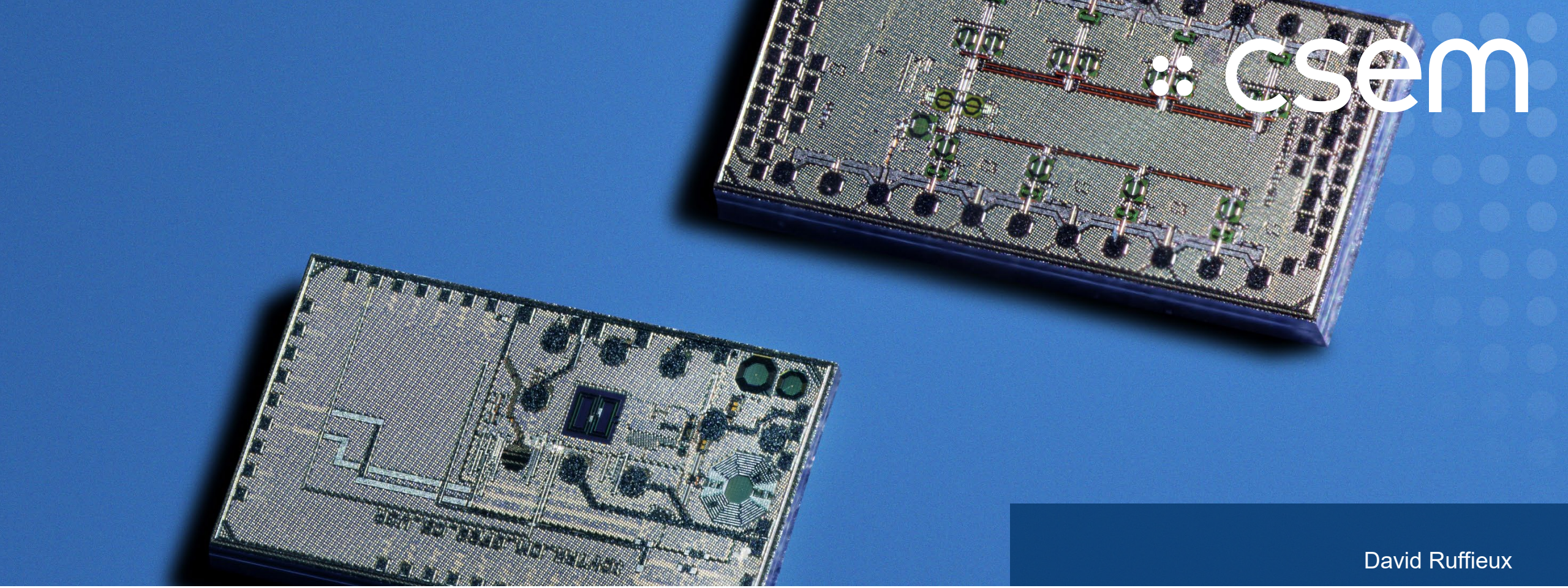


David Ruffieux

EE426
RADIO FREQUENCY DESIGN TECHNIQUES

ASICs for the EDGE …

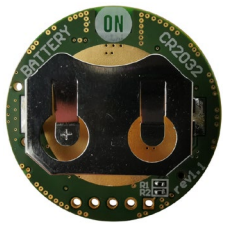
building devices
to sense our world

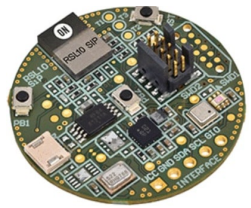
Extreme EDGE nodes

Middle EDGE nodes

Data Centers

Wireless
Sensor Nodes





Data generation
& Transmission

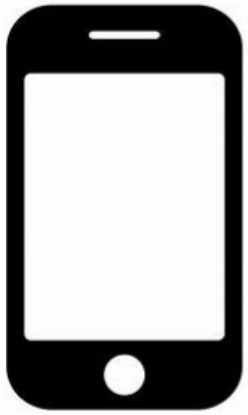
Tablets

S-Watches

WiFi

BLE

Earbuds

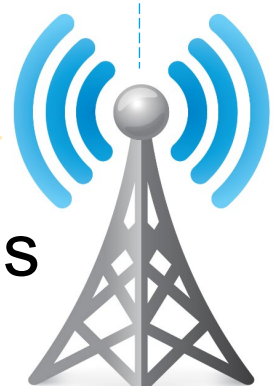


Phones

WiFi routers

Wired

Base stations



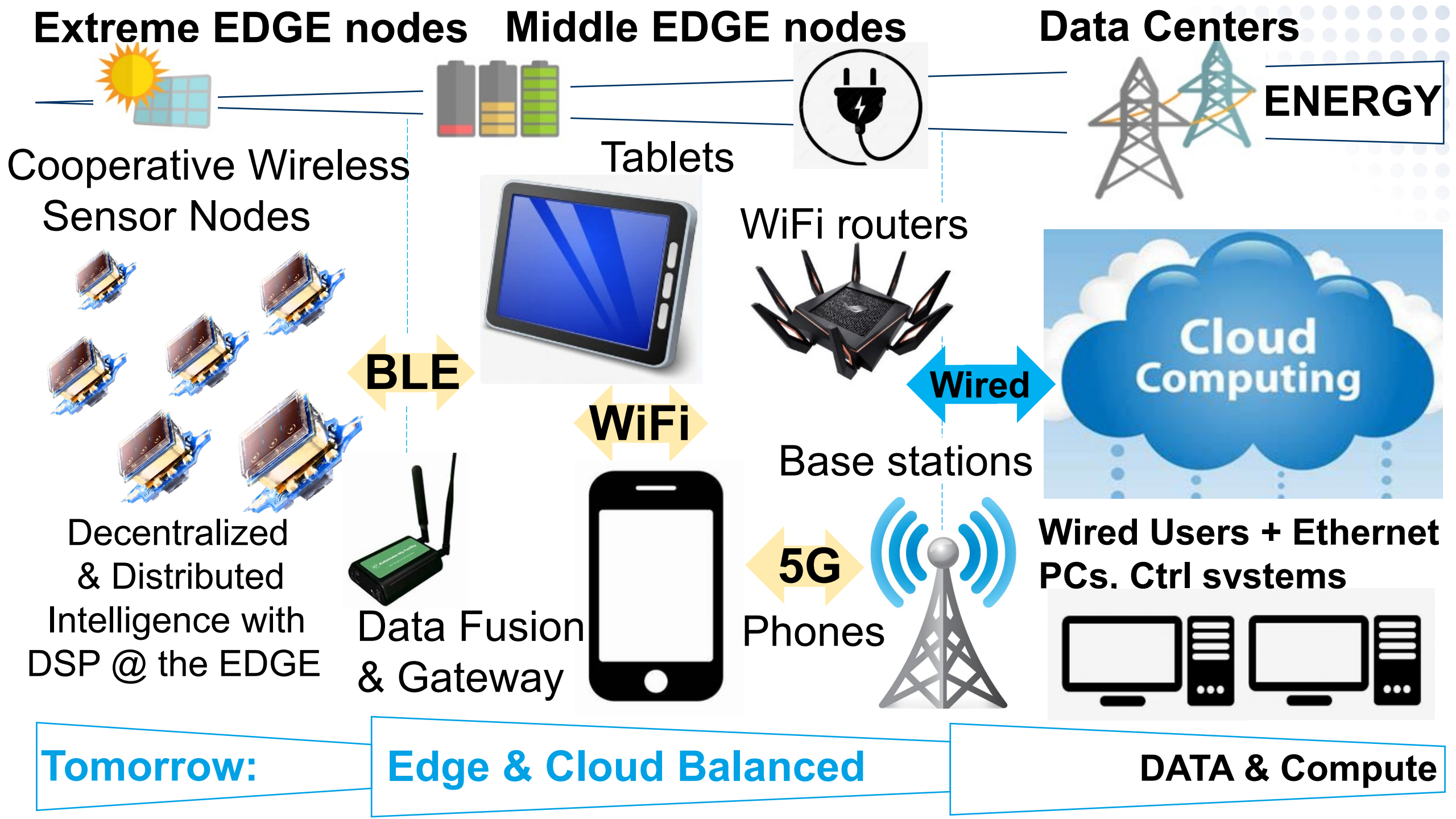
5G

Wired Users + Ethernet
PCs. Ctrl svstems

ENERGY

1% of GHGE

Today: Cloud Centric **DATA & Compute**


Extreme EDGE nodes
Middle EDGE nodes
Data Centers
ENERGY
Cooperative Wireless Sensor Nodes
Tablets
WiFi routers
BLE
WiFi
Wired
Cloud Computing
Base stations
Decentralized & Distributed Intelligence with DSP @ the EDGE
Data Fusion & Gateway
5G
Phones
Wired Users + Ethernet PCs. Ctrl svstems
Tomorrow:
Edge & Cloud Balanced
DATA & Compute

ENERGY AUTONOMOUS WIRELESS SENSORS

EXG acquisition

- 100pJ/bit

Digital microphone

- 300pJ/bit

Image sensor

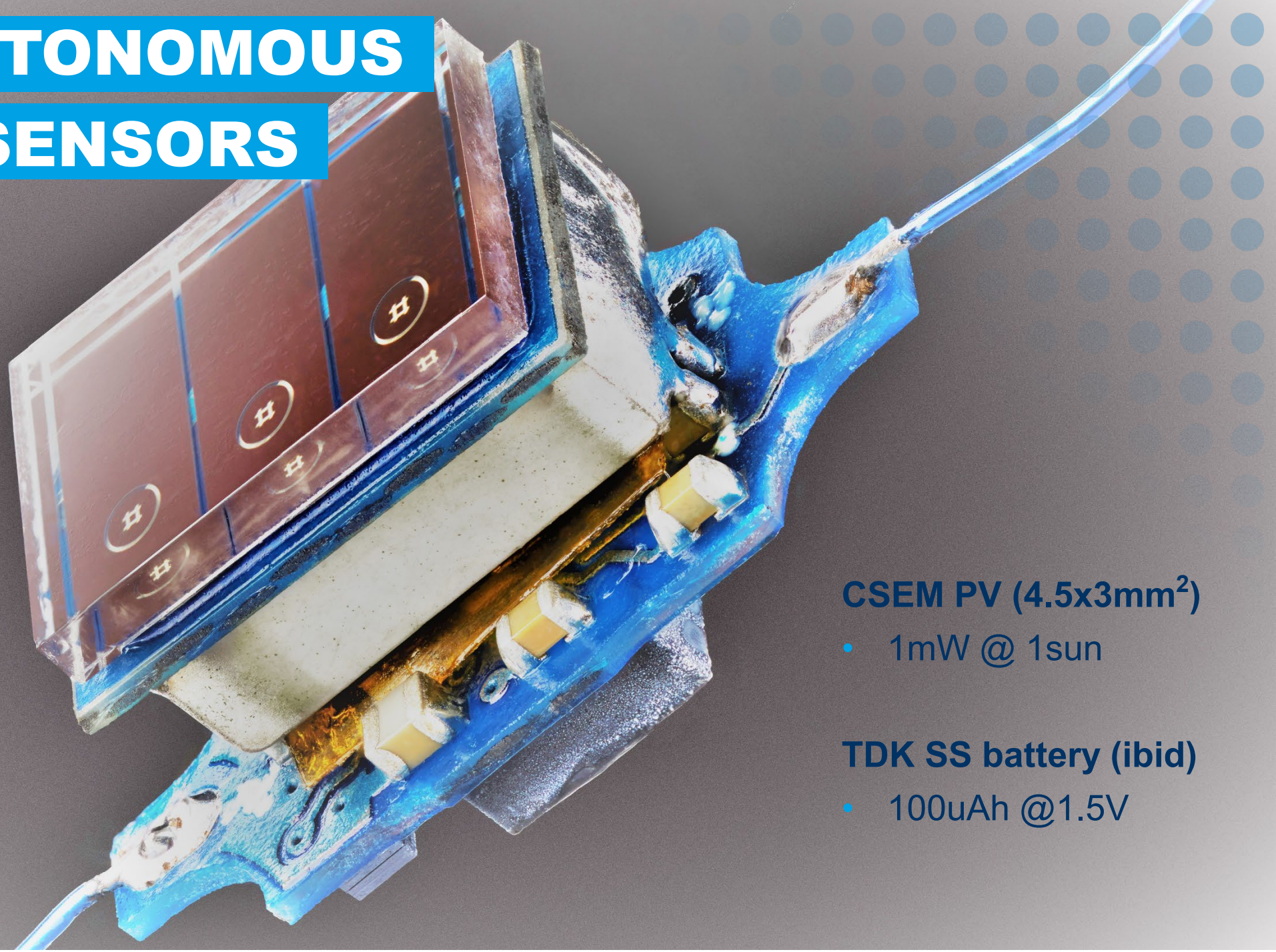
- 30pJ/bit

Processing

- 0.1pJ/bit

BLE TRX 1Mbps

- 5nJ/bit



CSEM PV (4.5x3mm^2)

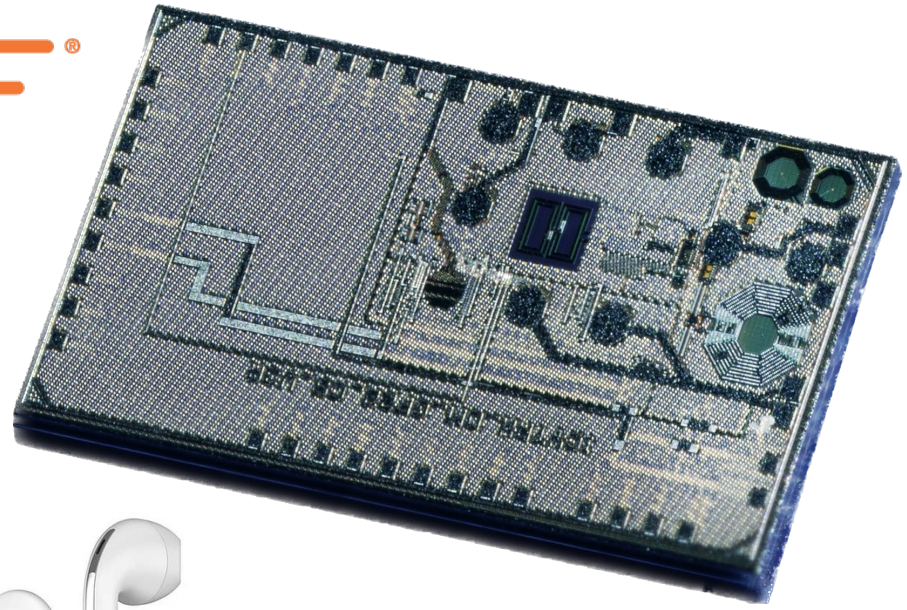
- 1mW @ 1sun

TDK SS battery (ibid)

- 100uAh @1.5V

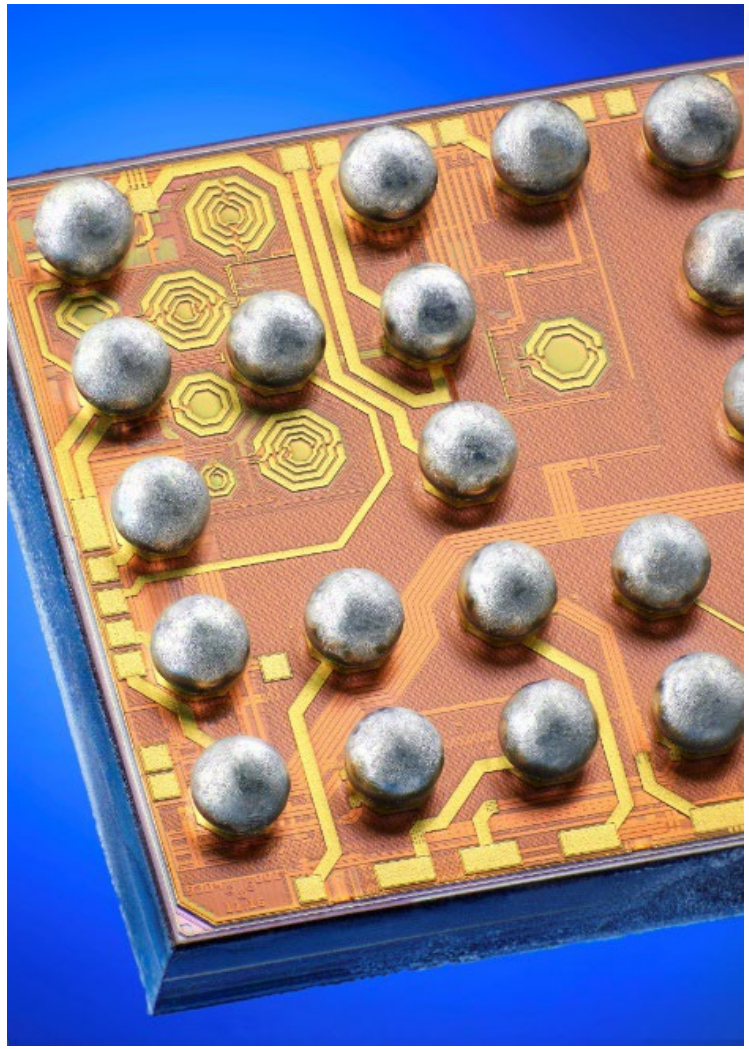
ICYTRX, -DM, -LE

- Bluetooth Radio Transceiver IP
- Bluetooth Low Energy (BLE)
  - Incl. Long Range (LR)
- Bluetooth Classic
  - Basic Rate (BR)
  - Enhanced Data Rate (EDR)
- Dual Mode (DM): BLE + Classic
- Partnership with Globalfoundries (Part of the FDX Network)
- Applications:
  - Hearing aids
  - True Wireless Stereo (TWS) headphones
  - Wireless sensors



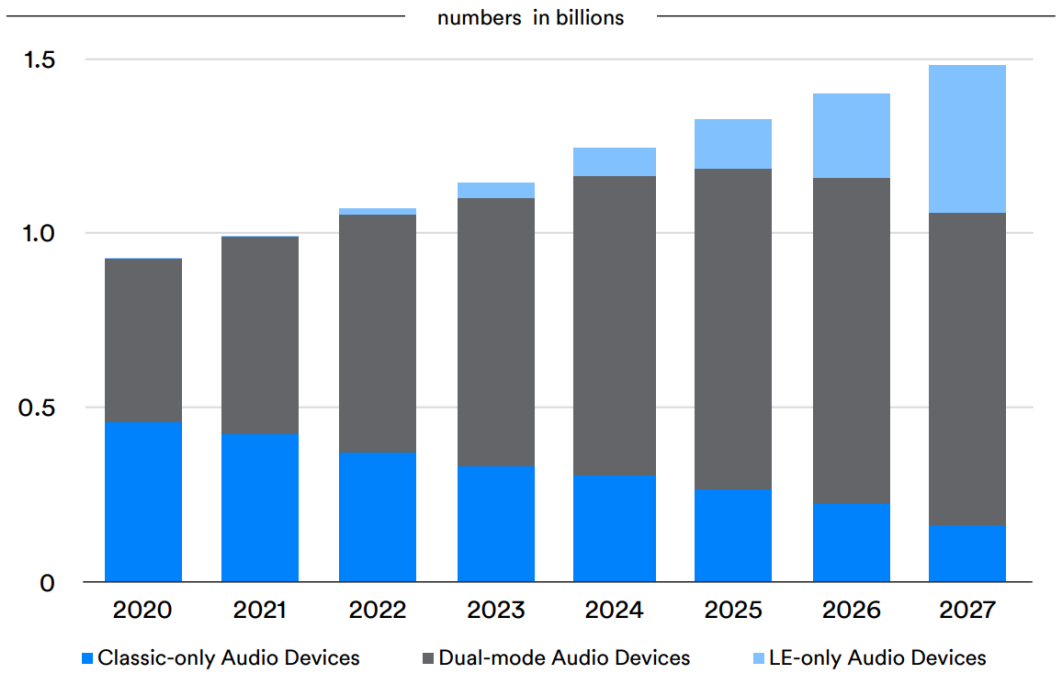
ICYTRX-55 : BLUETOOTH LE RADIO IN 55NM

- The first true sub-1V BT 5 LE silicon IP
- Ultra low power consumption
- Best-in-class sensitivity -97dBm (BLE 1Mbps)
- Bluetooth 5.4 compliant
- Supports IEEE802.15.4 (Zigbee, Thread…)
- Silicon-proven (GF55LPX, TSMC55,…) in various metal stacks
- In production with several major semiconductor vendors, e.g. ON Semiconductor, EM Microelectronics, Oticon



ICYTRX-DM-22 : BT DUAL MODE RADIO IN 22NM

- **Dual-mode Bluetooth**
  - Bluetooth LE for data/LE Audio
  - Bluetooth EDR for audio
- **Best quality audio streaming at the lowest power**
  - Game-changing autonomy on a battery cell
  - Industry leading budget link for reliable audio streaming
  - Excellent resilience to interferers



Source: ABI Research

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ICYTRX-DM-22 FEATURES

- **Various foundries with various options**
  - Global Foundries 22 nm FD-SOI
  - TSMC 22 nm

- **Key features**
  - Bluetooth 5.2 Dual-Mode radio: EDR and LE 2Mbps for flexible audio experience
  - Long Range (coded S2 & S8) and Direction Finding (DF) BLE options
  - Flexible modem compatible with 802.15.4-2015 and other modulations

5.0
5.1
...
5.4

ICYTRX-HDT-XX: BT DM WITH HIGH DATA THROUGHPUT

- **Features**
  - HDT compatible, with all datarate options
  - Classic full options (EDR2-3)
  - all existing LE features
  - High performances at low power

- **Parallel feature development**
  - Wake-up Radio
  - Higher Frequency Bands

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ICYTRX-DM PERFORMANCES

- **General conditions**
  - Industrial operating temperature range:
    -40°C to +85°C
  - RF core supply voltage: 0.9V
  - PA supply voltage:
    - Low-power mode: 0.9V
    - High-power mode: up to 1.6V
- **Peak RF analog power consumption**
  - Ultra-fast settling for minimal overhead
  - 4.2 mW in RX BLE1M/BR/EDR
  - 9.8 mW @ 0dBm in TX BR/BLE

ICYTRX-DM PERFORMANCES

TX

- Maximum peak output power
  - Low power mode:

    + 1.3 dBm @ 0.9V
  - High power mode :

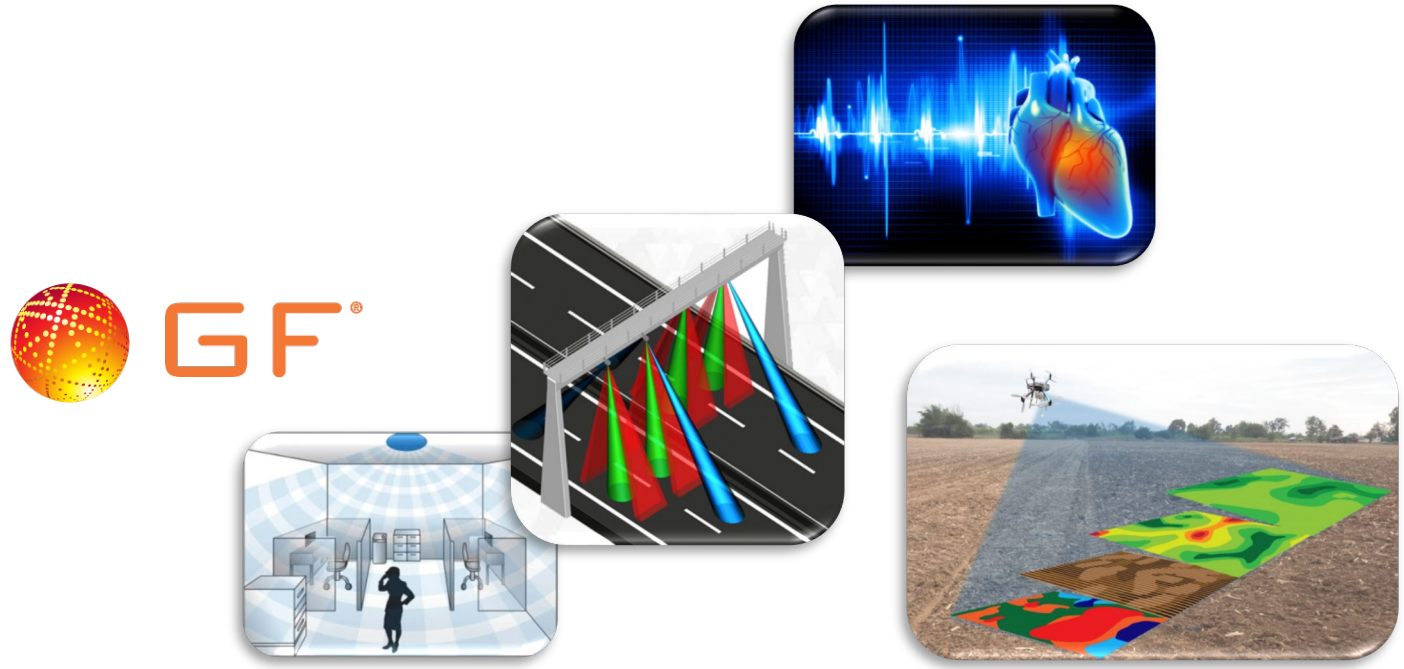
    +14.6 dBm @ 1.6V
- Wide range: -30 dBm to max

RX

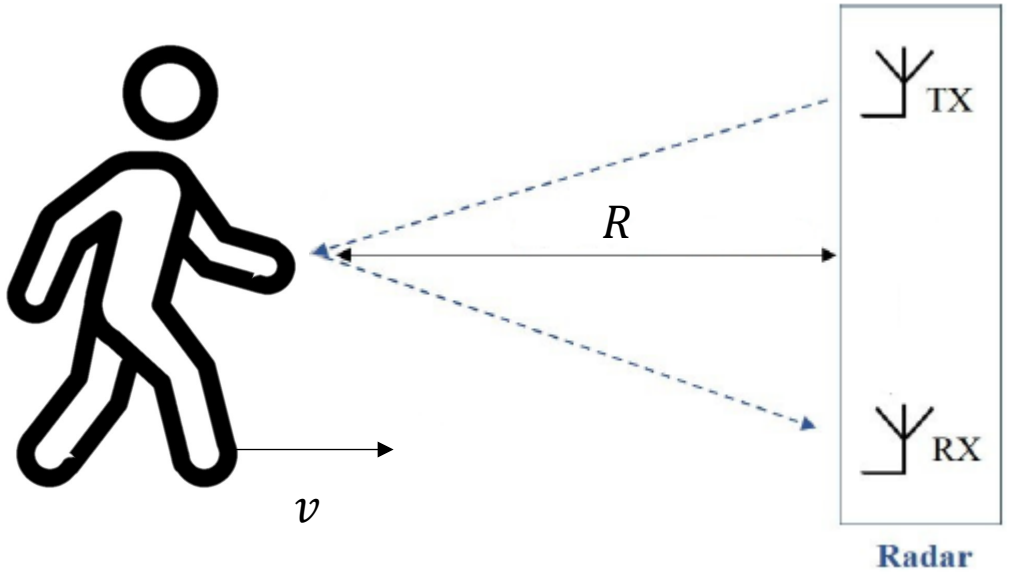
- -98 dBm for BLE @ 1 Mbps
- -95 dBm for BLE @ 2 Mbps
- -100 dBm for BLE @ 500kbps (LRS2)
- -104 dBm for BLE @ 125kbps (LRS8)
- -95 dBm for classic BR @ 1 Mbps
- -94 dBm for classic EDR @ 2 Mbps
- -88 dBm for classic EDR @ 3Mbps

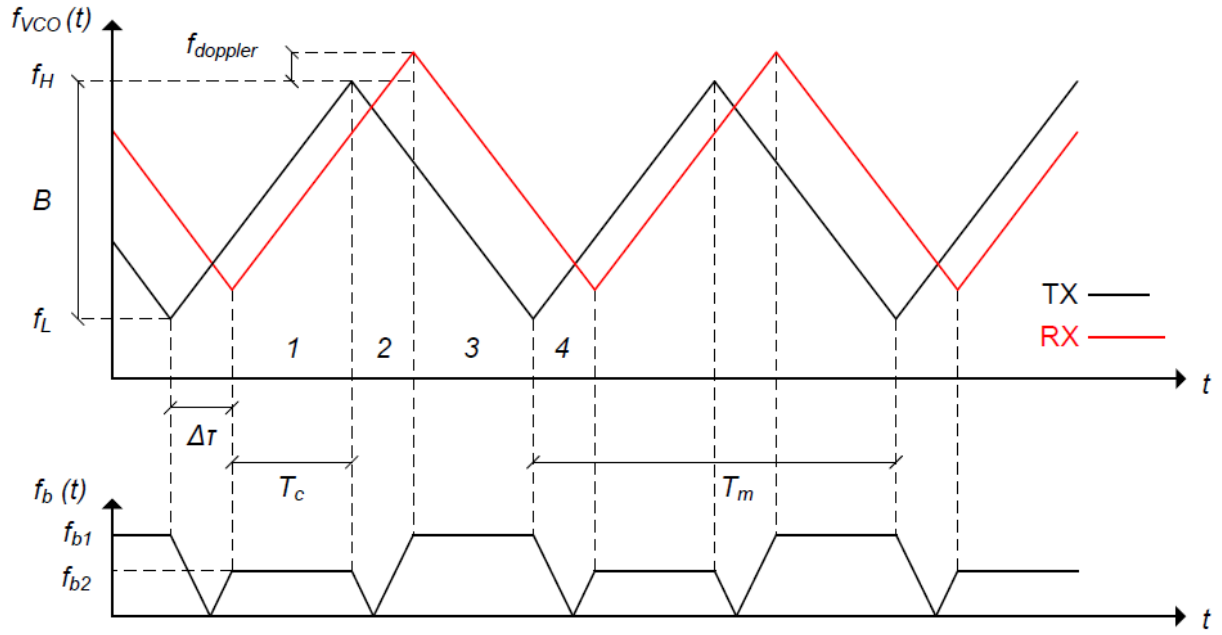
RADAR-ON-CHIP MOTIVATION

- Existing solutions: radars for self driving cars with long-range detection capability, associated with power consumption of several Watts.
- Any room for battery operated radars? Target: 100mW peak power!
- Potential applications:
  - **gesture recognition**
  - vital-sign monitoring for healthcare,
  - wellness or sleepiness detection
  - child presence detection in cars



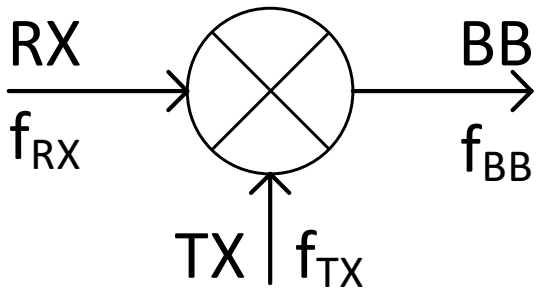
FMCW RADAR PRINCIPLE





$$R = \frac{f_{b1} + f_{b2}}{2} \frac{c}{4} \frac{T_m}{B}$$

$$v = \frac{f_{b1} - f_{b2}}{2} \frac{c}{f_L + f_H}$$



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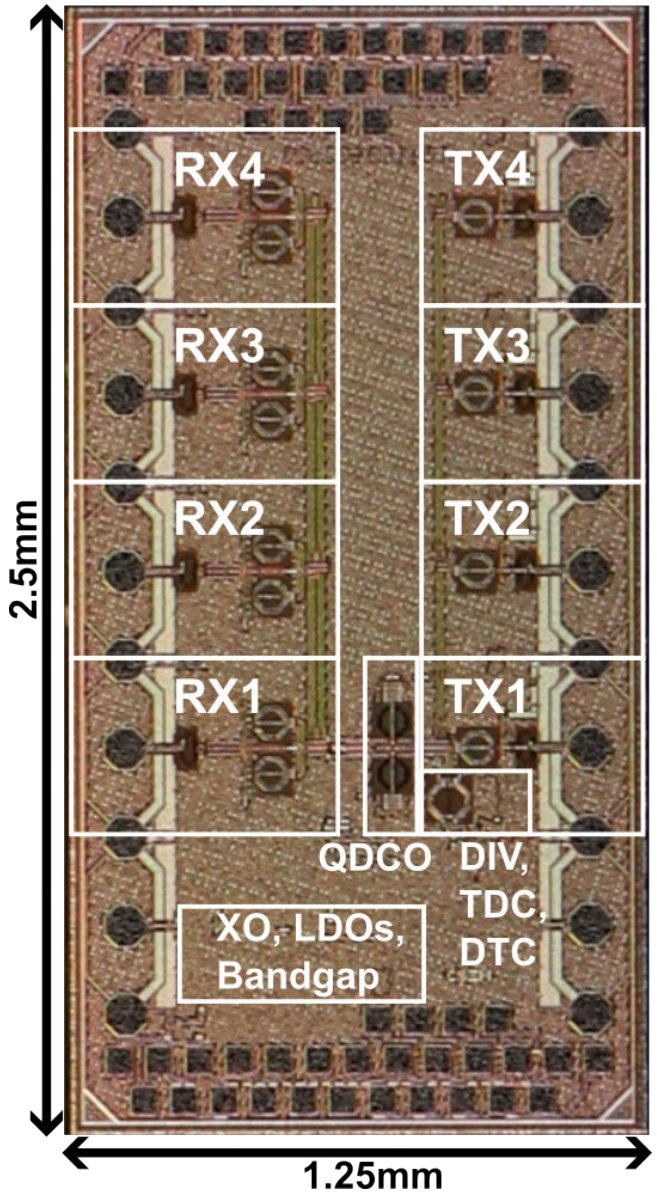
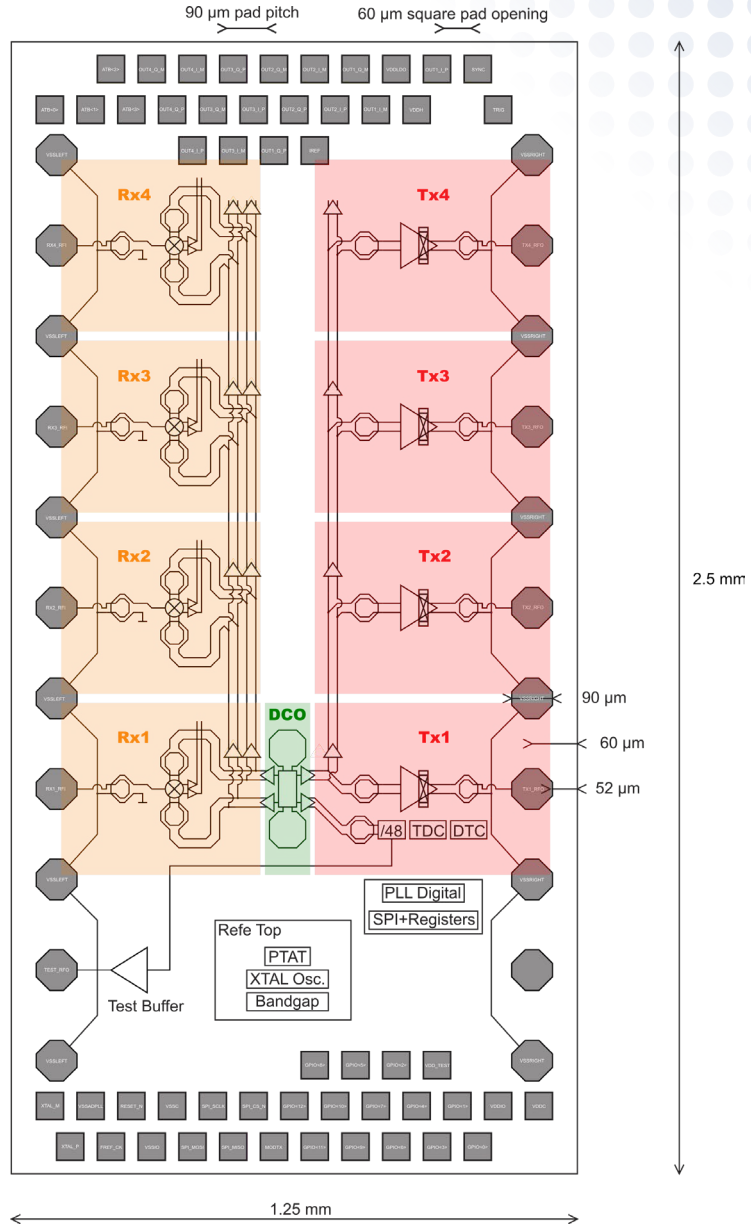
RADAR-ON-CHIP FRONT-END

Integrated:

- **57-66 GHz** quadrature DCO,
- **Fully integrated ADPLL**
- **Scalable** LO distribution
  (to facilitate addition of Tx & Rx slices),
- **4-TX** orthogonal BPSK modulation
- **4-RX** mixer-first with quadrature down-mixing
- Current & voltage tuneable references,
- LDOs, **Bandgap voltage reference, XTAL oscillator**
- Digital control **including FMCW modulation**
- **Control via SPI**





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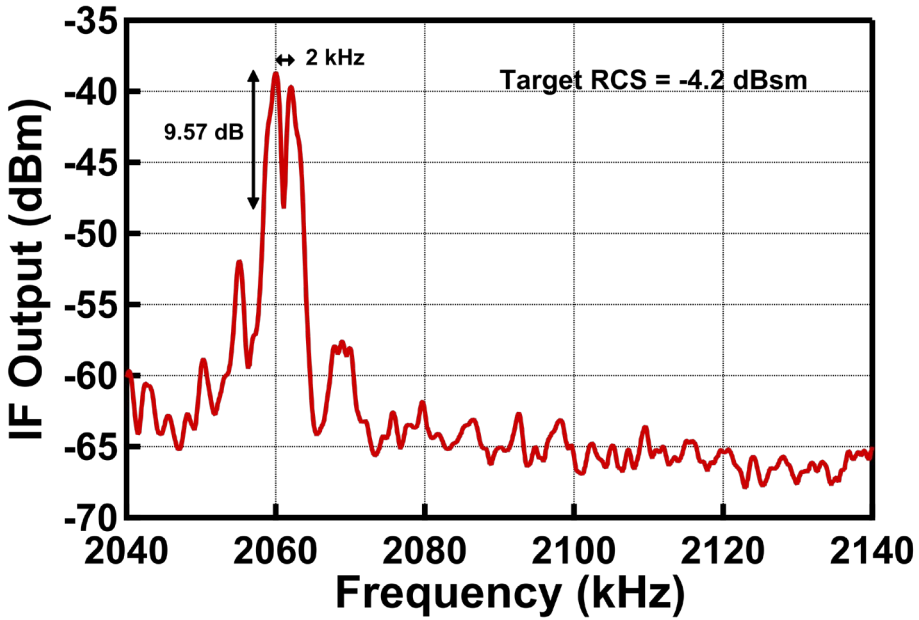
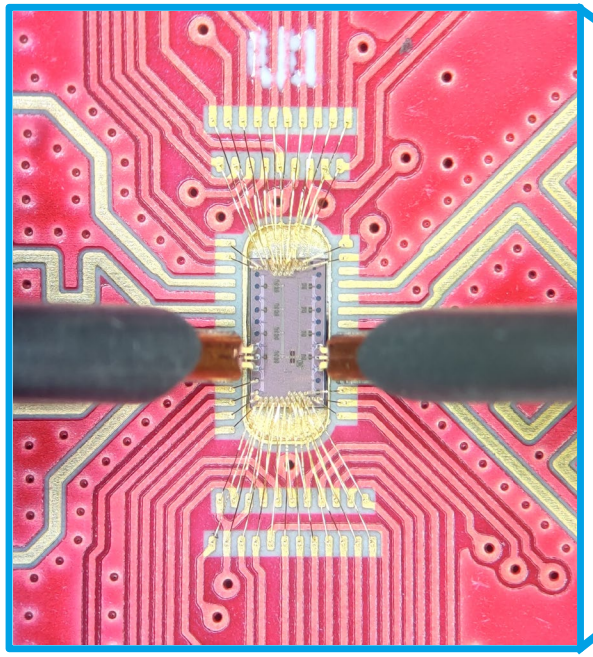
RADAR-ON-CHIP FRONT-END

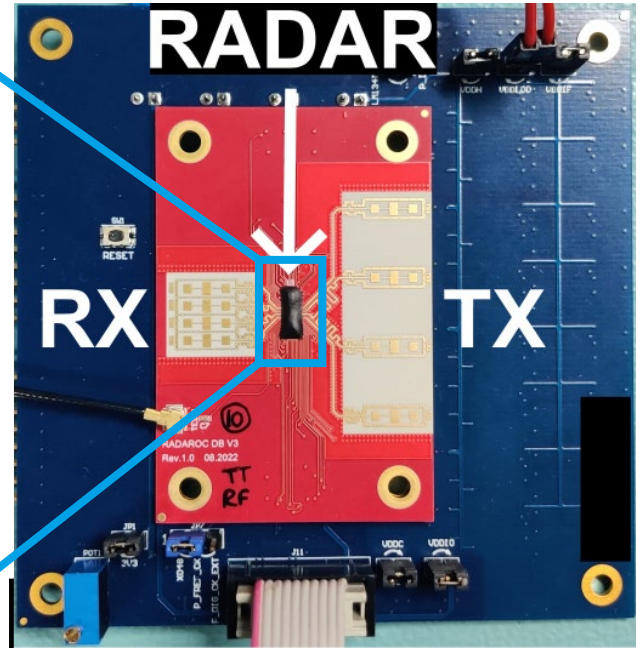
Demonstrated:

- Range resolution measured with a single FMCW chirp of 8GHz/500µs and 2 plane reflectors with a Radar Cross Section of -4.2dBsm: the RADAR achieves a resolution frequency of 2 kHz ⇔ 1.9 cm range resolution with a peak separation of 9.6 dB.





Un-bonded RF IOs for probing



RF IOs bonded to antennas

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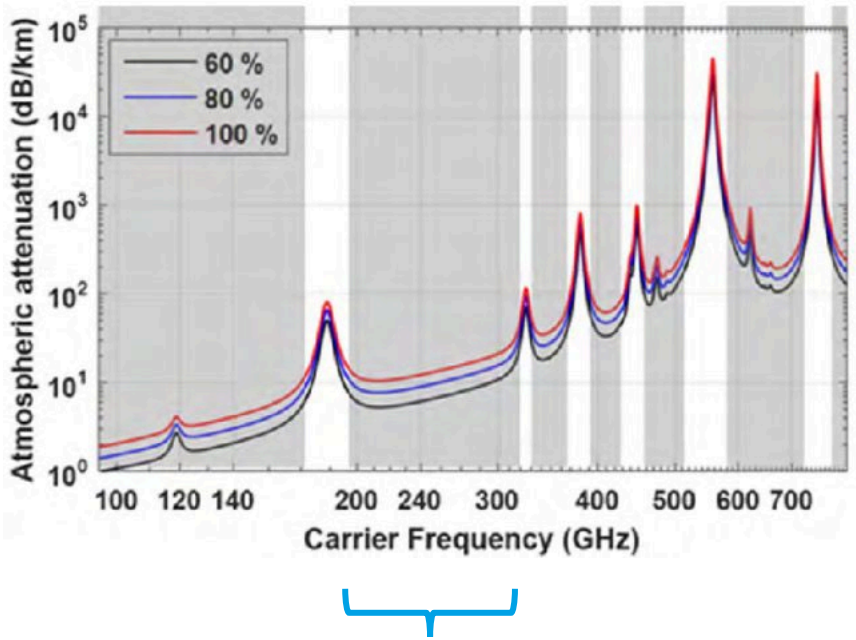
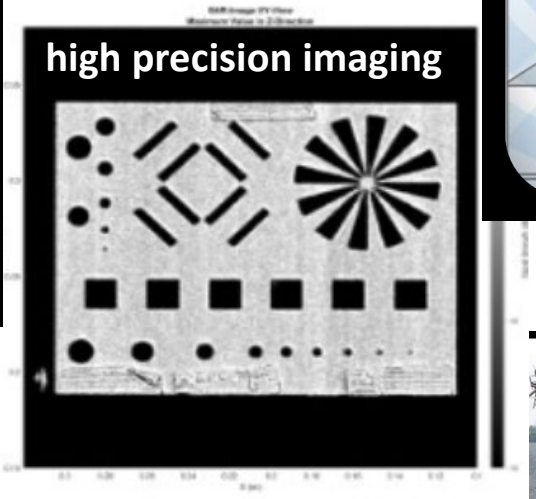
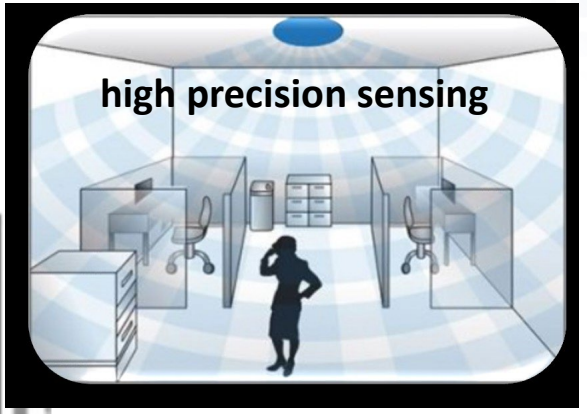
HIGH MMWAVE RADARS WITH INTEGRATED ANTENNAS

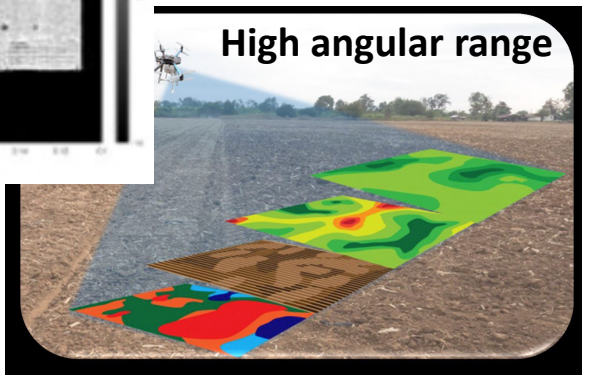


- Larger bandwidths
- Higher resolutions
- Miniaturization
- Energy efficiency

SWISSCHIPS







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INTERNSHIP POSITIONS RELATED TO HIGH MMWAVE

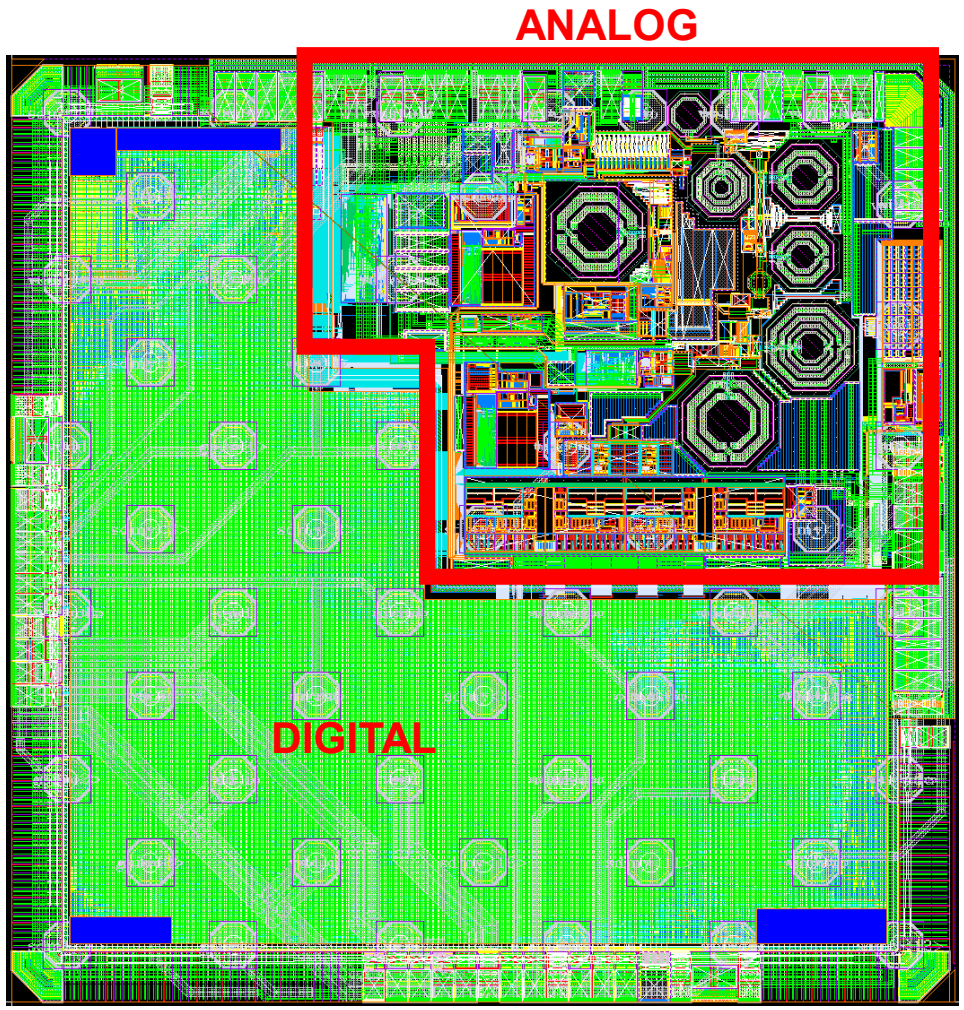
1. 60GHz Patch Antenna Design using theory & HFSS with practical implementation on a PCB and measurements (if time permits, consider extending to 140GHz or 240 GHz on chip but without practical implementation).

2. Use HFSS to emulate a Synthetic Aperture Radar (SAR) for Imaging Applications: Step a Patch at 240GHz with a Target model in HFSS, obtain reflections and construct the target image using back-projection algorithms.

3. Assuming a 1x1 radar, investigate principles of Temporal Convolutional Networks (TCN) for Vital Sign Monitoring (VSM) applications. Of interest would be the separation of breathing rate from heart rate.

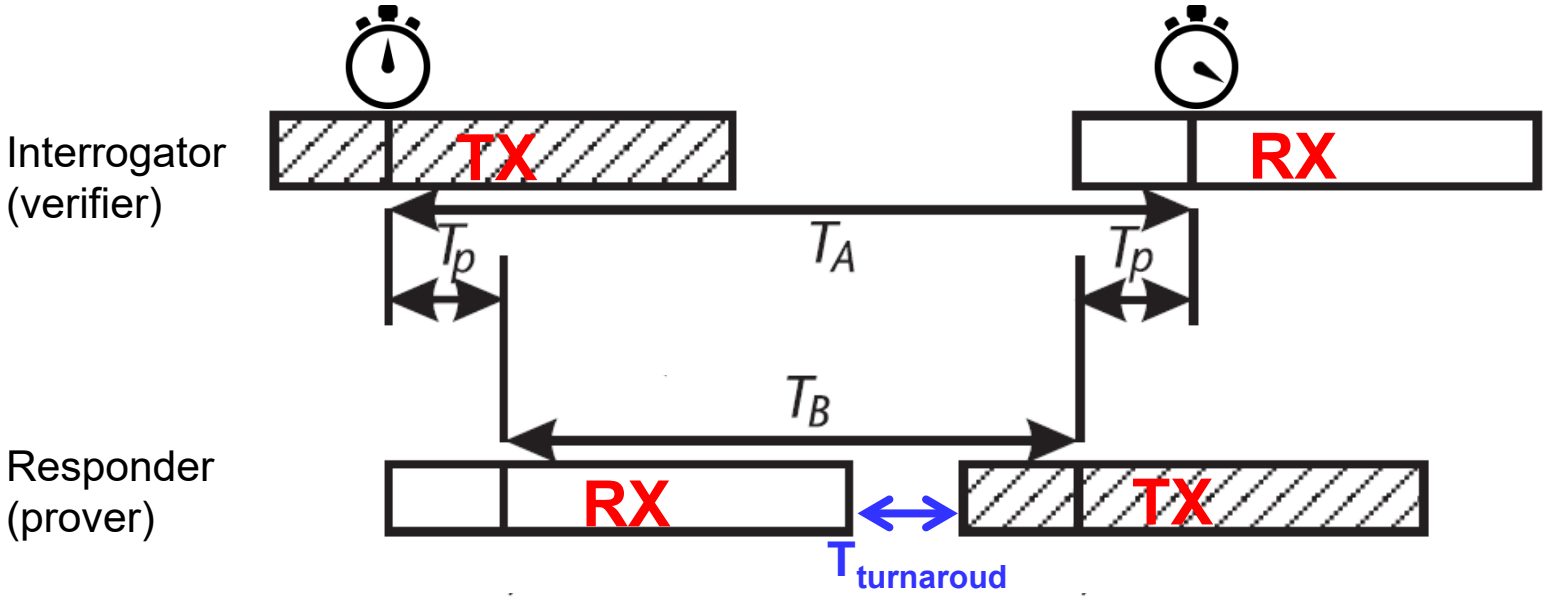
IR-UWB RANGING AND LOCALIZATION

- Ultra low power localisation on IR-UWB 802.15.4z LRP and HRP
  - Secure ranging (1D) for keyless access based Two-Way Time-of-Flight
  - Centimeter-precise positioning (2D/3D) using Time-Difference-Of-Arrival (TDoA) and Direction finding (DF)
- Applications:
  - Secure access and payment
  - Positioning for healthcare, warehouse, retail, asset tracking, agriculture, sports, drones,…



PRINCIPLE OF TWO-WAY TIME-OF-FLIGHT

- D is related to propagation time TP by **D = c0· TP** c0=speed of light (TP=1ns→D=30cm)
  - IR-UWB proprietary wireless technology using half-duplex protocol
  - Interrogator starts a «stopwatch» and stops it after TA, where TA=TB+2TP
  - TP=(TA- (Tframe+Tturnaround))/2



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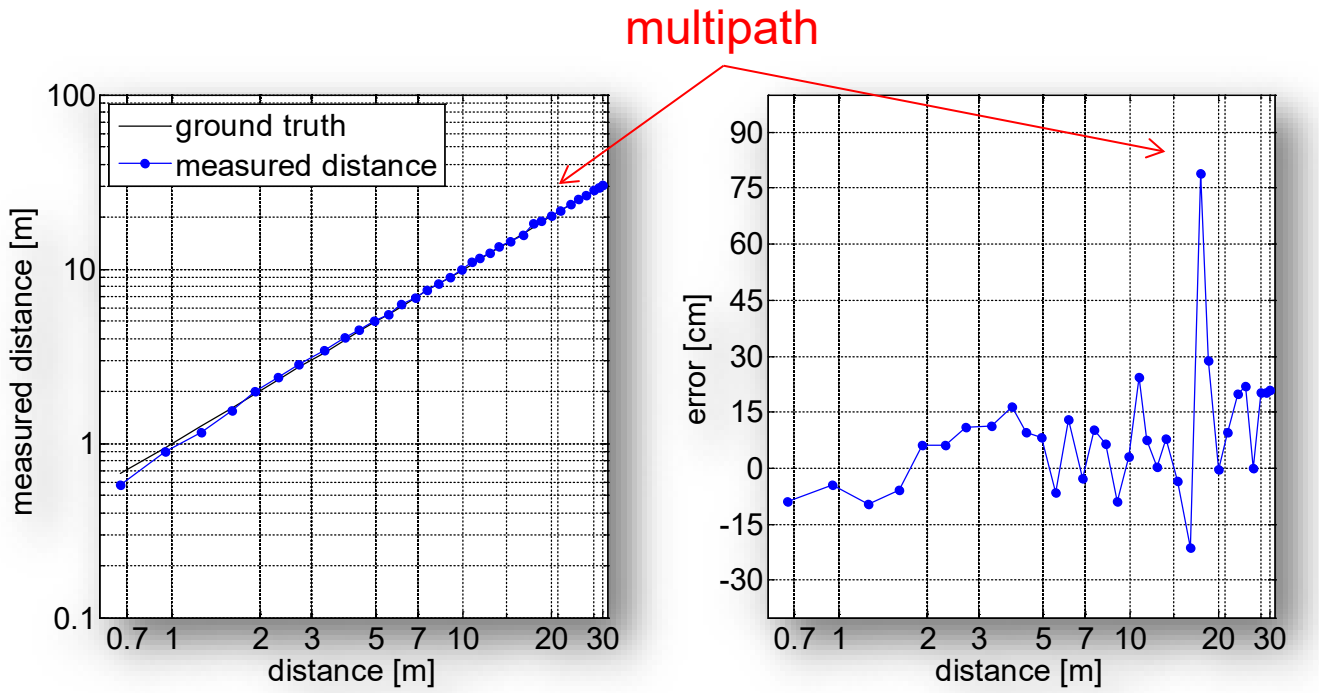
INDOOR DISTANCE MEASUREMENT

- Indoor distance measurements (10 meas./point)
- No outlier filtering, neither antenna nor frequency diversity use
- → Shows the reliabilty of IR-UWB in echoed environments



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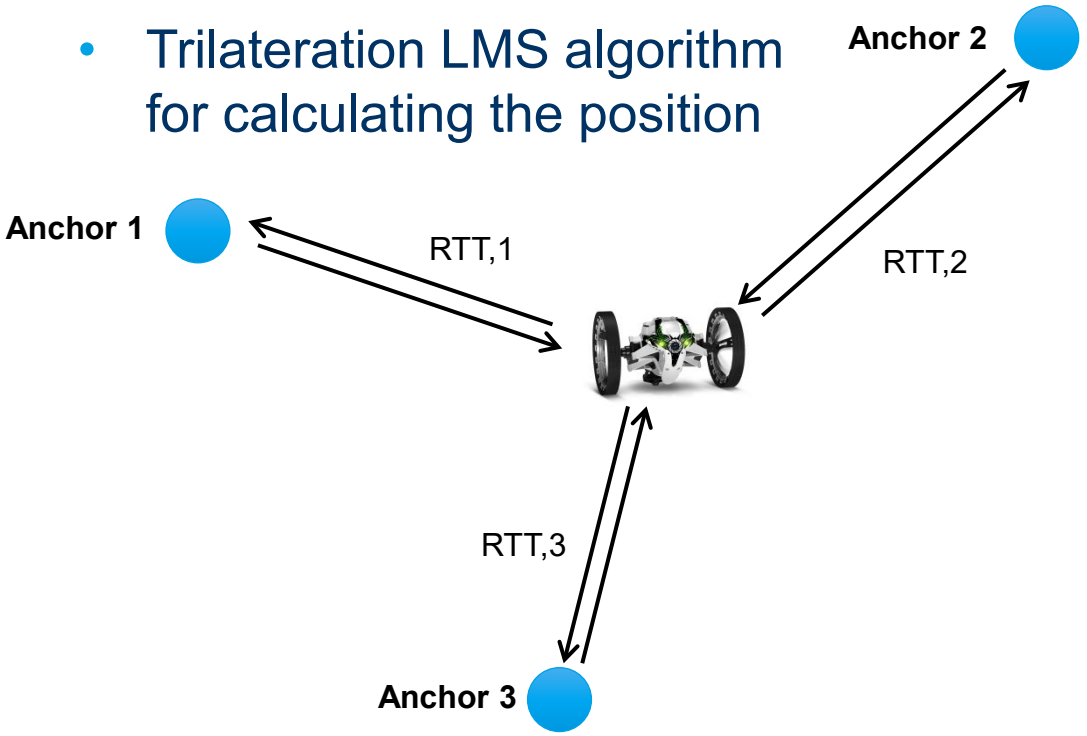
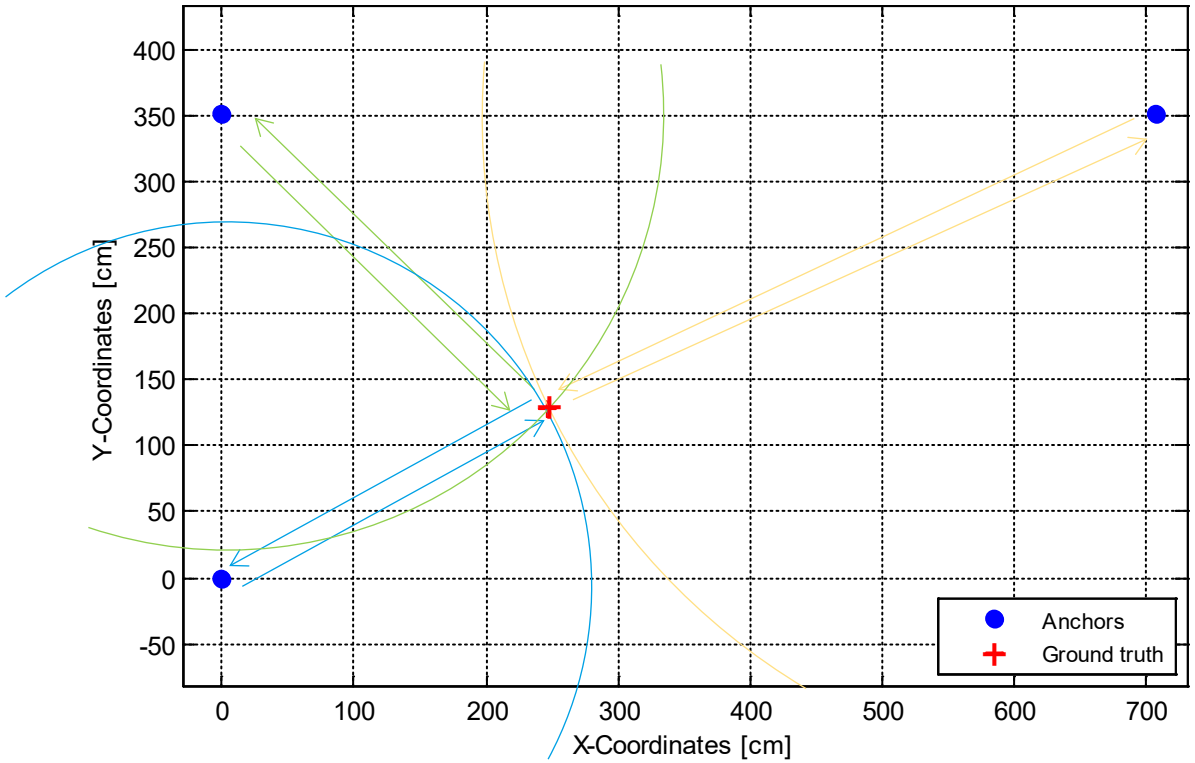
LOCALIZATION WITH TWTOF

- Two-way time-of-flight ranging enables reliable real-time 3D indoor localization
- Round-trip time (RTT) measurements successively taken between the unknown position (+) and the 3 anchors (●)
- Trilateration LMS algorithm for calculating the position





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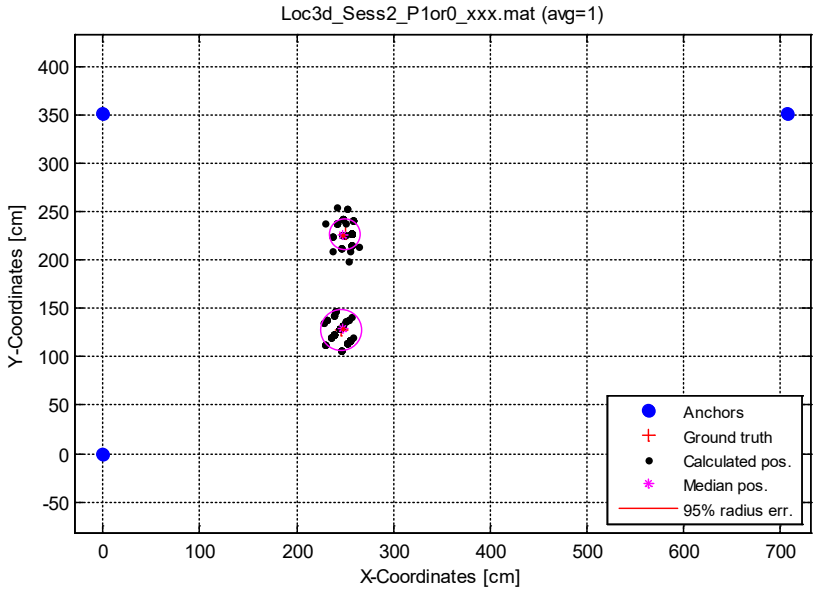
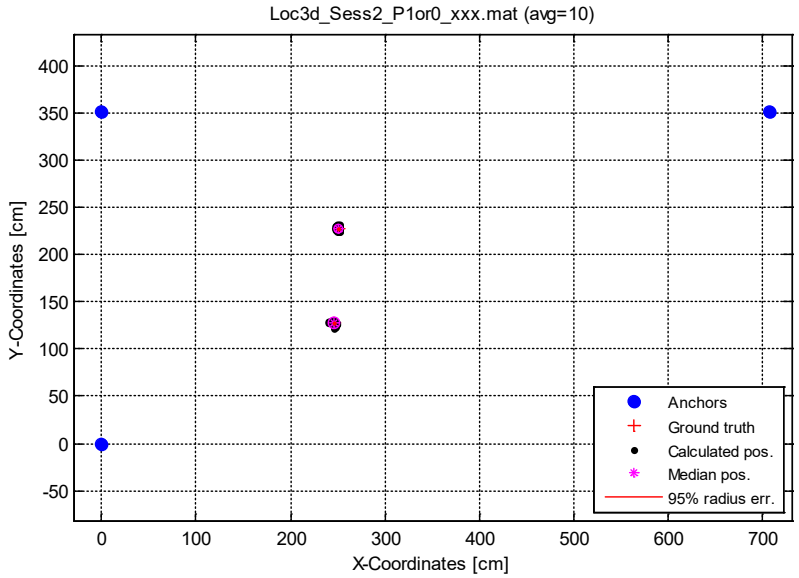
LOCALIZATION (TRIAL IN 2D)

- Area: 7m x 3.5m, Indoor Line-of-Sight (ILOS) conditions
- Blue points: 3 anchor nodes on the same plane (h=0)
- Red crosses: 2 “unknown” positions on the same plane



Raw 2D localization measurement from a single measurement (1 pos. in < 3 ms)

Accuracy better than 21 cm at 95% confidence level



Localization with averaging on 10 measurements (1 position in < 30 ms)

Accuracy better than 6 cm at 95% confidence level

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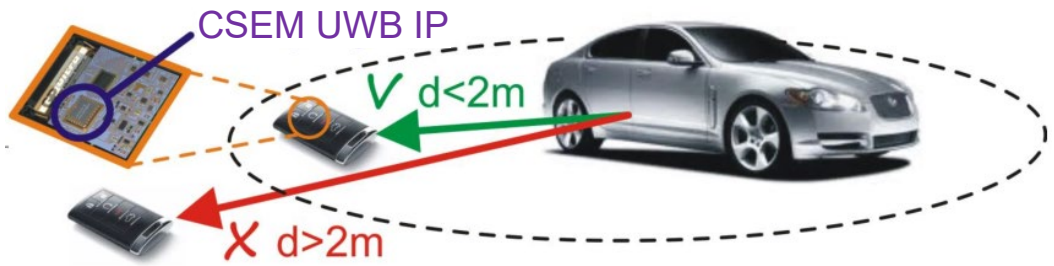
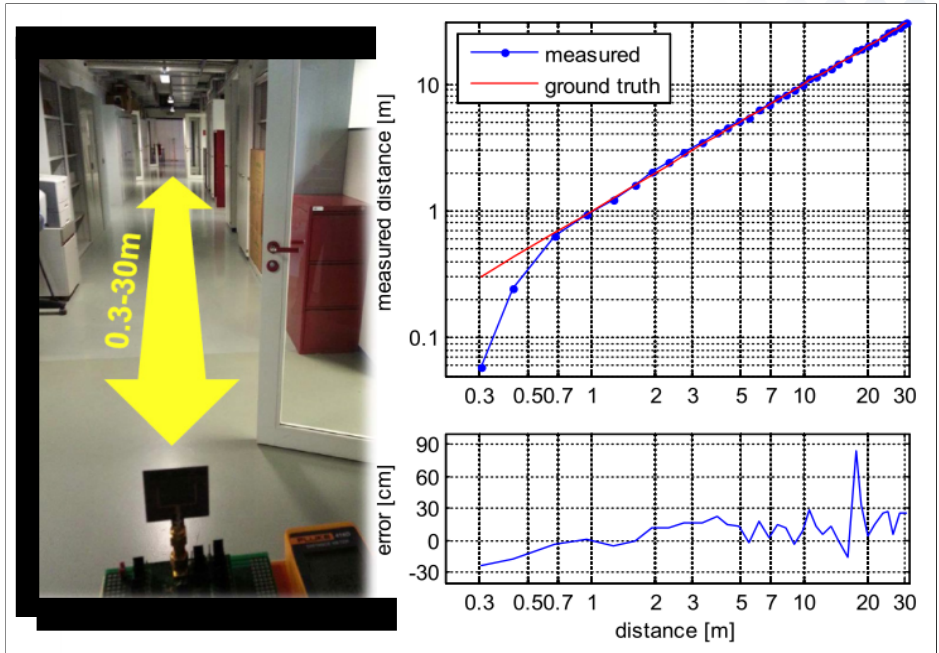
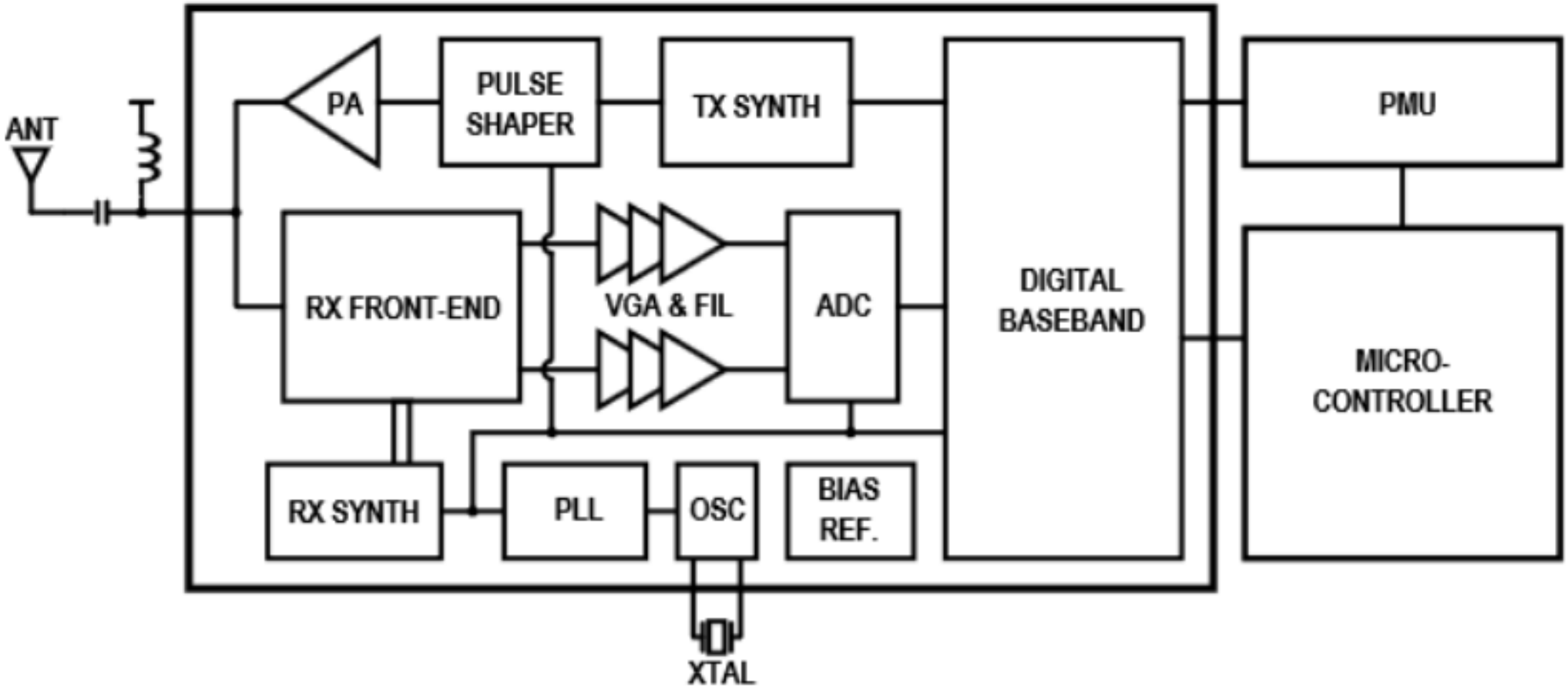
ULTRA-WIDE BAND (UWB) TRANSCEIVER

- Single RFIO (1RX-1TX)
- 6-8 GHz range, option to cover the lower UWB band
- External inductor used for the PA (up to 16 dBm peak)
- **10 µJ per ranging event**
- < 10 cm accuracy
- Typical consumption: RX: 27 mW, TX: 12 mW
- Available in TSMC:
  - 65nm: full analog/RF front-end (in product, MP)





UWB CIRCUIT BLOCK DIAGRAM



3DB6830 Block Diagram

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UWB FOR SECURE KEYLESS ACCESS
FROM 2 PHDS TO MAJOR EU CAR BRANDS

KICKSTARTING

ETH zürich

INCUBATING

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2012

3db

FOUNDED

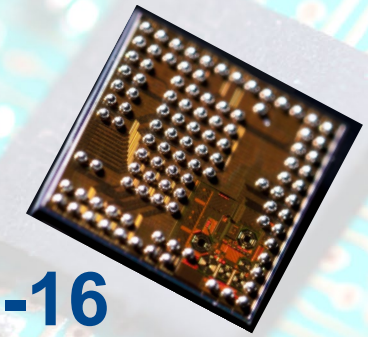
The roadmap to success !

Innosuisse

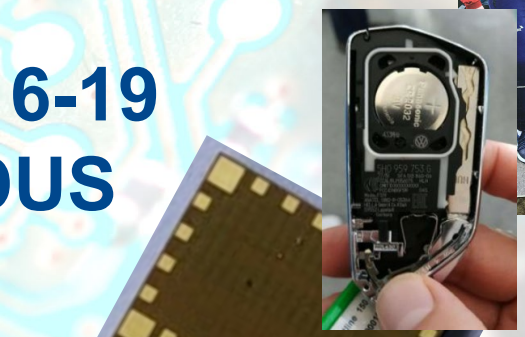
Σ EUREKA - EUROSTARS

Innosuisse

2013-16
MATURING



2016-19
INDUS



2019
MARKET
ENTRY

2023

infineon

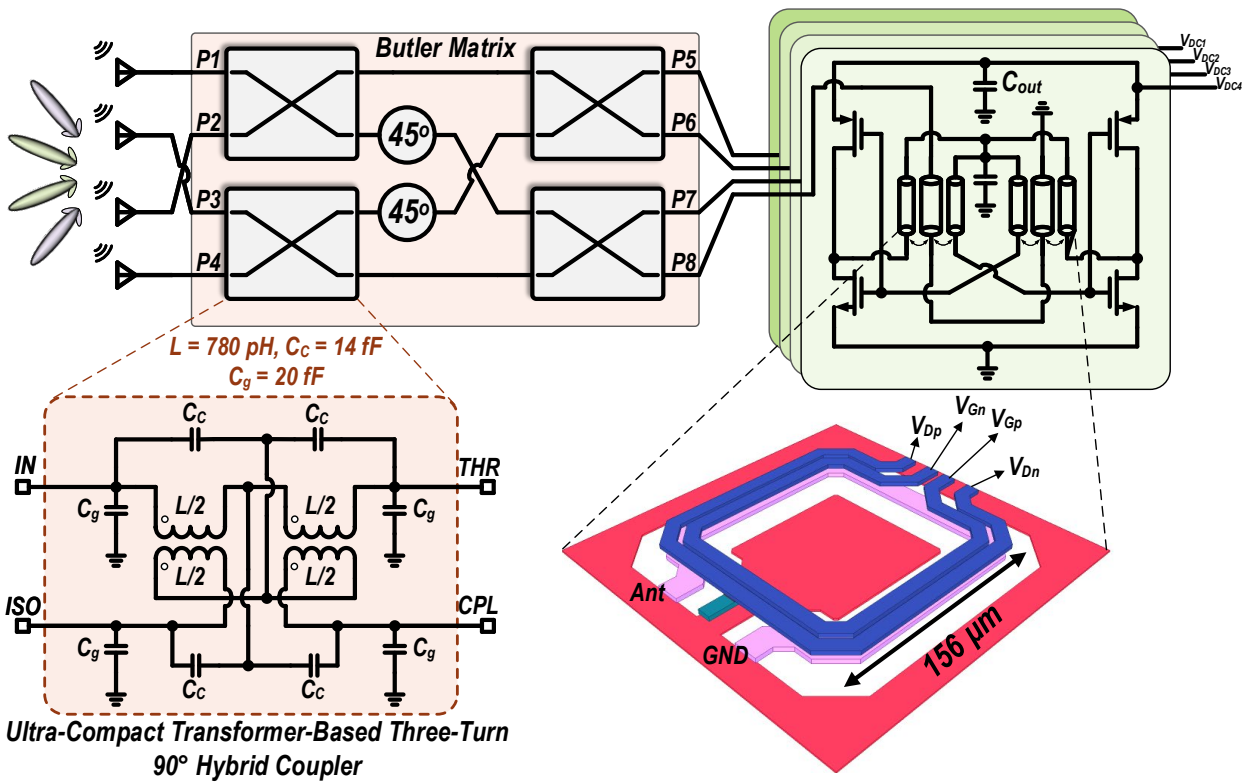
TECHNOLOGIES
SWITZERLAND
CREATED

OVER 20M CHIPS on the ROADS !

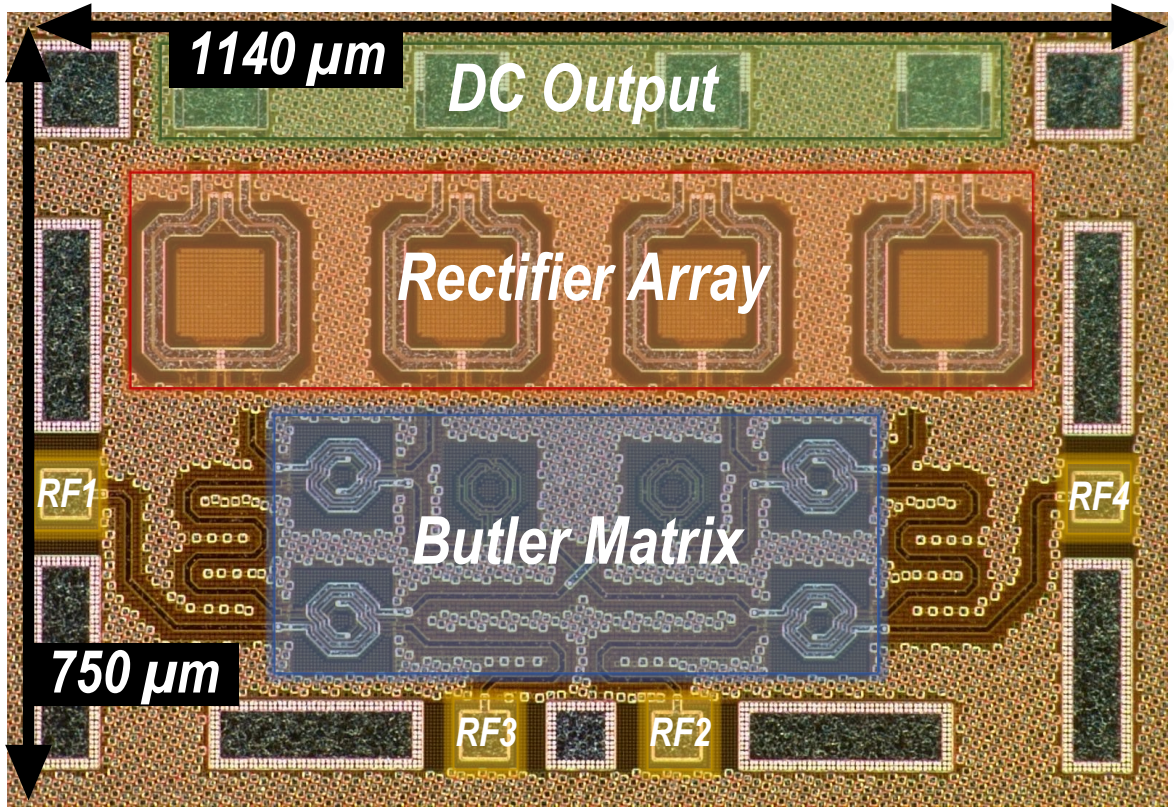
Marquee End Customers Across Automotive And Industrial Markets

DAIMLER · Audi · CUPRA · SEAT · SKODA · SIEMENS · MARPOSS

24GHZ WIRELESS POWER TRANSFER AS HARVESTER
PASSIVE CONCURRENT RECTIFYING ARRAY



System Schematic



System Chip Micrograph

ETH zürich

PhD student: Mohsen Ghorbanpoor

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