AN1280: RS9116W Power Save Application Notes

Version 1.4

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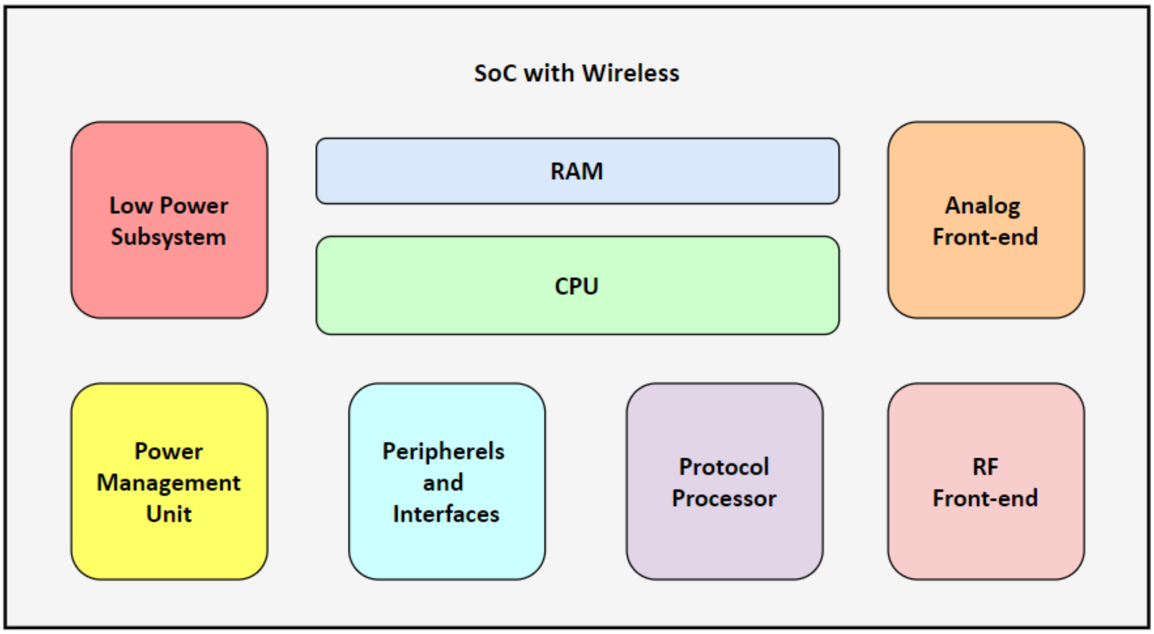
1 About

This document provides information about the different power save modes supported by RS9116 and the recommended modifications for an application. This Application Note also provides the power consumption details when RS9116 is in different operating states.

2 Device Architecture

The RS9116 chipsets have an internal power management subsystem that generates all the voltages required by the chipset to operate from a wide variety of input sources.

The top-level view of power domains of RS9116 is as below:



The Low Power Subsystem contains circuitry that operates and gives an extremely low current consumption. This includes a timer running off a 32 kHz clock and input pins monitored for activity enabling and sensing external inputs in Ultra-Low Power (ULP) mode.

When the device is put to its lowest power sleep state, only the Low Power Subsystem is active. When the wake-up event occurs, the ULP logic present in the Low Power Subsystem turns on the Power Management Unit (PMU) and/or external power switches and enables bringing the rest of the device into normal operation.

In regular operation, the device may still be able to turn on or off selective portions by itself based on the current profile used.

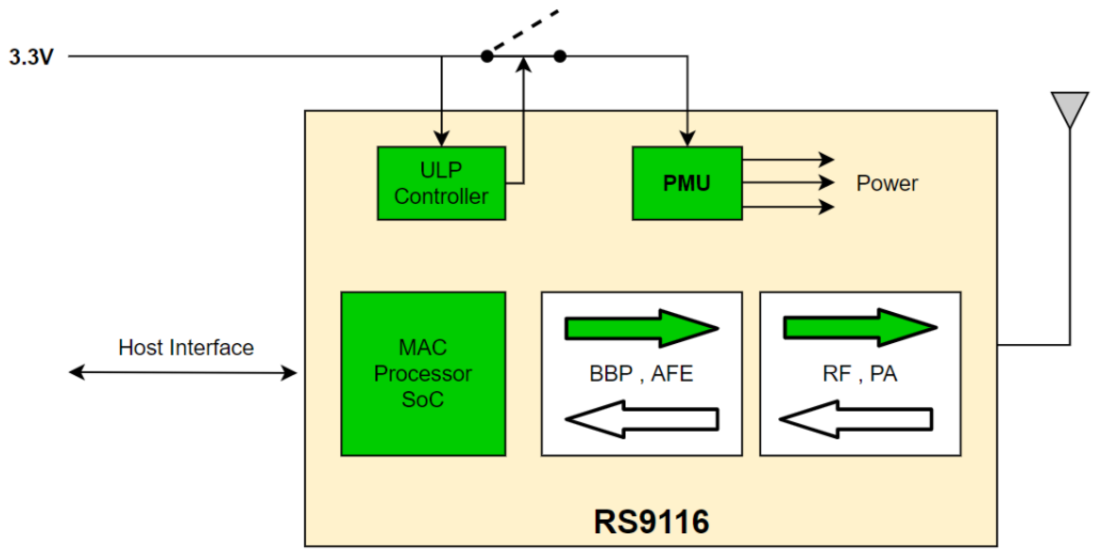
3 Operational Modes

In RS9116 modules, multiple operational modes consume different amounts of current. The RS9116 has three different operational modes.

3.1 Transmit Mode

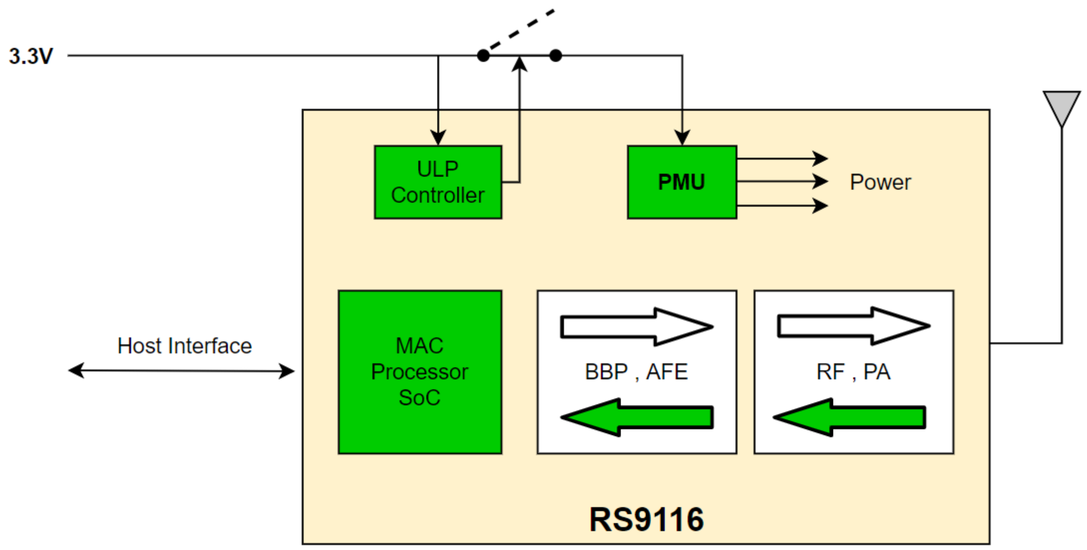
This is generally the highest power-consuming mode.

Transmit mode has all components of the module ON except the receiver section of the RF, AFE, and BBP.



3.2 Receive Mode

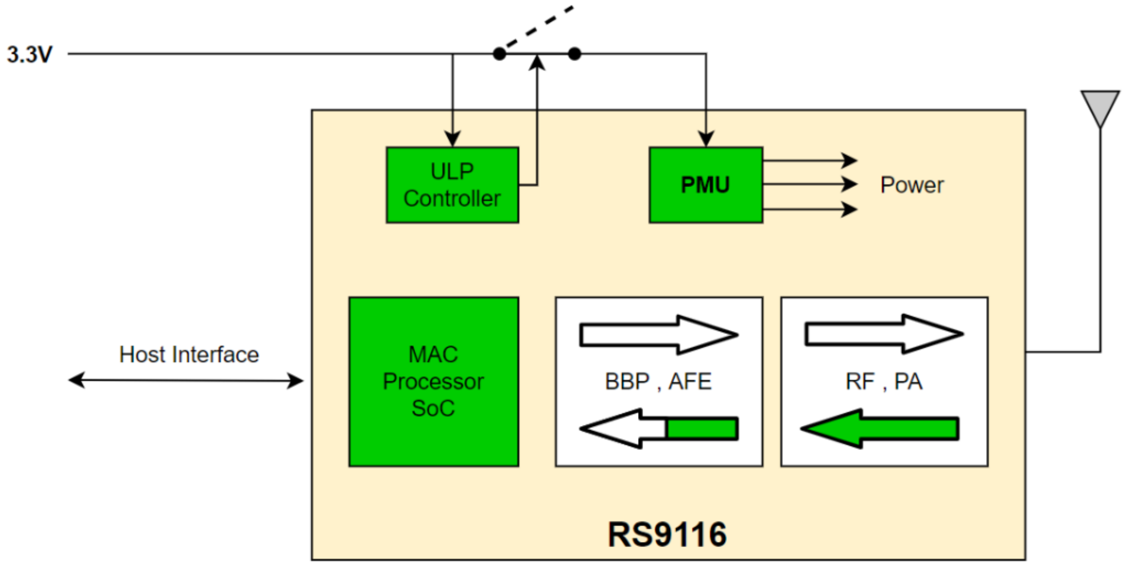
In Receive, the transmit sections of the BBP, AFE, and RF are not powered. In addition, the PA is also not powered.



3.3 Listen Mode

This mode is a subset of the Receive mode where certain portions of the receiver are turned off or are taken to lower power states because no packet is being actively received now.

Listen mode is a variant of the Receive mode where there is no active packet reception in progress. A portion of the AFE and BBP is kept OFF until the beginning of a packet is detected in the receiver.



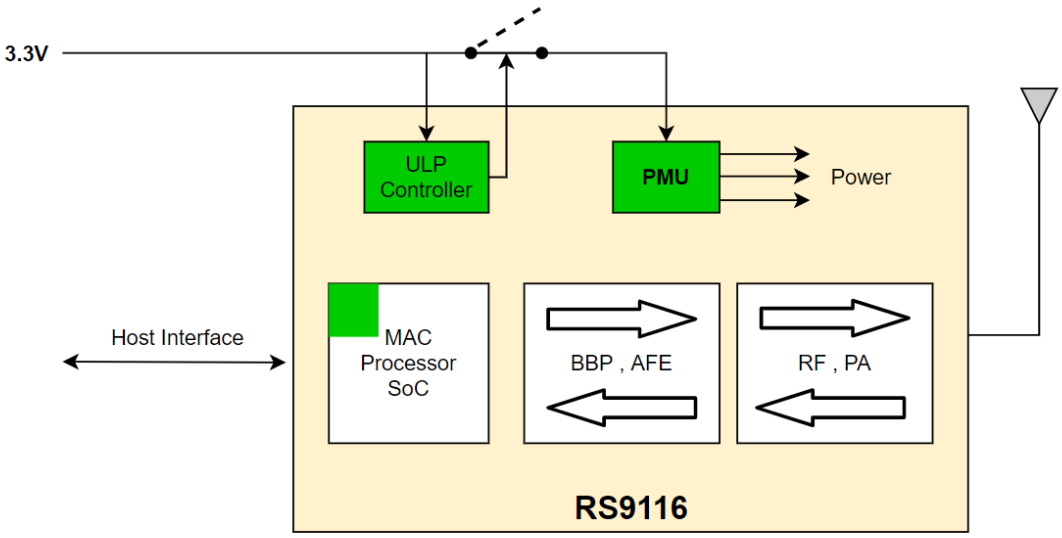
4 Basic Power Modes

RS9116 supports Low power and Ultra-Low power modes to reduce the system energy consumption. RS9116 has two basic power modes:

4.1 Low Power Mode

In this mode, the internal modem portions are turned off while the SoC is kept on, in a low power state. A Sleep State Machine in the SoC is active and responds to wake-up events. The host interface is active, and the device is ready to receive packets from the host. Network processor maintains system state and gates all internal high-frequency clocks.

In Low-Power sleep mode, the BBP, AFE, and RF are powered OFF. The SoC is kept in a low power mode.

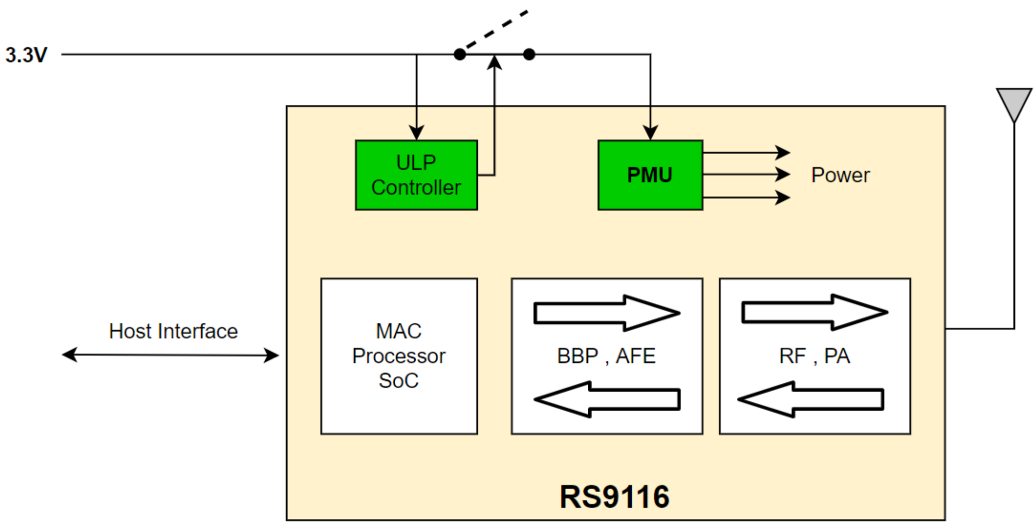


4.2 Ultra-Low Power Mode

In ULP mode, the entire device except the ULP sub-system is shut down. The host interface is not active in this mode. We can have two cases here:

a. With RAM Retention
b. Without RAM Retention

All portions of the module are OFF in Deep Sleep or Ultra-Low Power mode except the special ULP circuit.



- In power-save modes 2 and 3, only With RAM Retention is supported.
- In power-save modes 8 and 9, both With RAM Retention and Without RAM Retention are supported.

5 Handshake Signals

A Handshake signal means the method, which is used to wake up the module (RS9116) by the host.

There are two Handshake signals used in RS9116:

a. GPIO-Based
b. Message-Based

5.1 GPIO-Based

In this method, RS9116 and Host MCU uses GPIOs for wakeup/sleep indications.

In Ultra-Low Power(ULP) Mode

- UULP_VBAT_GPIO_2: Wake-up request from the host
- UULP_VBAT_GPIO_0/UULP_VBAT_GPIO_3: Wake-up indication from RS9116 (Any of these two GPIO's can be configured as the wake-up-indication GPIO pin).

In Low Power(LP) Mode

- ULP_GPIO_5: Wake-up request from the host
- UULP_VBAT_GPIO_0/UULP_VBAT_GPIO_3: Wake-up indication from RS9116 (Any of these two GPIO's can be configured as the wake-up-indication GPIO pin).

5.2 Message-Based

In cases where Host MCU has limited GPIOs available Message (MSG) based handshake can be used. RS9116 Module will indicate via a message.

- The module wakes up every DTIM or configured sleep time and sends a Wake-up message (WKP) to the host
- The host sends data/command to the module
- The module requests for going into sleep via a Sleep message (SLP)
- The host gives an acknowledgment (ACK) to the module to go into the sleep state
- The module does not go to sleep until it gets an ACK from the host
- The module cannot be woken up asynchronously

6 Power Save Modes in RS9116

The power save modes for RS9116 WiSeConnect can be classified into the connected sleep and deep sleep modes and differentiated based on the host's handshake signal. In connected sleep, the module enters the power-saving state and wakes up periodically for wireless activity. Deep sleep modes are applicable in un-connected states.

Power modes 1, 2, and 3 are variants of connected sleep, power modes 8 and 9 are variants of deep sleep. In power modes 2, 3, 8, and 9, the module can enter LP sleep or ULP sleep during the sleep period.

Classification of power modes:

Power Mode Value	Power Mode	Handshake with Host
1	Power Mode 1	No Handshake
2	Power Mode 2	GPIO Based Connected Sleep
3	Power Mode 3	Message-Based Connected Sleep
8	Power Mode 8	GPIO Based Deep Sleep(Unconnected sleep)
9	Power Mode 9	Message-Based Deep Sleep(Unconnected sleep)

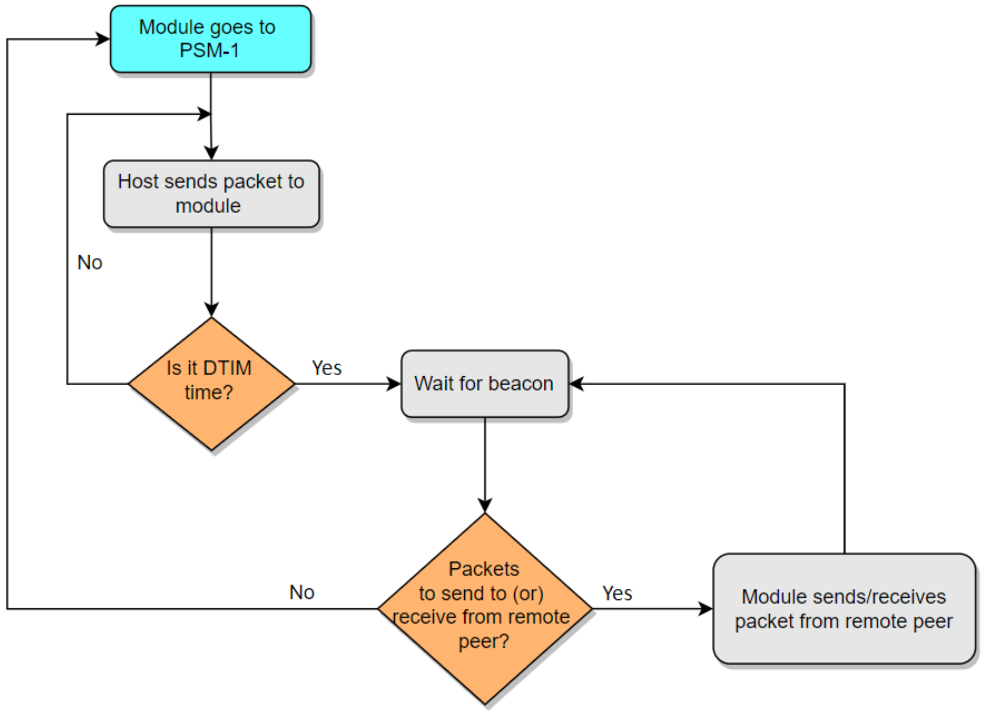
6.1 Power Mode 1

Once the module is configured in power save mode 1, it wakes up periodically based upon the DTIM interval configured in the connected AP. In power mode 1, only the RF part of the module is in power save while SoC continues to work normally. This command must be given only when the module is in the connected state (with the AP).

After configuring the module to power save mode 1, the host can issue subsequent commands. In power save mode 1, the module can receive data from the host at any point in time, but it can send/receive the data to/from the remote terminal (like a remote socket), only when it wakes up at DTIM interval.

The flow chart below shows the Power Save Mode 1 flow:

- The module gets connected to the Access Point and goes into power save mode 1.
- If the host has data, it will send it to the module. The module can receive data from the host at any point in time.
- The module will check if it is DTIM time, if not, it will continue to be in Power save mode 1. If it is DTIM time, the module waits for the beacon. Then it will check if there are packets to send or receive from the remote peer or terminal, if there are packets to send/ receive the module does the appropriate action and repeats this cycle until there are no more packets to send or receive.
- Later, it will go back to power save.



6.2 Power Mode 2

Power mode 2 uses GPIO based handshake. Once the module is configured in power save mode 2, it is woken up by the host using a GPIO-based handshake and it will periodically wake up during its sleep-wake-up cycle based upon the DTIM interval to send or receive data to/from remote-peer.

In ULP mode, feature_bit_map[4] must be set in opermode command. In this mode, when the host wants to send data to the module, it gives a wakeup request to the module by asserting ULP_GPIO_5 in the case of LP mode or UULP_GPIO_2 in case of ULP mode (which make the module wake up from power save). After wakeup, if the module is ready for data transfer, it sends a wakeup indication to the host by asserting the UULP_GPIO_3 or UULP_GPIO_0.

The host is required to wait until the module gives the wakeup indication, before sending any data to the module. After completion of data transfer, the host can give sleep permission to the module by de-asserting ULP_GPIO_5 in the case of LP mode or UULP_GPIO_2 in the case of ULP mode. After recognizing sleep permission from the host, the module confirms the host by de-asserting UULP_GPIO_3 or UULP_GPIO_0 and goes back to its sleep-wakeup cycle.

The module can send a received packet or response to the host at any point in time. No handshake is required on the receive path.

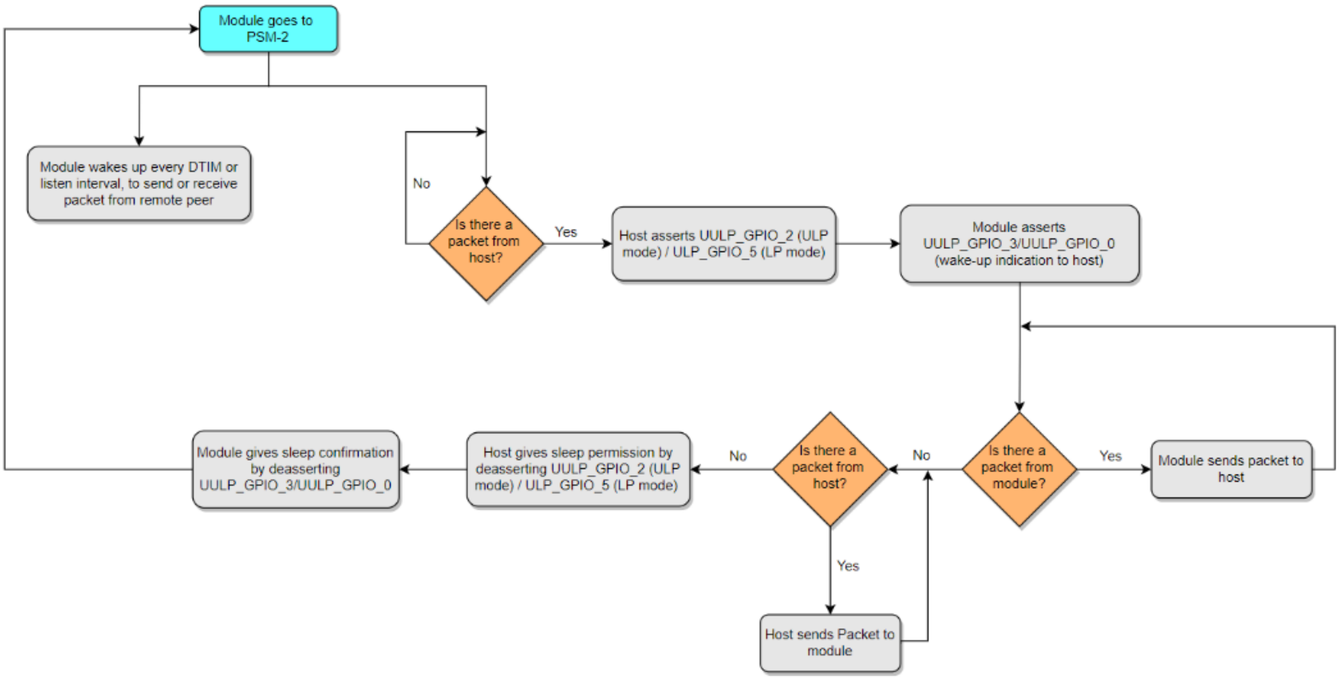
Note:

1. By default, UULP_GPIO_3 is used for wakeup indication to host.
2. If BIT(0) is set in config_feature_bit_map then UULP_GPIO_0 is used for wakeup indication to host.

The flowchart below shows the Power Save Mode 2 flow:

- The module goes to Power save mode 2, it will wake up periodically every DTIM or listen-interval, to send or receive data from the remote peer.
- If there is no packet from the host, the module will continue to stay in the sleep state.
- If there is a packet from the host, the host sends a wake-up request to the module by asserting the UULP_GPIO_2 in ULP mode and ULP_GPIO_5 in LP mode.
- The module responds by asserting the UULP_GPIO_3 or UULP_GPIO_0, thereby giving a wake-up indication to the host.
- The host checks if there is a packet from the module to be received, if it does, the module will send the packets to the host until there are no more packets to be sent to the host.
- If there is a packet from the host, it sends the packet to the module.
- If there are no packets to be sent from the host, it gives sleep permission to the module by de-asserting the UULP_GPIO_2 in ULP mode and ULP_GPIO_5 in LP mode.

- The module confirms that it's going to sleep by de-asserting the UULP_GPIO_3 or UULP_GPIO_0 and goes into power save.



6.3 Power Mode 3

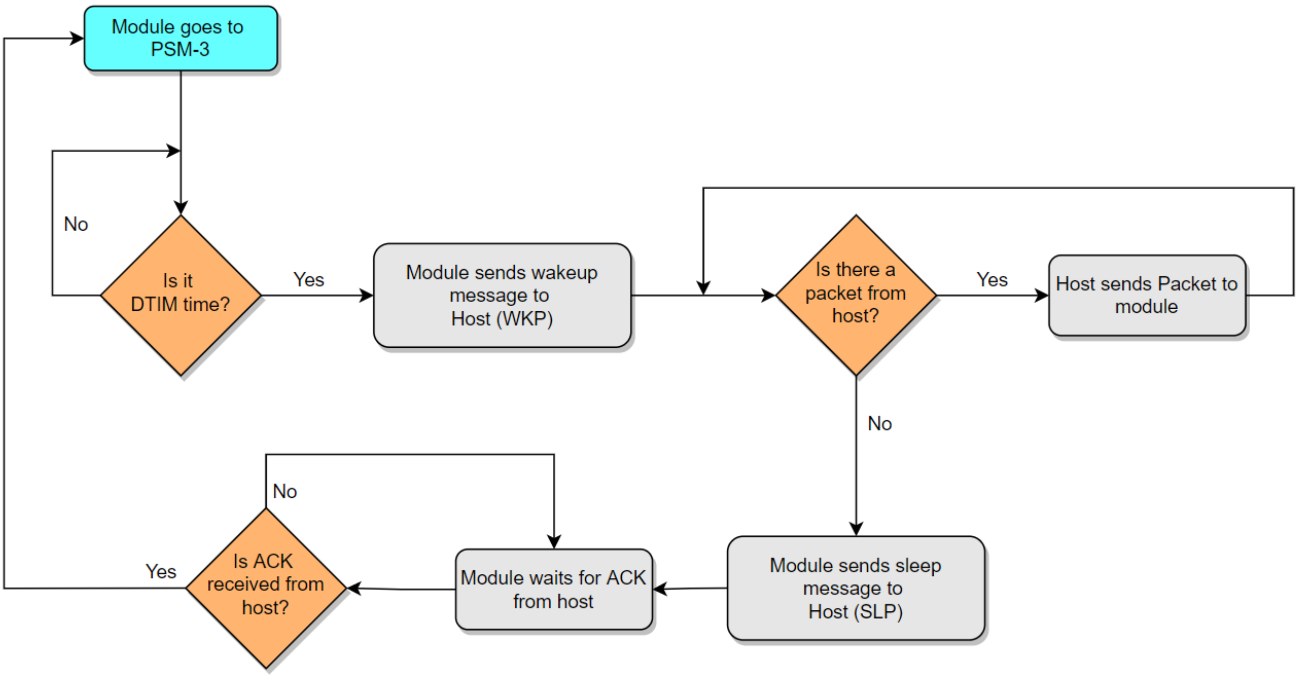
Power Mode 3 uses a Message-based handshake.

This mode is significant when the module is connected to AP. Module wakes up periodically every DTIM and gives a wakeup message ("WKP") to the host. The module cannot be woken up asynchronously. Every time module intends to go to sleep it sends a sleep request message ("SLP") to the host and expects the host to send the ACK message. Host either sends an acknowledgment message ("ACK") or any other pending message. But once ACK is sent, the host should not send any other message until the next wakeup message from the module is received.

The module will not go into the complete power save state if ACK is not received from the host for the sent sleep (SLP) message. The module can send a received packet or response to the host at any point in time. No handshake is required on the receive path.

The flow chart below shows the power save mode 3 flow:

- Module wakes up every DTIM in this case
- If it is not DTIM time, it continues to stay in power save state.
- When it is DTIM time, the module sends a wake-up (WKP) message to the host.
- If there is a packet from the host, it sends the packet to the module.
- When the host has no more packets to send, the module sends a sleep (SLP) message to the host and waits for an acknowledgment (ACK).
- When ACK is received from the host, the module goes to power save.



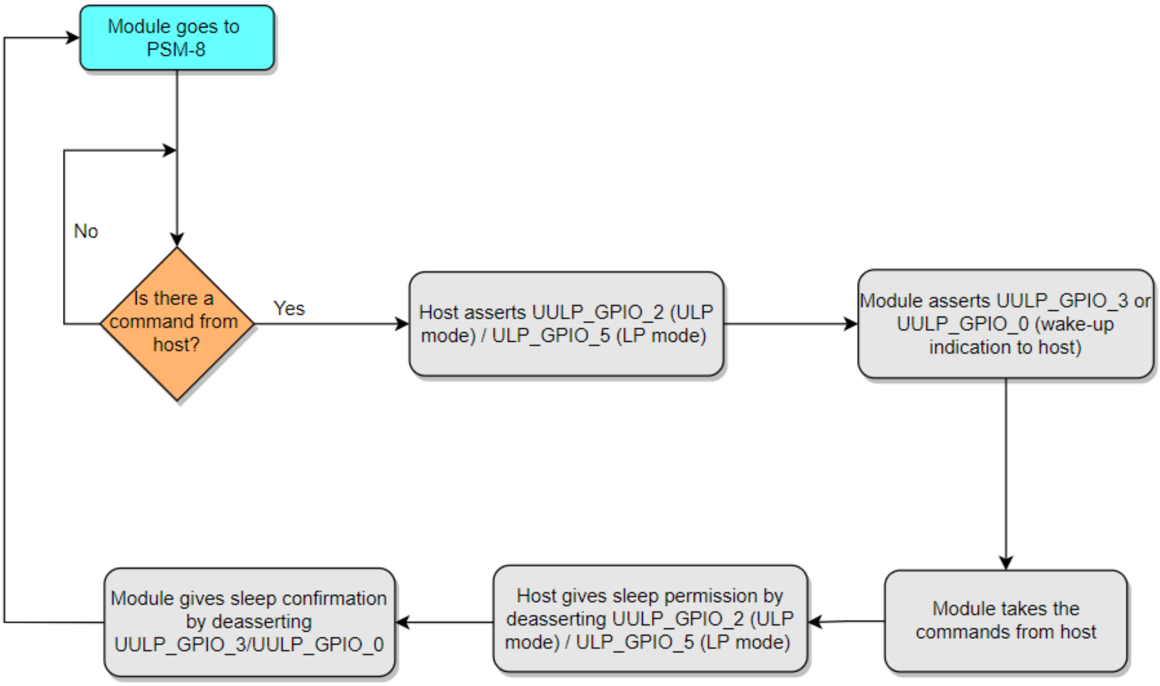
6.4 Power Mode 8

Power mode 8 uses GPIO based handshake. This command must be issued after the Init command. In Power Mode 8 both RF and SoC of RS9116-WiSeConnect are in complete power save mode. This mode is significant when the module is not connected with any AP.

In ULP mode, feature_bit_map[4] must be set in opermode command. In the case of LP mode (In power save command when ulp_mode_enable is '0') host can wake up the module from power save by asserting ULP_GPIO_5. In the case of ULP mode (In power save command when ulp_mode_enable is '1' or '2') host can wake up the module from power save by asserting UULP_GPIO_2.
When ulp_mode_enable is set to '0' (LP mode) or '1' (ULP mode -With RAM Retention), once the module gets a wake-up request from the host, it continues to be in the wake-up state until it gets power mode 8 command from the host.
When ulp_mode_enable is set to '2' (ULP mode - Without RAM Retention), after the module wakes up from sleep, the host needs to start giving commands from the beginning(opermode) as the module's state is not retained.

The flow chart below explains the power save mode 8 flow:

- The module goes to power save mode 8 and if there is no command from the host, the module continues to be in power save.
- If there is a command from the host, the host sends a wake-up request to the module by asserting the UULP_GPIO_2 in ULP mode and ULP_GPIO_5 in LP mode.
- The module responds by asserting the UULP_GPIO_3 or UULP_GPIO_0, thereby giving a wake-up indication to the host.
- The host sends commands to the module.
- And the module gives sleep confirmation to the host by de-asserting the UULP_GPIO_2 in ULP mode and ULP_GPIO_5 in LP mode.
- The module confirms that it's going to sleep by de-asserting the UULP_GPIO_3 or UULP_GPIO_0 and goes into power save.



6.5 Power Mode 9

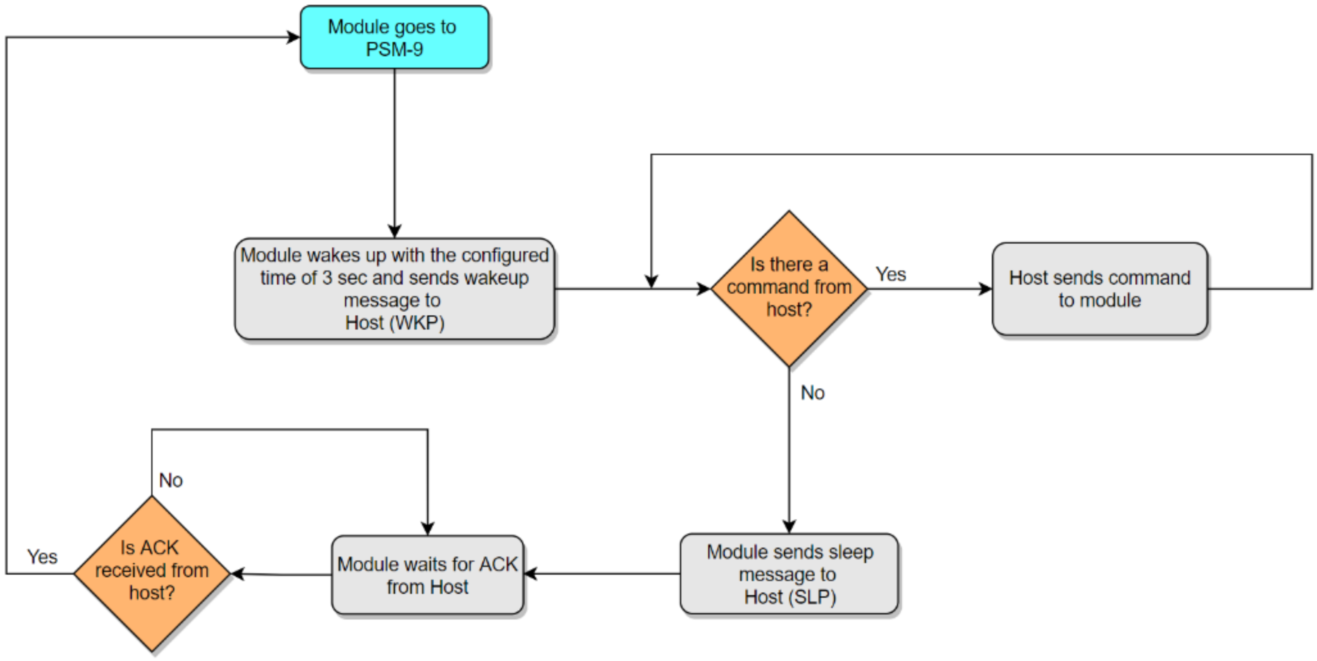
Power Mode 9 uses a Message-based handshake. In Power Mode 9 both the radio and SoC of RS9116-WiSeConnect are in complete power save mode. This mode is significant when the module is not connected with any AP.

Once the power mode 9 command is given to the module, it goes to sleep immediately and wakes up after sleep duration configured by the host using the sleep timer command. If the host does not set any time, then the module wakes up every 3 seconds by default (You can configure this time by using the sleep timer command). Upon wakeup, the module sends a wakeup message (WKP) to the host and expects the host to give an acknowledgment (ACK) before it goes into the next sleep cycle. Host either sends ACK or any other messages but once ACK is sent to the module, no other packet should be sent before receiving the next wakeup message from the module.

When ulp_mode_enable is set to '2' (Without RAM Retention), after waking up from sleep, the module sends the wakeup from sleep message (WKP FRM SLEEP) to the host. After receiving the message, the host needs to start giving commands from the beginning (opermode) as the module's state is not retained.

The flow chart below explains the power save mode 9 flow:

- Module wakes up with a default configured time of three seconds and sends a wake-up (WKP) message to the host.
- If there is a command from the host, it sends the command to the module.
- If the host does not have any more commands, the module sends a sleep (SLP) message to the host
- And the module waits for an acknowledgment (ACK) from the host.
- Once the module receives ACK from the host, it will go back to power save mode 9


Module goes to PSM-9
Module wakes up with the configured time of 3 sec and sends wakeup message to Host (WKP)
Is there a command from host?
Yes
Host sends command to module
No
Module sends sleep message to Host (SLP)
Module waits for ACK from Host
Is ACK received from host?
No
Yes

7 Power Save Profiles

RS9116 supports the following power save profiles and depending on the application these are used.

1. MAX Power Save Profile
2. FAST Power Save Profile
3. UAPSD Power Save Profile

Before getting into the power save profiles, let us understand the Power save polling procedure.

The following are the three building blocks of power save polling (PSP):

Wakeup Procedure - There are two reasons for a station (STA) to wake up:

1. Transmit pending data
2. Retrieve buffered data from an Access point (AP)

- Both waking up to transmit data and to receive data is also initiated by the STA, after it monitors its Partial Virtual Bitmap (PVB) bit in a periodic beacon frame sent out by the connected AP.
- Once the STA decides to transit from sleep to active mode, it notifies AP by sending a frame with Power Management (PWR MGT) bit set to Active.
- The STA remains active to enable, the AP to send the buffered frames.

Sleep Procedure

- An STA (in active mode) must complete an STA-initiated frame exchange sequence, with the PWR MGT bit set to Sleep – this is a successful transition to sleep.
- Following this operation, the AP buffers all the frames destined to this STA.

PS-Poll Procedure

- Instead of waiting for the AP to transmit the buffered frames, an STA (in sleep mode) can solicit an immediate delivery from its access point by using a PS-poll frame.
- Upon receiving this PS-poll, the AP can immediately send buffered frames (immediate data response); or it can send an acknowledgment message and response with a buffered data frame later (delayed data response).

DTIM or Listen interval-based:

- An STA can wake up based on the AP DTIM(Delivery Traffic Indication Map) or listen-interval(set on the STA side).
- When you want to save power from unnecessarily waking up every DTIM, you can go with listen-interval based.
- An AP transmits any multicast or broadcast data available every DTIM when a PSP station is associated with the AP. If not, it will send the multicast or broadcast data immediately.

7.1 MAX PSP

- You can opt for this profile when you want the device to be in maximum power save mode.
- Retrieval of data happens based on the PS poll.
- STA wakes up, listens based on the interval in Association request, and checks if data is buffered in AP for it.
- If data is buffered, it sends a PS poll and retrieves data, and this process continues until the last data frame from AP.
- In this case, the STA will be in power save most of the time.
- If you want to save more power and there is no requirement of multicast data, you will select listen interval-based power save.

Enhanced Max-PSP

This is a recent addition to the RS9116W.

- This is recommended PSP type. This essentially a MAX PSP mode but switches to Fast PSP mode if AP does not deliver data within 20ms for PS-Poll.
- To enable this mode please follow the below steps.
    1. Enable BIT(26) in CONFIG_FEATURE_BITMAP
    2. Set psp_type to 1 (Fast PSP)

7.2 FAST PSP

- When both throughput and power save are important for an application this power save profile is used.
- Whenever there is data buffered on AP, Rs9116 sends a Null/data frame with the PWR MGT bit set to 0 (STA will stay up for the monitor interval time set using the Monitor_interval in power save command) and receives the data buffered from AP.
- After successful retrieval of data, we go back to sleep mode.
- This helps in avoiding latency (total round-trip time it takes a data frame to travel), which is seen in MAX PSP.
- This way RS9116 can be in power save when there is no data and have good throughput when there is data to be transmitted or retrieved.

  Note: Currently we do not recommend using FAST PSP as there are some known issues. Please check Release notes.

7.3 UAPSD (WMM Power Save Mode)

The core technology used by Wi-Fi Multi-media (WMM) Power Save depends on enhancements to the 802.11 Media Access Control (MAC) layer.

WMM categorized Wi-Fi traffic into four different access categories:

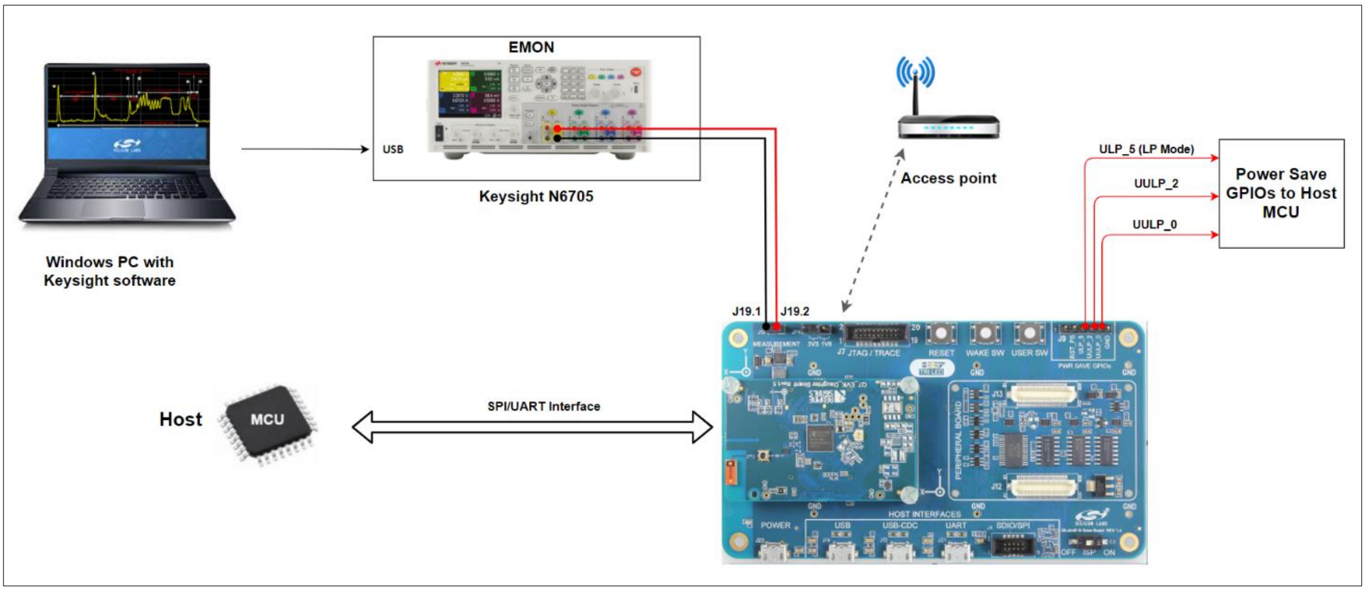
1. Voice
2. Video
3. Best Effort
4. Background

- WMM power save mode is the enhancement to the legacy power save mode.
- WMM Power Save was mainly designed for mobile and cordless phones that support VoIP.
- WMM Power Save promotes more efficient and flexible over-the-air transmission and power management by enabling individual applications to control capacity and latency requirements
- VOIP applications are extremely sensitive to delays.
- Increased Latency is the side effect of power save mode and WMM power save will address this.
- The application-based approach used in WMM Power Save enables individual applications to decide how often the client needs to communicate with the access point and how long it can remain in a dozing state.
- In legacy power save mode, it is based on listen-interval irrespective of active applications.
- Applications that do not initiate power save can still coexist with WMM Power Save enabled applications on the same device.
- In this case, data from the other applications will be delivered with legacy power save, while WMM Power Save applications will still enjoy their additional functionality as long as the access point also supports WMM Power Save.

For example, in a Wi-Fi network with WMM, voice receives priority over all other types of traffic, thus improving the performance of voice applications. WMM Power Save is based on Unscheduled Automatic Power Save Delivery (U-APSD)

8 Setup Diagram

The setup diagram for the current consumption of RS9116 measured by Keysight N6705B Power Analyzer is as below:



9 Power Save Mode Selection

You can choose the appropriate power save mode based on your application. For example, the following table has few cases mentioned when a particular power save mode must be chosen.

Power Save Mode	GPIO's Available for a Handshake	RS9116 Device is Always-on for Incoming Messages from the Host	RS9116 Wakes up and Receives Data from the Host in a Connected Sleep State	RS9116 Wakes up and Receives Commands from the Host in an Unconnected Sleep State
1	Not Applicable	YES	NO	NO
8	YES	NO	NO	YES
9	NO	NO	NO	YES
2	YES	NO	YES	NO
3	NO	NO	YES	NO

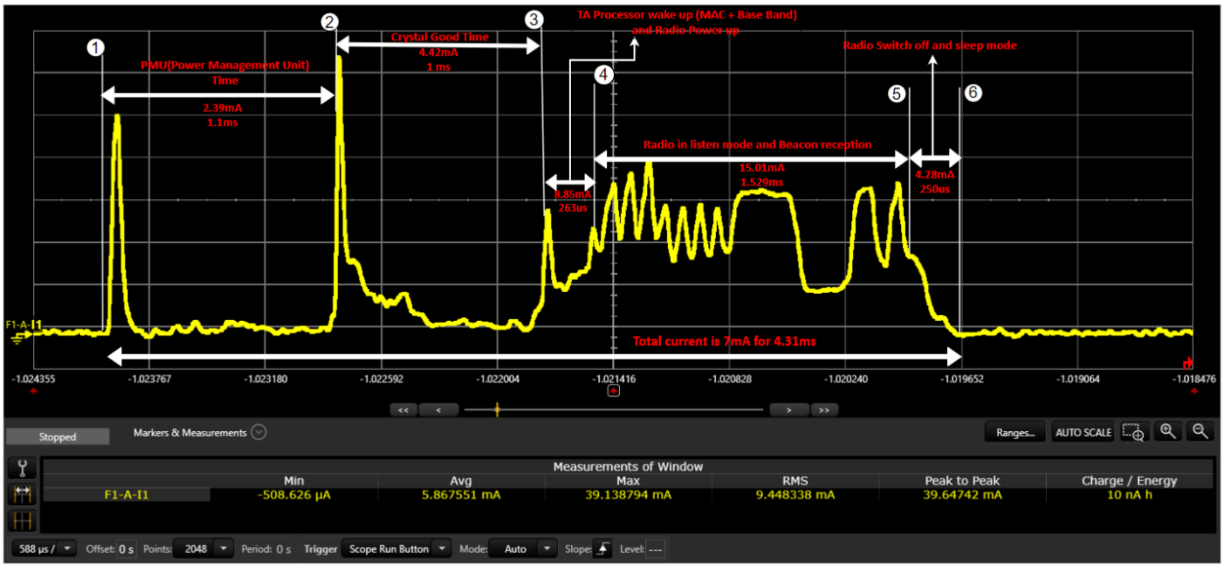
- When RS9116 is in a connected or unconnected sleep state, it can be woken up by the host using either GPIO or Message-based handshake.

10 Current Consumption

10.1 Beacon Current Profile

The following depicts the current consumption and time taken for different states in a single beacon.

S. No	State	Time Taken	Current Consumption
1	Power Management Unit (PMU) Time	1.1 ms	2.39 mA
2	Crystal good Time	1 ms	4.42 mA
3	TA Processor Wakeup (MAC + Base Band) and Radio Power up	263 µs	8.85 mA
4	Radio in listen mode and beacon reception	1.529 ms	15.01 mA
5	Radio Switch off and sleep mode	250 µs	4.28 mA



10.2 Network Processor Initialization

Below is the time-taken and current consumption during RS9116 initialization before accepting the first command.

RS9116 State	Current (Average Current)	Time Taken	Current (Average Current)	Time Taken
	3.3V - UART@115200 (Bootloader Bypass)		3.3V - SPI	
Device Power up to Card-Ready (During Firmware Loading)	18.9 mA	710 ms	18.9 mA	707 ms
After Firmware load completed (Before Opermode Command)	6.4 mA	NA	6.32 mA	NA

10.3 RS9116 States - Current Consumption

RS9116 Wi-Fi subsystem (Radio and Network processor) can be in the following atomic states

TX_ACTIVE - Active Transmission at a given on-air data rate e.g., 6 Mbps,54 Mbps, MCS-7, etc., and a given output power level (e.g., 8 dBm, 18 dBm)

RX_ACTIVE - Active Reception at a given on-air data rate

The below table shows the RS9116 in RX Active and TX Active states:

Parameter	Data Rate	Description	Value (QMS)	Value (CC1)	Units
RX Active	1 Mbps	LP Chain	22	NA	mA
RX Active	6 Mbps	HP Chain	36	115	mA
RX Active	72 Mbps	HP Chain	37	132	mA
TX Active	6 Mbps	Tx Power = Maximum (18 dBm)	208	339	mA
		Tx Power = 8 dBm	113	285	mA
TX Active	54 Mbps	Tx Power = Maximum (18 dBm)	149	274	mA
		Tx Power = 8 dBm	87	237	mA

10.4 Standby - Deep Sleep State

This mode can be implemented in multiple ways.

1. Power save mode 8: GPIO-based handshake
2. Power save mode 9: Message-based handshake

For GPIO Based, the **at+rsi_opermode** command is as follows:

at+rsi_opermode = 0,20,2147484806,2147483648,11010048,0,2147614728,0,0,1

Below are the current consumption values of RS9116 QMS (1.4 silicon version) with TP-Link Archer AX10 access point in an idle environment.

10.4.1 Without RAM Retention

Below are the AT mode command sequences for Power Save modes 8 and 9 along with the current consumption values.

Power Save Mode	Command Sequence	Current Consumption
8	at+rsi_opermode=0,20,2147484806,2147483648,11010048,0,2147614728,0,0,1 at+rsi_band=0 at+rsi_init at+rsi_pwmode=8,2	3.6 uA
9	at+rsi_opermode=0,4,4,2147483648,11534336,0,0,0,0,0 at+rsi_band=0 at+rsi_init at+rsi_pwmode=9,2	3.6 uA

10.4.2 With RAM Retention

Below are the AT mode command sequences for Power Save modes 8 and 9 along with the current consumption values

Power Save Mode	Command Sequence	Current Consumption
8	at+rsi_opermode=0,20,2147483652,2147483648,12058624,0,2147483648,0,0,1 at+rsi_band=0 at+rsi_init at+rsi_pwmode=8,1	11.6 uA
9	at+rsi_opermode=0,4,4,2147483648,11534336,0,0,0,0,0 at+rsi_band=0 at+rsi_init at+rsi_pwmode=9,1	12 uA

10.5 Standby Associated - Connected State

Wireless LAN (WLAN) protocol permits a client device to sleep during its idle periods. However, the client is expected to wake up periodically at intervals specified as DTIM or the listen-interval in the power save command mentioned in the application. During the period the client is asleep, the Access Point holds packets destined for them. These buffered packets are delivered to the clients when the clients wake up at DTIM, observes an indicator of traffic pending for it in the AP's beacon, and send a power-save poll message to request the AP to retrieve the buffered packets.

For DTIM 10 using TP-Link Archer AX 10 access point, the Standby Connected State current consumption values for power save mode 2 and 3 are as below:

Power Save Mode	Command Sequence	Current Consumption
2	at+rsi_opermode=0,20,2147483652,2147483648,12058624,0,2147483648,0,0,1 at+rsi_feat_frame=0,1,0,0,1,49 at+rsi_band=0 at+rsi_init at+rsi_scan=0,SILABS_AP at+rsi_psk=1,password at+rsi_join=SILABS_AP,0,2,2 at+rsi_ipconf=1 at+rsi_pwmode=2,1,0,0	56.8 uA
3	at+rsi_opermode=0,4,4,2147483648,11534336,0,0,0,0,0 at+rsi_feat_frame=0,1,0,0,1,49 at+rsi_band=0 at+rsi_init at+rsi_scan=0,SILABS_AP at+rsi_psk=1,password at+rsi_join=SILABS_AP,0,2,2 at+rsi_ipconf=1 at+rsi_pwmode=2,1,0,0 **Note:** Here Docklight is used, so there might be delay in sending ACK, so the current consumption might vary	198 uA

10.6 Current Consumption vs Listen Interval

The current consumption values for various power save modes with different listen intervals are mentioned in this section.

EVK: RS9116-SB-EVK1 Rev1.4 ; RS9116-DB-EVK1

Band: 2.4GHz, Channel - 1 ; 5GHz, Channel -36

Duration: 5 min Average

Router: Asus RT-AC1200G

Power Save Mode	Listen Interval (milliseconds)	Current Consumption (QMS)	Current Consumption (CC1)		Units
		2.4 GHz, Channel 1	2.4 GHz, Channel 1	5 GHz, Channel 36	
1	100	7.3	10.3	10.6	mA
	200	7.1	10.1	10.6	mA
	300	7	10	10.6	mA
	400	7	10	10.5	mA
	500	7	9.9	10.5	mA
	600	6.9	9.9	10.5	mA
	700	6.9	9.9	10.5	mA
	800	6.9	9.9	10.5	mA
	900	6.9	9.9	10.5	mA
	1000	6.9	9.9	10.5	mA
2	100	334.1	527.6	1.4	uA
	200	179.2	300.4	763.4	uA
	300	129.1	227.3	565.1	uA
	400	102.1	175.5	431.4	uA
	500	84.8	154.1	341	uA
	600	76.3	133.6	307.9	uA
	700	67.6	124.9	258	uA
	800	63.3	113.6	223.6	uA
	900	60.8	102.5	199.1	uA
	1000	56.3	101.3	184.1	uA
8 (With RAM Retention)	NA	11.9	9.7	9.5	uA
8 (Without RAM Retention)	NA	3.6	9.7	9.5	uA
9 (With RAM Retention)	NA	12.1	9.6	11.5	uA
9 (Without RAM Retention)	NA	3.6	9.6	11.5	uA

- You can configure the listen interval value using the **listen_interval** parameter in the power save command. The maximum listen interval in the power save command should be less than the listen interval configured in join command.

If you want to change the listen_interval dynamically, you need to disable power save and enable power save again with a new **listen_interval**.

Note:

- You can refer to *$: RS9116-release\examples\featured\powersave_standby_associated*, for power save application, which is used for the obtain the above-mentioned values.

  For related documentation and release refer https://docs.silabs.com/rs9116/.

11 Channel Utilization vs Current Consumption

Following are the current consumption values with various routers versus channel utilization.

EVK: RS9116-SB-EVK1 Rev1.4

Band: 2.4GHz, Channel - 1

Duration: 5 min Average

Power State: Standby associated mode with listen interval as 1 second

Application: TCP client sends application message from TCP Client to the server for every 55 seconds.

Test Environment: Ideal Environment (RF Chamber)

Router	**Model**	**Router Firmware Version**	**Current Consumption for 0% Channel Utilization**	**Current Consumption for 81% Channel Utilization**
TP-Link	AC1750	1.0.4 build 20180425	74.8uA	138.9uA
ASUS	RTAC68U	3.0.0.4.384	68.4uA	155.8uA
ASUS	AC1200	3.0.0.4.382_70222	71.7uA	128.5uA
D-Link	855	1.12	75.6uA	172.5uA
Tenda	AC1200 ac5	15.03.06.50_multi	74.3uA	134.8uA
D-link	882	1.01	72.5uA	130.3uA
MI	R3L		71.1uA	141.8uA
Netgear	R8000	1.0.3.46_1.1.32	88uA	166.4uA
Tenda	AC1200 ac6	v15.03.06.50_multi	74.05uA	132.5uA
D-link	810L	1.01	63.8uA	149uA

12 Wi-Fi Networking Power Consumption

12.1 Factors Affecting Power Consumption

- Type of router (make/model)
- Distance from the router
- Channel congestion
- Roundtrip time to a remote TCP server and TCP/TLS connection mechanism
- Type of power-save mechanism used
- One example of bulk data transfer “to” IoT devices is the OTA firmware upgrade. Similarly – an example of data transfer “from” IoT device is sensor-data captured by the device

The lowest “energy” consumption per kiloByte transferred is achieved by:

- Collecting the maximum amount of data possible and uploading it at one shot at full throughput.
- Downloading data at maximum throughput allowed by the link.
- Full throughput upload power consumption (maximum) occurs at the lowest on-air data rates.
- Full throughput download power consumption (maximum) occurs at the highest on-air data rates.

State	Current (mA)	Time (ms)	Voltage (V)	Charge (uC)	Energy (mJ)
Scan (Quick Scan)	56.59	6.02	3.3	340.67	1.12
WPA2 Association (Quick Join)	68.78	20.07	3.3	1380.41	4.56
DHCP	41.51	10.03	3.3	416.35	1.37
Throughput- TCP-TX (100Kbps)	1.67	1000	3.3	1670	5.51
Throughput- TCP-RX (100Kbps)	1.93	1000	3.3	1930	6.37
TCP & SSL/TLS Connection (Cipher - ECDHE-RSA-AES128-SHA)	9.23	426.00	3.3	3931.98	12.97553
TCP & SSL/TLS Connection (Cipher - AES128-SHA)	7.43	347.00	3.3	2578.21	8.50809
TCP & SSL/TLS Connection (Cipher - DHE-RSA-AES128-SHA)	9.16	1012.00	3.3	9269.92	30.59074

- Quick Scan - In this case, you will scan for a particular access point in a particular channel to avoid scanning all the channels and enable the BIT(0) in scan_feature_bitmap. This helps in reducing the time taken for scanning an AP.

Quick Join - In the Normal Join case, RS9116 will send a unicast probe request before join and get the response from the access point and will proceed further. Whereas, in Quick Join, RS9116 sends authentication and association without unicast probe request. To use the Quick Join feature, enable BIT(2) in join_feature_bit_map.

13 CO-EX (WLAN + BLE) Low Power Applications

In the case of CoEx mode, two APIs need to be called in SAPI.

For Wi-Fi, rsi_wlan_power_save_profile(PSP_MODE, PSP_TYPE) and for BT, rsi_bt_power_save_profile(PSP_MODE, PSP_TYPE)

Note: If the BLE is enabled in the opermode, there is no provision to disable BLE to make WLAN standalone.

14 Low Power and Interoperability Considerations

Based on the application different power profiles and modes are selected. We recommend the following to be considered for battery-operated devices to optimize battery life.

1. Select **Listen Interval** value that meets the application requirement and gives as much time as possible for the module to be in sleep. This is the interval at which the Module will wake up and check for data if any from Server/AP. **Note: If Listen interval-based power save is enabled, the DTIM period will not impact sleep_duration.** We highly recommend 1000 milliseconds listen interval value for low-power consumption.
2. After the rejoin/disconnection disable the power save and do the Scan, Join, Ipconfig and then enable power save again. This helps reducing connection time with some Access Points.
3. Recommended using connected power save only after Ipconfig command.
4. If the rejoin fails instead of scanning for the desired AP, it is recommended to do a couple of tries to scan the network and, if not found, put the module in deep sleep power save mode (e.g., power mode 8) and come back after some interval, disable power save and look for the desired AP.
5. We highly recommend using the Enhanced Max PSP type for Wi-Fi alone mode, which is recently added, where as for Co-ex mode it is recommended to use MAX PSP.
6. For applications where throughput is not a major concern, consider disabling higher data rates e.g., MCS5, MCS6, and MCS7. Enable config_feature_bit_map[19] in the opermode command.
7. Make smart use of WLAN Keep-Alive, TCP Keep-Alive, and MQTT Keep-Alive parameters to reduce the current consumption.
8. In case of DNS failures with few AP's, Aggregation is to be enabled using feature_bit_map[2] in the opermode command. Even enabling aggregation doesn't help in DNS success, we recommend disabling the power save during DNS query, and go back to power save mode again.
9. In Applications where the RS9116 module is kept in low power mode for a longer listen interval duration. If rejoin or disconnection happens with the longer listen interval, the listen interval value can be changed without disconnecting with the AP, for this enable join_feature_bitmap[7] in Join command parameters. To change the listen interval, disable the power save and re-enable the power save with the new listen interval.

If the application is not looking for any broadcast data, further power consumption can be reduced using the broadcast filter command.

15 Revision History

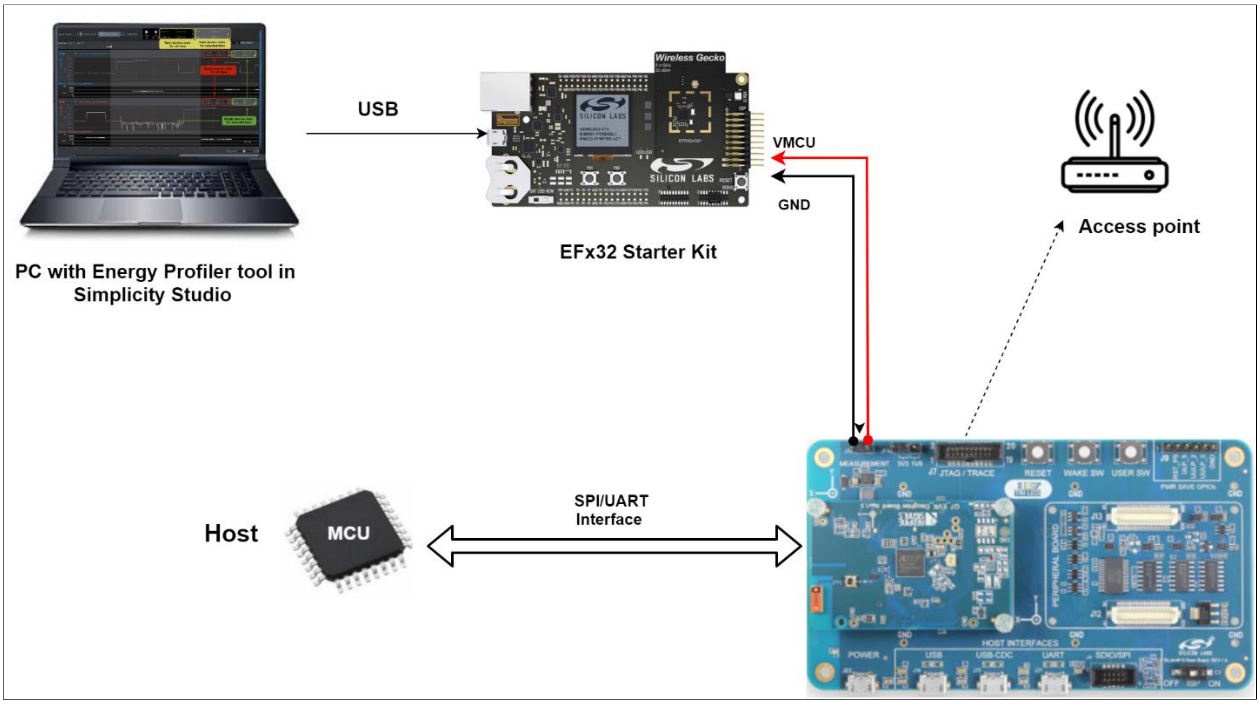
Revision No	Version No	Date	Changes
1	1.1	May 2020	Initial version
2	1.2	Oct 2020	• Updated the band image as per new TTL script info • Updated the new name of TTL script in the document • Updated the links and document names
3	1.3	Jan 2021	• Updated the Latest Current Measurements in the Expected Result table
4	1.4	Aug 2021	• Added details of Power Save Modes • Added latest Power Numbers • Edited/removed some sections • Added low power and interoperability considerations

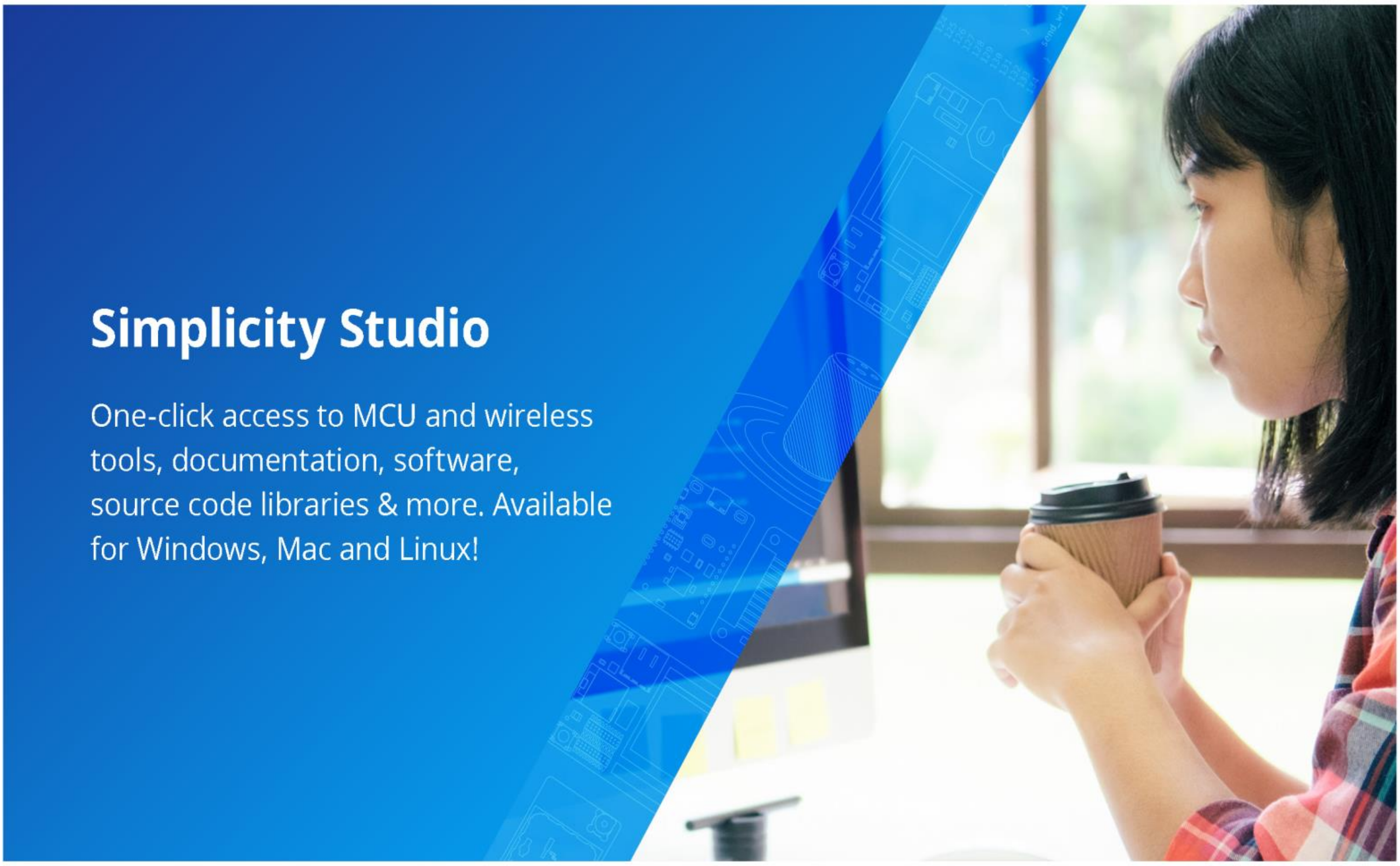
Appendix

EFM32 and EFR32 as Power Analyzers

We can use EFM32 (SLSSTK3701A) starter kit and EFR32 (SLWSTK6006A) starter kit for measuring the current consumption using the Energy Profiler tool in Simplicity Studio 5.

You can find more information at: https://www.silabs.com/community/mcu/32-bit/knowledge-base.entry.html/2014/05/21/using_aem_to_measure-BdWl and https://www.silabs.com/documents/public/user-guides/ug343-multinode-energy-profiler.pdf





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