Agenda

Technology Overview

Channel Sounding Applications

Silicon Labs Offerings

Algorithm Performance Data

Developer Tools

Q&A

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Why Bluetooth® Channel Sounding?

THE CHALLENGE:

IOT applications need 'spatial' awareness to be more secure, reliable, and responsive

Earlier Bluetooth LE versions lack native support for precise ranging

RSSI-based ranging is noisy and unreliable in real-world use

Direction Finding needs complex antennas, adding cost & complexity

UWB is accurate but often too costly, and bulky for IoT
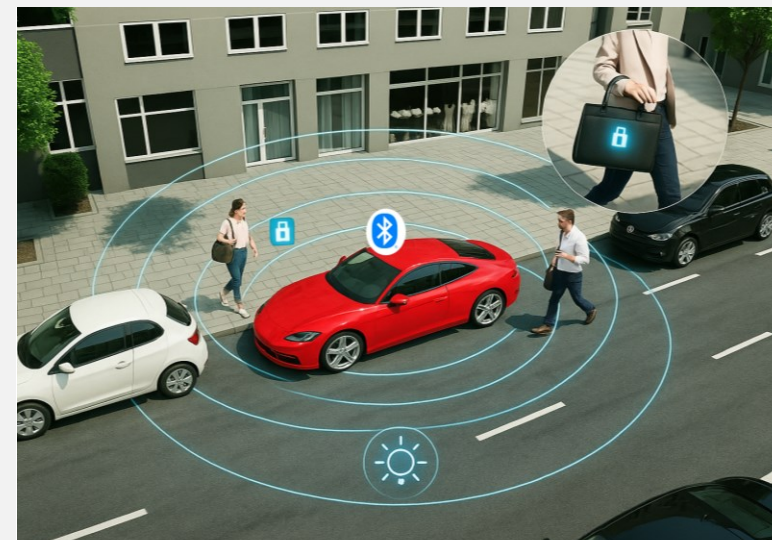
THE OPPORTUNITY:

Channel Sounding for Bluetooth

Standardized approach for accurate, secure ranging in Bluetooth 6.0

Enables sub-meter accuracy with robust performance, even in NLOS

Works with single or dual antenna setups - flexible for different form factors

More cost efficient than UWB; requires minimal external components

Built on existing Bluetooth infrastructure, simplifying adoption and ecosystem integration

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Bluetooth® 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 channel 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 locator/tag pair

Additional Resources

- <u>Webpage</u> – Learn more about Silicon Labs offerings and demos

- <u>Tech Talk</u> – Explore Bluetooth Channel Sounding

- <u>Workswith 2024</u> - Enable Accurate Distance Estimation Using Channel Sounding

- <u>Blog:</u> Learn more about Antenna Switching with Silicon Labs Channel Sounding

- <u>API Spec</u>: Getting Started with Silicon Labs Bluetooth Channel Sounding

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Bluetooth® Channel Sounding Comparison

	RSSI	UWB	Angle of Arrival	Channel Sounding
Localization metric	Resolve distance estimation from transmitter signal strength	Resolve distance between two points using high-resolution time-of-flight (ToF)	Resolve direction vector between two points	Resolve distance between two points using time of flight and phase-based ranging
Antenna requirements	Single antenna	Often complex hardware	Multi-antenna required by spec	Single or dual antenna
Connectivity	Connection-oriented and connectionless	Connectionless	Connection-oriented and connectionless	Connection-oriented
Performance metrics	+/- 5 m, high susceptibility to multipath interference	High accuracy (~10–30 cm)	+- 3 degrees accuracy – azimuth +- 5 degrees accuracy – elevation	+- .3 m < 5m with PBR +- 0.5 m > 5m with PBR
Solution advantages	Ubiquitous support for RSSI measurements in existing Bluetooth LE products	• High Precision • Low Latency	• Scalable solution for real time position tracking • Supports 5-10 year battery life	• Small form factor with flexible antenna design • Feature-add for security by proximity
Solution disadvantages	Highly susceptible to RF noise and multipath	Expensive and complex integration	• Needs complex antenna setup and calibration	Scalability

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Bluetooth® Channel Sounding - Target Markets & Use Cases
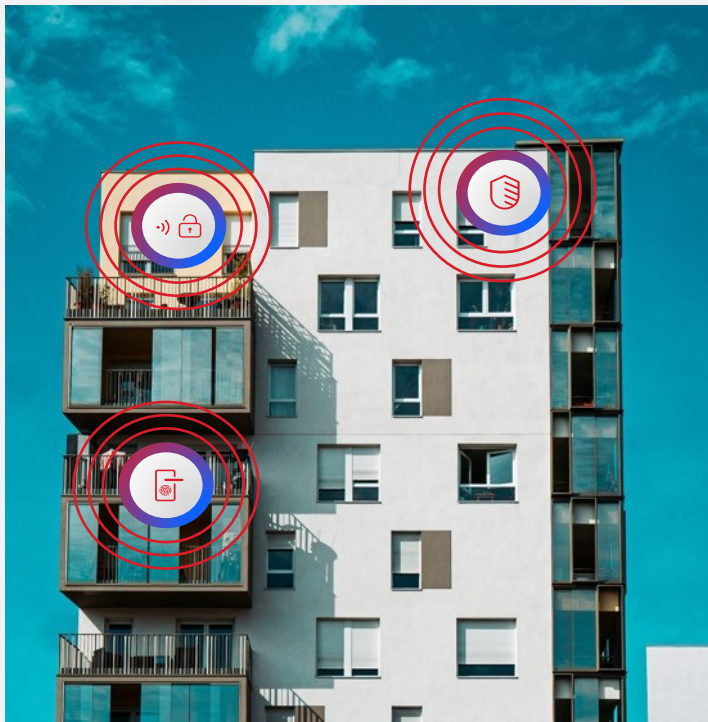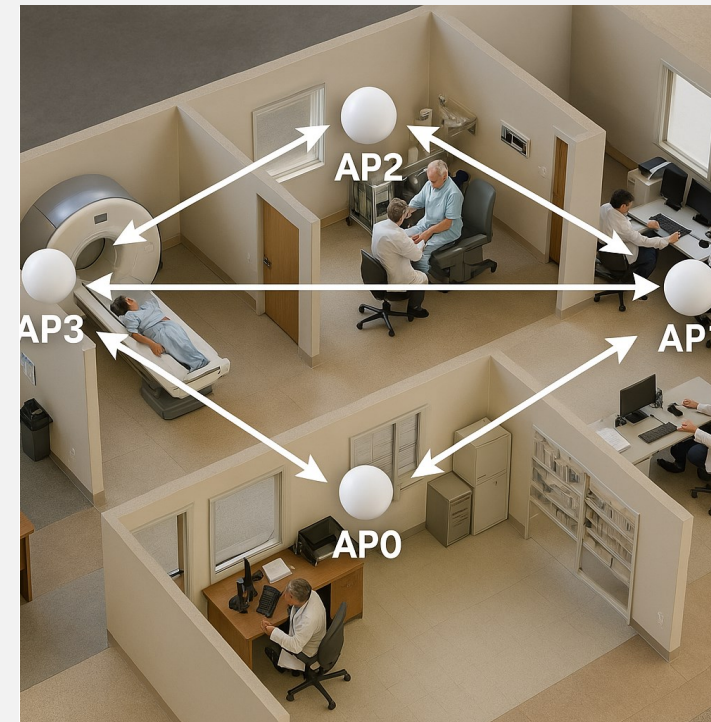

PROXIMITY AWARENESS

Door locks

Keyless entry

Building access systems

Geofencing - security alerts
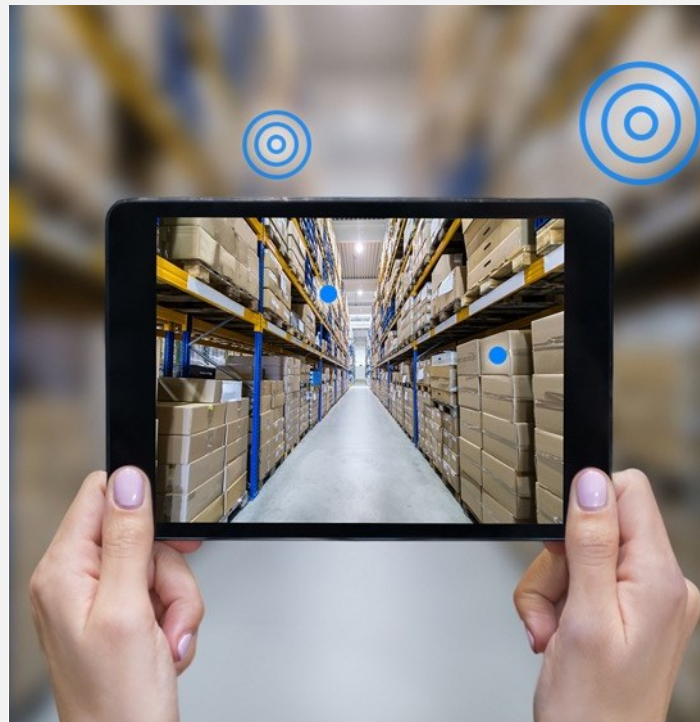
LOCALIZATION

Indoor asset management - hospitals, warehouses

Pet tracking

Item finding - wallet, keys

AUTOMAPPING

Solar Trackers

Luminaires, Access Points

Accurate Mapping for Battery Storage

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

BG24

Bluetooth®   Proprietary

- **5x5 QFN40 (26 GPIO), AEC-Q100**
- **6x6 QFN48 (32 GPIO), AEC-Q100**
- **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 µA/MHz (CoreMark)
  - 5.0 mA TX @ 0 dBm
  - 5.1 mA RX (802.15.4)
  - 4.4 mA RX (BLE 1 Mbps)
  - 1.3 µA EM2 sleep

- **Multiple protocol support**
  - Bluetooth 6.0 (1M/2M/LR), Bluetooth mesh, Proprietary 2.4 GHz

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BG24L: Channel Sounding Optimized, High-Performance & Low-Cost AI/ML Wireless SoC

BG24L

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Bluetooth®

- **5x5 QFN40 (26 GPIO)**

DIFFERENTIATED FEATURES

- **Supports Bluetooth 6.0**
  - Channel Sounding optimized BLE SoC
  - Single-connection two-way ranging
  - Ideal Solution for Channel Sounding tags
- **Lowest Power RF**
  - Increases battery life
- **PLFRCO**
  - Eliminates need for 32 KHz XTAL and lowers overall system cost
- **16-bit ADC**
  - Up to 14-bit ENOB for better analog sensing
- **AI/ML accelerator**
  - Accelerates inferencing while reducing power consumption
- **Secure Vault Mid**
  - Protects data and device from local and remote attacks
- **Improved Coexistence**
  - Ideal for gateways and hubs

DEVICE SPECIFICATIONS

- **High Performance Radio**
  - Up to +10 dBm TX
  - -97.6 dBm RX @ BLE 1 Mbps
- **Efficient ARM® Cortex®-M33**
  - Up to 78 MHz
  - 768kB Flash, 96kB RAM
- **Low Power**
  - 49.1 µA/MHz (CoreMark)
  - 5.0 mA TX @ 0 dBm
  - 5.1 mA RX (802.15.4)
  - 4.4 mA RX (BLE 1 Mbps)
  - 1.3 µA EM2 (16kB RAM retention)
- **Wide Operating Range**
  - 1.71 to 3.8 volts
  - +125ºC operating temperature
- **Multiple protocol support**
 - Bluetooth 6.0 (1M/2M/LR), Bluetooth mesh, Proprietary 2.4 GHz

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Bluetooth® Channel Sounding Dual Antenna Development Kit

- **xG24 Channel Sounding Development Kit**
  - Available since March 2025
  - Development Kit with two PCB antennas
    - Antenna diversity offers increased robustness and accuracy
  - Intra-event antenna switching for optimal non-line of sight performance
  - Includes IMU sensor to detect movement & wake-up the tag
  - Small form factor
    - Ideal for size-constrained applications like key fobs
  - AEC-Q100 Compliant
  - SoC/NCP Sample Apps
    - Initiator and Reflector examples supported
  - Ranging Library
    - Process IQ samples, post-filtering, and compute distance using configurable algorithm

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Antenna Diversity – What does it bring?
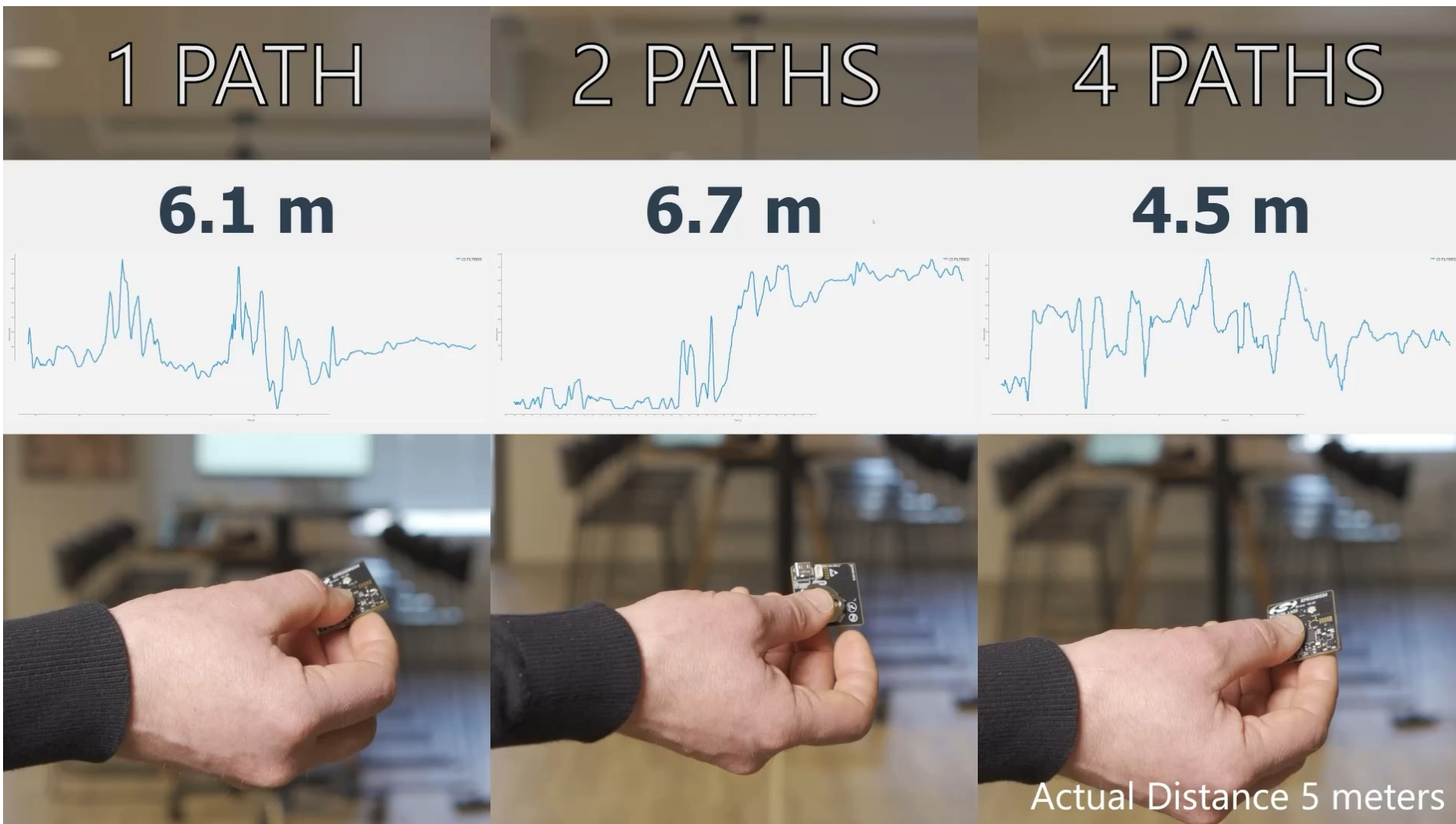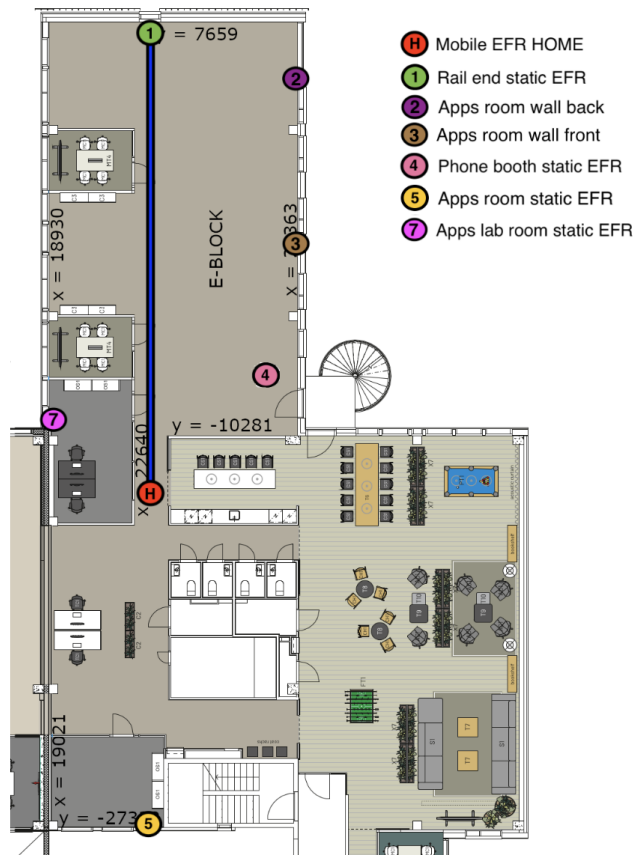
Silicon Labs Channel Sounding Algorithm

- **Algorithm Features**
  - Supports Multiple Channel Sounding Ranging Modes
    - ‣ PBR, RTT, PBR with RTT as sub mode
  - Antenna Switching
    - ‣ Built-in support for antenna diversity
    - ‣ Supports 1, 2 and 4 antenna paths
  - Supported Algorithm modes
    - ‣ Static mode – Delivers the highest accuracy with high measurement latency; optimized for ranging between stationary devices
    - ‣ Real Time Basic – Provides high accuracy with increased computational and measurement latency; supports tracking at speeds up to 1 m/s
    - ‣ Real Time Fast – Balances moderate accuracy and range with low latency; supports tracking at speeds up to 2.1 m/s, additionally produces velocity metric
  - Configurable Channel Selection (72, 37, or 20 Channels)
    - ‣ Selectable based on accuracy needs and power constraints

- **Key Benefits**
  - Licensing cost free
    - ‣ Eliminates third-party royalties, simplifying BOM cost structure
  - Optimized HW-SW Co-Design
    - ‣ Tight coupling between silicon & firmware ensures seamless performance & efficiency
  - Single-Vendor Lifecycle Support
    - ‣ Unified hardware & software ownership streamlines debugging, validation, and updates

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Algorithm Performance Test Setup

Legend:
- **H** Mobile EFR HOME
- **1** Rail end static EFR
- **2** Apps room wall back
- **3** Apps room wall front
- **4** Phone booth static EFR
- **5** Apps room static EFR
- **7** Apps lab room static EFR

Node Pairs		Distance (in m)	Obstacles
▮ (blue)	H & 1	20	Line-of-Sight
▮ (purple)	H & 4	7.9	Walls, Kitchen
▮ (green)	1 & 4	14.84	Cubicles, Luminaires
▮ (yellow)	1 & 5	33.9	Walls, Glass door

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Algorithm Performance Data[1]

Algorithm Mode	LOS 90th Pct. Absolute Error (in m)	LOS 95th Pct. Absolute Error (in m)	NLOS 90th Pct. Absolute Error (in m)	NLOS 95th Pct. Absolute Error (in m)	Computation time (in ms)
STATIC_HIGH_ACCURACY	0.5	0.6	1.7	2.7	20000[2]
REAL_TIME_BASIC	0.5	0.6	1.9	4.2	188
REAL_TIME_FAST	0.4	0.5	4.0	5.3	20

1. CS mode – PBR, CS channels – 72, number of antenna paths – 4
2. ~100 CS Procedures used to produce single distance estimate

*Fit For Purpose Algorithm Modes*

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Energy Consumption Profile – Reflector

Reference Board	Number of Antenna Paths (NAP)	Number of Channels	Mean Current Consumption (mA)	Mean Energy Consumption (nAh)
BRD2606A	4	72	~2.2	~191.0
		37	~1.2	~111.0
		20	~0.9	~75.4
	2	72	~1.7	~146.0
		37	~1.0	~91.0
		20	~0.8	~65.0
	1	72	~1.5	~122.8
		37	~1.0	~79.0
		20	~0.7	~58.0

Antenna Diversity Increases Total Energy Per Measurement

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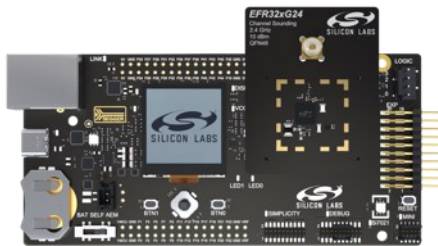# Algorithm Performance

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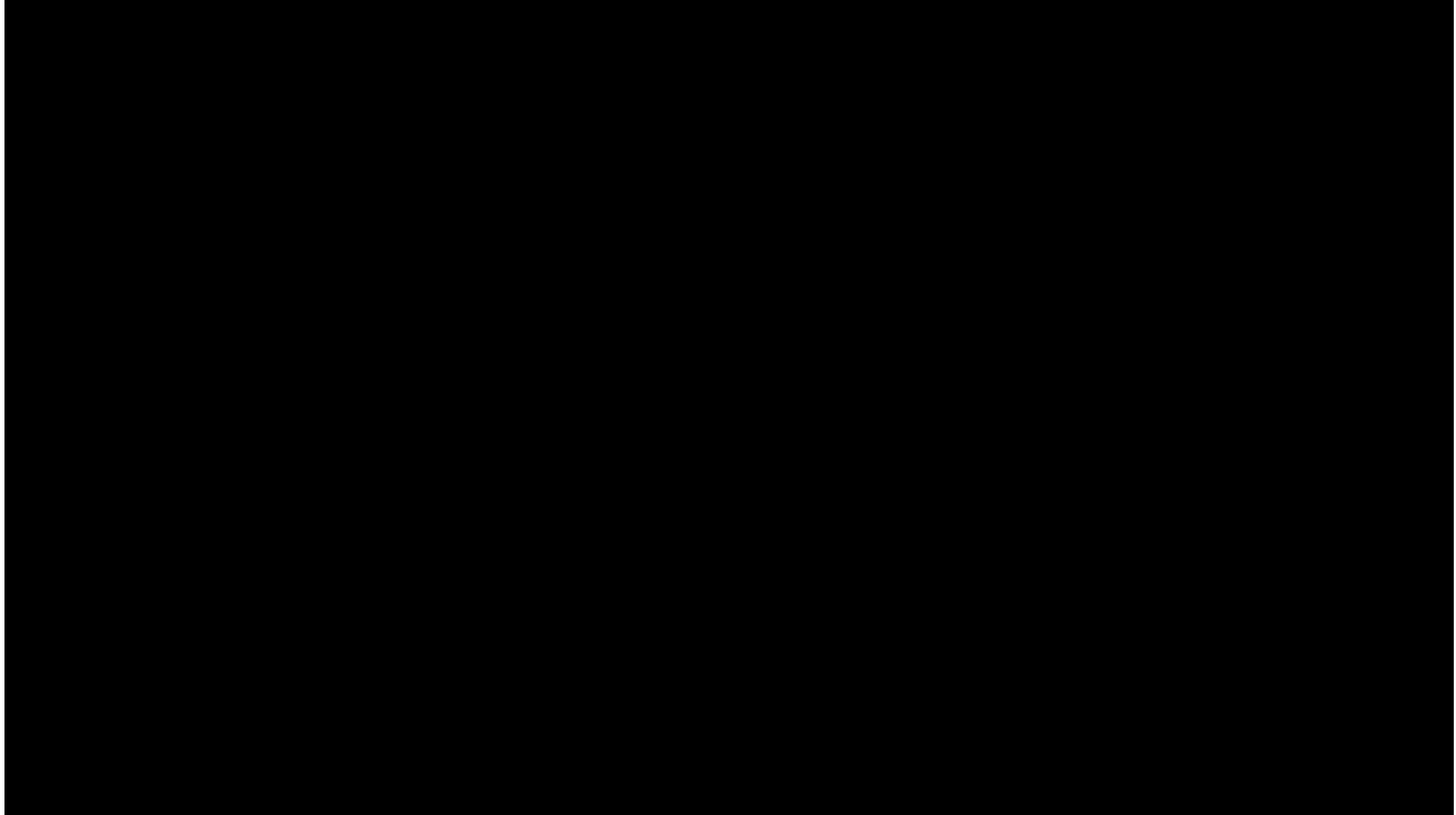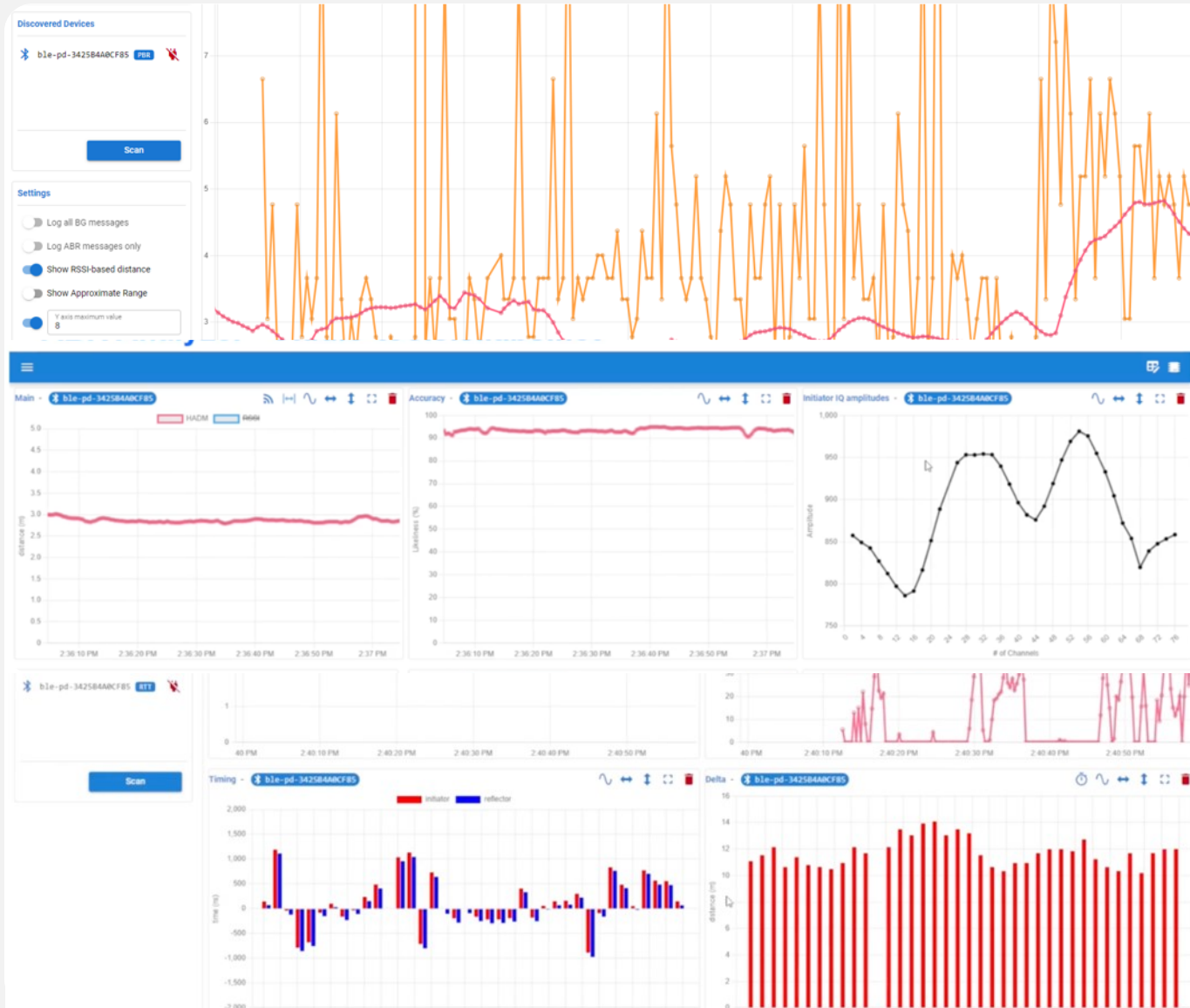
Visualizer Tool

Visualizer Tool displays real-time CS data

- CS configuration
  - ‣ Channel map selection
  - ‣ Antenna path configuration
  - ‣ Algorithm mode selection
- CS data visualization
  - ‣ RSSI based distance for comparison
  - ‣ Raw distance estimate and likeliness
  - ‣ Filtered distance estimate
  - ‣ IQ data visualization
- Interfaces with CS enabled EVKs

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Silicon Labs Bluetooth ® Channel Sounding Offering

Application

API

GATT

ATT

GAP

SM

RTL Library

Bluetooth Link Layer

I/Q data

Pre-processing

Distance computation

Post-processing

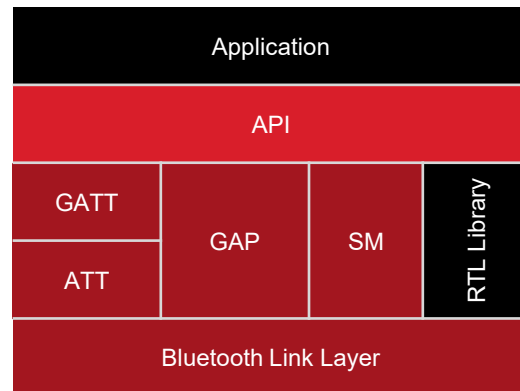Distance

SIMPLICITY STUDIO

ICS & DEVELOPMENT KITS

Channel Sounding Supported by **B/MG24**

Kits:

xG24-RB4198A single antenna kit

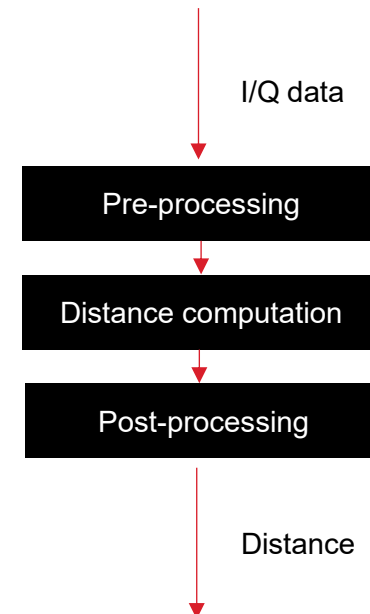**xG24-DK2606A** dual antenna kit

BLUETOOTH 6.0 STACK

In-house developed stack, supported and maintained stack

Bluetooth 6.0 qualified

PBR & RTT Modes

RTL LIBRARY

Computes distance from raw I/Q data

Developed and supported by Silicon Labs

New features added based on market needs
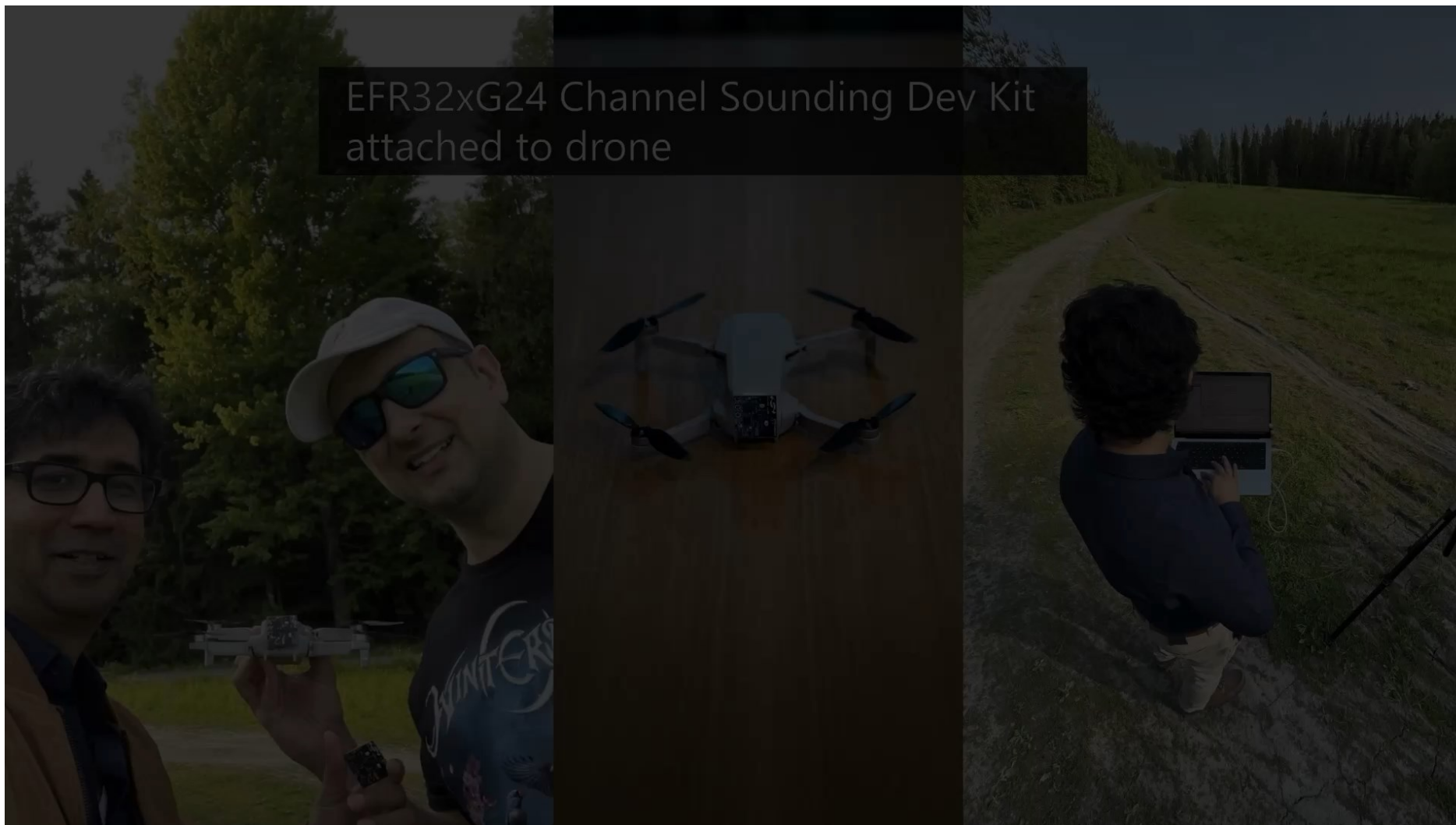
No 3rd party license fees

SDK & TOOLS

Initiator & Reflector examples

Real-time visualization tool for Bluetooth Channel Sounding

Energy Profiler etc.

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EFR32xG24 Channel Sounding Dev Kit attached to drone

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