

**Presentation Will
Begin Shortly**

4:00



BLUETOOTH

- FEB 29TH | Small Bluetooth Devices - How to Minimize Size without Compromising Performance and Reliability
- APR 4TH | Bluetooth LE Application Development Journey
- MAY 9TH | Unboxing Silicon Labs' Latest Bluetooth SoC for Energy Harvesting
- JUN 13TH | Explore Bluetooth Channel Sounding

Welcome

Explore Bluetooth Channel
Sounding

tech tals



Introduction



Priyanka Sukumar

- Priyanka Sukumar is a Product Manager at Silicon Labs. She is responsible for Commercial Lighting, Clinical Medical, and Location segments within the Commercial Business Unit. She joined Silicon Labs in 2022 and is based out of the office in Finland. Before Silicon Labs, she worked for a couple of years as an SoC Software Engineer.



Ganapathy Subramanian

- Ganapathy Subramanian (Gansu) leads the Bluetooth Direction Finding and Channel Sounding algorithm development team in Silicon Labs. He joined Silicon Labs in 2022 and is based out of the office in Espoo, Finland. With 20+ years of experience in software engineering he has worked on diverse software solutions ranging from resource constrained real-time embedded system to scalable web application for diverse application domains - audio/video, robotics, data analytics and Industrial IoT.



Claudio Filho

- Claudio Filho leads the West Coast Field Applications team providing technical expertise for connected applications across multiple industries. With 20+ years in semiconductors, heavily focused on low-power MCUs, Bluetooth and other wireless protocols, Claudio leverages Silicon Labs' solutions for customer success in consumer, networking, automotive, and industrial markets.

Agenda

- 01** Channel Sounding Protocol
- 02** Use cases
- 03** Performance data
- 04** Silicon Labs Offerings
- 05** Q&A

Overview

Channel Sounding Overview

- **Measure distance between two devices using**
 - Phase-based Ranging (PBR)
 - Round Trip Time (RTT)
- **RTT and PBR operates across 2.4 GHz band**
 - Standard specifies up to 72 channels
 - Random hopping pattern
- **Connection-Oriented 2-way ranging with two roles**
 - Initiator: device that wishes to calculate distance from itself to another device
 - Reflector: device responding to initiator
- **Supports up to 4 antenna paths between devices**
 - 8 possible antenna combinations
- **Multiple security features included in the standard**
- **Can be combined with Angle of Arrival / Departure (AoA/AoD)**
 - Enables position estimation with single initiator/reflector pair
- **Bluetooth SIG Specification adoption expected in 2024**
 - Draft Channel Sounding specification at:
<https://www.bluetooth.com/specifications/specs/channel-sounding-cr-pr/>

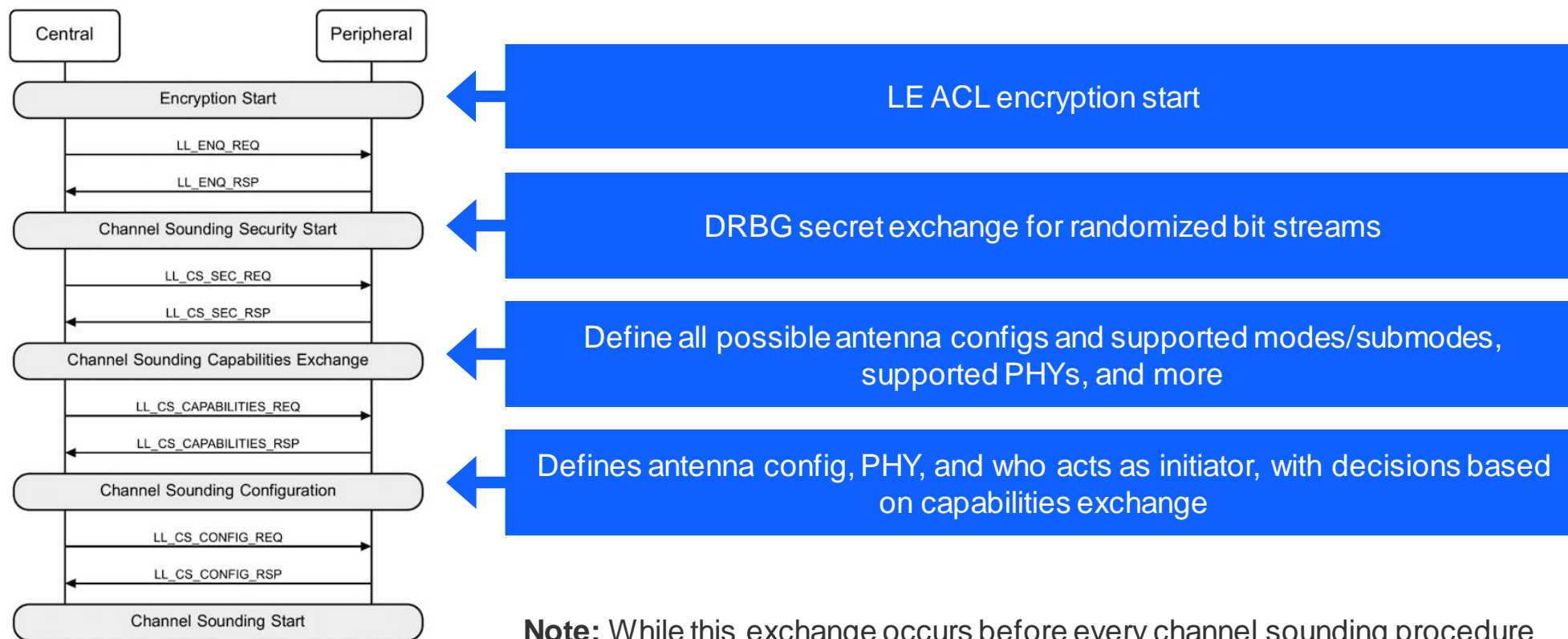
What's included in the spec

- RF and link layer timing and functional requirements
- Mandatory vs. optional features and modes
- Guidance on antenna configurations and security features

What's not included in the spec

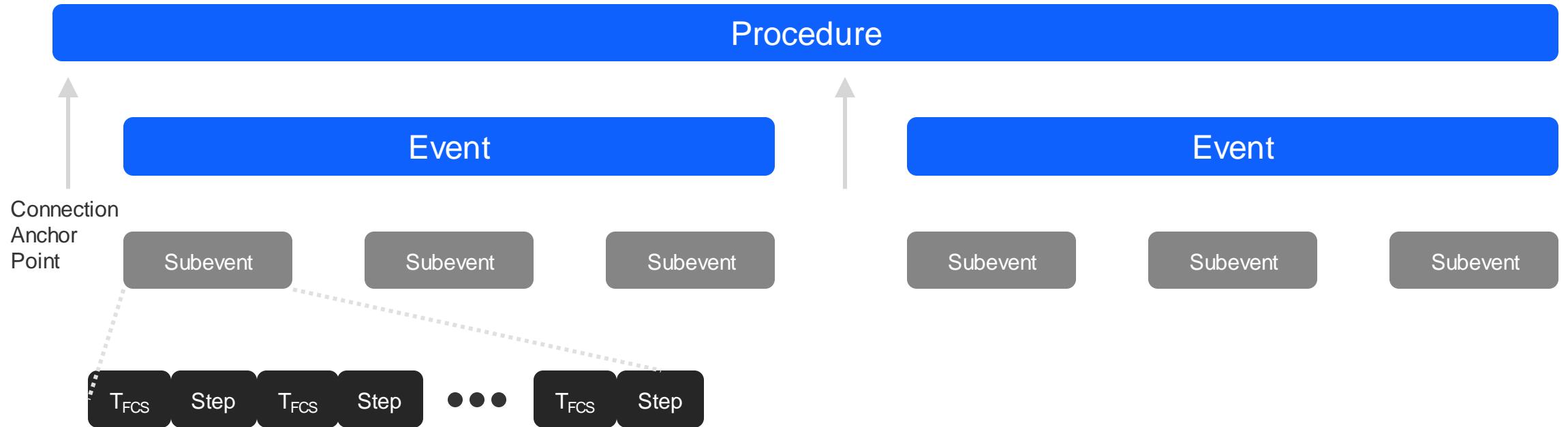
- Distance measurement algorithm recommendations and optimizations

Channel Sounding setup between central and peripheral



Note: While this exchange occurs before every channel sounding procedure start, some of these steps can be skipped during setup if information has been cached previously

Channel Sounding Procedure -> Events -> Subevents -> Steps



- **Procedures**, composed of **events**, can span multiple connection intervals
- **Subevents** are required to complete within single connection interval
- **Steps** correspond to setup, PBR, or RTT ranging, defined as **4 modes**

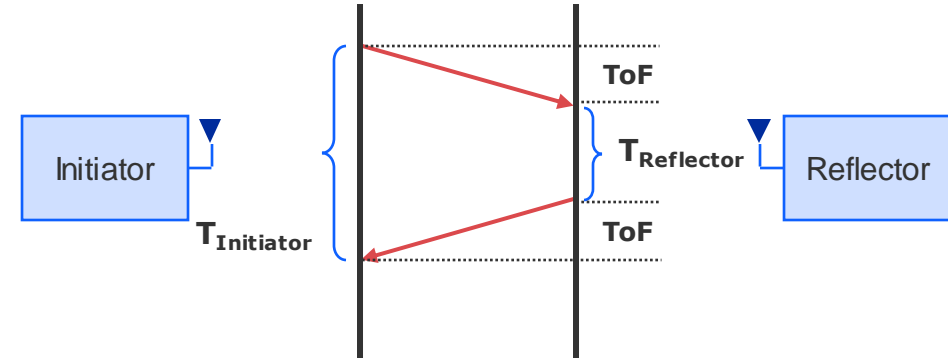
Channel Sounding Step Modes

Mode-0: Calibration

- Compensates for clock drift and frequency offset
- Results in fractional frequency offset table

Required

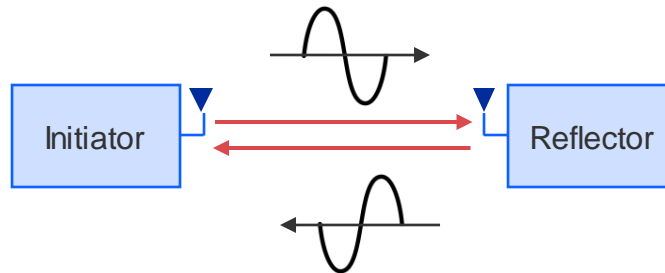
Mode-1: Round trip time



- CS SYNC packets exchanged between initiator and reflector

Required

Mode-2: Phasebased ranging



- CS Tone exchanged between initiator and reflector
- Each antenna path exercised in each step

Required

Mode-3: PBR+RTT

- Combined PBR and RTT in each step
- RTT distance measurement can be cross-checked with PBR results
- Provides higher security as a mismatch in distance estimation can indicate relay attack

Optional

Channel Sounding security features

- **Potential vulnerabilities**

- Spoofing
- Man in the middle (MITM) or relay attacks

- **Deterministic random bit generator (DRBG)**

- Initialized during security start data exchange
- Scrambles bit sequences between initiator and reflector
- Randomizes payloads in tone extensions, antenna path selection, and more

- **Cross-checking PBR with RTT**

- Can be done in Mode 1 steps with mode 2 as submode or using Mode 3
- Mismatch in distance estimation indicates relay attack

- **Normalized Attack Detector Metric (NADM)**

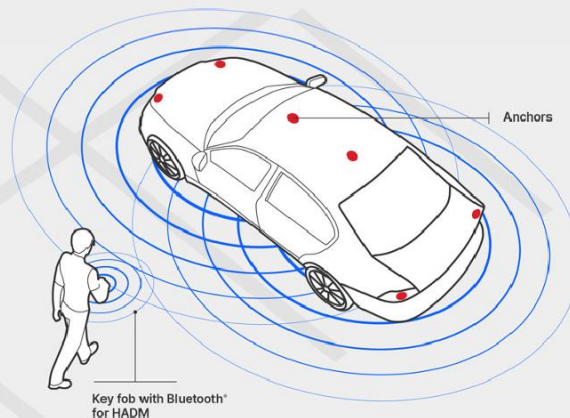
- Detects unexpected bit transitions or phase changes in received signals
- Standard does not include implementation requirements,
- Prescribes scale for how anomalies are classified
- Optional feature

Bluetooth® LE Location Services Comparison

	RSSI	Angle of Arrival	Channel Sounding
Localization metric	Resolve distance estimation from transmitter signal strength	Resolve relative angle between two points	Resolve distance between two points using time of flight and phase-based ranging
Antenna requirements	Single antenna	Multi-antenna required by spec	Multi-antenna not required, but useful for optimal position resolution
Bluetooth® LE connectivity	Connection-oriented and connectionless	Connection-oriented and connectionless	Connection-oriented
Performance metrics	+/- 5 m, high susceptibility to multipath interference	+/- 3 degrees accuracy – azimuth +/- 5 degrees accuracy – elevation	+/- .3 m < 5m with PBR ranging +/- 0.5 m > 5m with PBR ranging
Solution advantages	<ul style="list-style-type: none"> Ubiquitous support for RSSI measurements in existing Bluetooth LE products 	<ul style="list-style-type: none"> Scalable solution for real time position tracking Supports 5-10 year battery life 	<ul style="list-style-type: none"> Small form factor with flexible antenna design Feature-add for security by proximity

Use cases

Channel Sounding for Geo-Fencing Applications



Unlock on Approach:

- Remote Keyless Entry
 - Zonal detection through ranging for secure vehicle access
 - User enhancement with wake/welcome response
- Proximity-based locking and unlocking
 - Automatic door lock & unlock at a certain distance from it

Loss Prevention

- Retail theft prevention
 - Tracks the location of high-value items within the store and triggers alarms if they are moved outside designated areas.
- Geofenced Notifications for Unauthorized Movement
 - Sends alerts upon detection of unauthorized movement or movement of goods outside a certain defined boundary.



Channel Sounding in an Indoor Facility

Access Control

- Restrict access to unauthorized personnel
- Send alerts to local servers/cloud if anyone dwells in the area for too long

Entry access

Authenticate and grant access to authorized workers when they approach the door

Asset management

- Coarse localization of inventory inside the facility
- Increase worker efficiency



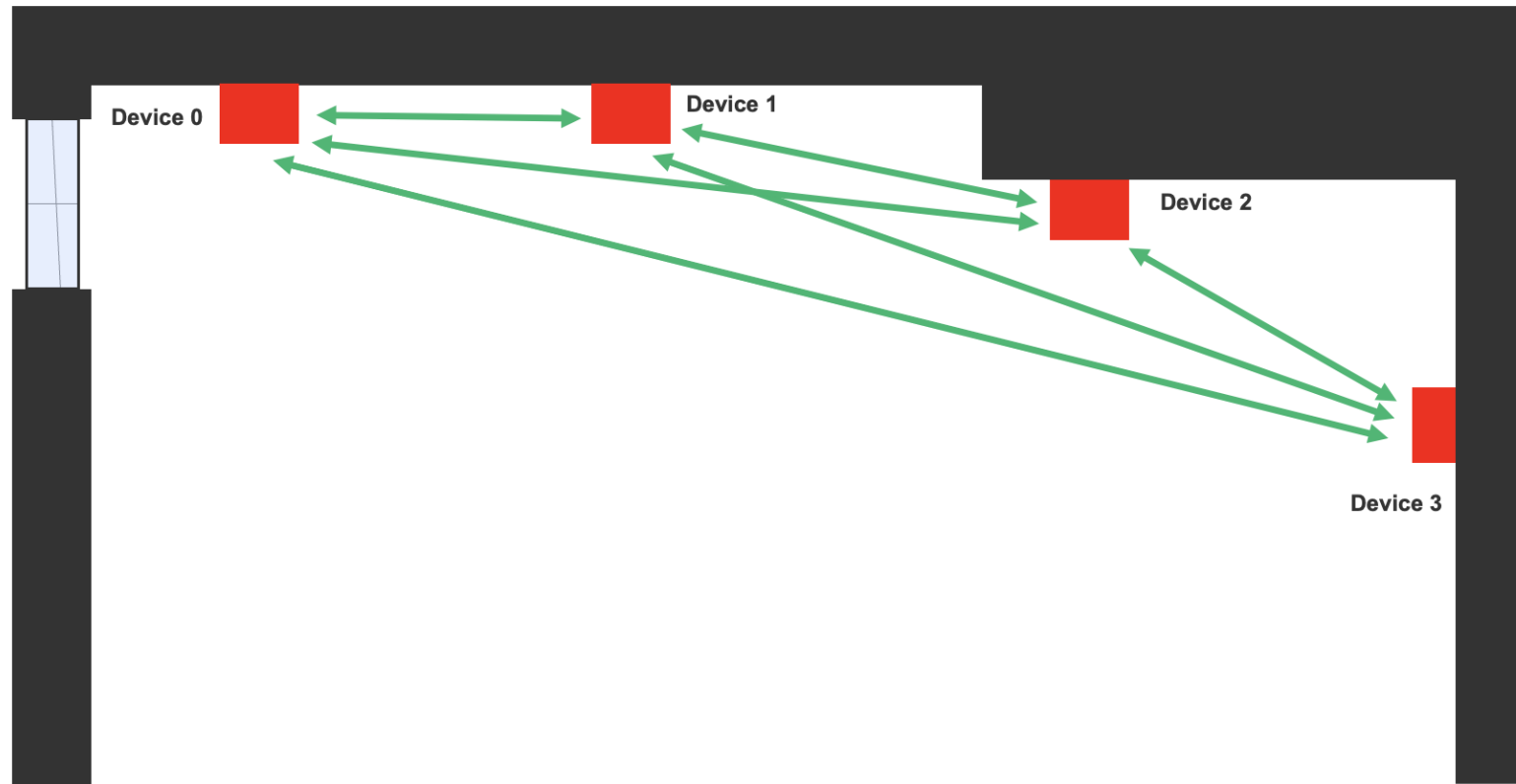
Distance Measurement Demo



Distance Measurement Demo



Channel Sounding for Static Device Positioning



- Enables device positioning for static devices like luminaries or access points.
- The devices act as initiators and reflectors to calculate the distance from each other to create a geometric map.

Static Device Positioning Demo



Static Device Positioning



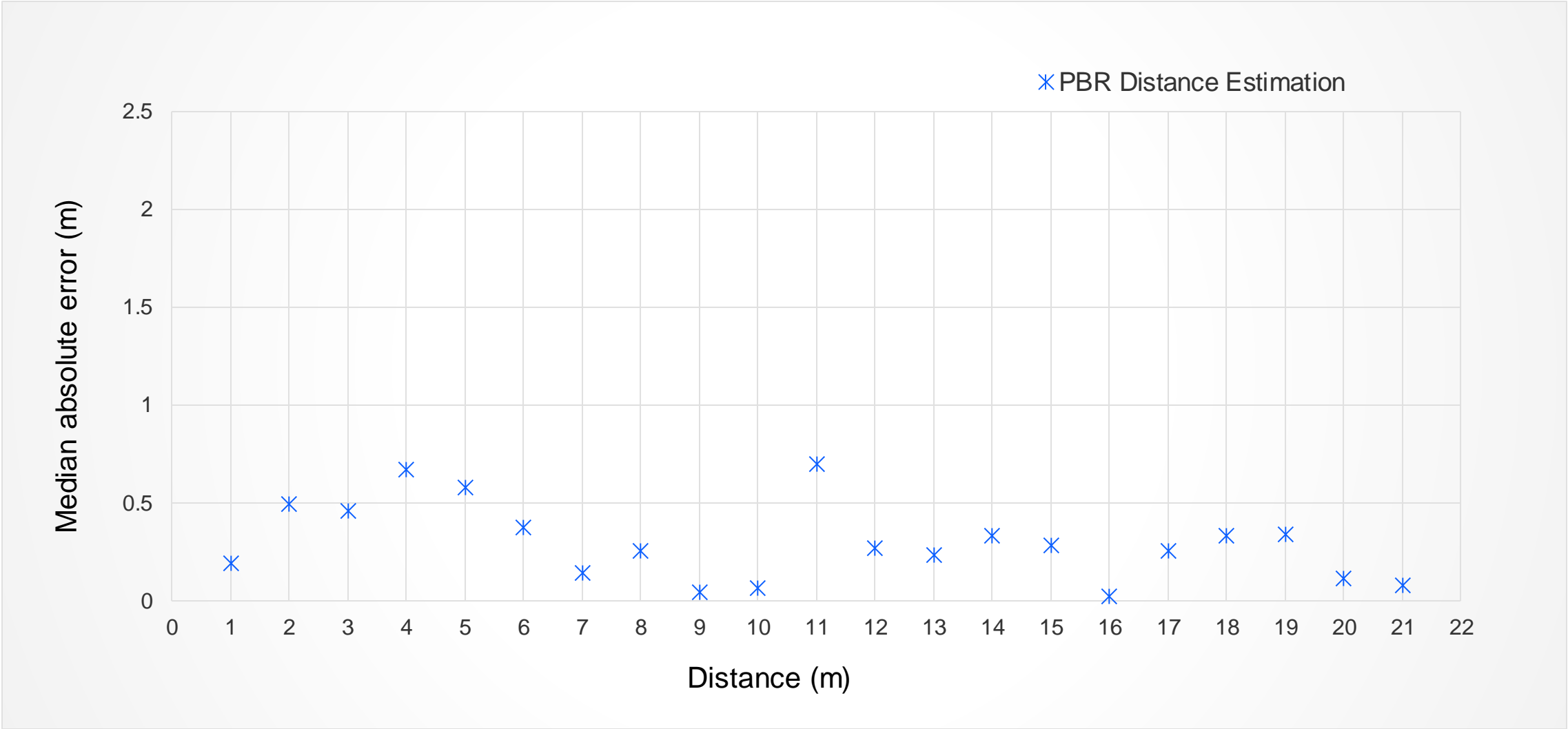
Performance

Performance in Indoor Office Environment

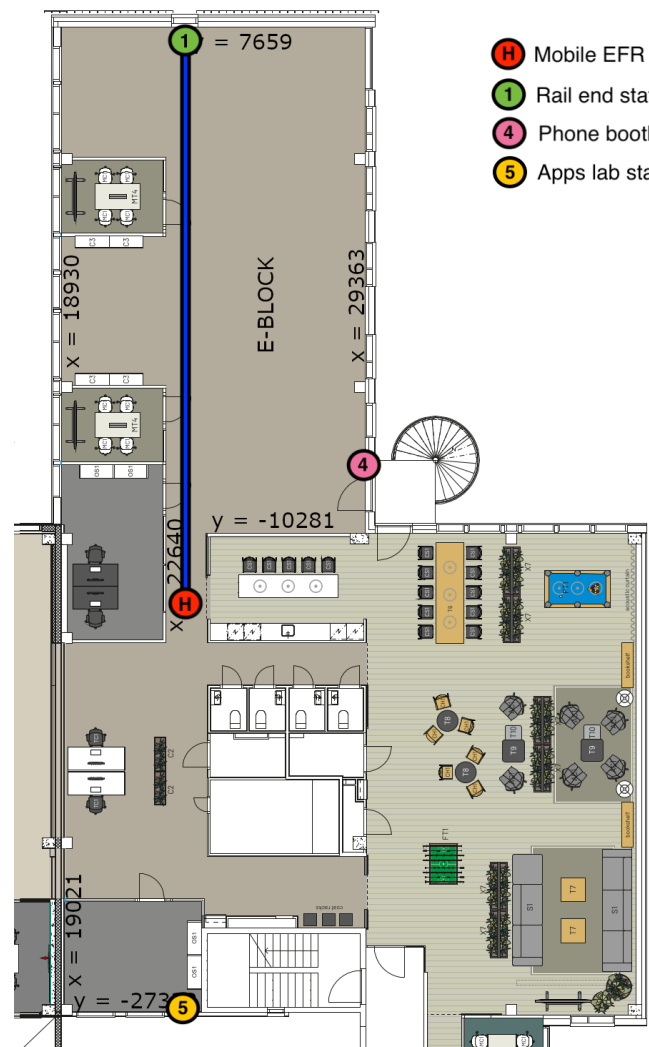


- **Ceiling rail infrastructure**
 - Internal test environment
 - Multiple stationary EFR32 devices placed at different locations
 - Mobile EFR32 device for controlled measurements (repeatability)
- **Challenges - heavy multi-path in an indoor office setting**
- **Statistical analysis**
 - Static measurements at multiple distances up to 30 meters
 - Hundreds of measurements per distance to determine min/max, mean, median, std, absolute error

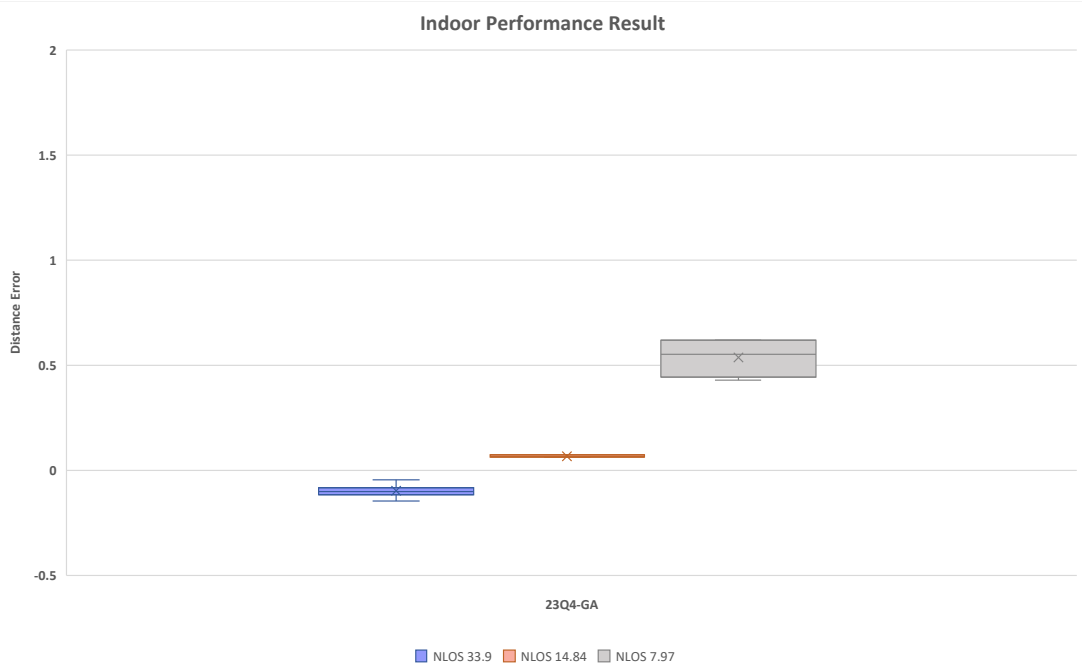
Indoor Performance Result – Line of Sight



Indoor Performance Result – Non - Line of Sight



1 – 5 = NLOS 33.9m
1 – 4 = NLOS 14.84m
H – 4 = NLOS 7.9m



Silicon Labs Offerings

BG24: Optimized for Battery Powered, Channel Sounding-enabled IoT Devices



- 5x5 QFN40 (26 GPIO)
- 6x6 QFN48 (32 GPIO)
- 3.1x3.0 WLCSP42

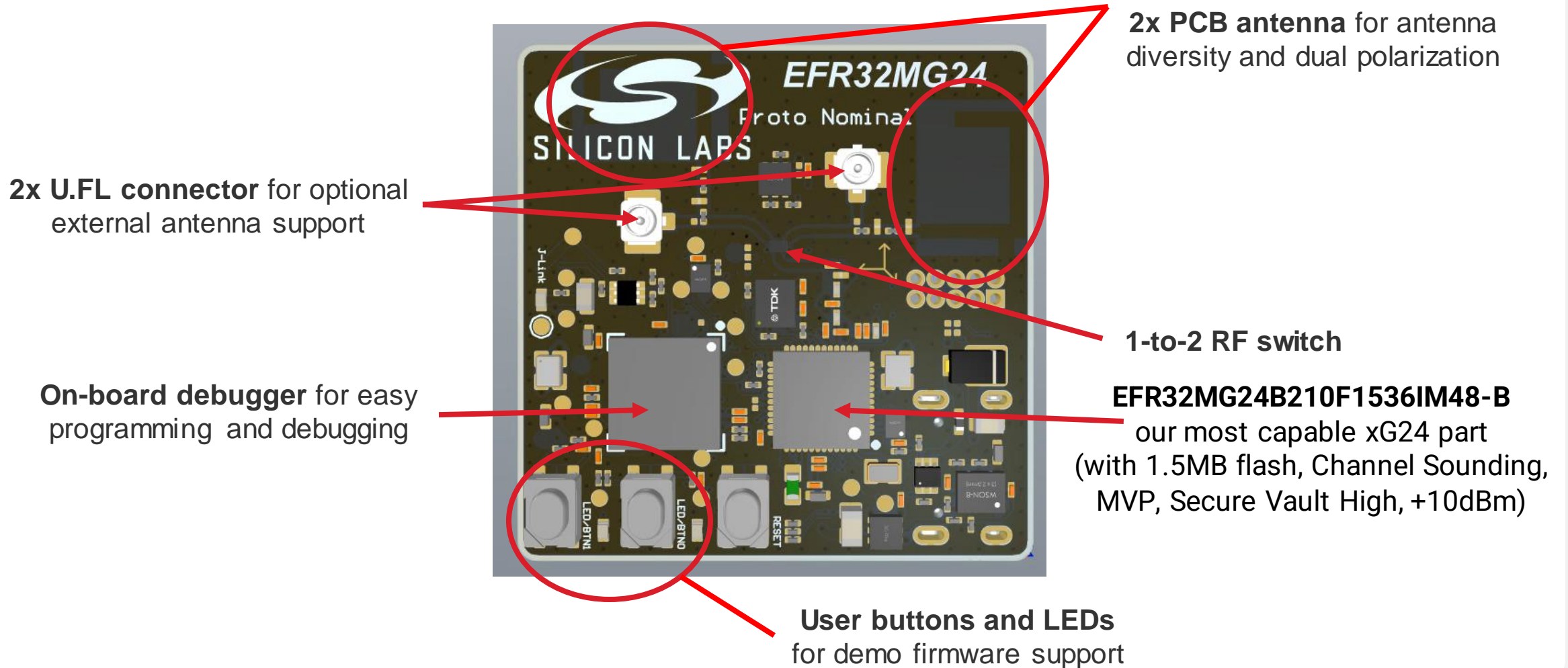
DIFFERENTIATED FEATURES

- **Ultra small form-factor**
 - 3.1 x 3.0 WLCSP package
- **+20 dBm output power**
 - Eliminates need for external power amplify
- **AI/ML accelerator**
 - Accelerates inferencing while reducing power consumption
- **Secure Vault High**
 - Protects data and device from local and remote attacks
- **20-bit ADC**
 - 16-bit ENOB for advance sensing
- **Improved Coexistence**
 - Ideal for gateways and hubs
- **PLFRCO**
 - Eliminates need for 32 KHz xtal

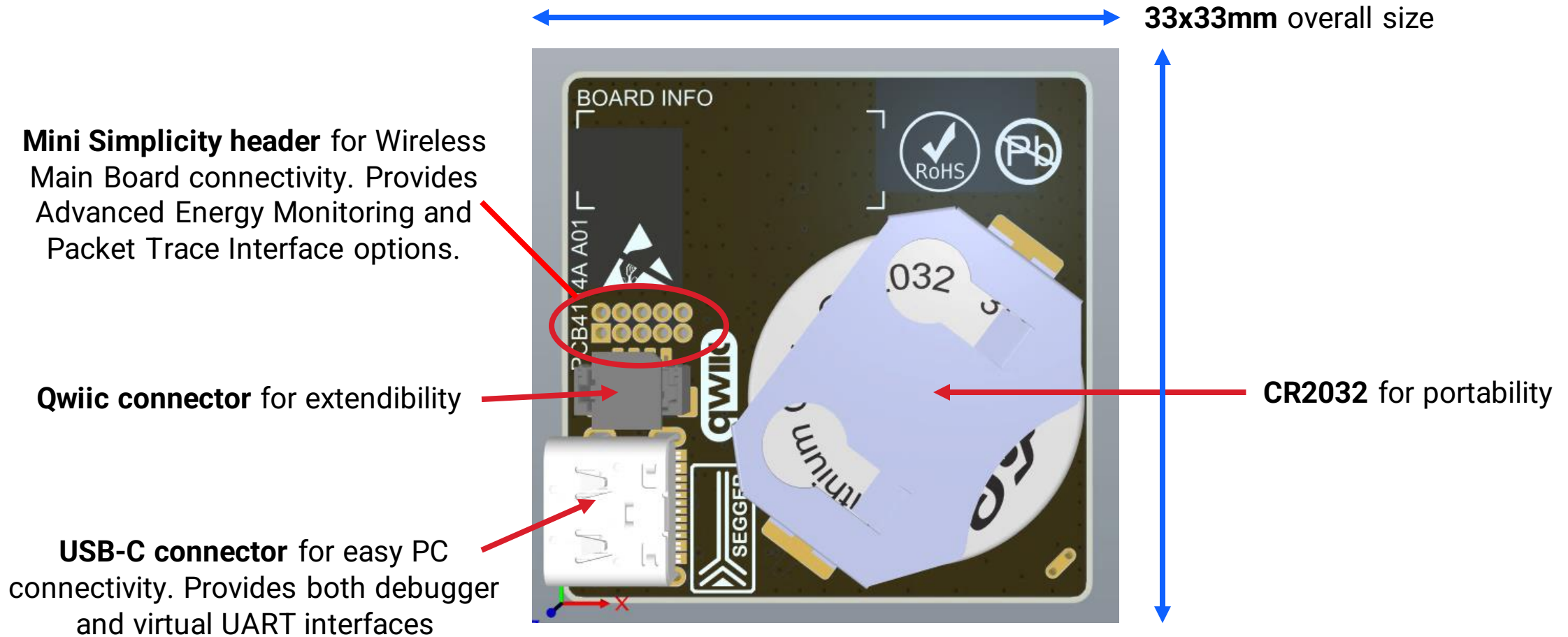
DEVICE SPECIFICATIONS

- **High Performance Radio**
 - Up to +19.5 dBm TX
 - -97.6 dBm RX @ BLE 1 Mbps
- **Efficient ARM® Cortex®-M33**
 - Up to 78 MHz
 - 1536kB Flash, 256kB RAM
- **Low Power**
 - 49.1 μ A/MHz (CoreMark)
 - 5.0 mA TX @ 0 dBm
 - 5.1 mA RX (802.15.4)
 - 4.4 mA RX (BLE 1 Mbps)
 - 1.3 μ A EM2 sleep
- **Multiple protocol support**
 - Bluetooth 5.4 (1M/2M/LR), Bluetooth mesh, Proprietary 2.4 GHz

Dual antenna Channel Sounding board - front



Dual antenna Channel Sounding board - back



Visualizer Tool



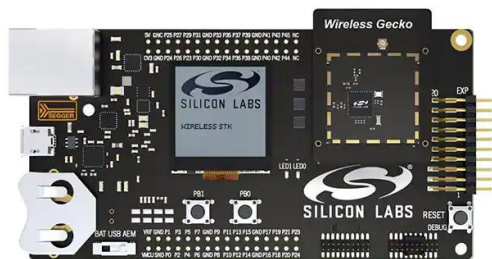
Visualizer Tool displays realtime data

- Channel sounding data with RSSI readings for comparison
- Interfaces with Channel Sounding-enabled EVKs

Upcoming features

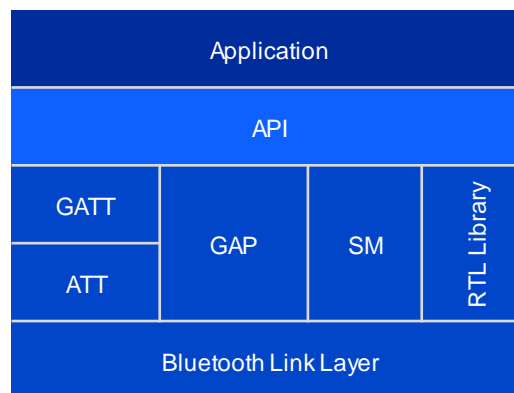
- Data logging
- Confidence metric display
- Channel map selection

Silicon Labs Channel Sounding – Complete Offering



DEVELOPMENT KITS

BRD4198A with Single Antenna
Wireless Pro Kit
EFR32MG24 + 10dBm OPN
BRD2606A with Dual Antennas



STACK SOFTWARE

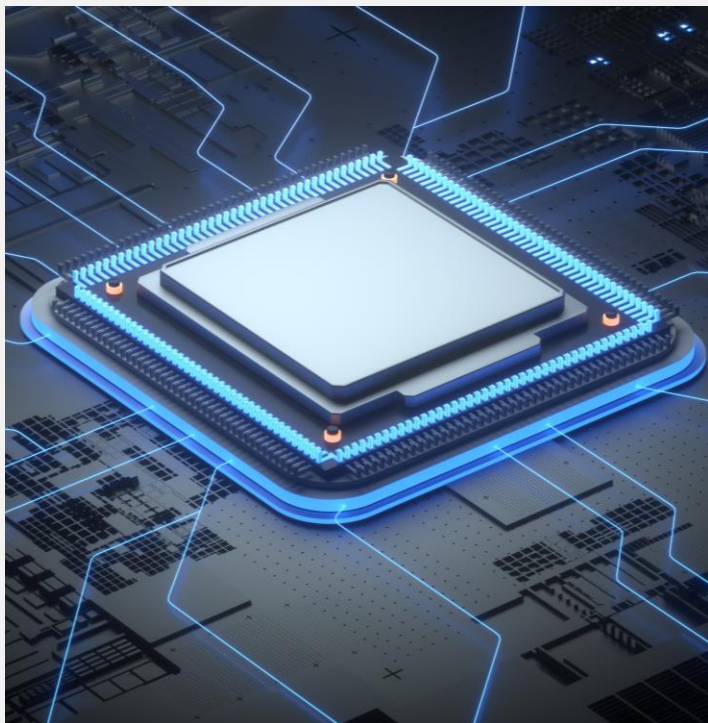
In-house developed stack
Supports Bluetooth 5.4 features + Channel
Sounding
New and improved Ranging features



DEVELOPMENT TOOLS

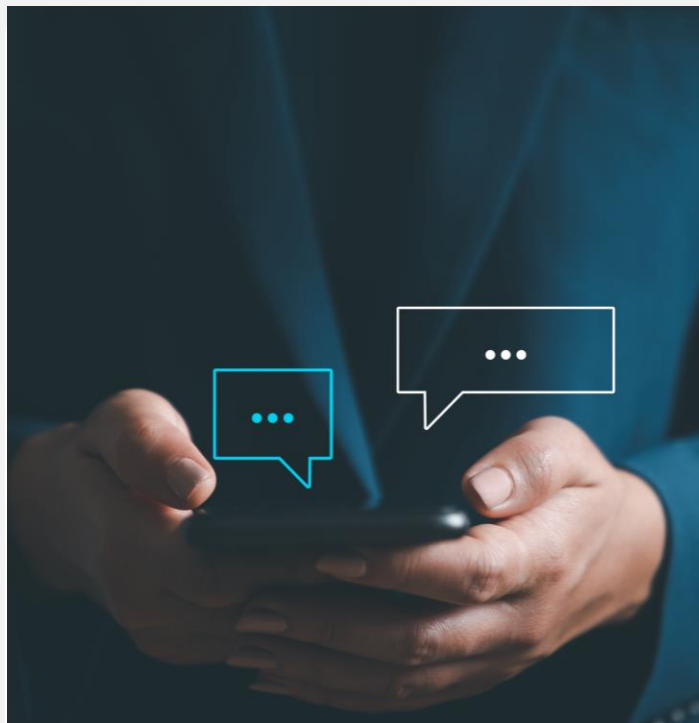
Real-time visualization tool
PBR, RTT modes
CS Sample projects
CS Analyzer + Energy Profiler +
Network Analyzer
App note + Salesforce Support

Call to Action!



GET EARLY ACCESS

Become a part of our ongoing Channel Sounding Early Access Program to get access to our development tools.



CONTACT US

For any questions or to join our Early Access Program, please contact our sales team.



LEARN MORE

To learn more about Channel Sounding and SiLabs offerings, please visit our [website](#).

Q&A



Thank you



BLUETOOTH

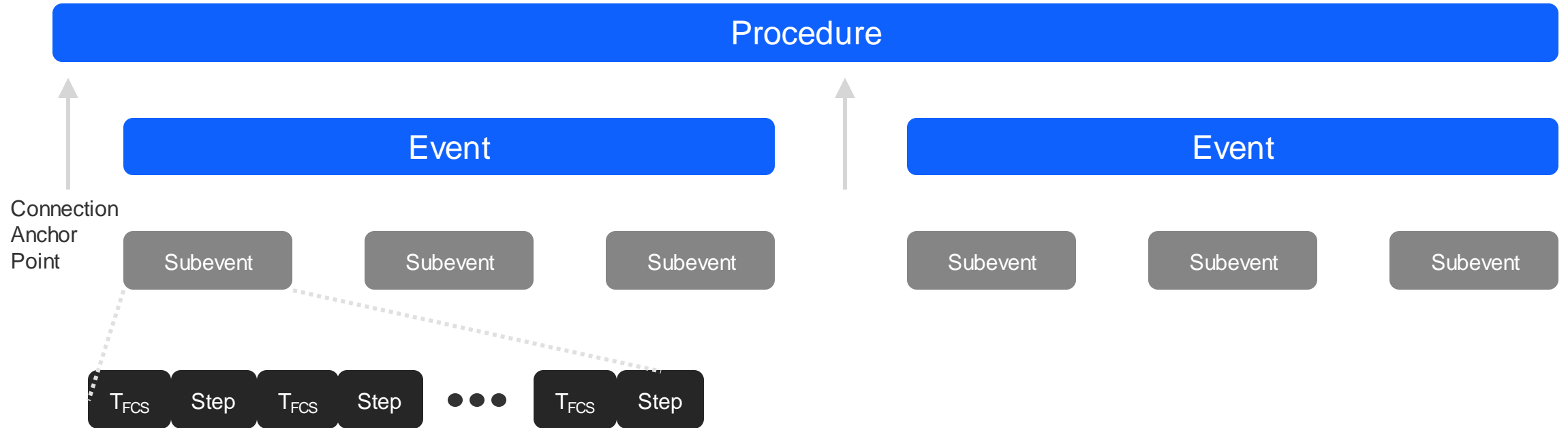
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Channel Sounding antenna options

Antenna Configuration Index (ACI)	Device A number of antennas	Device B number of antennas	Number of Antenna paths (N_AP)
0	1	1	1
1	2	1	2
2	3	1	3
3	4	1	4
4	1	2	2
5	1	3	3
6	1	4	4
7	2	2	4

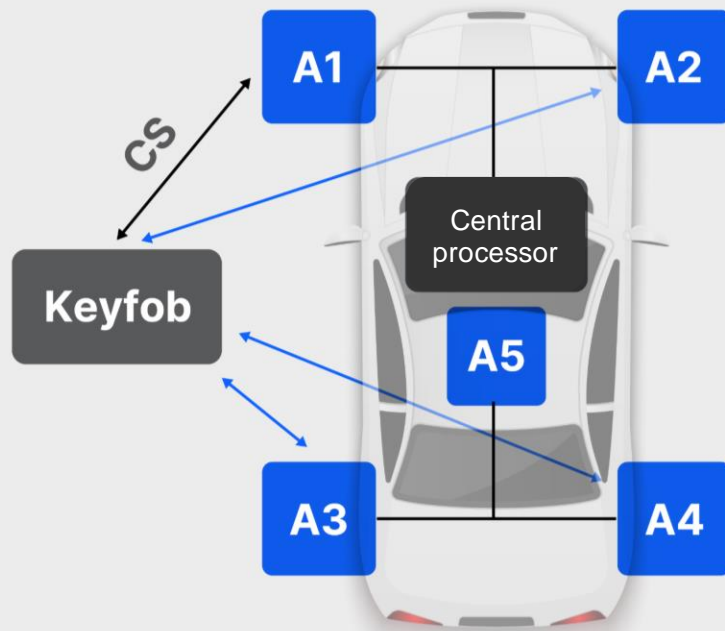
Possible antenna path configurations



Example board supporting 2 antenna paths

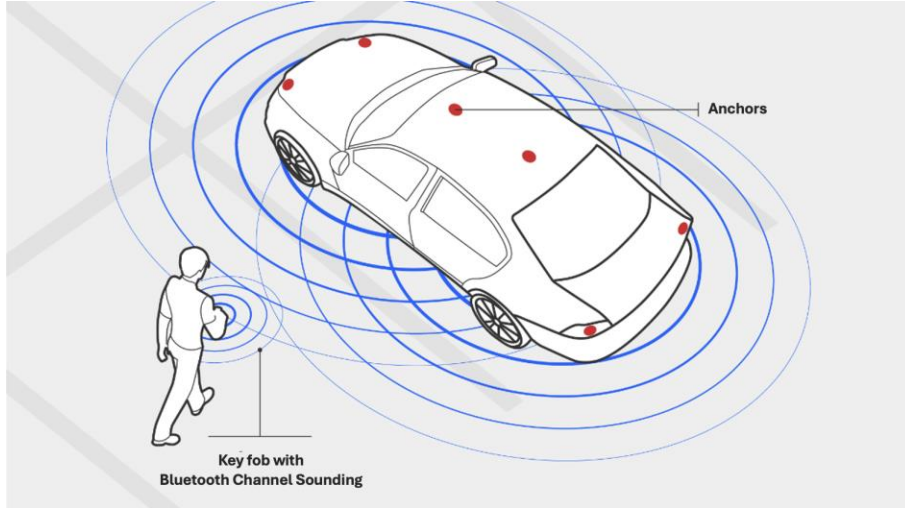
- Capabilities exchange indicates supported antenna configurations for that device
- During a PBR step, all configured antenna paths exercised on a channel
- Number of antennas used impacts:
 - The duration of PBR steps
 - Size of IQ data buffer transferred from reflector to initiator

Example Channel Sounding Application With Multiple Anchors



- **Connectionless RSSI** scan from all Ax anchors to find initial CS-connected anchor
- **Coordinator connects Ax with highest RSSI to fob**
- **CS ranging with connected anchor**
 - +/-5m or better accuracy
 - Up to 10 Hz refresh rate
 - Encrypted connection for key exchange
- **Remaining anchors sniff connection and read RSSI**
- **Disconnect and re-connection** determined by Coordinator if necessary

Theft Prevention + Vehicle Access



- **Unlock on approach**
 - Zonal detection through ranging for secure vehicle access
 - User enhancement with wake/welcome response
- **Bluetooth LE connection established**
 - Bluetooth LE connection for data channel
 - Channel Sounding ranging supported through connection
- **Multi-point Bluetooth ranging**
 - Between key fob/phone¹ and one+ anchor points on car
 - Trilateration possible with multiple anchors
- **Optional data channel for UWB ranging and Car Connectivity Consortium (CCC)²**

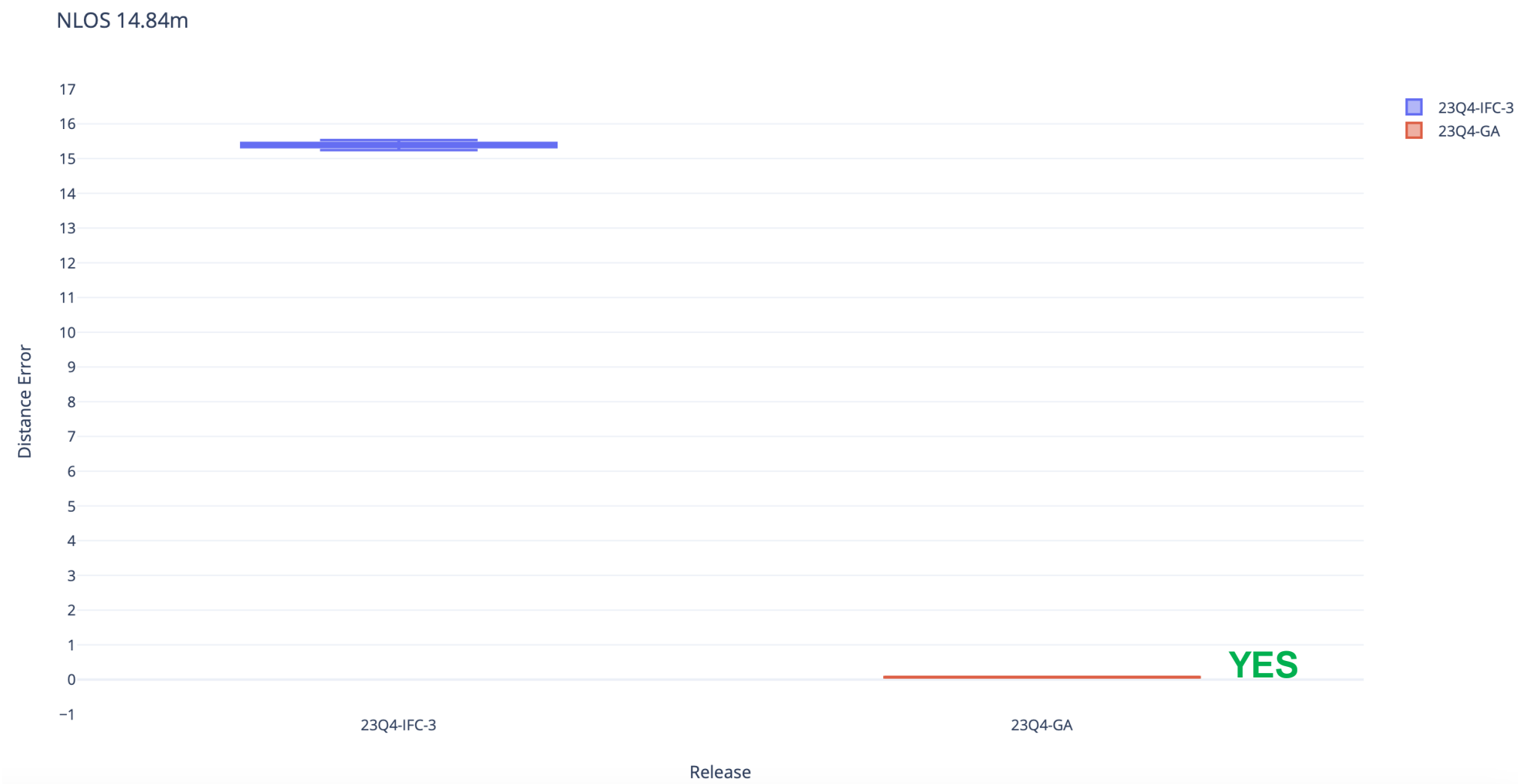
¹ Channel Sounding ranging pending CS support in phone

² Channel Sounding as optional pre-ranging feature under consideration at CCC

Silicon Labs NLOS 33.9m



Silicon Labs NLOS 14.84m



Silicon Labs NLOS 7.97m



Resources
