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Explaining the SiWx917 Low-Power Wi-Fi Features for IoT Product Developers

A comprehensive overview of Wi-Fi power optimization on the SiWx917 wireless MCU for developing energy-efficient smart IoT devices

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About this Whitepaper

The SiWx917 is the world's most energy-efficient Wi-Fi 6 wireless microcontroller unit (MCU) and can deliver years of battery-life for IoT devices. It is equipped with an intelligent power management solution that provides IoT developers more fine-grained energy optimization possibilities than any other product in the market. An independent testing provider estimated the SiWx917 is capable of providing up to 5-years of battery life for smart locks.

However, simply mounting the world's most energy-efficient Wi-Fi 6 chip on your product doesn't bring years of battery-life or low standby current: you need to know how to utilize the advanced ultra-low-power features of the SiWx917 and the Wi-Fi protocol.

This whitepaper helps you to become a master in developing energy-efficient, yet powerful and smart IoT devices using the SiWx917. It provides you with a comprehensive overview of SiWx917's low-power capabilities, power management, and Wi-Fi power saving techniques, including several best-practice tips.

Why Low-Power Wi-Fi

Historically, Wi-Fi has been a power-intensive wireless technology, prohibiting its use in energy-efficient and resource-constrained applications. However, the dramatic growth of IoT and the evolution of the energy-efficient Wi-Fi 6 protocol generation are coinciding and changing the course for the low-power Wi-Fi. With Wi-Fi 6, finally there is a simple, battery-friendly, and high-throughput way for developers to connect smart IoT devices to the cloud without bridges and protocol translations.

Wi-Fi Challenges in the IoT

Buyers seek energy-efficient, sustainable, and cost-effective products. To reflect the increasing awareness of green initiatives, new energy regulations are enforced constantly, increasing product development costs. The main challenge for the designers and developers of Wi-Fi IoT devices and smart appliances lies in power consumption.

Battery Life	Standby Power	Energy Regulations
Battery life is critical for IoT buyers. With a long battery replacement and recharging interval, you can enhance user experience, reduce costs and waste; and avoid battery depletions on industrial applications to reduce OPEX for your customers.	Dozens of smart devices are drawing ‘phantom’ current 24/7 in homes and enterprises, increasing energy costs and CO_2 emissions. With low-power Wi-Fi you can give users a more sustainable alternative and have buyers gravitating towards your brand.	Strict energy regulations are imposed on new product segments and regions constantly, increasing product development costs. With low-power Wi-Fi, you can score better energy ratings and unlock new markets for your products.

Where Are Low-Power Wi-Fi Devices Used?

Smart homes include dozens of energy-efficient and battery-powered IoT devices including smart locks, many types of sensors, thermostats, smart A/C units, air filters, smart switches, energy management equipment such as EV chargers, solar panel inverters, and home batteries.

Many types of low-power Wi-Fi devices are used in enterprises, commercial centers, smart hospitals, and other buildings for sensing, controlling, access management, and building automation.

Smart appliances are typically subject to various energy regulations and thus benefit from low-power Wi-Fi connectivity; these include e.g. whitegoods, washers, dryers, refrigerators, countertop devices, kitchenware, BBQ grills, fitness equipment, and other connected appliances used in homes.

Location and asset tracking devices used in logistics, warehouses, enterprises, hospitals, commercial centers, and other applications where indoor positioning is required are based use low-power Wi-Fi.

Connected health segment includes several applications using low-power Wi-Fi connectivity – personal health devices, physical training equipment, smart medical instruments, and asset tracking in hospitals.

SiWx917 Product Overview

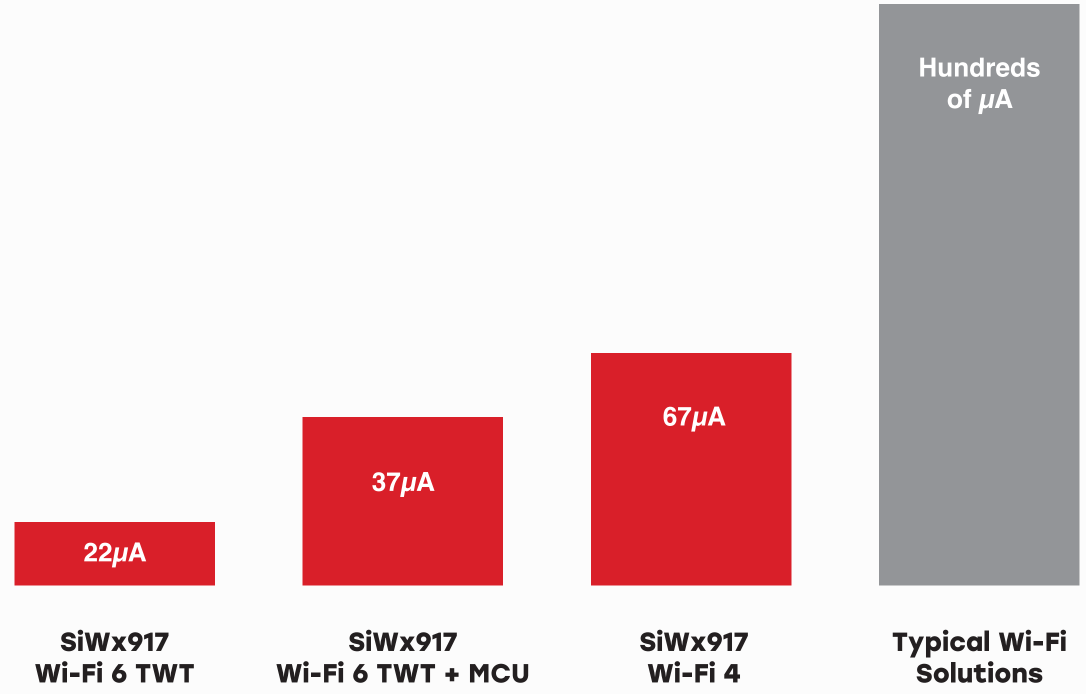
Silicon Labs' SiWx917 ultra-low-power wireless SoCs and modules provide Wi-Fi® 6, Bluetooth® Low Energy (LE), Matter, and IP networking for secure cloud connectivity. The SiWx917 is designed for advanced battery-powered IoT devices and energy-efficient smart appliances. The SiWx917 is based on a dual microprocessor architecture with a 160MHz network wireless processor (NWP) and the ARM® Cortex® M4 as the application MCU with up to 180MHz clock speed. The TCP/IP networking, security, and wireless stacks run on the NWP, off-loading the MCU, which is dedicated to run application, Matter, and peripherals. A separate AI/ML processor offloads the MCU, offering optimized machine learning (ML) inferencing at the Edge.

5-Year Battery Life for IoT Devices

SiWx917 features the lowest power consumption in its class, consuming only 22µA of power in the Wi-Fi 6 connected sleep mode when measured without MCU with the assumptions as listed on the right. Its combined system power consumption for Wi-Fi 6 connectivity with target wake time (TWT) (connected sleep) and the application MCU is just 37µA. An independent testing provider, Novus Labs estimated that SiWx917 can enable smart locks to reach a 5-year battery life with four AA batteries with a capacity of 3000mAh.

SiWx917 Configurations and Assumptions for a 5-year IoT Battery-life

- NWP in associated standby low-power mode
- SiWG917 SoC mode
- TCP client maintains socket connection
- 60 secs TCP keep-alive used
- WLAN keep-alive 30 secs
- 325kB SRAM retention
- TWT Auto Config feature enabled
- TWT Rx latency 60 sec with 8ms wakeup duration
- Arm Cortex-M4 in sleep mode (PS4) with 320kB SRAM retention
- Average current consumption for wireless and application MCU 37µA at 3.3V
- Measurements taken in a lab
- Battery capacity 4xAA 3000mAh



Learn More: An independent interoperability and power consumption test by Novus Labs estimated that the SiWx917 Wi-Fi 6 SoC can boost smart lock battery life to up to 5 years. [Read the full test report] with SiWx917 power consumption, throughput, and battery life in different network congestions.

Low-Power Wi-Fi Design Concept

The concept of low-power Wi-Fi design can be divided into three groups. First, low-power Wi-Fi design begins from the functional requirements of your IoT application. The second group contains the advanced low-power features and capabilities that SiWx917 can offer for IoT device makers. The SiWx917 features can be divided into multiple sections covering the product architecture, power management, peripherals, memory, and more. Finally, in the core of the low-power Wi-Fi design concept there is the Wi-Fi protocol, providing many settings to play with when optimizing the power consumption for the IoT application. These three areas of low-power Wi-Fi design finally constitute the overall energy-efficiency for your IoT device.

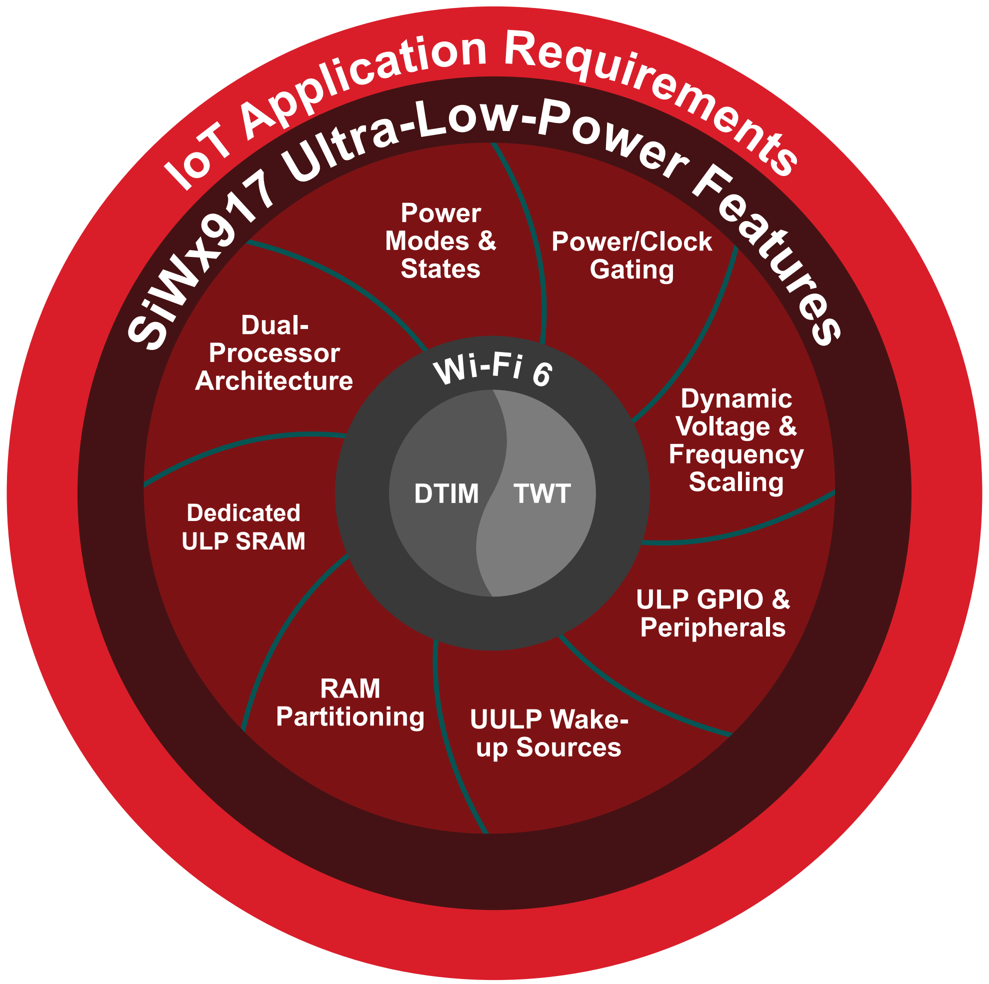


Figure: Low-power Wi-Fi design concept

SiWx917 Low-Power Features and Capabilities

This section gives an overview of all the main low-power features and capabilities available on SiWx917 including links to more in-depth materials.

Power Domains

The SiWx917 is divided into multiple power domains and partitioned subsystems to allow fine-grained power management using power-gating and clock-gating on per power domain and block basis. This smart power management solution enables developers to optimize power consumption flexibly in different portions of the chip based on the IoT application requirements. In the SiWx917, power domains and power- and clock-gating are implemented as part of the same power management strategy.

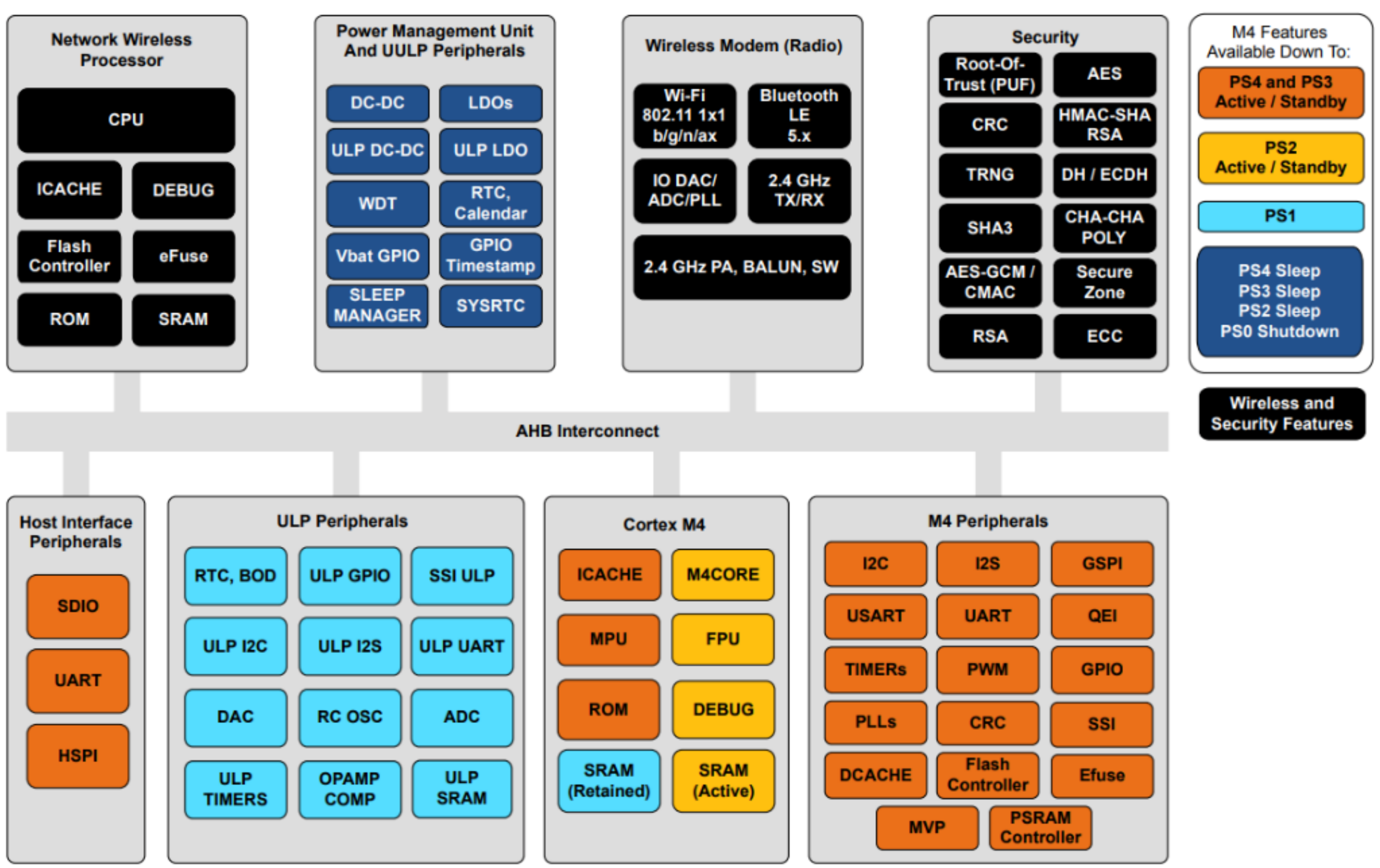


Figure: Low-power Wi-Fi design concept

Power-Gating

Power-gating is a technique to shut off the power supply to specific blocks on the SiWx917 when they are not needed, allowing developers to reduce device's power consumption. Even when some of the blocks are powered off, other parts of the chip can remain active to detect wake-up events, maintaining the ability to wake up quickly when needed. For instance, the ultra-Ultra-low-power (UULP) wake-up sources such as the UULP_VBAT GPIO are powered on when the Cortex-M4 application MCU is in PS0 shutdown state.

Examples of Power-Gating Options on SiWx917

1. MCU power-gating: In the PS0 shutdown, PS1, and PS4/3/2 sleep modes, the CPU is power-gated, reducing power consumption significantly. During MCU power-gating, SRAM can be retained in the sleep mode, but not in the shutdown mode.
2. SRAM power-gating: In the total SRAM of 672kB, there is a specific section from where designated portions can be power-gated, dividing it into multiple power domains.
3. Peripheral power-gating: In lower power states, unnecessary peripherals can be power-gated.

Clock-Gating

Clock-gating is a power-saving technique that allows the device to selectively disable clock signals to specific blocks to reduce power consumption when they are not in use. As opposed to power-gating, clock-gating enables faster wake-up of the blocks that are in standby while power-gating saves more energy but comes with a wake-up latency penalty. The exact implementation and control of clock-gating may vary depending on the specific operating mode and the current power state of the SiWx917.

Power Modes and States

Cortex-M4 Application Processor

The Arm Cortex-M4 application microcontroller unit (MCU) in the SiWx917 provides several combinations of power modes and states, which are part of the power management strategy of the SiWx917. They are designed to give developers more possibilities to optimize power consumption on their device. Here's a high-level breakdown of the power modes and states of the Cortex-M4 application MCU:

Learn More: Please refer to the [SiWx917 datasheet]() for an in-depth explanation of the power modes and states.

Active PS4, PS3, PS2, PS1

- PS4: Complete Cortex-M4 is functional and operating at full power
- PS3: Complete Cortex-M4 is functional at reduced voltage. 90MHz max. MCU clock speed.
- PS2: A limited set of peripherals available with a reduced voltage, 32/20MHz MCU clock speed, SRAM retention.
- PS1: Entered only from the PS2 state. MCU is power-gated, limited peripherals, RAM retention.

Standby PS4, PS3, PS2

- Entered from the Active states
- MCU is clock-gated
- SRAM inherits the voltage level from the respective Active states
- Peripherals, GPIO and SRAM inherit settings from the respective Active states
- Faster wake-up compared to Sleep mode, PS1, PS0

Sleep PS4, PS3, PS2

- Entered from the Active states
- MCU power-gated
- UULP and analog peripherals available
- Four GPIOs available as power sources (UULP_VBAT_GPIO)
- 320kB LP SRAM retained

Shutdown PS0

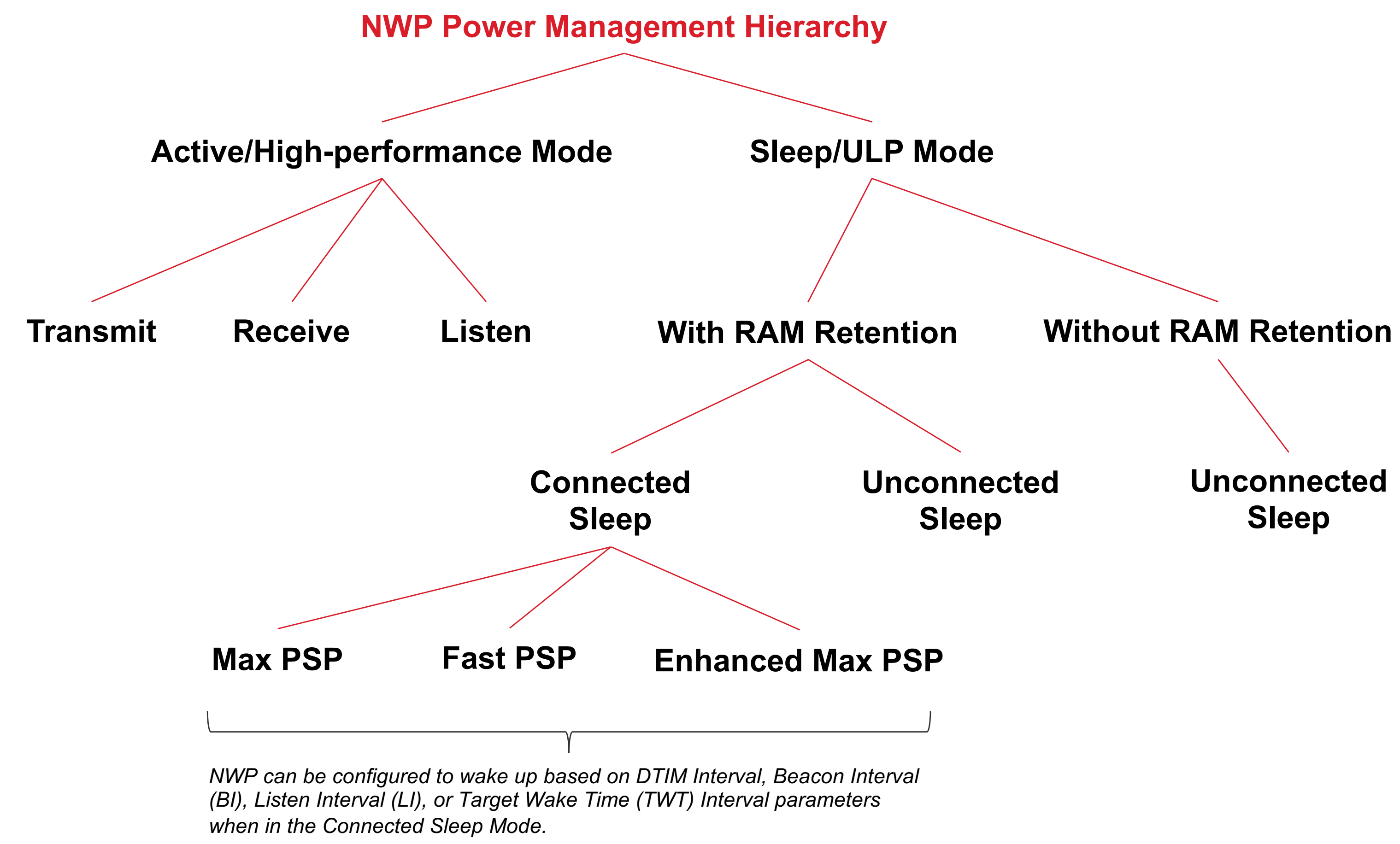
- Entered from the Active states
- MCU power-gated
- UULP and analog peripherals available
- Four GPIOs available as power sources (UULP_VBAT_GPIO)
- No SRAM retention

Network Wireless Processor

The NWP on the SiWx917 is an independent processor that runs the wireless protocols, networking stacks such as TCP/IP, TLS, and MQTT, and security engine, off-loading these tasks from the application MCU. It also serves various protocol keep alive protocols, allowing the application MCU sleep longer. The NWP has several power modes designed to help developers optimize power consumption based on network activity and application requirements.

On high-level, NWP's power states can be divided into active/high-performance states and sleep/low-power states. The active states can be in one of the three modes: transmit, receive, or listen. The sleep states can be either connected or unconnected, depending on whether the device should maintain its connection on the Wi-Fi network. For unconnected sleep, the NWP can be in two possible states: with SRAM retention or without SRAM retention. When in connected sleep state, NWP always retains RAM and wakes up based on the DTIM or TWT interval configurations. The NWP can assume three alternative power save profiles (PSP), which determine how it retrieves buffered data from the AP after having received a beacon with the TIM bit set.

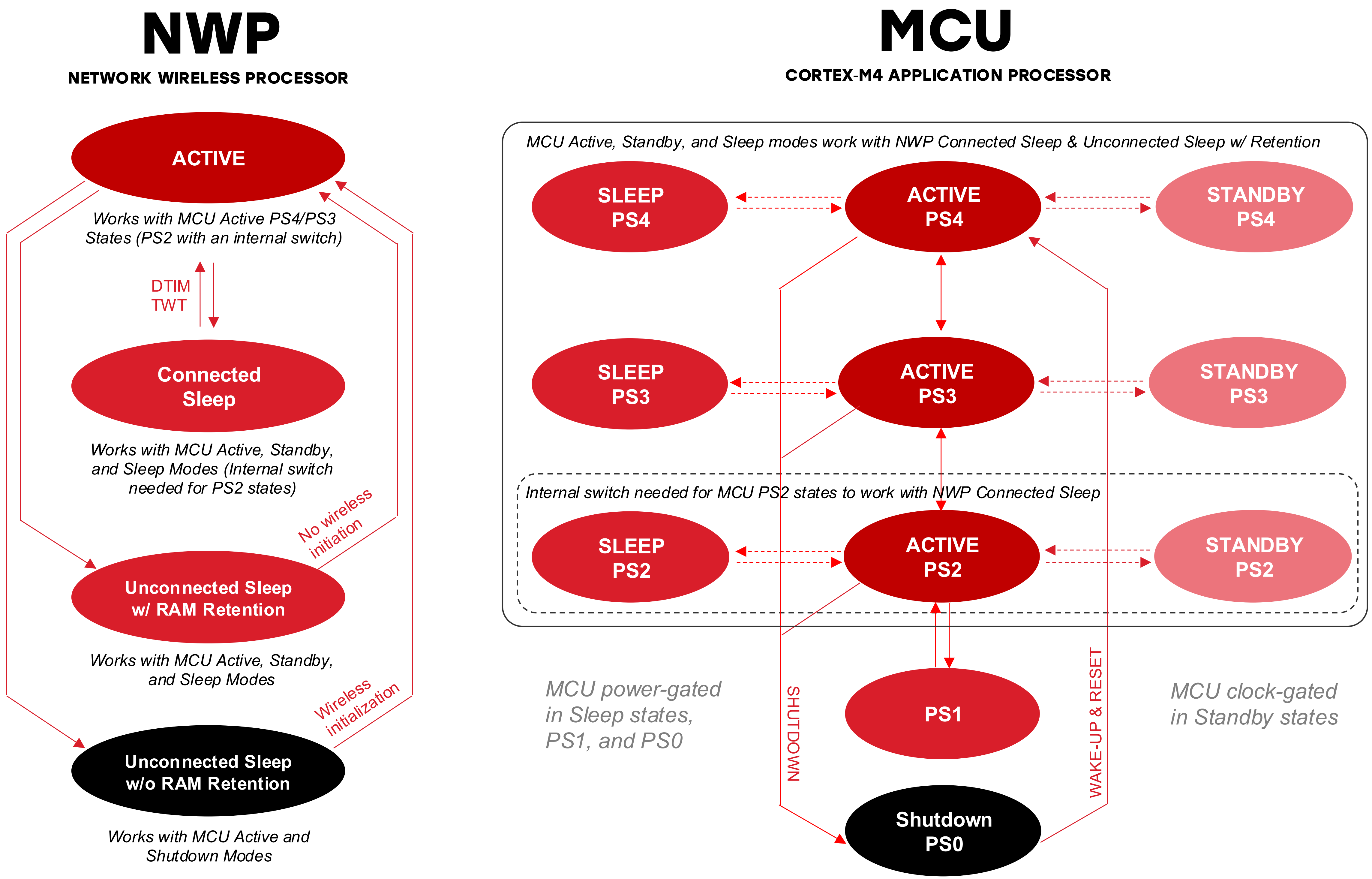
- **Max PSP:** Data retrieved via power save polling (PS-Poll) frames. Saves power but increases delay and reduces throughput.
- **Fast PSP:** Streamlined data retrieval without polling. Client transitions to the active state and sends a null data frame to the AP for data retrieval.
- **Enhanced Max PSP**: If the AP acknowledges PS-Poll but does not deliver buffered data within 20 ms due to e.g. an interoperability issue, the NWP switches to the active state, and sends null data frame, and waits for Monitor Interval time to retrieve the buffered data.



Network Wireless Processor (NWP) Power States	Active	Connected Sleep	Unconnected Sleep with Retention	Unconnected Sleep without Retention
	• Complete NWP is active • Supports Transmit, Receive, and Listen operational modes	• NWP connects to AP and goes to sleep • NWP wakes-up per DTIM and TWT • SRAM Retained	• NWP, modem, and security engine are inactive • SRAM is retained	• NWP, modem, and security engine are inactive • SRAM is not retained

SiWx917 State Machine

The NWP and application MCU processors operate based on their own state machines. The combined state diagram below gives an overview of the power state transitions of both sides, and how they can interact with each other, and which power state combinations are supported between the processors.



Learn More: Please refer to the [AN1430: SiWG917 Low-Power Application Note] for more details on the state machine and power management.

Dynamic Voltage and Frequency Scaling

Dynamic voltage and frequency scaling allows adjusting the clock frequency of the SiWx917 processor and other blocks on the chip to balance between power consumption and performance for the application – for instance, using a high-performance mode when executing computationally intensive tasks and switching to a power-save mode during idle periods to conserve energy. The SiWx917 can be configured as either power-save or performance mode. After each state change, the clock sets into power-save mode by default.

Performance and Power-Save Modes on SiWx917	
PS4	Performance Mode: 180 MHz clock Power-Save Mode: 100 MHz clock
PS3	Performance Mode: 80 MHz clock Power-Save Mode: 40 MHz clock
PS2	20 MHz clock is used by default

SRAM Partitioning

The SiWx917 features a total of 672kB of SRAM which can be segregated into different areas based on power to reduce current consumption. In addition to the regular SRAM areas, there are two main power-saving areas: low-power (LP) SRAM of 320 kB and ULP SRAM of 8 kB. Both are further partitioned into multiple domains consisting of one or several banks allowing flexible and energy-efficient power management. The power of these SRAM domains can be controlled flexibly in different ways depending on the power state. In the Sleep mode and PS1, both the LP SRAM and ULP SRAM can be retained. Neither LP SRAM nor ULP SRAM can be retained in the PS0 shutdown mode.

Learn More: Please refer to the [AN1416: SiWx917 SoC Memory Map]() for more insights on the SiWx917 memory configurations.

Ultra-Low-Power Peripherals

The ultra-low-power (ULP) peripherals are a crucial element of the low-power capabilities of SiWx917. They enable sensor data collection while the Cortex-M4 application MCU and NWP are sleeping, saving considerable amounts of energy. SiWx917 includes several ULP versions of analog and digital peripherals designed to operate with minimal power consumption. In Sleep mode, GPIO states are not retained. SiWx917 also provides ultra-ultra-low-power (UULP) peripherals. The UULP pins such as UULP_VBAT_GPIO can be used to power external devices on the system.

Peripherals with ULP Versions:

- I2C, I2S, UART, GPIO, Timers
- ADC, DAC (Analog/Digital Converters)
- DMA (Direct Memory Access)
- SSI Primary (Synchronous Serial Interface)
- RTC (Real-Time Clock)
- BOD 2 (Brown-Out Detector)

MCU Power States	High-performance Peripherals	ULP Peripherals	UULP Peripherals	Analog Peripherals
Active Mode				
PS4	X	X	X	X
PS4	X	X	X	X
PS4	–	X	X	X
PS4	–	X	X	X
Standby Mode				
PS4	X	X	X	X
PS4	X	X	X	X
PS4	–	X	X	X
Sleep Mode				
PS4	–	–	X	–
PS4	–	–	X	–
PS4	–	–	X	–
Shutdown PS0	–	–	X	X

The table above shows which peripheral groups are supported in which power modes and states.

DC-DC Converter

The SiWx917 includes an internal power management subsystem with DC-DC converters and linear regulators to generate all the voltages required for the chip to operate from various input sources and to power external components, helping developers to reduce power consumption. There are two types of DC-DC switching converters which can be powered with either 1.8 V or 3.3 V. The LC DC-DC converters feed RF and digital blocks and SC DC-DC converters the always-on core logic domain.

Learn More: Please refer to the AN1448: SiWx917 Power Supply Architecture and Configurations document for more insights on power management.

Wi-Fi Protocol and Low-Power Design Aspects

The Wi-Fi 6 is the most energy-efficient Wi-Fi generation, yet Wi-Fi 4 is still the most ubiquitous protocol generation and offers sufficient power efficiency for many IoT applications. In this section, we discuss the most significant low-power design aspects of the Wi-Fi protocol.

Delivery Traffic Indication Message (DTIM)

A delivery traffic indication message (DTIM) is a specific type of traffic indication message (TIM) through which Wi-Fi APs inform the clients if there is multicast or broadcast data waiting for them on the AP buffer.

DTIM is delivered as part of the beacon message, at a frequency defined by the DTIM interval (DTIM is not part of every beacon). DTIM interval is set by the AP and it is expressed in increments of 100ms for multicasting and broadcasting to several clients.

Listen Interval (LI) can be configured on the client to enforce it to wake up at the nearest multiples of DTIM beacon/beacon interval broadcasted by the AP, which is lower than or equal to the LI. Setting LI to 1000ms, the client wakes up once per second, i.e., every tenth DTIM interval. A LI above 1000 milliseconds can lead to AP disconnecting the client.

TIMs are present in every beacon indicating that there is pending data for the client in the AP. If the TIM bit is set, it indicates that there is data for a specific client.

DTIM interval and other settings affect Wi-Fi client's power consumption and battery life:

- If the LI is set, the client wakes up upon the LI interval to check whether there is data for them on the AP. If the LI is not set, the client wakes up per the DTIM interval set by the AP.
- The client goes back to sleep after the data is retrieved.
- Also, the data retrieval process defined by the power save profile (PSP) on the NWP affects power consumption.

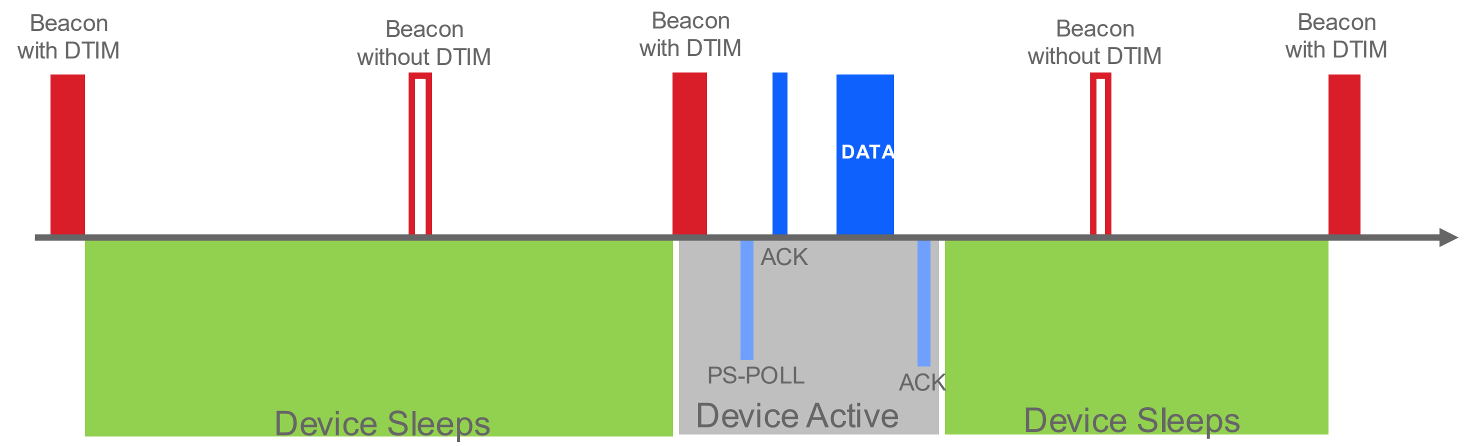


Figure: : Illustrating the use of DTIM for multicast and broadcast. TIM, which is used for unicast is similar.

Target Wake Time (TWT)

In the legacy power save modes such as DTIM, Wi-Fi 4 clients go to sleep and wake up at predefined intervals to check for incoming data and transfer data regardless of the wake-up schedules of other clients. With Target Wake Time (TWT) in Wi-Fi 6, the clients negotiate the wakeup scheduling with the AP, ensuring no two clients wake up at the same time. This method helps avoid packet collisions, thus reducing retransmissions and, in turn, reducing the current consumption for all the clients. The multicast TWT feature enables to set several devices to be awake at the same time. In general, TWT allows Wi-Fi clients to remain in sleep for longer durations, increases power efficiency on connected clients, and reduces network congestion.

Configuring individual TWT on SiWx917

- **Manual TWT Configuration:** The TWT parameters such as sleep duration, wake-up duration, and wake interval are calculated based on the TWT specification parameters configured in the application.
- **Automatic (Auto) TWT:** A Silicon Labs implementation that configures TWT parameters automatically based on the application requirements such as the average throughput and RX latency. Based on these inputs, the NWP configures the TWT parameters and negotiates them with the AP. The Auto-TWT also checks if the TWT is optimal for a specific combination of latency and throughput parameters. If deemed inefficient, legacy listen Interval-based power saving (DTIM) is enabled instead of the TWT. Auto-TWT is recommended for better throughput, interoperability, power efficiency.
- A Wi-Fi 6 client that has subscribed to a TWT agreement should not transmit outside of its service period (SP) to reduce the risk of media contention with other devices. Adhering to the TWT improves the energy efficiency of the device, and other Wi-Fi 6 devices in the network with a TWT agreement.
- If a Wi-Fi 6 device is expected to transmit frequently with a short notification time (e.g. a few seconds), a short TWT interval is recommended. If the occurrence of low-latency transmissions is very sporadic (e.g. fire alarm), transmitting outside the SP could turn out to be a more energy-efficient solution. However, in this case a power consumption penalty should be factored in due to potential media contention with other devices.
- If a Wi-Fi 6 device is expected to receive a large amount of data (e.g. firmware update), TWT teardown or re-negotiation of TWT agreement should be considered. The additional procedure increases power overhead, but due to rare occasions, the impact on the overall power consumption is limited.

Learn More: Please refer to the AN1433: SiWx917 NCP Low Power Application Note for more about TWT teardown.

When to Use DTIM and TWT?

Although Wi-Fi 6 and TWT are typically recommended for low-power IoT applications, the legacy Wi-Fi power saving mechanisms such as DTIM have their place too. The table below gives tips for when to choose which technique.

When to Use DTIM?

- Wi-Fi 6 and TWT is not always supported or enabled by Wi-Fi routers. However, DTIM is a legacy functionality that is supported generally on Wi-Fi routers.
- When the network traffic is very low, the overhead of negotiating and maintaining TWT (depending on TWT settings) is not worthwhile. DTIM does not require negotiation.
- When there is a lot of unpredictable network traffic
- Use DTIM when there are many devices not supporting TWT, because they can potentially collide with the service period of TWT enabled clients.

When to Use TWT?

- When the IoT application or use-case can tolerate a long sleep time, TWT can save energy
- When there are a lot of TWT-enabled clients in the network and the wake-up times can be arranged so that they won't overlap. This ensures a more efficient radio resource utilization, saving power.

Learn More: Please see AN1430 SiWx917 Low-Power Application Note for more details on the Wi-Fi power saving techniques.

Conclusions – IoT-Optimized Wi-Fi

We hope you have found this whitepaper helpful for advancing your low-power Wi-Fi design. The focus of the whitepaper is purely on power optimization because it still remains one of the most complicated challenges for the makers of IoT and smart devices. However, IoT is more than just optimizing power consumption. Modern IoT-optimized Wi-Fi devices must have powerful compute, sophisticated features, and robust security to deliver upon the requirements of the fast-paced consumer and enterprise markets. The SiWx917 Wi-Fi 6 wireless MCU is an IoT-optimized solution that provides you with a perfect balance of ultra-low-power and advanced computing and features.

Features of IoT-Optimized Wi-Fi

The lowest system power for Wi-Fi 6 and application MCU	Dual processor for application and wireless networking	The largest SRAM, PSRAM, and Flash memory in the class	Dedicated AI/ML processor for Edge computing
Single-chip Matter solution - Pre-certified Matter and Bluetooth LE 5.4	A dedicated security engine. Broad security feature set. PSA level 2 certifiable	A dedicated security engine. Broad security feature set. PSA level 2 certifiable	Customize at order: your part number, markings, software, and other settings!
A rich set of peripherals, GPIO, and Analogs with ultra-low-power operation			

Benefits of SiWx917

- **Maximize Battery Life**
- **Minimize Standby Current**
- **Score Better Energy Ratings**

Low-Power Wi-Fi Design Guidelines for Six IoT Devices

Best-practice low-power Wi-Fi design guidelines from distinguished specialists – Six IoT device examples

Silicon Labs SiWx917 is an ultra-low-power Wi-Fi 6 wireless MCU tested to enable years of battery-life and low standby current on smart IoT devices. However, optimizing the SiWx917 wireless MCU and the Wi-Fi protocol for your design can be challenging. In this document, the distinguished specialists from the Silicon Labs Developer Services Team and Sigma Connectivity, a global design and engineering service provider, share their best-practice design guidelines for six low-power Wi-Fi device examples, helping you to avoid common pitfalls and save time.

Learn More

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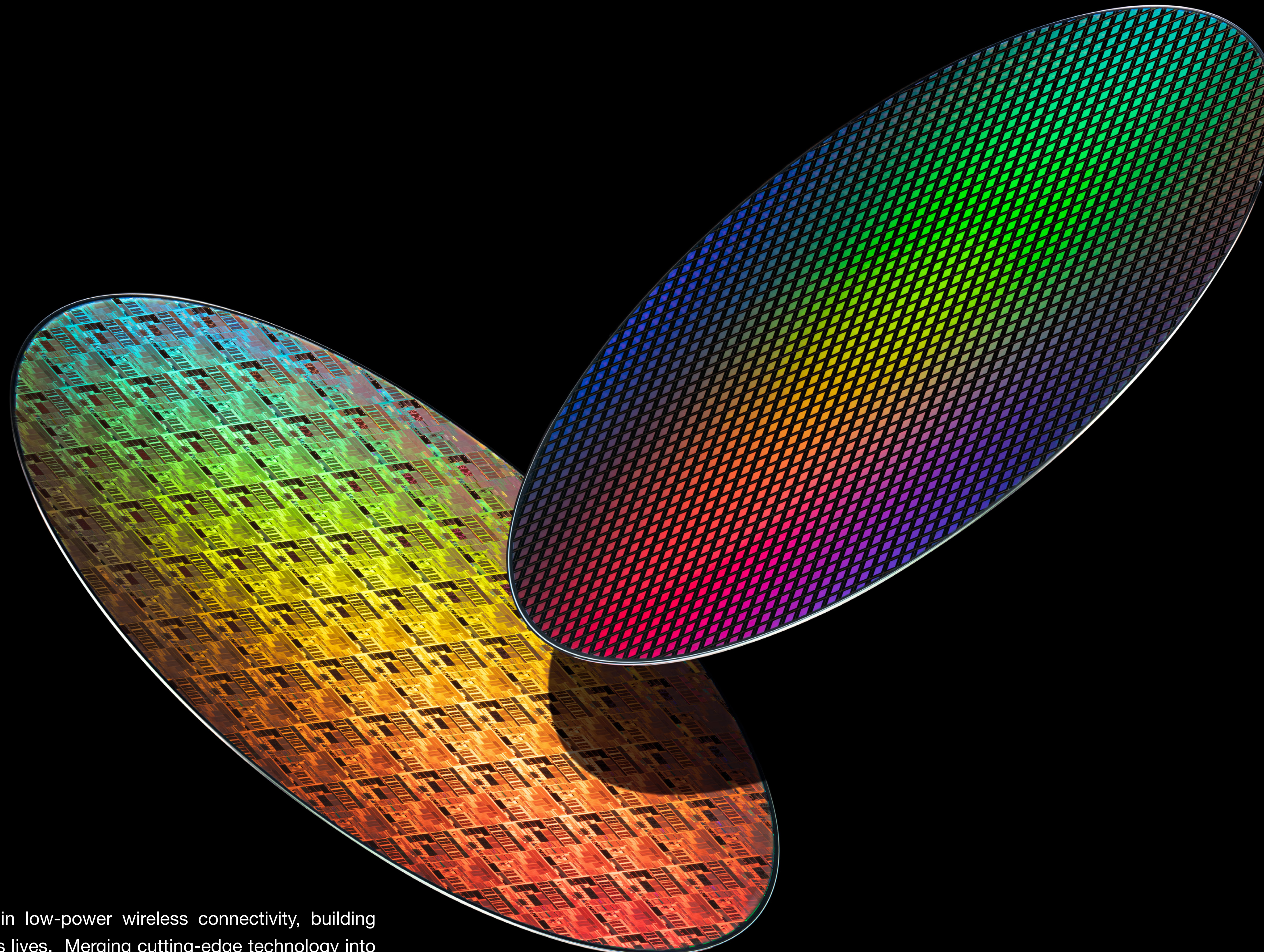

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