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CONNECTED INTELLIGENCE

2025 tech talks
WEBINAR SERIES

The Most Application-Optimized Bluetooth SoCs for Future-Ready Applications

Vikram Pochampally, Lead FAE

Agenda

“Lite” Wireless SoCs

BG24L

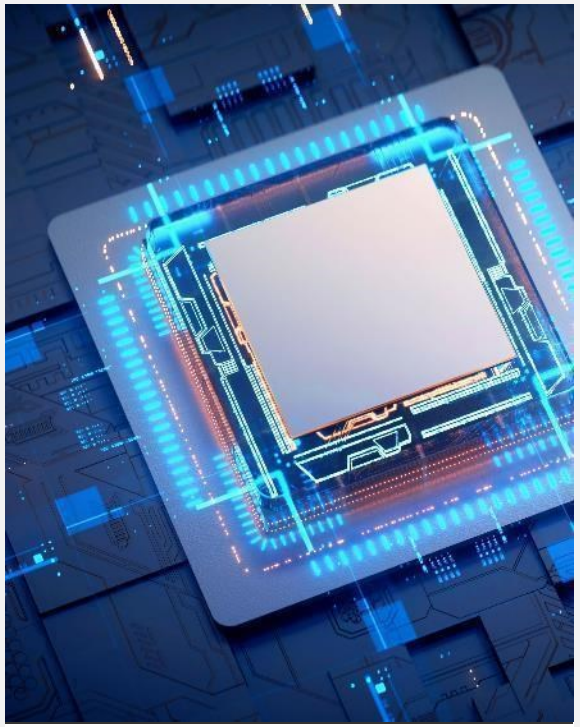
Channel Sounding

AI/ML at the Edge

BG22L

Q&A

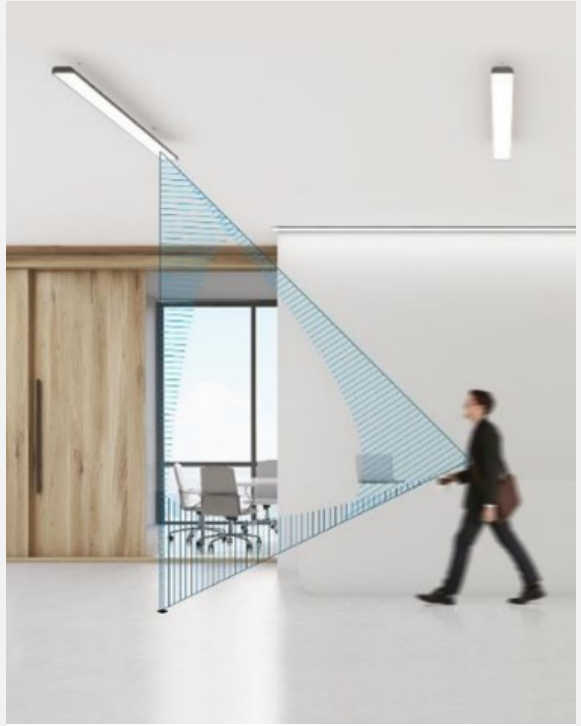
Demystifying Bluetooth SoC Selection



ENERGY EFFICIENT

Extended Battery Life

Lowest Power consumption w/ Support for Battery-Less operations



HIGH PERFORMANCE RF

Minimize Interference

Extended Range

Improved Data Transfer

SYSTEM COST

Simplified Design

Small Form-Factor

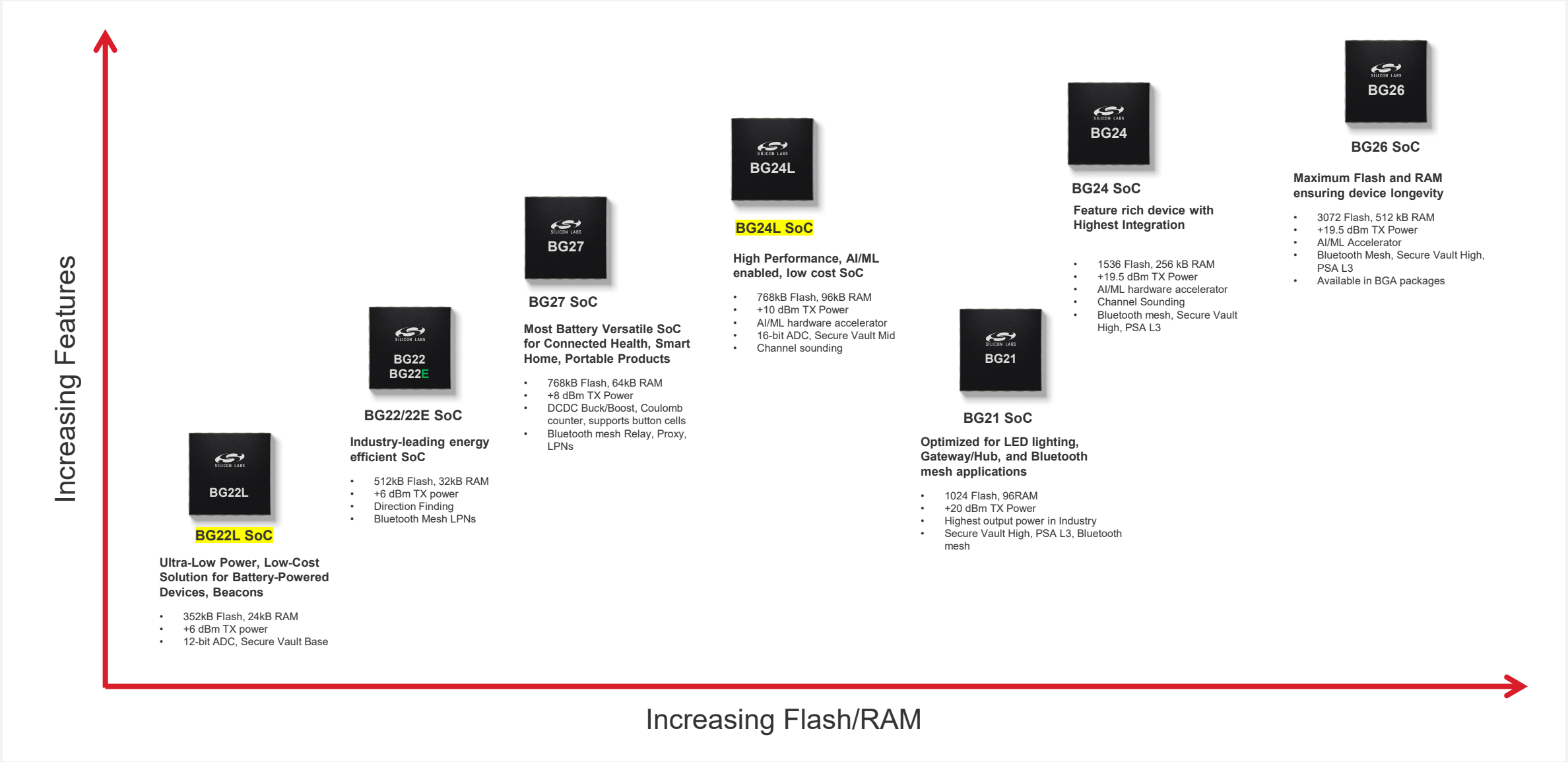
BOM Savings

DEVELOPMENT TOOLS

Fully Featured Kits

Debugging Tools (Network Analyzer, Energy Profiler etc.)

Silicon Labs Bluetooth Portfolio



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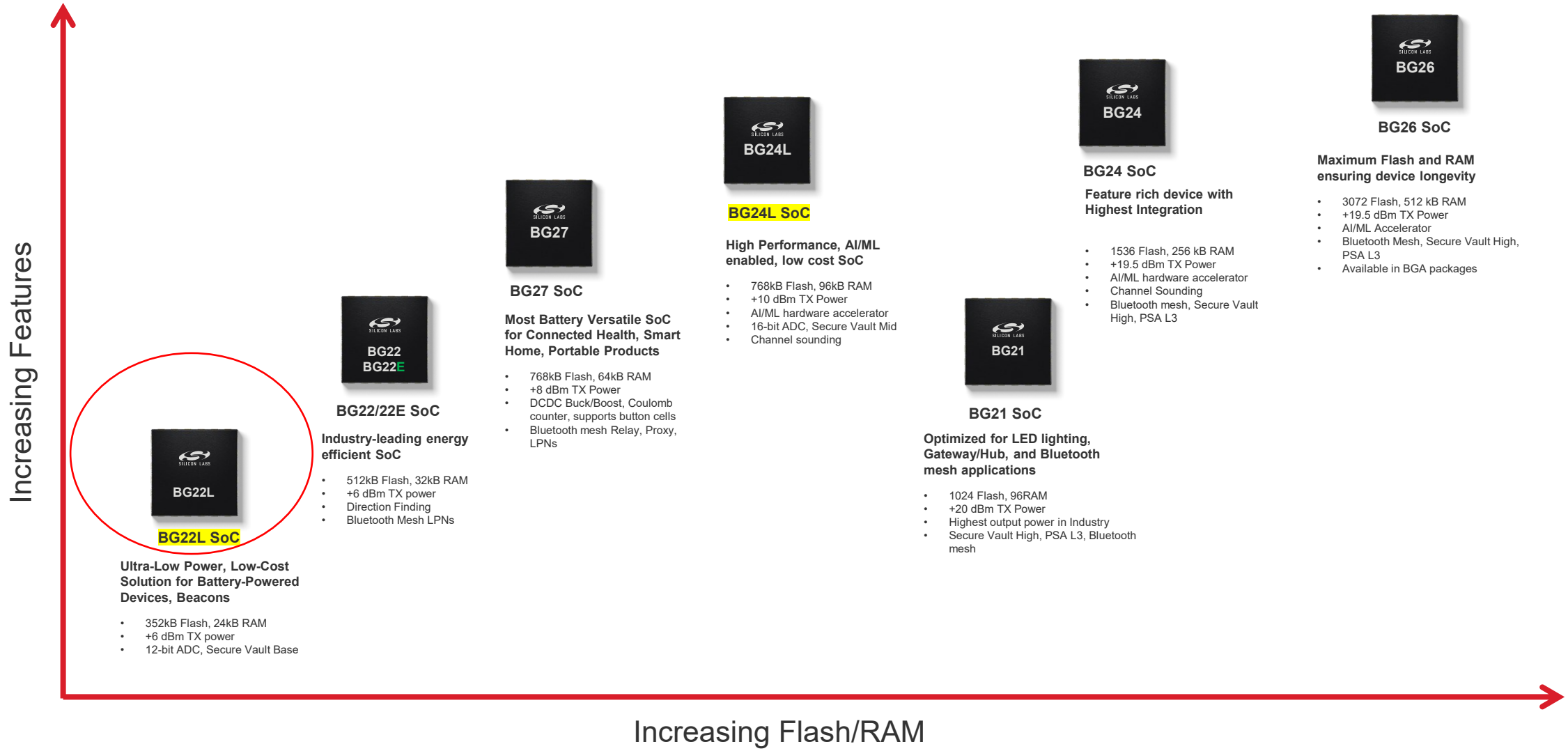

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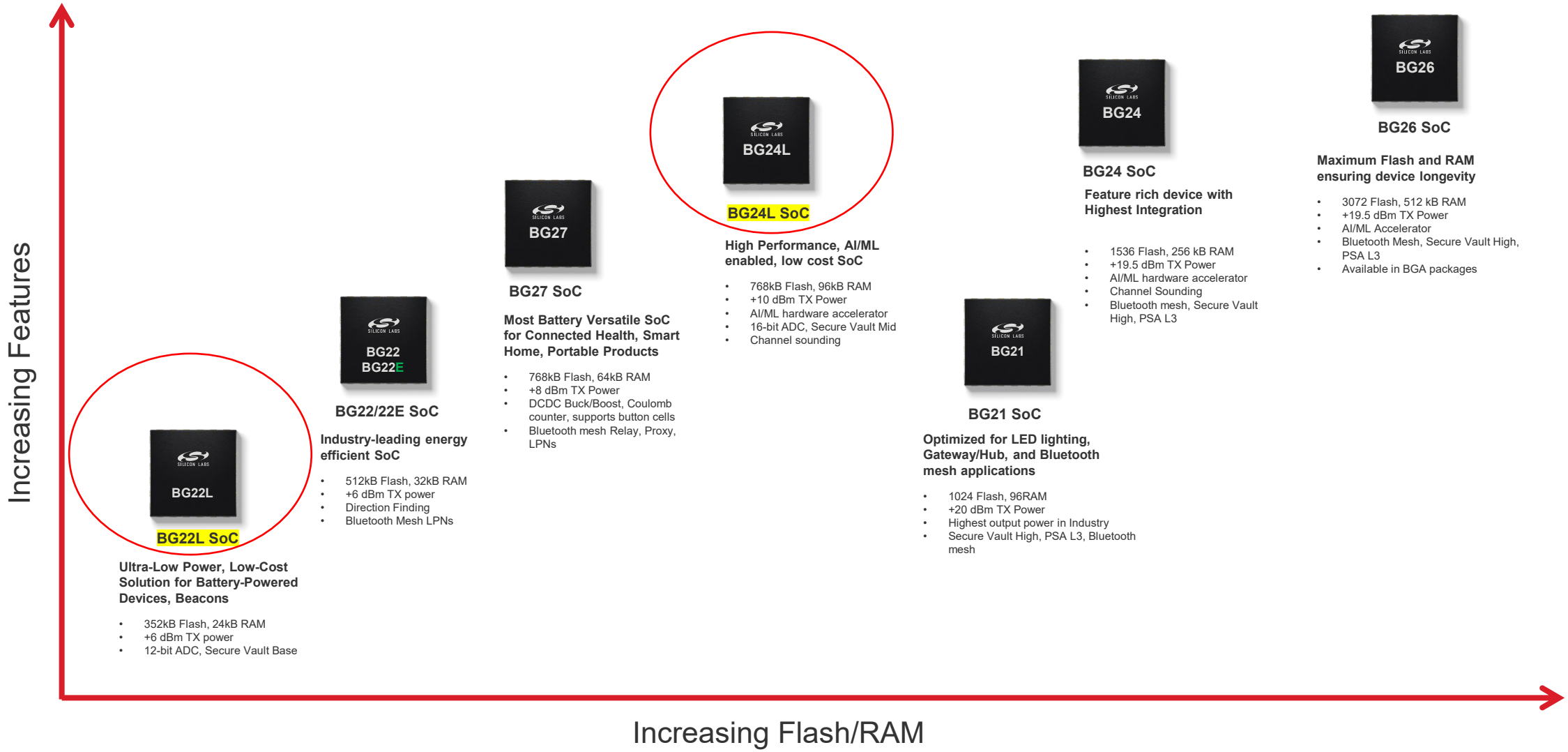

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BG24L

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

Bluetooth®

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

Differentiated features

- **Supports Bluetooth 6.0**
  - Channel Sounding optimized SoC
  - Single-connection two-way ranging
  - Ideal Solution for Channel Sounding tags
- **Low 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 sleep
- **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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Channel Sounding

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**
  - Channel Sounding specification https://www.bluetooth.com/channel-sounding-tech-overview/

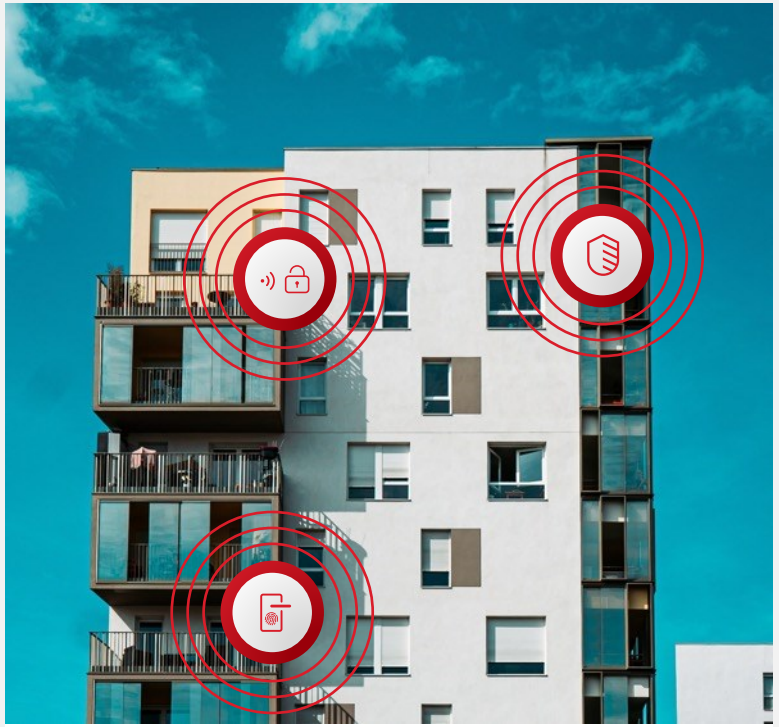
What's included in the spec

- 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

Bluetooth Channel Sounding - Target Markets & Use Cases



PROXIMITY AWARENESS

Door locks

Keyless entry

Building access systems

Geofencing - security alerts

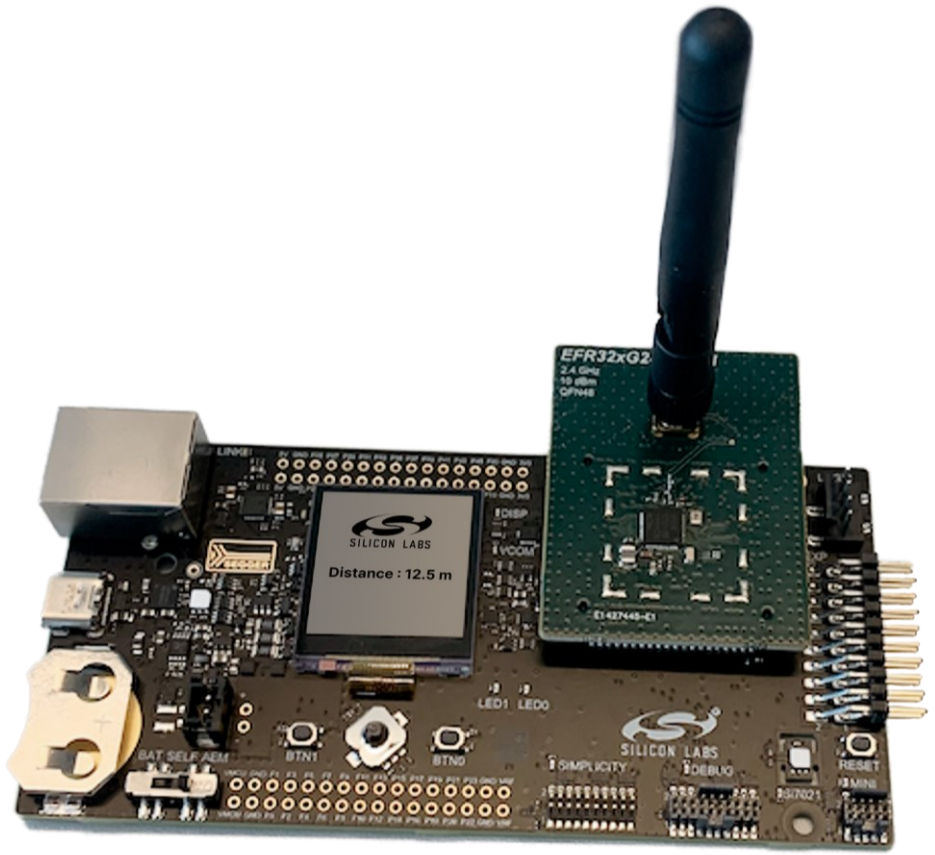
LOCALIZATION

Indoor asset management - hospitals, warehouses

Pet tracking inside home

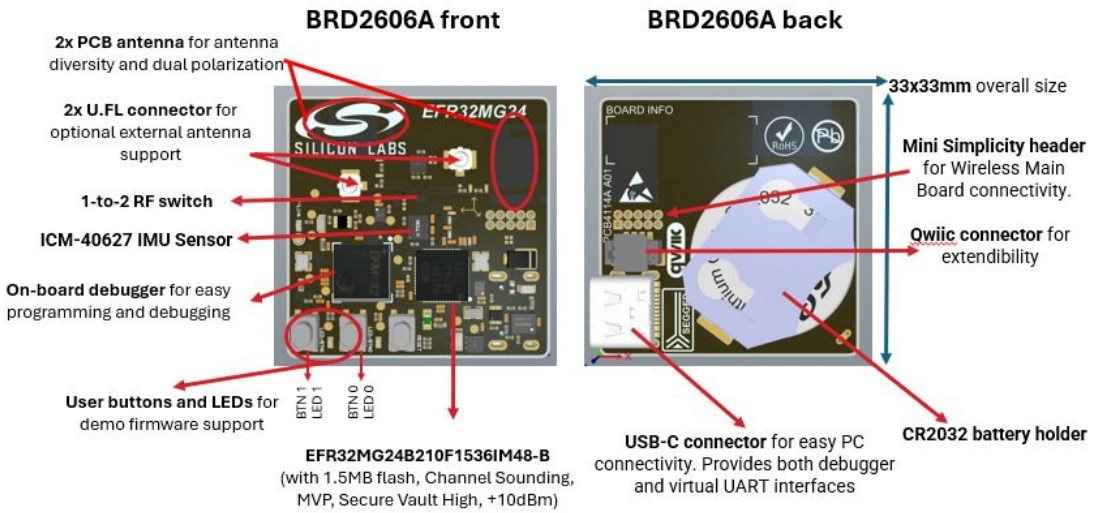
Item finding - wallet, keys

Single-Antenna Channel Sounding Board



- **Channel Sounding evaluation using Ranging Kit**
  - EFR32xG24 Pro Kit with external antenna
  - Full featured development option leveraging WPK features
  - 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
- **Optimized antenna designs**
  - EFR32xG24 reference designs with optimized PCB antenna solutions for indoor location systems

Dual Antenna Channel Sounding Development Kit



- **OPN: xG24-DK2606A**
- EFR32MG24B210F1536IM48-B
  - AEC-Q100 Grade 1
- Two PCB antennas + external RF switch
  - Antenna diversity offers optimal non-line of sight performance
- Includes IMU sensor to detect movement
- Small form factor – 33mm x 33mm
  - Ideal for size-constrained applications like tags
- SoC/NCP Initiator and Reflector Examples
- Channel Sounding Analyzer Tool

Single vs Dual Antenna - Accuracy

Board	Environment	90th Percentile Absolute Error	95th Percentile Absolute Error	Std. deviation	Mean signed error (in m)
BRD4198A (1x1 = 1 antenna path, 72 channels)	Line of sight	0.57	0.58	0.24	0.21
	Non-line of sight	3.79	4.56	1.79	1.38
BRD2606A (2x2 = 4 antenna paths, 72 channels)	Line of sight	0.57	0.69	0.2	-0.41
	Non-line of sight	1.91	4.07	1.64	0.89

Antenna Diversity Substantially Improves Distance Estimation Accuracy Performance in Non-line of Sight Scenarios

Single vs Dual Antenna – Energy Consumption

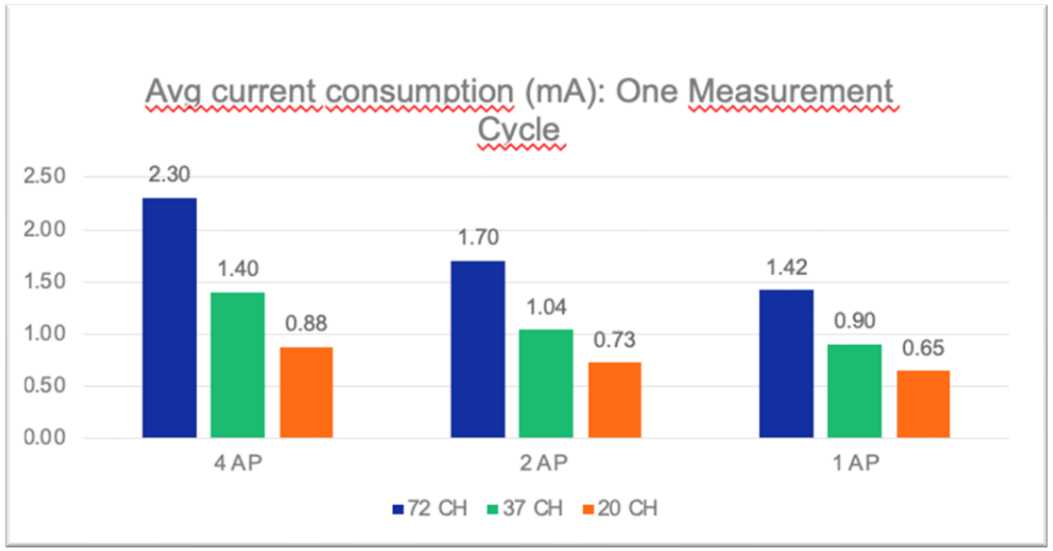
Board	Number of Channel Sounding Channels[1]	Algorithm computation time[1] (ms)	Measurement Update Frequency[1] (Hz)	Total Energy[2] (nAh)	Theoretical Measurement Range (m)
BRD4198A (1x1 = 1 antenna path)	72	~43.4	~6.1	124	150
	37	~12.6	~8.9	73	75
BRD2606A (2 x 2 = 4 antenna paths)	72	~189	~3.05	222	150
	37	~47	~6.3	116	75

1 Measured per measurement at Initiator with algorithm mode SL_RTL_ALGO_MODE_REAL_TIME_BASIC
2 Measured per measurement at Reflector

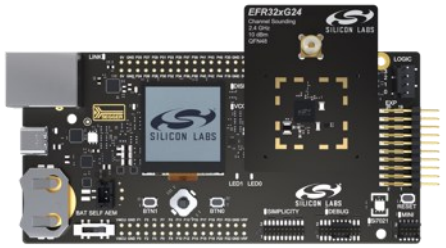
Antenna Diversity Increases Measurement Latency and Total Energy Per Measurement

What can I do to reduce energy consumption?

- **Reduce TX power**
  - Default: 10dBm
- **Increase CS Interval and connection interval**
- **Reduce number of Antenna Paths (AP)**
  - 4 AP
  - 2 AP
  - 1 AP
- **Reduce number of channels**
  - High: 72 channels
  - Medium: 37 channels
  - Low: 20 channels
- RTT packet payload length
  - Reduce the payload decreases the consumption.
- Use 2M PHY over 1M PHY
  - Shorter packets, device can go sleep faster.



Silicon Labs Bluetooth ® Channel Sounding Offering



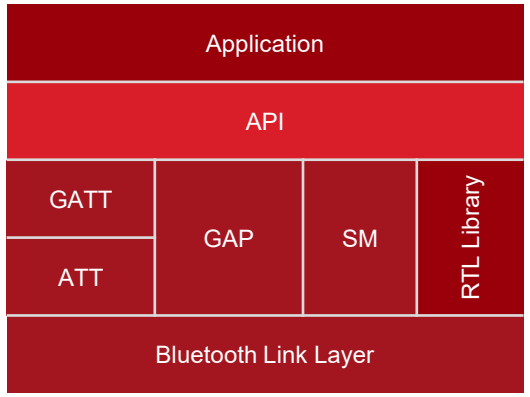
ICS & DEVELOPMENT KITS

Channel Sounding Supported by **B/MG24**

Kits:

xG24-RB4198A single antenna kit

xG24-DK2606A dual antenna kit

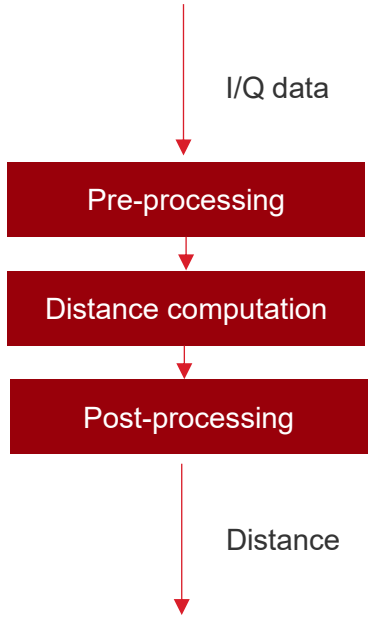


BLUETOOTH 6.0 STACK

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.

Distance Measurement Demo

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Distance Measurement Demo

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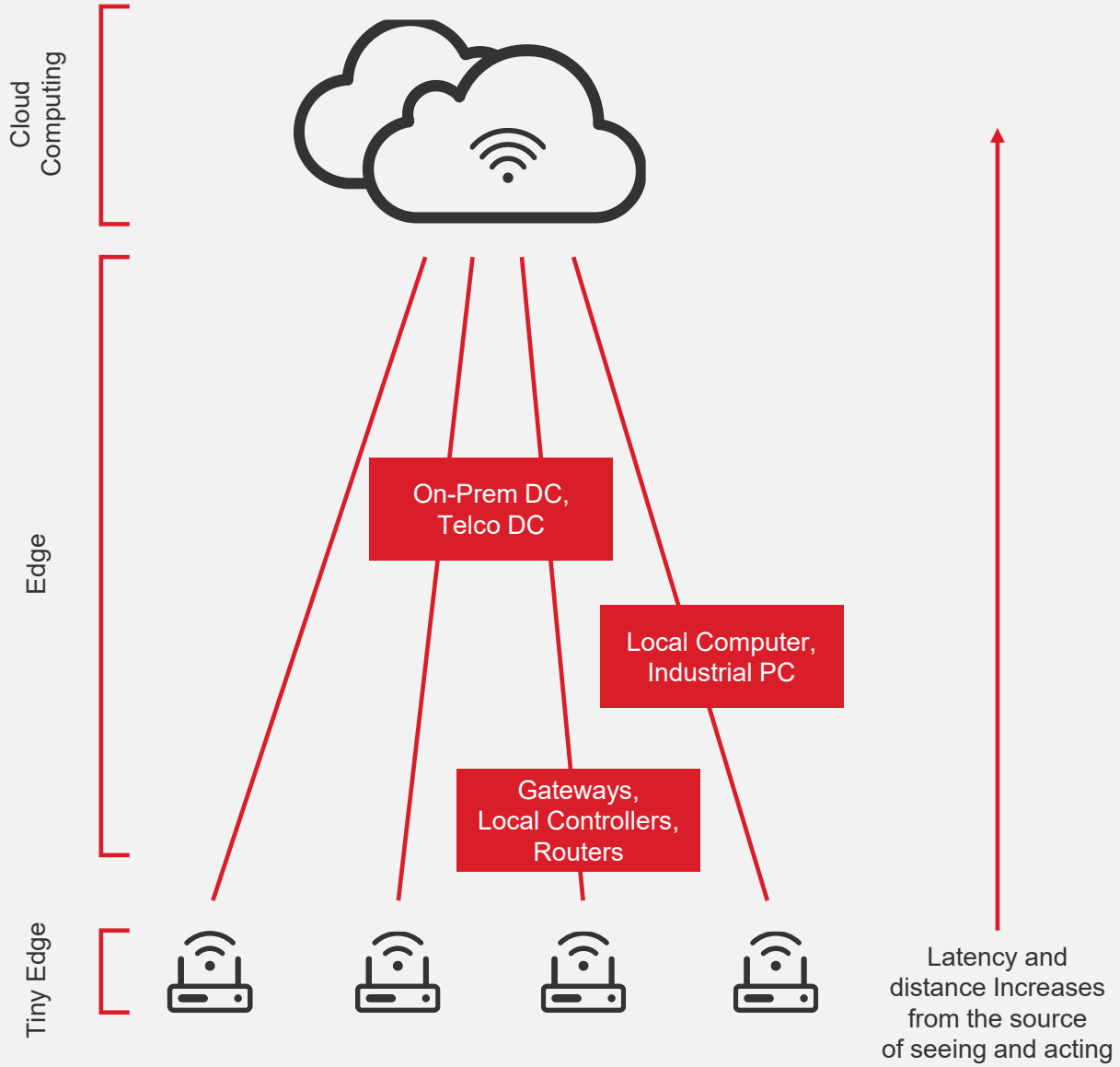
AI/ML at the Edge

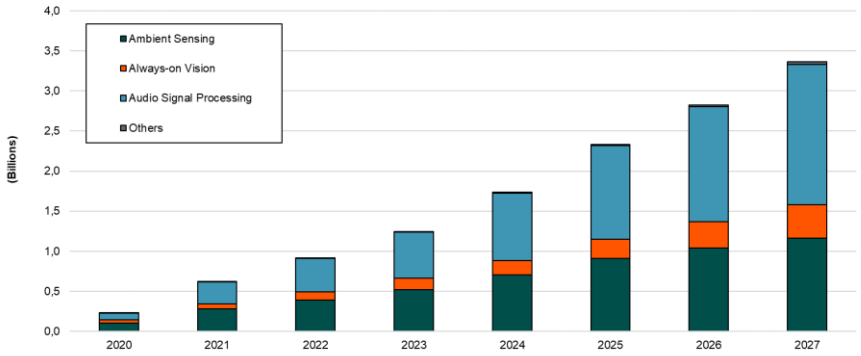


Artificial Intelligence(AI) and Machine Learning(ML) at the Tiny Edge

Key Benefits

- Low Latency
- Privacy, IP Protection, Security
- Bandwidth Constraints
- Offline Mode Operation
- Cost Reduction

>3B Devices sold with TinyML in 2027



Source: ABI Research, Artificial Intelligence and Machine Learning, 2 QTR 2022

Why Machine Learning on Microcontrollers?

Low Latency Required

- Mission or safety-critical applications require real-time reactions
- Large data to process - typically at vision use cases - no time to upload to anywhere to process

Privacy and IP Protection, Security

- Data never leaves the sensing device, only inference result/metadata is transferred
- Less sensitive data to transmit, less chance to be hacked
- Protecting IP

Bandwidth Constraints

- Long range, low power, and slow networks can't transfer all TimeSeries data to process somewhere else
- Overloading of mesh network is an issue
- Large data to chunk e.g. hi-res images

Offline Mode Operation

- Local system keeps operating standalone in case of any network issue
- Connectivity is occasional or blocked by admin

Cost Reduction

- Network and infrastructure costs
- Data ingestion costs
- Data storage costs
- Cloud services
- Ops, maintenance
- Compact edge with ML solutions integrated to wireless SoC
- Cheaper devices

Power Constraints

- Ultra-low power applications
- Always-on systems
- Healthy tradeoff in transmit to higher level compute vs. locally process

Data processing is more efficient with Machine Learning at the sensor level

Event Detection using Machine Learning

Sensors
- Acceleration, Temperature, Current/Voltage
- Time-series data on ADC or GPIO

ML methods based on Time-series Data
- Data anomaly detection
- Data pattern matching

Microphones

Analog or Digital
- Audio mic array with beamforming
- Audio mic input with Audio Front End, DSP

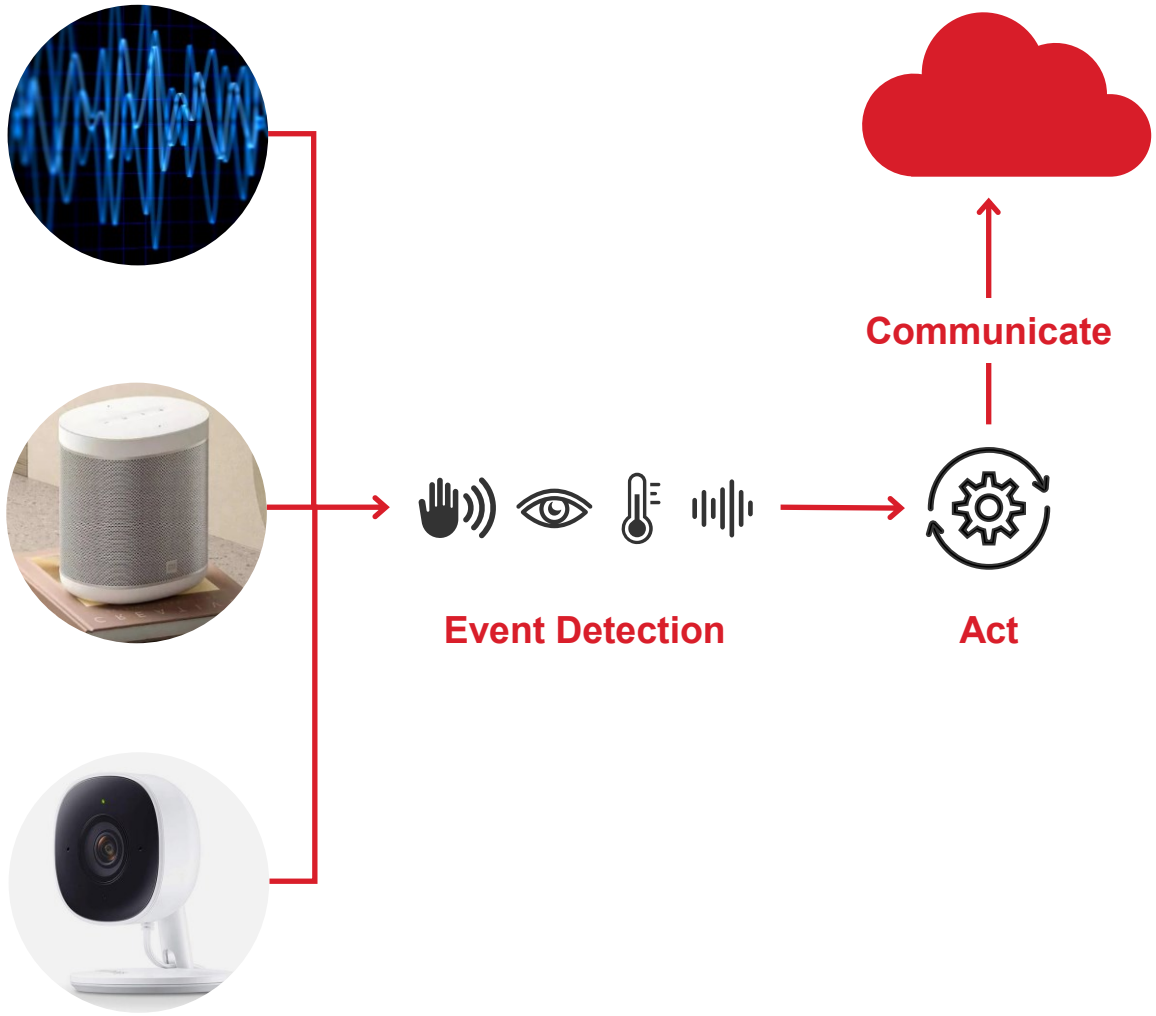
ML methods based on Audio
- Audio pattern matching (ex. glass break)

ML methods based on Voice
- Wake word/command word detection

Camera

Low resolution imaging
- Image capture (including fingerprint reader)

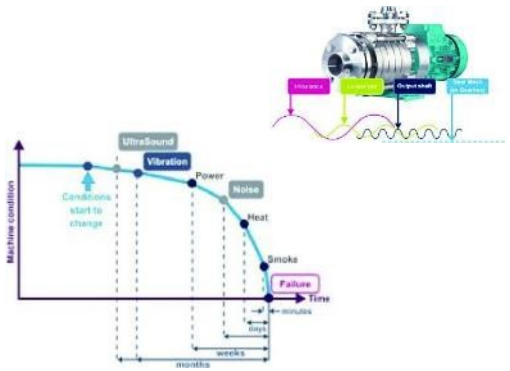
ML methods based on Vision
- Fingerprint reading
- Always-on vision – object detection
- Image classification and detection



Machine Learning Application Examples on BG24L

Wireless SoC's typical/recommended Resource needs with ML applications in Order of Magnitudes

RAM: 64kB
Ops/s: 5M-40M



SENSOR

Signal Processing (time series, low-rate data)

- Predictive/Preventative Maintenance
- Anomaly detection (e.g. air quality, abnormal usage, leak detection)
- Condition based monitoring – machine health, Cold chain monitoring, Battery monitoring
- Bio-signal analysis -healthcare and medical (e.g., pulse detection, EKG)
- Accelerometer use-cases e.g., fall detection, pedometer, step counting
- Agricultural use-cases (e.g. cow health)

EFR32BG24L

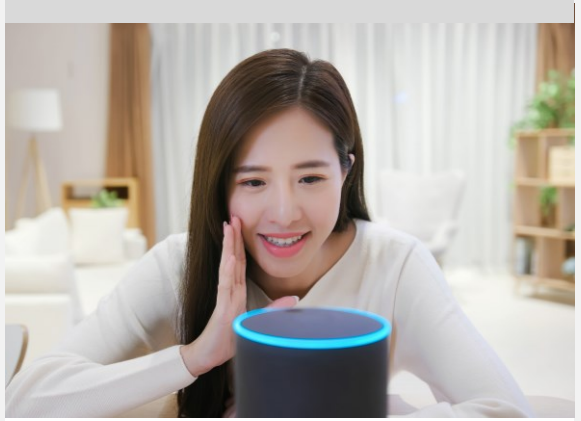
RAM: 128kB
Ops/s: 40M-100M

AUDIO

Audio Pattern Matching

- Security applications e.g., Glass break, scream, shot detection
- Cough detection
- Machine malfunction detection
- Breath monitoring

RAM: 256kB
Ops/s: 50M-500M

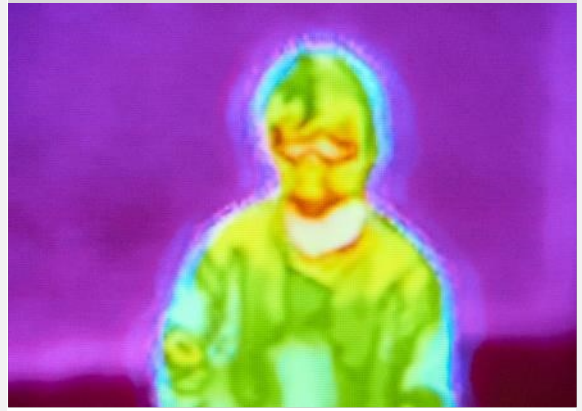


VOICE

Voice Commands

- 10 words command set for smart appliance
- Wake-word detection (Always-On voice)
- Smart device voice control
- Voice assistant

RAM: 256kB
Ops/s: 200M-1.5G w /hardware accelerator



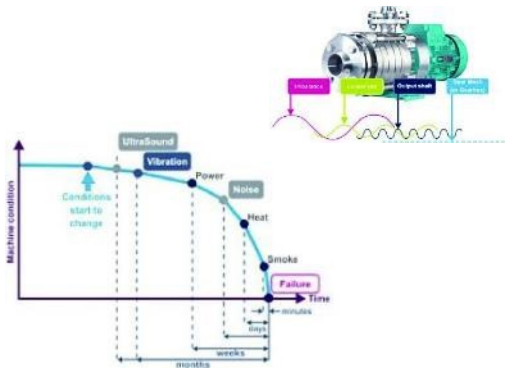
VISION

Low-resolution vision

- Wake-up on object detection (always-on)
- Presence detection
- People counting, people-flow counting
- Movement detection
- Smart city monitoring (e.g. Parking spot)
- Fingerprint matching

Machine Learning Application Examples on BG24, BG26

RAM: 64kB
Ops/s: 5M-40M



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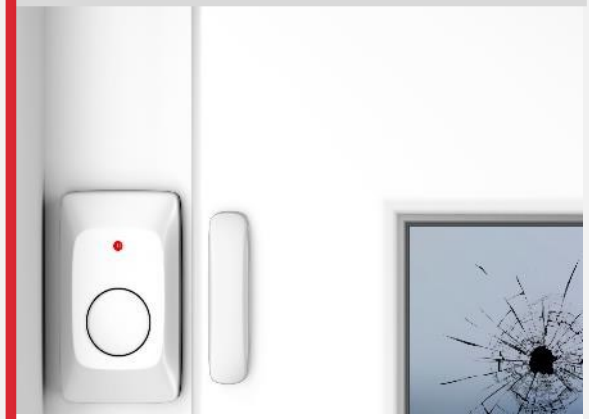

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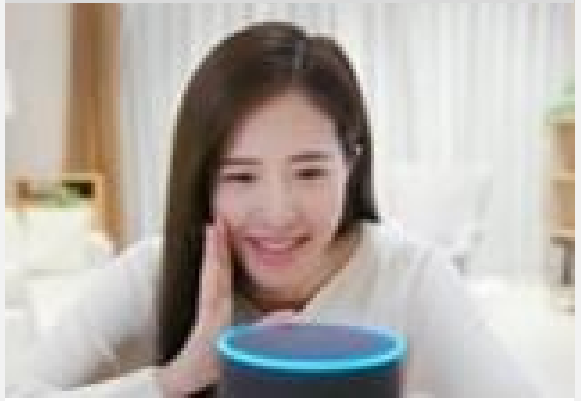

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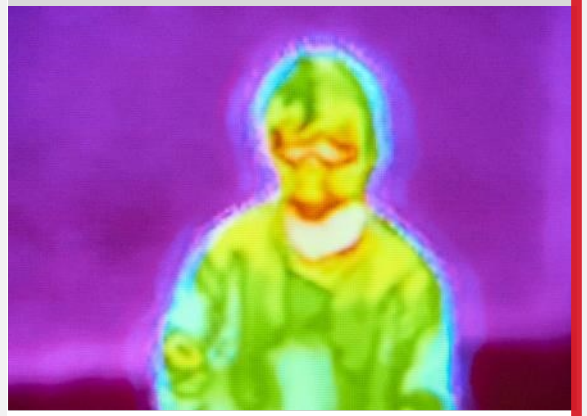

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- Smart city monitoring (e.g. Parking spot)
- Fingerprint matching

BG24, BG26

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Intelligent Agent
Neuton

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New feature in GSDK: MVP Math library

- **Accelerate and do more efficient linear algebra operations with internal MVP subsystem**
- **Math APIs (alternative to CMSIS_DSP) available in GSDK**

VECTOR OPERATIONS

- Vector Add
- Vector Absolute Value
- Vector Clip
- Vector Dot Product
- Vector Multiply
- Vector Negate
- Vector Offset
- Vector Scale
- Vector Sub
- Complex Vector Conjugate
- Complex Vector Dot Product
- Complex Vector Magnitude
- Complex Vector Magnitude Squared
- Complex Vector Multiply
- Complex Vector Multiply Real
- Vector Copy
- Vector Fill

MATRIX OPERATIONS

- Matrix Initialize
- Matrix Multiply
- Matrix Scale
- Matrix Sub
- Matrix Transpose
- Matrix Multiply Vector
- Matrix Add
- Complex Matrix Multiply
- Complex Matrix Transpose

✓ **Faster and more efficient execution of many algorithms with large data for example filtering algorithms**
✓ **Saving CPU cycles, saving power, resulting longer battery life**
✓ **Option to win sockets against faster CPUs**

CortexM only

Matrix dims.		CMSIS f32 cpu-cycles	CMSIS f16 cpu-cycles	MVP cpu-cycles	instr	stalls
2x2	2x2	226	304	403	8	0
4x2	2x4	602	913	424	32	0
6x2	2x6	1210	1921	464	72	0
8x2	2x8	2050	3321	516	128	0
10x2	2x10	3122	5113	592	200	0
12x2	2x12	4426	7297	676	288	0
14x2	2x14	5962	9873	784	392	0
16x2	2x16	7730	12841	904	512	0
18x2	2x18	9730	16201	1036	648	0
20x2	2x20	11962	19953	1192	800	0
20x4	4x20	17962	27956	1593	1200	1
20x6	6x20	23742	39956	2193	1600	201
20x8	8x20	27562	47556	2793	2000	400
20x10	10x20	33162	59556	3393	2400	601
20x12	12x20	37162	67156	3993	2800	801
20x14	14x20	42762	79156	4593	3200	1000
20x16	16x20	46762	86756	5193	3600	1201
20x18	18x20	52362	98756	5793	4000	1401
20x20	20x20	56362	106356	6393	4400	1600

~ 9x less cycles

Benefits of the MVP ML Hardware Accelerator

Dedicated ML computing subsystem next to the CPU: Matrix Vector Processor (MVP)

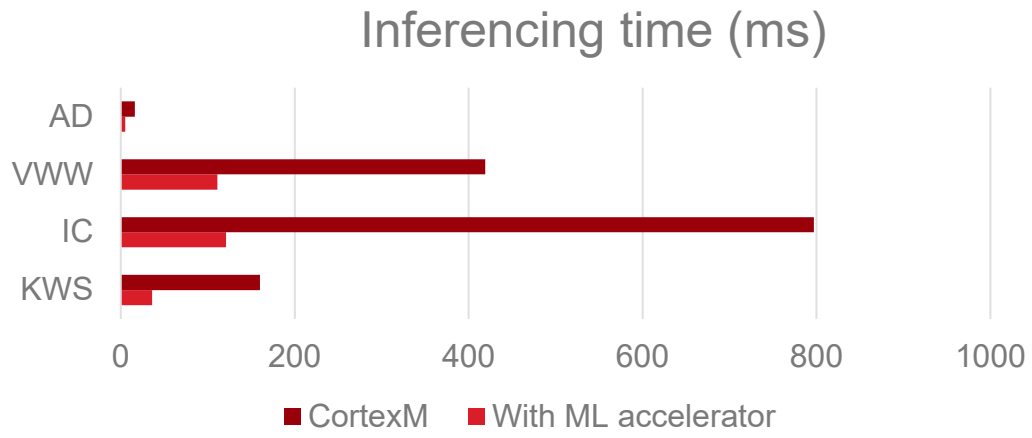
Optimized MVP to accelerate ML inferencing with a lot of processing power **offloading the CPU**

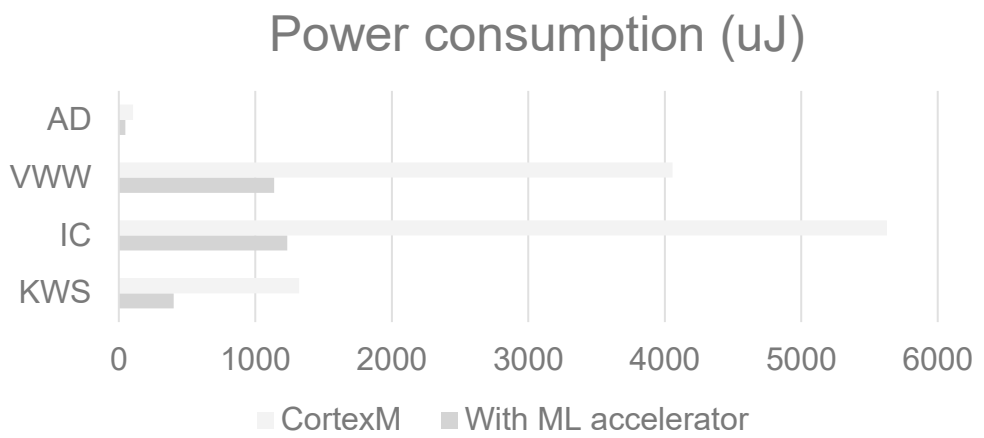
Up to 8x faster inferencing over Cortex-M (see below perf. benchmark)

Up to **6x lower power** for inferencing (see below perf. benchmark)

Dedicated OPNs for MVP accelerated parts → EFR32MG24B[2]… or [3]

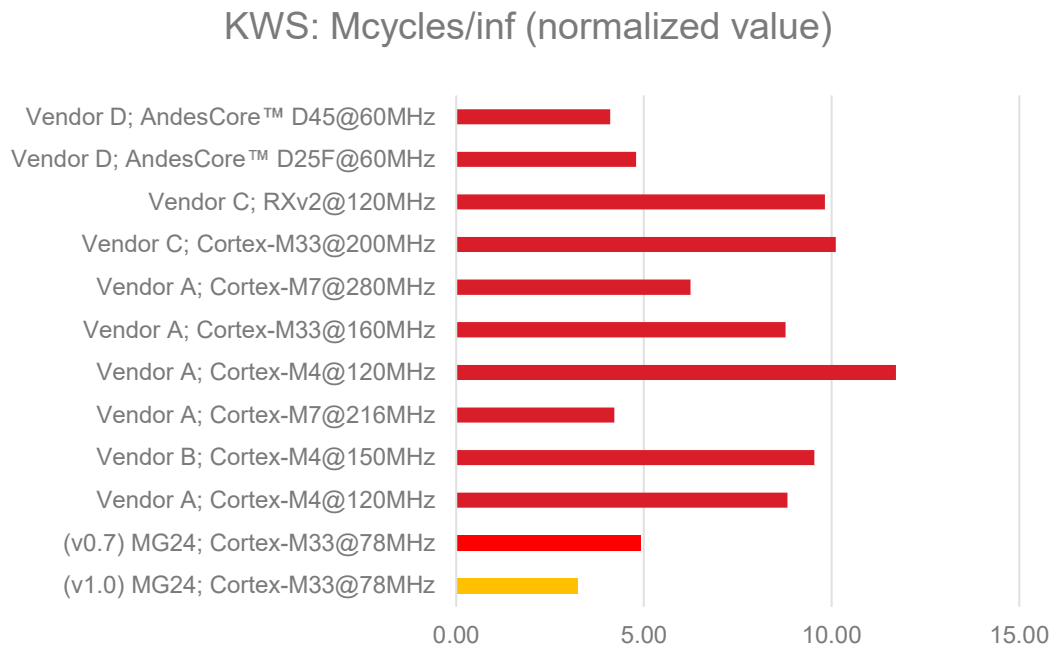
Performance data with ML hardware accelerator vs. pure SW on CortexM*

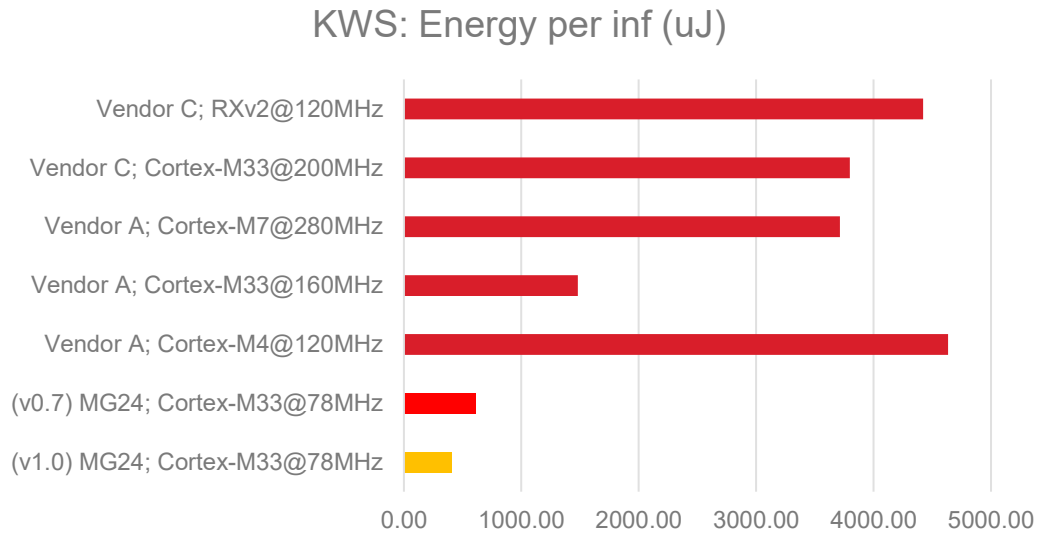




*Standardized performance benchmark validated by independent benchmarking body **MLCommons.org**. Published in MLPerf Tiny v1.0. Results are for inferencing only (not for the complete application). You can refer to MLCommons as validated results-

ML_Perf-Tiny v0.7 (and v1.0) Performance Benchmark*





MLPerf Tiny 0.7 benchmark results on xG24-DK2601B board; source: mlcommons.org

ML Commons

*Standardized performance benchmark validated by independent benchmarking body.
Results are for inferencing only (not the complete application).

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BG22L

BG22L: Ultra-Low Power, Low-Cost Solution for Battery-Powered Devices

Bluetooth®

- 4x4 QFN32 (18 GPIO)

Device specifications

- **Lowest Power RF**
  - Increases battery life
- **RFSense with OOK mode**
  - Ultra low-power receive mode to wake-up MCU from EM2 or EM4
  - Results in longer 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

Differentiated features

- **High Performance 2.4 GHz Radio**
  - Up to +6 dBm TX
  - -98.9 dBm RX @ BLE 1 Mbps
- **Efficient ARM® Cortex®-M33**
  - Up to 38.4 MHz
  - 352kB Flash, 24kB RAM
- **Low Power**
  - 37 µA/MHz (CoreMark)
  - 4.1 mA TX @ 0 dBm
  - 3.6 mA RX (BLE 1 Mbps)
  - 3.9 mA RX (802.15.4)
  - 1.4 µA EM2 (32kB RAM retention)
- **Wide Operating Range**
  - 1.71 to 3.8 volts
  - +85ºC operating temperature

Long-Range to Last-Mile Asset Monitoring

As global supply chain challenges continue, more assets are being monitored

Asset Monitoring – Challenges & Trends

TRENDS IN ASSET MONITORING

- Migrating from dataloggers to real-time tracking networks
  - multiple radio solutions for long-range and short-range fallback
- Bluetooth LE Positioning (Channel Sounding, AoA, AoD)
- Energy Harvesting / Ambient IoT
  - Solar, RF and other energy harvesting for battery-less tracking

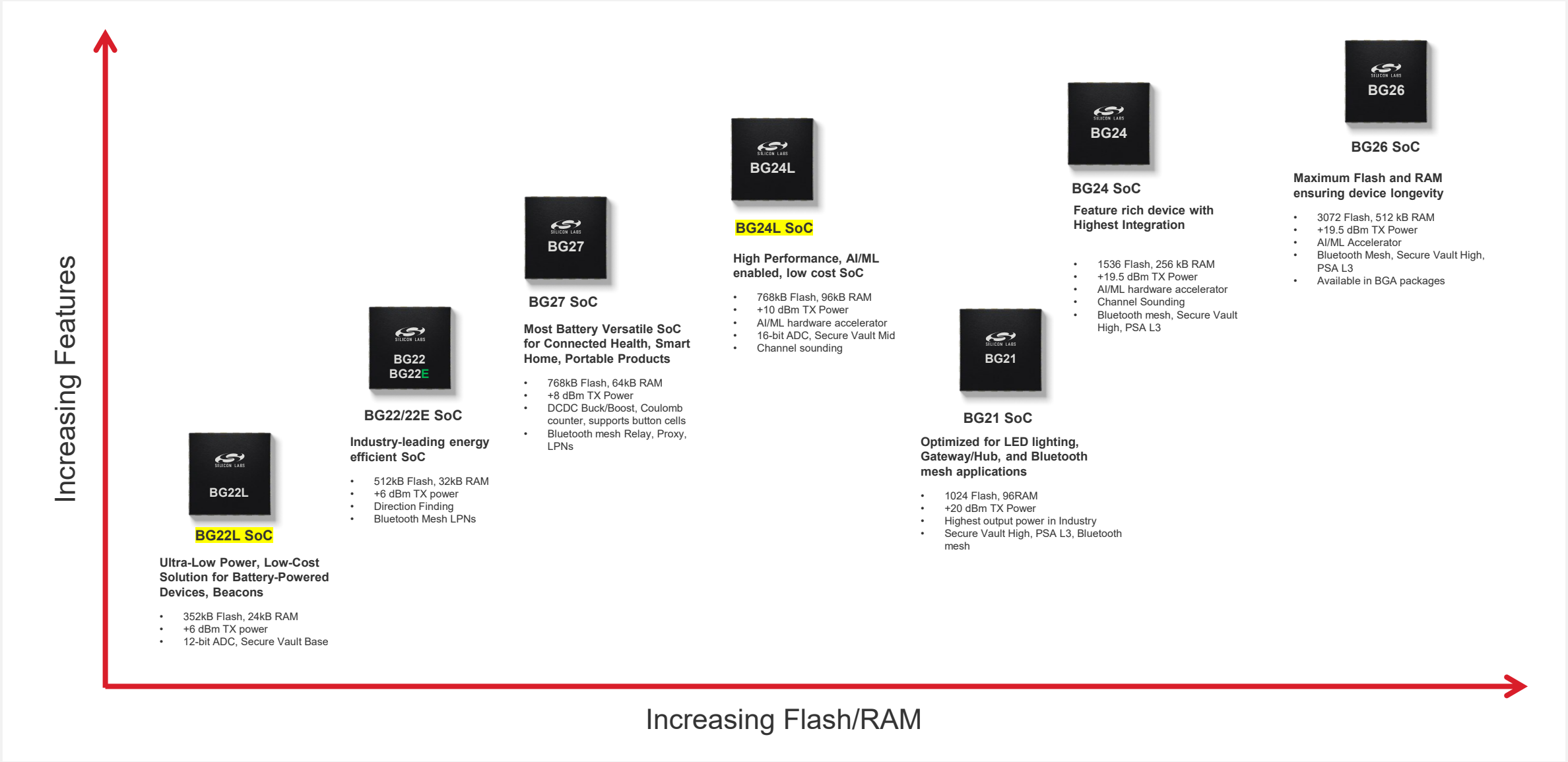
CHALLENGES IN ASSET MONITORING

- Battery life:
  - Isolated nodes run on a battery for long periods of time
  - Configurability of sleep, advertisement and connection interval compromised for power
- Unpredictable RF environments:
  - Assets are frequently encased in large metal containers
  - Asset frequently travel through very RF-crowded atmospheres causing wireless traffic issues.
  - Asset frequently leave and rejoin multiple networks

Why BG22L is an Ideal fit?

- **Fit for purpose tags that lasts for a while**
  - Ultra-Low Power
  - Low sleep current
- **Listen when they are shouted for**
  - Low Rx sensitivity
  - RFSense with OOK
  - Up to +6dBm Tx power for high link budget
- **Ideal for small form-factor**
  - BOM savings with PLFRCO
- **Lean SoC tailored for asset tracking**
  - Plastic tags
  - Envelope tracking
  - Disposable Labels

Silicon Labs Bluetooth Portfolio



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Q&A

Works With 2025 - Bangalore, India

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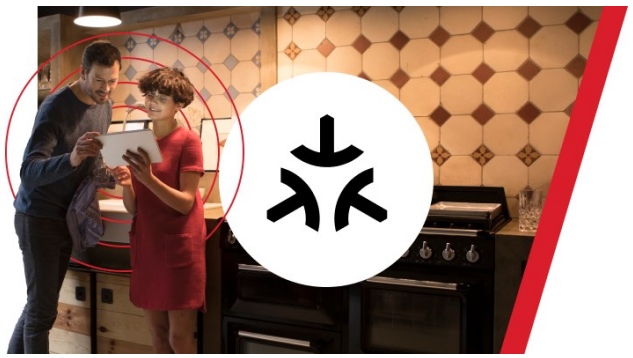
Where innovation meets implementation.

BANGALORE | October 30
AUSTIN | October 1-2
SHENZHEN | October 23
VIRTUAL | November 19-20



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Thank you

APAC Tech Talks - SEA & India Series

Date (Thursday)	Time (Singapore Time)	Topic
August 21	13:30-14:30	The Most Application-Optimized Bluetooth SoCs for Future-Ready Applications
September 11	13:30-14:30	Beyond Metering: Unlocking New Potential with Wi-SUN
On-demand		
June 26	What's new in Matter	
July 24	Bringing Bluetooth 6.0 Channel Sounding to Market: Precision Ranging for Secure & Smart Applications	