THE EVOLVING AUTOMOTIVE RADAR LANDSCAPE: WAVEFORM, SYSTEM SOLUTIONS AND TECHNOLOGY PARTITIONING

CWTe RESEARCH RETREAT 2018

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Safe & Secure Mobility – 90% Innovation through Electronics

Seamlessly Connected Mobility Experience

One hour per day in the vehicle

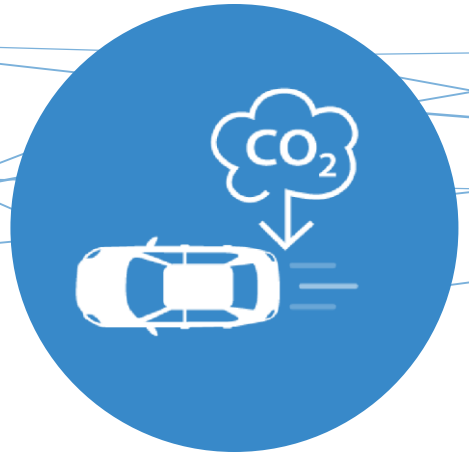
Enjoying Life

ADAS Towards Self-Driving

1.3M global road fatalities every year

Saving Lives

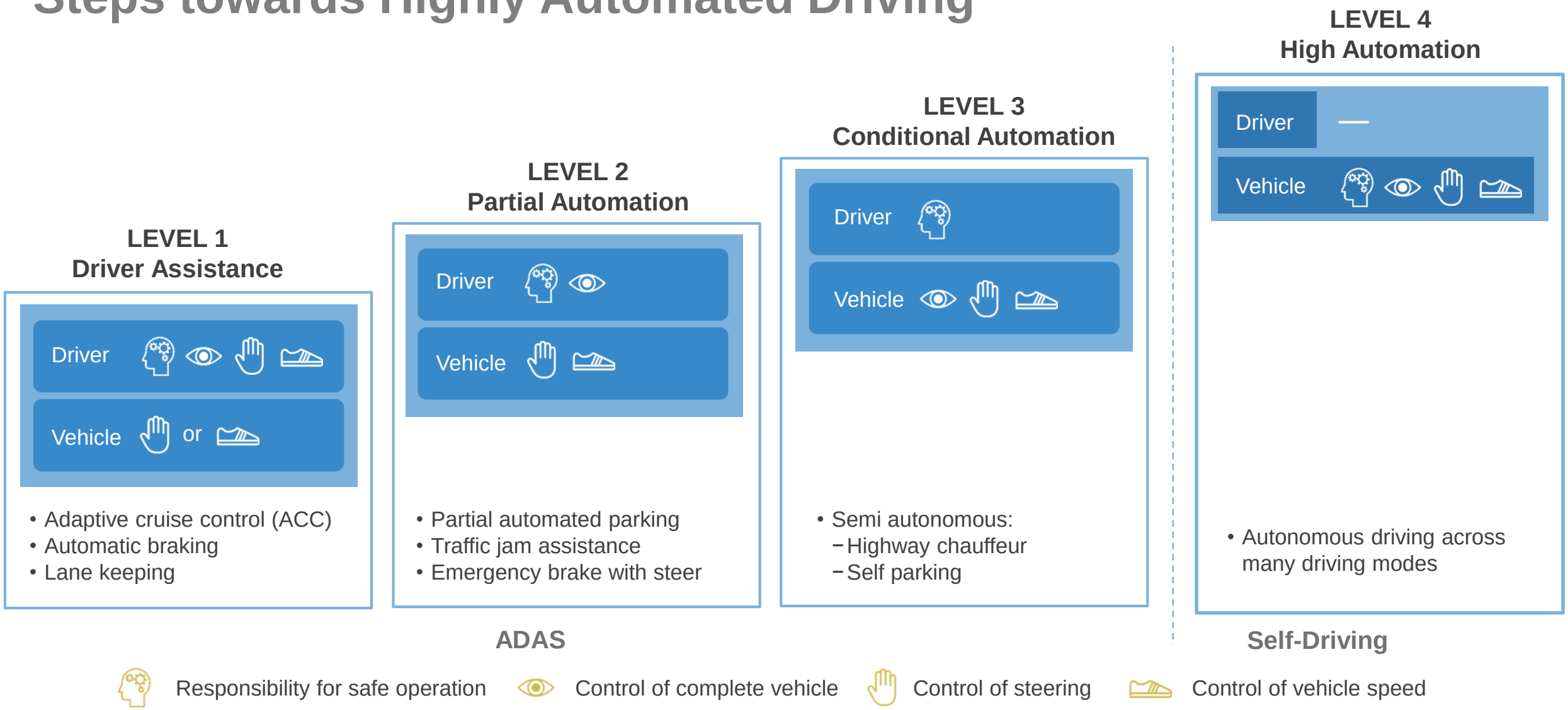
Energy Efficiency



US mandates 163 grams / mile and 54.5 MPG by 2025

Reducing CO_2

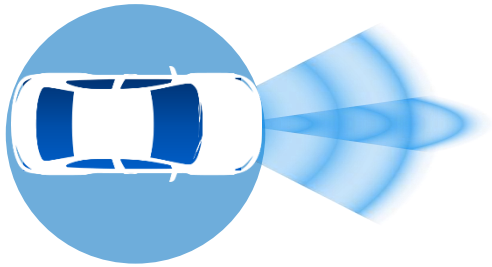
Steps towards Highly Automated Driving



Radar as a enabler for safety and autonomous vehicles

LEVEL 1-2

FRONT



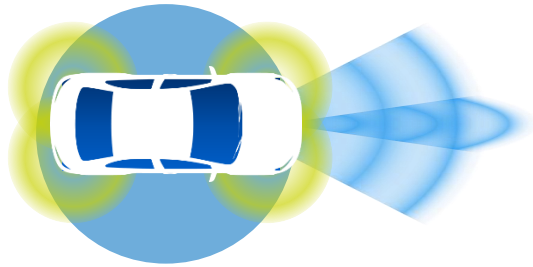
1-3 radars per vehicle

Scalable Transceiver Platform

Processor

LEVEL 3

CORNER + FRONT



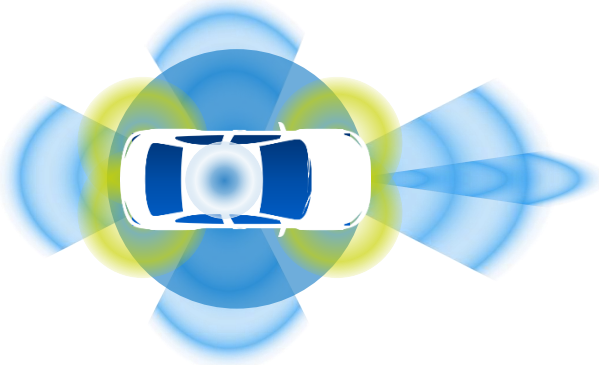
3-6 radars per vehicle

One-Chip Transceiver

Processor

LEVEL 4

360° COCOON



up to 20 radars per vehicle

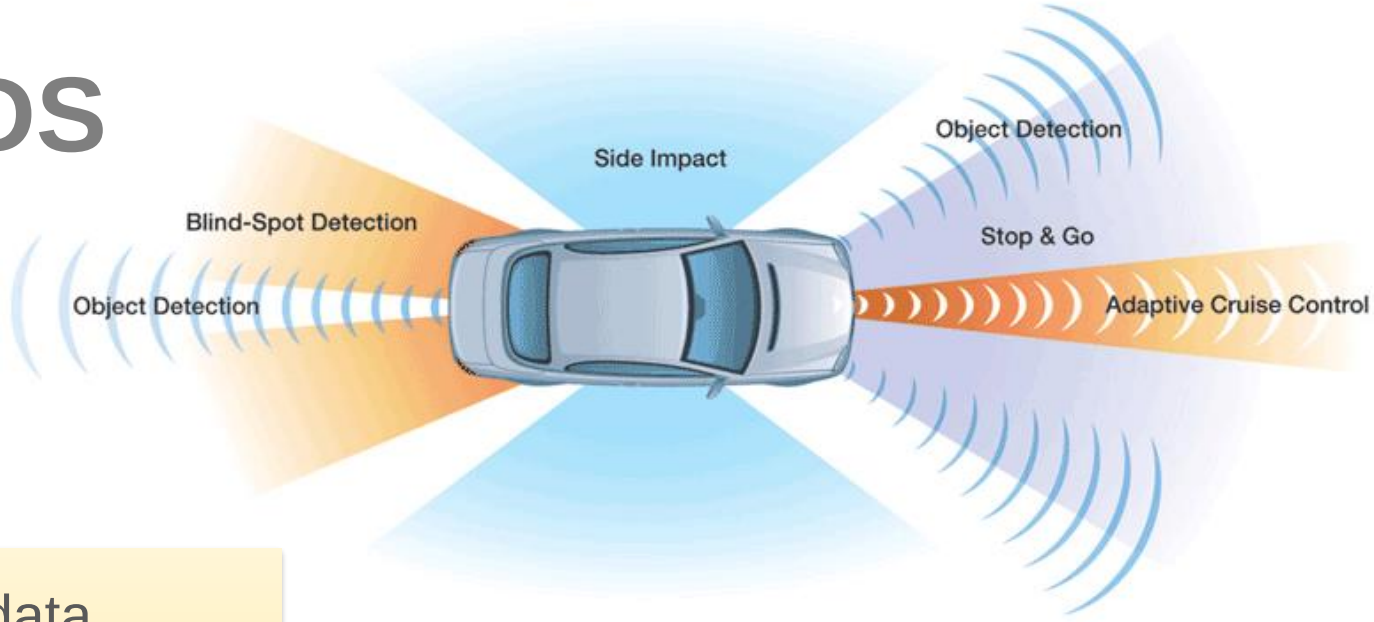
RFCMOS

One-Chip Transceiver

Processor

CAR RADAR TRENDS

76 – 81 GHz



Precise range, approach speed, angle data

Short-, mid-, long-range functionality

Excellent multi-target discrimination

One radar for multiple safety systems

Lower cost, high market penetration by regulation

Transition from slow-chirp to fast-chirp sequence measurements

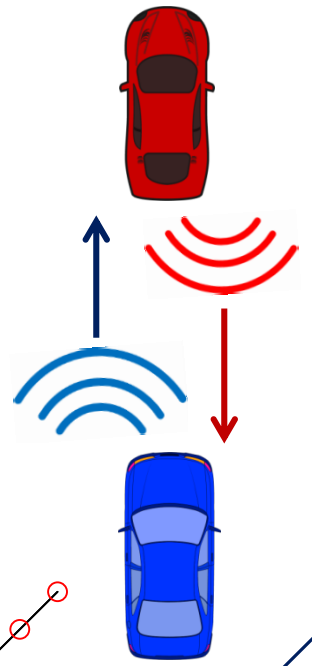
Large number of antenna's

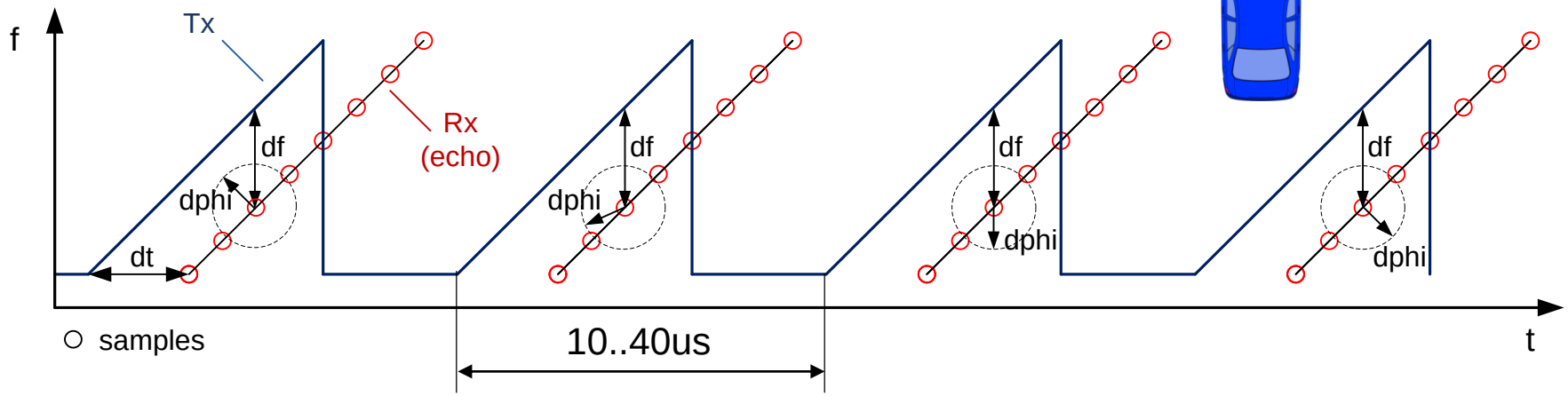
Super-resolution algorithms

MIMO techniques

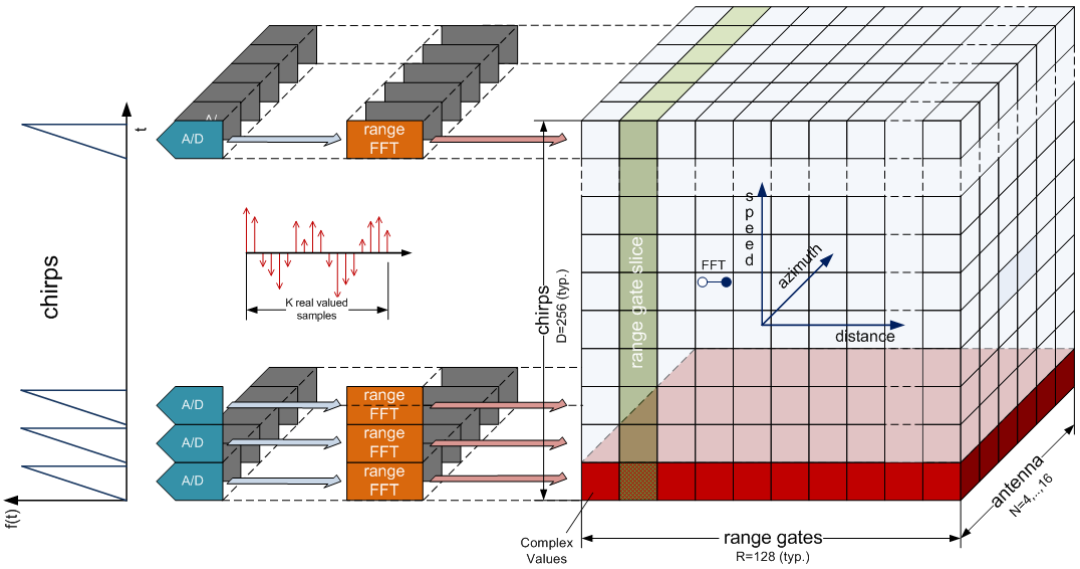
Fast Chirp Sequence Radar

- Combines FMCW & Pulse Method
  - Efficient usage of bandwidth
  - High resolution of distance and speed
  - High scan rate – high redundancy – better immunity
  - Multiple-target capable, no range – velocity ambiguity

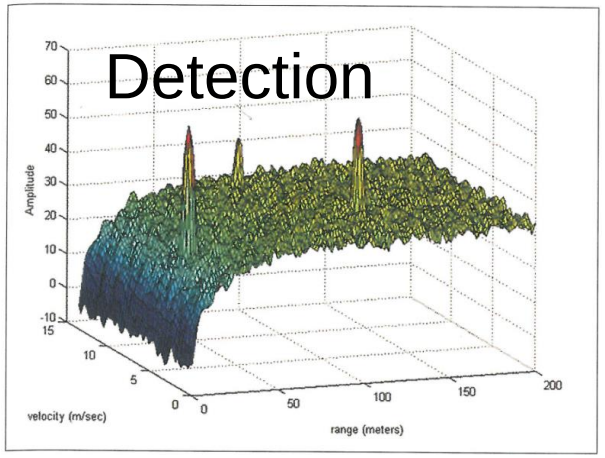


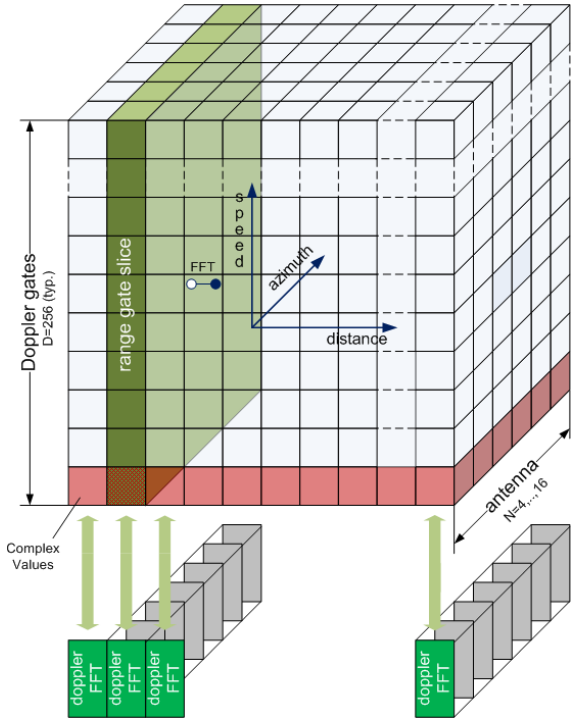


Fast Chirp Sequence Signal Processing



- Range Processing
  - real to complex FFTs
  - provide SNR gain
  - Calculates range gates





- Doppler FFTs
  - Complex to complex FFTs
  - Provide SNR gain
  - Determine the relative speed (Doppler gates)

CMOS TECHNOLOGY

mmWave LNA and RX designs in 40nm technology

"Complete On-Wafer Noise-Figure Characterization of 60-GHz Differential Amplifiers" - NXP paper on T-MTT June 2010

60 GHz LNA

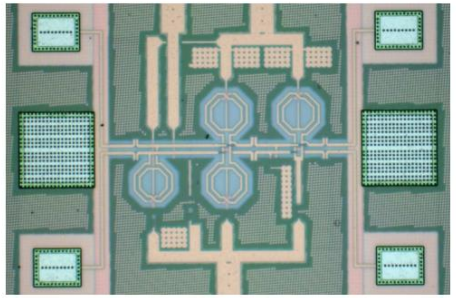


Fig. 8. 60-GHz differential LNA studied in this paper.

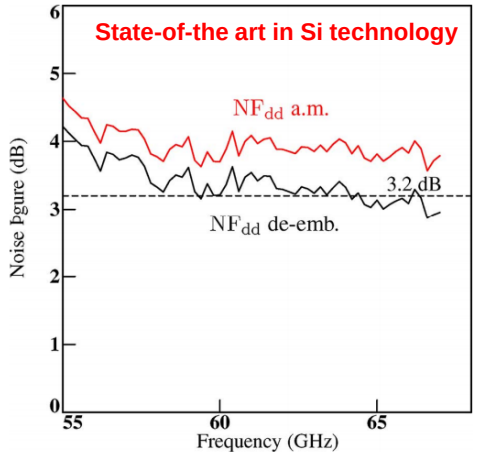
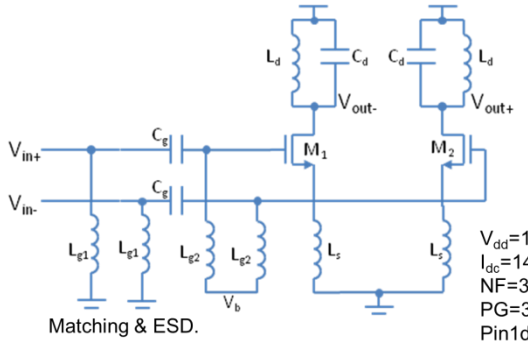
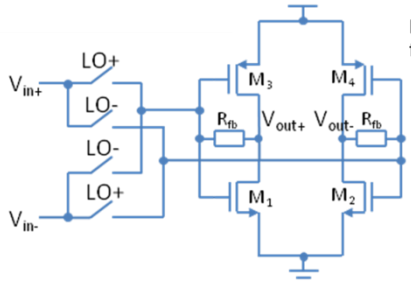


Fig. 11. Minimum differential noise figure as measured (a.m.) and after removal of the deteriorating effects of the measurements pads using OSL noise de-embedding (de-emb.).

76-81 GHz LNA – Mixer – IF stage



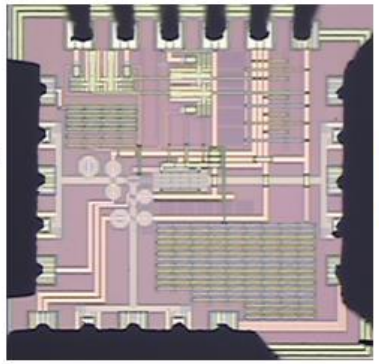
V$_{dd}$=1.1V
I$_{dc}$=14.7mA.
NF=3.5dB.
PG=3.1dB.
Pin1dB=7.8dBm.



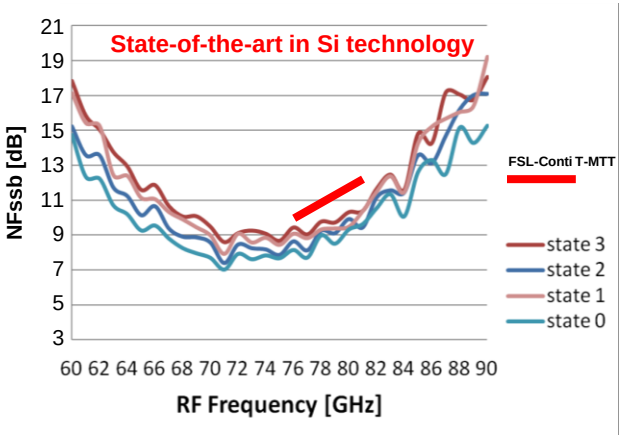
M1-M4 use large W*L for low flicker nosie.

V$_{dd}$=1.1V
I$_{dc}$=22mA.
NF=10.7dB@1MHz.
PG=2.1dB.
Pin1dB=4.8dBm.

DC power and control



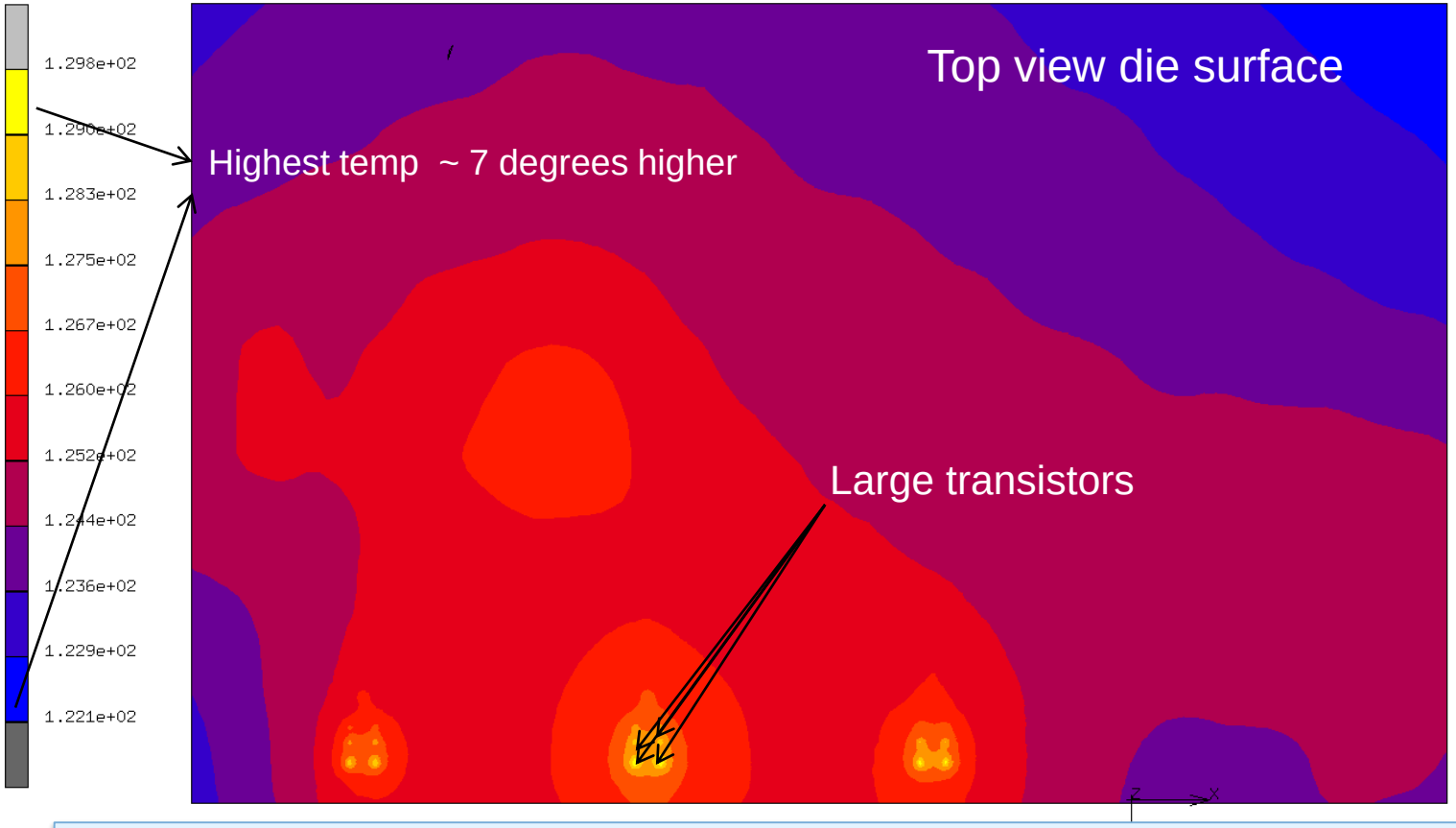
Measured NF on-wafer



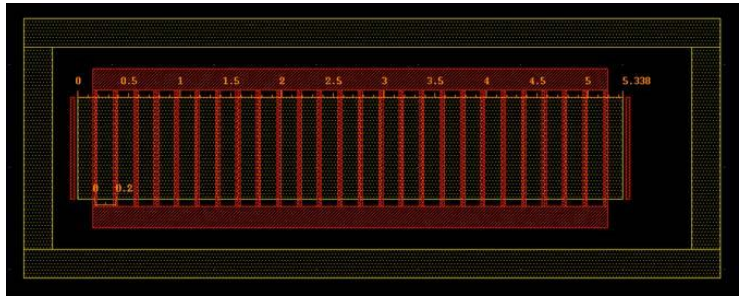
Robust, stable broad-band performance

CMOS TECHNOLOGY

THERMAL BEHAVIOR



Temperature gradients limited to about ***7 degrees*** across the silicon surface.



The distributed nature of a CMOS transistor spreads the heat much better across the silicon surface.

Absence of deep-oxide trenches in CMOS favors heat spreading towards the silicon substrate.

Dolphin: TEF8102/4 Car Radar IC

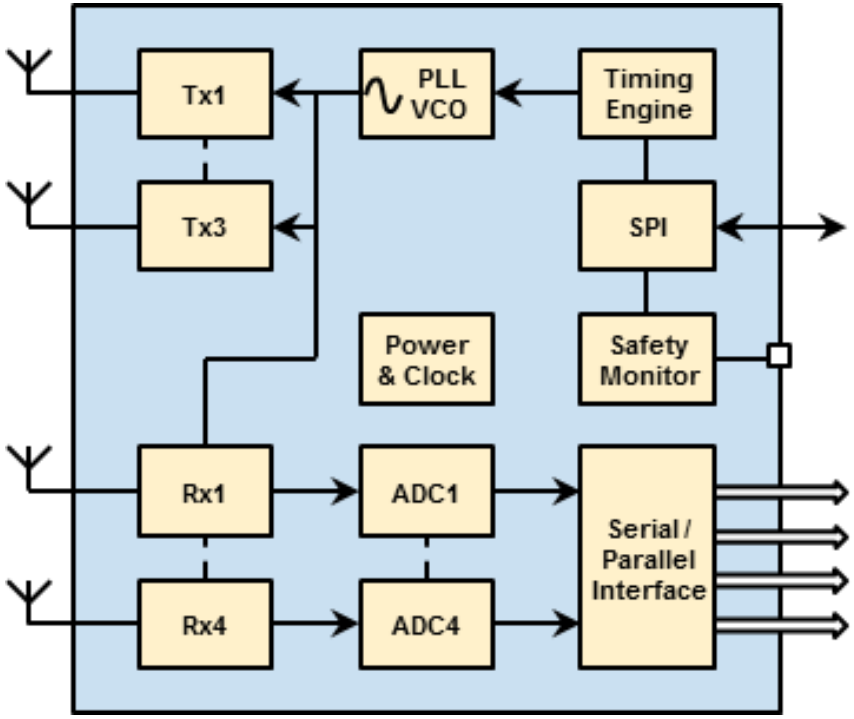
RFCMOS Car Radar Transceiver for 76-81 GHz

Features

- Fully integrated RFCMOS Radar Frontend for 76-81GHz
- 3 TX, 4 RX Channels
- Optimized for Fast Chirp Modulation
- Integrated IF Filter
- Digital Interfaces (CSI-2, CIF, LVDS)
- ISO26262 compliant development: ASIL Level B

Benefits

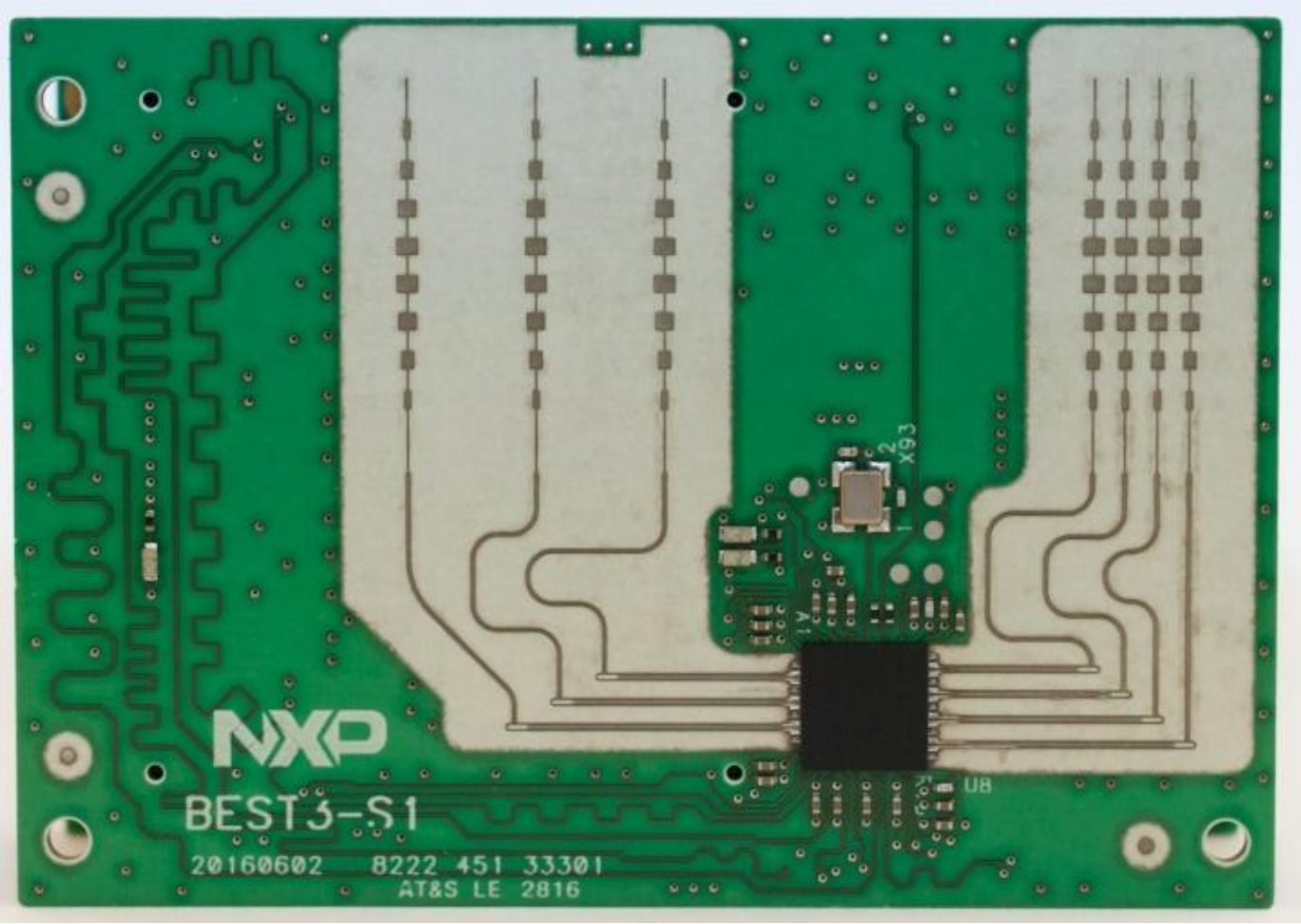
- Very Low Power
- Small Footprint enabling small Sensor Designs
- Easy Integration



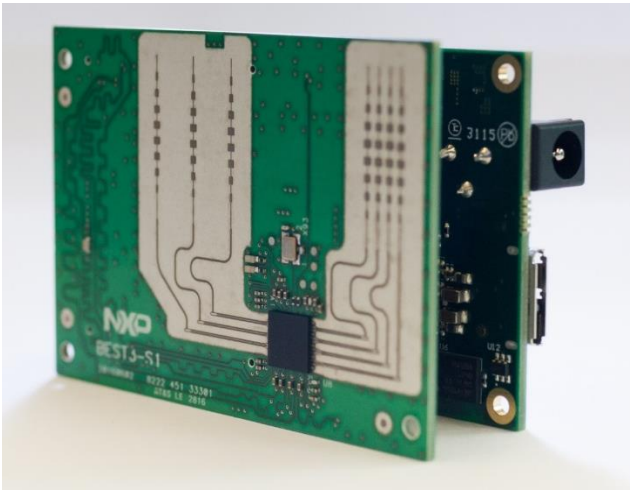
Dolphin

Digital Out, Low Power, Highly Integrated

Packaged chip and demonstration board

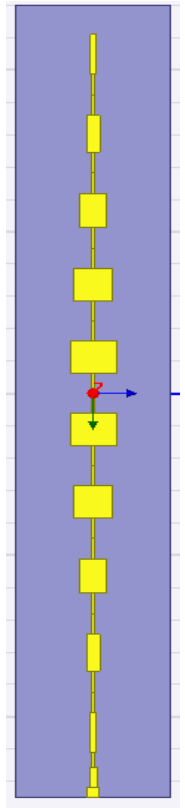


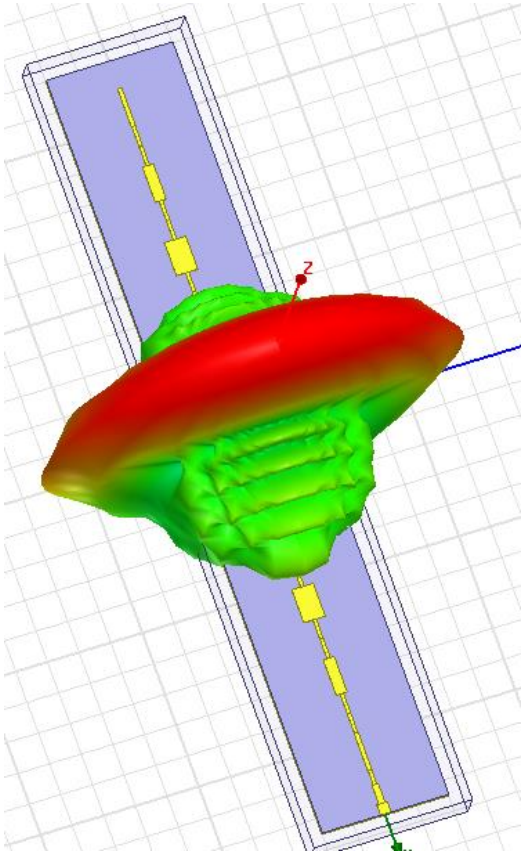
- Dolphin ES1
- Antenna PCB
- Opal Kelly PCB (PC interface)
- PC Software
- Documentation

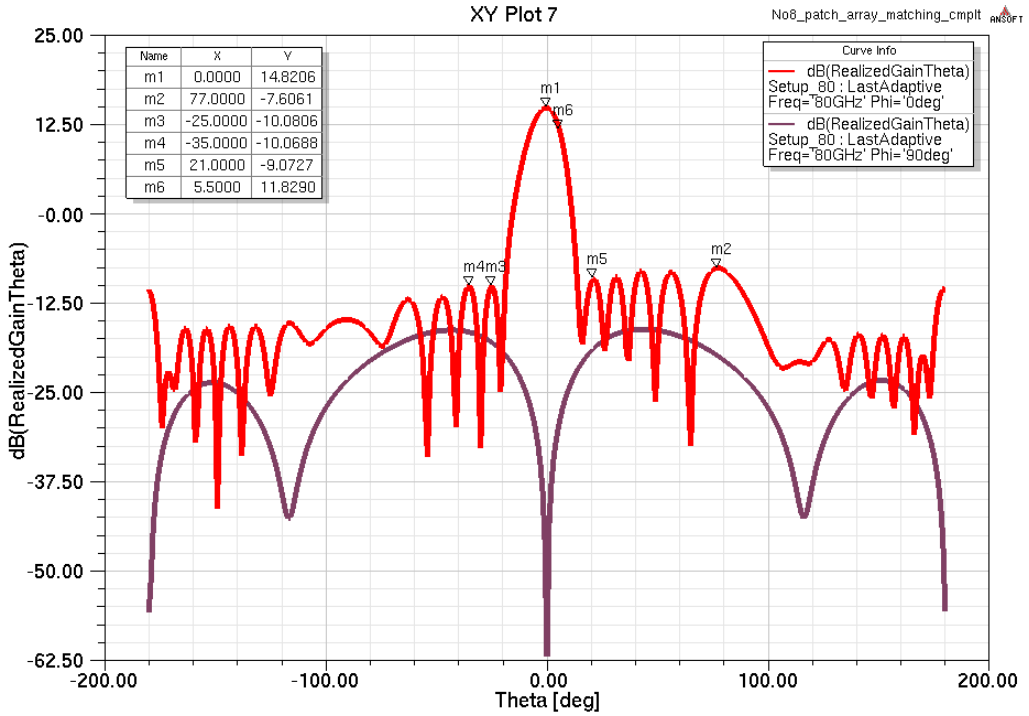


Antenna Design

HFSS Simulation 10 elements Franklin Array



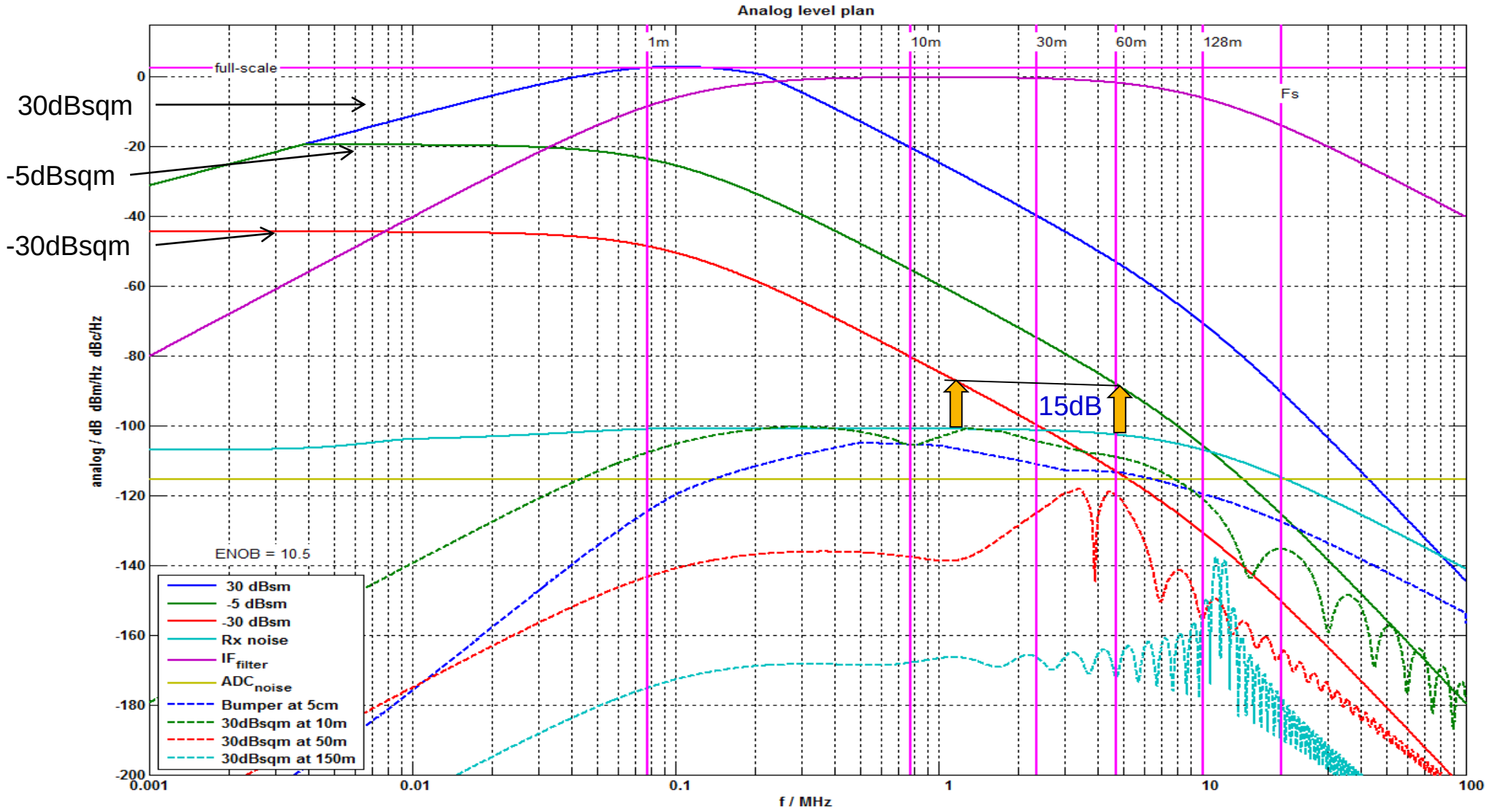




High Gain Fan Beam antenna array for sufficient Range and low Road Clutter.

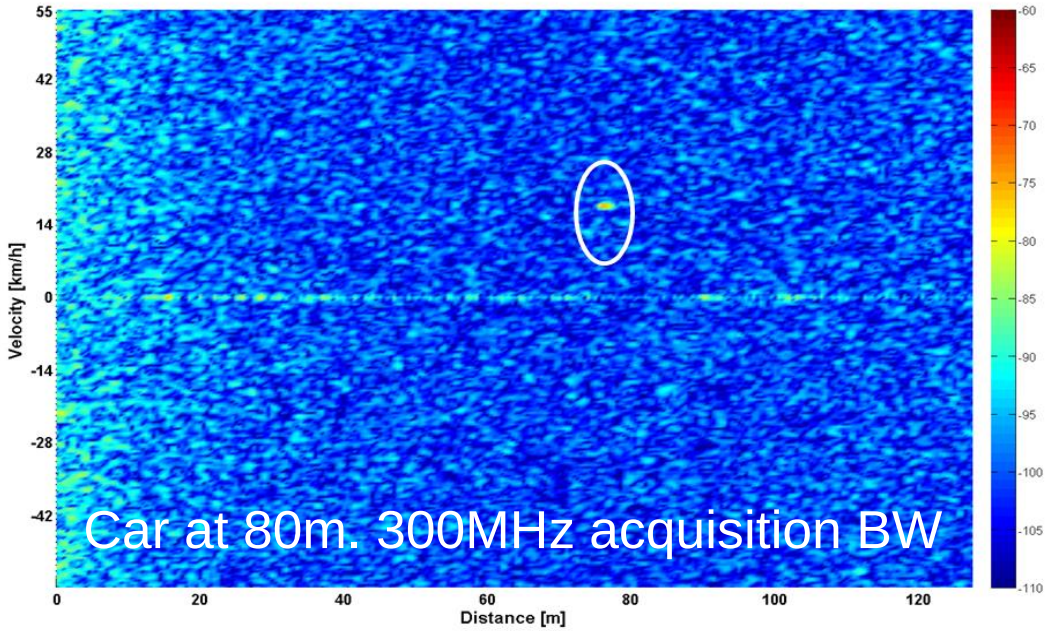
Analog level plan for 300MHz in 30us, N = 512

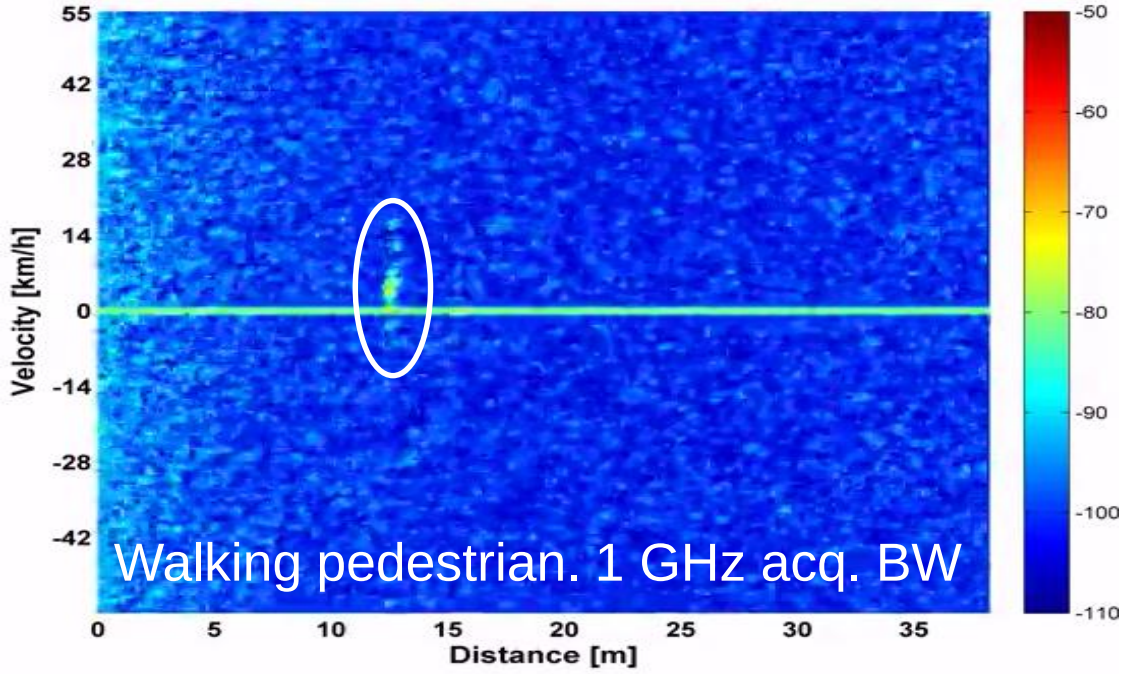
ADC sample rate 20MHz, NBW=100Hz

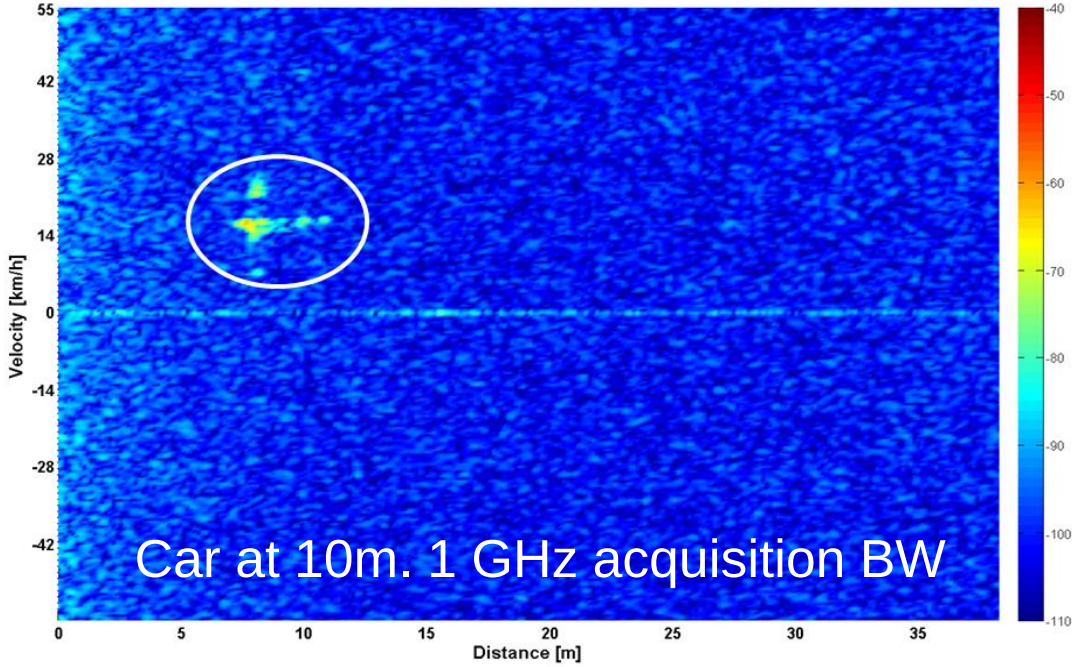


Radar system measurements

Test site



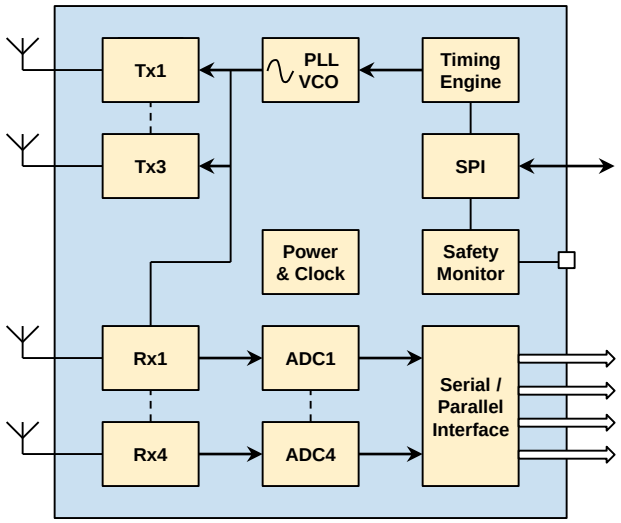




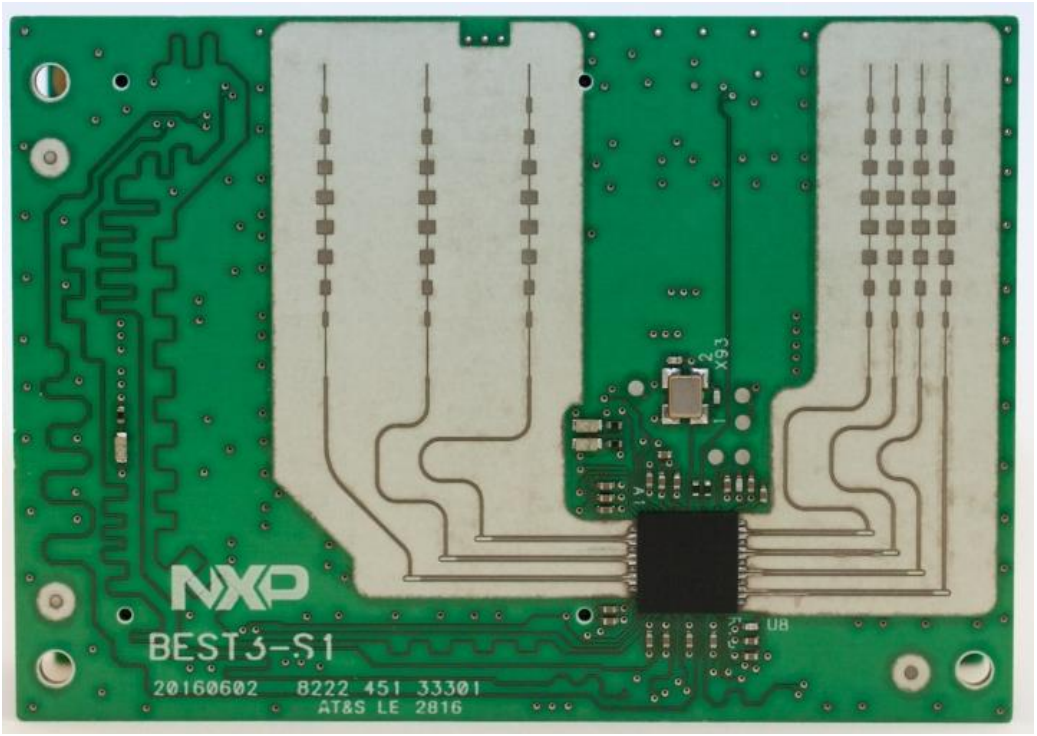
Increasing angular resolution

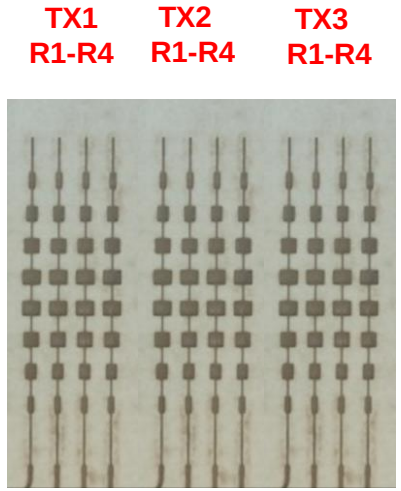
- Sparse arrays
- Analogue beam steering: RX and/or TX
- Super resolution algorithms
- MIMO virtual arrays

Dolphin MIMO antenna array configuration



TX1 TX2 TX3 RX1..RX4



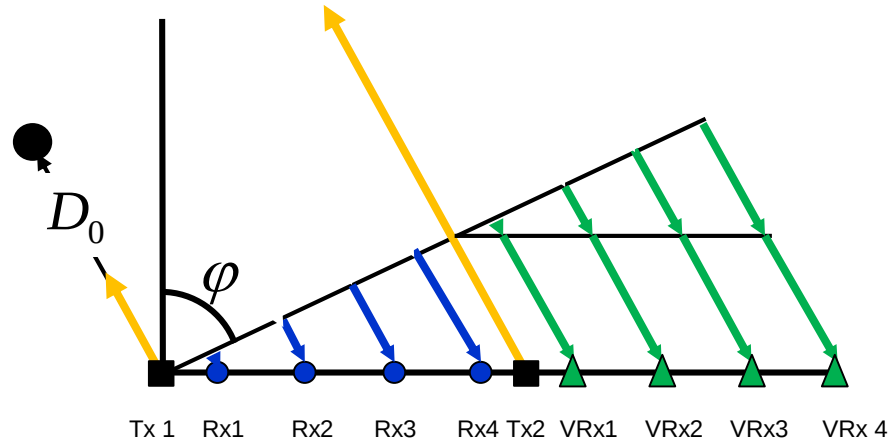


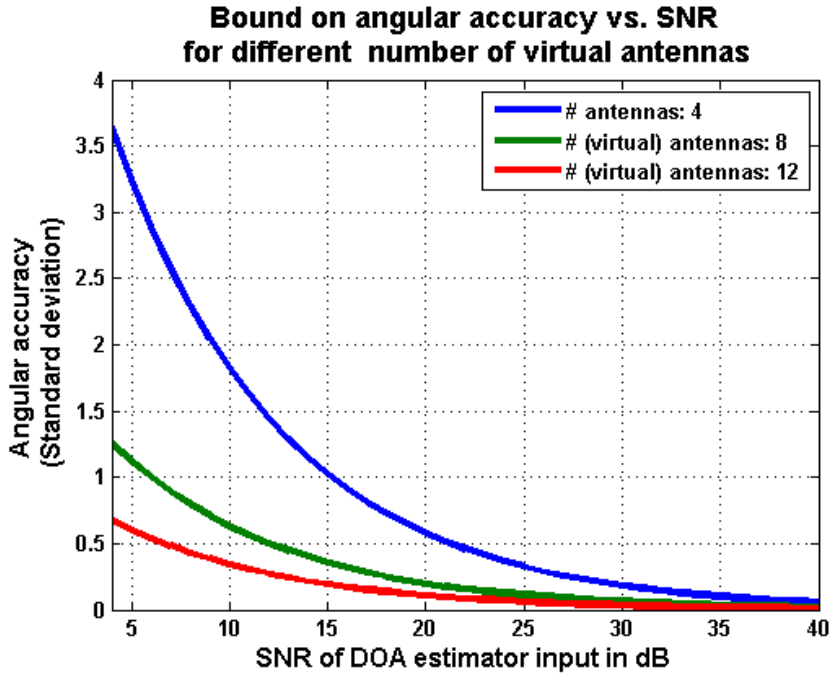
Virtual RX1 … RX12 array

Coherent MIMO radar

- Maximum number of (virtual) antennas: N = 3 (Tx) x 4 (Rx)
- Angular resolution as a function of array aperture:
  - Res ~ 70º λ_0/aperture.
  - 4 RX antennas at $\lambda_0/2$ → 4 RX array -> ~ 35º resolution.
  - With 3x MIMO -> ~ 12º resolution.

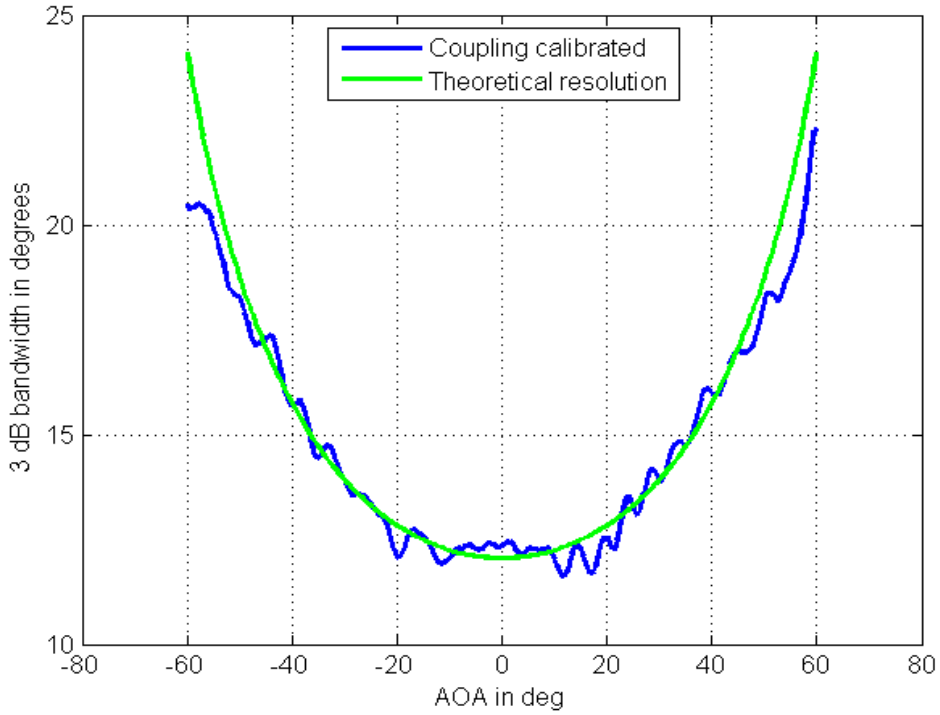
$$\varphi_{res,\deg}(\varphi) = 180\alpha_{window}\frac{1.772}{\pi N_{Tx} N_{Rx}\cos(\varphi)}$$





Angular resolution with Dolphin board, 3TX-4RX MIMO

- 3 dB beamwidht measured for various pointing angles.
- 3 Tx, 4 Rx MIMO operation.
- Conventional Bartlett beamformer.
- Maximum resolution 12 deg, in agreement with aperture ~ $6\lambda_o$



Angle of arrival resolution measurement

Summary

Fast-chirp sequence took over: no range-doppler ambiguities, unlimited number of detectable targets.

RFCMOS transceivers combines high-performance with low-power.

Key to enable small-corner sensors as well a multiple-transceivers high-resolution imaging radars.

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FOR A SMARTER WORLD