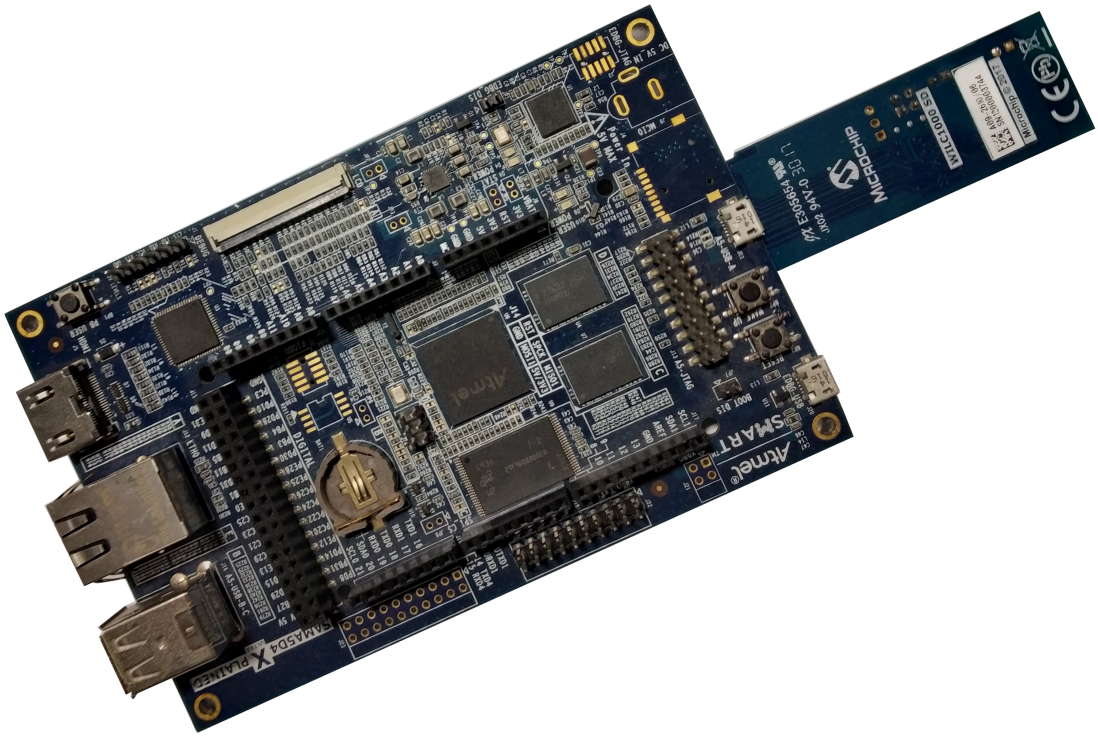
AN2797

ATWILC1000 Power Measurement for Wi-Fi® Link Controller Module

Introduction

This application note provides information about how to perform current measurement on the ATWILC1000 Wi-Fi module.

Figure 1. ATWILC1000 Wi-Fi Module



Prerequisites

The following are the hardware and software prerequisites to start with current measurement for the ATWILC1000 Wi-Fi module.

Hardware Prerequisites

- Supported Xplained Pro Evaluation kit
  Note: The SAMA5D4 Xplained Ultra is used for current measurement of the ATWILC1000 Wi-Fi module.
- ATWILC1000-SD Evaluation kit
- USB Micro cable (TypeA / MicroB)
- FDTI USB to Serial cable
- Oscilloscope or power debugger
- Digital multimeter

Software Prerequisites

- Linux® host machine
- Buildroot package
- Linux kernel image
- ATWILC1000 driver from GitHub
- Atmel Studio Data Visualizer tool
- SAM-BA v2.17 Flash downloader tool

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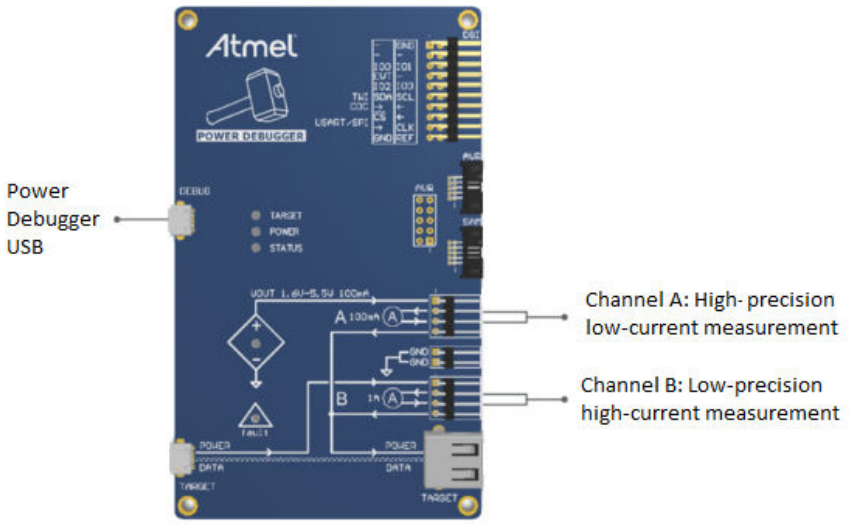
1. ATWILC1000 Power Measurement Setup

This chapter demonstrates the setting up of hardware for power measurement and how to interpret the measurements.

1.1 Hardware Setup

A Power Debugger with Data Visualizer tool is used to measure the timing and power consumption parameters of the ATWILC1000-SD Evaluation kit. Some of the current measurements can be performed using Digital Multimeter (DMM) if the current is constant during most of the measurement time. The following figure illustrates the power measurement setup used for measurement in this application note.

Figure 1-1. Power Debugger Setup



Perform the following to construct power measurement setup:

1. Connect the Channel B of Power Debugger to current measurement header pins (J102) on the ATWILC1000-SD Evaluation kit, using general purpose single wires.
2. Plug the ATWILC1000-SD Evaluation kit with the SAMA5D4 Xplained Pro board SD extension.
3. Load the SAMA5D4 Xplained Pro board with Linux kernel and cross compile the root file system for the SAMA5D4 ARM MPU.
4. After booting with kernel and root file system, copy the updated ATWILC1000 host driver modules in their respective location as mentioned in the ATWILC Linux User Guide.

The ATWILC1000 updated firmware image is part of the *Buildroot* kernel file system */lib/firmware*, and also available in the GitHub repository. For more information on SAMA5D4 Xplained Pro board and its supported kernels, refer to the ATWILC Linux User Guide.

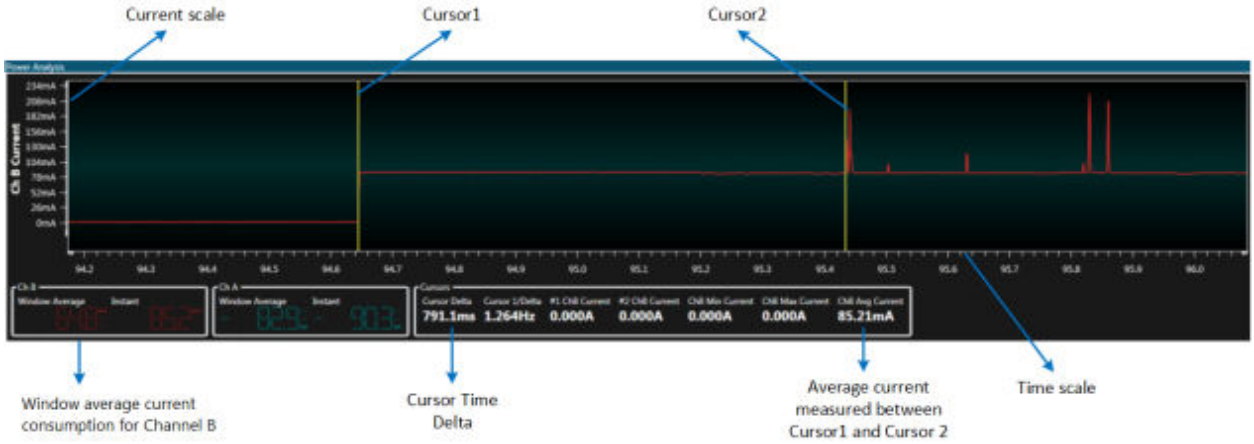
Note:

- WILC1000 Linux Driver version: 15.00
- WILC1000 Linux Firmware version: 15.00
- Linux kernel version: 4.9
- Voltage condition: 3.3V
- Temperature: 26°C

1.2 Interpreting the Measurements

The following figure explains how to interpret the measurements in the graph.

Figure 1-2. Interpreting the Measurements



2. ATWILC1000 Interfaces and Power Save Modes

The following table provides available ATWILC1000 interfaces and its supported Power Save modes.

Table 2-1. ATWILC1000 Interfaces and Power Save Modes

S. No.	ATWILC1000 Interfaces	Supported Power Save (PS) Modes	Default PS Mode
1	Station mode	Automatic PS mode and No PS mode	Automatic
2	SoftAP mode	No PS mode	No PS mode
3	P2P mode	No PS mode	No PS mode
4	Concurrent mode	No PS mode	No PS mode

3. ATWILC1000 WLAN Mode Setup for Power Profiling

The ATWILC1000 WLAN module current measurement process is performed using different virtual interfaces as mentioned in the ATWILC1000 Interfaces and Power Save Modes. The power consumption values are measured individually for all the WLAN interfaces.

The following section details the Station mode configuration on Linux driver for power profiling. For other modes, refer to ATWILC Linux User Guide.

3.1 Station Mode Setup

Perform the following steps to configure the ATWILC1000 module in Station mode.

1. Download the demo package which contains the Linux image and root file system with the available ATWILC devices kernel modules. The Linux kernel 4.9 and 4.12 demo images with root filesystem for host MPU SAMA5D4 target board are available in the GitHub.
   Note: Do not copy the modules separately, as the ATWILC1000 kernel modules are part of the root files system.
2. Use the SAMA5D4 SAM-BA Flash downloader tool to download the kernel image and root file system to the target board.
3. Flash the image in to the target board. For detailed information, refer the Updating Binary and System Image into the Target Board section in the ATWILC Linux User Guide.
4. After successfully programming the kernel image and root file system, load the kernel modules in to the root file system.
5. Initialize the host driver and register with the Secure Digital Input/Output (SDIO) kernel driver using the *wilc.ko* and *wilc-sdio.ko* driver modules. The module initializes the network driver and creates the *wlan0* network interface.
6. The *wlan0* network interface is used by the *wpa_supplicant* to initialize the ATWILC1000 WLAN module and download the firmware using the SDIO interface.
   After successfully downloading and initializing the firmware, the ATWILC1000 module is ready to receive the WLAN commands such as, scan, connect operations and so on, from *wpa_supplicant* through host driver API's.
7. Issue the commands to the ATWILC1000 WLAN module, using the Wpa_cli command interface application. For more information on the wpa_cli command details refer to ATWILC Linux User Guide.
8. Once the ATWILC1000 WLAN interface is connected with desired Access Point (AP), the user can measure the power consumption values for different scenarios.
   The Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) sample applications used in this application note are available in the GitHub link sample applications.

Note: For more information to compile the kernel and program the SAMA5D4 MPU, refer to the ATWILC Linux User Guide.

3.1.1 Power Save Mode

The ATWILC1000 firmware supports either only the automatic Power Save mode or no Power Save mode in different interface modes as mentioned in the ATWILC1000 Interfaces and Power Save Modes table. The receive and transmit current consumption is as per the values in datasheet for all the modes. The ATWILC1000 in Station mode supports the following Power Save modes.

1. Automatic Power Save Mode – When the device is connected to AP and obtains the IP address, the ATWILC1000 switches to automatic Power Save mode. In this mode, the device periodically wakes up to receive the beacon and broadcast packets based on the beacon interval and the device again goes back to sleep. By default, DTIM interval is 1 and beacon period is 100 ms.
2. Power Down Mode – The radio and digital core power is switched-off in this mode.
3. No PS Mode - In the Power Save mode, RF Receiver is always ON.

4. ATWILC1000 Power Profiling Scenarios

This chapter details different power profiling scenarios for the ATWILC1000. For more details on the summary of current and time measurements, see ATWILC1000 Current and Time Measurements.

4.1 SDIO Card and Kernel Module Initialization

Prerequisites:

- Boot the Linux kernel image successfully.
- Load the root files system in the target board (SAMA5D4).

This ensures that kernel detects the ATWILC1000-SD Evaluation kit and initializes the same.

Perform the following steps to initialize the SDIO card and kernel module.

1. Insert the ATWILC1000-SD Evaluation kit after kernel boot-up or insert the card before board boot-up. The current consumption for SDIO card initialization and loading kernel modules (*wilc.ko* and *wilc-sdio.ko*) is the same.
   Note: In this case, the current consumption only pertains to the digital interface power consumption.
2. Load the ATWILC1000 kernel modules, using the following commands:

```
# insmod wilc.ko
# insmod wilc-sdio.ko
(or)
# modprobe wilc.ko
# modprobe wilc-sdio.ko
```

When the modules are loaded successfully, the ATWILC1000 host driver initializes the network driver and creates the WLAN interfaces “wlan0” and “p2p0”.

In this scenario, no Power Save mode is applied, and only standard current is consumed for SD card initialization and maintains the same current until the firmware download in the ATWILC1000 WLAN module is complete.

The current consumption for SDIO card and kernel module initialization is 31.81 mA.

Figure 4-1. SDIO Card and Kernel Module Insertion and Initialization

4.2 Wpa_supplicant Initialization and Scan Operation

The interfaces “wlan0” and “p2p0” are used to initialize the wpa_supplicant and to download the firmware in to the ATWILC1000 module.

- Load the Wpa_supplicant, using the following commands:

```
# wpa_supplicant -i wlan0 -D nl80211 -c /etc/wpa_supplicant.conf -B &
```

When the firmware is loaded successfully and starts to respond for the wpa_supplicant commands, the ATWILC1000 WLAN module switches ON the 2.4 GHz WLAN radio and receives the scan commands from wpa_supplicant. The Wpa_supplicant performs the periodic scan operation and gets the scan results in periodic intervals of five seconds until it receives the connect commands.

The user can also start the scan operation by using wpa_cli application commands.

An average current consumption for five scan operation is 22.41 mA

Figure 4-2. Average Power Consumption for Scan Operation

Single scan operation completes in around 1240 ms. In this operation, the ATWILC1000 module sends the probe-request in all the channels and waits for the probe-response from the near by Access Points (AP).

Note: The switching and waiting time for each channel is pre-defined in the firmware.

An average current consumption for single scan operation is 93.83 mA.

Figure 4-3. Power Consumption for Single Scan Operation

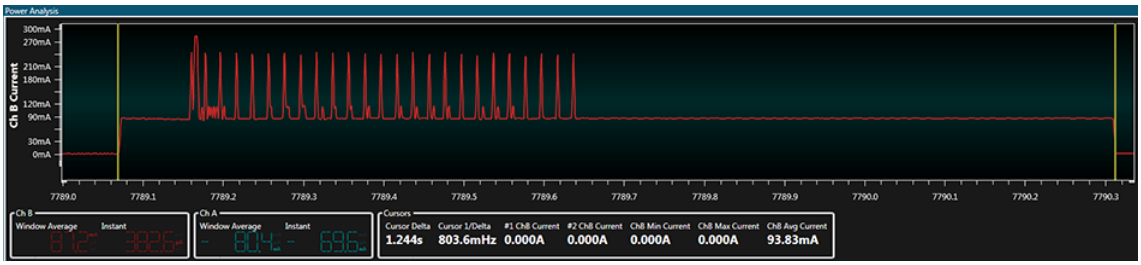


Figure 4-4. Idle Time Between Scan Operation

Between the periodic scan, the WLAN module switches to sleep for five seconds and starts another scan operation.

The current consumption of idle time between scan operation is 327.2 uA.

4.3 Connection Time Power Profile

After successful completion of wpa_supplicant and firmware download, initiate the association with the required AP using the “wpa_cli” commands. For more information on commands, refer the ATWILC Linux User Guide.

The following are the AP association commands:

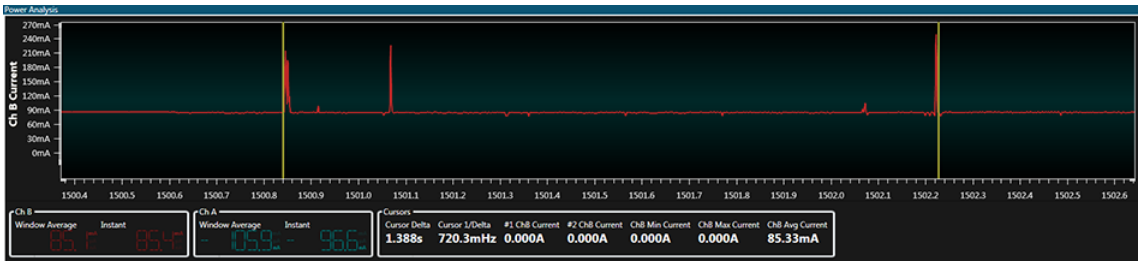
```
wpa_cli -p/var/run/wpa_supplicant ap_scan 1
wpa_cli -p/var/run/wpa_supplicant add_network
wpa_cli -p/var/run/wpa_supplicant set_network 0 ssid '"WSG_TPLINK"'
wpa_cli -p/var/run/wpa_supplicant set_network 0 key_mgmt WPA-PSK
wpa_cli -p/var/run/wpa_supplicant set_network 0 psk '"12345678"'
wpa_cli -p/var/run/wpa_supplicant select_network 0
```

Figure 4-5. Analog RF Initialization Before Initiating the Association

When the user initiates the connection with AP, the radio is ON for around 800 ms initializing the firmware and the analog RF initialization sequence, and initiates the specific scan operation to complete the association sequence.

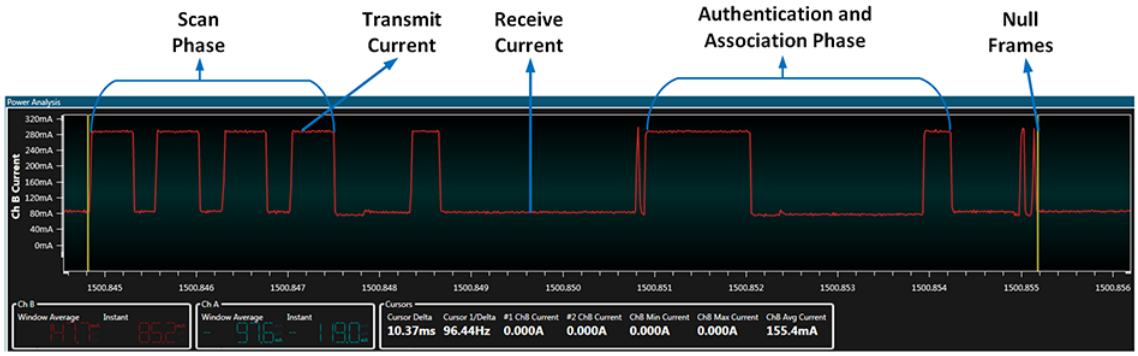
The total time to complete association including the open connection to WPA key handshake is 1.4 seconds.

Figure 4-6. Complete Association Sequence



The average power consumption for complete association is 85.33 mA.

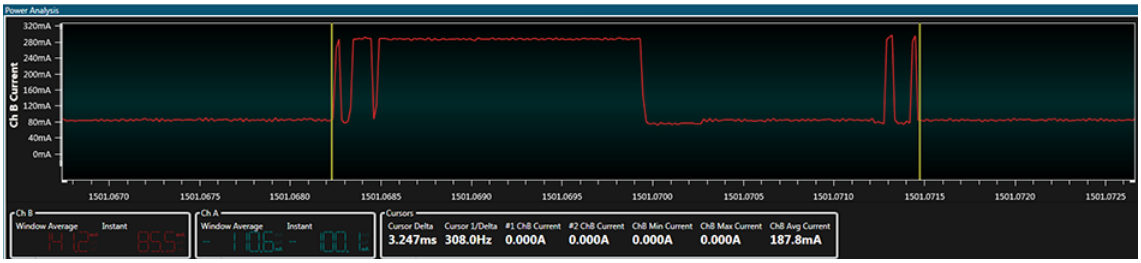
Figure 4-7. Detailed Association in Open Connection Sequence



The association process initiates scanning for desired AP and processes with authentication and association frames.

The current consumption for association is 155.4 mA.

Figure 4-8. 4-Way WPA Key Handshake



The ATWILC1000 is connected with AP in open authentication and followed by the 4-way key handshake to complete the connection with desired AP.

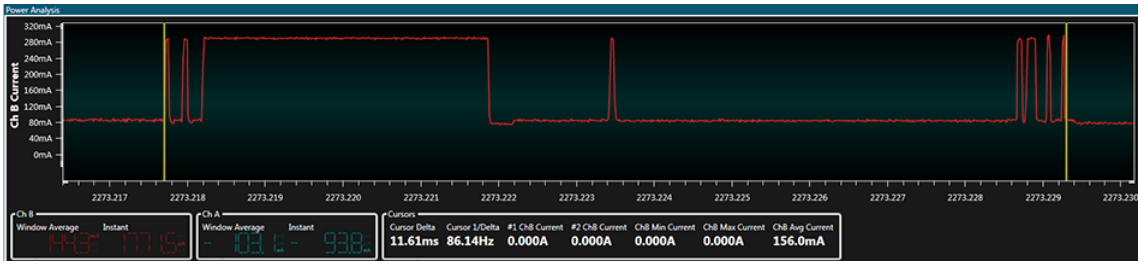
The current consumption for 4-way key handshake is 187 mA.

When the ATWILC1000 WLAN module completes the connection with desired AP, the user can run the DHCP client with interface “wlan0”. Run the DHCP client, using the following command:

```
dhcpcd wlan0 &
```

This Linux application initiates the DHCP communication with the DHCP server in the network and obtains the IP address for “wlan0” interface of the ATWILC1000.

Figure 4-9. DHCP Obtain IP Address



The current consumption for the DHCP operation is 156 mA.

4.4 Automatic Sleep Mode

Based on the AP configurations such as, DTIM period and beacon interval, the device periodically wakes up from sleep to receive the beacons. When the DTIM period is set as 1, and beacon interval as 100, the device wakes up for every 100 ms. If DTIM period is ‘n’and beacon interval is 100, the device wakes up for every 300 ms to receive the multicast frames. Irrespective of the DTIM period the device wakes-up thrice the beacon interval to receive the multicast frames. The automatic Sleep mode scenarios are as follows:

- Automatic Power Save mode.
- When the DTIM period is 1, and the data is not received or transmitted (Idle Connect).
- When the DTIM period is 3, and the data is not received or transmitted (Idle Connect).
- When the ATWILC1000 is in periodically Awake or Sleep mode.

4.4.1 Automatic Power Save Mode

The power debugger is used to measure current consumption across the ATWILC1000 current measurement jumper. In this mode, the ATWILC1000 is connected to the access point. This is the lowest Power Save mode in ATWILC1000.

Connect the access point and obtain the IP address using DHCP client. The ATWILC1000 automatically switches to sleep and periodically wakes up to receive the beacon.

In this mode, the ATWILC1000 also wakes up to receive the broadcast and multicast packets, periodically based on the beacon interval and Delivery Traffic Indication Message (DTIM) period.

It also wakes up and sends the NULL packet frame for every second. The wake-up period of the ATWILC1000 varies based on the beacon receive, broadcast and multicast packets receive.

To measure the Power Down mode, using fly wire, set the chip enable and reset pins to low or connect to ground.

Figure 4-10. Automatic Power Save Mode

The average current consumption in the automatic Power Save mode is 377.2 uA.

4.4.2 DTIM Period 1 and No Data Received or Transmitted

The ATWILC1000 switches to automatic Sleep mode after successful completion of AP connection and is followed by the DHCP operation.

In this case, the ATWILC1000 wakes up for every DTIM period to receive the broadcast and unicast packets. In Linux, driver does not have options to control the broadcast or multicast packet receive. The ATWILC1000 firmware wakes up based on the beacon interval and DTIM period. Sometimes, the ATWILC1000 is awake for longer duration depending on the broadcast or multicast packet receive.

The following screen shot shows the sequence periodic awake and NULL packet transfer.

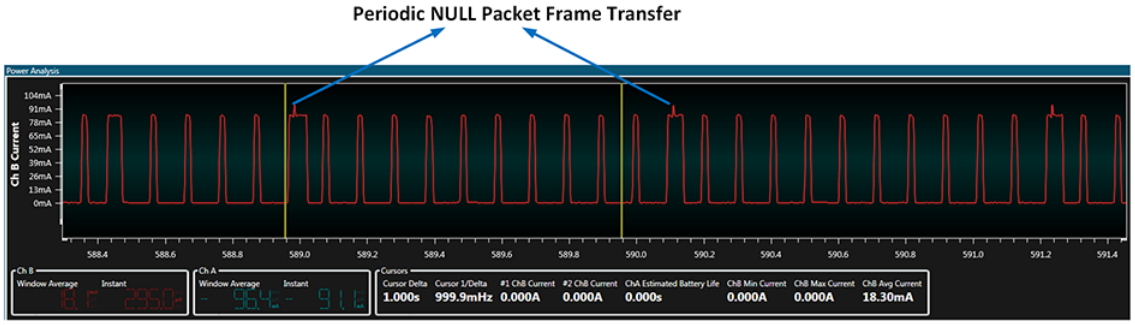
Figure 4-11. Automatic Power Save Mode Sequence

The average power consumption for five seconds is 19.96 mA.

The ATWILC1000 WLAN module wakes up for every three times of beacon interval to receive the muticast packets irrespective of the DTIM period. To receive unicast packets it wakes up for every DTIM period.

For every periodic interval, the ATWILC1000 sends the NULL packets to maintain the connection between the AP.

Figure 4-12. ATWILC1000 Waking Up Every Beacon Interval



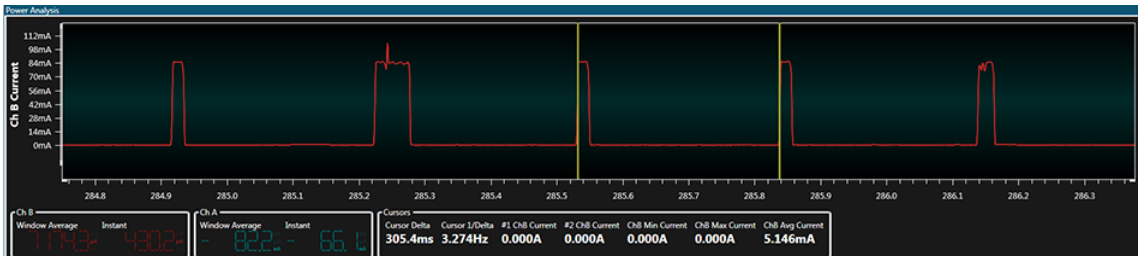
An average current consumption for one second is 18.30 mA.

4.4.3 DTIM Period 3 and No Data Received or Transmitted

When the DTIM period is set as three and beacon interval is 100 ms, the ATWILC1000 wakes up to receive the beacon and broadcasts the packets for every 300 ms. This multiplication of DTIM period and beacon interval.

Even if the DTIM period is thrice of beacon interval, the ATWILC1000 is awake to receive the multicast packets.

Figure 4-13. ATWILC1000 is Awake During DTIM Period 3

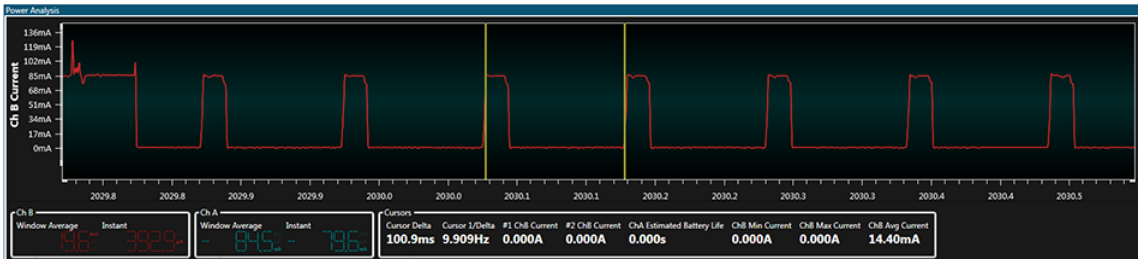


4.4.4 ATWILC1000 in Periodic Awake and Sleep Mode

After connecting with the desired AP, the ATWILC1000 switches to Sleep mode and wakes up for every DTIM interval to receive the beacon frame. The ATWILC1000 receives the beacon and sends the NULL frame with the Power Management bit set in the Frame Check Sequence (FCS). This is called Idle Connection state of the ATWILC1000 firmware. In this scenario, the ATWILC1000 firmware is idle, when there is no data communication. If there is any data communication, ATWILC1000 wakes up until the communication is complete.

The DTIM period and beacon interval is as per the AP configuration. By default, DTIM period is one and beacon interval is 100 ms. The ATWILC1000 firmware supports auto data rate of 802.11 b/g/n.

Figure 4-14. ATWILC1000 Periodic Awake and Sleep



One full cycle of wake-up and sleep period is equal to beacon interval 100 ms when DTIM period is one to receive beacons.

The ATWILC1000 is awake for 18 ms to receive the beacon period.

Figure 4-15. ATWILC1000 Awake to Listen Beacon

4.5 Power Down Mode

A digital multimeter is used to measure the current consumption across the ATWILC1000 current measurement jumper.

In this mode, the ATWILC1000 is not connected to the access point. This is lowest power mode the ATWILC1000 can operate. The ATWILC1000 chip enable (CHIP_EN) and reset (RESETN) pins are disabled in this mode.

To measure the Power Down mode, set the chip enable and reset pins to low. This can be performed by connecting the CHIP_EN and RESETN pins to GND through loose wires or by controlling CHIP_EN and RESETN from the host MCU/MPU GPIO pins.

An average current consumption is 1.25 uA. When the module goes to Power Down mode, the ATWILC1000 re-initializes including the firmware download sequence.

5. Summary of Measurements

The following table provides the summary of ATWILC1000 current and time measurements.

Table 5-1. ATWILC1000 Current and Time Measurements

ATWILC1000 Mode	Average Current (mA)	Time (milliseconds)
Connection to AP current from wake up	85.33	1400
Open association with AP	155	10.3
4-way Key Handshake	187	3.3
DHCP IP Obtain	156	11.6
Analog RF initialization before association	85.21	791
Average automatic Sleep mode for five seconds	19.96	5000
Sleep between beacons (Idle connect, assuming 100 ms beacon interval)	14.4	100
Awake	82	18.36
Automatic Power Save Mode	0.377	85
Power down current	0.00125	Continuous

6. Appendix

6.1 Beacon Interval

The beacon transmissions announce the presence of an 802.11 network at regular intervals. Beacon frames carry information about Basic Service Set (BSS) parameters and the frames buffered by the access points, so mobile stations must listen to beacons [(2)].

6.2 DTIM

The broadcast or multicast frames are buffered by the access point until the DTIM period, which is multiple of beacon interval and delivered at the DTIM period. If Stations intend to receive Broadcast or Multicast frames they need to be awake at DTIM interval [(2)].

6.3 Listen Interval

The listen interval is the number of beacon intervals that the stations wait during listening the beacon frames. The listen interval is registered when the station is associated with the access point. This allows the access point to buffer frames for the station when it is dozing [(2)].

6.4 Null Frame

In 802.11 networks, null frames do not carry any data. They are used by stations to indicate the access point about any changes in the Power mode of station. The access points buffer the data when the station indicates that it is about to sleep. The stations use the Power Management bit in the frame control field to report the Power state to the access point[(2)].

6.5 Probe Request and Response Frame

The stations use probe request frames to scan an area for 802.11 networks. The access points with compatible parameters respond to the probe requests sent by the station with a probe response[(2)].

Note:

1. ATWILC Devices Linux User Guide
2. 802.11 Wireless Networks the Definitive Guide Second Edition

7. Document Revision History

Rev A - 10/2018

Section	Changes
Document	Initial release

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