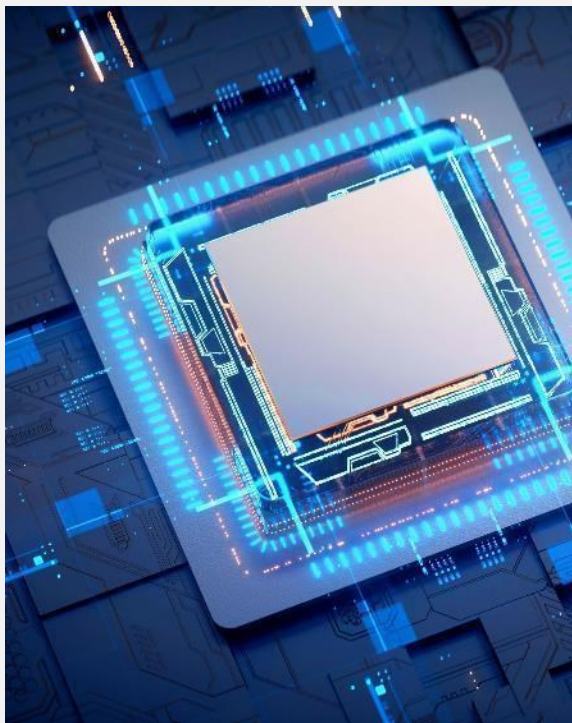# Agenda

"Lite" Wireless SoCs

BG24L

Channel Sounding

AI/ML at the Edge

BG22L

Q&A

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# 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**

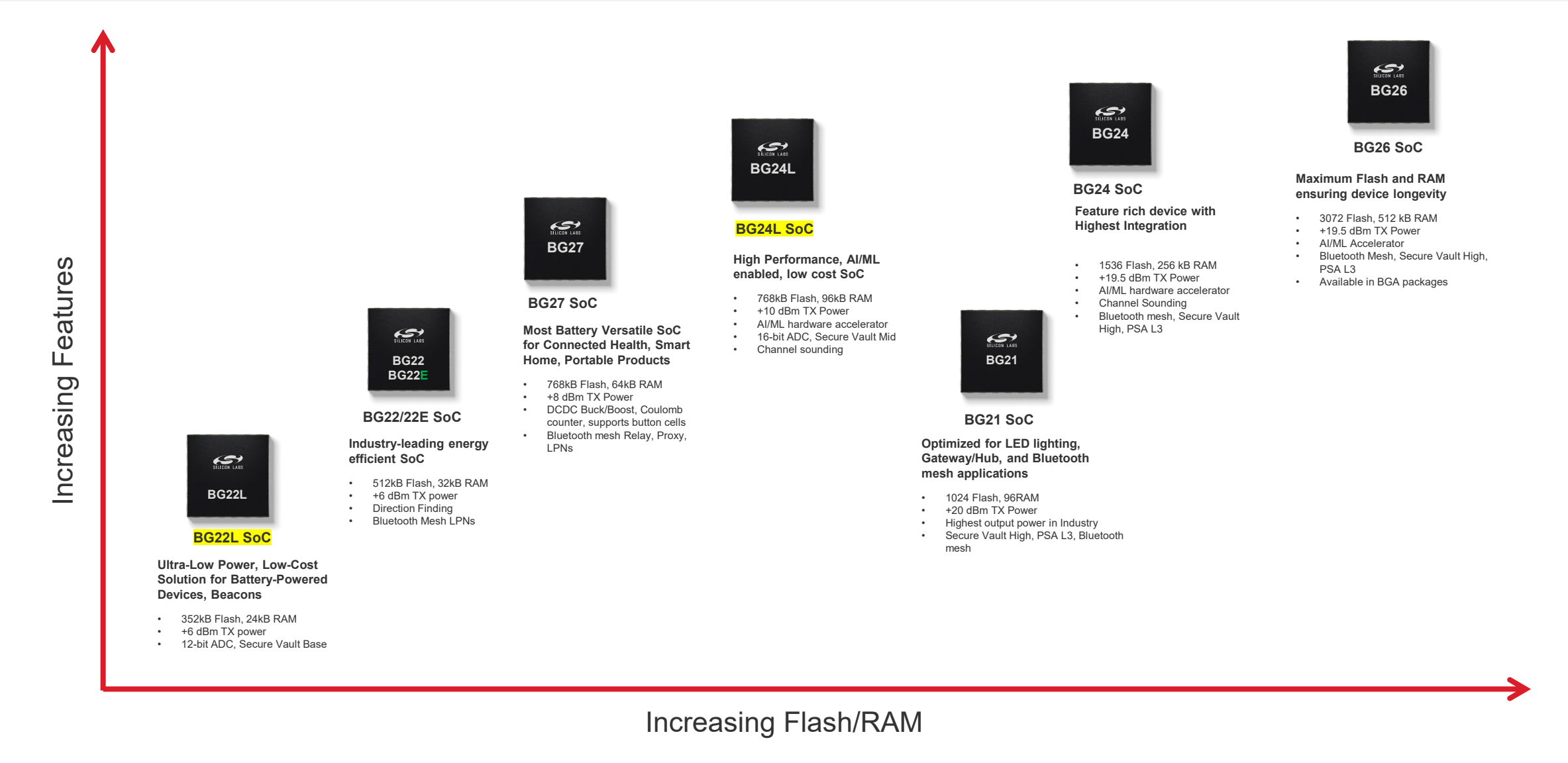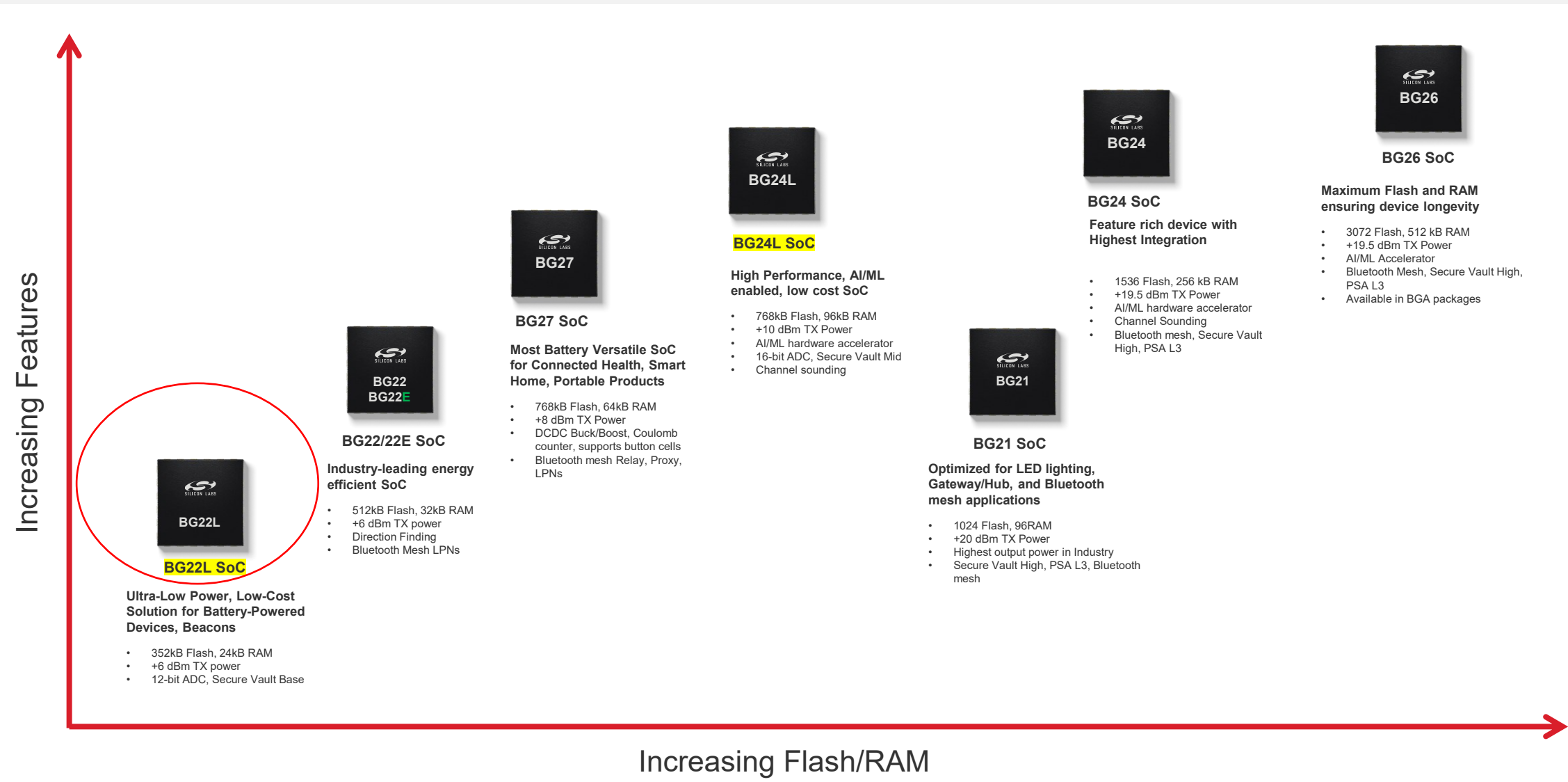**Simplified Design**

**Small Form-Factor**

**BOM Savings**



**DEVELOPMENT TOOLS**

**Fully Featured Kits**

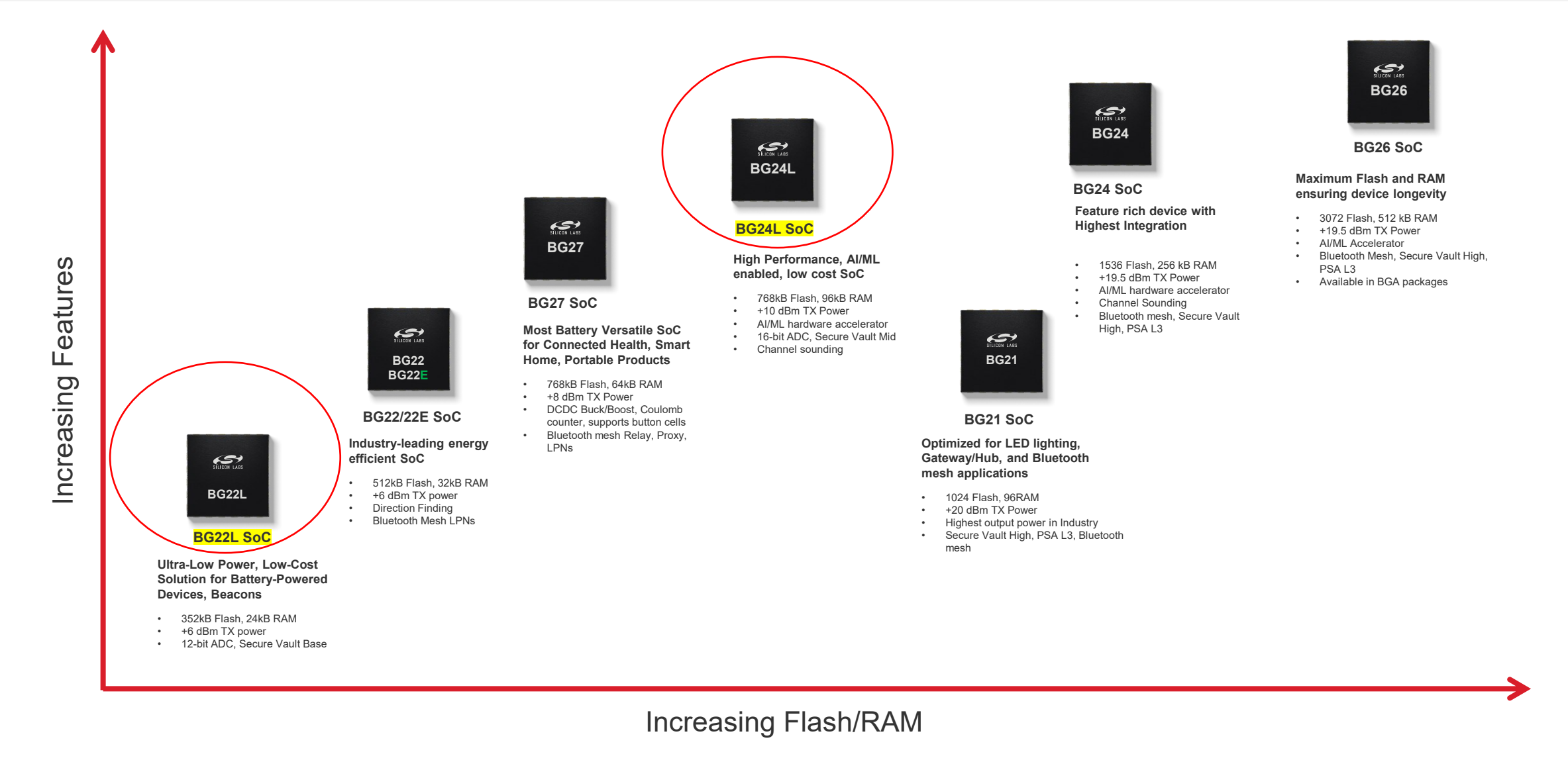**Debugging Tools (Network Analyzer, Energy Profiler etc.)**

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# Silicon Labs Bluetooth Portfolio

**Increasing Features** (vertical axis)

**Increasing Flash/RAM** (horizontal axis)

**BG22L SoC**

**Ultra-Low Power, Low-Cost Solution for Battery-Powered Devices, Beacons**

- 352kB Flash, 24kB RAM
- +6 dBm TX power
- 12-bit ADC, Secure Vault Base

**BG22/22E SoC**

**Industry-leading energy efficient SoC**

- 512kB Flash, 32kB RAM
- +6 dBm TX power
- Direction Finding
- Bluetooth Mesh LPNs

**BG27 SoC**

**Most Battery Versatile SoC for Connected Health, Smart Home, Portable Products**

- 768kB Flash, 64kB RAM
- +8 dBm TX Power
- DCDC Buck/Boost, Coulomb counter, supports button cells
- Bluetooth mesh Relay, Proxy, LPNs

**BG24L SoC**

**High Performance, AI/ML enabled, low cost SoC**

- 768kB Flash, 96kB RAM
- +10 dBm TX Power
- AI/ML hardware accelerator
- 16-bit ADC, Secure Vault Mid
- Channel sounding

**BG21 SoC**

**Optimized for LED lighting, Gateway/Hub, and Bluetooth mesh applications**

- 1024 Flash, 96RAM
- +20 dBm TX Power
- Highest output power in Industry
- Secure Vault High, PSA L3, Bluetooth mesh

**BG24 SoC**

**Feature rich device with Highest Integration**

- 1536 Flash, 256 kB RAM
- +19.5 dBm TX Power
- AI/ML hardware accelerator
- Channel Sounding
- Bluetooth mesh, Secure Vault High, PSA L3

**BG26 SoC**

**Maximum Flash and RAM ensuring device longevity**

- 3072 Flash, 512 kB RAM
- +19.5 dBm TX Power
- AI/ML Accelerator
- Bluetooth Mesh, Secure Vault High, PSA L3
- Available in BGA packages

SILICON LABS

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# BG24L

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

**BG24L**

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

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# 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 <u>not</u> included in the spec**

- Distance measurement algorithm recommendations and optimizations

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# Bluetooth Channel Sounding - Target Markets & Use Cases
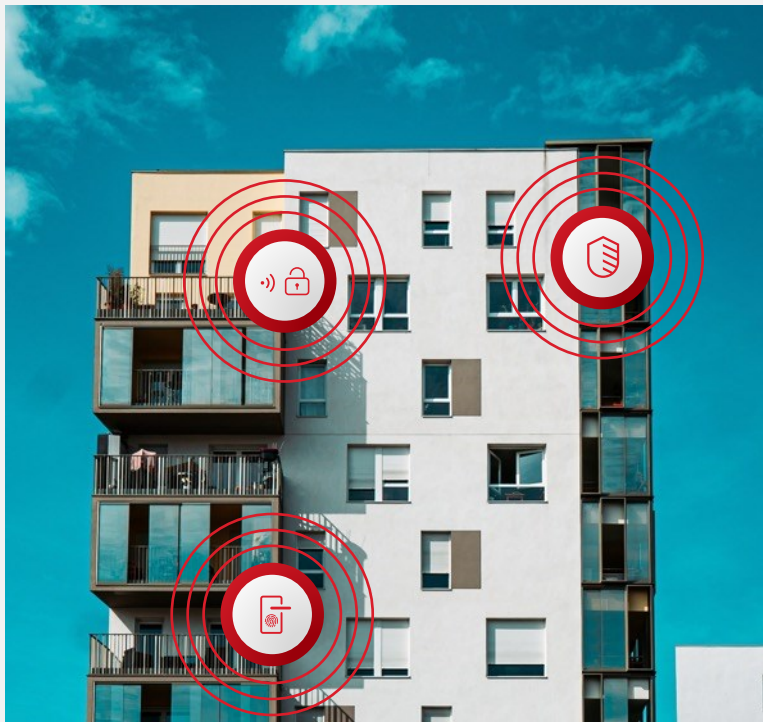


**PROXIMITY AWARENESS**

**Door locks**

**Keyless entry**

**Building access systems**

**Geofencing - security alerts**



**LOCALIZATION**

**Indoor asset management - hospitals, warehouses**

**Pet tracking inside home**

**Item finding - wallet, keys**

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# Single-Antenna Channel Sounding Board
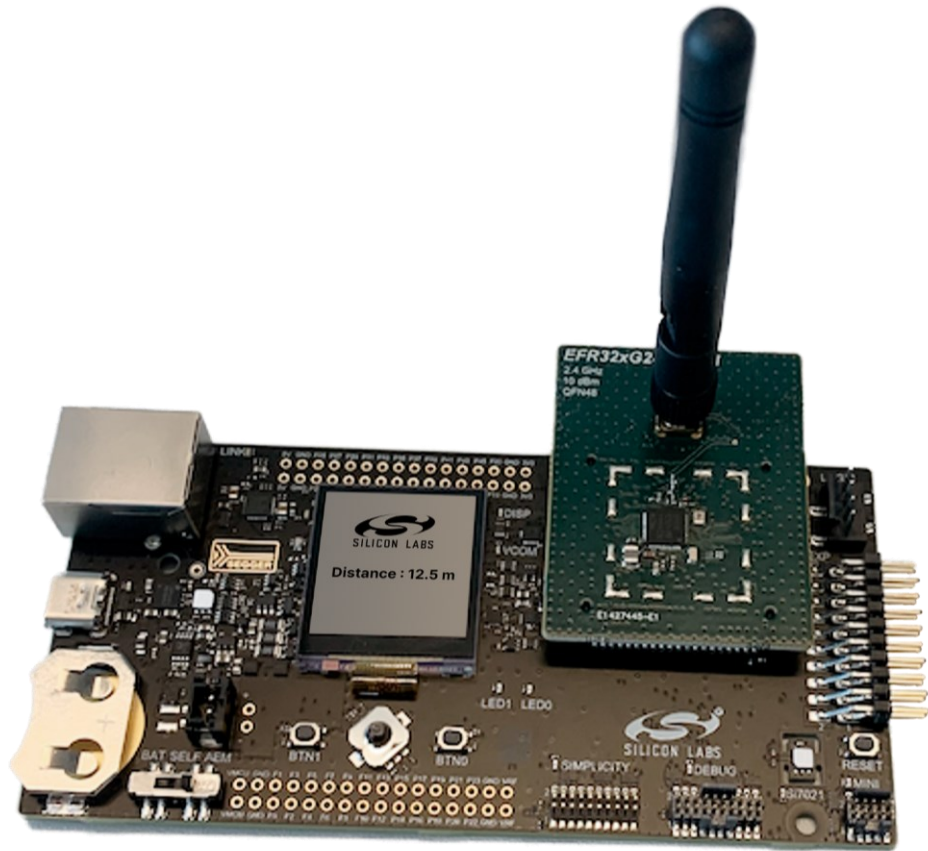
- **Channel Sounding evaluation using Ranging Kit**
  - EFR32xG24 Pro Kit with external antenna
  - Full featured development option leveraging WPK features
  - AEC-Q100 Compliant
  - SoC/NCP Sample Apps
    - Initiator and Reflector examples supported
  - Ranging Library
    - Process IQ samples, post-filtering, and compute distance using configurable algorithm
- **Optimized antenna designs**
  - EFR32xG24 reference designs with optimized PCB antenna solutions for indoor location systems

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# Dual Antenna Channel Sounding Development Kit



**BRD2606A front**

2x PCB antenna for antenna diversity and dual polarization

2x U.FL connector for optional external antenna support

1-to-2 RF switch

ICM-40627 IMU Sensor

On-board debugger for easy programming and debugging

User buttons and LEDs for demo firmware support

EFR32MG24B210F1536IM48-B
(with 1.5MB flash, Channel Sounding, MVP, Secure Vault High, +10dBm)

**BRD2606A back**

33x33mm overall size

Mini Simplicity header for Wireless Main Board connectivity.

Qwiic connector for extendibility

CR2032 battery holder

USB-C connector for easy PC connectivity. Provides both debugger and virtual UART interfaces

- **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

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# 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**

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# 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**

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# 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.

Avg current consumption (mA): One Measurement Cycle

| | 72 CH | 37 CH | 20 CH |
|---|---|---|---|
| 4 AP | 2.30 | 1.40 | 0.88 |
| 2 AP | 1.70 | 1.04 | 0.73 |
| 1 AP | 1.42 | 0.90 | 0.65 |
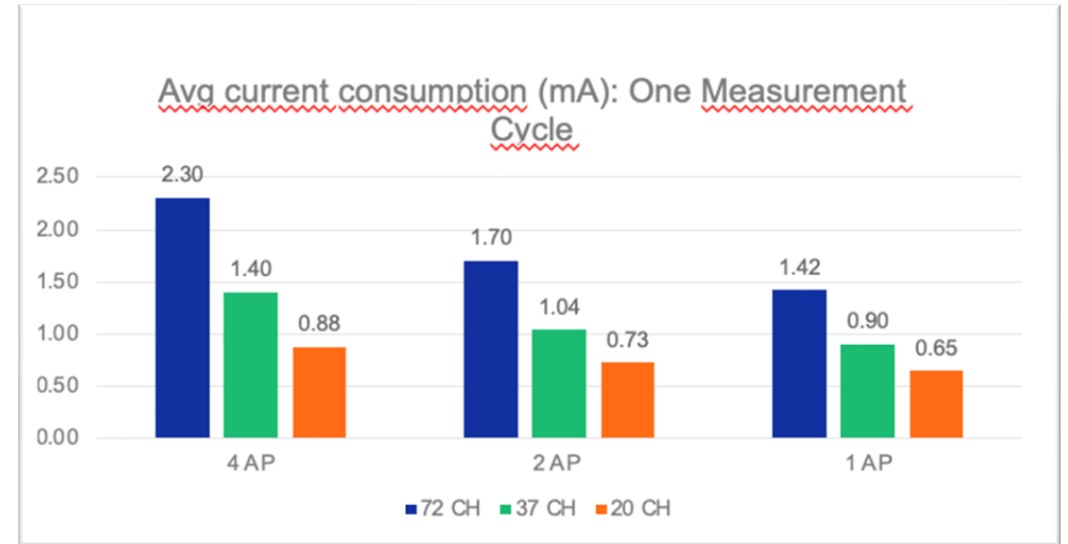
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# Silicon Labs Bluetooth ® Channel Sounding Offering
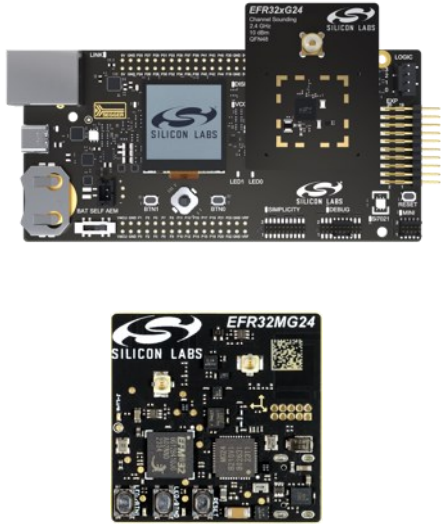


## ICS & DEVELOPMENT KITS

Channel Sounding Supported by **B/MG24**

**Kits:**

**xG24-RB4198A** single antenna kit

**xG24-DK2606A** dual antenna kit

---

Application

API

| GATT | GAP | SM | RTL Library |
| ATT | | | |

Bluetooth Link Layer
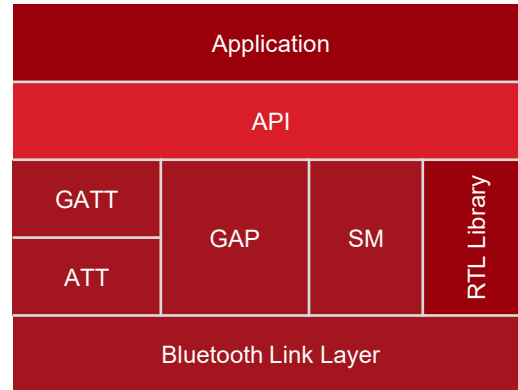
## BLUETOOTH 6.0 STACK

In-house developed stack, supported and maintained stack

Bluetooth 6.0 qualified

PBR & RTT Modes

---

I/Q data

Pre-processing

Distance computation

Post-processing
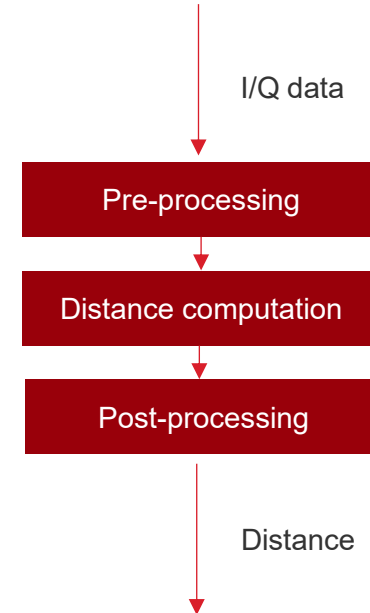
Distance

## 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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# Distance Measurement Demo

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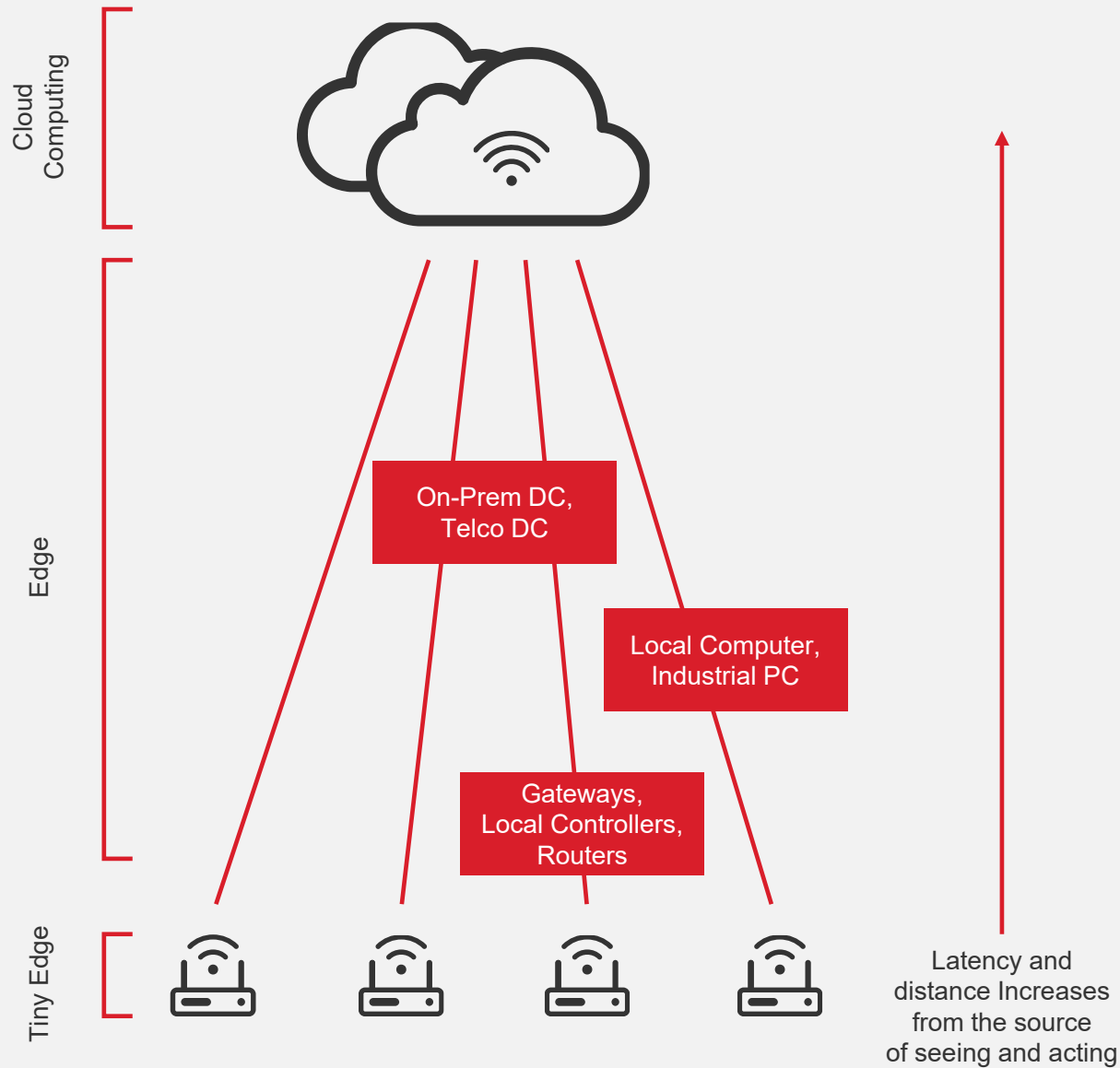
# Artificial Intelligence(AI) and Machine Learning(ML) at the Tiny Edge

## Key Benefits

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

## >3B Devices sold with TinyML in 2027
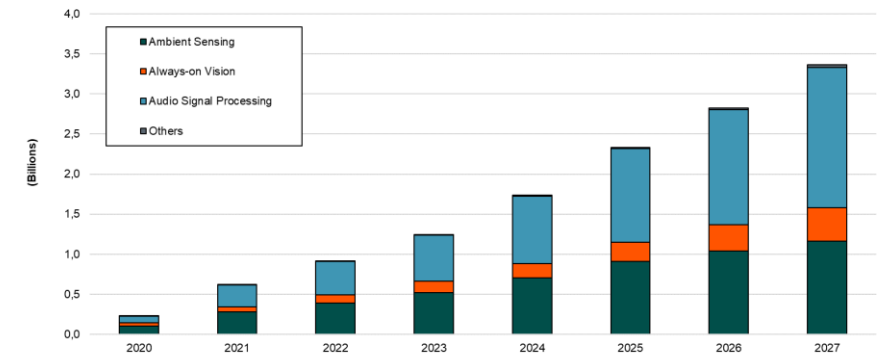


*Source: ABI Research, Artificial Intelligence and Machine Learning, 2 QTR 2022*

# 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**

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# 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**
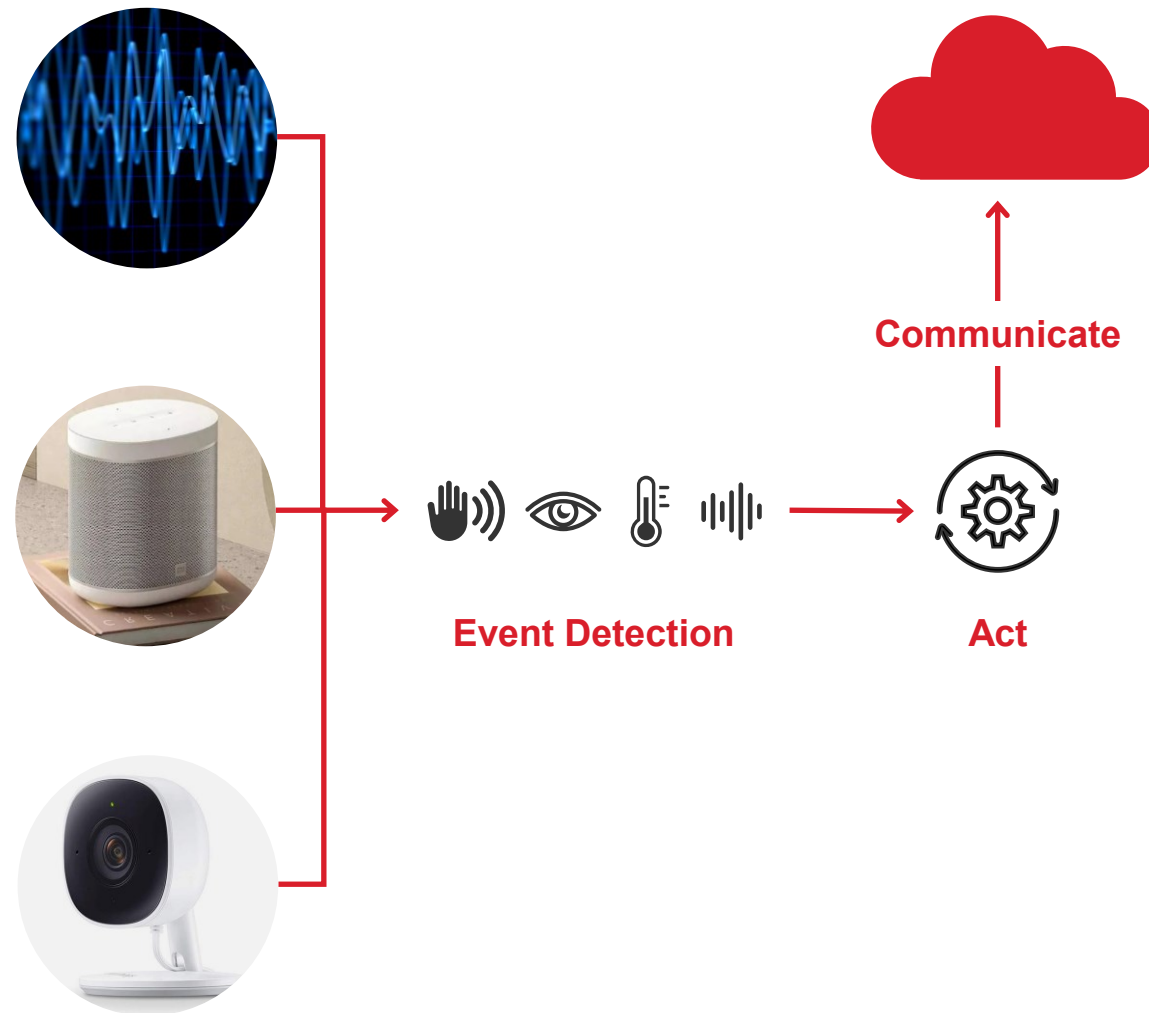- Wake word/command word detection

**Camera**
Low resolution imaging
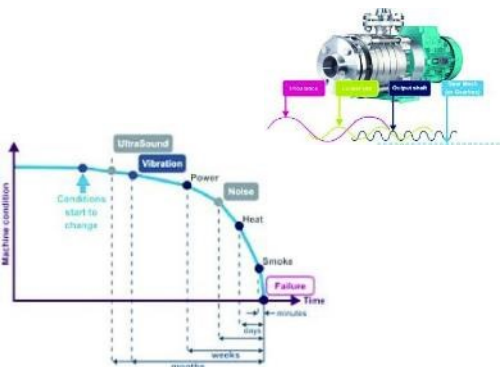- Image capture (including fingerprint reader)

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

**Communicate**

**Event Detection**

**Act**

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# Machine Learning Application Examples on BG24L

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

| RAM: 64kB<br>Ops/s: 5M-40M | RAM: 128kB<br>Ops/s: 40M-100M | RAM: 256kB<br>Ops/s: 50M-500M | RAM: 256kB<br>Ops/s: 200M-1.5G w /hardware accelerator |



### 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**

### AUDIO

**Audio Pattern Matching**

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

### VOICE

**Voice Commands**

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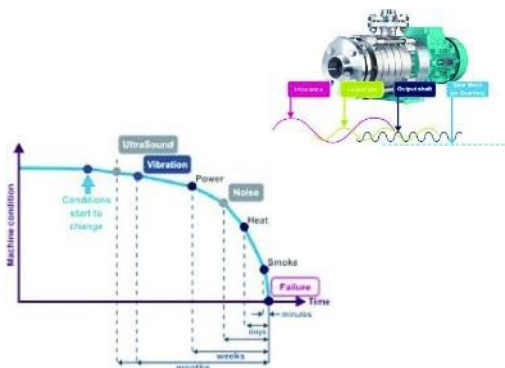- Smart device voice control
- Voice assistant

### 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

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# Machine Learning Application Examples on BG24, BG26

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

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

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

RAM: 256kB
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## SENSOR

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**BG24, BG26**

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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**

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# 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*

### Inferencing time (ms)



Legend: ■ CortexM  ■ With ML accelerator

### Power consumption (uJ)



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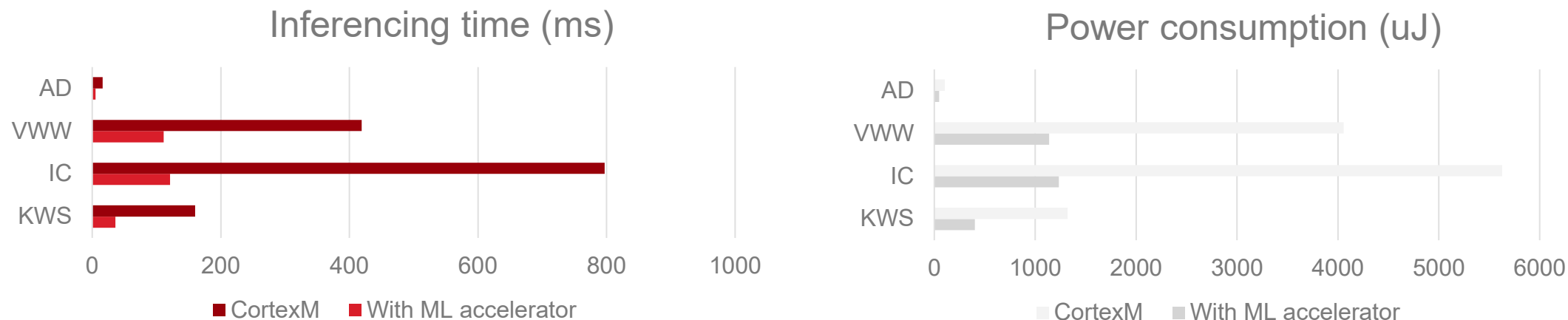
*Standardized performance benchmark validated by independent benchmarking body **MLCommons.org**. Published in MLPerf Tiny v1.0. Results are for inferencing only (not for the complete application). You can refer to MLCommons as validated results-

ML Commons

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

### KWS: Mcycles/inf (normalized value)

| Label | |
|---|---|
| Vendor D; AndesCore™ D45@60MHz | |
| Vendor D; AndesCore™ D25F@60MHz | |
| Vendor C; RXv2@120MHz | |
| Vendor C; Cortex-M33@200MHz | |
| Vendor A; Cortex-M7@280MHz | |
| Vendor A; Cortex-M33@160MHz | |
| Vendor A; Cortex-M4@120MHz | |
| Vendor A; Cortex-M7@216MHz | |
| Vendor B; Cortex-M4@150MHz | |
| Vendor A; Cortex-M4@120MHz | |
| (v0.7) MG24; Cortex-M33@78MHz | |
| (v1.0) MG24; Cortex-M33@78MHz | |

Axis: 0.00  5.00  10.00  15.00

### KWS: Energy per inf (uJ)

| Label | |
|---|---|
| Vendor C; RXv2@120MHz | |
| Vendor C; Cortex-M33@200MHz | |
| Vendor A; Cortex-M7@280MHz | |
| Vendor A; Cortex-M33@160MHz | |
| Vendor A; Cortex-M4@120MHz | |
| (v0.7) MG24; Cortex-M33@78MHz | |
| (v1.0) MG24; Cortex-M33@78MHz | |

Axis: 0.00  1000.00  2000.00  3000.00  4000.00  5000.00

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

**BG22L**

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

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# Long-Range to Last-Mile Asset Monitoring



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

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# 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

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# 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

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# Silicon Labs Bluetooth Portfolio

**Increasing Features** (vertical axis)

**Increasing Flash/RAM** (horizontal axis)

**BG22L SoC**

**Ultra-Low Power, Low-Cost Solution for Battery-Powered Devices, Beacons**

- 352kB Flash, 24kB RAM
- +6 dBm TX power
- 12-bit ADC, Secure Vault Base

**BG22/22E SoC**

**Industry-leading energy efficient SoC**

- 512kB Flash, 32kB RAM
- +6 dBm TX power
- Direction Finding
- Bluetooth Mesh LPNs

**BG27 SoC**

**Most Battery Versatile SoC for Connected Health, Smart Home, Portable Products**

- 768kB Flash, 64kB RAM
- +8 dBm TX Power
- DCDC Buck/Boost, Coulomb counter, supports button cells
- Bluetooth mesh Relay, Proxy, LPNs

**BG24L SoC**

**High Performance, AI/ML enabled, low cost SoC**

- 768kB Flash, 96kB RAM
- +10 dBm TX Power
- AI/ML hardware accelerator
- 16-bit ADC, Secure Vault Mid
- Channel sounding

**BG21 SoC**

**Optimized for LED lighting, Gateway/Hub, and Bluetooth mesh applications**

- 1024 Flash, 96RAM
- +20 dBm TX Power
- Highest output power in Industry
- Secure Vault High, PSA L3, Bluetooth mesh

**BG24 SoC**

**Feature rich device with Highest Integration**

- 1536 Flash, 256 kB RAM
- +19.5 dBm TX Power
- AI/ML hardware accelerator
- Channel Sounding
- Bluetooth mesh, Secure Vault High, PSA L3

**BG26 SoC**

**Maximum Flash and RAM ensuring device longevity**

- 3072 Flash, 512 kB RAM
- +19.5 dBm TX Power
- AI/ML Accelerator
- Bluetooth Mesh, Secure Vault High, PSA L3
- Available in BGA packages

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