AN1219: Power Consumption Measurement Setup and Results on WF(M)200

WF(M)200 is a Wi-Fi network co-processor optimized for low-energy consumption. This application note describes how to perform current consumption measurements and get the lowest current consumption with WF(M)200.

Additionally, this document shows how to achieve accurate measurements using BDR8022 or BRD8023 and provides measurement examples for different use cases. This document applies to both WF200 and WFM200. For simplicity, both devices are referred to as WF(M)200.

KEY POINTS

- WF200 and WFM200 are optimized for low consumption
- Improving WF(M)200 usage for low-current consumption
- Performing accurate current measurements with BRD8022/BRD8023
- Measurement examples

Table of Contents

1. WF200 and WFM200 Overview

WF200 is a Wi-Fi network co-processor optimized for RF performance, low energy, and low cost, with two antenna ports, Crystal Oscillator, One Time Programmable Memory, and several GPIOs for interfacing with multi-protocol and controls for a potential external RF Front End Module.

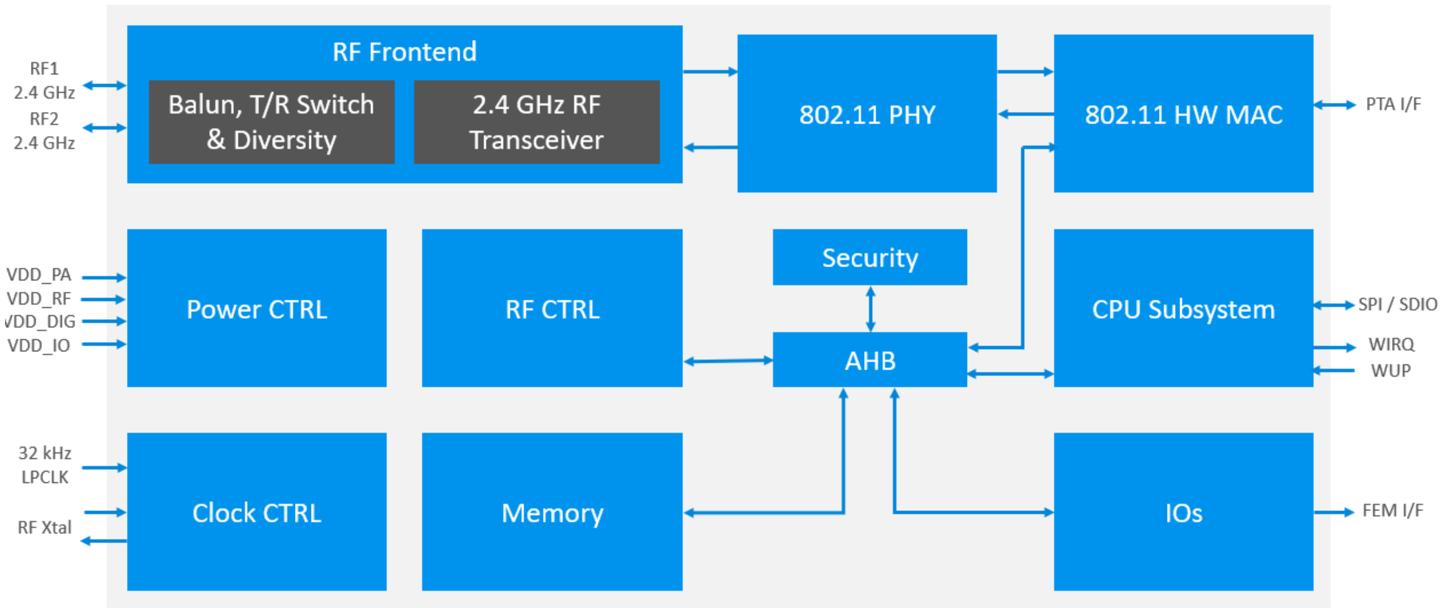


Figure 1.1. WF200 Overview

In addition to WF200, WFM200 integrates:

- 50 ohm matching networks on WF200 RF_1 and RF_2 pins
- 38.4 MHz crystal oscillator
- Antenna for RF_1 port (according to the part number)

Therefore, the WFM200 consumption is expected to be the same as the WF200 consumption.

1.1 Power Supplies

WF200 has four different power domains and four supply pins, namely VDD_PA, VDD_RF, VDD_DIG, and VDD_IO. WFM200 has three supply pins, given that a single pin on WFM200 feeds both VDD_RF and VDD_DIG pins of WF200 inside the module.

The table below provides basic description and summarizes the requirements for the supply pins.

Table 1.1. Supply Pins

WFM200 supplies	WF200 supplies	Description	Voltage range	Recommendations and Comments
VDD_PA	VDD_PA	Supply of the Power amplifier part.	3.0 <VDD_PA< 3.6V	VDD_PA voltage should not be lower than: • VDD_RF on WF200 • VDD_D on WFM200 Very limited current drawn while not transmitting.
VDD_D	VDD_RF	Supply of the RF part part	1.8 <VDD_RF< 3.6 V	Internal LDO (current does not vary much with voltage)
	VDD_DIG	Supply of the digital part	1.8 <VDD_DIG< 3.6 V	Internal LDO (current does not vary much with voltage)
VDD_IO	VDD_IO	Supply of I/Os part	1.8 <VDD_IO< 3.6 V	VDD_IO should be set such that the levels are compliant with other devices it interfaces with.

For details including currents on each supply in various conditions, see the power supplies section of WF200 or WFM200 data sheets. Note that some current values in the data sheets are typical and might vary depending on the part used.

Currents in the data sheets are measured with specified supply voltages. Usually VDD_RF and VDD_DIG voltages are set to 1.8 V, which ensures the lowest power consumption. Note that both VDD_RF and VDD_DIG supplies are regulated with LDOs within WF(M)200, so the current drawn does not vary much with supply voltage.

Both BRD8022A (WF200) and BRD8023A (WFM200) boards are using a single power supply for the board (VMCU_NCP) set to 3.3 V.

1.2 Clocks

WF200 requires a 38.4 MHz reference clock, which can be generated either with an XTAL attached to WF200 XTAL pins or provided by an external XO. The 38.4 MHz XO is embedded in WFM200. Additionally, WF(M)200 has a provision for a 32 kHz clock input (LP_CLK pin) that allows achieving the lowest power consumption (sleep state) while in power save mode.

Most hosts have 32 kHz that can be shared with WF(M)200.

Two low-consumption modes occur (when power-save is enabled) depending on LP_CLK presence.

- If a 32 kHz clock is available at LP_CLK input, the device goes in **sleep mode** between receptions of beacons. In this mode, most of the chip is turned off (including XTAL oscillator and host interface) to reduce the consumption as much as possible. Given that the host interface is shut down in this mode, the host should assert the WUP pin to wake up the device before any communication with the host can be achieved.
- If the clock is not available on LP_CLK, the device goes in **snooze mode** between receptions of beacons. In this mode, a smaller part of the device is shut down, so the typical consumption is higher.

The LP_CLK is detected automatically by the WF(M)200 after reset.

If the XTAL is shared with another device, additional mode exists for WF200 only. In this case, the XTAL oscillator cannot be shut down between beacons (even if LP_CLK is provided), which results in additional consumption. This use case is referred to as **sleep with XO** and should be configured according to PDS settings.

1.3 Power Profiles Definitions

The current consumption on WF(M)200 is highly dynamic and varies significantly depending on the following factors.

- Wi-Fi data traffic activity depends on the application. The more transmit and receive data, the higher the consumption.
- Wi-Fi Power-save enabled depends on the application. It saves power consumption if the data throughput is low or if the host uses short period of high throughput and no data traffic between them.

Table 1.2. Power States Description

Modes	State	Definitions
Traffic modes (STA and Soft-AP)	WF(M)200 is associated with an Access Point, handling some traffic in transmitting or in receiving data frames traffic or in listen state	
	TX	Transmitting Wi-Fi frames
	RX	Receiving Wi-Fi frames.
	Listen	Listening to the channel to receive frames or between RX and TX. This is also the default mode if power save is not enabled.
Additional modes when power save is enabled (STA only)	WF(M)200 is associated with an Access Point and set in power save. TX, RX and listen states listed above are still valid. States below are observed between beacons reception, provided that WUP pin is Low. These states also occur if there is no activity with the host before association.	
	Sleep	This state is using LP_CLK and switching off the XTAL.
	Snooze	Occurs when there is no LP_CLK provided to WF(M)200.
	Sleep with XO	This state is using LP_CLK but maintains XTAL oscillator active and switching off the XTAL.
Idle modes (STA and Soft-AP)	WF(M)200 is shut down. Resuming operation requires a complete start-up sequence triggered by a rising edge on RESETn pin.	
	Shut-down mode	Occurs when the host has sent the HIF message requesting the WF(M)200 to switch in Shutdown mode. Achieved only when WUP pin is Low.
	Reset mode	Occurs when RESETn pin is set low.

1.4 Host Interface (SPI/SDIO)

WF(M)200 can be controlled by an MCU or SoC using either SPI or SDIO (upon SDIO_DAT2/HIF_SEL pin state during the rising edge of RESETn) through the host interface.

The SPI/SDIO clock frequency has an impact on consumption during sleep. As a result, during this state, when possible, the lowest consumption is achieved when the clock is stopped. Moreover, when the wake-up is set to high to exchange message between the host and the WF(M)200, use the highest possible serial clock to reduce this duration.

Note: With Linux driver on Raspberry Pi, it is not possible to get the lowest current consumption in sleep state with SDIO interface because the serial clock is not stopped. As a result, the measurements presented in 3. Measurement Setup use the SPI interface.

1.5 RESETn

WF(M)200 RESETn pin has an internal pull-up (43 Kohm typical).

This pin should be kept high when in Shutdown mode to achieve the lowest current consumption.

1.6 Other Pins

Two signals are used between the host and the WF(M)200 to help reduce the current consumption.

- WUP : the signal WUP (for Wake-UP) comes from the host
- WIRQ : the signal WIRQ comes from WF(M)200. It raises when the WFM200 is ready to receive or transmit frame on the serial interface

Table 1.3. Summary of the Possible WUP and WIRQ Pin Names

Signal	SPI	SDIO
WUP	GPIO/WUP	GPIO/WUP
WIRQ	SPI_WIRQ	SDIO_DAT1 or GPIO/WIRQ

Note: The SDIO_DAT1 is a bidirectional data line which can be used as an interrupt from WF(M)200 to the host when no data is present. If the host does not allow usage of SDIO_DAT1, the GPIO/WIRQ can be used instead.

Below are details on GPIO/WUP and GPIO/WIRQ pins:

- The GPIO/WUP pin should be used by the host to wake up the WF(M)200 when in power-save mode. This pin is programmable and if power save is not enabled on the device, this pin can be configured as a GPIO. Note that this pin should be LOW to enable the WF(M)200 to reach sleep or Shutdown modes. To be used like WUP, the GPIO/WUP pin must be configured in the PDS file in functional mode: PIN_MODE : "func".
- The GPIO/WIRQ pin can optionally be used in SDIO mode to provide the Interrupt request to the host if a given host does not support in-band IRQ. It is also used to wake up the host if it's in a power saving mode with the host interface inactive. If this is not required, the pin can be configured as GPIO. To be used like WIRQ, the GPIO/WIRQ pin must be configured in the PDS string in functional mode: PIN_MODE : "func".

In this document, the assumption is that GPIO/WUP and GPIO/WIRQ use the following PDS configuration recommended for low power (no pull-up and no pull-down).

```
GPIO_WUP: {
        SLEW_RATE: 4,
        PULL_UP_DOWN: none,
        SLEEP_CFG: none,
        PIN_MODE: func,
        GPIO_ID: L
    },
    GPIO_WIRQ: {
        SLEW_RATE: 4,
        PULL_UP_DOWN: none,
        SLEEP_CFG: none,
        PIN_MODE: func,
        GPIO_ID: M
    },
```

Details about managing these two signals are provided in 6. Appendix B: Details on WUP and WIRQ.

Power consumption may also vary upon configuration of pins (pull-ups or pull-downs) and the way they are potentially connected to other devices. Pins are configured using the PDS settings. All measurement results shown in this document assume that all GPIO pins except WUP and WIRQ have the following PDS configuration:

```
PULL_UP_DOWN: none,
    SLEEP_CFG: none,
    PIN_MODE: tri,
```

Any GPIO used on WF(M)200 can add additional current consumption and increase the lowest current consumption. The GPIO pin level during sleep state can be set using the settings SLEEP_CFG in the PROG_PINS_CFG section of the PDS file with the following enumerate: 'none', 'down', 'up', and 'maintain'.

2. Measurement Summary

Static use cases for current consumption are mentioned in the table below.

These current consumptions are detailed in the data sheet.

Dynamic use cases:

- Power save mode when associated under DTIM provides the WF(M)200 average current consumption when there is no TX/RX of data (only receiving Beacons with the DTIM interval and using the sleep state). The current consumption for DTIM1, DTIM3, and DTIM10 is described in the data sheet.
- Time and consumption during boot and firmware download
- Time and consumption during scan: An active scan is performed on channels 1 up to 11 and a passive scan on channel 12 up to 14
- Time and consumption during Association to an Access Point: The current consumption to get the association with a selected Access Point
- Consumption during data traffic: Low bit rate and short burst of high bit rate, ping current consumption

All current consumption figures provide a better understanding for the global consumption of the WF(M)200 according to the targeted application.

The table below includes a summary of measurements detailed in the following sections:

Static power states:

Table 2.1. Current Consumption Summary for Static States

Use Case	Typical current consumption at 3.3 V	Comments
TX burst	154.4 mA	Depends on the constellation and code rate used in TX and depending of the maximum power allowed
RX burst	41.8 mA	
Listen	45.4 mA	
Sleep	24.33 µA	Depends on the WF(M)200 parts used (some variations are possible)
Sleep with XO ON	438.4 µA	
Snooze (No LP_CLK)	1.48 mA	
Shutdown	~513 nA	WUP low and RESETn stay high
Reset	~75.5µA	When RESETn is low. Depends on the internal pull-up resistor in the WF(M)200 part.

Dynamic use cases:

Table 2.2. Current Consumption Summary for Dynamic States

Use Case	Measurement Duration	Averaged current consumptionat 3.3 V	Comments
Wi-Fi Power save DTIM1	1.02 s	~927 µA	Can depend on the Access Point and Wi-Fi context.
Wi-Fi Power save DTIM3	2.45 s	~327 µA	Can depend on the Access Point and Wi-Fi context.
Wi-Fi Power save DTIM10	4.1 s	~115 µA	Can depend on the Access Point and Wi-Fi context.
Firmware download	264.16 ms	~16.38 mA	Depends on the SPI/SDIO clock and firmware size.

Use Case	Measurement Duration	Averaged current consump-tionat 3.3 V	Comments
Wi-Fi Scanning	951.26 ms	~51.76 mA	Can depend on the Access Point and Wi-Fi context.
Wi-Fi association	31.2 ms	~59.64 mA	Can depend on the Access Point.
Host to WF(M)200 SPI ex-change (when no Wi-Fi activity during sleep)	2 ms	~7.8 mA	Depends on the SPI/SDIO clock and exchange frame length.
Ping traffic with 1 packet per second in DTIM1 (1 ICMP pack-et of 64 bytes)	5 s	~7.36 mA	Can depend on the Access Point and Wi-Fi context.
UDP downstream traffic of 100 kbps in DTIM3 with burst profile use case 1	13.2 s	~5.6 mA	Can depend on the Access Point and Wi-Fi context. It de-pends also on the burst profile.
UDP downstream traffic of 100 kbps in DTIM3 with burst profile use case 2	10.4 s	~1.91 mA	Can depend on the Access Point and Wi-Fi context. It de-pends also on the burst profile.
UDP upstream traffic of 100 kbps in DTIM3 with burst profile use case 1	11 s	~6.5 mA	Can depend on the Access Point and Wi-Fi context. It de-pends also on the burst profile.
UDP upstream traffic of 100 kbps in DTIM3 with burst profile use case 2	10.5 s	~1.93 mA	Can depend on the Access Point and Wi-Fi context. It de-pends also on the burst profile.

Note: To optimize power consumption in DTIM modes, the frequency drift of LP_CLK should be within 1 second lower than +-100 ppm.

3. Measurement Setup

This section describes how to perform current measurements and get expected results.

3.1 Hardware and Software Requirements

The figure below provides the typical setup to perform WF(M)200 current measurements:

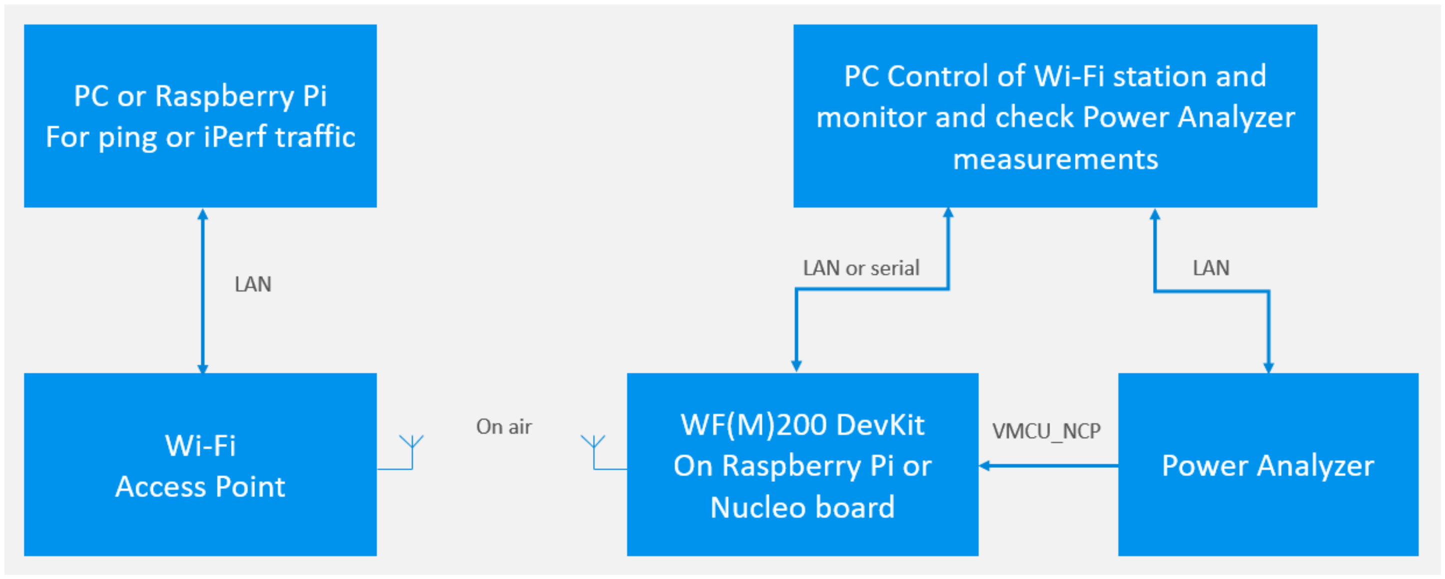


Figure 3.1. Measurement Testbed

WF(M)200 DevKit:

- BRD8022A for WF200
- BRD8023 for WFM200

The same firmware and driver is used for both use cases.

Wi-Fi Access Point: see 9. Appendix E: Access Point Configuration

- Alfa Access Point with a Raspberry Pi for Beacon duration of 1ms for DTIM1, DTIM3, and DTIM10 current measurements.
- TP-Link Archer C3150 configured with a PC to perform data traffic.

Power analyzer:

- Keysight N6705C DC power analyzer with software Keysight 14585A on PC to Monitor and check results.

Data Traffic generator:

- iPerf version 3.7 on Raspberry Pi

Related documentation

For WF200:

- https://www.silabs.com/documents/login/data-sheets/wf200-datasheet.pdf
- https://www.silabs.com/documents/login/user-guides/ug382-wf200-hardware-design-ug.pdf

For BRD8022A hardware and software:

- https://www.silabs.com/documents/login/user-guides/ug379_slexpwfx200-users-guide.pdf
- The Raspberry Pi uses the SD card provided with the BRD8022A: https://www.silabs.com/documents/login/quick-start-guides/qsg166-wf200-wifi-devkit.pdf

3.2 Setup Configuration Requirements

The measurements assume setup configurations described below:

- The Software requirements are provided in 5. Appendix A: WF(M) Software Requirements and 6. Appendix B: Details on WUP and WIRQ.
- The BRD8022A or BRD8023 must be modified to measure the lowest current consumption. More details about hardware requirements are provided in 7. Appendix C: Devkit Hardware Setup for Measurements.
- The Keysight N-6705C DC power analyzer has been configured as described in 8. Appendix D: N6705C Configuration.
- Details about the Access Point usage and configuration are provided in 9. Appendix E: Access Point Configuration.
- Another way to perform current measurements without the N-6705C is described in 10. Appendix F: Advanced Energy Monitoring Usage to Measure Current Consumption.

4. Detailed Measurements

4.1 Static Use Cases and DTIM

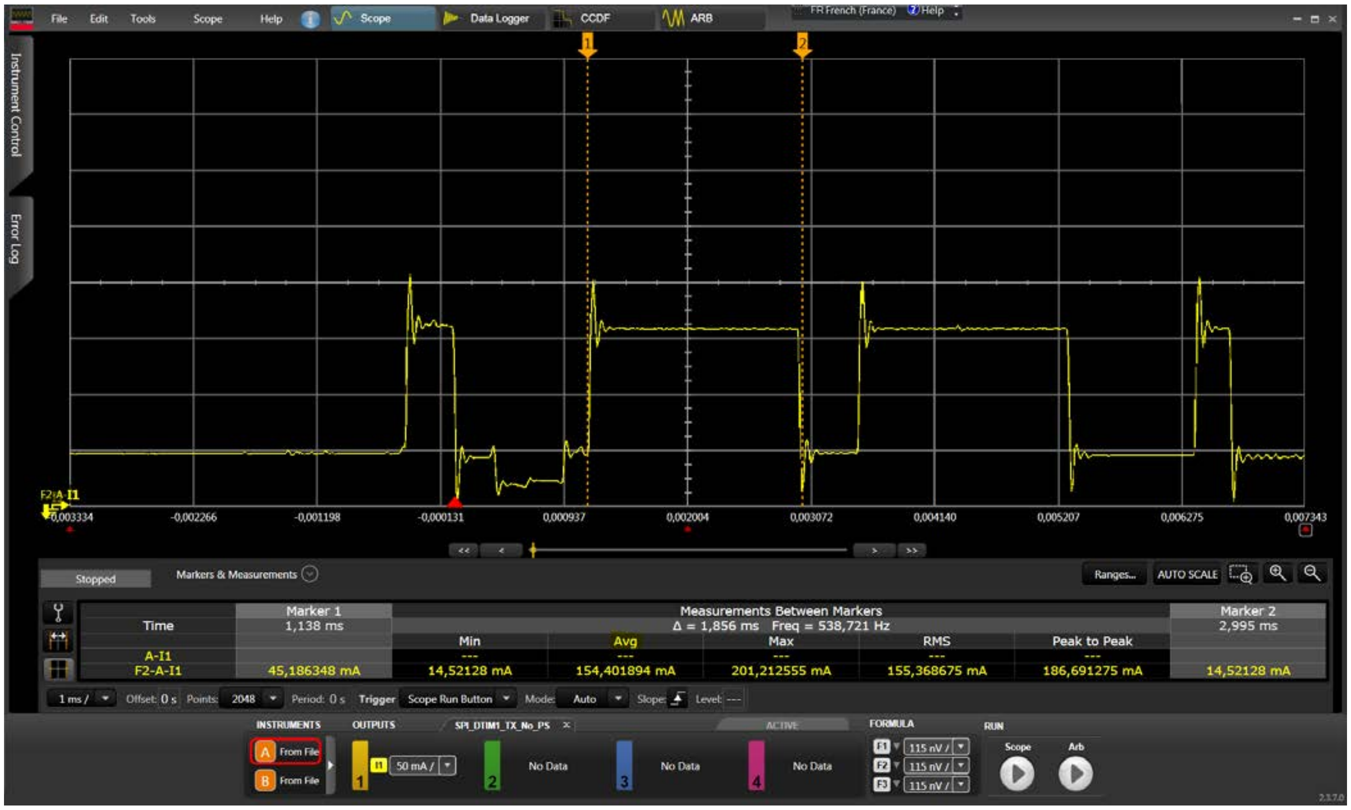
In this section, two Wi-Fi power save settings are used which can be set in Linux OS using the following commands:

- Power save mode disabled: [**sudo iw dev wlan0 set power_save off**]
- Power save mode enabled: [**sudo iw dev wlan0 set power_save on**]

4.1.1 TX Burst Current Consumption

This current consumption depends on the constellation and code rate used in TX and its transmitted power.

The following is an example of TX current consumption with power save mode disabled:



	Marker 1	Measurements Between Markers					Marker 2
Time	1,138 ms	Δ = 1,856 ms Freq = 538,721 Hz					2,995 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	45,186348 mA	14,52128 mA	154,401894 mA	201,212555 mA	155,368675 mA	186,691275 mA	14,52128 mA

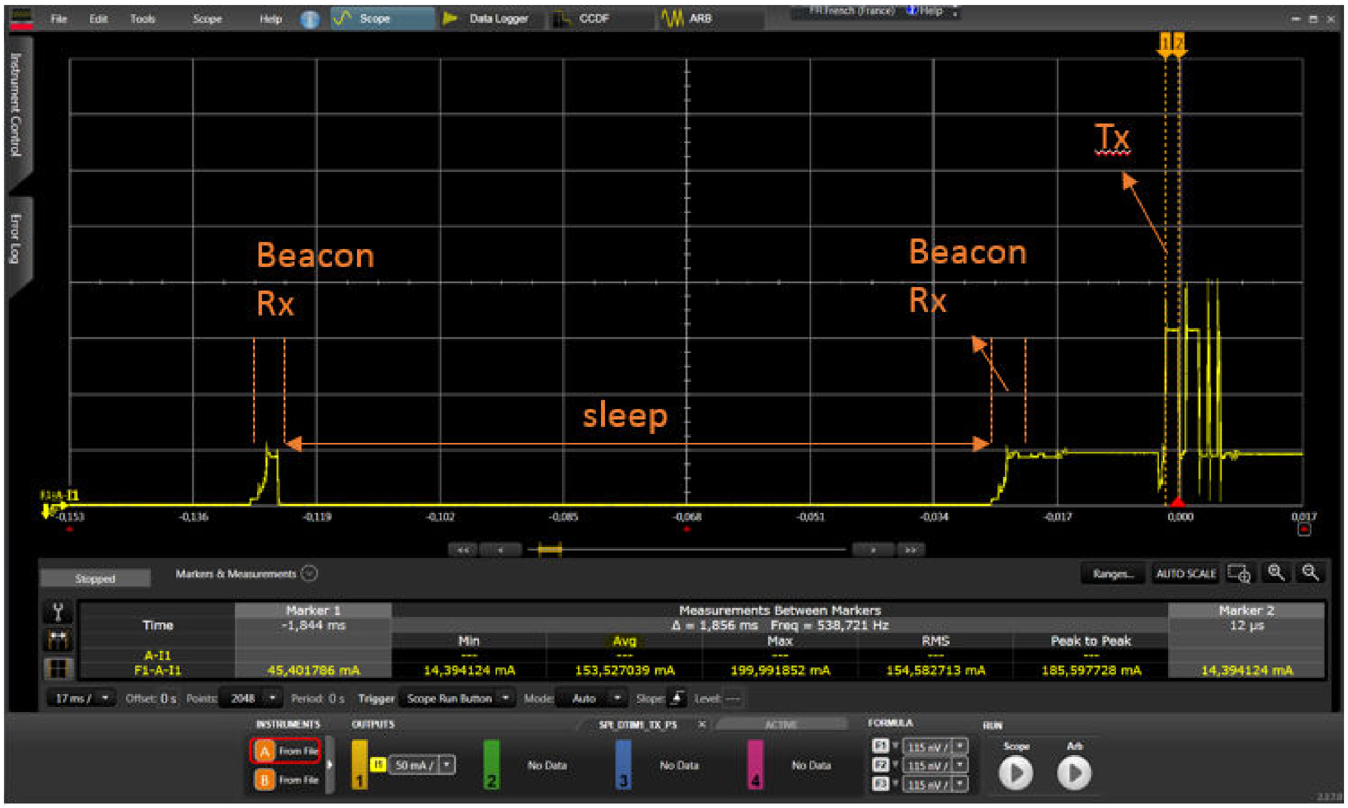
Figure 4.1. TX Burst Current Consumption Snapshot

The TX current consumption is easy to detect because the consumption is higher than 45 mA during RX (between marker 1 and 2).

To get TX current consumption, the WF(M)200 can be associated to an Access Point and then the host can do the following:

- Request to re-associate with the Wi-Fi Access Point (in Linux OS using command: [**wpa_cli –i wlan0 reassociate**])
- Request a scan (in Linux OS using command: [**wpa_cli –i wlan0 scan**])
- Request data traffic: for example doing a ping between the WF(M)200 Wi-Fi station and another Wi-Fi station associated on the same Access Point.

This is an example of TX current consumption with power save mode enabled in DTIM1:

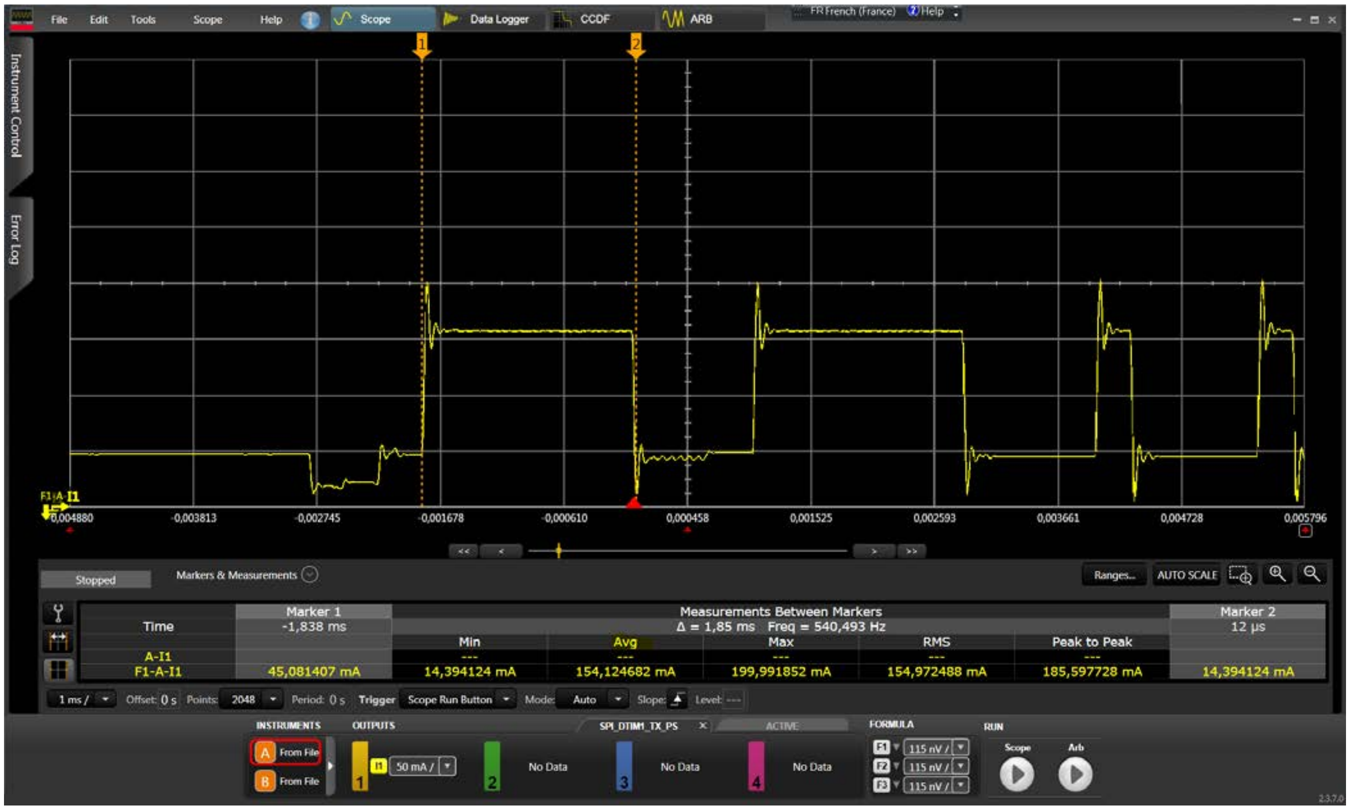


Time	Marker 1	Measurements Between Markers					Marker 2
	-1,844 ms	Δ = 1,856 ms Freq = 538,721 Hz					12 µs
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	45,401786 mA	14,394124 mA	153,527039 mA	199,991852 mA	154,582713 mA	185,597728 mA	14,394124 mA

17 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.2. TX Burst Current Consumption in Power Save Mode Snapshot

Zoom on the TX power burst:



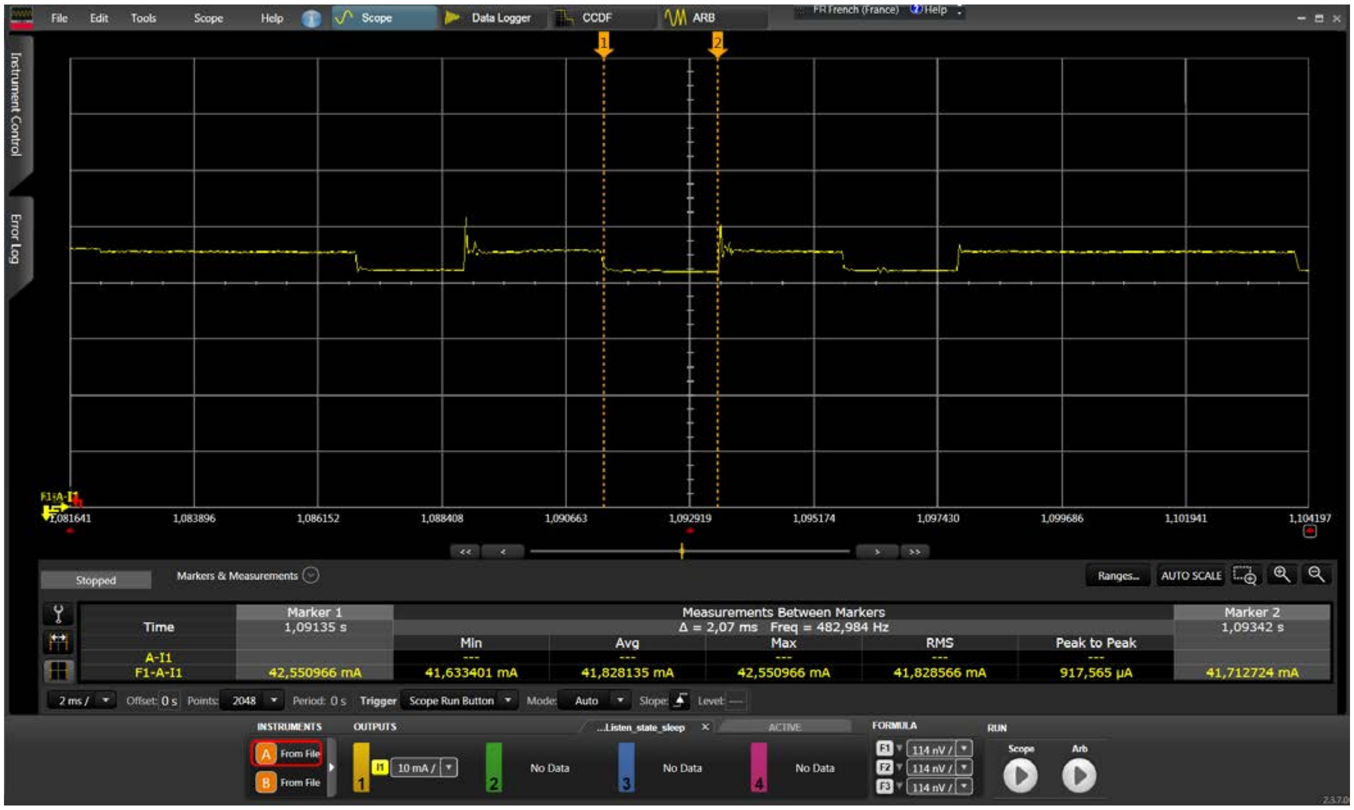
Time	Marker 1	Measurements Between Markers					Marker 2
	-1,838 ms	Δ = 1,85 ms Freq = 540,493 Hz					12 µs
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	45,081407 mA	14,394124 mA	154,124682 mA	199,991852 mA	154,972488 mA	185,597728 mA	14,394124 mA

1 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.3. Zoom on TX Burst Current Consumption in Power Save Mode

4.1.2 RX Burst Current Consumption

Use this command for RX current consumption with power save mode disabled in Linux OS: [**sudo iw dev wlan0 set power_save off**].

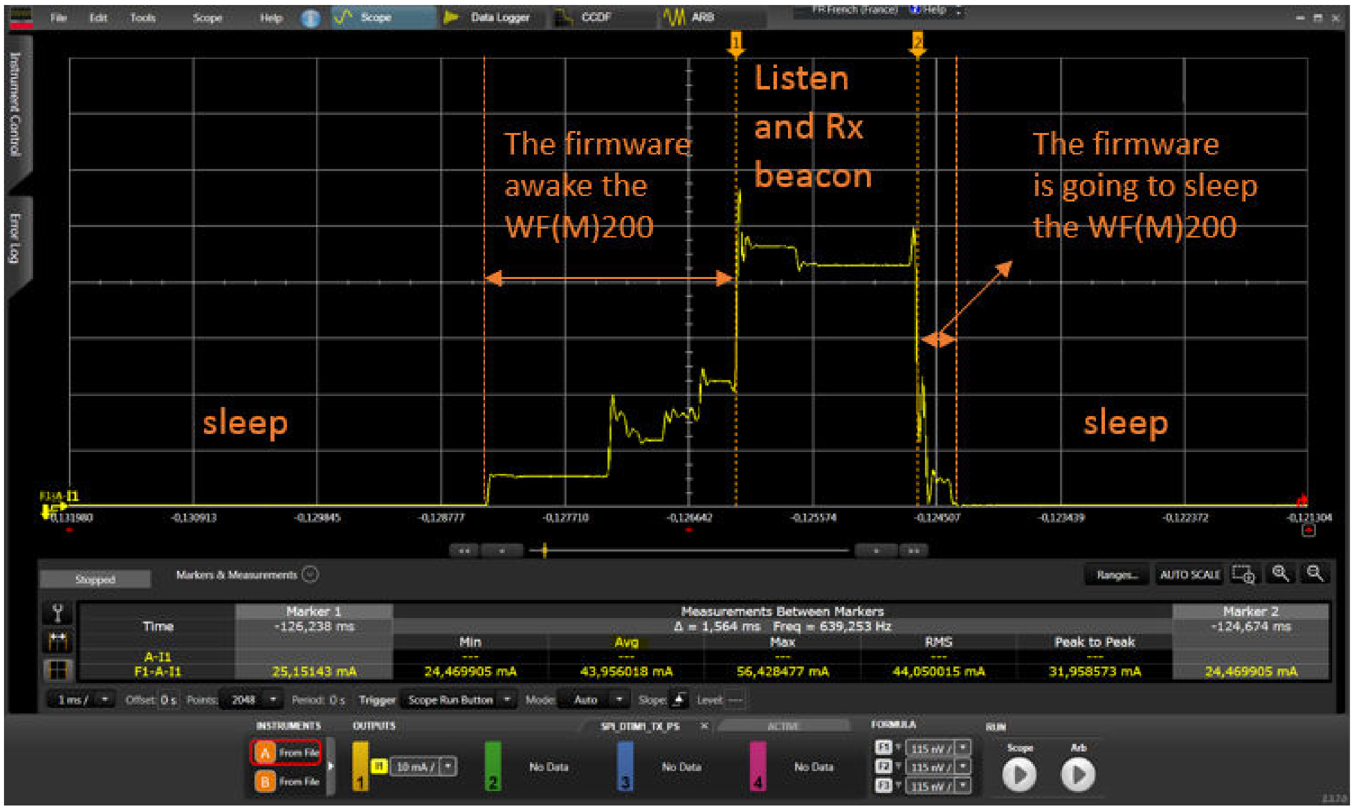


Time	Marker 1	Measurements Between Markers					Marker 2
	1,09135 s	Δ = 2,07 ms Freq = 482,984 Hz					1,09342 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	42,550966 mA	41,633401 mA	41,828135 mA	42,550966 mA	41,828566 mA	917,565 µA	41,712724 mA

2 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: —

Figure 4.4. RX Burst Current Consumption

Use this command for RX current consumption with power save mode enabled in DTIM1 in Linux OS: [**sudo iw dev wlan0 set power_save on**].



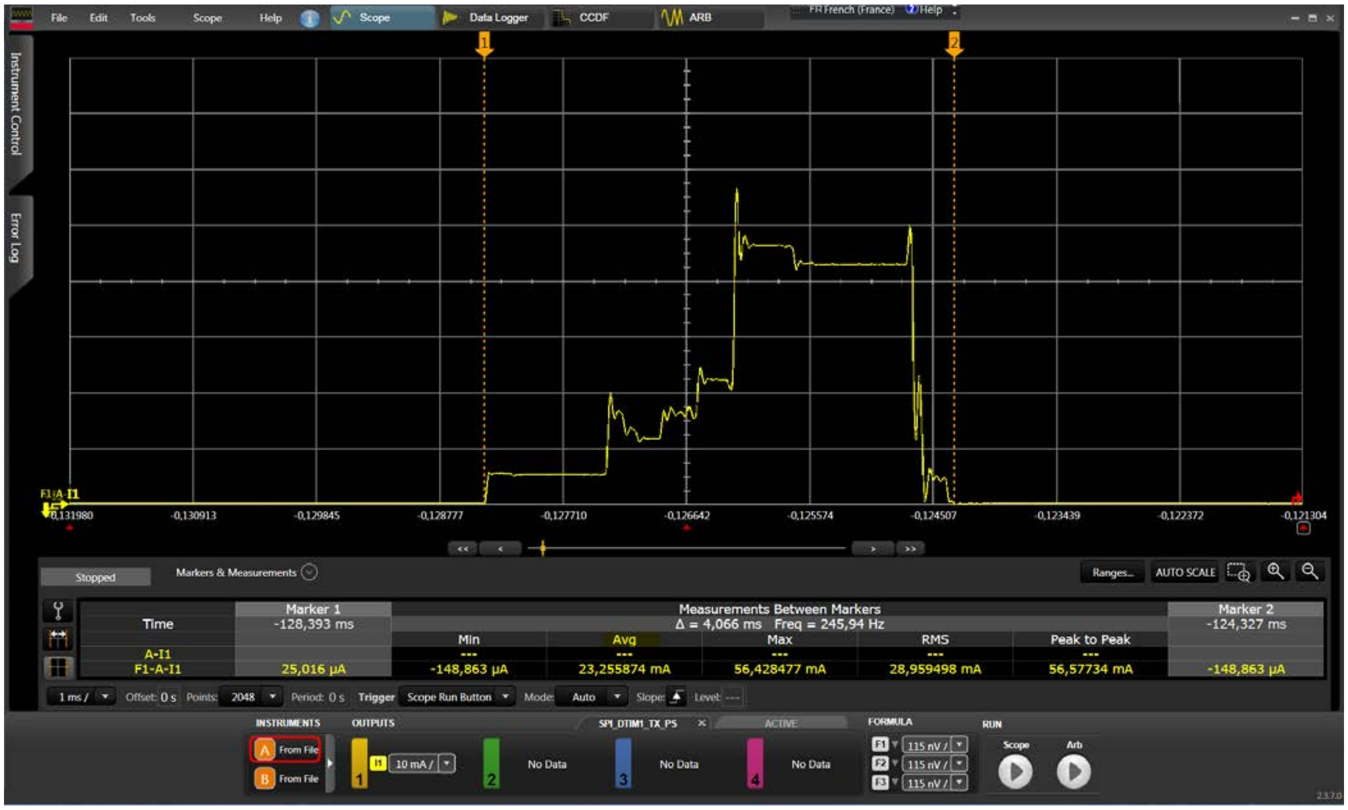
Time	Marker 1	Measurements Between Markers					Marker 2
	-126,238 ms	Δ = 1,564 ms Freq = 639,253 Hz					-124,674 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	25,15143 mA	24,469905 mA	43,956018 mA	56,428477 mA	44,050015 mA	31,958573 mA	24,469905 mA

1 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.5. RX Burst Current Consumption in Power Save Mode

Nothing is required for the RX current consumption. In power save mode, after association with an Access Point without data traffic, you should only see the RX beacon with a time interval equal to DTIM period multiply by the beacon interval. However, you could also see some TX or longer RX because TCP/IP or upper layers need to send or receive packets.

Global RX beacon current consumption and time duration in DTIM:



Time	Marker 1 -128,393 ms	Measurements Between Markers Δ = 4,066 ms Freq = 245,94 Hz					Marker 2 -124,327 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	25,016 µA	-148,863 µA	23,255874 mA	56,428477 mA	28,959498 mA	56,57734 mA	-148,863 µA

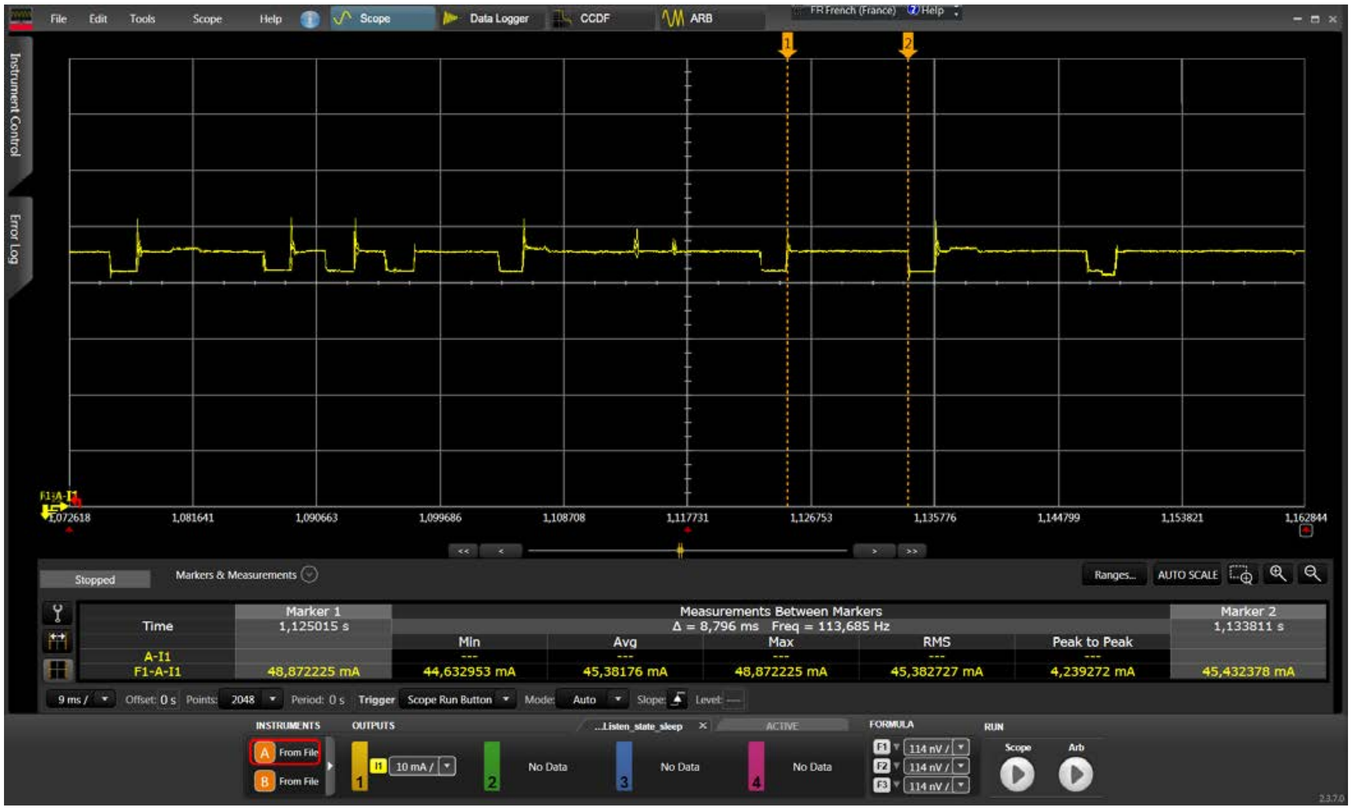
1 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.6. Global RX Burst Current Consumption in Power Save Mode

4.1.3 Listen State Current Consumption

To get this state, the power save mode should be disabled using the following command: [**sudo iw dev wlan0 set power_save off**].

This is an example of averaged current consumption in the listen state.



	Marker 1	Measurements Between Markers					Marker 2
Time	1,125015 s	Δ = 8,796 ms Freq = 113,685 Hz					1,133811 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	48,872225 mA	44,632953 mA	45,38176 mA	48,872225 mA	45,382727 mA	4,239272 mA	45,432378 mA

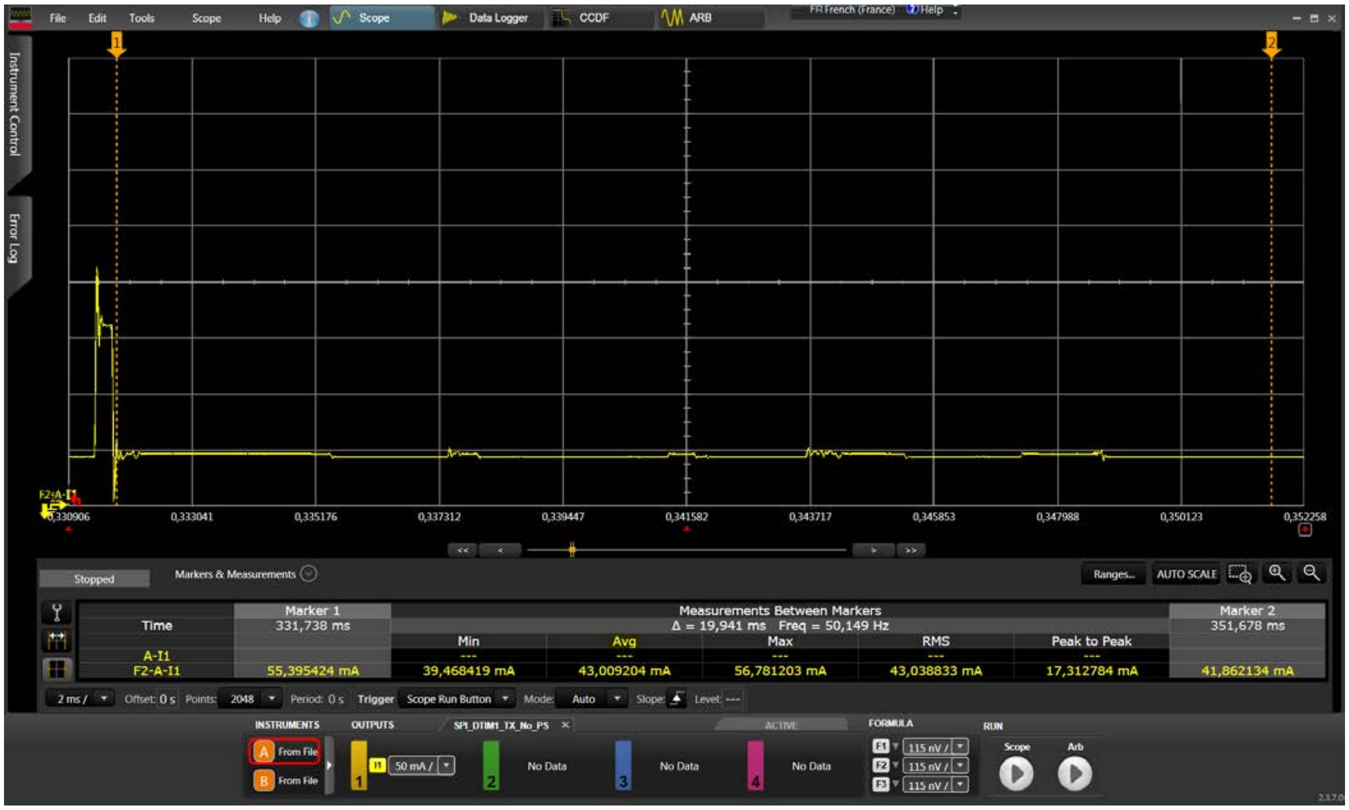
9 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.7. Listen Current Consumption

The averaged current consumption in listen state is ~45.4 mA.

This figure shows the RX state with a lower current consumption step with ~42 mA. It also shows the WF(M)200 switching between Listen and RX modes. In listen, the current consumption is higher because the detection algorithm is running in this mode.

Averaged current consumption with RX and Listen state between marker 1 and 2 (after a TX burst):



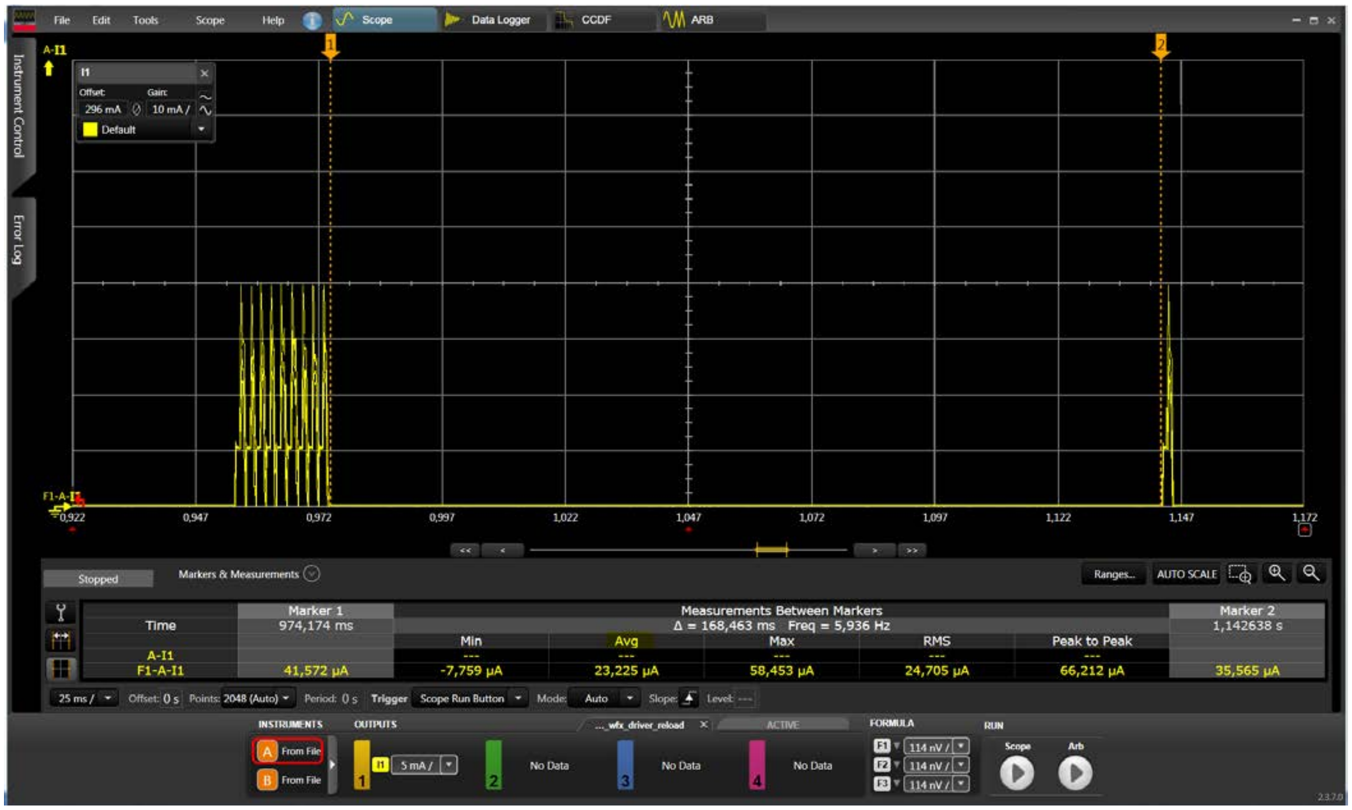
	Marker 1	Measurements Between Markers					Marker 2
Time	331,738 ms	Δ = 19,941 ms Freq = 50,149 Hz					351,678 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	55,395424 mA	39,468419 mA	43,009204 mA	56,781203 mA	43,038833 mA	17,312784 mA	41,862134 mA

2 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.8. Global RX and Listen Current Consumption

4.1.4 Sleep Mode/State Current Consumption

This is an example of averaged current consumption in sleep between SPI accesses from the Host to WF(M)200 after the firmware download and the boot is done.

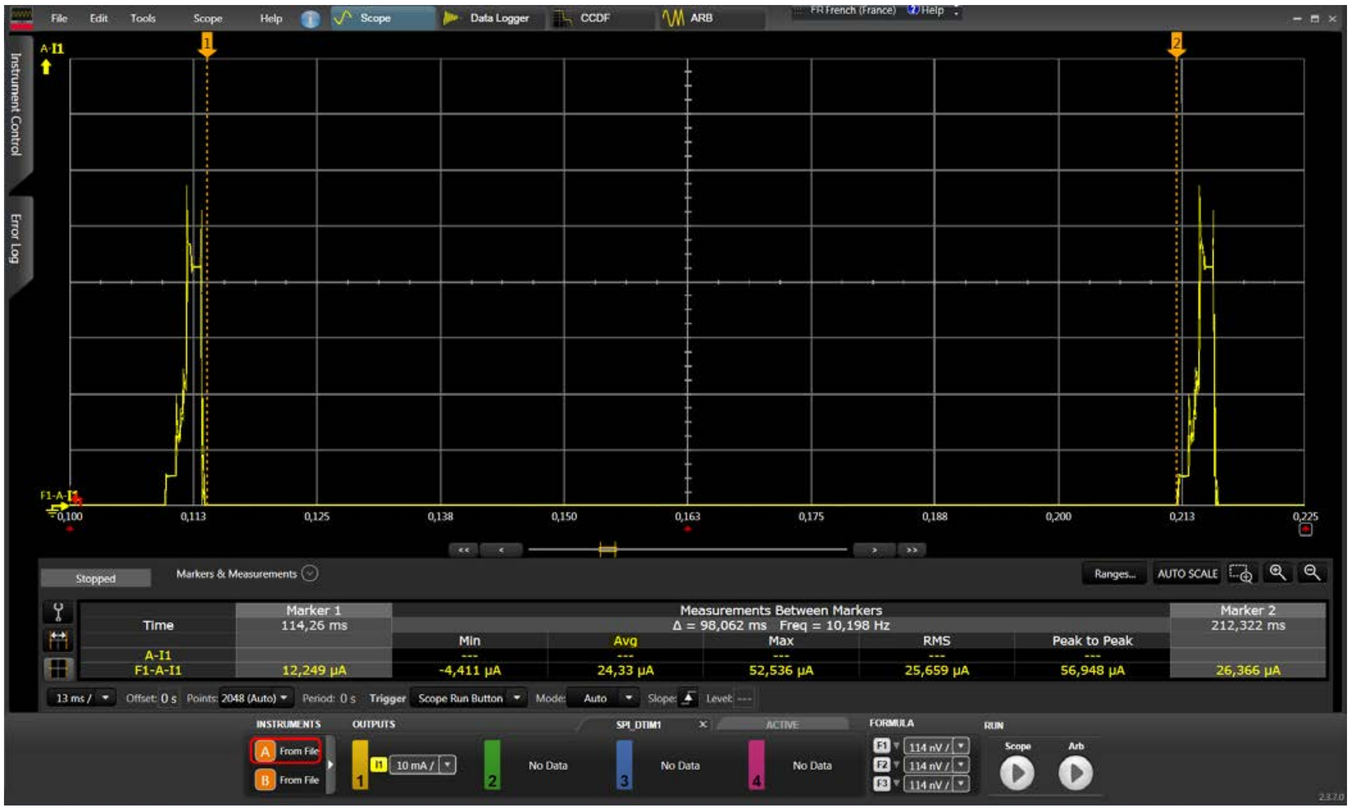


	Marker 1	Measurements Between Markers					Marker 2
Time	974,174 ms	Δ = 168,463 ms Freq = 5,936 Hz					1,142638 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	41,572 µA	-7,759 µA	23,225 µA	58,453 µA	24,705 µA	66,212 µA	35,565 µA

Figure 4.9. Sleep Current Consumption when not Associated

When not associated to a Wi-Fi Access Point, the WF(M)200 can switch to this mode.

To get this state when associated to an Access Point, the power save mode should be enabled using the following command: [**sudo iw dev wlan0 set power_save on**]. This is an example of averaged current consumption in DTIM1 between two RX beacons:



	Marker 1	Measurements Between Markers					Marker 2
Time	114,26 ms	Δ = 98,062 ms Freq = 10,198 Hz					212,322 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	12,249 µA	-4,411 µA	24,33 µA	52,536 µA	25,659 µA	56,948 µA	26,366 µA

13 ms / Offset: 0 s Points: 2048 (Auto) Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.10. Sleep Current Consumption in Power Save Mode DTIM1

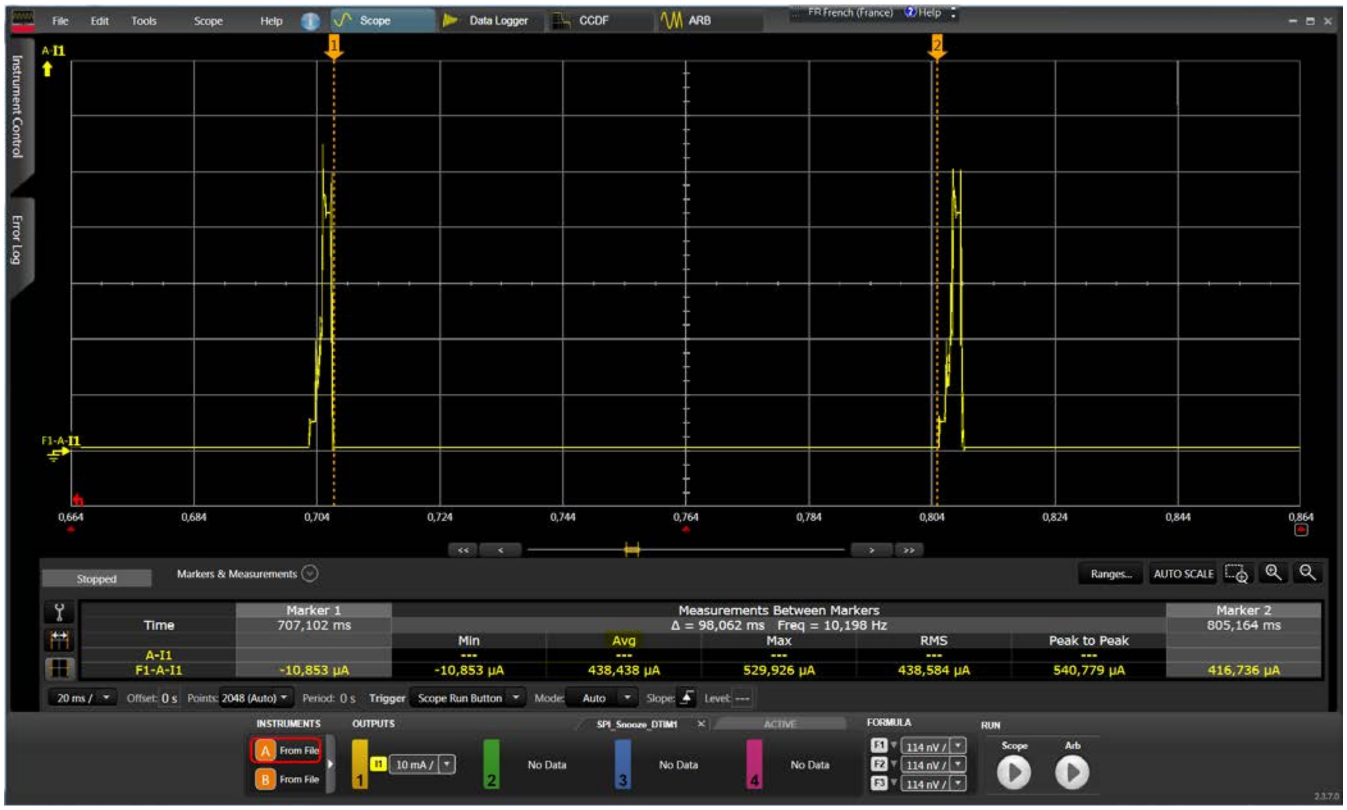
The averaged current consumption is close to ~24 µA for the part measured. Keep in mind that some fluctuations are possible depending on the part used.

4.1.5 Sleep with XO ON Current Consumption

To get this level of current consumption, set the field XTAL_SHARED in the PDS file in the section HF_CLK to yes as follows:

```
HF_CLK: {
    // XTAL_SHARED to indicate if the crystal is shared with another IC and thus must be kept ac-tive during
sleep
    XTAL_SHARED : yes,
}
```

This is an example of averaged current consumption profile in this mode in DTIM1 between two RX beacons with power save mode enabled:



	Marker 1	Measurements Between Markers					Marker 2
Time	707,102 ms	Δ = 98,062 ms Freq = 10,198 Hz					805,164 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	-10,853 µA	-10,853 µA	438,438 µA	529,926 µA	438,584 µA	540,779 µA	416,736 µA

20 ms / Offset: 0 s Points: 2048 (Auto) Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.11. Sleep with XO ON Current Consumption in Power Save Mode DTIM1

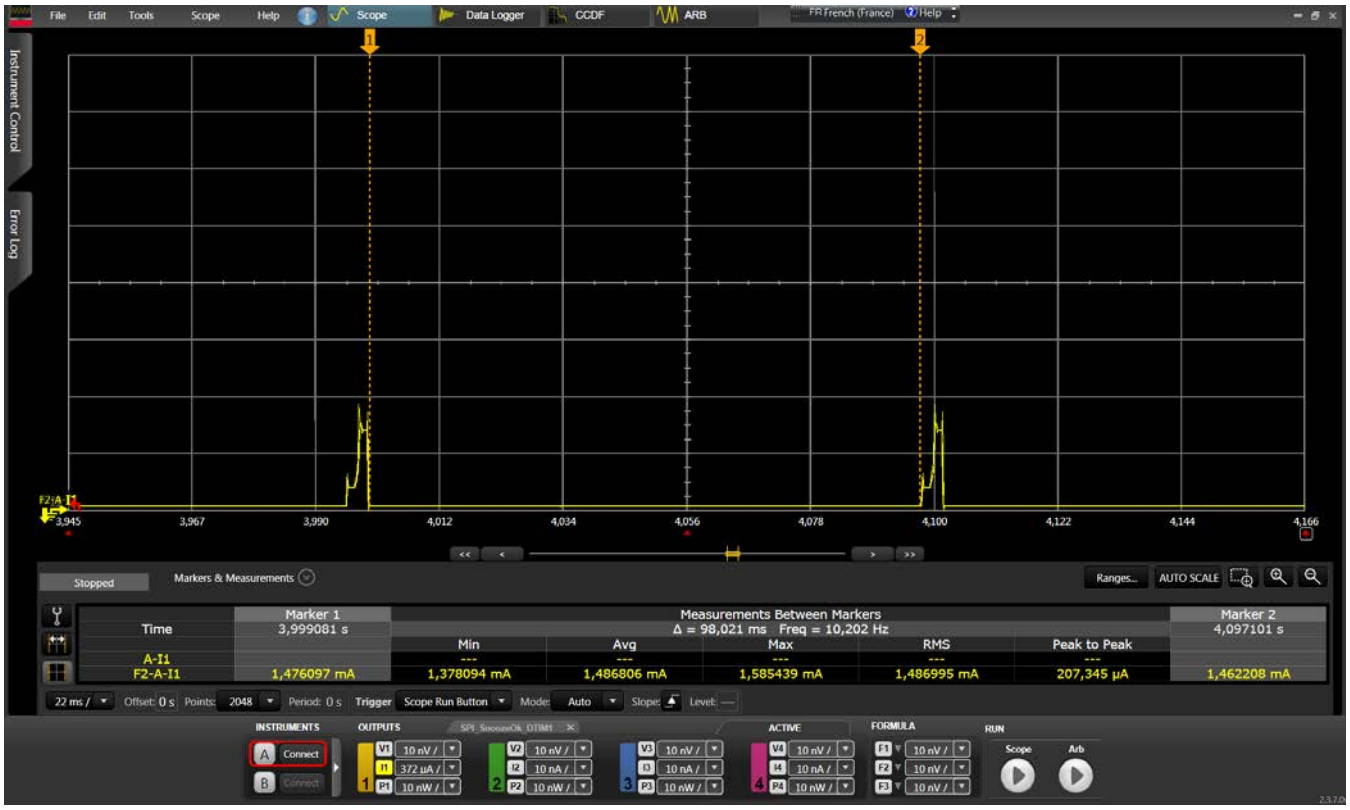
The average current consumption in this state between marker 1 and 2 is 438.4 µA.

In sleep with XO ON mode, the averaged current consumption in DTIM1 is ~1.330 mA.

4.1.6 Snooze Current Consumption

To get this level of current consumption, disable the LP_CLK. With BRD8022/BRD8023, this can be done by removing the R645 (0 Ohm) resistor.

As expected, the current consumption in power save mode during the snooze mode is higher than in sleep mode.



	Marker 1	Measurements Between Markers Δ = 98,021 ms Freq = 10,202 Hz					Marker 2
Time	3,999081 s	Min	Avg	Max	RMS	Peak to Peak	4,097101 s
A-I1		---	---	---	---	---	
F2-A-I1	1,476097 mA	1,378094 mA	1,486806 mA	1,585439 mA	1,486995 mA	207,345 µA	1,462208 mA

22 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level:

Outputs: V1 10 nV / I1 372 µA / P1 10 nW / ; V2 10 nV / I2 10 nA / P2 10 nW / ; V3 10 nV / I3 10 nA / P3 10 nW / ; V4 10 nV / I4 10 nA / P4 10 nW / ; F1 10 nV / F2 10 nV / F3 10 nV /

Figure 4.12. Snooze Current Consumption in Power Save Mode DTIM1

The average current consumption in this state between marker 1 and 2 is 1.48 mA.

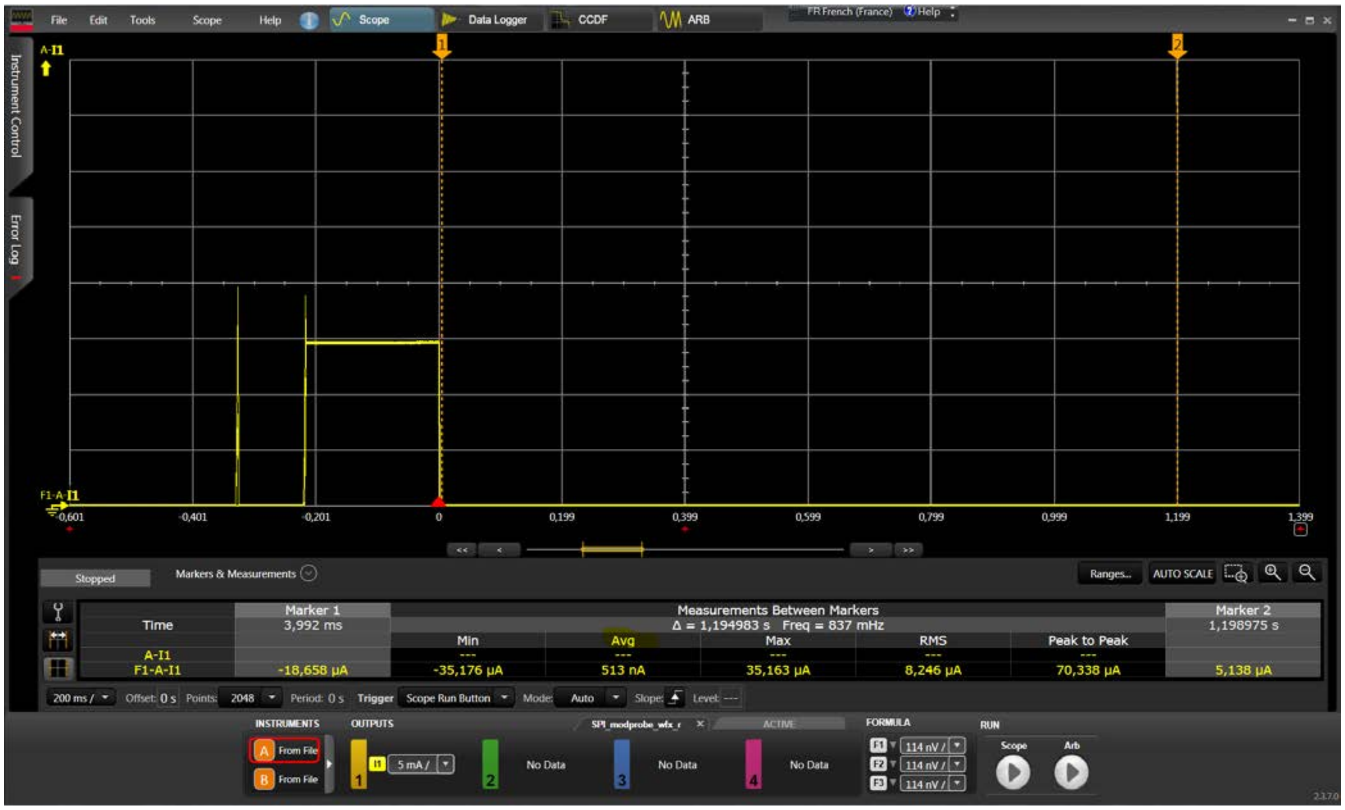
In snooze mode, the averaged current consumption in DTIM3 is ~2.43 mA.

4.1.7 Shutdown Current Consumption

To get this mode, after loading the firmware in the WF(M)200 and booting it, launch the following Linux OS command to release the WFX driver: [**sudo modprobe wfx –r**]

Before marker 1, note the current consumption from the host to request the shutdown.

Between marker 1 and 2, the averaged current consumption is achieved during shutdown:



	Marker 1	Measurements Between Markers					Marker 2
Time	3,992 ms	Δ = 1,194983 s Freq = 837 mHz					1,198975 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	-18,658 µA	-35,176 µA	513 nA	35,163 µA	8,246 µA	70,338 µA	5,138 µA

200 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

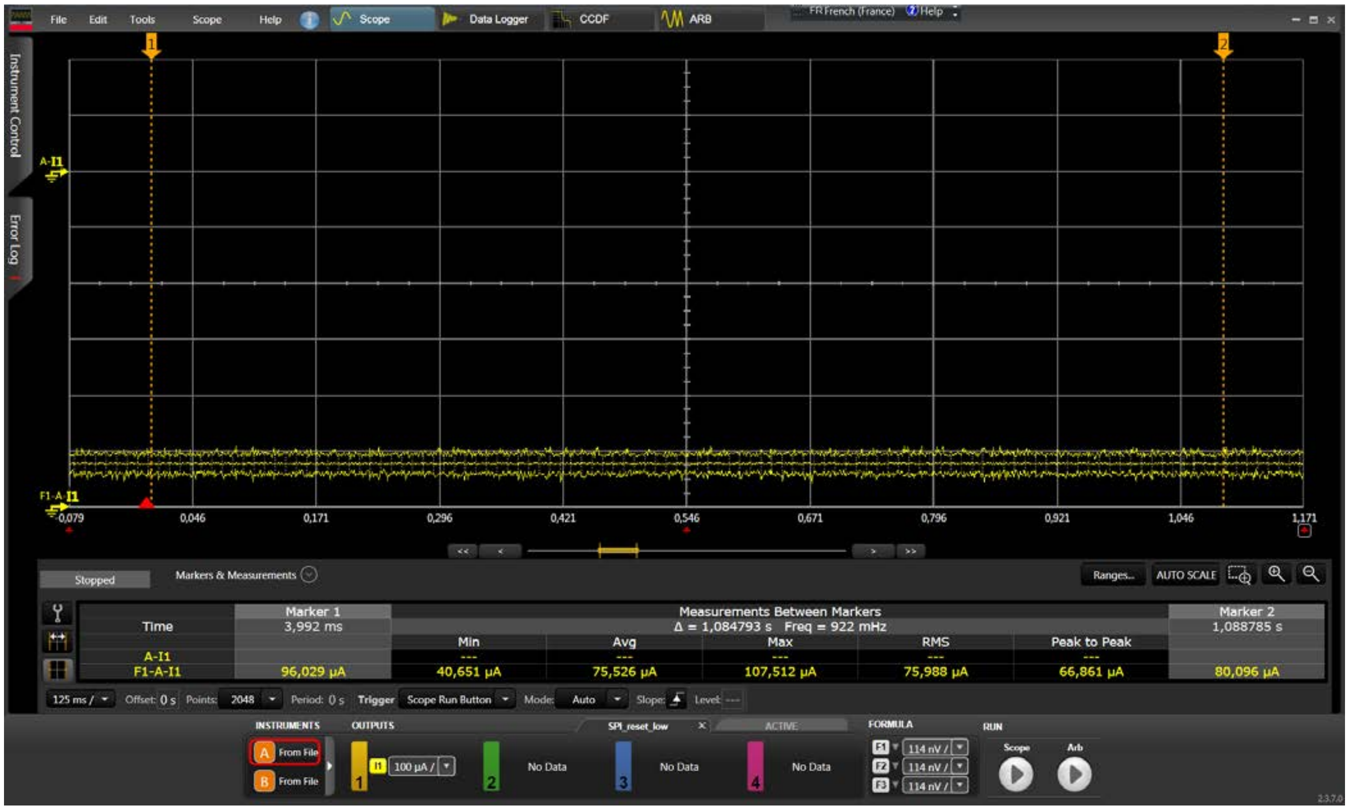
Figure 4.13. Shutdown Current Consumption

The averaged current consumption is ~513 nA.

After this mode, reload the firmware and the PDS file. In Linux OS, use: [**sudo modprobe wfx**] (or use the script provided with SD card: wfx_driver_reload).

4.1.8 Reset Current Consumption

The following is the current consumption after getting the Shutdown mode ([**sudo modprobe wfx –r**]) and pressing the Push Button RESETn on the board. You have to push on the button during all the measurement to get RESETn low during this time.



	Marker 1	Measurements Between Markers					Marker 2
Time	3,992 ms	Δ = 1,084793 s Freq = 922 mHz					1,088785 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	96,029 µA	40,651 µA	75,526 µA	107,512 µA	75,988 µA	66,861 µA	80,096 µA

125 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

I1 100 µA / | 2 No Data | 3 No Data | 4 No Data | F1 114 nV / | F2 114 nV / | F3 114 nV /

Figure 4.14. Current Consumption with WF(M)200 in Reset

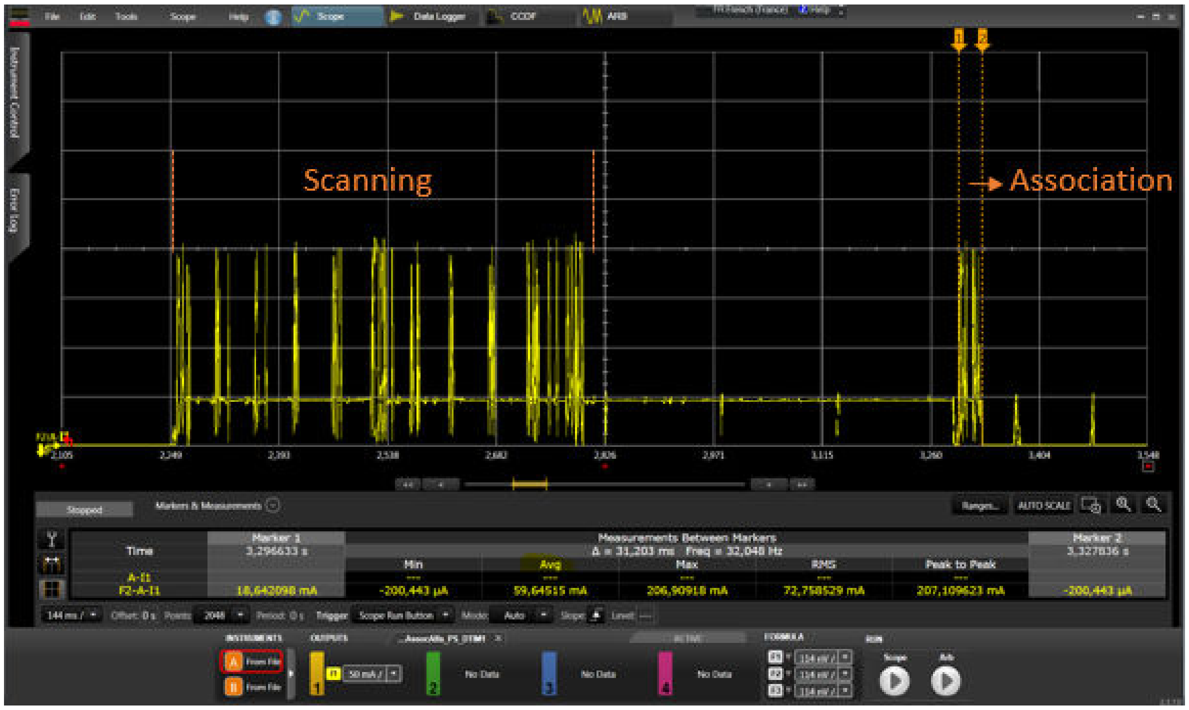
The averaged current consumption of ~75.5 µA results from the internal pull-up in the WF(M)200 on RESETn pin. The current consumption could depend on this internal resistor value (43 Kohm typical) inside the part. This consumption is higher than in shutdown mode.

Note: After a RESETn low and when high (without firmware loaded), the WF(M)200 current consumption is ~4.6 mA (the same after power supply off on cycle)

After this mode, reload the firmware and the PDS file. In Linux OS, use the following command: [**sudo modprobe wfx**] (or use the script provided with SD card: wfx_driver_reload).

4.1.9 Time and Consumption during Association to an Access Point

The following is an example current consumption during association to an Access Point after a scan step:

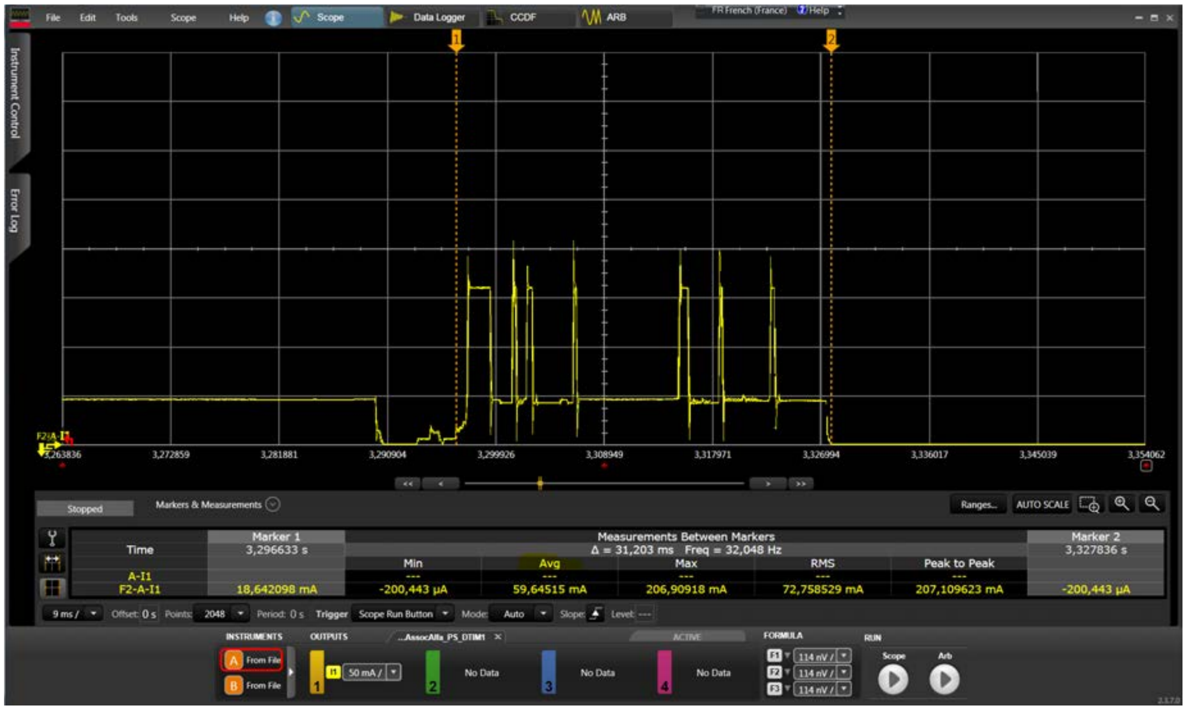


	Marker 1	Measurements Between Markers					Marker 2
Time	3,296633 s	Δ = 31,203 ms Freq = 32,048 Hz					3,327836 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	18,642098 mA	-200,443 µA	59,64515 mA	206,90918 mA	72,758529 mA	207,109623 mA	-200,443 µA

144 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.15. Association Current Consumption

Zoom on the Association step showing an averaged current consumption of 59.65 mA:



	Marker 1	Measurements Between Markers					Marker 2
Time	3,296633 s	Δ = 31,203 ms Freq = 32,048 Hz					3,327836 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	18,642098 mA	-200,443 µA	59,64515 mA	206,90918 mA	72,758529 mA	207,109623 mA	-200,443 µA

9 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

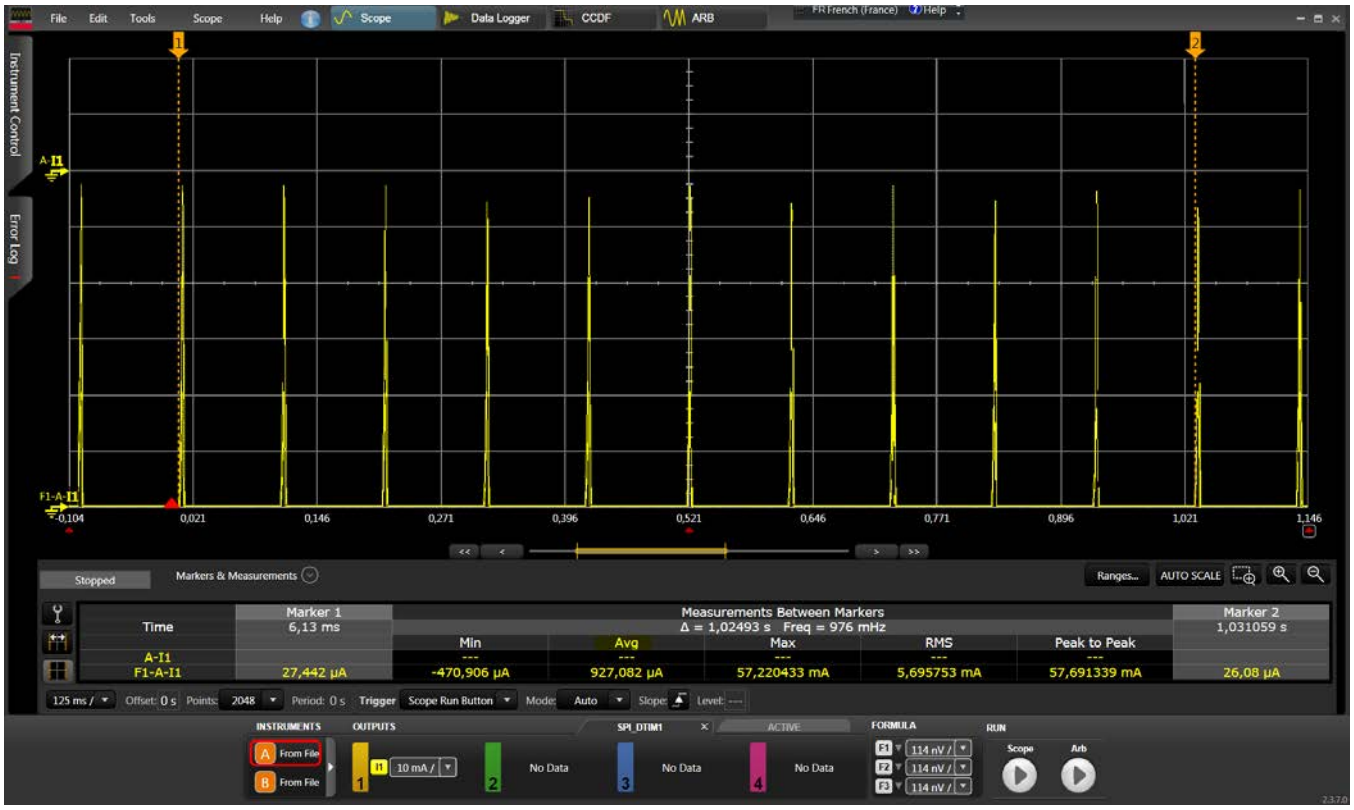
Figure 4.16. Zoom on Association Current Consumption

4.1.10 Power Save Mode when Associated under DTIM 1

To get this mode, associate the WF(M)200 with an Access Point with power save mode enabled using the following command in Linux OS: [**sudo iw dev wlan0 set power_save on**].

Then, configure the Access Point in DTIM1 with a beacon interval of 102.4 ms and a beacon time duration of 1ms.

The following is an example of DTIM1 current consumption:



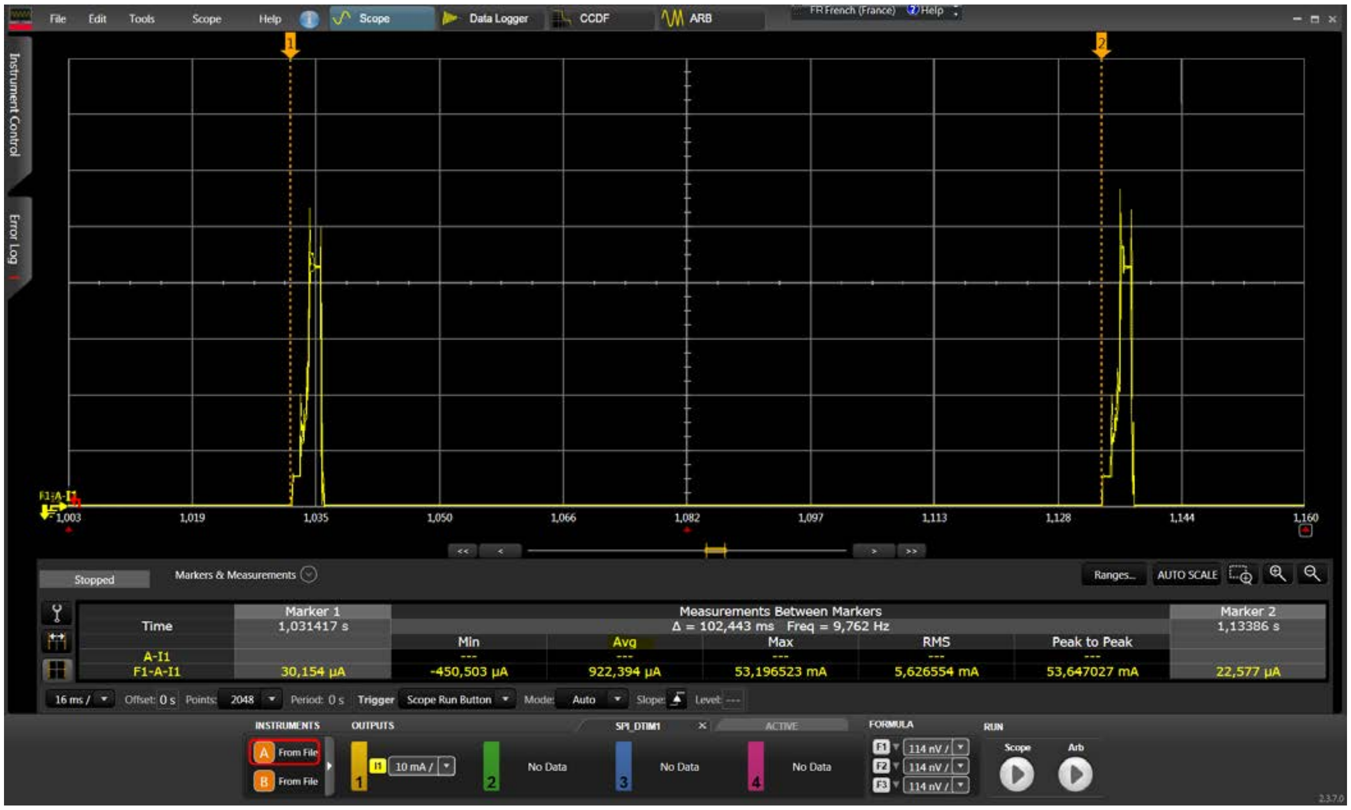
	Marker 1	Measurements Between Markers Δ = 1,02493 s Freq = 976 mHz					Marker 2
Time	6,13 ms	Min	Avg	Max	RMS	Peak to Peak	1,031059 s
A-I1		---	---	---	---	---	
F1-A-I1	27,442 µA	-470,906 µA	927,082 µA	57,220433 mA	5,695753 mA	57,691339 mA	26,08 µA

Figure 4.17. Averaged Current Consumption in DTIM1

The 927 µA is measured in DTIM1 when the WF(M)200 receives all beacons (averaged on 10 DTIM intervals). Ensure that you do not include a use case with TX inside the two markers.

Note: DTIM figures in this document are not identical to those mentioned in WF(M)200 data sheets. Figures in the data sheet are meant for comparison with competitive devices and are measured with a firmware implementing a lower time margin during wake up for beacons reception. The firmware used for measurements in this document implements a little bit more margin to improve interoperability because some APs have a potential drift on beacons.

The following is a zoom on two RX beacons:

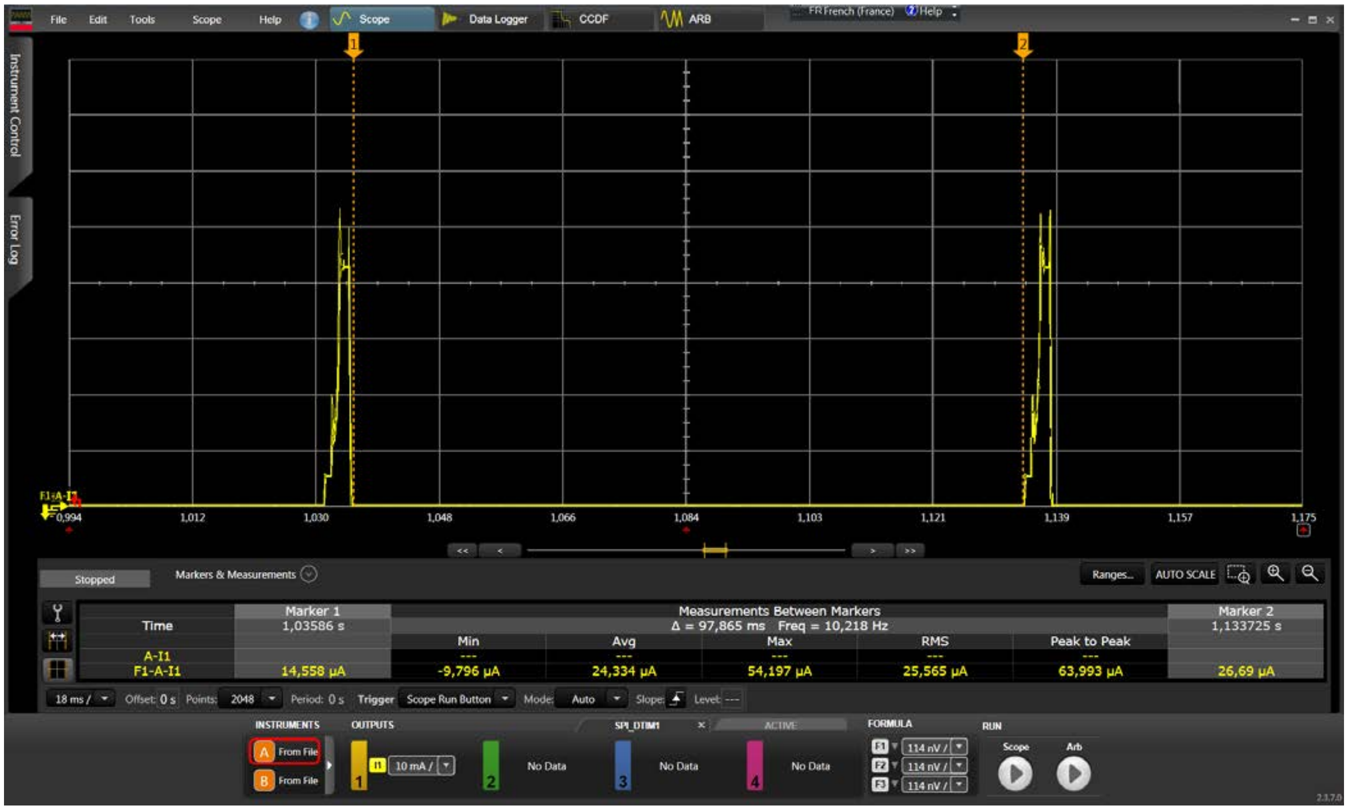


	Marker 1	Measurements Between Markers					Marker 2
Time	1,031417 s	Δ = 102,443 ms Freq = 9,762 Hz					1,13386 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	30,154 µA	-450,503 µA	922,394 µA	53,196523 mA	5,626554 mA	53,647027 mA	22,577 µA

16 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.18. Current Consumption in DTIM1

The following is a use case with a marker between the two RX DTIM1 beacons providing the sleep state current consumption:



	Marker 1	Measurements Between Markers					Marker 2
Time	1,03586 s	Δ = 97,865 ms Freq = 10,218 Hz					1,133725 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	14,558 µA	-9,796 µA	24,334 µA	54,197 µA	25,565 µA	63,993 µA	26,69 µA

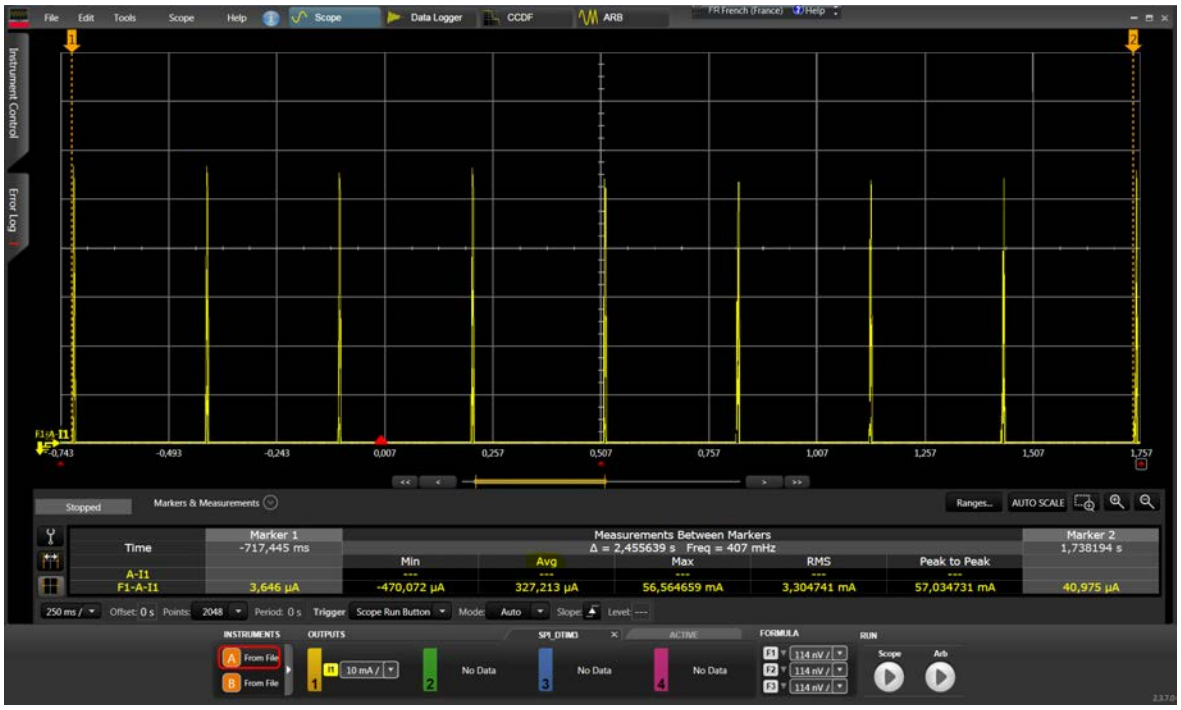
18 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.19. Sleep Current Consumption between RX in DTIM1

4.1.11 Power Save Mode when Associated under DTIM 3

To get this mode, associate the WF(M)200 with an Access Point with power save mode enabled. Then, configure the Access Point in DTIM3 with a beacon interval of 102.4 ms and a beacon time duration of 1 ms.

The following is an example of DTIM3 current consumption:



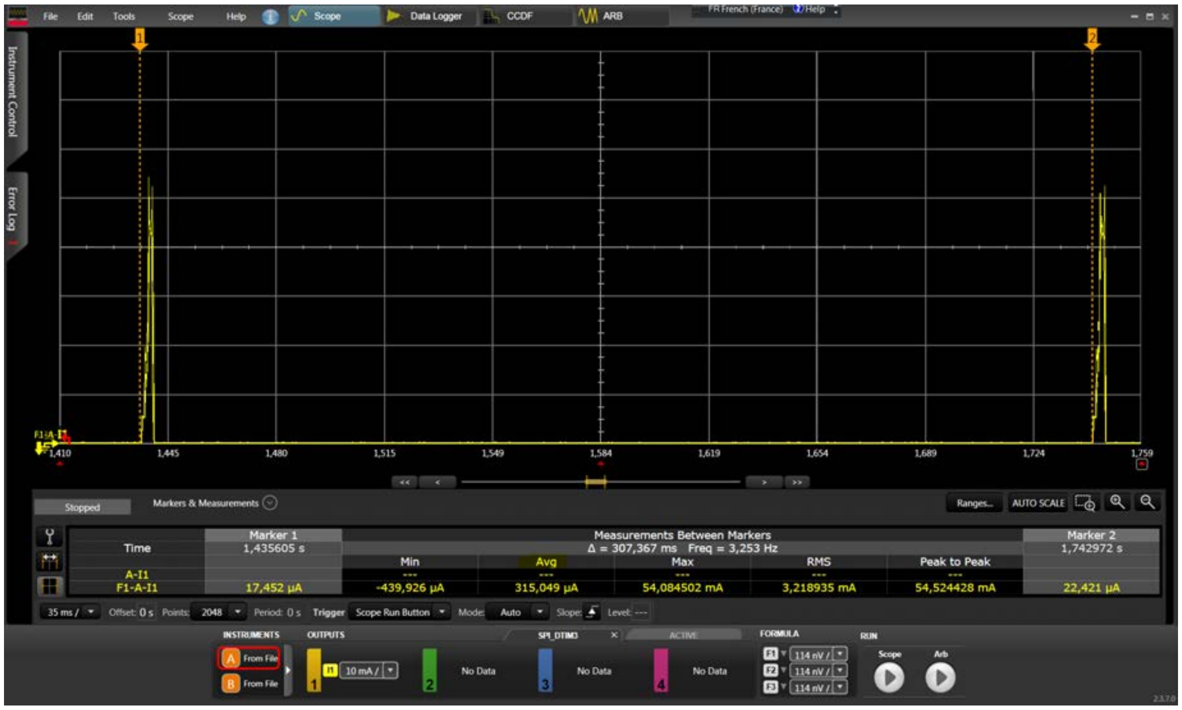
	Marker 1	Measurements Between Markers Δ = 2,455639 s Freq = 407 mHz					Marker 2
Time	-717,445 ms	Min	Avg	Max	RMS	Peak to Peak	1,738194 s
A-I1		---	---	---	---	---	
F1-A-I1	3,646 µA	-470,072 µA	327,213 µA	56,564659 mA	3,304741 mA	57,034731 mA	40,975 µA

250 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.20. Averaged Current Consumption in DTIM3

The ~327 µA are measured in DTIM3 when the WF(M)200 receives only one over 3 beacons (averaged on 8 DTIM3 periods).

The following is a zoom on two RX beacons:



	Marker 1	Measurements Between Markers Δ = 307,367 ms Freq = 3,253 Hz					Marker 2
Time	1,435605 s	Min	Avg	Max	RMS	Peak to Peak	1,742972 s
A-I1		---	---	---	---	---	
F1-A-I1	17,452 µA	-439,926 µA	315,049 µA	54,084502 mA	3,218935 mA	54,524428 mA	22,421 µA

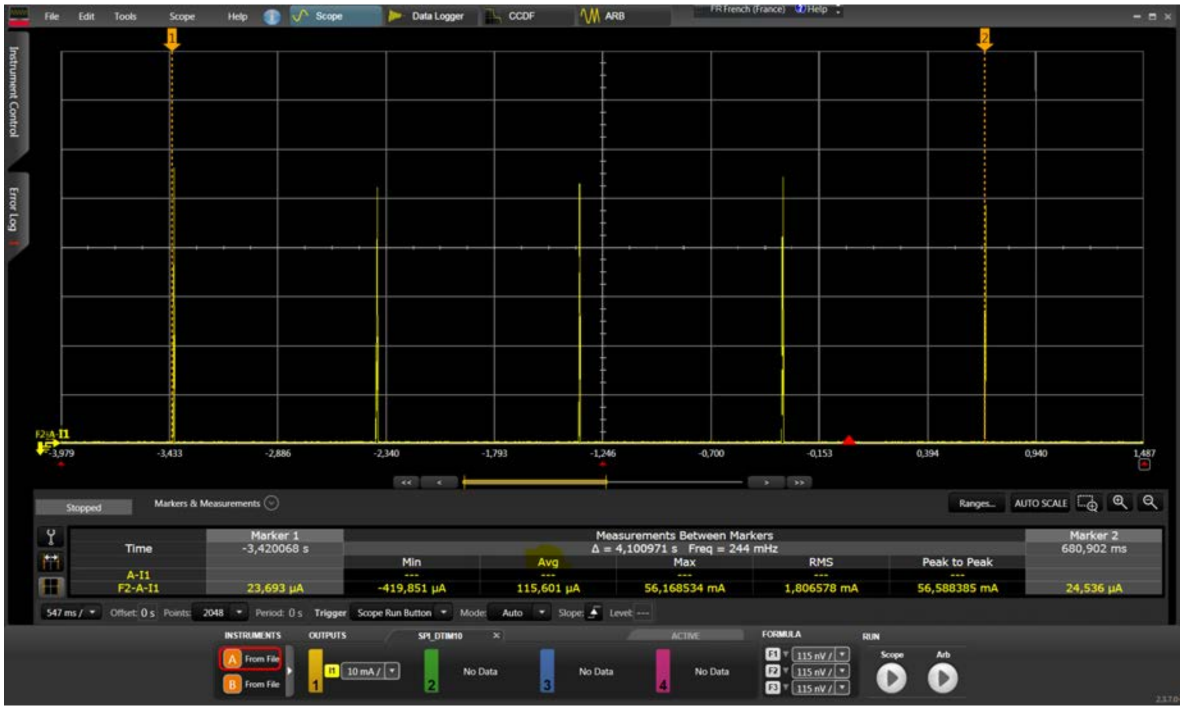
35 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.21. Current Consumption in DTIM3

4.1.12 Power Save Mode when Associated Under DTIM 10

To get this mode, associate the WF(M)200 with an Access Point with power save mode enabled. Then, configure the Access Point in DTIM10 with a beacon interval of 102.4 ms and a beacon time duration of 1 ms.

The following is an example of DTIM10 current consumption:

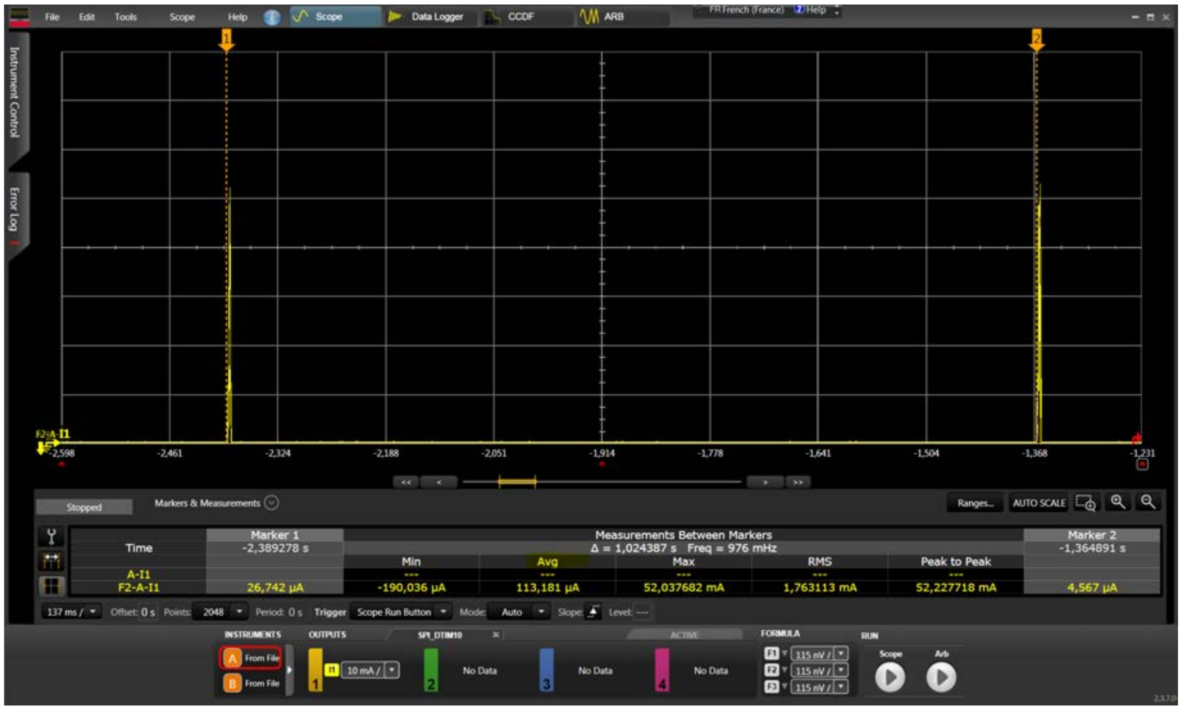


Time	Marker 1	Measurements Between Markers					Marker 2
	-3,420068 s	Δ = 4,100971 s Freq = 244 mHz					680,902 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	23,693 µA	-419,851 µA	115,601 µA	56,168534 mA	1,806578 mA	56,588385 mA	24,536 µA

Figure 4.22. Averaged Current Consumption in DTIM10

The 115 µA is measured in DTIM10 when the WF(M)200 receives only one over 10 beacons (averaged on 4 DTIM10 periods).

The following is a zoom on two RX beacons:



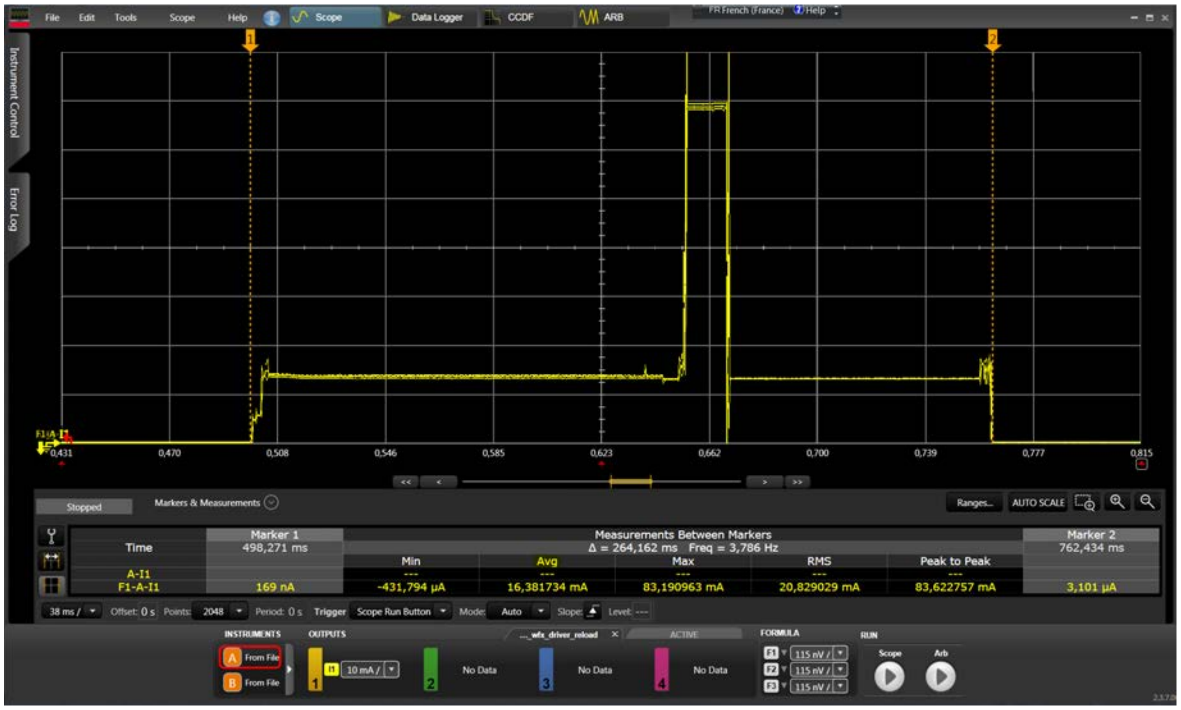
Time	Marker 1	Measurements Between Markers					Marker 2
	-2,389278 s	Δ = 1,024387 s Freq = 976 mHz					-1,364891 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	26,742 µA	-190,036 µA	113,181 µA	52,037682 mA	1,763113 mA	52,227718 mA	4,567 µA

Figure 4.23. Current Consumption in DTIM10

4.2 Other Use Cases

4.2.1 Firmware Download, Boot and Calibration Time, and Current Consumption

The following is an example of the activity you can get on Linux OS after using this command: [**sudo modprobe wfx**] (or the script command [**wfx_driver_reload**]).

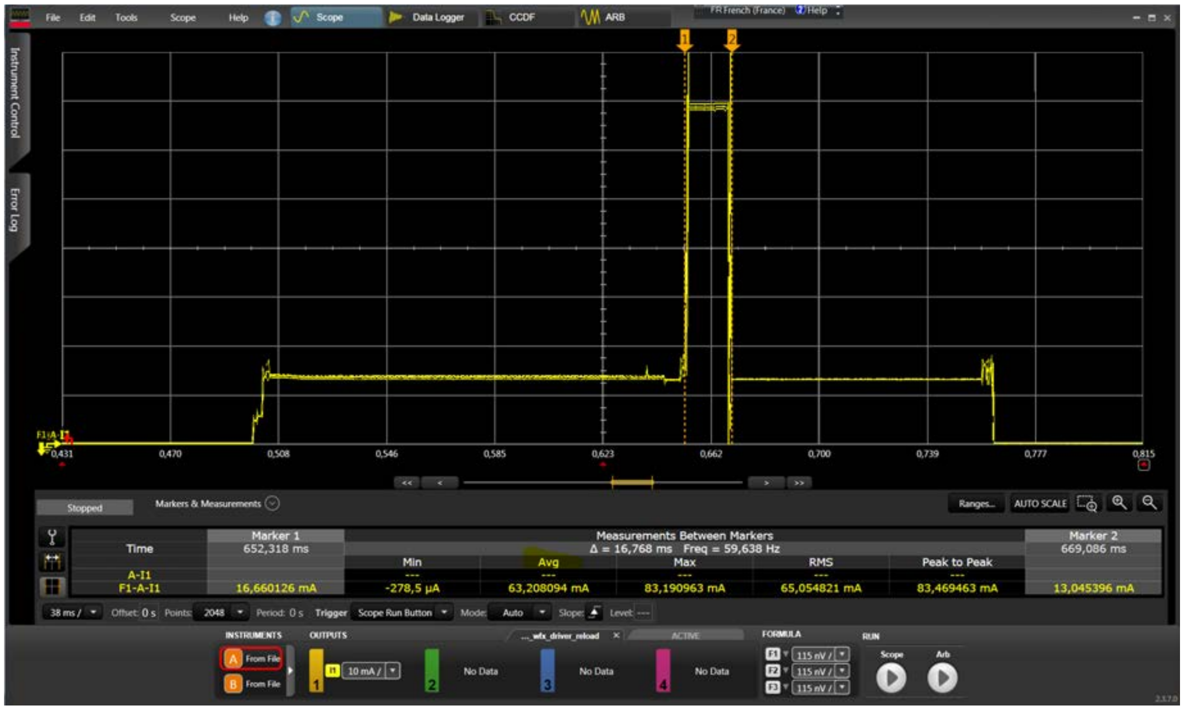


	Marker 1	Measurements Between Markers					Marker 2
Time	498,271 ms	Δ = 264,162 ms Freq = 3,786 Hz					762,434 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	169 nA	-431,794 µA	16,381734 mA	83,190963 mA	20,829029 mA	83,622757 mA	3,101 µA

38 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.24. Firmware Download, Boot, Calibration Current Consumption

The calibration step is between the marker 1 and 2:



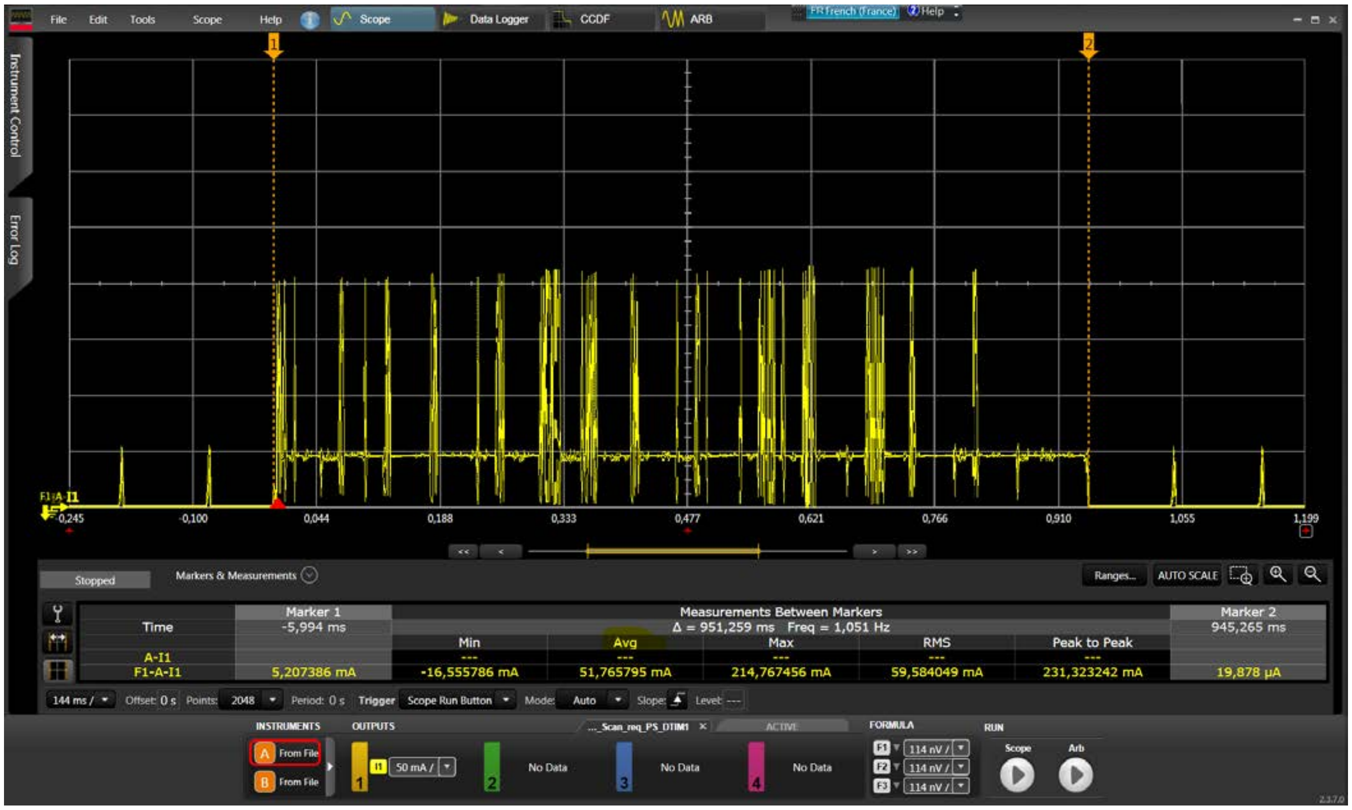
	Marker 1	Measurements Between Markers					Marker 2
Time	652,318 ms	Δ = 16,768 ms Freq = 59,638 Hz					669,086 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	16,660126 mA	-278,5 µA	63,208094 mA	83,190963 mA	65,054821 mA	83,469463 mA	13,045396 mA

38 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.25. Calibration Current Consumption

4.2.2 Time and Consumption during Scan

This is an example of current consumption when requesting a scan using the following command in Linux OS: [**wpa_cli scan**]



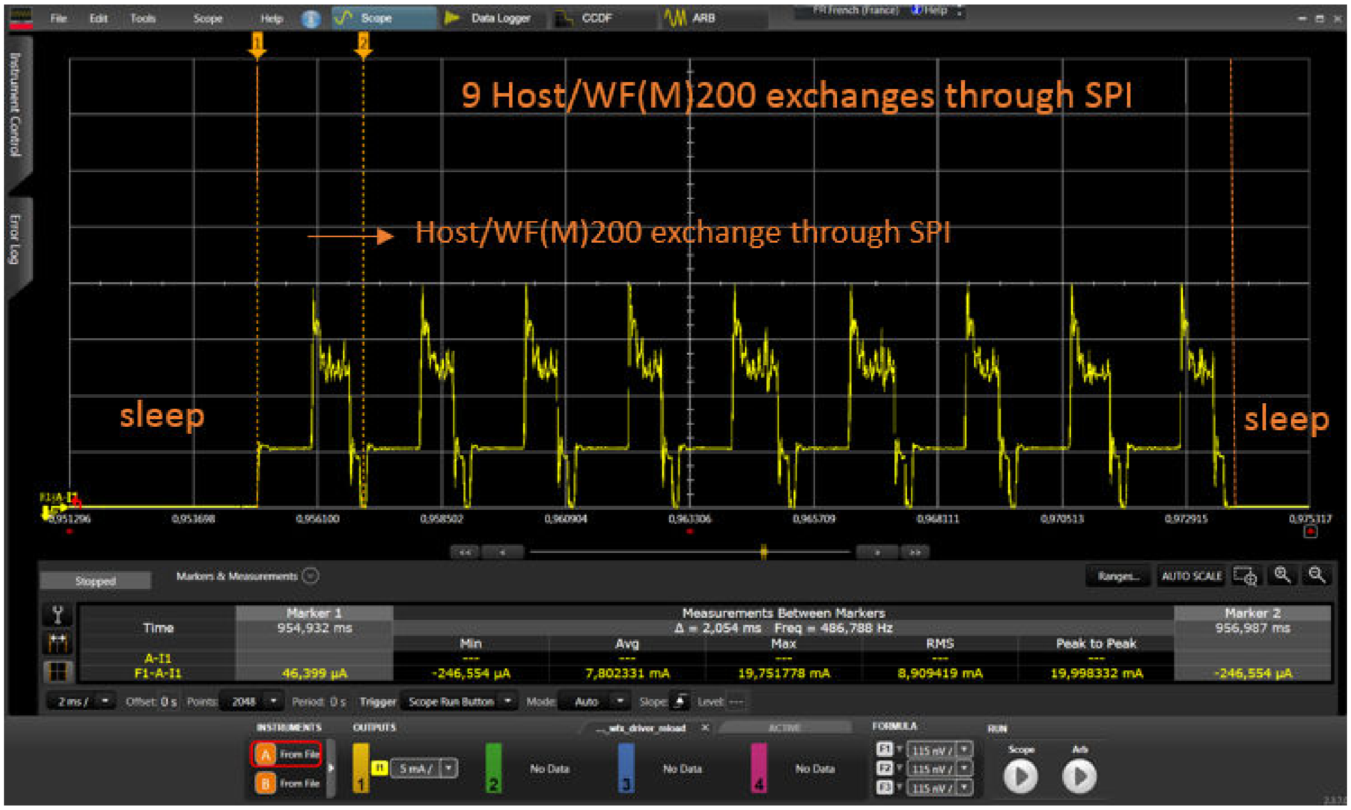
	Marker 1	Measurements Between Markers					Marker 2
Time	-5,994 ms	Δ = 951,259 ms Freq = 1,051 Hz					945,265 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	5,207386 mA	-16,555786 mA	51,765795 mA	214,767456 mA	59,584049 mA	231,323242 mA	19,878 µA

Figure 4.26. Scanning Current Consumption

The Wi-Fi channel scanning causes significant current consumption over a long period of time. To reduce current consumption, avoid this task whenever possible.

4.2.3 Host Sending a Request to the WF(M)200 during Sleep State

The following is an example of current consumption when the WF(M)200 is in sleep mode and the host sends messages through the SPI (9 SPI accesses).



	Marker 1	Measurements Between Markers					Marker 2
Time	954,932 ms	Δ = 2,054 ms Freq = 486,788 Hz					956,987 ms
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	46,399 µA	-246,554 µA	7,802331 mA	19,751778 mA	8,909419 mA	19,998332 mA	-246,554 µA

2 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

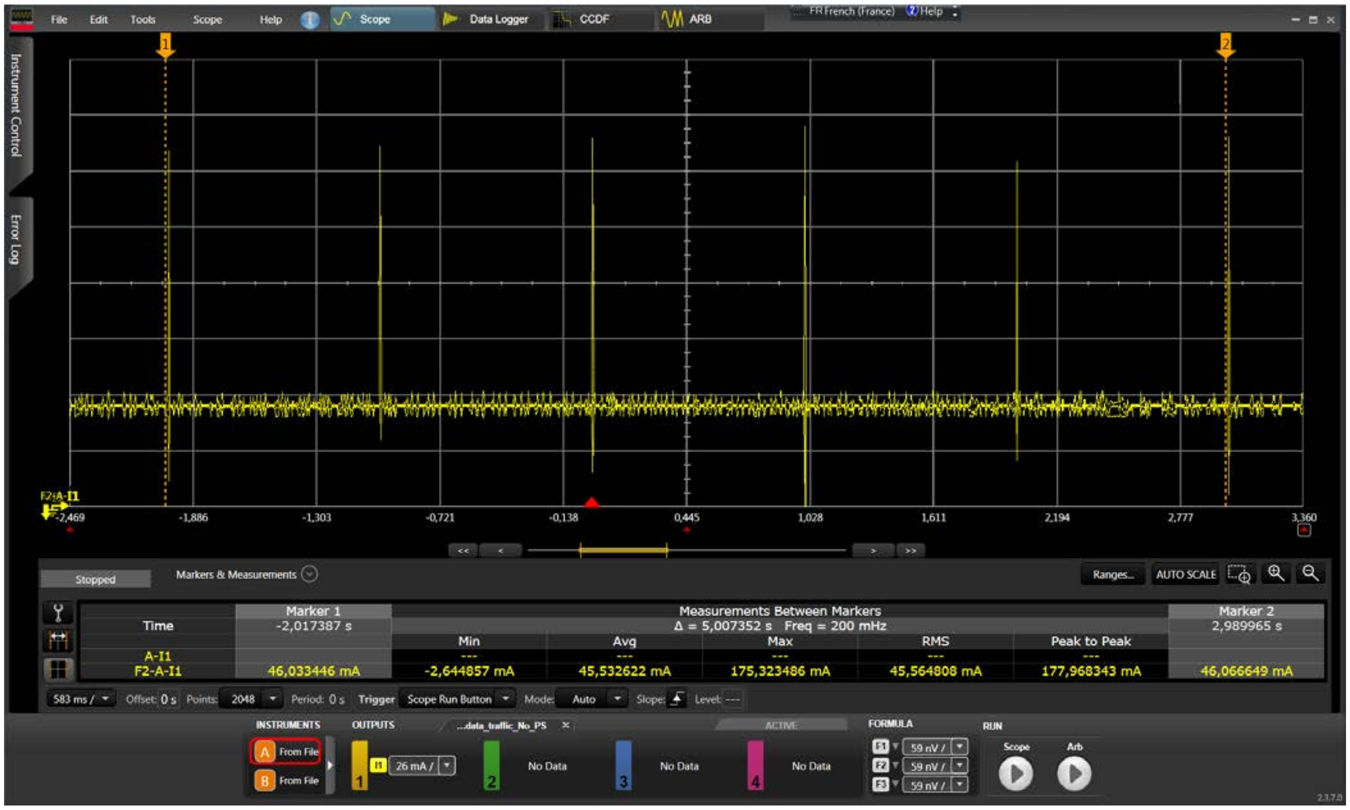
Figure 4.27. Current Consumption when Host Sends Request during Sleep State

The duration of this consumption depends of the SPI/SDIO serial clock used.

4.2.4 Ping Data Traffic

For this measurement, a ping data traffic is launched with 1 ping packet per second (ping packet size of 64 bytes). This is the command in Linux OS: [**ping -I wlan0 IP_address_connected_with_the_access_point**].

The following is an example when the Wi-Fi power save mode is not enabled on WF(M)200.



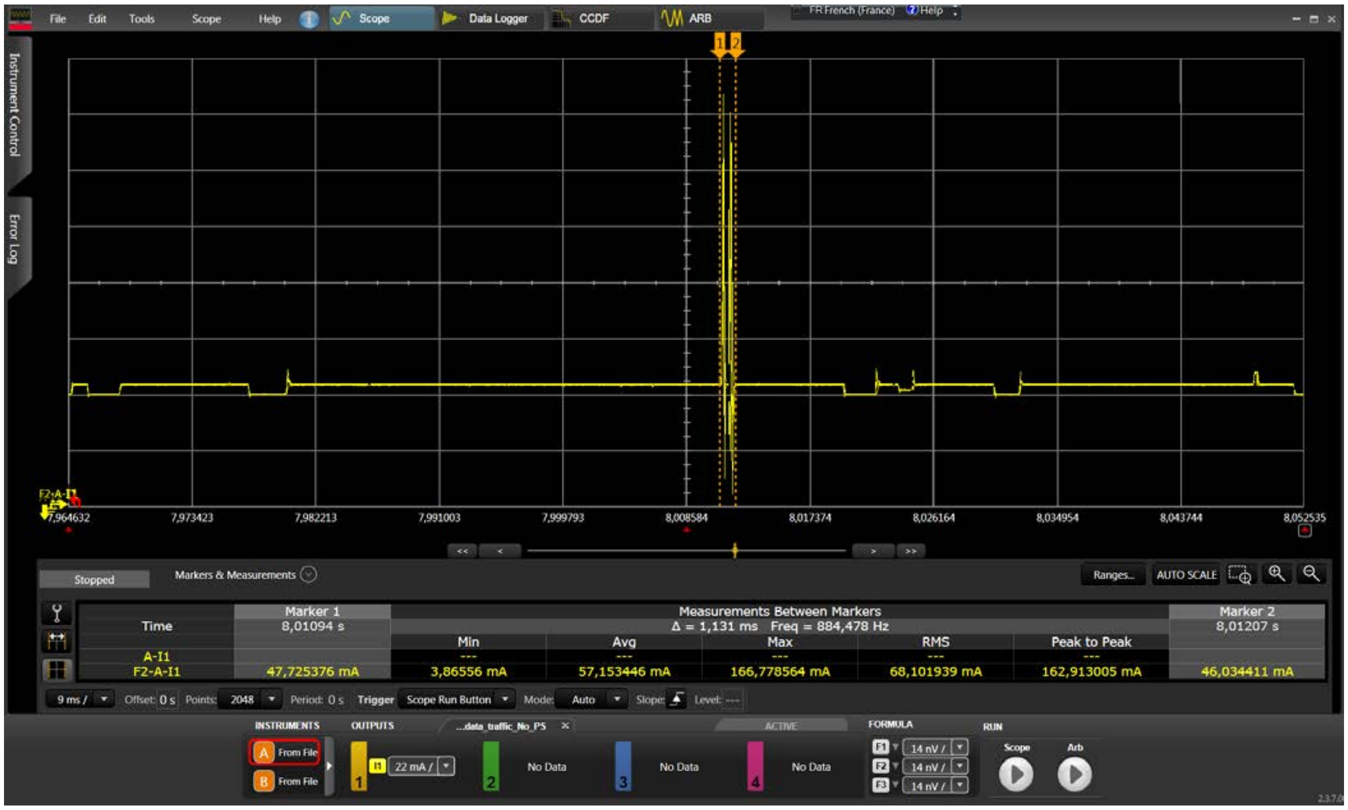
	Marker 1	Measurements Between Markers					Marker 2
Time	-2,017387 s	Δ = 5,007352 s Freq = 200 mHz					2,989965 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	46,033446 mA	-2,644857 mA	45,532622 mA	175,323486 mA	45,564808 mA	177,968343 mA	46,066649 mA

583 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.28. Current Consumption during Ping Traffic without Power Save Mode

The averaged current consumption in this case is 45.5 mA.

The following is a zoom on ping TX that shows TX for the ping request, RX of the ping reply, and finally TX of ACK.

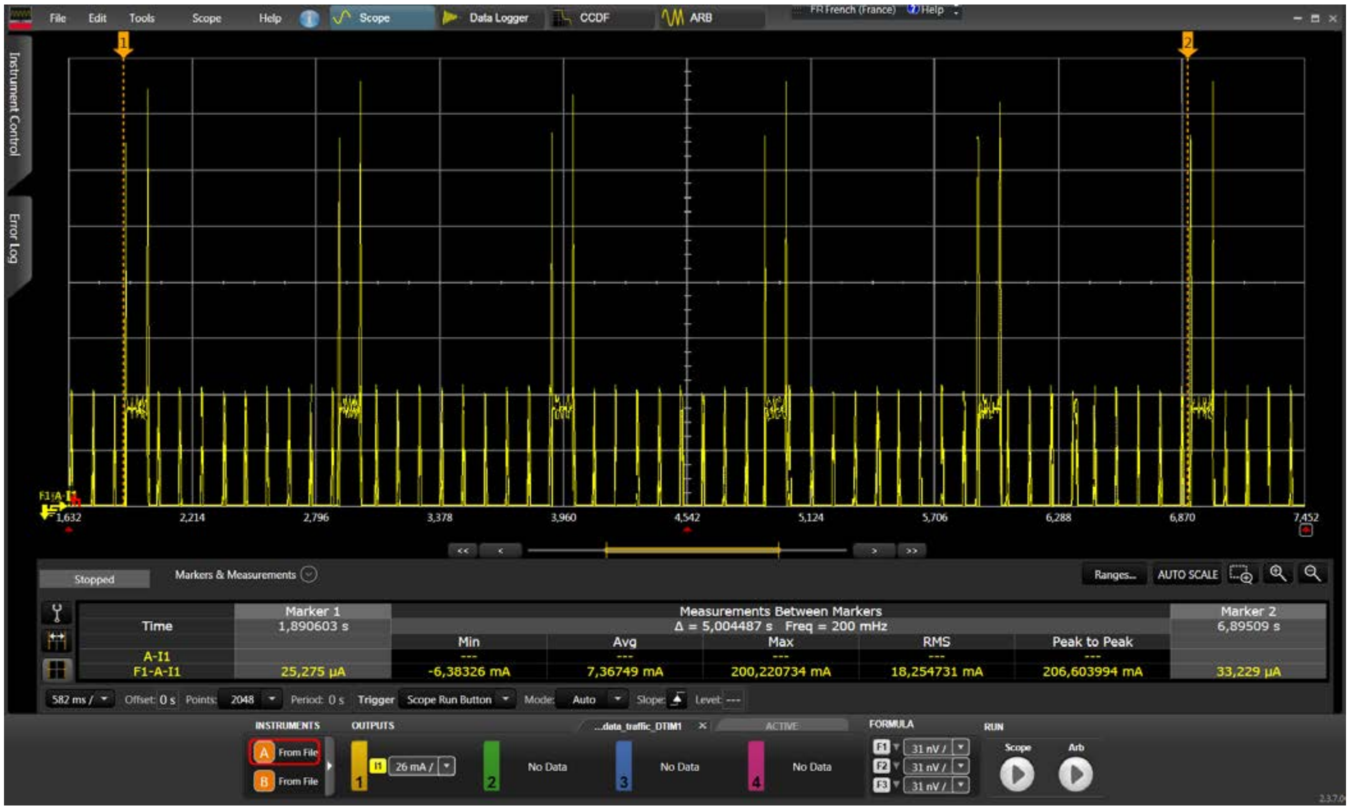


	Marker 1	Measurements Between Markers Δ = 1,131 ms Freq = 884,478 Hz					Marker 2
Time	8,01094 s	Min	Avg	Max	RMS	Peak to Peak	8,01207 s
A-I1		---	---	---	---	---	
F2-A-I1	47,725376 mA	3,86556 mA	57,153446 mA	166,778564 mA	68,101939 mA	162,913005 mA	46,034411 mA

9 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.29. Current Consumption Zoom during Ping Traffic without Power Save Mode

The following is an example of ping traffic with Wi-Fi power save mode enabled in DTIM1:



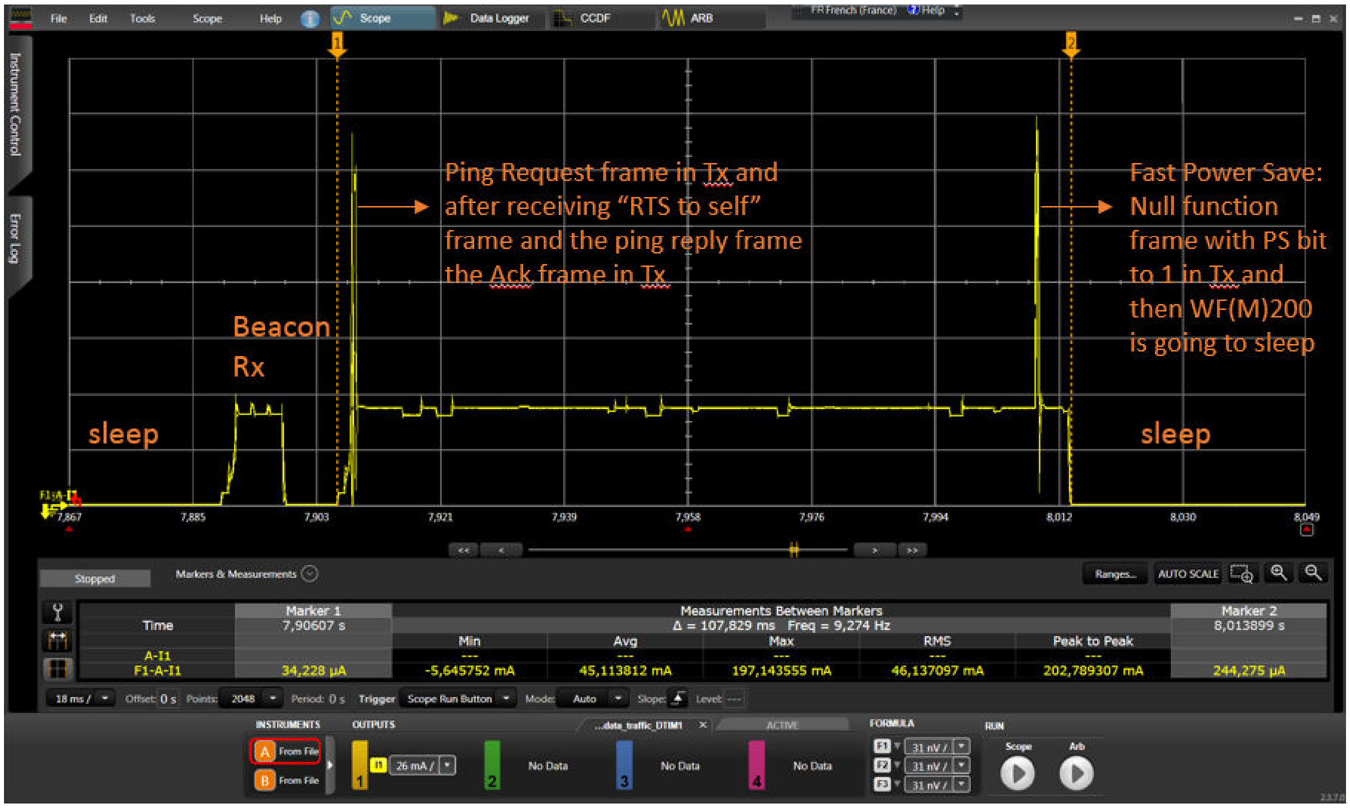
	Marker 1	Measurements Between Markers Δ = 5,004487 s Freq = 200 mHz					Marker 2
Time	1,890603 s	Min	Avg	Max	RMS	Peak to Peak	6,89509 s
A-I1		---	---	---	---	---	
F1-A-I1	25,275 µA	-6,38326 mA	7,36749 mA	200,220734 mA	18,254731 mA	206,603994 mA	33,229 µA

582 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.30. Current Consumption during Ping Traffic with Power Save Mode in DTIM1

The averaged current consumption in this use case is 7.36 mA.

The following is a zoom on the previous snapshot on the TX phase:



	Marker 1	Measurements Between Markers					Marker 2
Time	7,90607 s	Δ = 107,829 ms Freq = 9,274 Hz					8,013899 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	34,228 µA	-5,645752 mA	45,113812 mA	197,143555 mA	46,137097 mA	202,789307 mA	244,275 µA

18 ms / Offset: 0 s Points: 2048 Period: 0 s Trigger: Scope Run Button Mode: Auto Slope: Level: ---

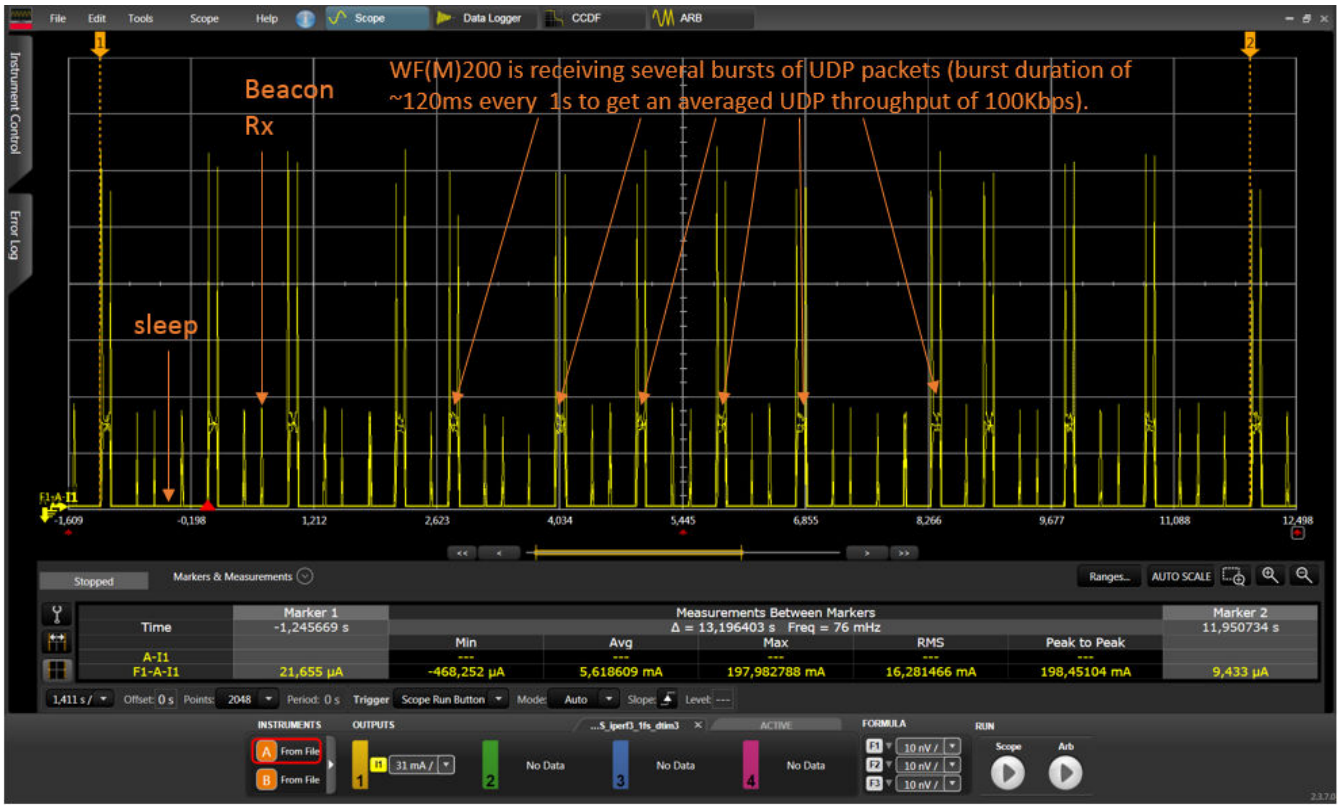
Figure 4.31. Current Consumption Zoom during Ping Traffic with DTIM1

4.2.5 Downstream UDP Data Traffic of 100 kbps

To generate a UDP throughput from the TP-Link Access Point using DTIM3 to the WF(M)200, use iPerf 3 with an average throughput target of 100 kbps. The effect of the burst profile to receive the UDP throughput on the current consumption for two burst configurations is shown as follows:

1. UDP burst traffic of 100 Kbits during ~120 ms every second (average UDP throughput of 100 kbps).
2. UDP burst traffic of 500 Kbits during ~120 ms every 5 seconds (average UDP throughput of 100 kbps).

The following figure shows power save mode and current consumption for the first use case:



	Marker 1	Measurements Between Markers					Marker 2
Time	-1,245669 s	Δ = 13,196403 s Freq = 76 mHz					11,950734 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F1-A-I1	21,655 µA	-468,252 µA	5,618609 mA	197,982788 mA	16,281466 mA	198,45104 mA	9,433 µA

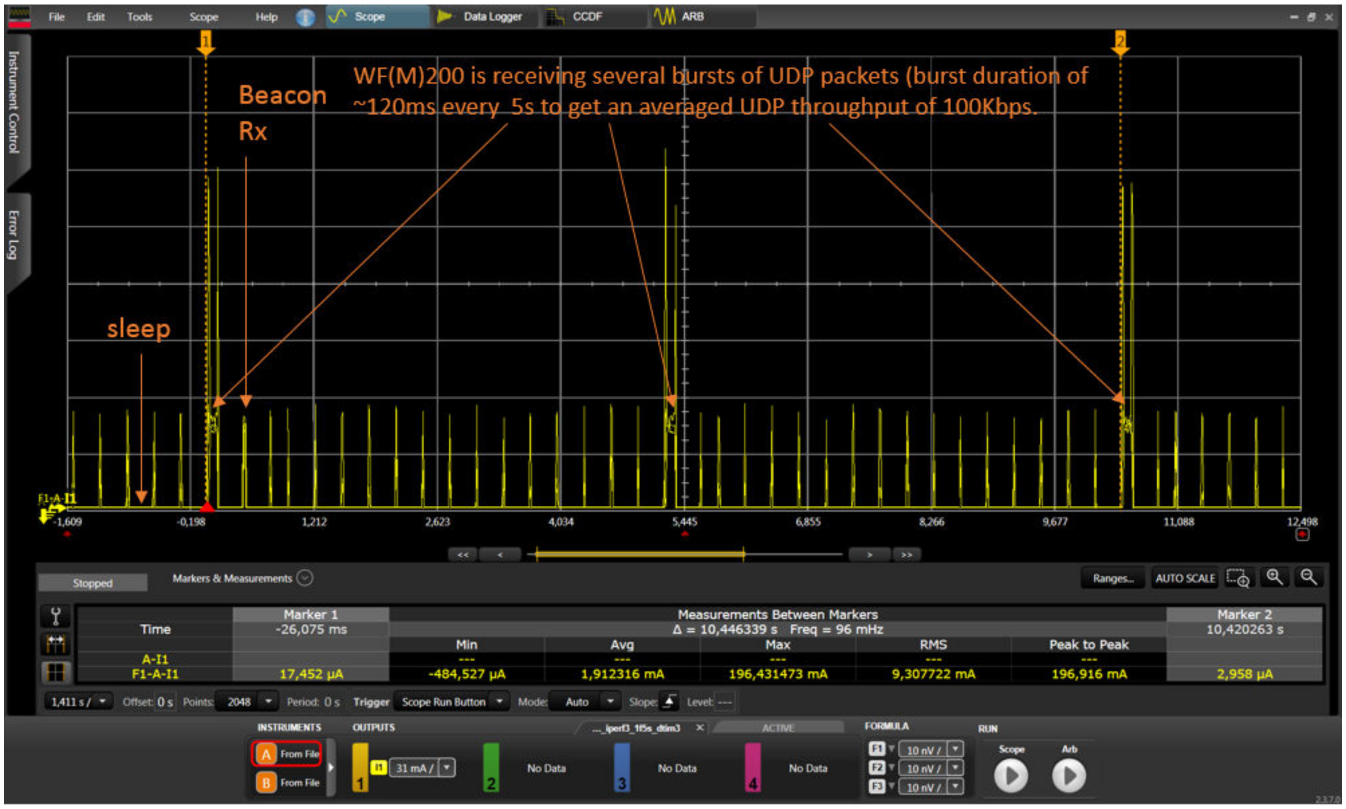
1,411 s / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

I1 31 mA /
F1 10 nV /
F2 10 nV /
F3 10 nV /

Figure 4.32. Current Consumption during Downstream Burst UDP Traffic (Use Case 1)

Note that in this example the averaged current consumption between marker 1 and 2 is ~5.6 mA.

The following figure shows the power save mode and current consumption for the second use case:



Time	Marker 1 -26,075 ms	Measurements Between Markers Δ = 10,446339 s Freq = 96 mHz Min	 Avg	 Max	 RMS	 Peak to Peak	Marker 2 10,420263 s
A-I1		---	---	---	---	---	
F1-A-I1	17,452 µA	-484,527 µA	1,912316 mA	196,431473 mA	9,307722 mA	196,916 mA	2,958 µA

Figure 4.33. Current Consumption during Downstream Burst UDP Traffic (Use Case 2)

Note that in this example the averaged current consumption between marker 1 and 2 is ~1.91 mA.

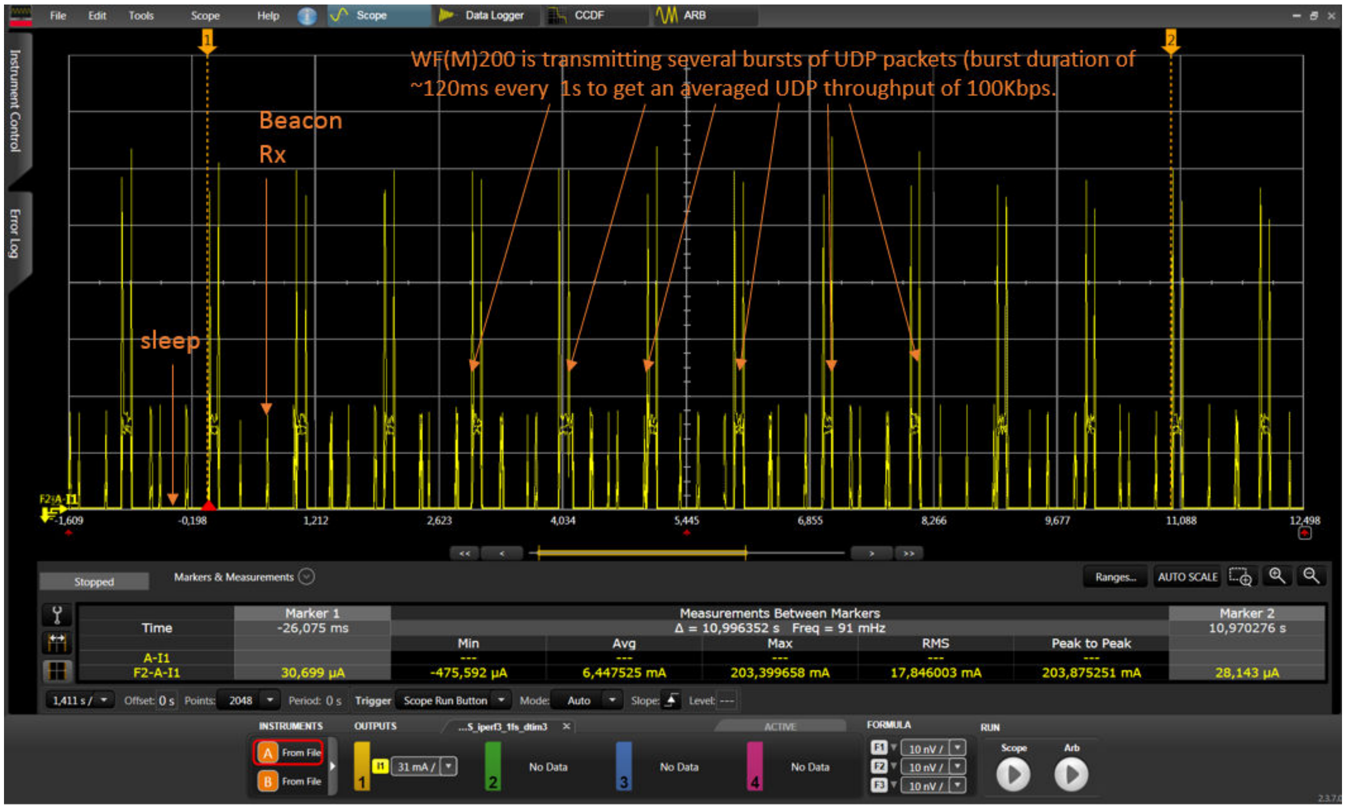
These two use cases show the impact of the throughput profile provided by the application. Moreover, with a burst profile with UDP packets spread regularly (every ~100 ms) to get the same UDP throughput of 100 kbps, the averaged current consumption can be higher than 30 mA.

4.2.6 Upstream UDP Data Traffic of 100 kbps

To generate a UDP throughput from the WF(M)200 to the TP-Link Access Point using DTIM3, use iPerf 3 with an average throughput target of 100 kbps. As in the previous section, two burst configurations are shown as follows:

1. UDP burst traffic of 100 Kbits during ~120 ms each second.
2. UDP burst traffic of 500 Kbits during ~120 ms every 5 seconds.

This following figure shows power save mode and current consumption for the first use case:



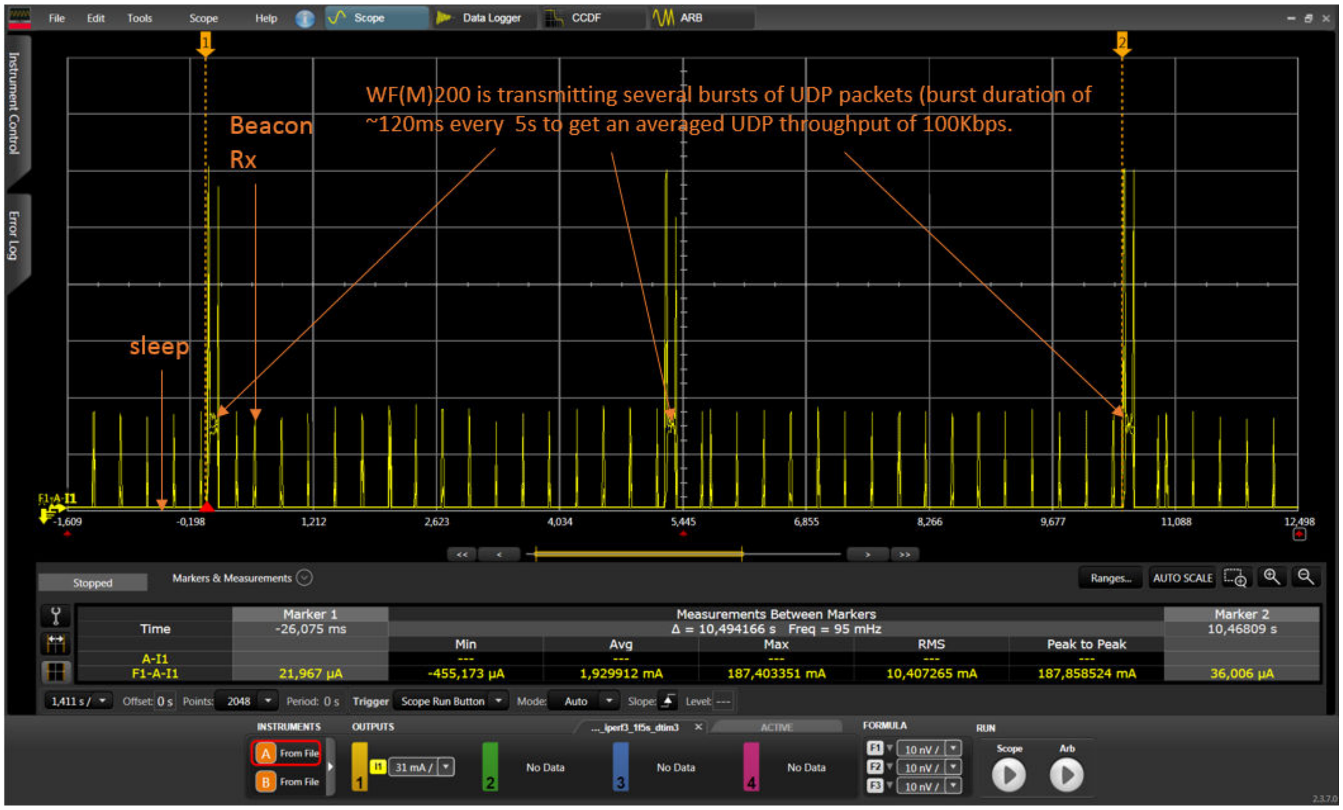
	Marker 1	Measurements Between Markers					Marker 2
Time	-26,075 ms	Δ = 10,996352 s Freq = 91 mHz					10,970276 s
		Min	Avg	Max	RMS	Peak to Peak	
A-I1		---	---	---	---	---	
F2-A-I1	30,699 µA	-475,592 µA	6,447525 mA	203,399658 mA	17,846003 mA	203,875251 mA	28,143 µA

1,411 s / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.34. Current Consumption during Upstream Burst UDP Traffic (Use Case 1)

Note that in this example the averaged current consumption between marker 1 and 2 is ~6.5 mA.

The following figure shows power save mode and current consumption for the second use case:



	Marker 1	Min	Avg	Max	RMS	Peak to Peak	Marker 2
Time	-26,075 ms	Measurements Between Markers Δ = 10,494166 s Freq = 95 mHz					10,46809 s
A-I1		---	---	---	---	---	
F1-A-I1	21,967 µA	-455,173 µA	1,929912 mA	187,403351 mA	10,407265 mA	187,858524 mA	36,006 µA

1,411 s / Offset: 0 s Points: 2048 Period: 0 s Trigger Scope Run Button Mode: Auto Slope: Level: ---

Figure 4.35. Current Consumption during Upstream Burst UDP Traffic (Use Case 2)

Note that in this example the averaged current consumption between marker 1 and 2 is ~1.93 mA.

These two use cases show the impact of the throughput profile provided by the application. Moreover, with a burst profile with UDP packets spread regularly (every ~100 ms) to get the same UDP throughput of 100 kbps, the averaged current consumption can be higher than 30 mA.

5. Appendix A: WF(M) Software Requirements

Use the following document to get software requirements for Lower MAC Linux driver or Full MAC driver example on STM32 with Free-RTOS OS and LwIP:

https://docs.silabs.com/wifi/ for various WF(M)200 documentation needs including the Quick Start Guide.

The measurements done in 3. Measurement Setup are based on SLEXP8022 using the SD card provided for the Raspberry Pi with the BRD8022 with hardware modifications described in 7. Appendix C: Devkit Hardware Setup for Measurements.

The current measurement presented in this document are done with Firmware 2.3.0 and Linux driver 2.2.0.

All “wfx” GitHub repositories contain driver implementation examples and tools related to the WF(M)200 Wi-Fi solution. The repositories can be found at the following link:

https://github.com/SiliconLabs?utf8=%E2%9C%93&q=wfx&type=&language=

6. Appendix B: Details on WUP and WIRQ

The WF(M)200 firmware manages Wi-Fi power save mode when enabled by the driver or from upper layer in the host.

To get the lowest current consumption in sleep mode, the driver manages the wake-up signal (WUP) and the wake-up IRQ signal (WIRQ) with the following definition:

WUP is used by the host to allow the WF(M)200 device to go in sleep/snooze mode. To get the lowest current consumption achievable, the serial interface has to be disabled.

WIRQ is used by the WF(M)200 to wake up the host to read the message available in the WF(M)200 through the serial interface. It is also used to acknowledge that the WF(M)200 is awake as described below.

The driver in the host requests wake-up of WF(M)200 SPI/SDIO interface and the firmware decides when it is ready. Independently of this, the WF(M)200 firmware manages the Wi-Fi activity. For instance, the WF(M)200 will wake-up autonomously to receive frames when due without any host intervention.

The WUP and WIRQ and the serial clock activity are managed by the host according the following steps.

- As long as the WUP signal is high, the WF(M)200 stays awake and processes incoming commands on the serial interface. The serial clock is running.
- If the host sets the WUP signal to zero, the WF(M)200 may stop processing incoming commands on the serial bus and may enter sleep mode. The serial clock is stopped by the host.
- The host does not access the serial interface while the WUP signal is low.
- If the host wants to send a command to the WF(M)200, it must first raise the WUP pin and wait for the WIRQ interrupt signaling the WF(M)200 is awake. The serial clock is started after WIRQ is raised.
- The WIRQ interrupt indicates that the HI_WAKUP_IND_BODY message is ready for the host to read. The serial clock is started to get this message.
- If the WF(M)200 needs to send a message to the host while the WUP is down, it will raise the WIRQ. Then, the host must raise the WUP signal and start the serial clock before reading the message. When the message is read, the WF(M)200 sets the WIRQ to low.

The following chronogram provides the overview of this behavior managed by the driver:

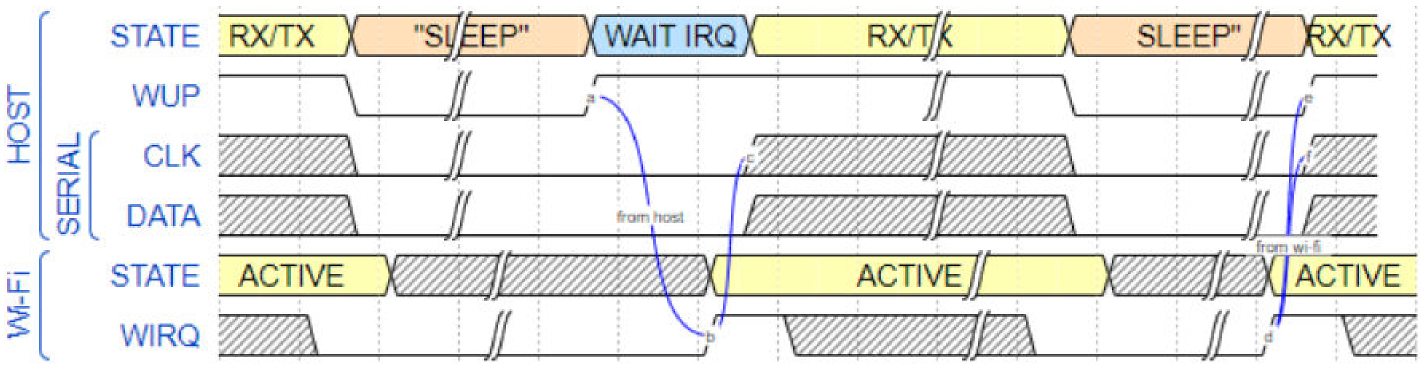


Figure 6.1. Chronogram of the State Transition on Host and WF(M)200 Side

Note: When the Wi-Fi STATE is unknown, it covers both ACTIVE (TX or RX state) and SLEEP state.

When he WUP goes up, the WIRQ should go up in a maximum of 1.5 ms. When the WIRQ goes up, the host raises the WUP signal and the serial clock as quickly as possible to avoid losing Wi-Fi frames.

Note: To get the lowest current consumption in DTIM, the host should manage WUP and WIRQ correctly and efficiently. More details are available using the driver example on GitHub (for Lower MAC or Full MAC driver).

7. Appendix C: Devkit Hardware Setup for Measurements

The BRD8022A provides a way to perform accurate WF200 current measurement (the same way is possible with the BRD8023A for WFM200). For this, simple hardware modifications are required as described below.

The snapshot below provides the top overview of the BRD8022A board where U1 is the WF200.

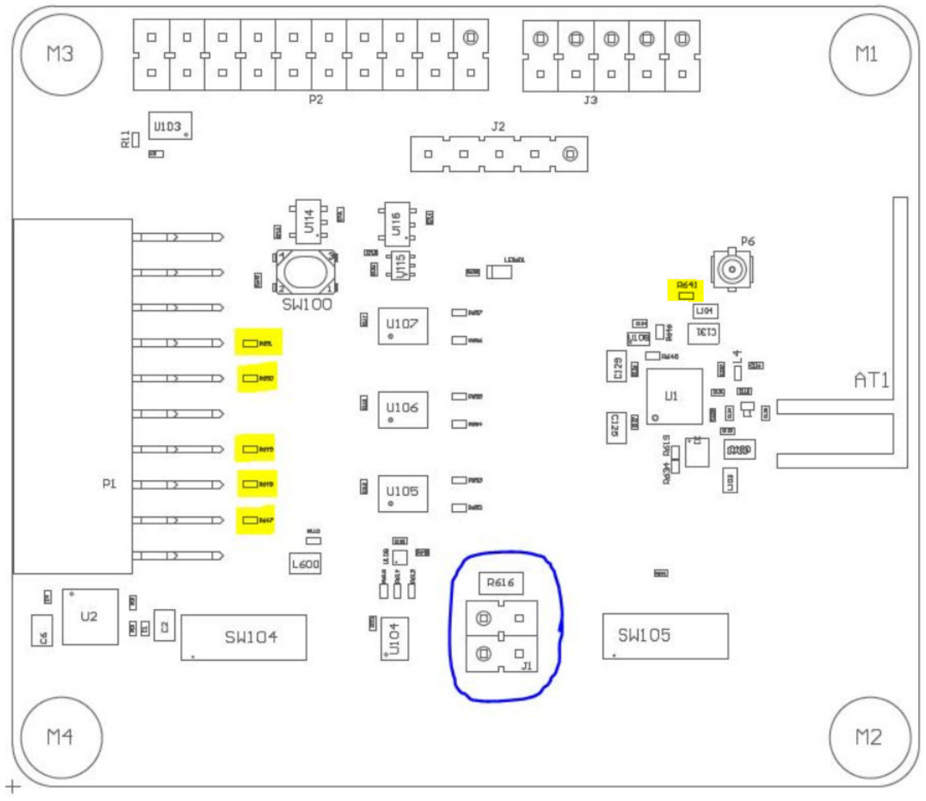


Figure 7.1. BRD8022 Top Overview

The BRD8022A uses a pull-up resistor on the WF200 RESETn pin which is not useful because an internal pull-up already exists. As a result, the R641 resistor (in yellow close to P6 and higher than U1) should be removed to get the lowest current consumption when RESETn is at low level.

For SDIO interface, the standard requires pull-up resistors on signals in the host. The BRD8022A provides five 82 K pull-up resistors and with the Raspberry Pi, they should be removed to get the lowest current consumption because they are not useful. These five pull-up resistors to remove in SPI or SDIO interface are highlighted in yellow close to P1 in the previous figure.

The elements contained in the blue circle above are necessary to perform current measurement of the WF(M)200. The schematic of this part is described below:

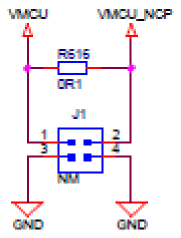


Figure 7.2. R616 and J1 Schematic

The R616 is a 0.1 Ohm resistor which connects the VMCU with the VMCU_NCP (WF200).

The J1 can be used to solder a HE10 connector (2.54 mm), which is useful for measurements.

Therefore, using R616 and J1 provides two ways to perform WF200 current measurements during TX, RX, or averaged on DTIM3, as follows:

- Using a Voltmeter on J1-1 and J2-2, you can monitor the R616 voltage and then compute the current consumption
- Using an Ampere meter in serial between J1-1 and J1-2 after removing the R616 resistor

To get more accurate current measurements after you've removed the R616 resistor, use a monitored power supply using J1, as described in the image below.

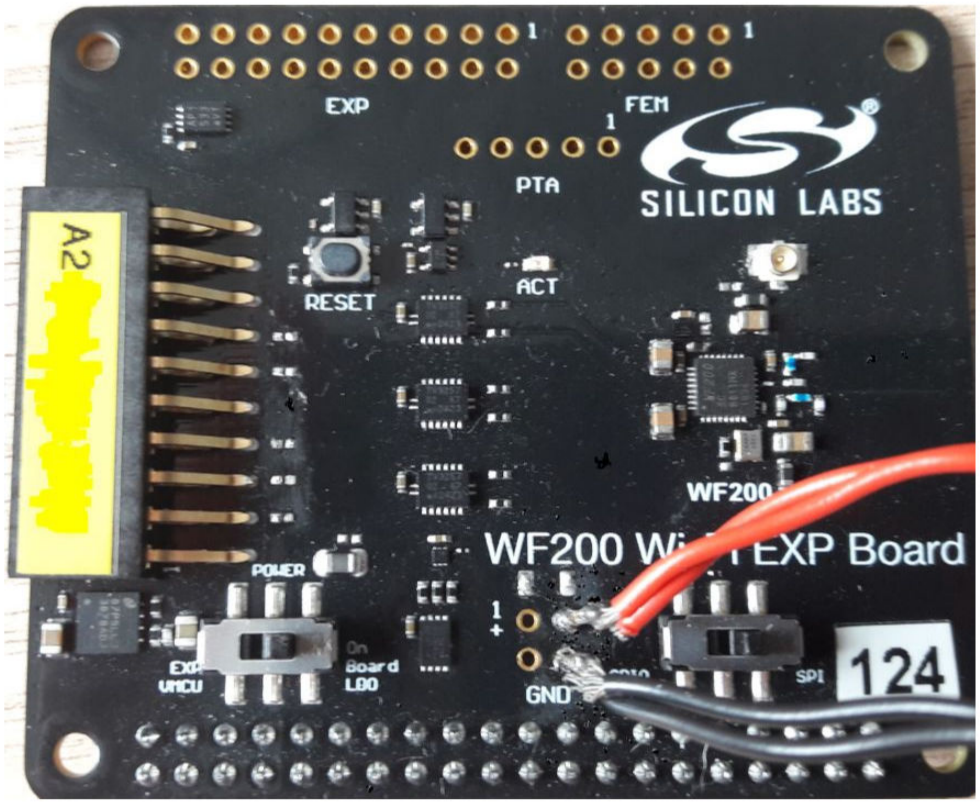


Figure 7.3. BRD8022 Removing Pull-up Resistors, R641 and R616 and Using J1

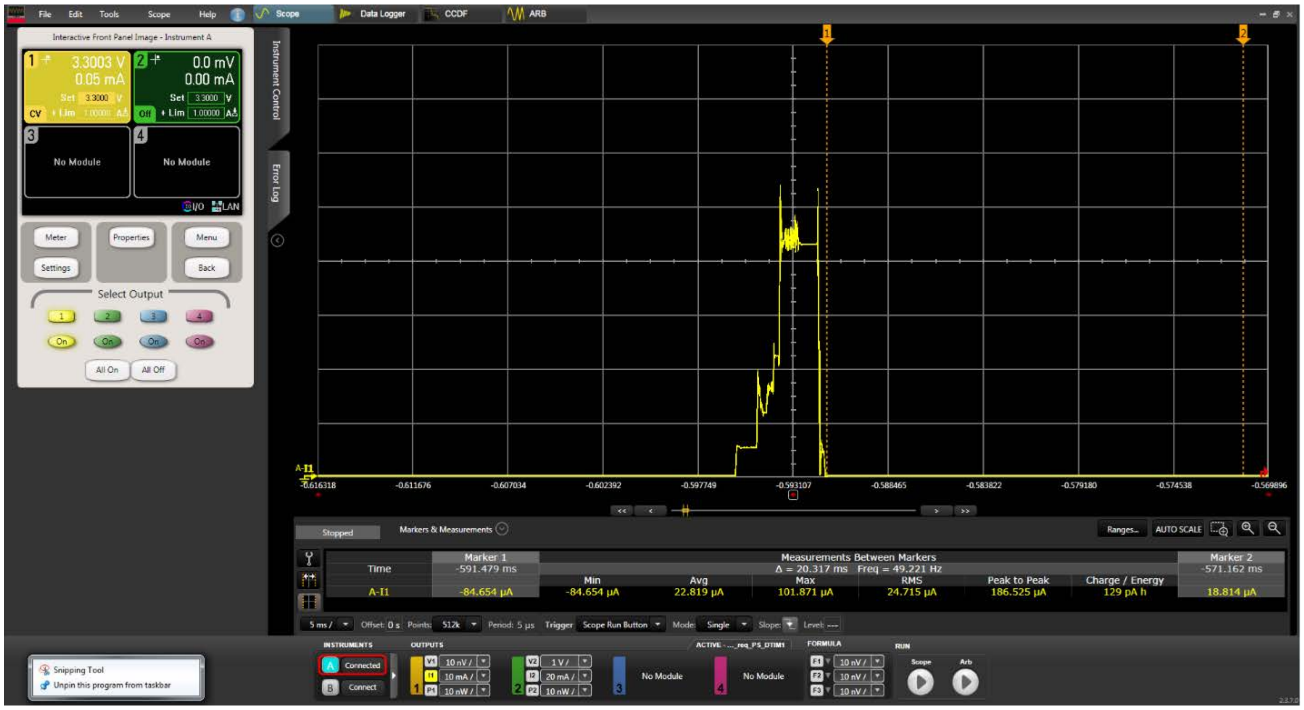
This is also a preferred method to measure the average lowest current consumption during the sleep state.

To get the lowest current consumption in sleep state using Raspberry Pi, set the interface using SPI interface because the clock is stopped during sleep (not possible with the kernel SDIO driver).

Additional details are available in https://www.silabs.com/documents/login/user-guides/ug379_slexpwfx200-users-guide.pdf.

8. Appendix D: N6705C Configuration

The N6705C DC Power Analyzer provides a way to measure DC voltage and current into the DUT. The DC Power Analyzer provides 4 GB of non-volatile data storage for scope traces and all functions and measurements are available at the front panel. For even greater control and analysis functions, the DC Power Analyzer can be used with the 14585A Control and Analysis Software.



1	2	3	4
3.3003 V, 0.05 mA, Set 3.3000 V, CV, + Lim 1.00000 A	0.0 mV, 0.00 mA, Set 3.3000 V, Off, + Lim 1.00000 A	No Module	No Module

	Marker 1	Min	Avg	Max	RMS	Peak to Peak	Charge / Energy	Marker 2
Time	-591.479 ms	Measurements Between Markers: Δ = 20.317 ms Freq = 49.221 Hz						-571.162 ms
A-I1	-84.654 µA	-84.654 µA	22.819 µA	101.871 µA	24.715 µA	186.525 µA	129 pA h	18.814 µA

Time axis: -0.616318, -0.611676, -0.607034, -0.602392, -0.597749, -0.593107, -0.588465, -0.583822, -0.579180, -0.574538, -0.569896

5 ms / Offset: 0 s Points: 512k Period: 5 µs Trigger: Scope Run Button Mode: Single Slope: Level: ---

INSTRUMENTS: A Connected, B Connect
OUTPUTS: 1 V1 10 nV /, I1 10 mA /, P1 10 nW /; 2 V2 1 V /, I2 20 mA /, P2 10 nW /; 3 No Module; 4 No Module
ACTIVE - ..._req_PS_DTIM1
FORMULA: F1 10 nV /, F2 10 nV /, F3 10 nV /
RUN: Scope, Arb

Figure 8.1. 14585A Snapshot

N6705C Key features and specifications:

- Voltmeter or Ammeter with range and accuracy depending of DC Power module (N6781A)
- Scope function: Digitizes voltage and current at up to 200 kHz, 512 kpts, up to 18 bits
- 4 GB of non-volatile data storage for data log, scope traces, instrument settings

Table 8.1. DC Power Module Key Performance Specifications

DC power Module	DC output ratings (volts/ amps/watts)	Ripple & noise (p-p / rms)	Voltage programming accuracy	Current programming accuracy	Voltage measurement accuracy	Current measurement accuracy
N6781A	20 V / ± 3 A / 20 W	12 mV / 1.2 mV	0.025% + 1.8 mV	0.04% + 0.3 mA	0.025% + 1.2 mV	0.03% + 0.25 mA

The current measurement accuracy is a function of the current range selected by the user with the 14585A software or the N6705C user interface.

Table 8.2. N6781A Current Measurement Accuracy Table

Current range selection	Current accuracy
3 A range	0.03% + 0.25 mA
100 mA range	0.025% + 10 µA
1 mA range	0.025% + 100 nA
10 µA range	0.025% + 8 nA

Because the WF200 current consumption varies dynamically, use the auto range feature. This can be selected using the range button on 14585 software:

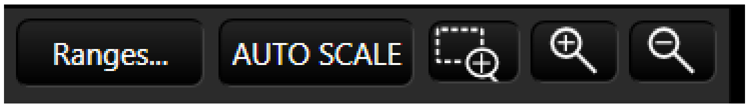
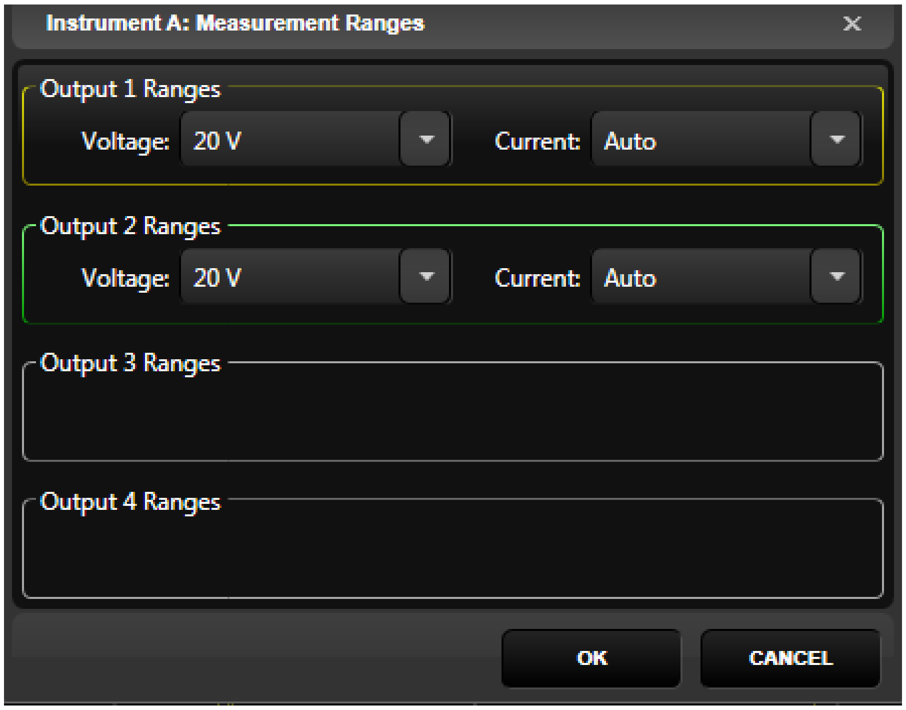


Figure 8.2. 14585A Ranges Selection Snapshot

Then, set the “Current” field to “Auto”:



Instrument A: Measurement Ranges

Output 1 Ranges
Voltage: 20 V Current: Auto

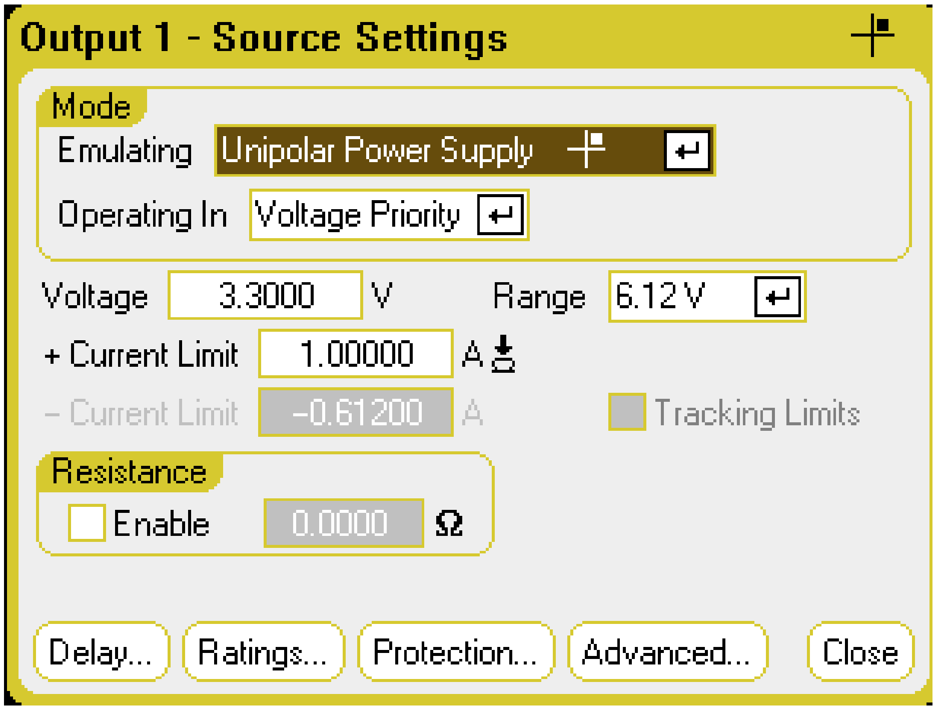
Output 2 Ranges
Voltage: 20 V Current: Auto

Output 3 Ranges

Output 4 Ranges

Figure 8.3. 14585A Measurements Ranges Snapshot

The following is the configuration used to perform current measurement with the WF200:



Output 1 - Source Settings

Mode

Emulating: Unipolar Power Supply

Operating In: Voltage Priority

Voltage: 3.3000 V

Range: 6.12 V

+ Current Limit: 1.00000 A

− Current Limit: −0.61200 A

☐ Tracking Limits

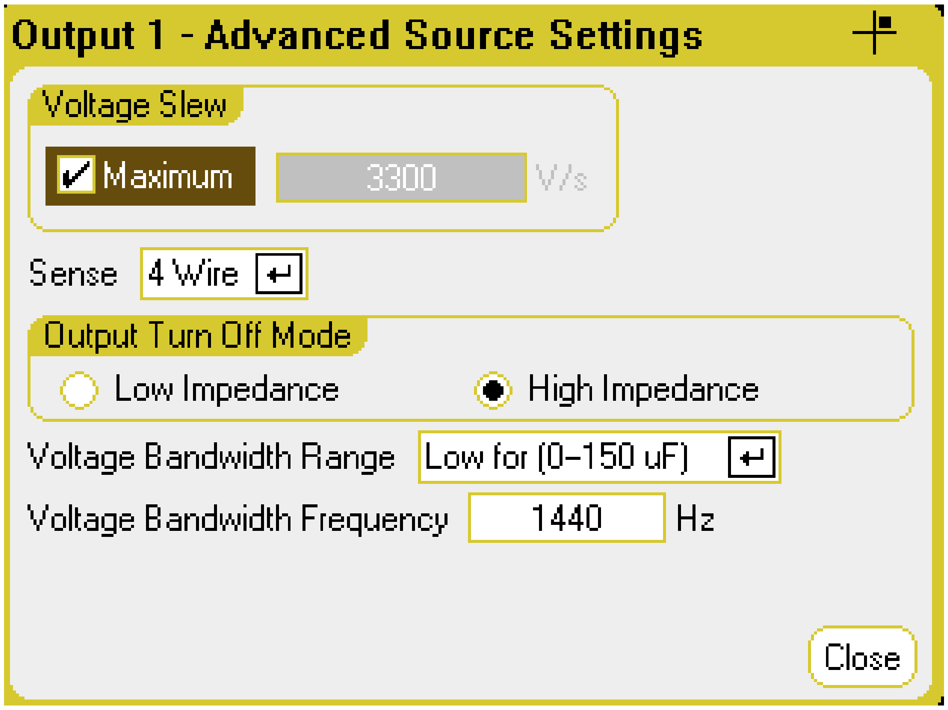
Resistance

☐ Enable 0.0000 Ω

Figure 8.4. Source Settings

Moreover, the Keysight DC power analyzer N6705C set in in 4-wire sensing (voltage is monitored at the load and automatically compensate for any voltage drop within supply cables) is used.

The configuration for this on the user interface is:



Output 1 - Advanced Source Settings

Voltage Slew

✓ Maximum 3300 V/s

Sense: 4 Wire

Output Turn Off Mode

○ Low Impedance [● High Impedance]

Voltage Bandwidth Range: Low for (0–150 uF)

Voltage Bandwidth Frequency: 1440 Hz

Figure 8.5. Advanced Source Settings

The hardware 4 wires connection is as follows.

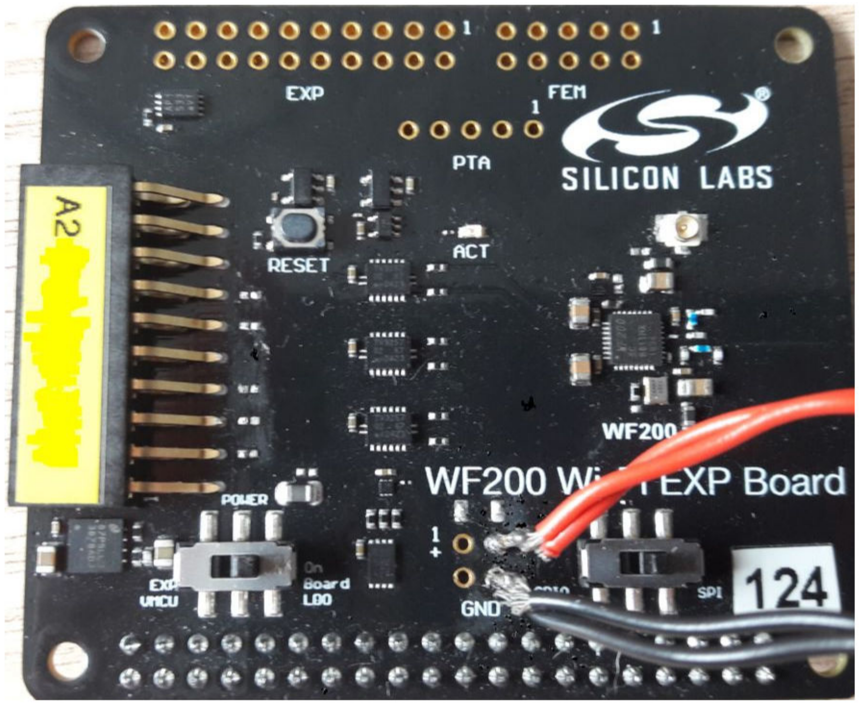


Figure 8.6. J1 Connector with 4 Wires Connection

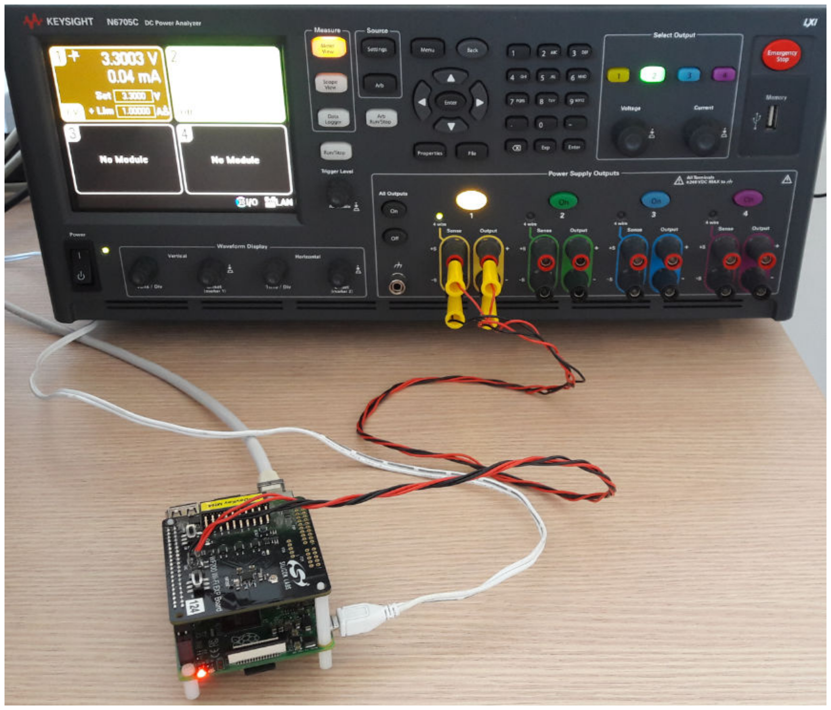


Figure 8.7. N6705C 4 Wires Connection

9. Appendix E: Access Point Configuration

Two Wi-Fi Acces Points are used:

- TP-Link Archer C3150 Wi-Fi Gigabit Tri-Band Router configured with a PC to handle data traffic (high-throughput Access Point). Configured in 2.4 GHz 11 bgn 20 Mhz. Used for UDP iPerf throughput test
- ALFA Network AWUS036NHA – USB Wi-Fi adaptor, 150 Mbps, 802.11b/g/n, connector RP-SMA, chipset Atheros AR9271L used with a Raspberry Pi and Hostapd configuration to get Beacon duration of 1 ms for DTIM1, DTIM3, DTIM10 current measurements

The Alfa is a Wi-Fi adaptor on USB usable on a Raspberry Pi and can be easily configured in Access Point using Hostapd. Below is the command to launch Hostapd with the configuration file hostapd_1ms_DTIM3.conf.

```
Sudo hostapd -B hostapd_1ms_DTIM3.conf
```

The following is the Hostapd configuration file hostapd_1ms_DTIM3.conf, necessary to get the beacon time duration of 1 ms with beacon interval of 102.4 ms and DTIM period set to 3.

```
# Configuration to generate beacons 1ms long (127 bytes)
interface=wlan0
driver=nl80211
ctrl_interface=/var/run/hostapd

ssid=AP_Beacon_1ms
channel=6
hw_mode=g
auth_algs=1

beacon_int=100
dtim_period=3

# +8B
vendor_elements=dd06000000000000
```

You can modify the DTIM interval by modifying the dtim_period parameter.

10. Appendix F: Advanced Energy Monitoring Usage to Measure Current Consumption

Using Advanced Energy Monitoring (AEM) is simple. To set it up, see the Knowledge Base Article (KBA) below: https://www.silabs.com/community/mcu/32-bit/knowledge-base.entry.html/2014/05/21/using_aem_to_measure-BdWl

AEM is capable of measuring currents in the 0.1 µA to 95 mA range with a frequency close to 10 kHz. The following is a snapshot the BRD8022A on top of the Raspberry Pi using the SPI interface, the EFM32GG-STK3700A with AEM.

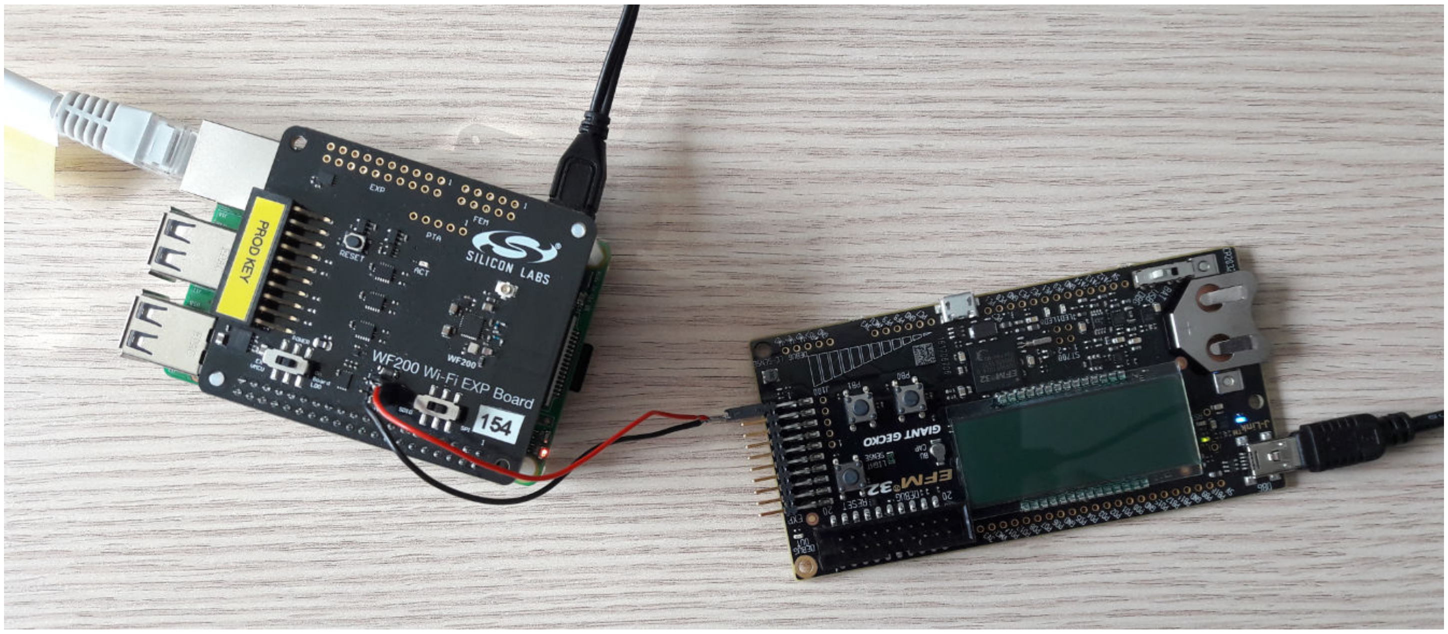


Figure 10.1. EFM32GG-STK3700A and BRD8022A Connection

You have to remove the 5 SDIO pull-up resisitors, the R641 RESETn Pull-up, the R616 (0.1 Ohm) and to connect J1 on the BRD8022A to use power supply and AEM from STK, as shown in the previous figure. See also this KBA:

https://www.silabs.com/community/wireless/wi-fi/knowledge-base.entry.html/2019/03/19/kba_how_to_do_curr-U9le.

Below are examples from AEM measurement:

RX current consumption in DTIM3 (beacon interval de ~102 ms; beacon ~2 ms; Average DTIM3 current consumption of 559.46 µA):

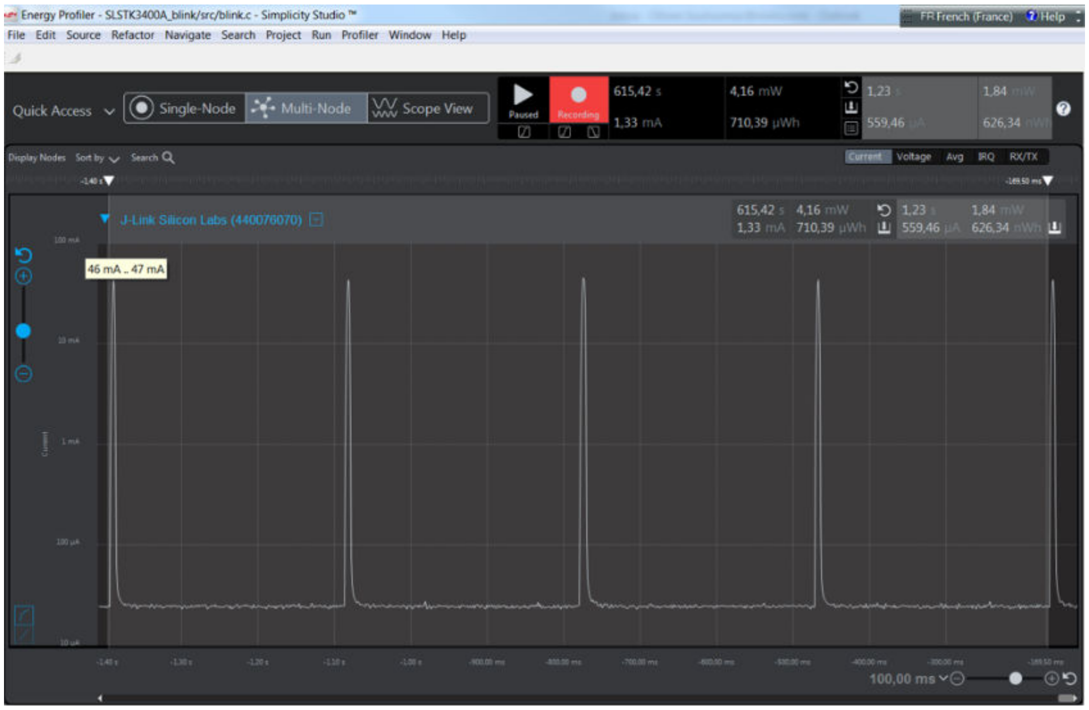


Figure 10.2. RX Current Consumption in DTIM3

Warning: The vertical scale is in Log in the above snapshot (you can switch between linear or log scale).

Zoom on RX beacon current consumption (~42 µA):

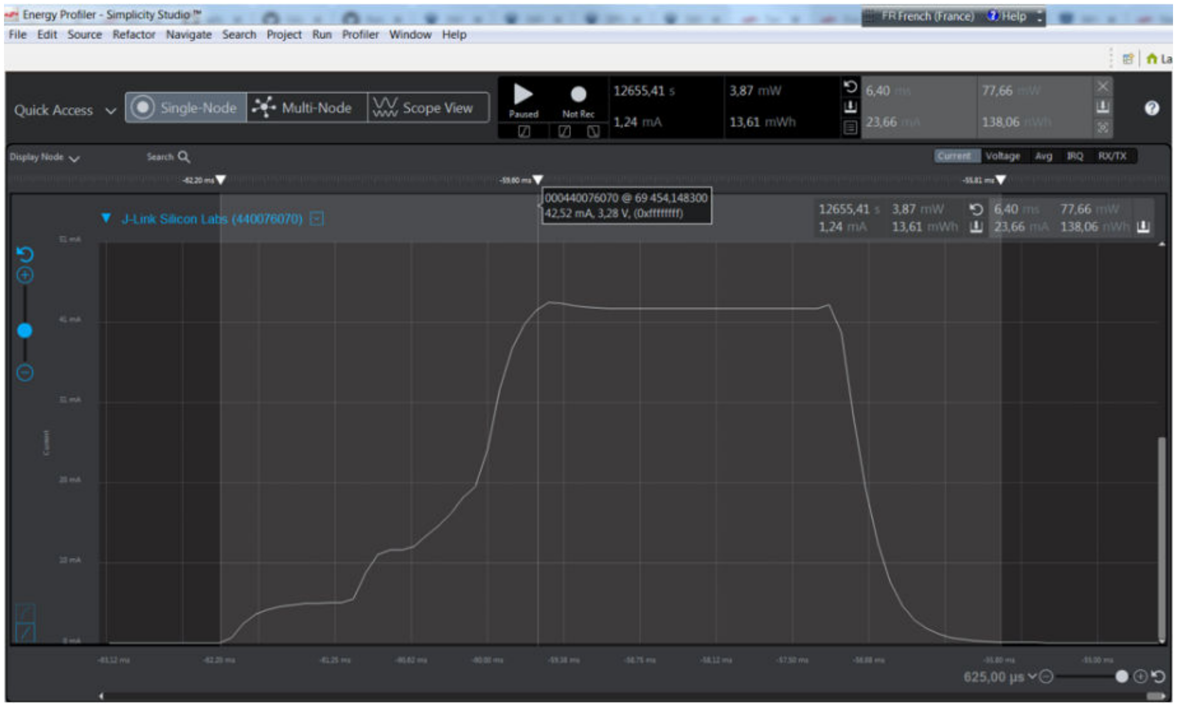


Figure 10.3. Zoom on RX Beacon Current Consumption

Note that the average sleep state current consumption is 23.11 µA.

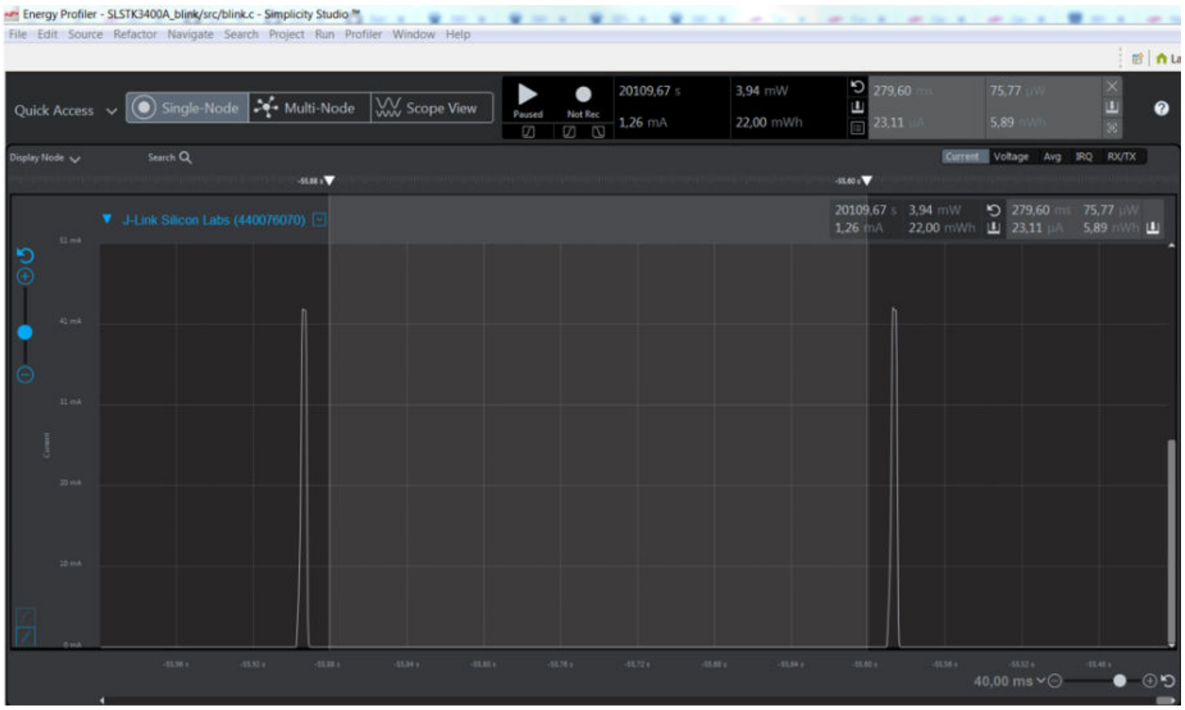


Figure 10.4. Average Sleep State Current Consumption

Note a wide overview of the current consumption with DTIM3 (log scale in current consumption), but with such scale then the RX peak consumption is not at the correct value. Use a maximum 200 ms per division to get an accurate level:

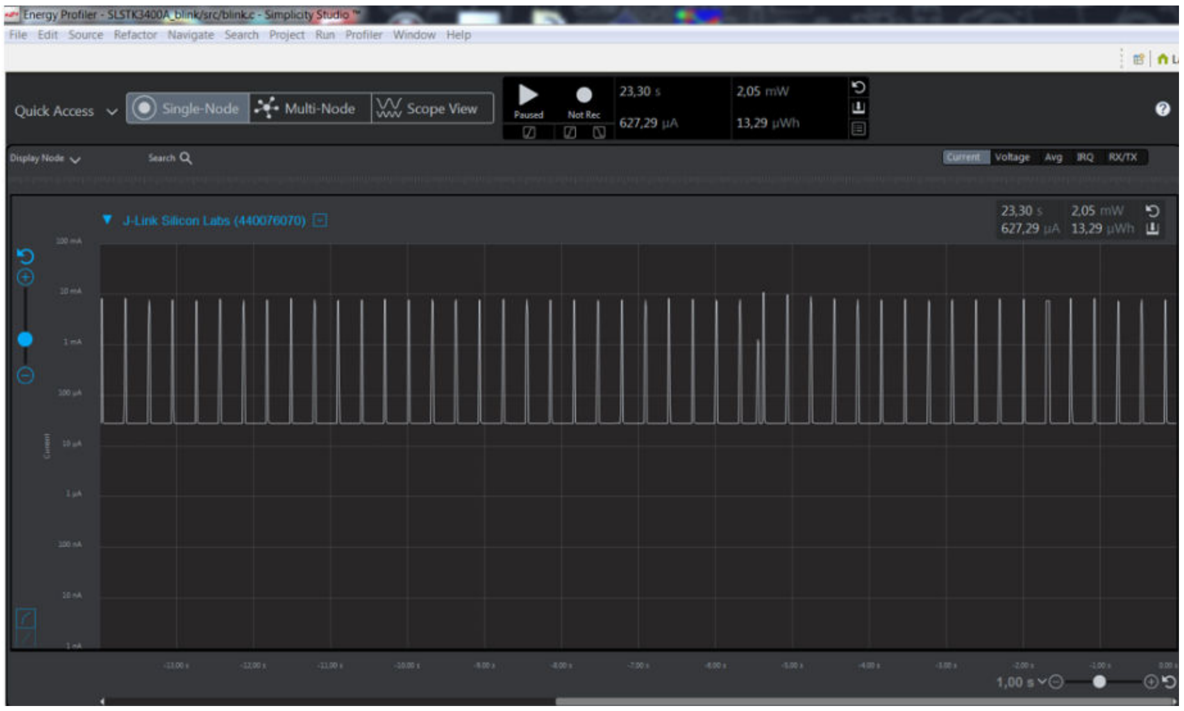
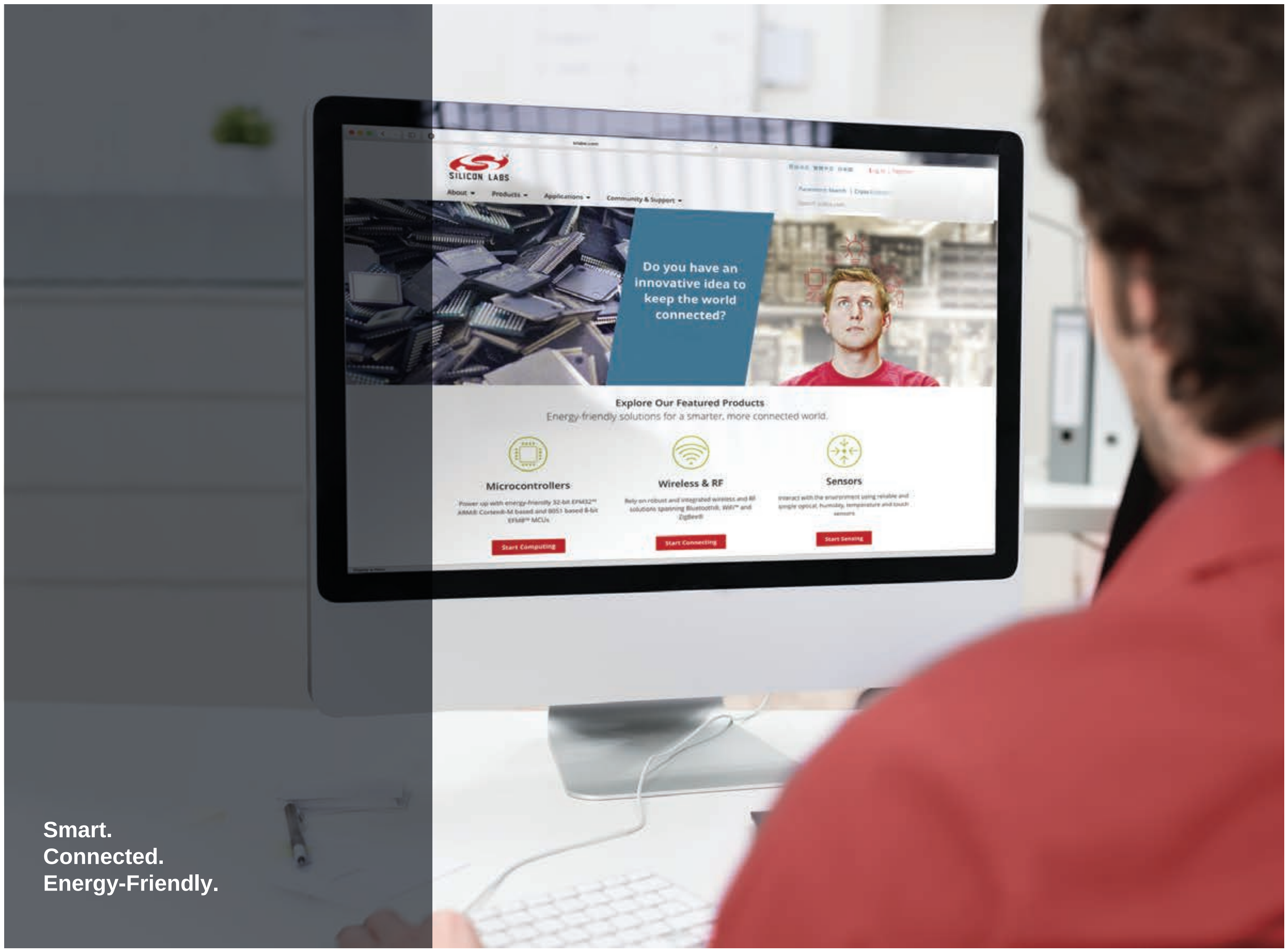


Figure 10.5. Average DTIM3 Current Consumption

Nevertheless, the sleep state current consumption is acceptable.

In TX, the current measurement is not possible because the AEM is limited to 95 mA max. However, it is possible to do ping traffic without packet loss. Therefore, this limitation is for the measurement and not for delivering the current.



Products
www.silabs.com/products

Quality
www.silabs.com/quality

Support and Community
community.silabs.com

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

http://www.silabs.com