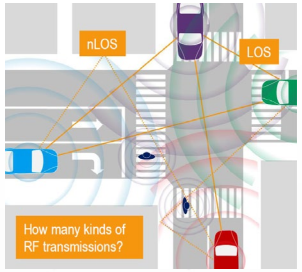


- Interference or interoperability issue
  - Interference : Increase of Noise floor, Saturation of input channel, wrong decision(ghost Target for radar)
  - Interference between same type of sensors
    - Same modulation and same frequency (FMCW Radar and FMCW Radar)
    - FMCW vs Coded modulation/different physical/logical layer
  - Between different type of sensors and applications
    - Wifi and DSRC, ITS and V2X,….5G BH

    and FMCW radar,……

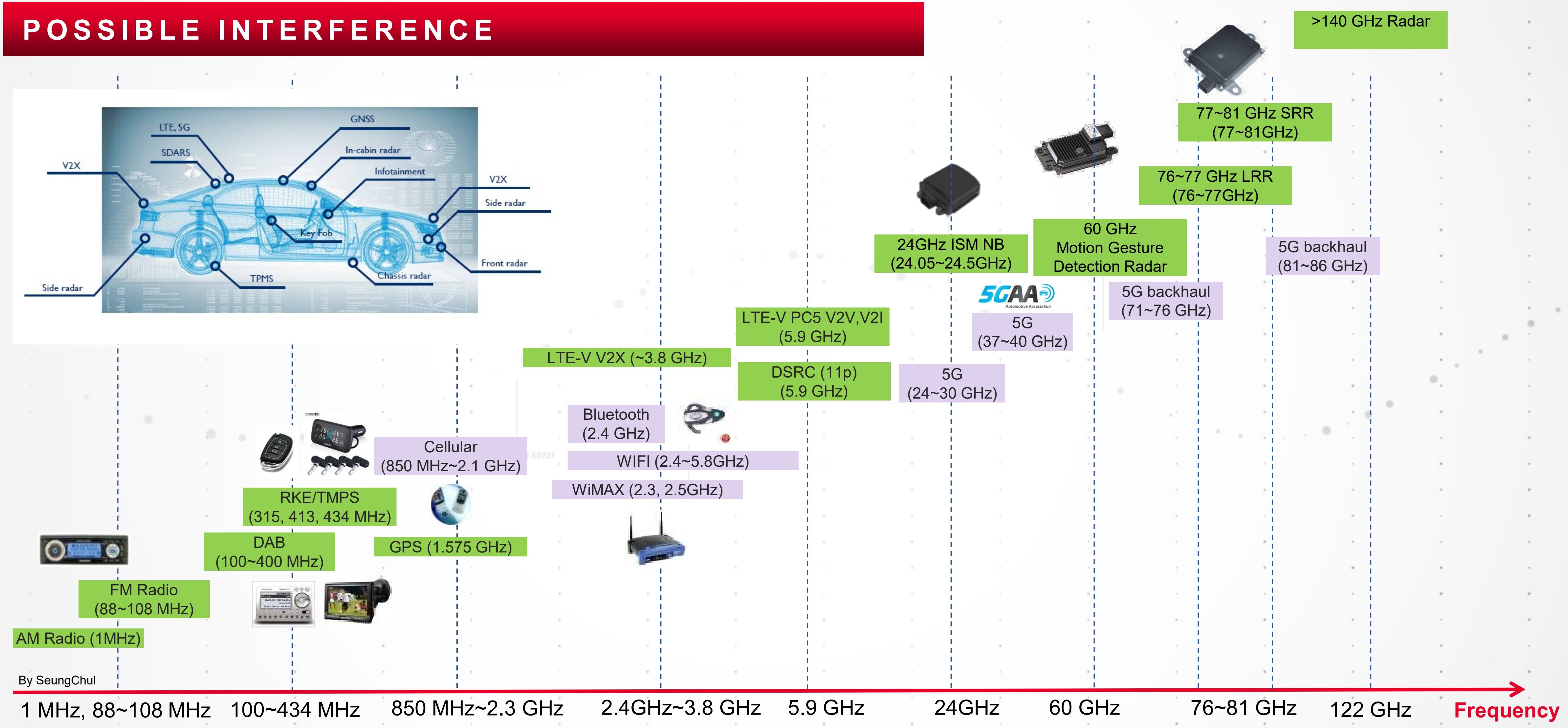


- Immunity testing under real environment



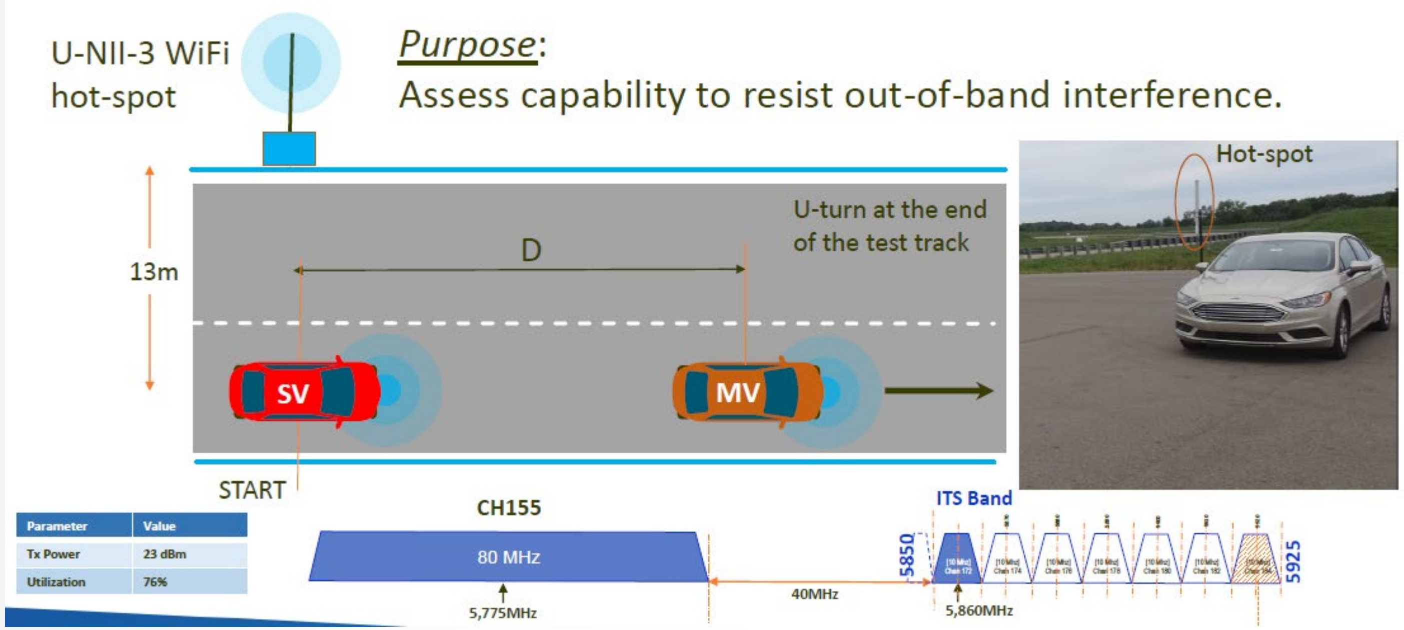
Automotive Application Frequency range

POSSIBLE INTERFERENCE



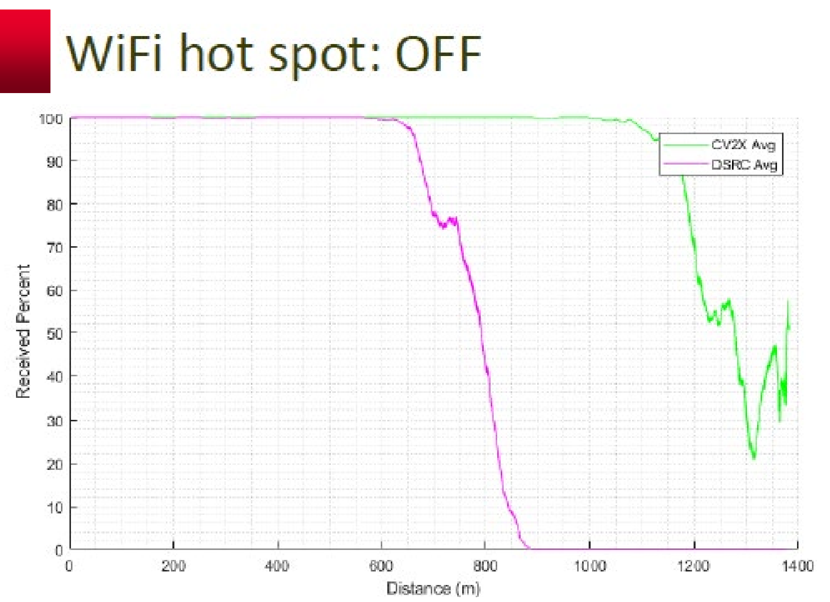
Automotive CV2X and DSRC

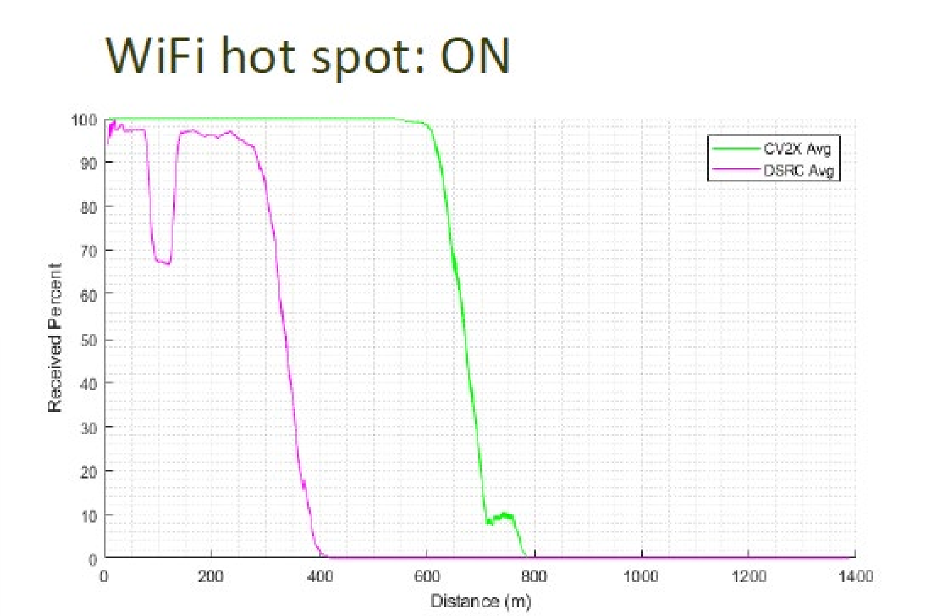
LINE OF SIGNAL OUT OF BAND INTERFERENCE TEST



Parameter	Value
Tx Power	23 dBm
Utilization	76%

Source: 5GAA V2X benchmark Testing 2018

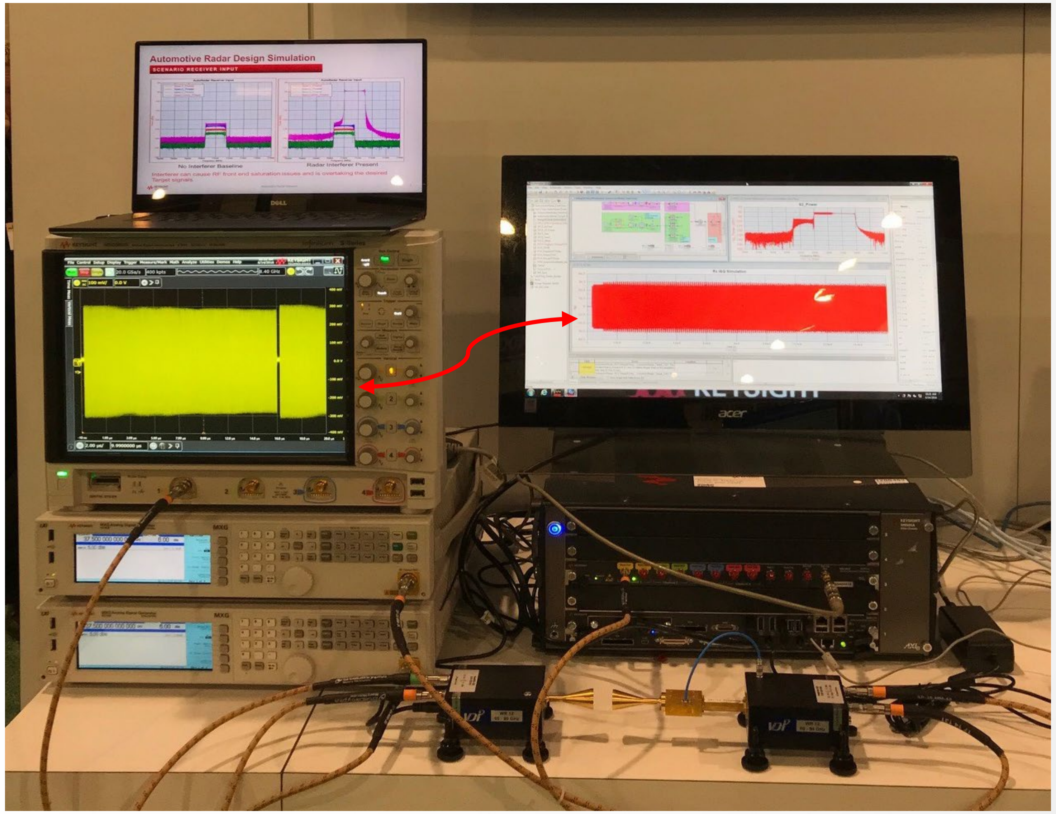




Automotive Radar

SIMULATION AND MEASUREMENT FOR INTERFERENCE TEST

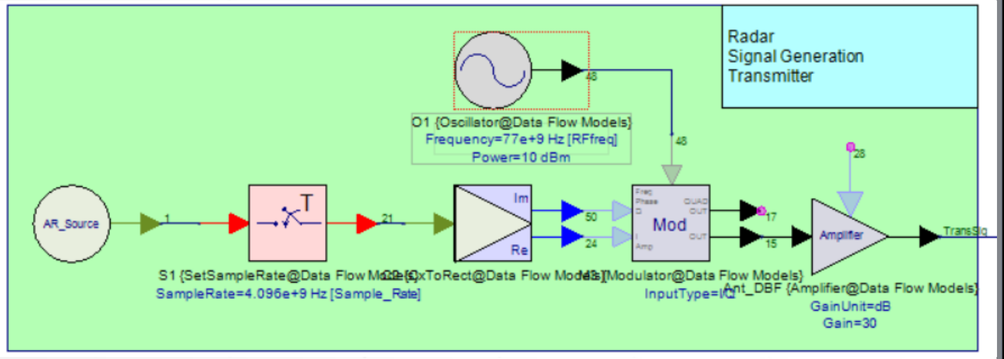
- Test Plan :
  - Interference between FMCW dual mode radar and OFDM (5G BH/coded radar)
- Test Condition :
  - FMCW dual mode radar signal
  - OFDM for 5G Backhaul and coded radar
  - 3 moving targets and 1 static station
- Test Case :
  - Functional test for detecting targets under victim Radar distance to OFDM 5G Backhaul station 100m~1000m
- Test Setup
  - Signal creation and simulation : Keysight SystemVue W1908
  - Signal generation and analysis : Keysight E8740A solution

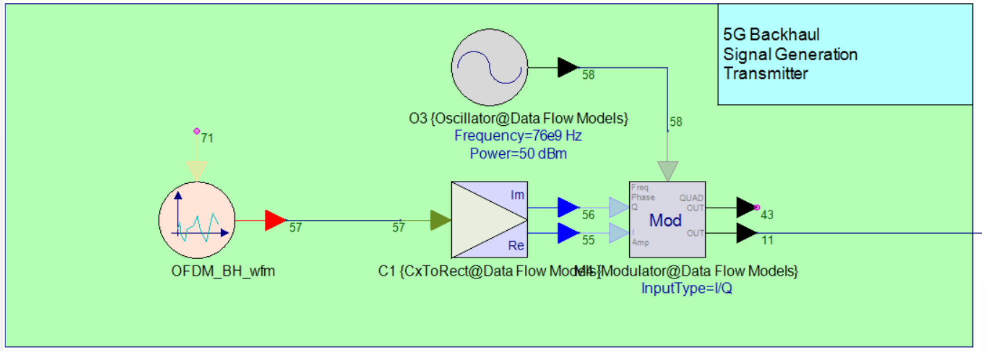


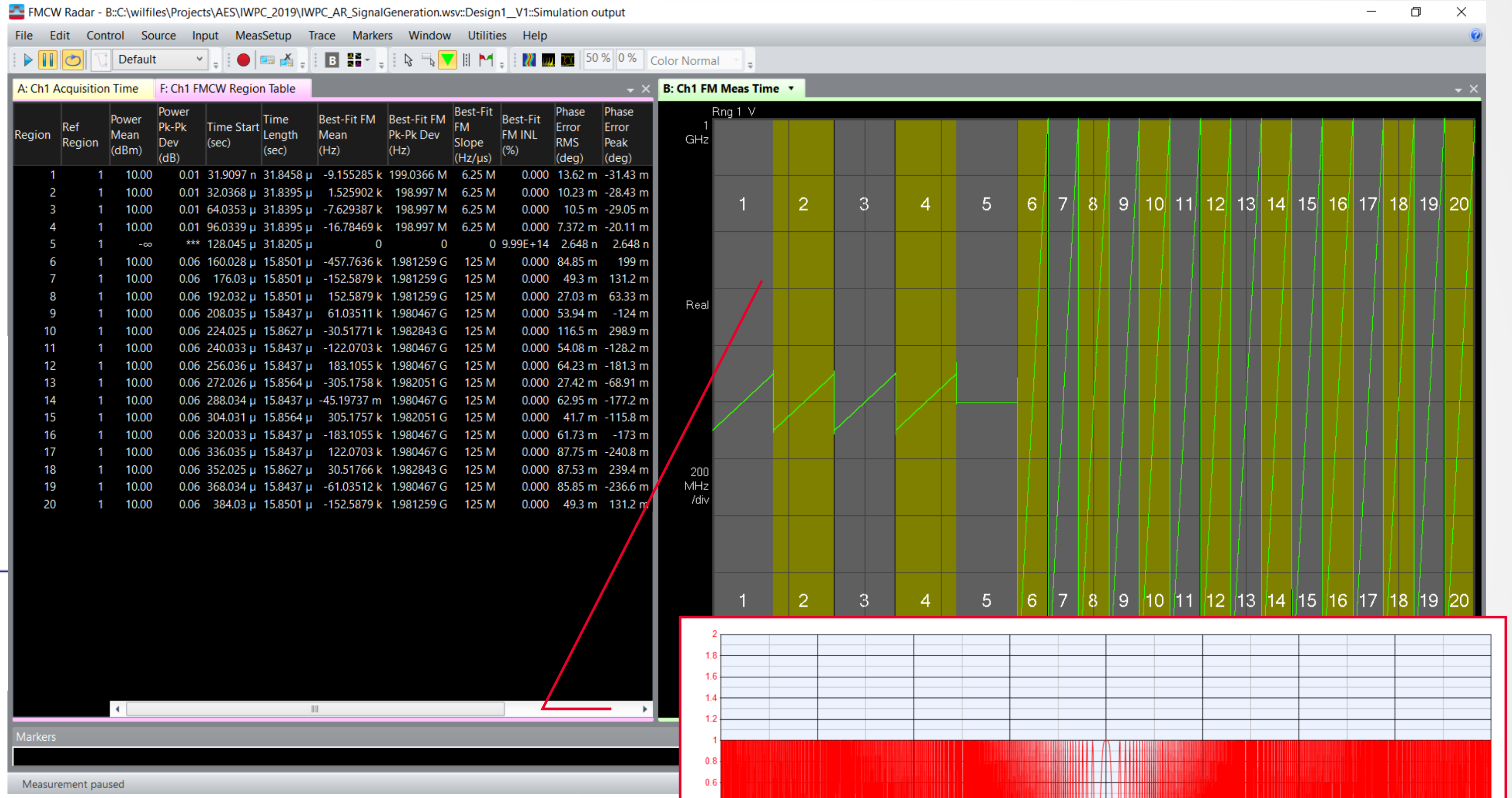
Creating FMCW Signal and OFDM(5G BH, coded radar)

AUTOMOTIVE RADAR DUAL MODE, OFDM SIGNAL GENERATION W/SYSTEMVUE

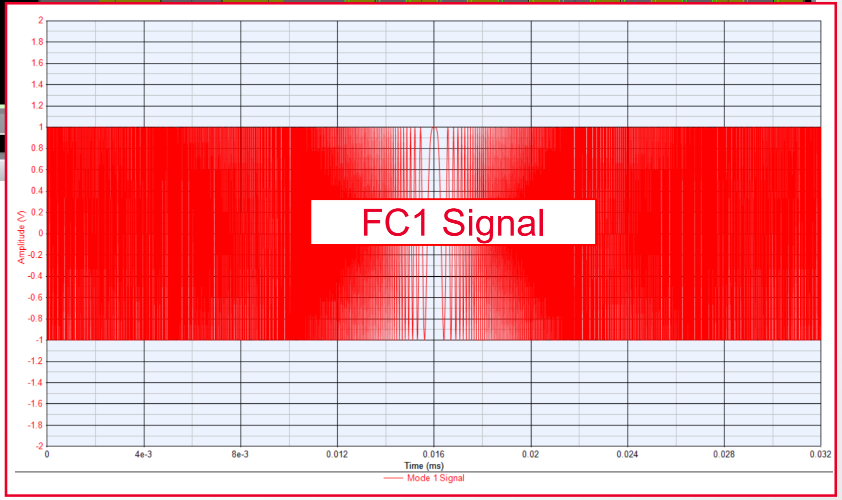
Parameter	FC1	FC2
BandWidth (MHz)	200	2000
Chirp Duration (us)	32	16
Frame Time (ms)	8.192	2.048
CPI Cells	256	128
Range Resolution (m)	0.749	0.075
Max Range (m)	767.469	38.373
Velocity Resolution (Km/hr)	0.855	3.422
Maximum Velocity (Km/hr)	109.502	219.004



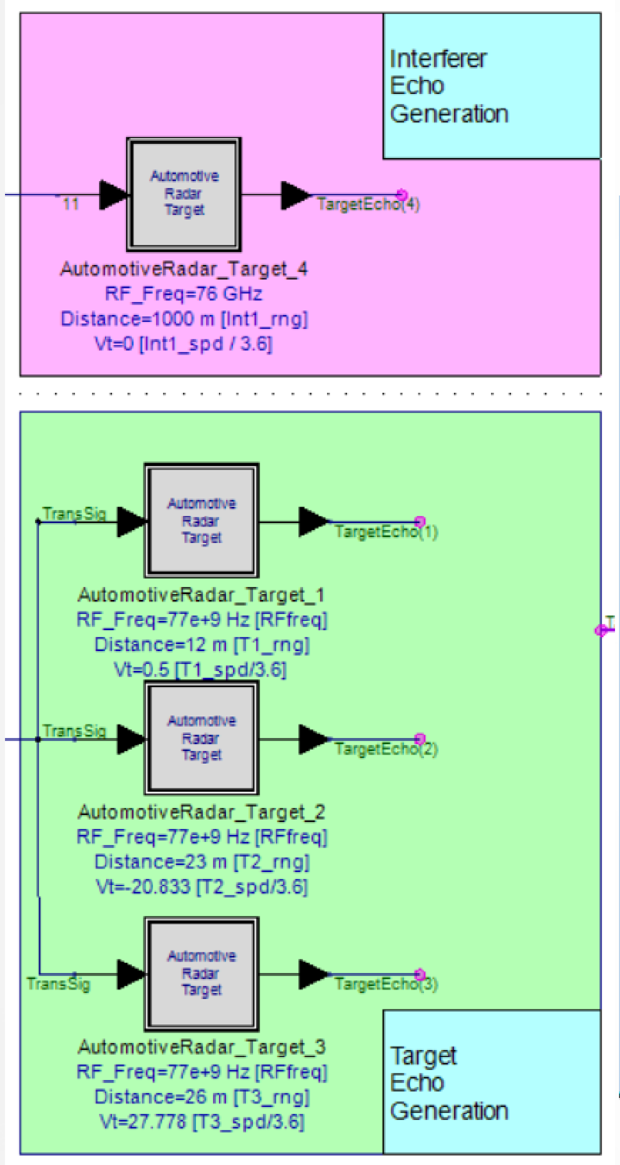




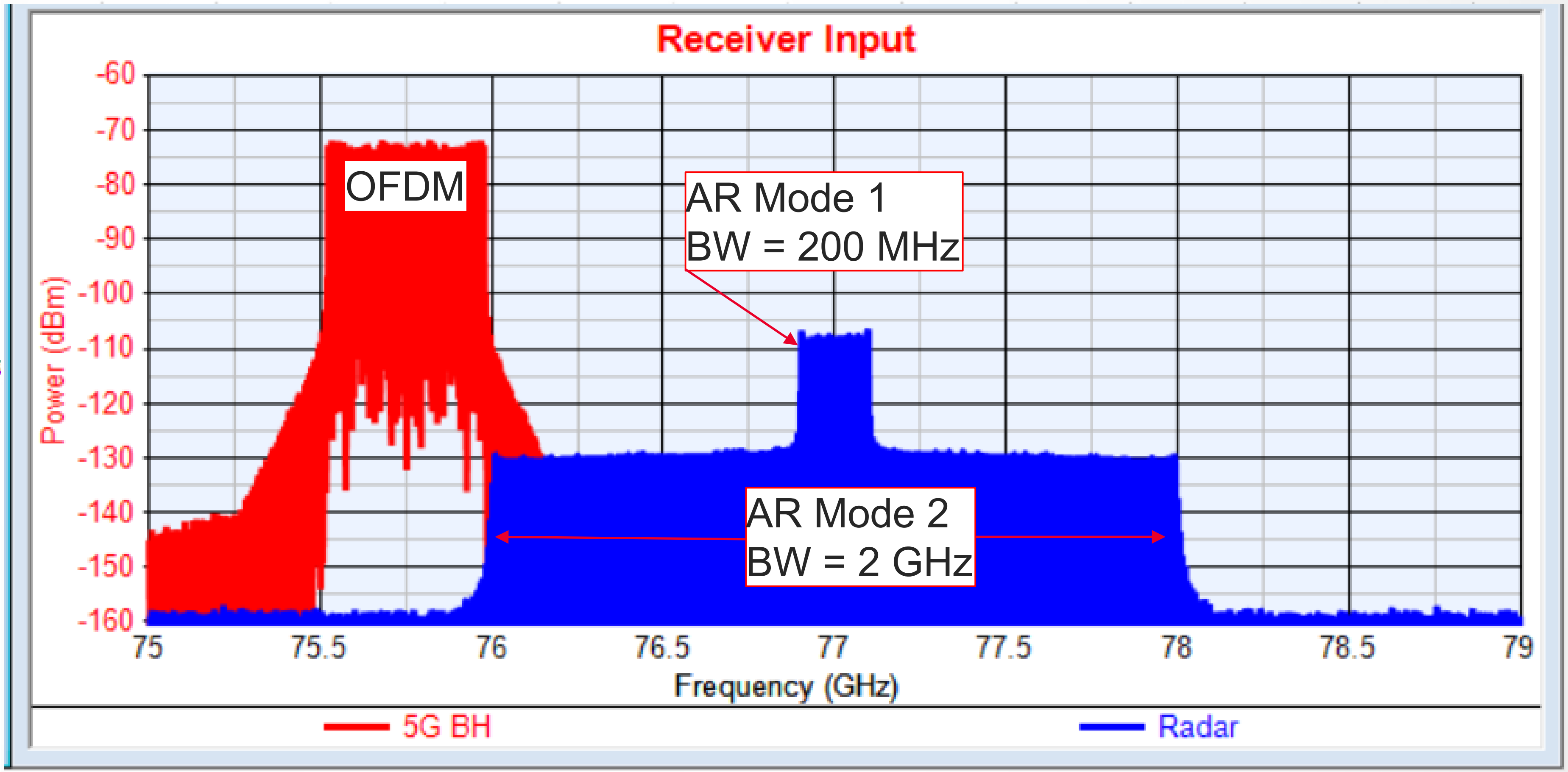
Region	Ref Region	Power Mean (dBm)	Power Pk-Pk Dev (dB)	Time Start (sec)	Time Length (sec)	Best-Fit FM Mean (Hz)	Best-Fit FM Pk-Pk Dev (Hz)	Best-Fit FM Slope (Hz/µs)	Best-Fit FM INL (%)	Phase Error RMS (deg)	Phase Error Peak (deg)
1	1	10.00	0.01	31.9097 n	31.8458 µ	-9.155285 k	199.0366 M	6.25 M	0.000	13.62 m	-31.43 m
2	1	10.00	0.01	32.0368 µ	31.8395 µ	1.525902 k	198.997 M	6.25 M	0.000	10.23 m	-28.43 m
3	1	10.00	0.01	64.0353 µ	31.8395 µ	-7.629387 k	198.997 M	6.25 M	0.000	10.5 m	-29.05 m
4	1	10.00	0.01	96.0339 µ	31.8395 µ	-16.78469 k	198.997 M	6.25 M	0.000	7.372 m	-20.11 m
5	1	-∞	***	128.045 µ	31.8205 µ	0	0	0	9.99E+14	2.648 n	2.648 n
6	1	10.00	0.06	160.028 µ	15.8501 µ	-457.7636 k	1.981259 G	125 M	0.000	84.85 m	199 m
7	1	10.00	0.06	176.03 µ	15.8501 µ	-152.5879 k	1.981259 G	125 M	0.000	49.3 m	131.2 m
8	1	10.00	0.06	192.032 µ	15.8501 µ	152.5879 k	1.981259 G	125 M	0.000	27.03 m	63.33 m
9	1	10.00	0.06	208.035 µ	15.8437 µ	61.03511 k	1.980467 G	125 M	0.000	53.94 m	-124 m
10	1	10.00	0.06	224.025 µ	15.8627 µ	-30.51771 k	1.982843 G	125 M	0.000	116.5 m	298.9 m
11	1	10.00	0.06	240.033 µ	15.8437 µ	-122.0703 k	1.980467 G	125 M	0.000	54.08 m	-128.2 m
12	1	10.00	0.06	256.036 µ	15.8437 µ	183.1055 k	1.980467 G	125 M	0.000	64.23 m	-181.3 m
13	1	10.00	0.06	272.026 µ	15.8564 µ	-305.1758 k	1.982051 G	125 M	0.000	27.42 m	-68.91 m
14	1	10.00	0.06	288.034 µ	15.8437 µ	-45.19737 m	1.980467 G	125 M	0.000	62.95 m	-177.2 m
15	1	10.00	0.06	304.031 µ	15.8564 µ	305.1757 k	1.982051 G	125 M	0.000	41.7 m	-115.8 m
16	1	10.00	0.06	320.033 µ	15.8437 µ	-183.1055 k	1.980467 G	125 M	0.000	61.73 m	-173 m
17	1	10.00	0.06	336.035 µ	15.8437 µ	122.0703 k	1.980467 G	125 M	0.000	87.75 m	-240.8 m
18	1	10.00	0.06	352.025 µ	15.8627 µ	30.51766 k	1.982843 G	125 M	0.000	87.53 m	239.4 m
19	1	10.00	0.06	368.034 µ	15.8437 µ	-61.03512 k	1.980467 G	125 M	0.000	85.85 m	-236.6 m
20	1	10.00	0.06	384.03 µ	15.8501 µ	-152.5879 k	1.981259 G	125 M	0.000	49.3 m	131.2 m



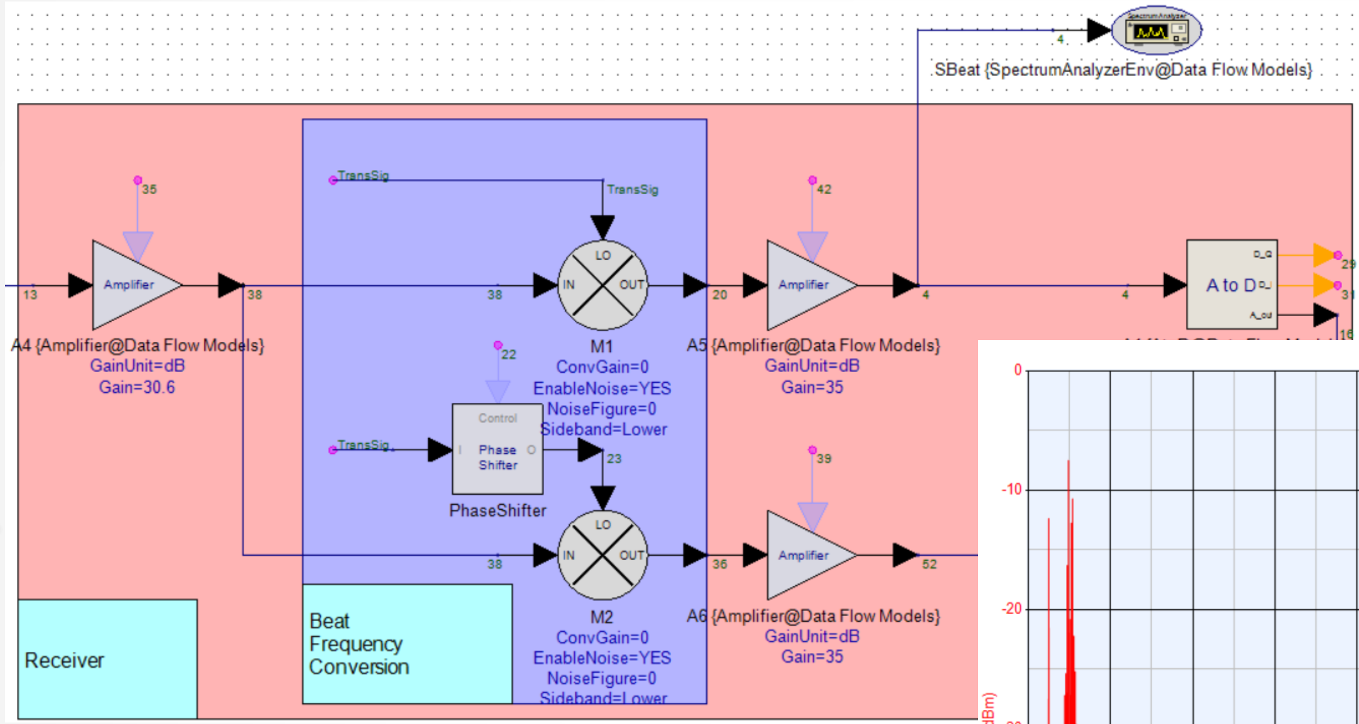
Echo Signals and Receiver Input

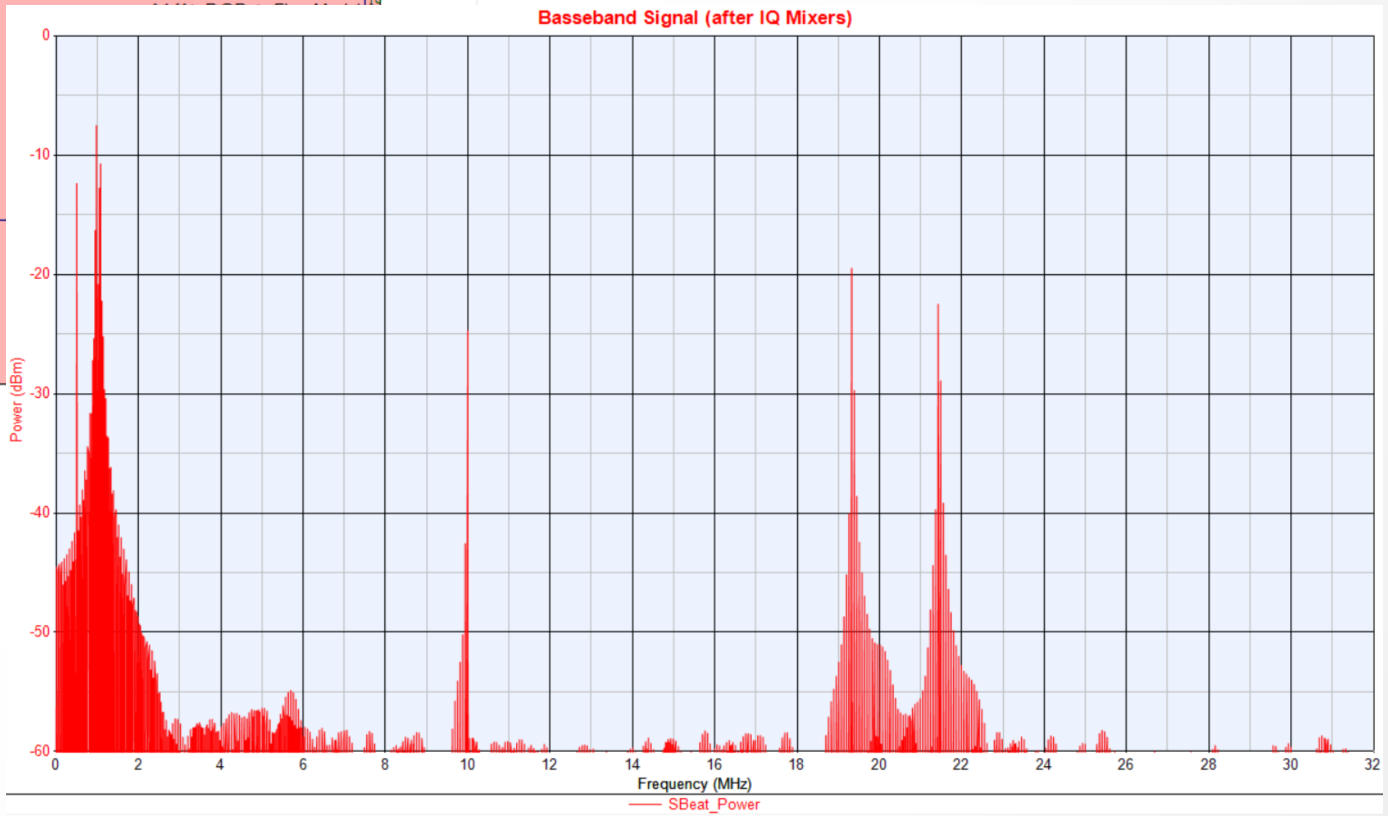


'Parameter'	'Target #1'	'Target #2'	'Target #2'	'5G BH'
Speed (Km/hr)	1.8	-75	100	0
Range (m)	12	23	26	1000
RCS (m^2)	1	50	50	



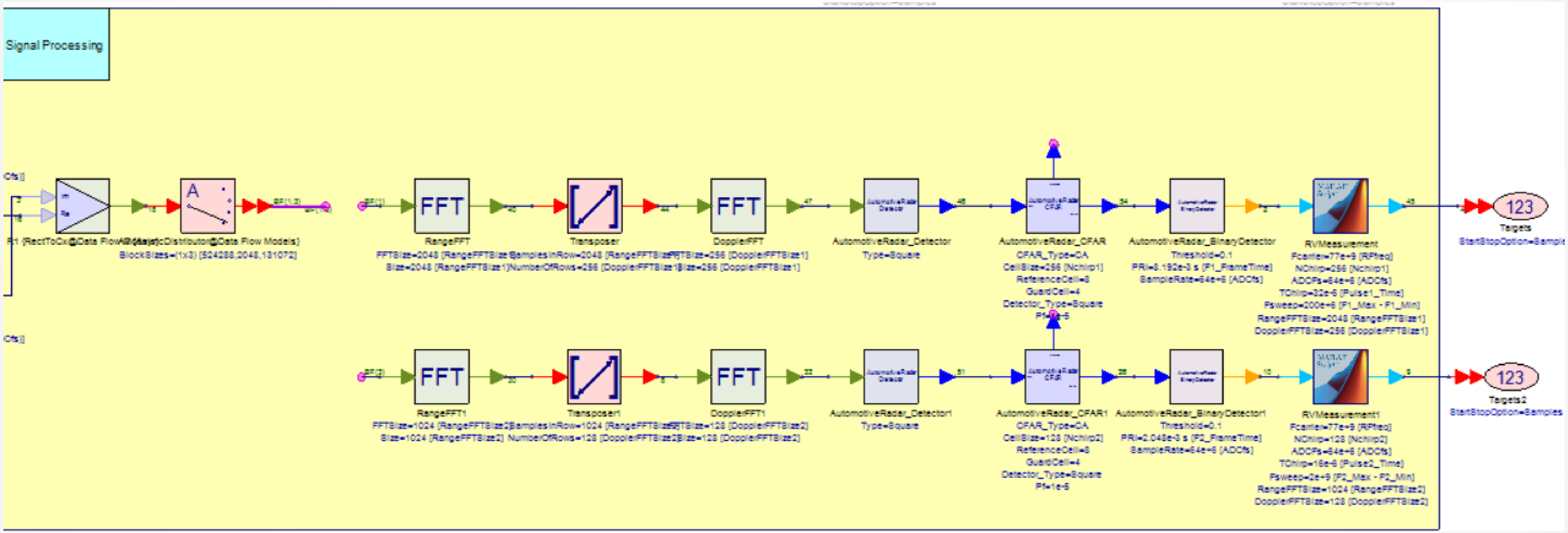
Automotive Radar Receiver





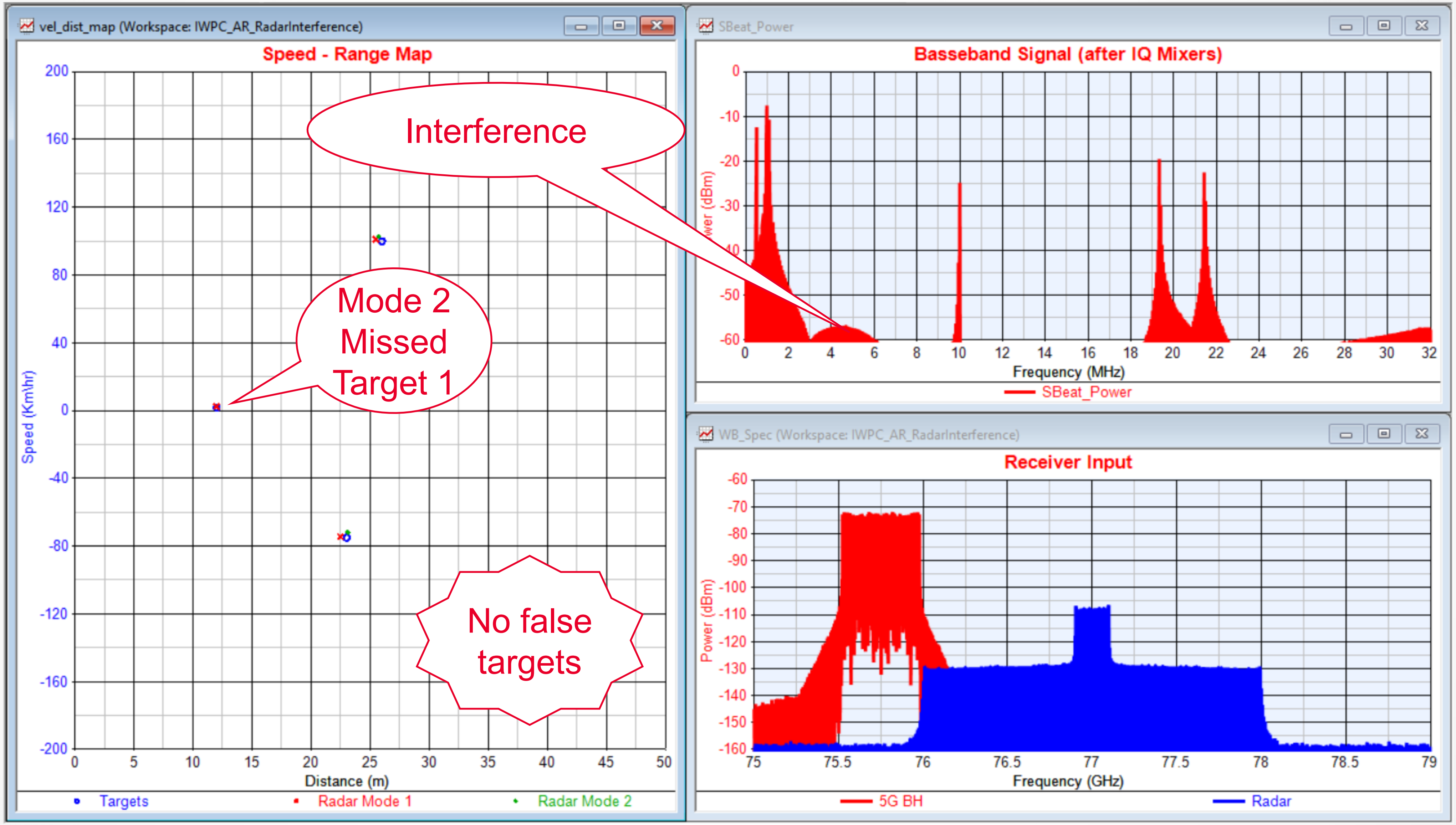
Signal Processing Layer

DUAL MODE AUTOMOTIVE RADAR PROCESSING



Target Dist (m)	FC1 Dist (m)	FC2 Dist (m)	Target Speed (Km/hr)	FC1 Speed (Km/hr)	FC2 Speed (Km/hr)
26	25.482	25.707	100	100.947	102.658
23	22.484	23.084	-75	-74.427	-71.861
12	11.992	11.992	1.8	2.566	3.422

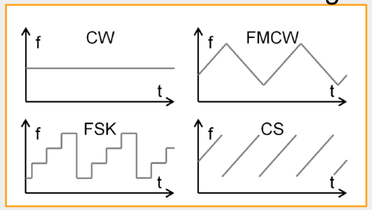
Test #1: Radar Distance to 5G BH = 100m



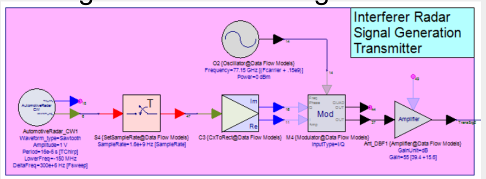
E8740A-080 Automotive Radar Rx/Interference test solution with Scorpion

IN-BAND INTERFERENCE TESTING 76~81GHZ

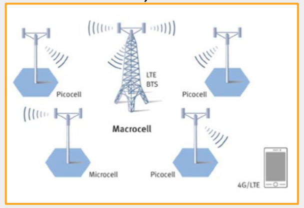
MOSARIM interference signals



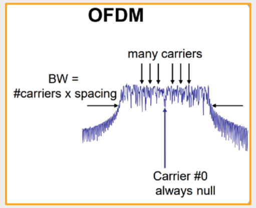
Moving Radar transmit signals as interferer



71~76GHz, 81~86GHz 5G mmW Backhaul

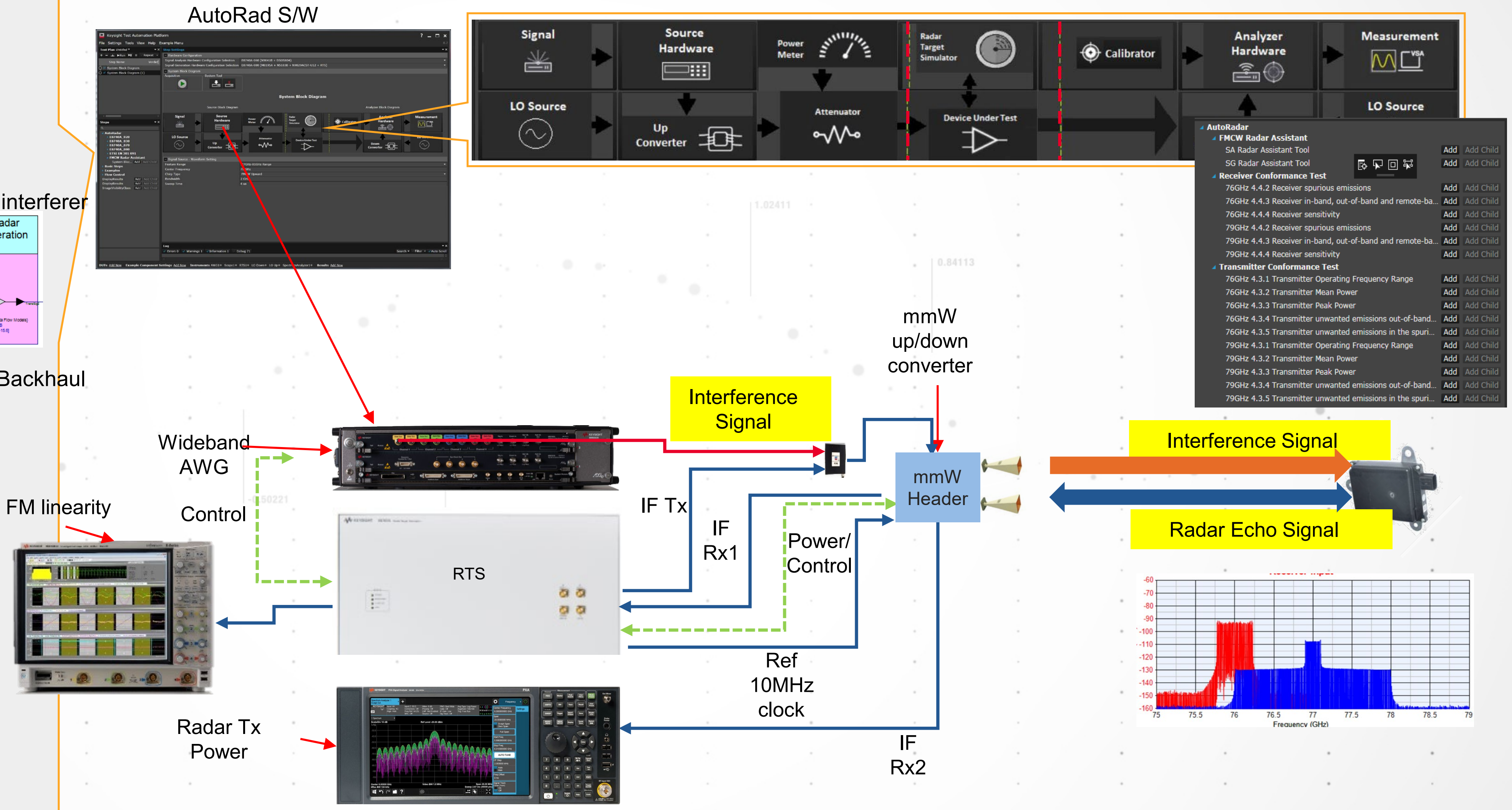


PMCW/OFDM/Coded Next Gen Automotive Radar



CW

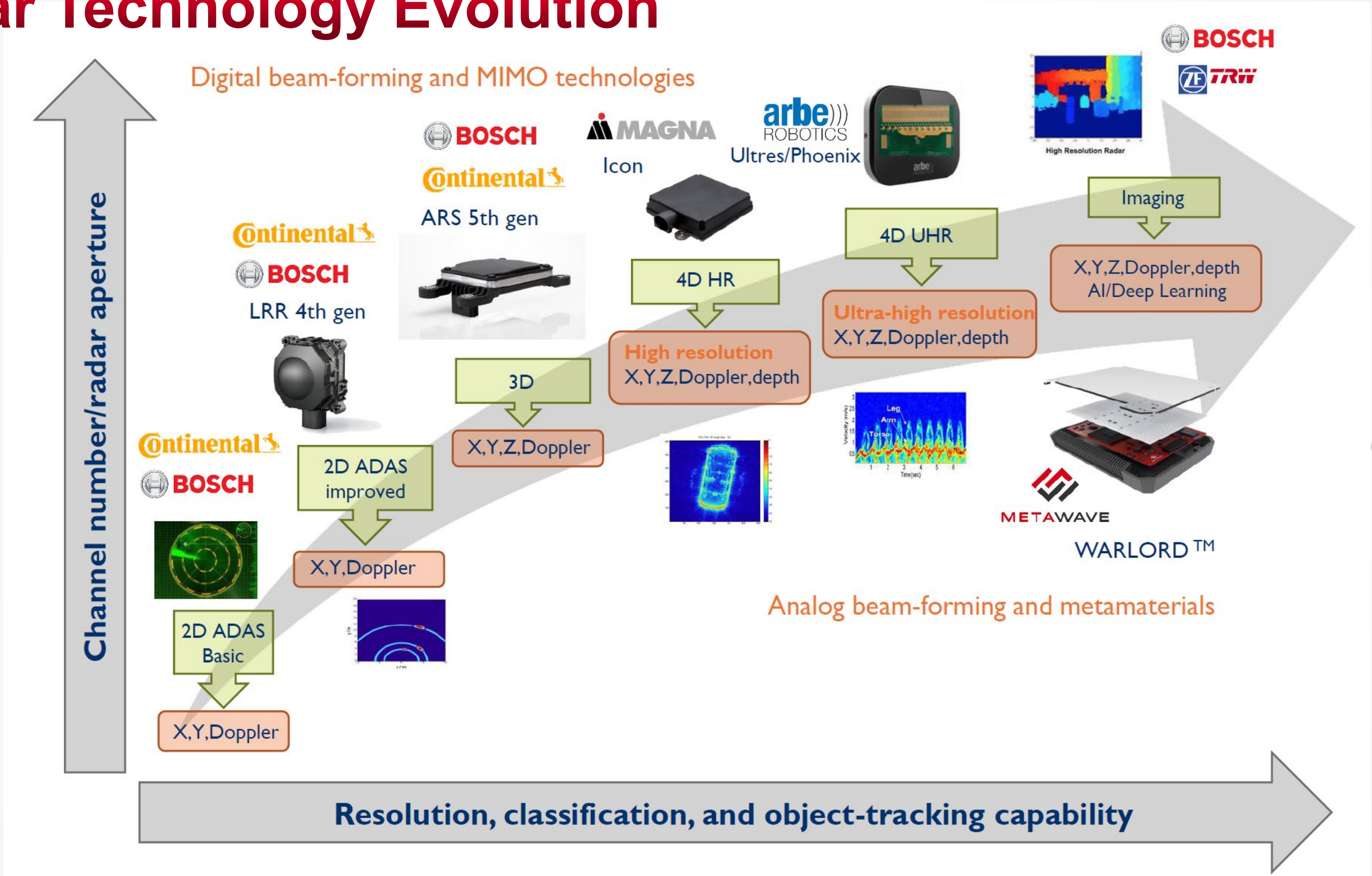
Any type of Noise signals



Consideration of Evolved Sensor Tech Issue

(Evolution of Automotive Radar Tech)

Radar Technology Evolution



Source : 2019 Yole Report (Radar and wireless technologies for Automotive

Challenges of Evolved Sensor Technologies

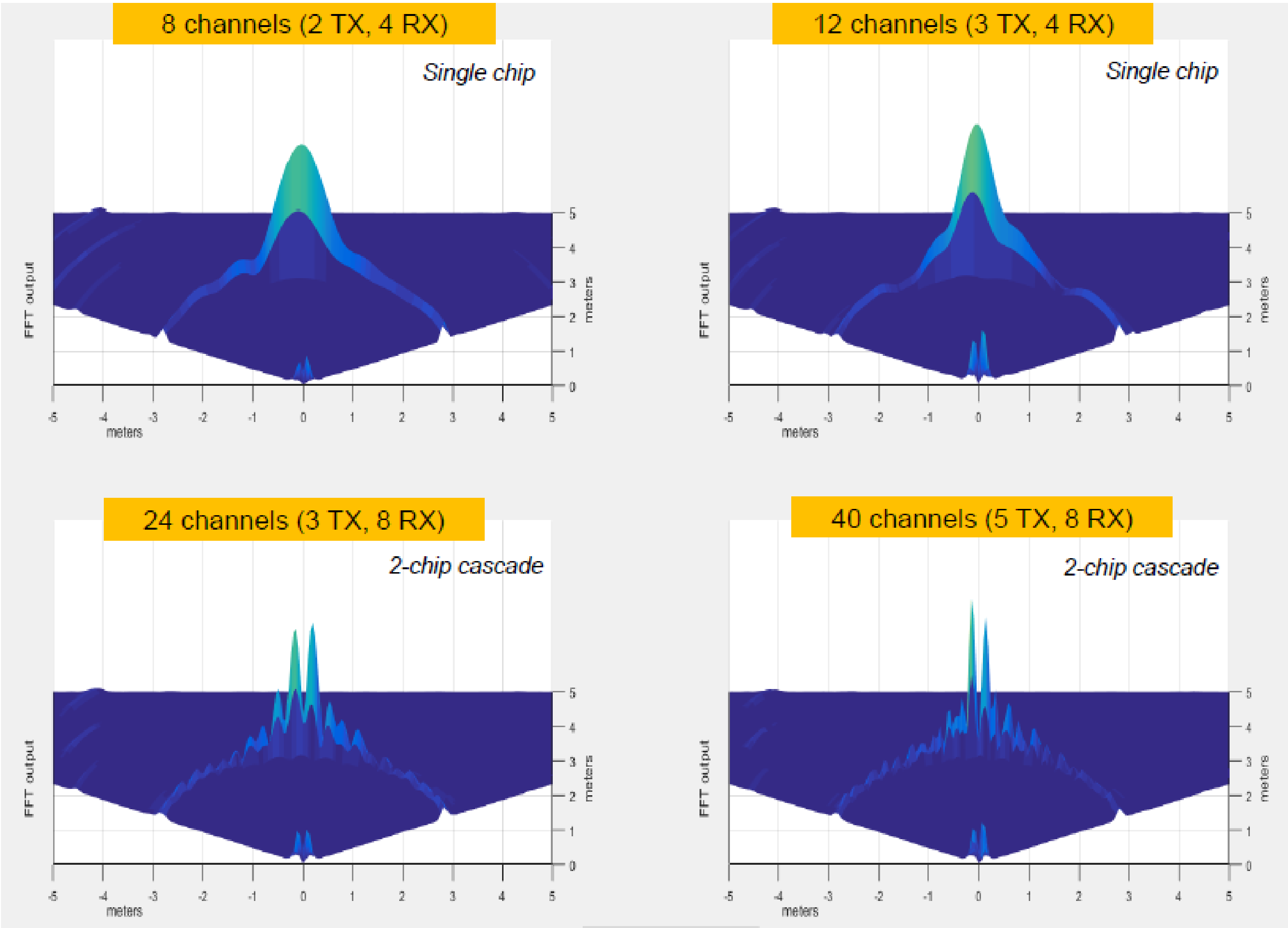
RADAR CHALLENGES

- Coded Phase-Modulated Continuous Wave Radar
  - Need to consider backward compatibility with existing FMCW radar
    - OBW depend on modulation rate
    - Interference susceptibility depend upon code type
  - Calibration required for Linear AMP
- New Antenna structure with MIMO/DBF/APA
  - Combined Antenna Aperture multi-function (Long-, Mid-, and Short-range) Radar
    - Characterizing of various angles and beam distance
  - Ultra-high Resolution Image Radar :
    - Bigger Ant size with bigger far-field distance :
    - Required conversion algorism between near-field and far-field for short distance detection
  - Cascade multiple transceivers for more Ant array :
    - Time/phase synchronization
- Requirement for higher Frequency range
  - New Assignment of next Gen Radar with Wideband Frequency band for better resolution
  - Emission regulation toward higher Frequency (up to 2^{nd} or 3^{rd} Harmonic of highest Frequency > ~230GHz)

KEYSIGHT TECHNOLOGIES

Radar Aperture Size

Measurement results with 2 corner reflectors at ~4deg separation



Array length	Ang. Resolution (deg)
8	14.32
12	9.55
24	4.77
40	2.86

Far Field distance $d = \frac{2D^2}{\lambda}$

Large antenna aperture increases far field distance !!

Source:TI

Pass Loss of Imaging radar with large Ant D

FAR-FIELD D AND PATH LOSS

Far Field distance Calculation $d = \frac{2D^2}{\lambda}$

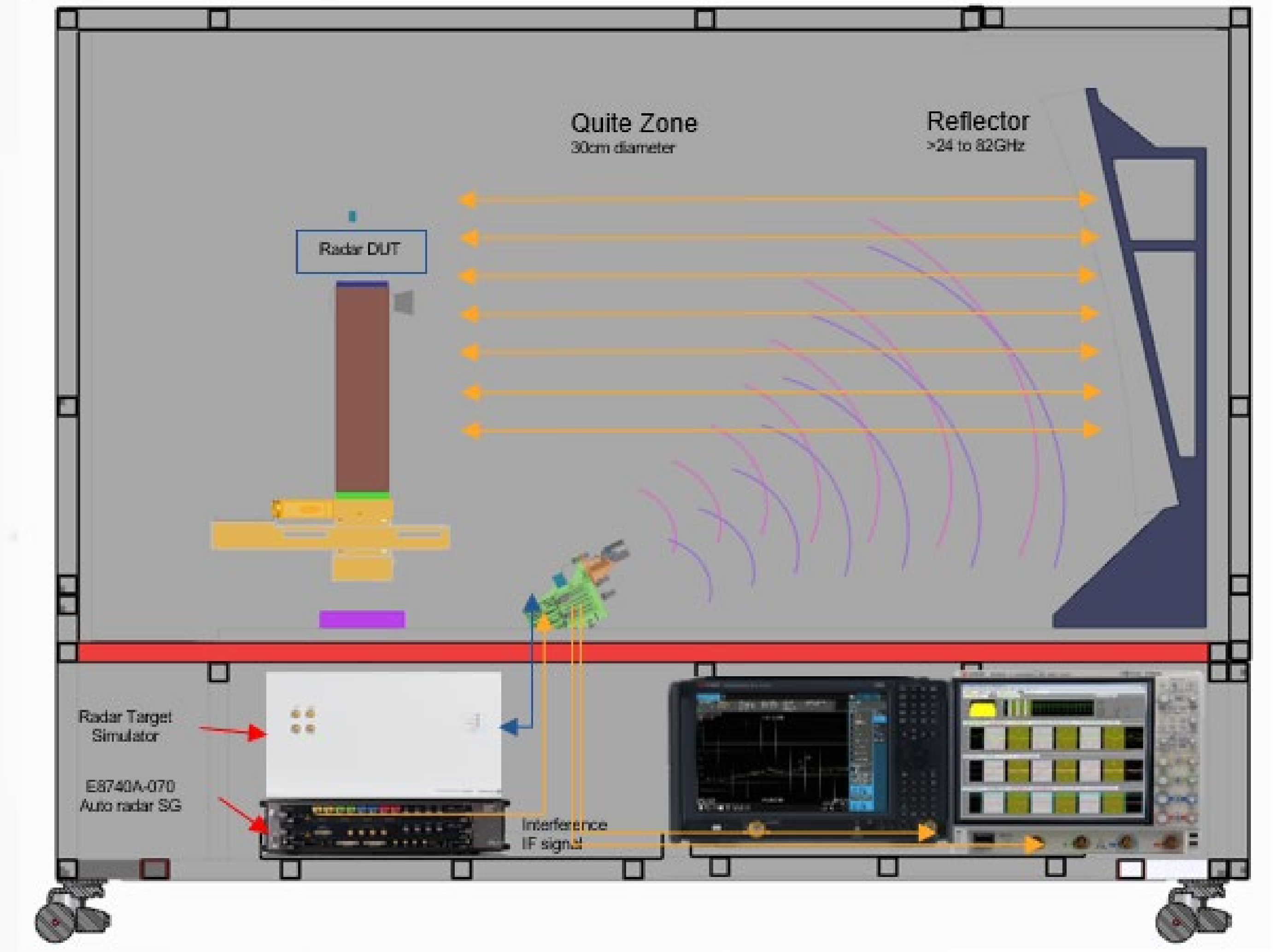
Free Space Far-field Path Loss Calculation $FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$

D* (cm)	24GHz Radar			76~77GHz Radar			77~81GHz Radar			2nd harmonic (2 x 81GHz)			3rd harmonic (3 x 81GHz)		
	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)
3	24.5	0.15	43.57	77	0.46	63.46	81	0.49	64.34	162	0.97	76.39	243	1.46	83.43
10	24.5	1.63	64.49	77	5.13	84.38	81	5.4	85.26	162	10.8	97.30	243	16.2	104.34
15	**24.5**	**3.68**	**71.53**	**77**	**11.55**	**91.42**	**81**	**12.15**	**92.30**	**162**	**24.3**	**104.34**	**243**	**36.45**	**111.39**
30	24.5	14.7	83.57	77	46.2	103.46	81	48.6	104.34	162	97.2	116.39	243	145.8	123.43

- At 81GHz, for a D of 10cm, path loss will be 85dB and far field distance is **5.4m**

Keysight CATR Far-field Chamber

Pass loss advantage >21dB w/ 15cm Ant D



77~81GHz Radar				
D* (cm)	Far field (m)	Path Loss (dB)	CATR Path Loss(dB)	CATR Path Loss Gain(dB)
10	5.4	85.25935	70.78347	14.47587
15	**12.15**	**92.303**	**70.78347**	**21.51952**
30	48.6	104.3442	70.78347	33.56072
100	540	125.2593	70.78347	54.47587

KEYSIGHT TECHNOLOGIES

OFDM/PMCW signal analysis

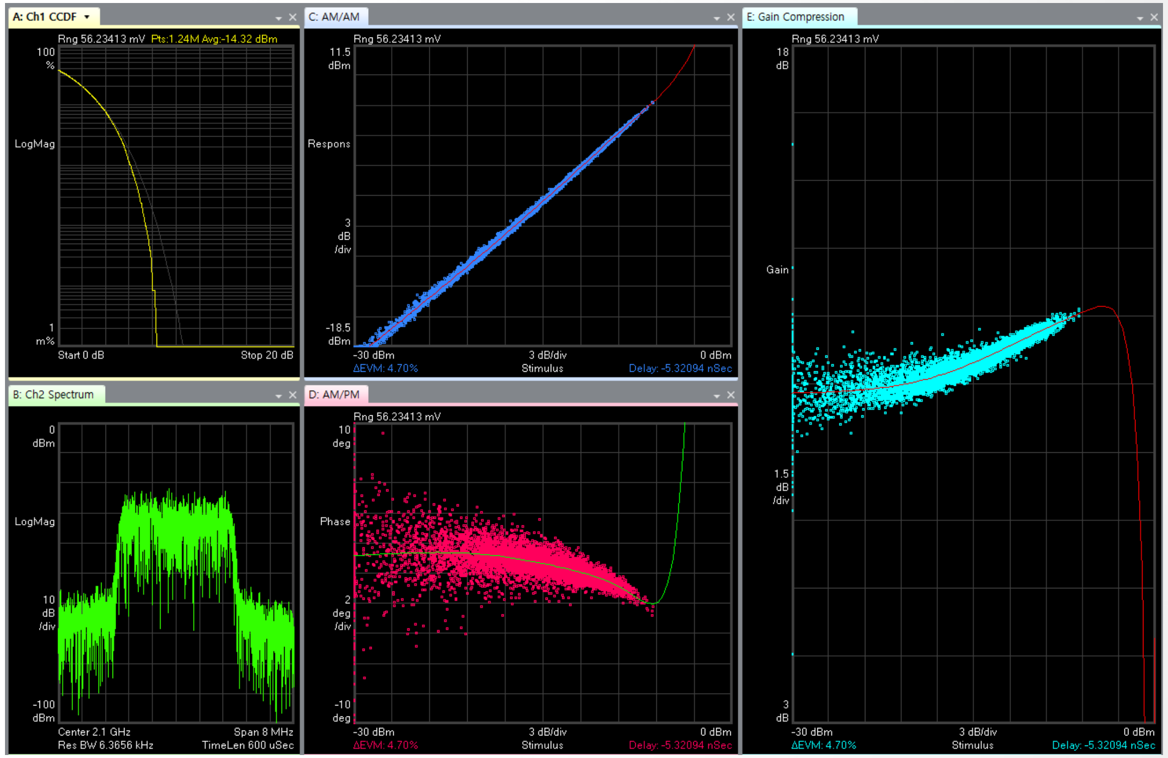
PA CALIBRATION REQUIRED FOR LINEAR AMP

Fast LFM, FCM (chirp) : Majority of current radar

- Small scale MIMO
- ADC sample rate : several 10's MHz
- Linear FM waveform
- Complex analog RF Tx and Rx with PLLs
- Low PAPR, Signal operates at saturation area of AMP
- Simple digital processing with FFT

Coded PMCW :

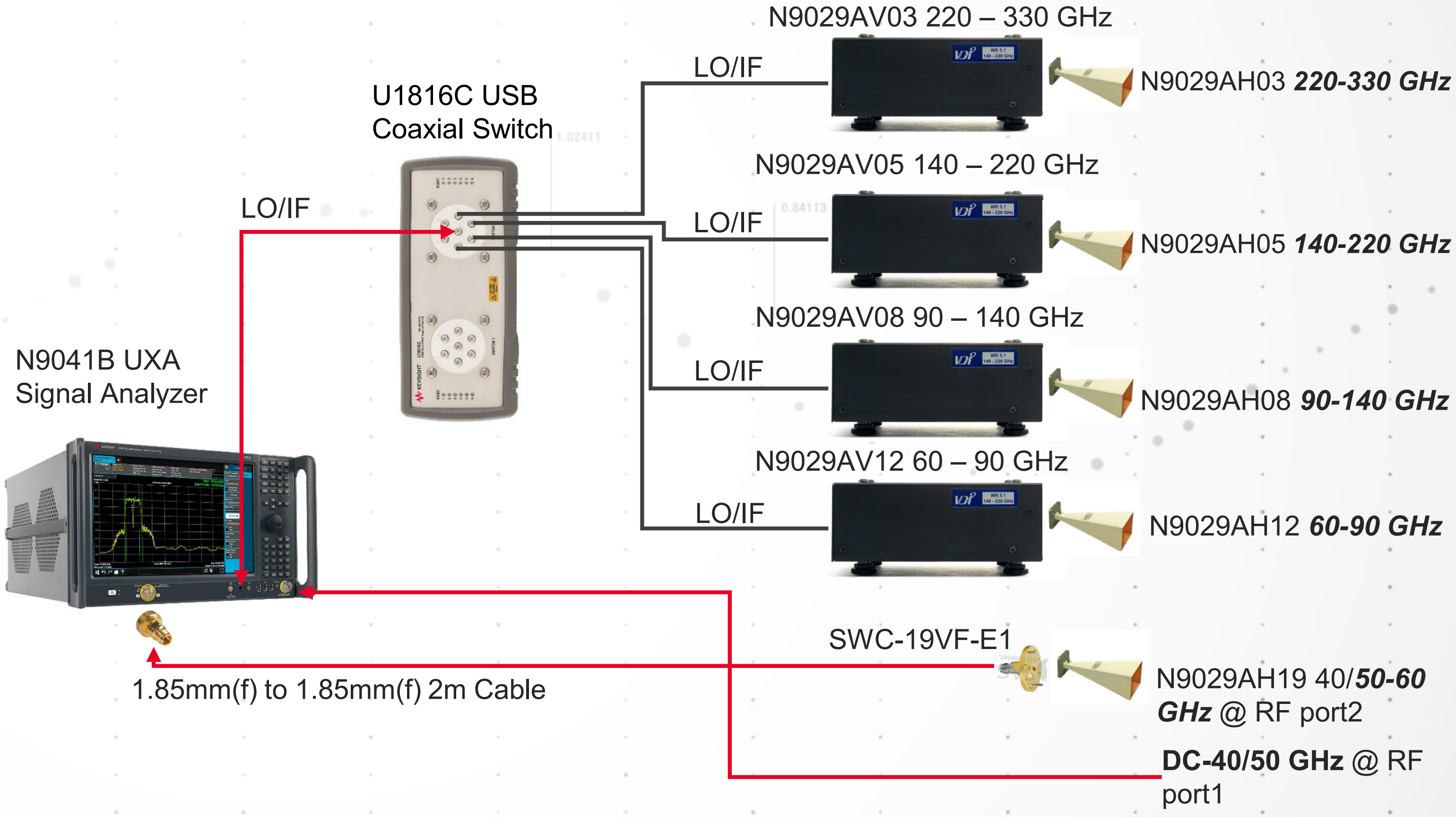
- Large and massive MIMO
- ADC sample rate : several GHz
- Phase coded waveform
- Simple analog RF Tx and Rx with PLLs
- High PAPR, Signal operates at linear area of AMP
- Required PA calibration at production line and AM-AM/PM measurement
- complex digital processing



89600B VSA S/W

Higher Frequency Emission Measurements

E8740A-090 AUTOMOTIVE EMISSION TEST UP TO ~330GHZ



KEYSIGHT TECHNOLOGIES

Summary and Conclusion

- Sensor fusion and evolved sensor technologies.
- Sensor fusion helps better decision in all environment, the evolution of automotive radar technologies is moving to ultra high resolution radar.
- Understanding of challenges for Sensor fusion and evolved sensor technologies
  - How to estimate challengeable Issues
  - How to verify issues with simulation and test measurement

KEYSIGHT
WORLD 2019