AN2479

Power Measurement on WINC1500 Wi-Fi® Module

INTRODUCTION

This application note provides useful information to perform current measurements on the WINC1500 Wi-Fi® module.

PREREQUISITE

Hardware Prerequisites:

- Supported Xplained Pro Evaluation Kit
- WINC1500 extension
- USB Micro Cable (TypeA/MicroB)
- Oscilloscope
- Differential probe
- Digital Multimeter

Software Prerequisites:

- Atmel Studio 7.0 with latest ASF
- Firmware update project

WINC1500 POWER MEASUREMENT SETUP

Hardware Setup

A differential probe has been used to measure different timing and power parameters of WINC1500. Figure 1 outlines the setup used for the purpose of this document. Some of the current measurements can be done over DMM if the current remains constant during most of the measurement time.

FIGURE 1: EXAMPLE DIFFERENTIAL PROBE SETUP TO MEASURE VARIOUS PARAMETERS ON THE WINC1500

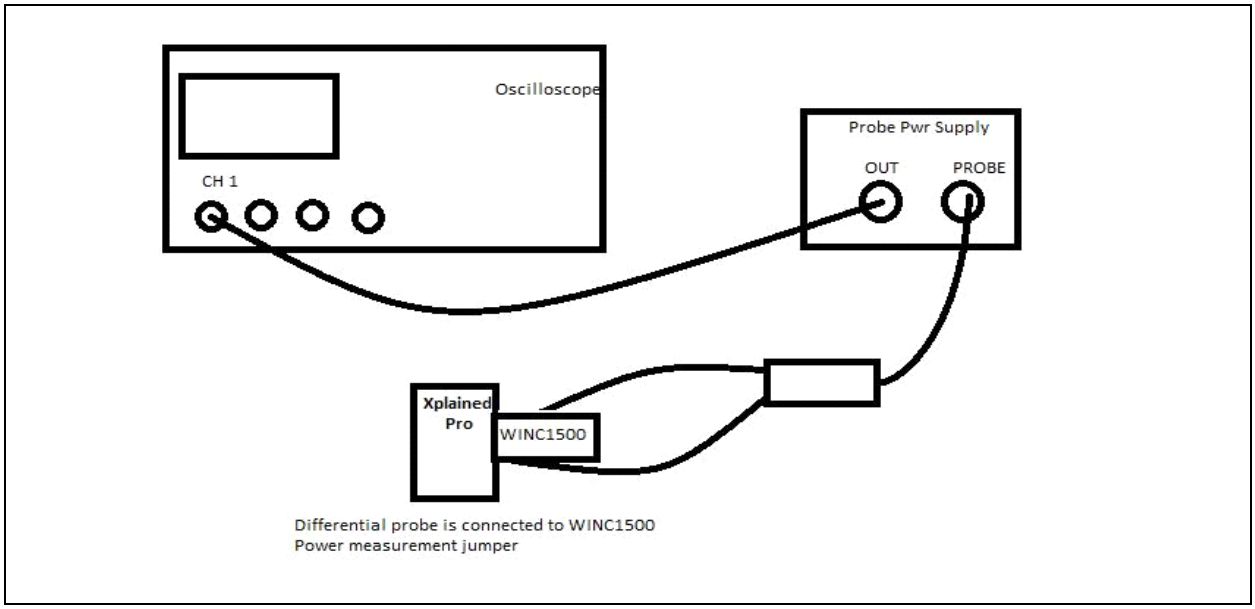
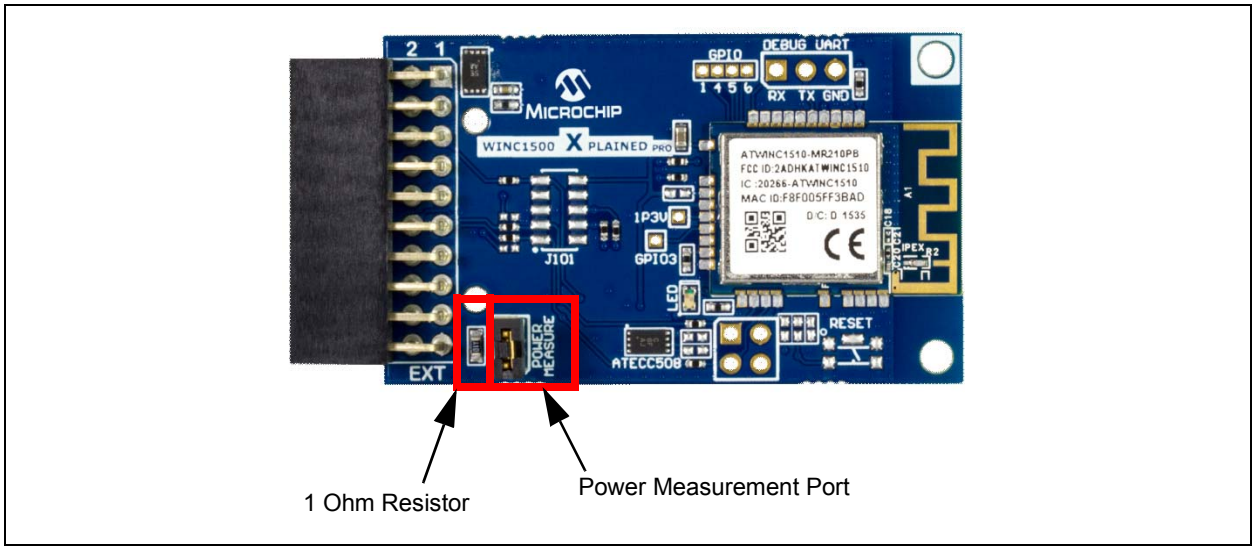


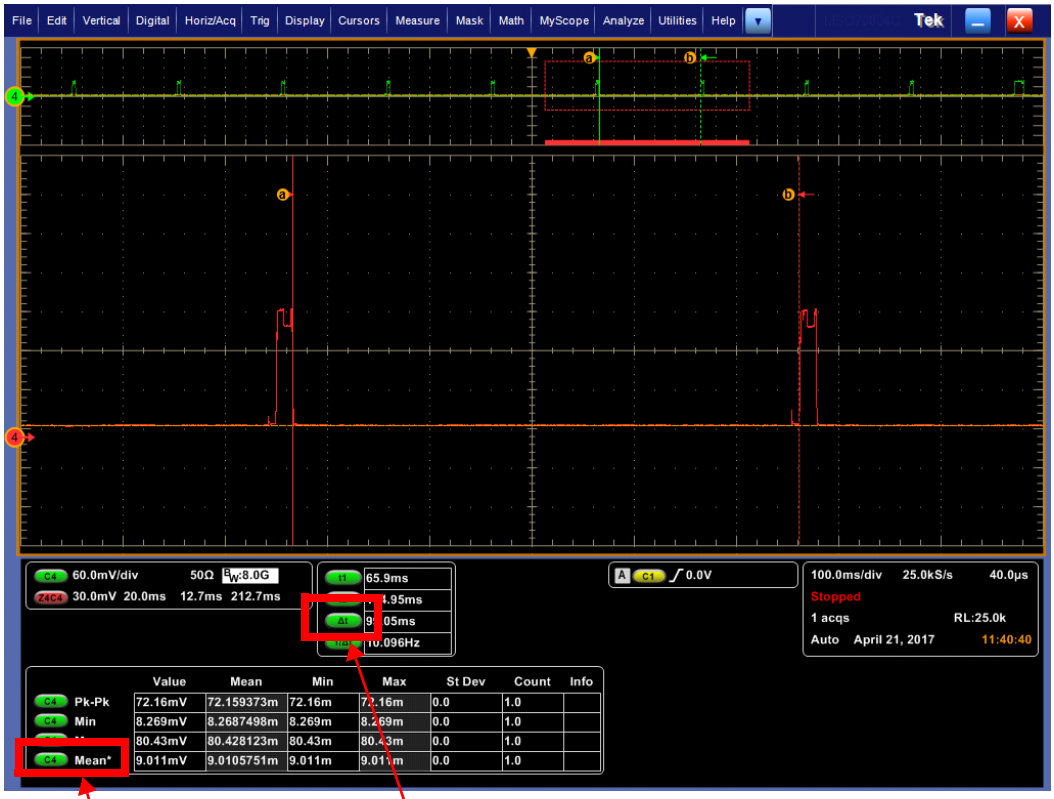
FIGURE 2: WINC1500 POWER MEASUREMENT PORT USED FOR CURRENT MEASUREMENT AND PROFILING



Connect your probe to the power measurement jumper on the WINC1500 Xplained Pro Board after plugging it into the SAMD21 Xplained Pro Board extension. The Xplained Pro Board along with the WINC1500 should be programmed with the power measurement application. The WINC1500 should be programmed to use the latest firmware. Refer to the Getting Stared Guide [1] for programming the WINC1500 and Xplained Pro Boards.

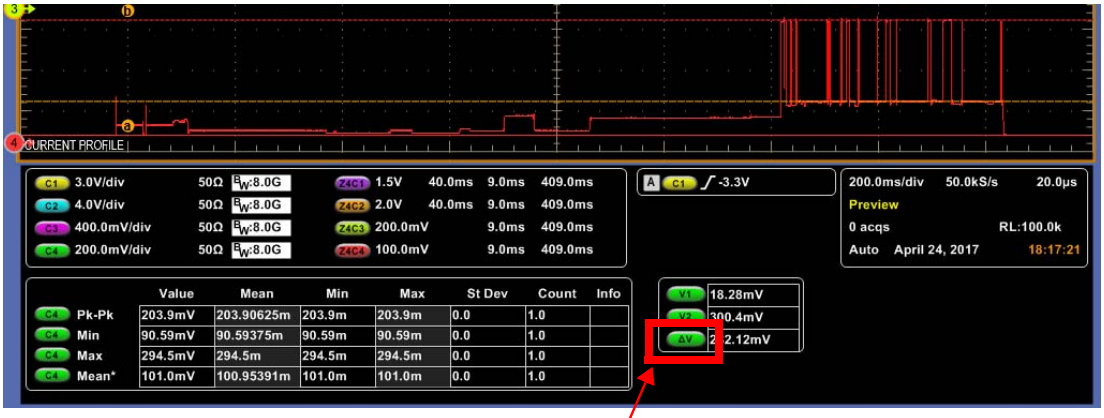
For static current measurement using DMM, the 1 Ohm resistor, which is used for power profiling, needs to be removed so that the DMM can be put in Current Measurement mode and connected in series.

FIGURE 3: HOW TO INTERPRET THE MEASUREMENTS



Average current during the period between two cursors

Time difference between cursor A and cursor B



Voltage difference between cursor A and B

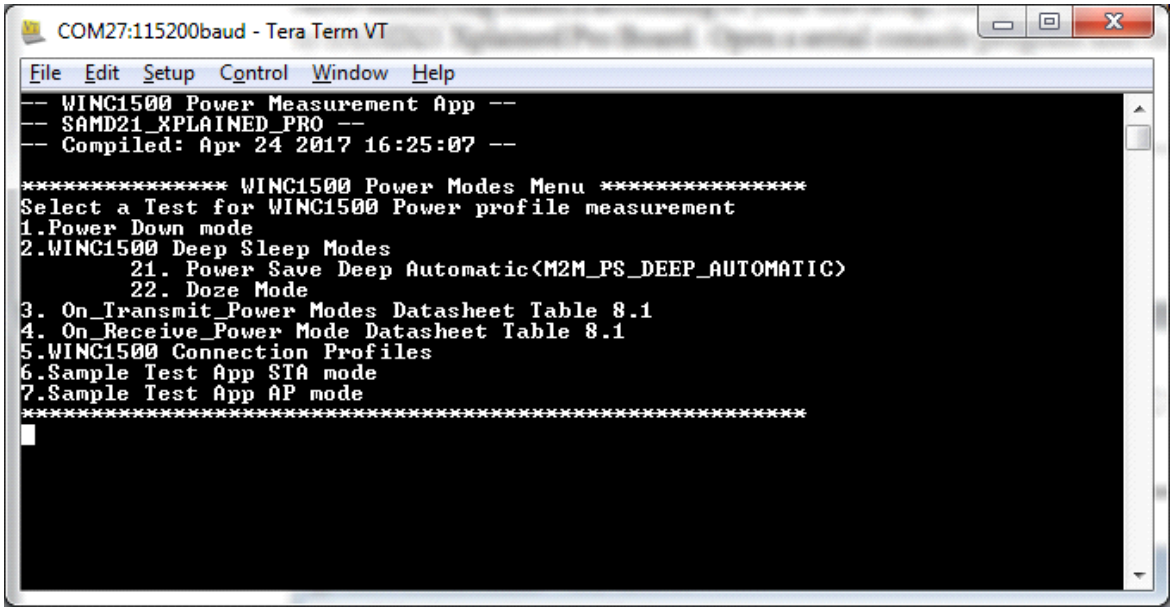
Note: If only one channel is present in the scope, it would correspond to the voltage reading on the WINC1500 Xplained Pro. If other channel data is presented, the signal would be explained as necessary.

CURRENT AND TIME MEASUREMENTS

Before programming, make sure you have changed the following settings in main.h of the project according to your test setup. TCP and UDP servers are provided along with the test application, which must be running on the PC that is connected to same network if TCP, SSL or UDP are to be profiled.

```
#define TEST_WLAN_SSID "ATMELSSID" /
*Destination SSID */
#define TEST_WLAN_AUTH M2M_WIFI_SEC_WPA_PSK /
*Security Type*/
#define TEST_WLAN_PSK "atmelpass" /* Password
for SSID */
/*Server or Client IP settings*/
#define TEST_WINC_RECEIVE_BUFFER 1460 /
*Receive Buffer for WINC1500*/
#define TEST_WINC_SERVER_PORT 6666 /*WINC1500
Listen Port or destination port if UDP is
used*/
#define TEST_WINC_SERVER_IP "255.255.255.255"
/*WINC1500 Listen IP address*/
#define TEST_SSL_TCP_IP "192.168.1.138" /*SSL
or TCP IP address of the server*/
#define TEST_SSL_SERVER_PORT 443 /*SSL server
port number*/
#define TEST_TCP_SERVER_PORT 6666 /*TCP
server port number*/
/*Default Profile Settings*/
#define TX_PACKET_SIZE 64 /*Packet size used
in profiling*/
#define TX_DELAY_MS 100 /*Delay between
packets in TX profiling*/
#define DEFAULT_TX_POWER TX_PWR_HIGH /
*Default TX power mode in the test*/
#define TEST_SSL_UPLOAD_SIZE 1 /*Number of
time
"TX_PACKET_SIZE" bytes are sent out*/
//Only one should be enabled at a time, probe
on PB30 on SAMD21 Xplained Pro
#define AP_CONNECTION_TOGGLE 1
#define TCP_CONNECTION_TOGGLE 0
#define TCP_UPLOAD_TOGGLE 0
```

After modifying main.h according to your test setup, compile the project and flash it onto the SAMD21 Xplained Pro Board. Open a serial console program and the following screen should appear:



Let's walk through each menu item and analyze the WINC1500 power and timing parameters. Only one menu item can be used in each run of the SAMD21 Xplained. To select a different test, the SAMD21 Xplained Pro has to be reset.

Disabling pull-ups on WINC1500 to reduce leakage current

Any I/O that is being driven by either side (either the host or the WINC1500) should have the pull-up resistor disabled. However, if the host is driving a pin to the WINC1500 and may at some time float that pin, either the host driver needs to change to always drive the pin, or the pull-up should be enabled whenever the pin is floating. These pins have been setup correctly in the example application.

Key API Used: `m2m_periph_pullup_ctrl`

Power Down Mode

Reset the SAMD21 Xplained. Select 1.

A DMM can be used to measure the voltage across the WINC1500 jumper to measure the voltage.

In this mode, the WINC1500 is disconnected from the Access Point. This is lowest power mode the WINC1500 can be in. The WINC1500 Chip Enable is disabled.

Current measured: 1.56 uA

Key API Used:

```
socketDeinit();
m2m_wifi_deinit(NULL);
nm_bsp_deinit();
```

Deep sleep modes

M2M_PS_DEEP_AUTOMATIC

A High resolution multimeter or differential probe must be used to measure currents in this mode:

1. Reset the SAMD21 Xplained. Select 21. Enter Listen Interval after selecting 21.
2. Select Listen Interval: 1 (Listen Interval of 1 is used in this sample run)
3. Enter the listen interval that needs to be tested.
4. Next, enter if you want the WINC to wake up to listen for DTIM beacons
5. Do you want WINC to listen to DTIM (1. yes or 0. no). Select 1:
   - When 1 is selected, the WINC1500 wakes up at every DTIM interval if the DTIM interval of the AP is less than the Listen Interval. If 0 is entered, the WINC1500 ignores receiving DTIM frames from the AP
   - After entering this, the WINC1500 would get connected to the AP, and open a UDP socket to listen for incoming data packets. You should see an output similar to this:

```
Putting WINC in (M2M_PS_DEEP_AUTOMATIC)
wifi_cb: M2M_WIFI_RESP_CON_STATE_CHANGED:
CONNECTED wifi_cb: M2M_WIFI_REQ_DHCP_CONF: IP
is 192.168.1.140 socket_cb: bind success!
```

This is lowest power mode of the WINC1500 with the connection to the AP maintained. In this mode, the WINC1500 implements the Wi-Fi standard power saving method.

Current measured: 280-380 µA (measure with the Listen Interval: 1, DTIM 1 (Idle Connect))

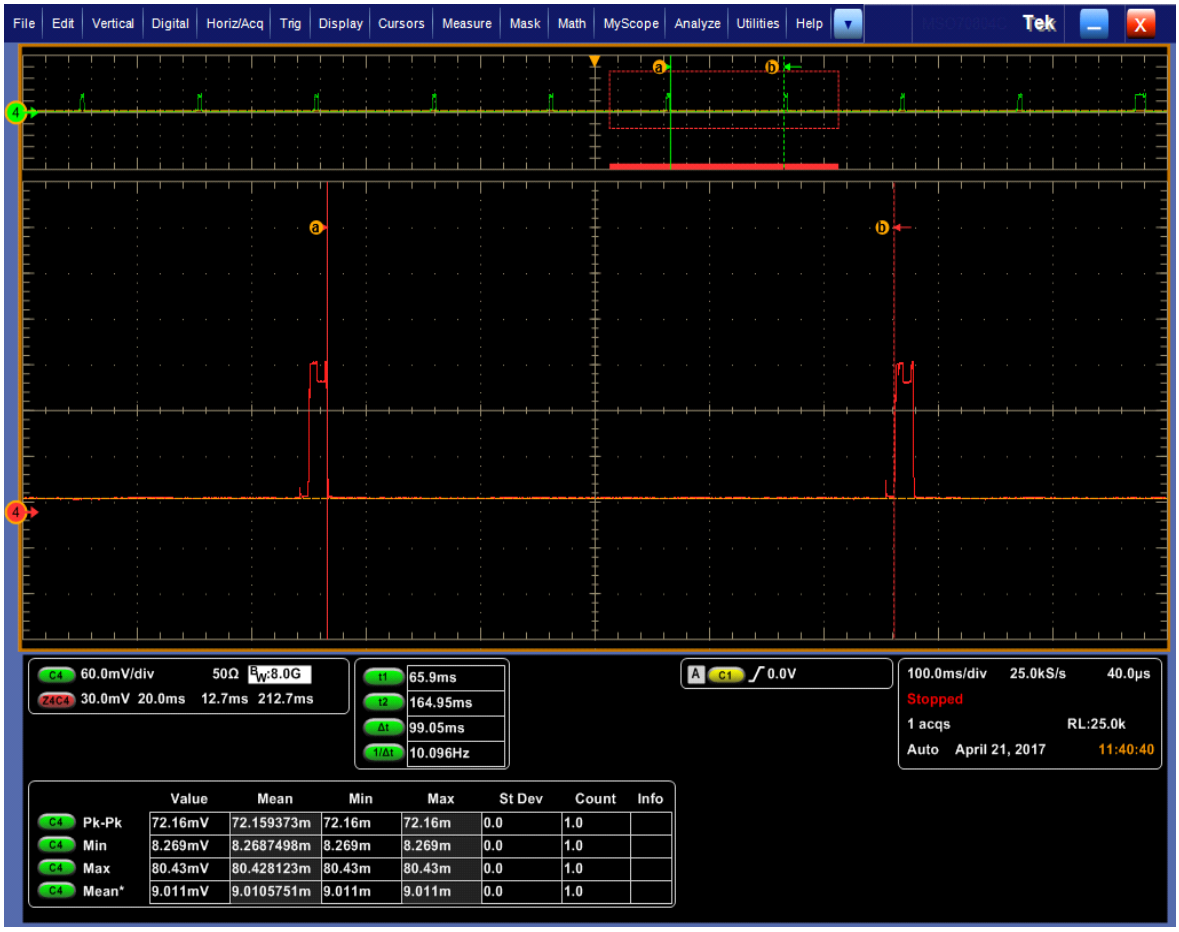
The following tests can be performed in this mode by selecting different listen intervals and DTIM configurations. However, for each different configuration, the SAMD21 Xplained must be reset and the parameters must be reset all over again.

Key API Used: `m2m_wifi_set_lsn_int (&strM2mLsnInt);`

```
m2m_wifi_set_sleep_mode (ps_mode,dtim);
```

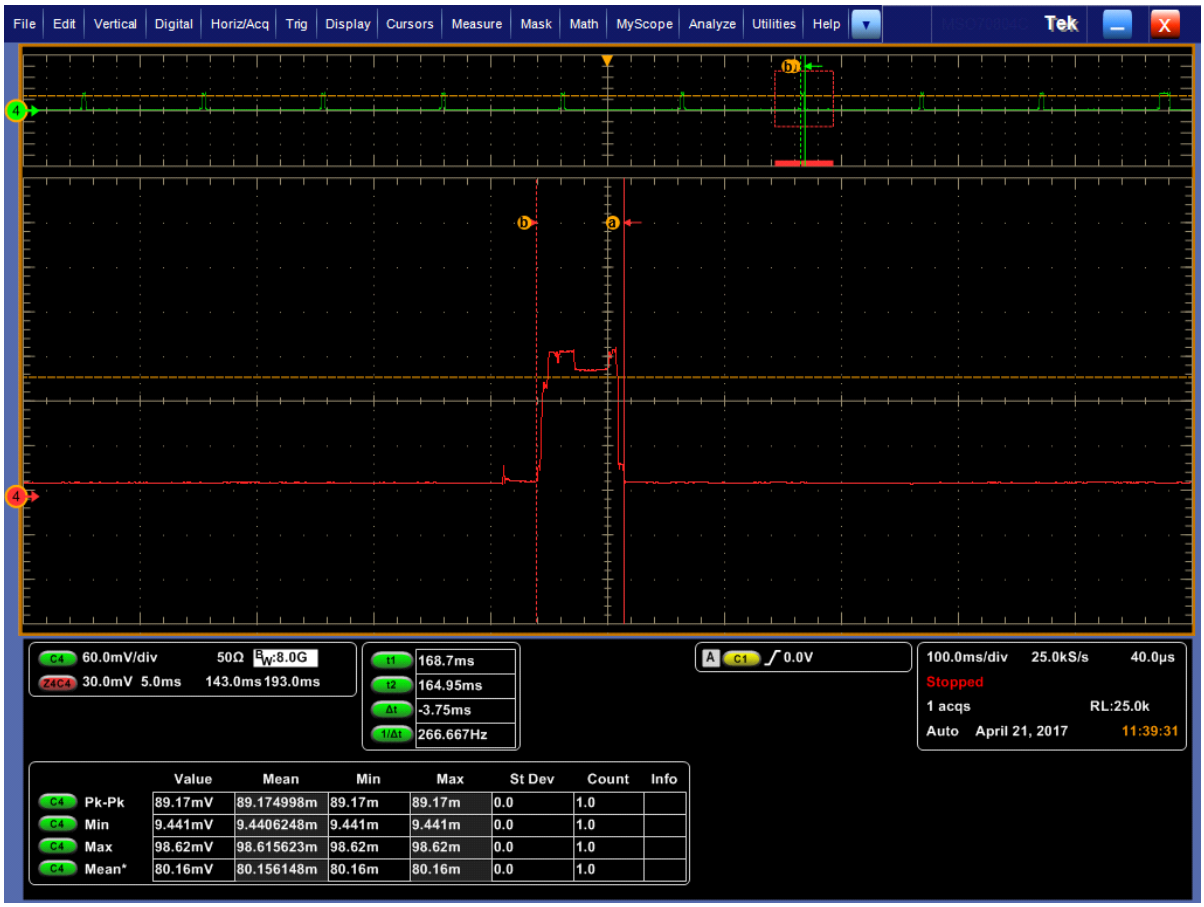
LISTEN INTERVAL = 1, NO DATA RECEIVE OR TRANSMIT (IDLE CONNECT)

FIGURE 4: WINC1500 WAKING UP EVERY BEACON INTERVAL



The WINC1500 wakes up every beacon interval to listen for the beacon. If there is any data for it from the AP, it stays awake to receive the data, but if there is no data transmitted or received in this setup, it sleeps as soon as possible. Depending on how often the WINC1500 has been hearing the beacon frame, awake time varies. In this case, we observed awake time of 3.75 ms as indicated in Figure 5; however, worst case awake time could be up to 26 ms if the WINC1500 misses a beacon. If the WINC1500 misses three beacons consecutively, it will be awake for a full beacon interval to listen for the next beacon. The WINC1500 can miss beacons because of a synchronization error on its sleep clock. Because the WINC1500 wing board uses an internal low power clock with an accuracy of 10,000 ppm, the wake-up time in Beacon Monitoring mode has to be increased by 1% of the sleep time to compensate for oscillator inaccuracy. If the applications are targeting lower power than this, an external 32 kHz RTC clock should be used.

FIGURE 5: WINC1500 AWAKE TO LISTEN FOR THE BEACON



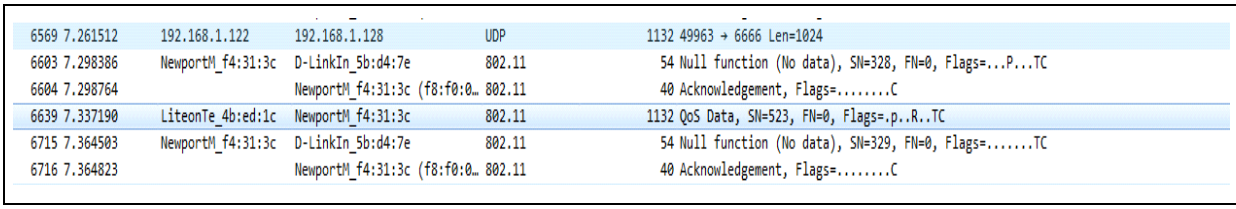
UDP UNICAST RECEIVE WITH LISTEN INTERVAL SET TO 1

Unicast packets of a length of 1024 bytes are sent every 100ms.

FIGURE 6: WINC1500 WAKING UP EVERY BEACON INTERVAL TO RECEIVE DATA FRAME FROM THE AP

FIGURE 7: WINC1500 RECEIVING 1024 BYTES OF UDP UNICAST PACKET, ▲t SHOWN HERE IS THE TIME BETWEEN WINC WAKE UP AND SENDING NULL FRAME

FIGURE 8: WIRESHARK TRACE FROM UDP UNICAST TO WINC RECEIVING AND GOING BACK TO SLEEP



In Figure 8, the device with MAC address Newport-M_f4:31:3C is the device under test. Packet 6569 is the UDP transmission from the laptop using a script. The WINC1500 indicates to the AP that it is awake by transmitting a NULL frame at 7.298386 seconds (Packet 6603), and receives the UDP packet at 7.337190 seconds (Packet 6639) and sends out a Null frame indicating it will be going back to sleep.

M2M_PS_MANUAL MODE

In manual mode, the host MCU controls the WINC1500 sleep cycle. The WINC1500, upon receiving the sleep request from the host MCU, sends a WLAN NULL frame (doze state) to the AP. After the ACK is received for the NULL frame, the WINC1500 turns off all system clocks and stops its CPU. After a period of time decided by the host application, the WINC1500 wakes up automatically and sends another NULL frame, and sleeps immediately. This cycle is repeated in multiples of the sleep period passed in `m2m_wifi_request_sleep` API. The WINC1500 also wakes up when the host wants to send data out, and any API that would lead to transmitting data from the WINC1500 can wake it up. If the host decides to set a sleep value that could potentially lead to disconnecting from the AP (like a large sleep period), the host will have to send a data packet periodically to maintain the connection with the AP. Commercial APs usually disconnect devices that are

dormant for few tens of seconds (and the time is implementation dependent on the AP and can vary from AP to AP).

Also note that since the WINC1500 is not synchronized to beacon frames from the AP in this mode and could be sleeping when data is sent to it, this mode could lead to losing data frames. A typical application of this mode would be to send data occasionally, but require that connection to the AP be maintained so that data can be sent as quickly as possible without having to establish the connection before sending data. If the connection has been lost, it would add an additional 200 ms delay to establish a connection before sending out data. Refer to menu item 6, a sample application that can be run in this mode.

Key API Used: `m2m_wifi_set_lsn_int (&strM2mLsnInt);`

```
m2m_wifi_request_sleep (sleep_time);
```

DOZE MODE CURRENT

Reset the SAMD21 Xplained. Select 22.

In this mode, the WINC1500 remains in Sleep mode for a minute after establishing connection with an AP. A DMM can be used to measure the current in this mode.

Current measured: 270 µA-380 µA.

Doze mode current varies from part to part.

Key API Used: `m2m_wifi_request_sleep (sleep_time);`

Transmission Current

There is no API to control the code rate of the WINC1500 in Wi-Fi STA mode. The WINC1500 would automatically choose the code rate based on link quality and other factors, so the current in this mode would vary according to the data rate the WINC1500 is transmitting at. The WINC1500 data rates can be configured in ATE mode if more accurate measurements are needed

In these tests, a UDP packet of size `TX_PACKET_SIZE` with a delay of `TX_DELAY_MS` will be sent out.

TRANSMIT OUTPUT POWER

Reset the SAMD21 Xplained. Select 3.

Current Measured: 266mA-316 mA at various data rates.

Key API Used: To control the transmission power `m2m_wifi_set_tx_power();`

Connection timing and power profiles

Reset the SAMD21 Xplained. Select 5.

Next, you will be asked to select between SSL, TCP or UDP connection. Select the parameter according to the profile you want to test.

Select 1. SSL enable, 0. TCP, 2. UDP:

Next, you will be asked for the listen interval.

Select Listen Interval:

Next, you will be asked for the DTIM configuration.

Do you want the WINC1500 to listen to the DTIM (1. yes or 0. no):

After entering the DTIM configuration, we can get started with profiling the WINC1500 AP connection, TCP or SSL server connection, and TCP, SSL or UDP uploads.

Press the SWO button on the SAMD21, and with the first button press, the WINC1500 connects to the AP.

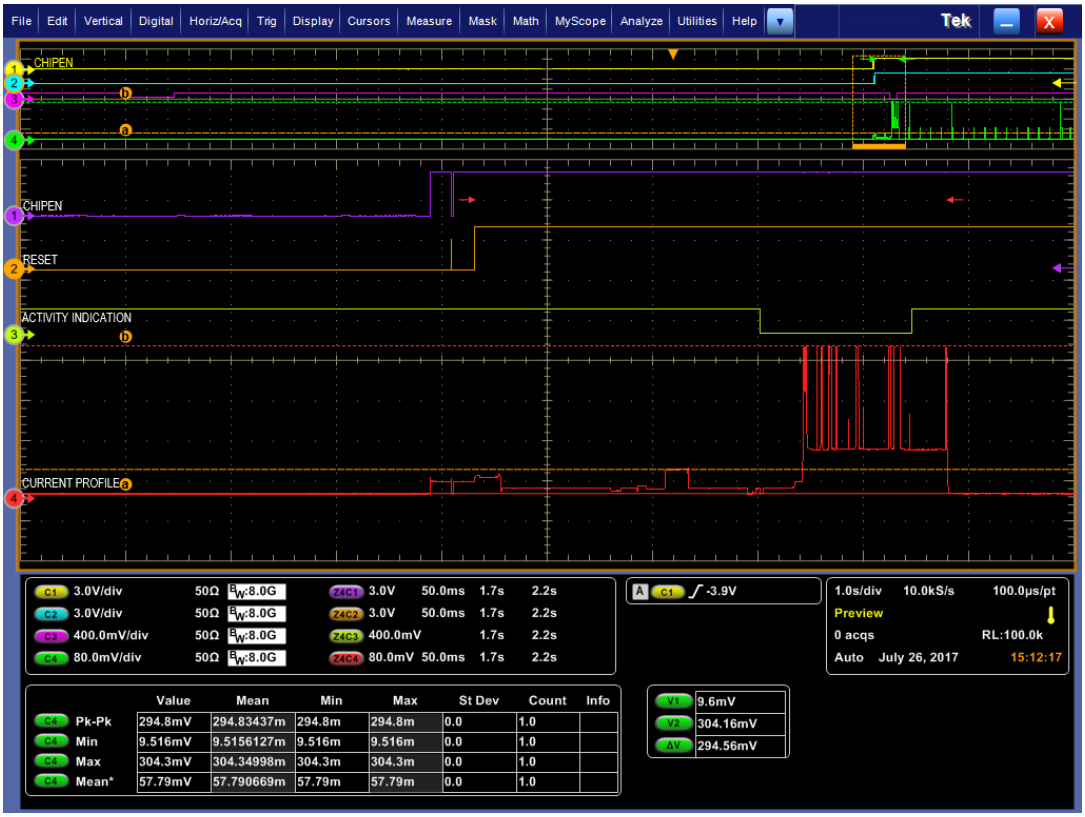
The second button press will setup the TCP or SSL connection if one of those modes is selected; otherwise, it sets up a UDP socket. On the next button press, either a TCP, SSL or UDP packet will be uploaded to the server.

WINC1500 CONNECTION TO THE AP TIME AND POWER PROFILE

The connection profile in Figure 9 is generated with a listen interval of 1, and WINC1500 listening for DTIM.

FIGURE 9: WINC TIME AND POWER PROFILE FROM BOOT TO CONNECTION WITH THE AP

FIGURE 10: PEAK CURRENT FROM BOOT TO CONNECTION WITH AP



The Green trace (Channel 3) in the figure indicates a connection event at the application layer on the host MCU.

The Red trace (Channel 4) in the figure indicates the voltage measurement on the WINC1500 over the power measurement jumper.

The Yellow trace (Channel 2) in the figure indicates the reset issued from the host MCU to the WINC1500.

The Purple trace (Channel 1) in the figure indicates the chip enable issued from the host MCU to the WINC1500.

Channel 3 in Figure 9 goes low when:

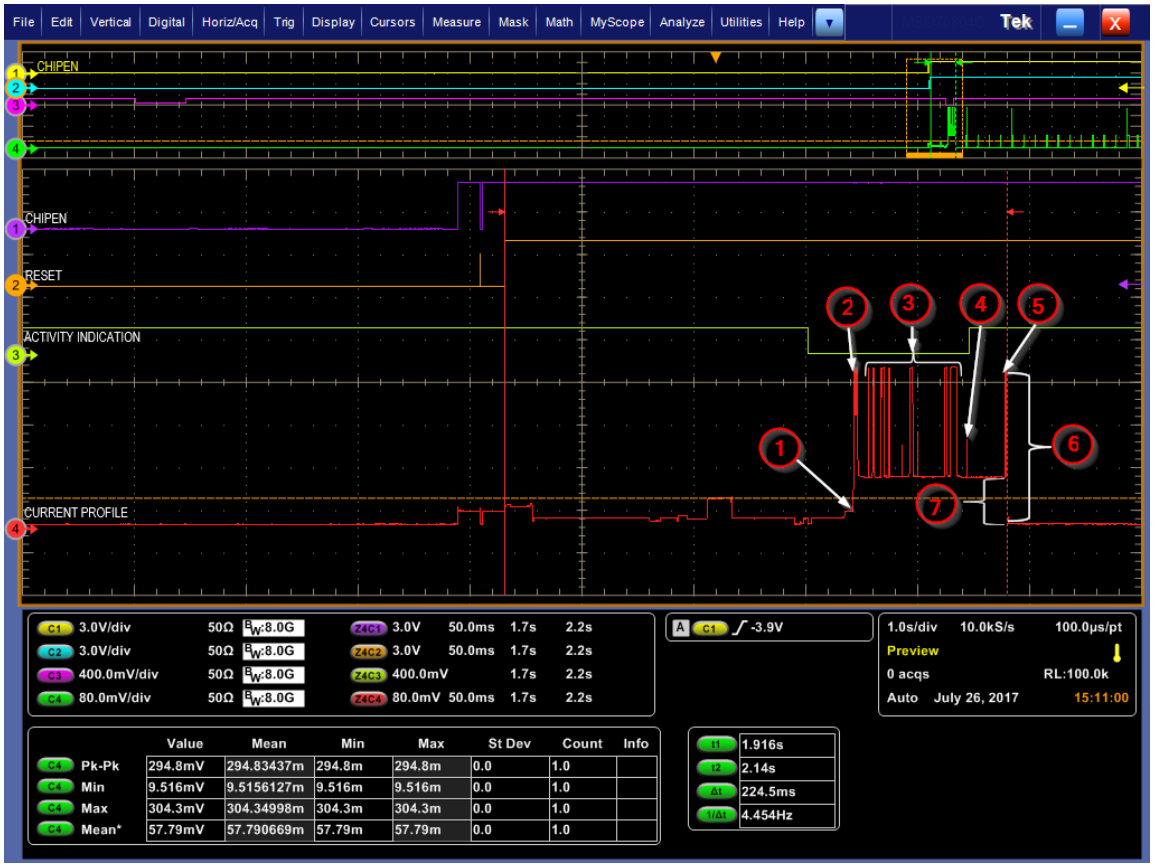
- The `m2m_wifi_connect` command is issued to WINC, until the callback function is called after DHCP ACK is completed

A delay from the probe request to the DHCP ACK is observed around 67 ms as indicated in Figure 11.

FIGURE 11: WIRE SHARK CAPTURE FROM PROBE REQUEST TO DHCP ACK DURING CONNECTION

No.	Time	Source	Destination	Protocol	Length	Info
5629	11.901545	NewportM_f4:31:3c	Broadcast	802.11	114	Probe Request, SN=0, FN=0, Flags=........C, SSID=SAMWINCTest
5630	11.902510	NewportM_f4:31:3c	Broadcast	802.11	114	Probe Request, SN=1, FN=0, Flags=........C, SSID=SAMWINCTest
5631	11.904149	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	802.11	205	Probe Response, SN=3045, FN=0, Flags=........C, BI=100, SSID=SAMWIN…
5633	11.906180	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	802.11	205	Probe Response, SN=3046, FN=0, Flags=........C, BI=100, SSID=SAMWIN…
5646	11.918280		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5647	11.918765	NewportM_f4:31:3c	D-LinkIn_5b:d4:7e	802.11	60	Authentication, SN=3, FN=0, Flags=........C
5648	11.919131		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5650	11.923172	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	802.11	60	Authentication, SN=3048, FN=0, Flags=........C
5652	11.925958	NewportM_f4:31:3c	D-LinkIn_5b:d4:7e	802.11	146	Association Request, SN=4, FN=0, Flags=........C, SSID=SAMWINCTest
5653	11.926263		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5655	11.929465	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	802.11	154	Association Response, SN=3049, FN=0, Flags=........C
5657	11.936486	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	EAPOL	163	Key (Message 1 of 4)
5659	11.941455	NewportM_f4:31:3c	D-LinkIn_5b:d4:7e	EAPOL	185	Key (Message 2 of 4)
5660	11.941671		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5661	11.944519	D-LinkIn_5b:d4:7e	NewportM_f4:31:3c	EAPOL	243	Key (Message 3 of 4)
5663	11.956746	NewportM_f4:31:3c	D-LinkIn_5b:d4:7e	EAPOL	163	Key (Message 4 of 4)
5664	11.957067		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5667	11.964114	0.0.0.0	255.255.255.255	DHCP	381	DHCP Request - Transaction ID 0x4b7a0023
5668	11.964476		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C
5669	11.967794	0.0.0.0	255.255.255.255	DHCP	383	DHCP Request - Transaction ID 0x4b7a0023
5670	11.968064	192.168.1.1	192.168.1.128	DHCP	408	DHCP ACK - Transaction ID 0x4b7a0023
5676	11.983565	NewportM_f4:31:3c	D-LinkIn_5b:d4:7e	802.11	54	Null function (No data), SN=5, FN=0, Flags=...P...TC
5677	11.983592		NewportM_f4:31:3c (f8:f0:05:f4:31…	802.11	40	Acknowledgement, Flags=........C

FIGURE 12: ZOOMED IN CAPTURE OF WINC1500 CONNECTION TO AP



1	Analog RF Initialization
2	Scanning Phase
3	Assoc. and 4-way handshake
4	DHCP Ack
5	Null frame
6	Transmit Voltage
7	Receive Voltage

The connection time observed from wake-up to connect in this experiment is 309.2 mS. This number can vary based on different parameters, depending on what channel the AP is on, which would vary the scan phase in Figure 12. Also, the WINC1500 needs to listen for the beacon from the AP as per the Wi-Fi Specification before sleeping, which can affect the connection time. If the beacon interval is configured to 100 ms, the worst case delay between the DHCP ACK and the WINC1500 sleeping will be close to 100 ms.

Peak current during connection (transmission): 294.56 mV/1.1 ohms = 267.78 mA (▲V in Figure 10).

Receive current during connection: 74.65 mA.

Average current during boot up to connection: 52.53 mA.

Connection time from boot up: 224.5 mS (▲t in Figure 9).

Sample Test App in STA Mode

Reset SAMD21 Xplained. Select 6.

Next, you will be asked to select a Power mode

Select 1.Manual or 2.Automatic PS mode:

Next, you will be asked to select between SSL, TCP connection. Select the parameter according to profile you want to test

Select 1.SSL enable, 0.TCP:

Next, you will be asked for the listen interval

Select Listen Interval:

Next, you will be asked for DTIM configuration

Do you want WINC to listen to DTIM (1. yes or 0. no):

In the sample test app, upon a button press, a connection is established to a TCP or SSL server and data is sent to the server in two different power save modes. This can be used to evaluate if Manual mode or Automatic Deep Sleep mode is more appropriate for you application.

SAMPLE TEST APP IN AP MODE

Reset the SAMD21 Xplained. Select 7.

Next, you will be asked to select TX output power since this is only power-related trade-off in this mode.

Select 1, 2 or 3 based on the desired TX output power.

The WINC1500 starts as an access point as `WINC1500_POWERSAVE_AP`. Connect to it using another device (a laptop or mobile). We can profile WINC behavior in AP mode using this selection.

SUMMARY OF MEASUREMENTS

TABLE 1: WINC1500 CURRENT AND TIME MEASUREMENTS

WINC1500 Mode	Average Current in mA	Time in milliseconds
Connection to AP current from wake-up	52.53	224.5
Boot ROM to analog RF Init	19.63	150.76
Analog RF Init to WINC Doze	86.48	72.5
Sleep between beacons (Idle connect, assuming 100 ms beacon interval)		
Awake	72.87	3.75
Doze	0.280	96.25
Power Down Current	0.00156	Continuous

APPENDIX

Beacon Interval

Beacon transmissions announce the presence of an 802.11 network at regular intervals. Beacon frames carry information about BSS parameters and the frames buffered by access points, so mobile stations must listen to Beacons [2].

DTIM

Broadcast or multicast frames are buffered by the Access Point until the DTIM period, which is a 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 the DTIM interval [2].

Listen Interval

The Listen Interval is the number of beacon intervals that the stations wait between listening for beacon frames. 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].

Null Frame

In 802.11 Networks Null frames do not carry any data. They are used by stations to indicate to the Access Point any changes in the power mode of the station. Access Points buffer the data when the station indicates that it is about to sleep. Stations use the power management bit in the frame control field to report the power state to the Access point [2].

Probe Request and Response Frame

Stations use Probe request frames to scan an area for 802.11 Networks. Access points with compatible parameters respond to the probe requests sent by the station with a probe response [2].

References

1. Getting Started Guide for ATWINC1500 Wi-Fi using SAMD21 Xplained Pro
2. 802.11 Wireless Networks the Definitive Guide Second Edition

REVISION HISTORY

TABLE 2: REVISION HISTORY

Document Revision	Date	Comments
0	6/5/2015	Initial release of the document
1	7/23/2015	Updated power measurements with the example app
2	12/10/2015	Removed Low Power mode-related measurements
3	3/4/2015	Added AP mode
4	7/2017	Measurements updated with latest ASF. Migrated to the Microchip template and given application note number AN2479.

NOTES:

Note the following details of the code protection feature on Microchip devices:

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