Battery-Powered Edge AI Sensing: A Case Study Implementing Low-Power, Always-On Capability

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Avnet

Agenda

- Designing for low power consumption
- Edge AI design goals, constraints and applications
- “Always on” smart sensors and AI/ML processing
- Wireless connectivity low-power techniques
- Device security in low-power use-cases
- Case study: Sensors, NPU, Secure-MCU, Wi-Fi/BT + more…
- Revisit of design trade-offs and lessons learned
- References and resources for more info…

Designing for low power consumption

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Battery-powered IoT/Edge devices need to be energy-efficient!

- Average Current Consumption is a key specification (i.e. the "area under the energy curve")

```
Power  = V x I
Energy = V x I x Time
       = V x mAh
```

Battery energy needed to achieve the application's functionality should be analyzed over time!

Answer design questions like these:

- What sensor sample-rate is needed?
- How much processing latency is acceptable?
- Can components sleep between events?

What needs to be powered-on and when..?

	Always-on	Interrupt Activated	Periodic Reporting
Smart Sensors	Y		
AI Processing	Y		
Host MCU		Y	Y
Wireless			Y

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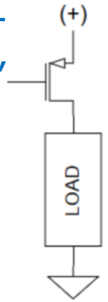
Designing for low power consumption

Low Power design techniques include the use of

- High-value pull-up / pulldown resistor values
- High-efficiency PMIC/voltage-regulator devices
- DVFS (Dynamic Voltage & Frequency Scaling)
  (dynamic power is proportional to the voltage squared!)
- Minimizing the ON time "duty-cycle" of devices
- FET load-switches to turn-off non-active circuits

High-side FET
"Load Switch"



$$P_{dynamic} \propto V^2 f$$

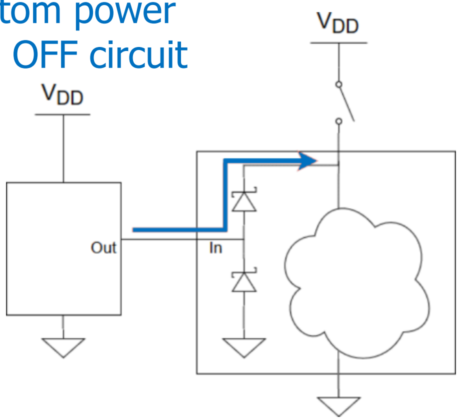
Designing for low power consumption

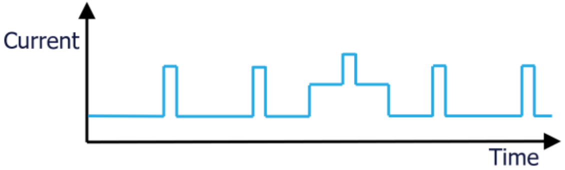
<u>Low Power design techniques (continued…)</u>

- Reduced rail voltage for power-hungry peripherals
- Clock gating (and/or reducing clock frequencies)
- Strapping unused digital inputs (don't let them float)
- Taking advantage of MCU & wireless low-power modes
- Prevention* of phantom power and latch-up
  *(*use a buffer with power-down isolation for signal connected to OFF device)*

Reduce "area under the curve" for smaller battery size!

Phantom power to an OFF circuit





MCU standby power, operating power and wake-up time…

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Significant power-consumption differences often show-up in the MCU Low Power modes

- This table compares two microcontrollers from the Renesas RA series

MCU Device	Normal	Sleep	SW standby	Wakeup	Comments
RA6M4 Cortex M33 @200MHz	19.8 mA 99uA/MHz	10 mA (all SRAM)	1.6 mA	55 µs (HOCO wake)	running coremark @200MHz
RA2E1 Cortex M23 @48MHz	4.80 mA 100uA/MHz	1.05 mA (all SRAM)	0.25 uA	7.3 µs (HOCO wake)	running coremark @48MHz

- RA6M4 is a power-efficient MCU with multiple functions that reduce power consumption e.g. clock-dividers, stopping of modules and transitioning to low power modes (Sleep / Software Standby / Snooze / Deep Software Standby)
- An RA2E1 MCU however is more power-efficient in "low duty-cycle" applications, as it requires substantially lower Standby power and has a faster wake time
  - RA6M4 still a good fit for applications that require low-power operation *plus* an advanced feature-set

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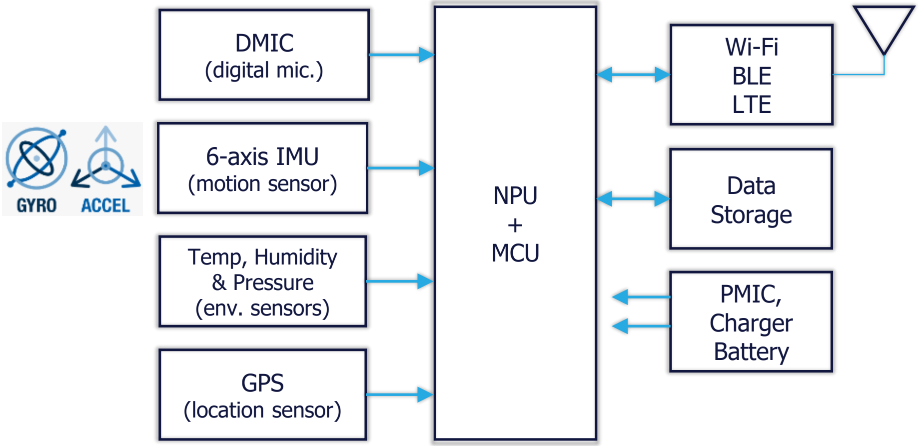
Edge AI design-goals, constraints and applications

Typical design requirements & constraints

- Sensors and autonomous Edge AI processing
- Wireless connectivity for:
  - transmitting processed data
  - receiving software and security updates
- Security and data privacy
- Low-power, battery operation
- Small dimensions, compact form-factor

Sensor fusion Edge AI use by cold chain monitoring device:



Edge AI design-goals, constraints and applications

Common use cases and examples

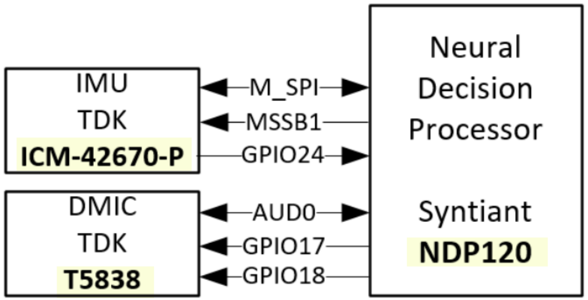
- Security monitoring (glass-break detection, intruder alerts)
- Sensor fusion (environment and context monitoring)
- Voice control (keyword detection, touchless controls)
- Predictive maintenance (motor-anomaly detection)
- Cold chain monitoring (shipment integrity monitoring)
- Health monitoring (fall detection, vital-sign alerts)

"Always on" smart-sensors + AI/ML

- Take advantage of smart sensors that have configurable measurement thresholds, filtering functions and features like event-type detection (e.g. setting GPS geo boundaries, gesture recognition, fall-detection, etc)
- Complex sensor-fusion, voice-recognition or acoustic event applications require that deep learning NPU functionality also remain "always on"
- Increased availability of ultra-low power smart sensors and Edge AI compute solutions

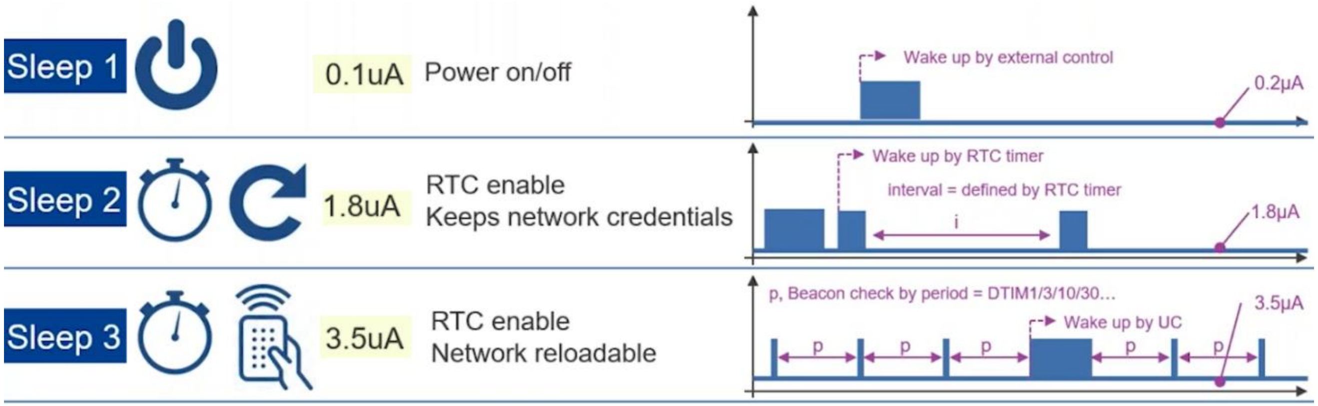
Sensor and Edge AI processing consumes < 1.5 mW on RASynBoard (the case-study discussed later)

TDK IMU sensor (InvenSense ICM-42670-P)	0.99 mW *(0.55mA @1.8V)* (in low-noise mode)
TDK digital microphone (InvenSense T5838)	0.22 mW *(0.12 mA @1.8V)* (in low-power mode)
AI/ML NPU device (Syntiant NDP120)	0.25 mW (always-on/listening mode)



Wireless connectivity low-power techniques

- Use of Low Power protocols (BLE, Zigbee/Z-wave,etc) are one approach, but they lack interoperability and a gateway is needed for connection with the cloud
- Latest IoT Wi-Fi implementations provide a versatile alternative, using dynamic power management of sleep modes and ultra-fast wakeup/sleep transitions
- RASynBoard uses Renesas VirtualZero version of this



< 100ms wakeup (timer or ext. event)

< 50μA <u>average</u> current!

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Device security for low-power use-cases

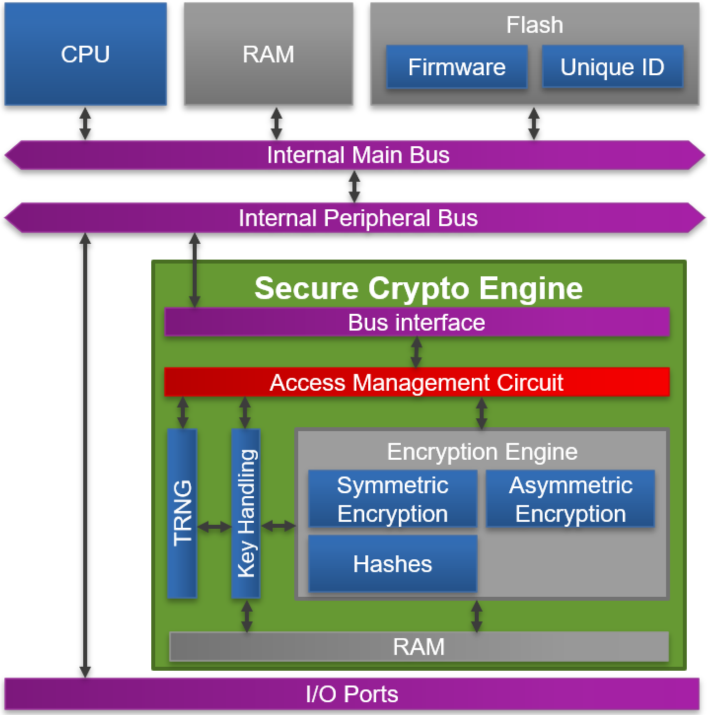
Typical Security Requirements

ID provisioning, certificate and key installation

- to authenticate with cloud and private infrastructure

Secure bootloader, firmware updates, data encryption

- for secure field-updates and secure data comms



Crypto Subsystem (RA6M4 MCU)

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Device security for low-power use-cases

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Reduce power & cost by choosing…

an MCU with secure services & crypto unit

- Arm TrustZone
- Secure Cryptographic Engine

an MCU with secure provisioning

- to establish identity
- to create hardware Root of Trust
- for unlimited secure key storage

Functions		RA6M4, RA6M5 RA4M2, RA4M3
Identity		
	Chip Unique ID	128-bit
Isolation		
	Flash and RAM	Arm TrustZone®
	Peripherals	TrustZone, Bus Master MPU
	Pins	Arm TrustZone
	Arm Core MPU	S and NS
	Crypto Engine	SCE9
Key Handling		
	Secure Key Installation	Programmer, FSP
	Secure Key Storage	Wrapped w/ 256-bit HUK
	Plaintext Key Support	Y
	Integrated Wrapped Key Support	Y
Code Protection and Lifecycle Management		
	Flash Program/Erase Protection	Per Block
	Code Encryption	-
	Advanced DLM	Y
	Debug and Program I/F Protection	Authentication w/key
Physical Protection		
	Tamper Pins	3
	SPA/DPA Resistance	Included

Create a trusted region for secure services

Isolate cryptographic operations

Unlimited secure key storage

HW Security Features (RA6M4 MCU)

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Case Study: RASynBoard Deep Learning Sensor-Fusion Wireless Edge AI/ML Module

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Case study: Integrating it all…

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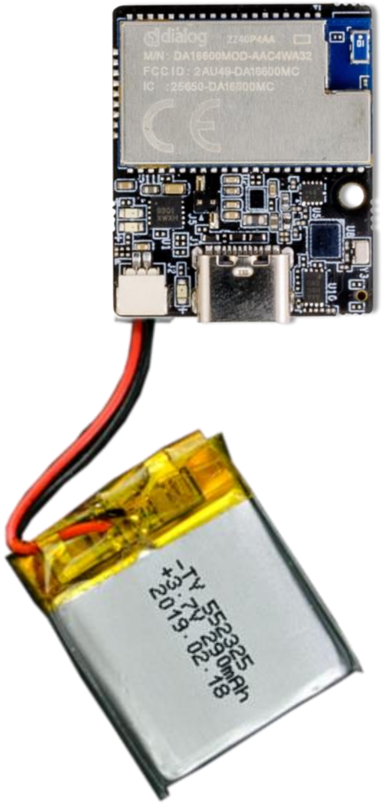
- Goal was a tiny, battery-powered, secure wireless-connected smart-sensor sub-system with strong Edge-AI processing skills
- Developer-friendly integration with feature-rich RA6M4 MCU and power-efficient Wi-Fi/BLE DA16600 module
- Ultra low-power Syntiant NDP120 for reliable, accurate, low-latency, accelerated Edge-AI/ML performance
- Self-sufficient with IMU sensors & digital microphone, good memory resources and expansion options



RASynBoard = Secure **RA**6M4 MCU + **Syn**tiant NDP120 AI/ML + Wi-Fi/BT wireless + sensors + more…

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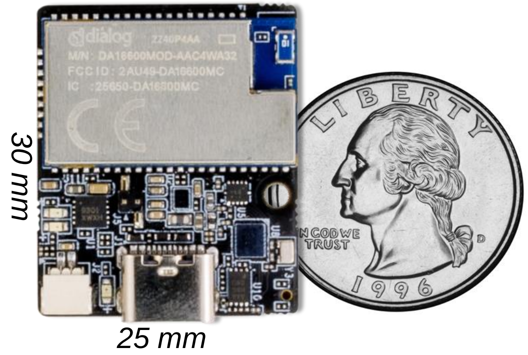
Case study: RASynBoard

- Targets industrial and consumer applications, e.g.
  - Always-on sound detection and sensor fusion
  - Motor anomalies / predictive maintenance
  - Industrial smart sensors
  - Smart factory / smart home



IOT ENDPOINTS

SMART HOME APPLICATIONS

HEARABLES/ WEARABLES

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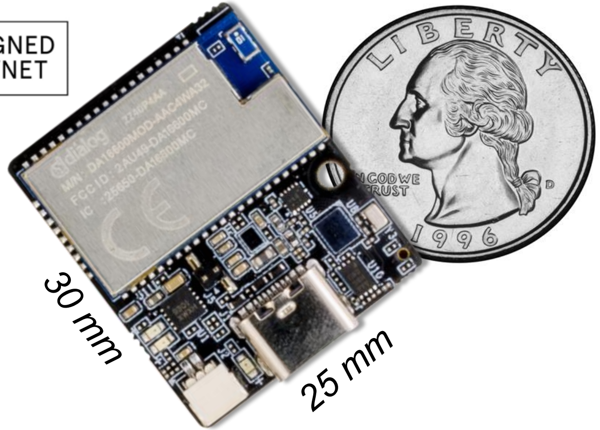
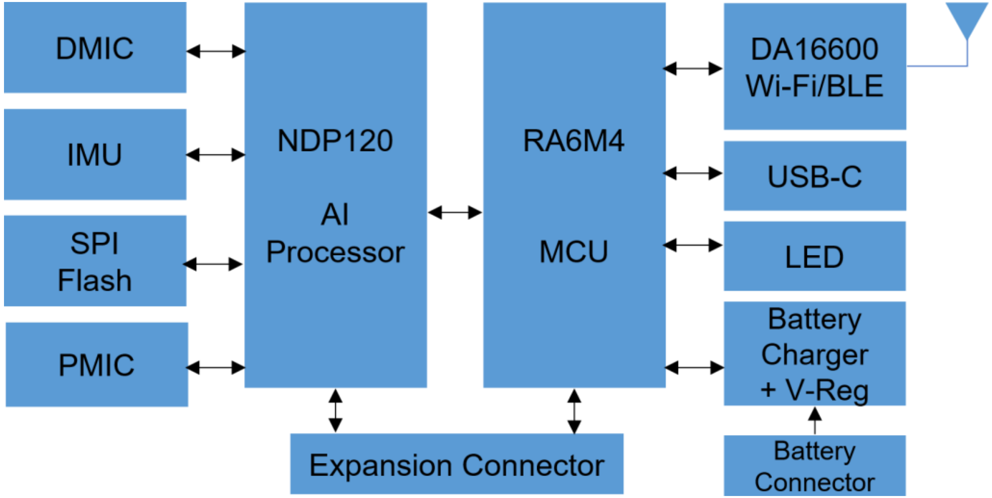
RASynBoard

Core Board





- Designed for integration into small OEM products
- Onboard sensors (digital MIC and 6-axis IMU)
- Battery-operated, low-latency Edge-AI intelligence
- Wi-Fi/BT5 wireless connectivity

RASynBoard

Core Board

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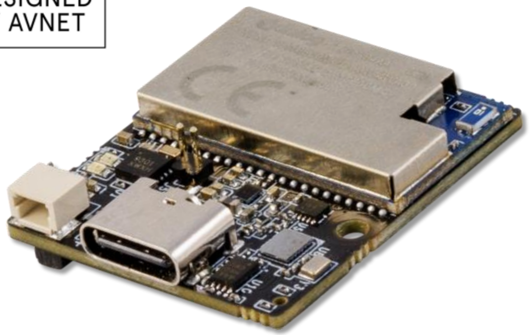

RENESAS RA + SYNTIANT

Ideal for "always-on" front-end to wake-up a vision subsystem

- **Syntiant NDP120 Neural Engine**
  - Syntiant Core 2 Deep Neural Network
  - Arm Cortex M0 and Cadence® Tensilica® HiFi 3 DSP
- **Renesas RA6M4 Microcontroller**
  - 1x Arm Cortex M33 (200 MHz)
  - 1 MB flash memory, 256 KB SRAM
- **Renesas DA16600 Wi-Fi/BT Module**
  - 802.11bgn 1x1 2.4 GHz Wi-Fi and BT 5.1
- **Onboard Memory, Sensors & Interfaces**
  - 16 Mbit SPI NOR Flash
  - IMU 6-axis motion sensor (ICM42671)
  - PDM digital microphone (MMICT5838)
  - USB 2.0 type-C peripheral device interface
  - 2x28 pin 1.0mm pitch expansion connector
  - JST 1.0mm LiPo battery connector
  - 1x User LED

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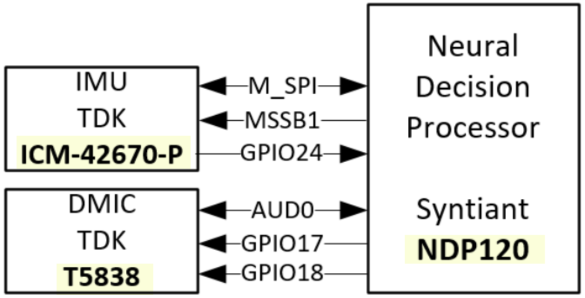
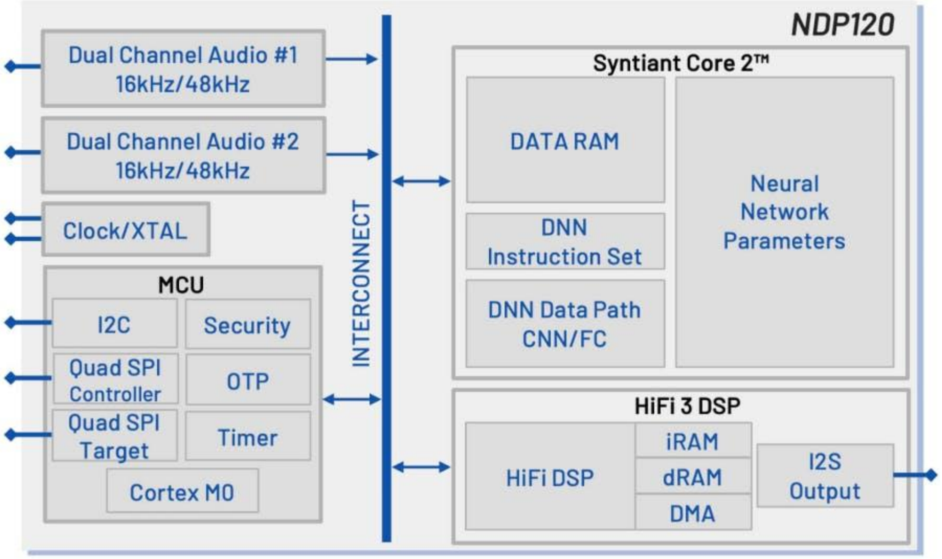
RASynBoard "always on" Edge AI/ML

- The Avnet RASynBoard implementation uses an "always on" ultra low-power subsystem of TDK DMIC and IMU smart sensors plus Syntiant NDP120 Neural Decision Processor



NDP120 - Neural Decision Processor

Always-on speech & sensor-fusion processor



NDP120 can run multiple AI models simultaneously using under 1 mW !

Wireless connectivity using DA16600 Wi-Fi/BLE Module

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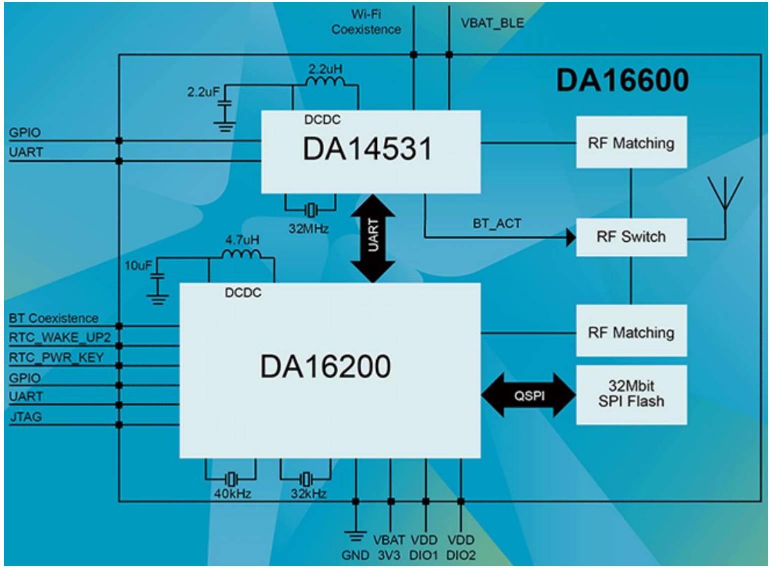
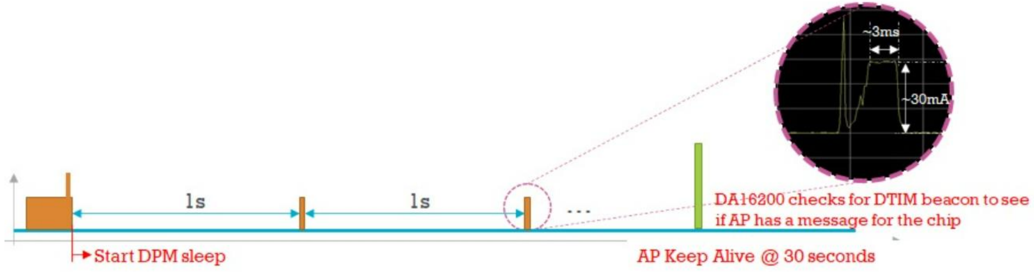
- Connection with wireless sensors, handheld devices and cloud services
- DA16600 shuts-down micro elements of the chip if not in use (near-zero consumption if not active!)
- DPM software APIs (Dynamic Power Management) for precise setup of sleep/wake operating modes
- Wi-Fi/BLE co-existence (can operate at same time)





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Battery power calculations

Tabled from datasheets is calculated power (in mW)

Power (W) = V x I

More useful is estimated energy over time (in mJ)

Energy (J) = W/sec

Use this to calculate needed battery capacity (in mAh)

mAh* = E / (V x 3.6)

* 1mAh = 1/1000 x 3600 sec
**for simplicity this not tabled

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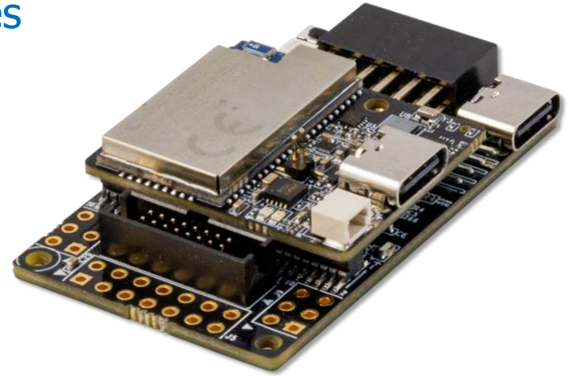
What needs to be powered-on and when..?

	Always-on	AI Inference Interrupt Event	Wi-Fi Keep-Alive Periodic Event	Comments
	MCU is in SW standby	Keyword match (200ms)	Wi-Fi DTIM event (3ms ea. 100ms)	
IMU	0.99 mW	0.99 mW	0.99 mW	in low noise mode
DMIC	0.22 mW	0.22 mW	0.22 mW	in low power mode
NDP120	0.25 mW	0.25 mW	0.25 mW	always-on/listening
Misc.	5.00 mW	5.00 mW	5.00 mW	pull-ups, etc
RA6M4	5.28 mW	65.3 mW		short duration 20mA
Wi-Fi		**	99.0 mW	short duration 30mA
LED UI		2.52 mW		short duration 1.2mA
Totals:	12.74 mW	74.28 mW (for 200ms,10 events/hr)	105.46 mW (for 3ms ea 100ms)	Wi-Fi DTIM=100ms Longer non-active interval will drastically reduce energy use!
E=44.4 mJ	E_Q=12.74 mJ	E_{AI} = 0.041 mJ	E_{WiFi}= 31.64 mJ	10 inference events/hr Exaggerated low duty-cycle, has MCU in software standby for > 99% of the time

Design trade-offs and lessons learned

- Optimize average power over time using MCU low-power modes
- Reduce MCU clock to just what is needed for the task
- Separate "Always on" components from circuits that can be turned OFF or held in RESET
- Minimize the wireless module's TX/RX active duty-cycle, combine wireless TX events and limit transmission retries
- Review again the low power design techniques on slide 4 !
- Use pre-engineered RASynBoard EVK and example code for:
  - hardware prototyping (+more sensors via expansion connectors)
  - software development (see Avnet & Renesas FSP example code)
  - testing of AI/ML models developed with third-party tools
- Check-out avnet.me/avnetboards for further ideas…



RASynBoard EVK (for app development)

Core Board
+ IO Board

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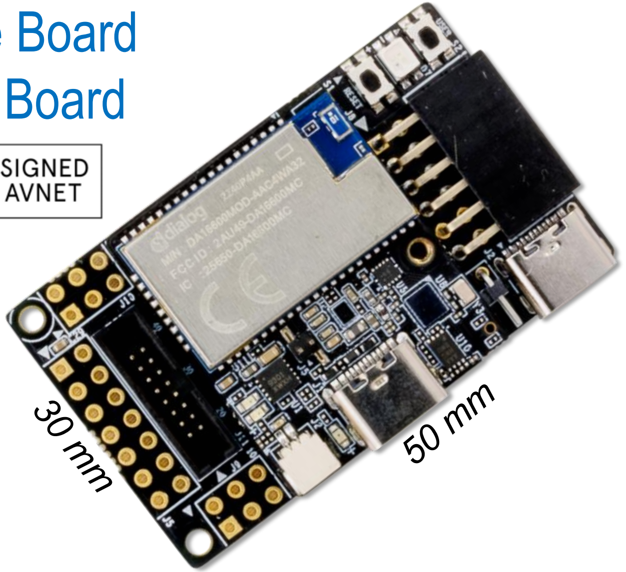

- Starter Kit assembly for app development
- Pmod, Click, USB & custom I/O expansion
- Onboard debugger, RGB LED & switches
- MicroSD card for local mass storage

- **Onboard Debugger & USB-Serial interface**
  - Renesas E2OB (E2Lite) debugger MCU (USB-C to SWD and UART interfaces)
  - 3.3V buck regulator for debugger circuits
- **Expansion Interfaces & Storage**
  - 2x28 pin board-to-board connector
  - 2x8 pin MikroE Click shuttle box header
  - 2x6 pin Pmod type-6A (I2C) socket
  - 2x7 pin MCU expansion header
  - 2x3 pin DMIC expansion headers (two)
  - 3.3V logic-level expansion interfaces
  - uSDcard cage for removable storage
- **User Interfaces**
  - 2x Button Switches (Reset and User)
  - 1x User RGB LED

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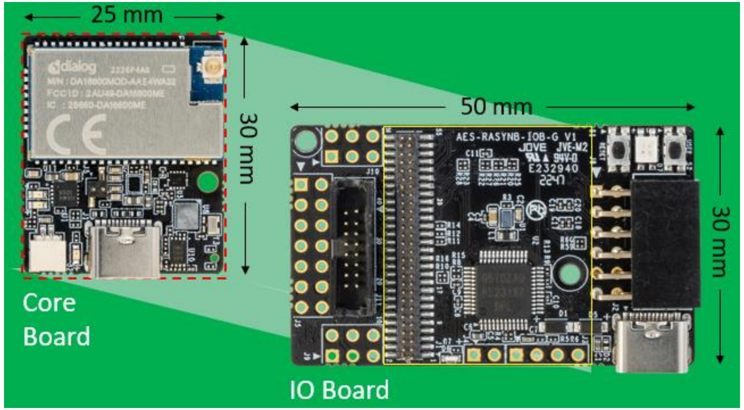
References & resources for more info…

- **RASynBoard** product page avnet.me/rasynboard
- **Avnet Boards** website avnet.me/avnetboards (avnet.com > Products > Avnet Boards…)
- **NDP120** AI/ML page www.syntiant.com/ndp120
- **RA6M4** MCU page www.renesas.com/RA6M4
- **DA16600** Wi-Fi/BT www.renesas.com/DA16600MOD
- See RASynBoard plus other AI hardware & software in action at the Avnet booth!



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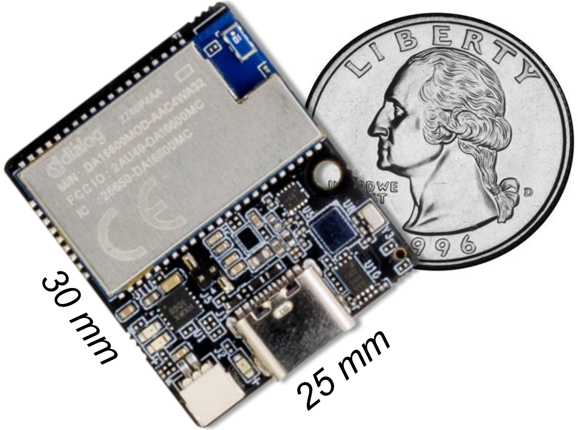
		$E = \frac{(0.2 * 10 * 74.28)}{(60 * 60)}$	$E = \frac{(0.03 * 105.46) * 10}{1}$	

RASynBoard

Core Board



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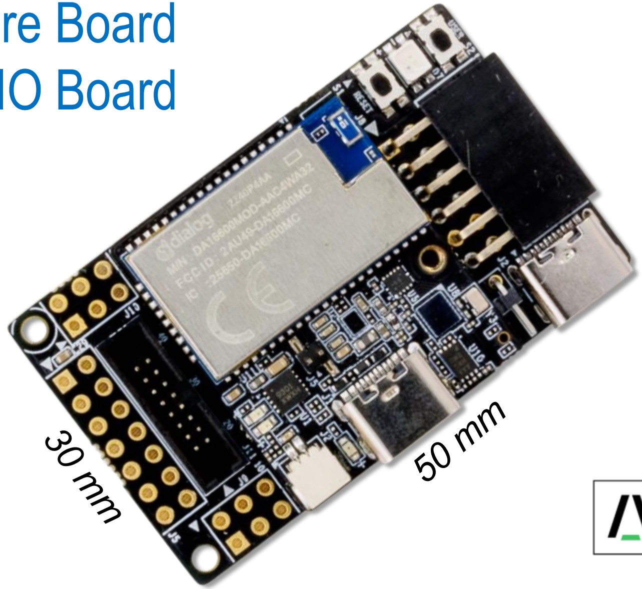
RASynBoard EVK

embedded VISION SUMMIT

Core Board
+ IO Board



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