APPLICATION NOTE

AT03663: Power Consumption of ZigBee End Device

Atmel MCU Wireless

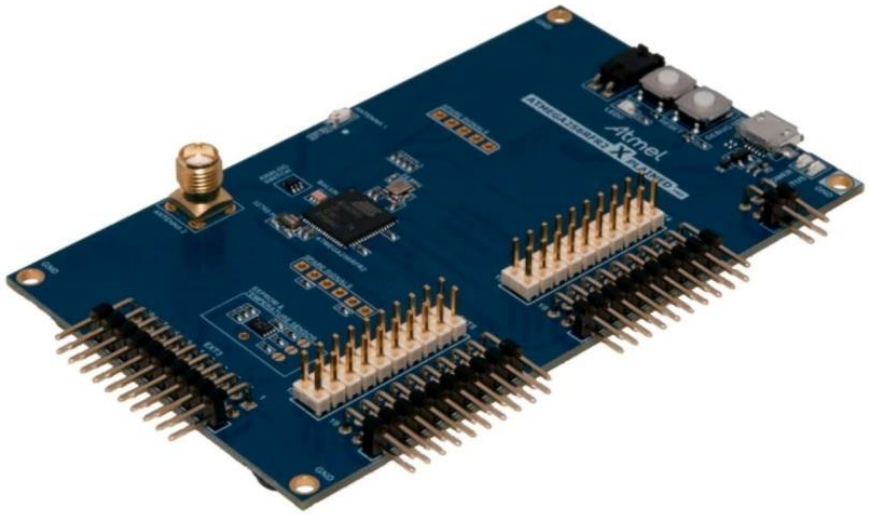
Description

This Application note provides a detailed description on the power consumption of the Atmel® ZigBee® end device in various scenarios along with creating test setups and common usage scenarios.

Battery lifetime is an important criteria for a ZigBee End Device, this application note helps customer to arrive at a tentative battery consumption of the Atmel ATmega256RFR2 device with BitCloud® stack.

Features

- Current profiles of ZigBee End Device
- Current measurement procedure
- Sniffer logs and corresponding current profile
- Segmenting current profiles based on transceiver states



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1 Overview

Table 1-1 lists all the scenarios covered in this application note along with consumption details.

Table 1-1. Consolidated Power Consumption Chart

	Result at 8MHz			Result at 16MHz		
Scenario	**Avg. current [mA]**	**Duration [ms]**	**Charge [mA X ms]**	**Avg. current [mA]**	**Duration [ms]**	**Charge [mA X ms]**
Power-on Initialization With Serial/OTA Bootloader	3.19	1680.00	5359.2	9.19	266.00	2445.34
Power-on Initialization Without Serial/OTA Bootloader	14.92	1992.00	29724.62	8.87	117.00	1037.56
Sleep in Power Save Mode	0.002	-	-	0.00169	-	-
Sleep in Power Down Mode	0.0007	-	-	0.00064	-	-
Sleep Timer Overflow	2.41	0.35	0.85	1.70	1.93	3.29
Wake-up by Application Timer	1.219	4.15	5.06	3.47	3.44	11.94
Wake-up by External Interrupt	3.81	4.10	15.62	3.77	3.84	14.46
Parent Polling	1.49	8.82	13.15	6.17	6.95	42.85
Data Transmission without APS ACK	2.50	24.4	61.04	6.89	17.38	119
Data Transmission with APS ACK	0.67	540	361.8	0.58	519.00	299.31
Beacon Scanning	14.42	73.8	1064.34	18.14	111.10	2015.69
Classical Join	6.40	1243.00	7963.90	9.95	1228.00	12221.92
Rejoin to Parent	2.67	579.6	1551.70	6.32	1120.00	7078.40
Parent Loss Detection and Rejoining	0.75	21900.00	16425	0.62	10950.00	6798.86
Touchlinking	2.42	10190.00	24690.33	4.52	12900.00	58296.39
OTAU Server Discovery with no Response	2.59	4882.00	12649.26	0.44	5664.00	2503.49
OTAU Server Discovery with no New Image	1.33	1070.00	1423.1	0.60	1025.00	603.73
Image Block Request and Response	0.701	1092.00	765.49	0.63	1031.00	648.50
Upgrade End Response	4.85	63.30	307.19	6.31	57.10	360.47
Clock Stabilization	1.63	62.20	101.57	1.83	82.20	150.67
Bootloader Initialization	3.14	4754.00	14941.82	4.44	2390.00	10618.77
Flash Read and Write	4.98	17350.00	86455.05	6.60	14980.00	98912.94

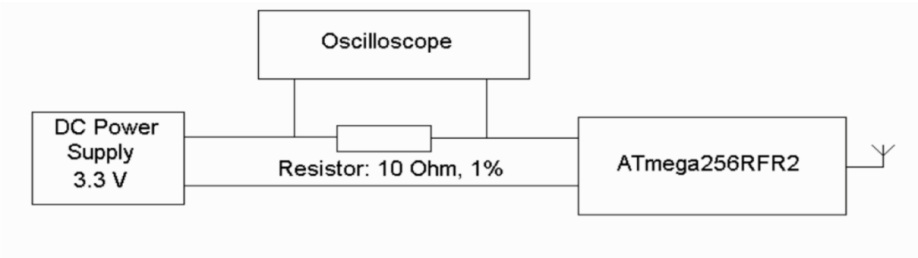
2 Setup

- Hardware: ATmega256RFR2 Xplained Pro (ATmega256RFR2-XPRO) as ZigBee End Device

Scenario	8MHz	16MHz
Fuse Settings without Boot-loader	0xFF (Extended): 0x9B (High): 0xE2 (Low)	0xFF (Extended): 0x9B (High): 0xF7 (Low)
Fuse Settings with Bootloader	0xFF (Extended): 0x9A (High): 0xE2 (Low)	0xFF (Extended): 0x9A (High): 0xF7 (Low)
Voltage	3.0V	3.0V

- Firmware: BitCloud_SDK v 3.2.0
- Test setup:
  - Fluke289 Multimeter
  - Tektronix MSO 4054 Mixed signal oscilloscope (500MHz 2.5GS/s)
  - With 10Ω 1% metal film resistor as shunt resistor
  - External power supply is connected to VCC_P3V3 and GND pins in ATmega256RFR2 Xplained Pro board

Figure 2-1. Oscilloscope Setup



Oscilloscope measurements are expected to have offset of around +0.05mA. This error was calculated by measuring a constant current using both Multimeter and Oscilloscope. This has been deduced from the average consumption for every scenario except sleep (Power Down / Power Save).

Average current (Mean) is calculated by the oscilloscope and it is the average of all the current samples between the cursor points as shown in the scope plots throughout this document.

- Min. is the reference offset in the Oscilloscope
- Max. is the peak current measured for that Profile
- Total Duration is the time delta between the two cursor points
- All profiles are taken with fuse settings without bootloader unless otherwise mentioned

Note: All measurement results are typical values.

Hence, the calculations are as below:

Average Current [mA] = Mean – Min. – 0.05

Peak Current [mA] = Max. – Min.

Total Duration [ms] = Time difference between cursor a and b

Total Consumption for a profile [mA.ms] = Average Current x Total Duration

3 Power-on Initialization of Factory New Device

This chapter characterizes the power consumption during the device power-on initialization with and without Serial/OTA Bootloader [3] of a factory new end device. Power-on initialization covers device stabilization, HAL (Hardware Abstraction Layer), and RF initialization, and internal stack reset procedures.

Table 3-1 provides measurements of power-on initialization with and without Serial/OTA Bootloader at 8 and 16MHz.

Note: Fuse Settings used for this scenario is with bootloader, refer Chapter 2.

Table 3-1. Current Consumption for Power-on Initialization with/without OTA Bootloader

Description	With Serial/OTA Bootloader		Without Serial/OTA Bootloader	
	Result at 8MHz	Result at 16MHz	Result at 8MHz	Result at 16MHz
Total duration [ms]	1682.00	266.00	1992.00	117.00
Average current [mA]	3.19	9.19	14.92	8.87
Total charge consumed [mA x ms]	5359.2	2445.34	29724.62	1037.56
Peak Current [mA]	13.03	22.92	31.65	24.34
Current Profile	Figure 3-1	Figure 3-2	Figure 3-3	Figure 3-4

Figure 3-1. Current Consumption Profile of Power-on Initialization with Serial/OTA Bootloader at 8MHz

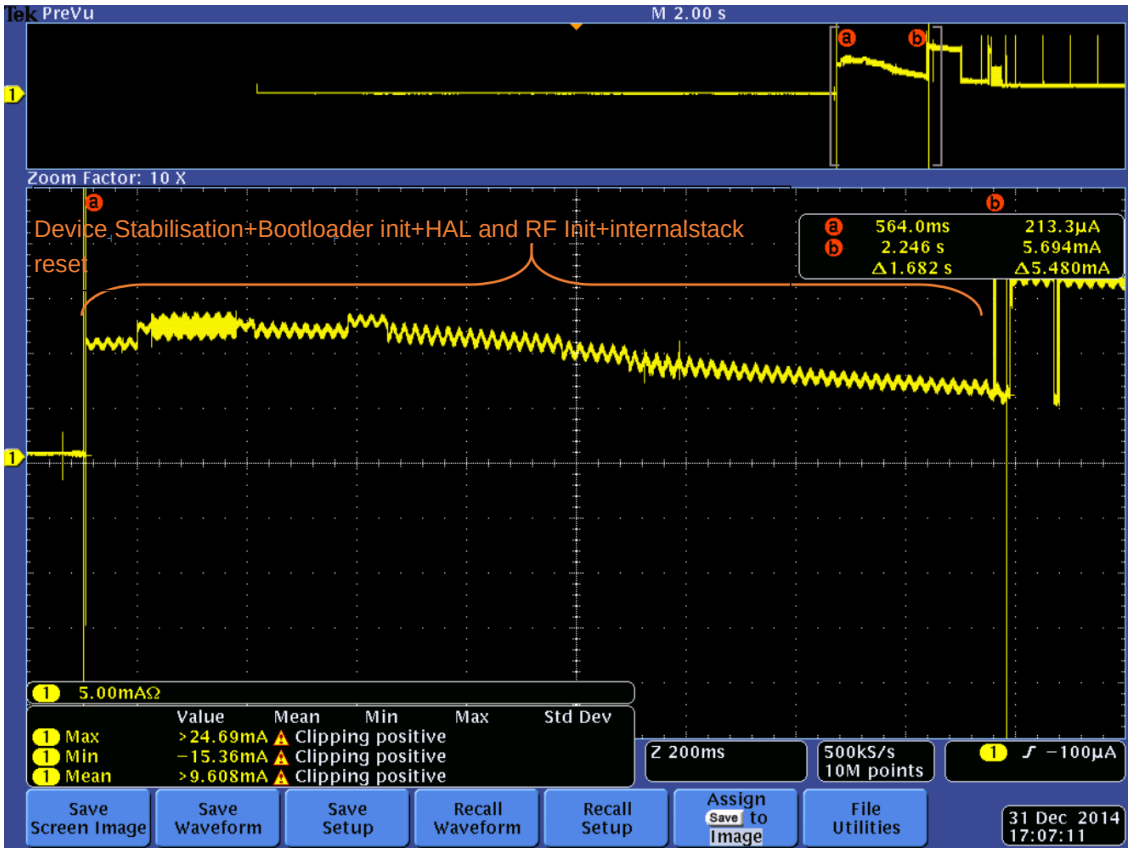


Figure 3-2. Current Consumption Profile of Power-on Initialization with Serial/OTA Bootloader at 16MHz

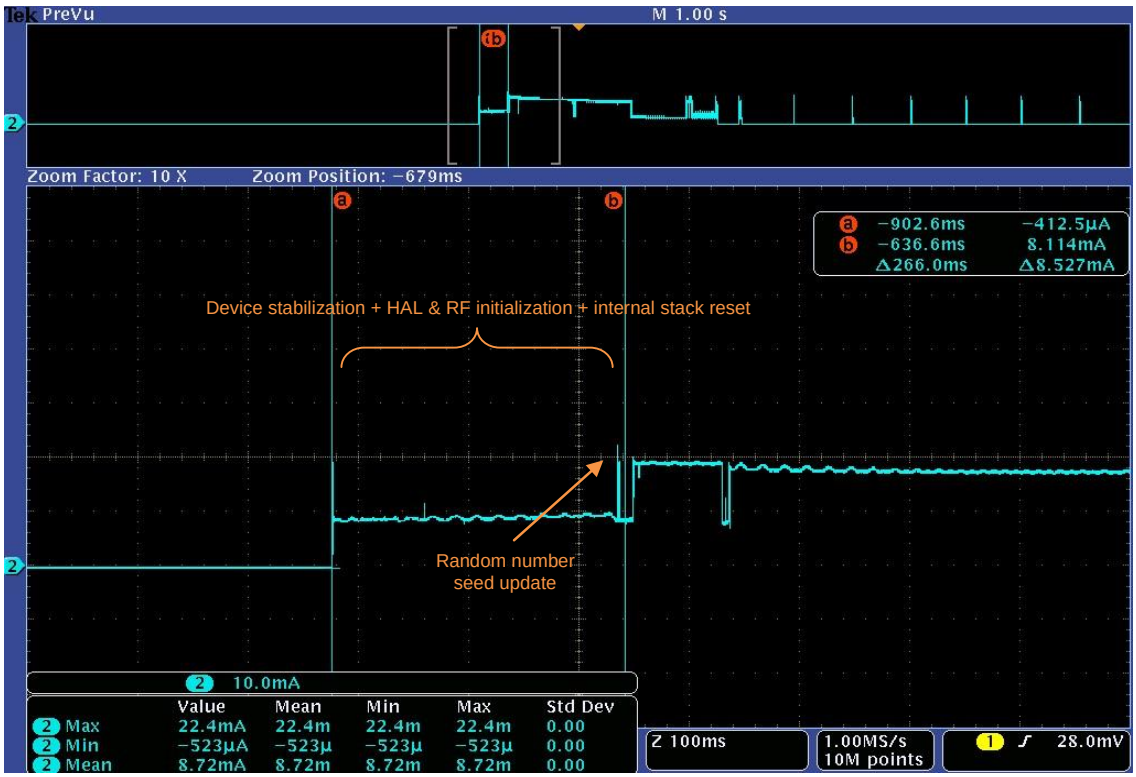


Figure 3-3. Current Consumption Profile of Power-on Initialization without Serial/OTA Bootloader at 8MHz

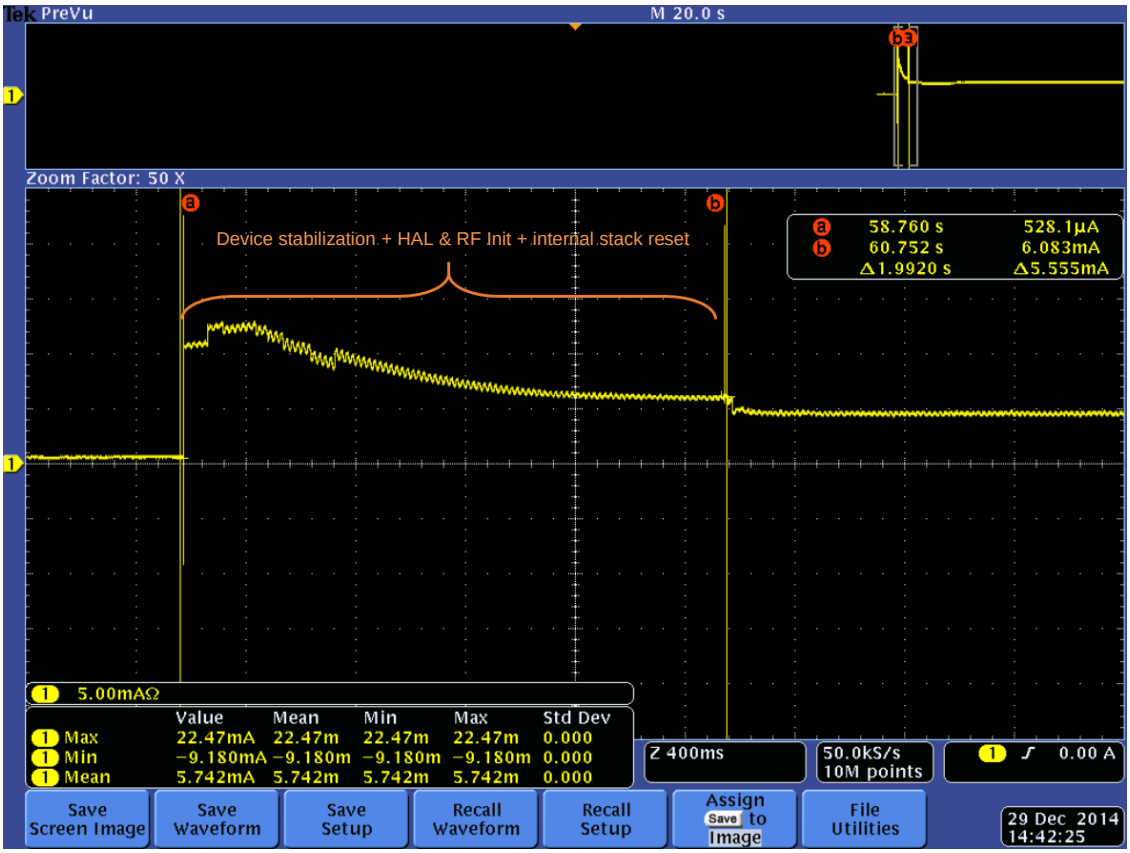
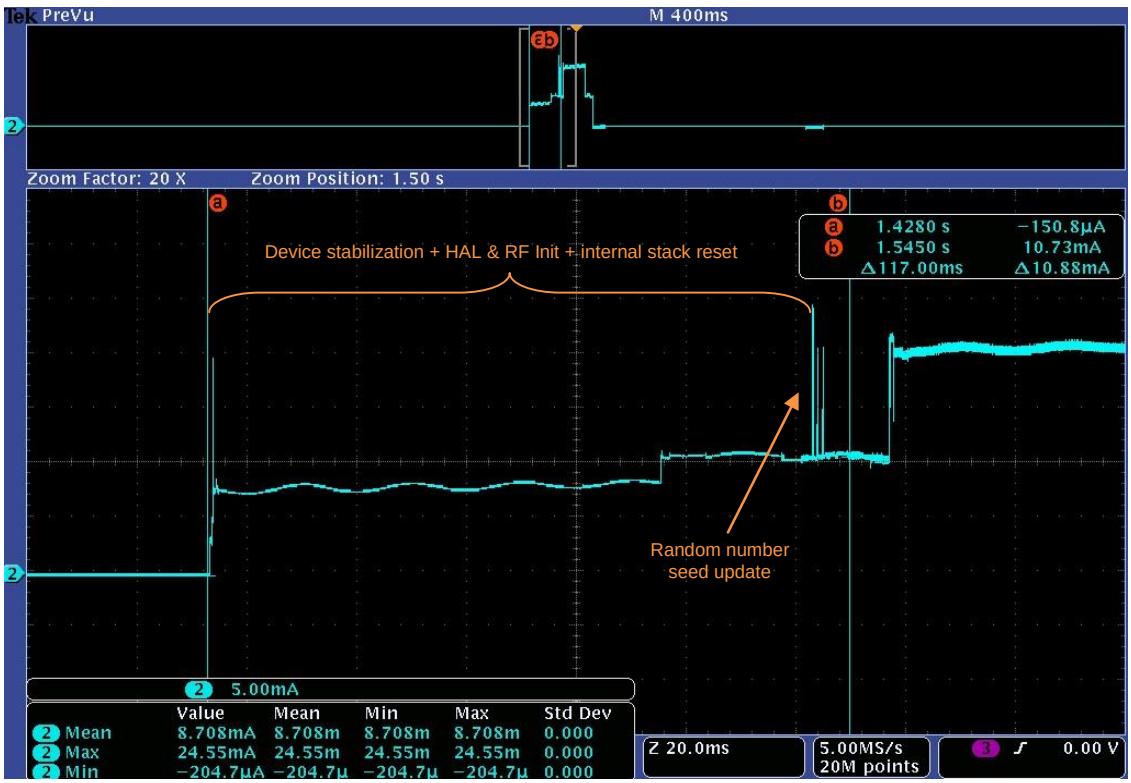


Figure 3-4. Current Consumption Profile of Power-on Initialization without Serial/OTA Bootloader at 16MHz



4 Deep Sleep Current Consumption

Deep sleep power consumption is measured in this chapter. ZigBee End device will be in deep sleep state in most of their lifetime, so deep sleep consumption is more important.

End device can be configured to two deep sleep modes [1]:

- Power Save mode – In this mode end device woken up based on scheduled interval and the time base is maintained by the asynchronous RTC timer (Timer2 based on the external 32kHz crystal) [1]. Detailed description and measurement for such wake up procedure is given in Section 5.1.
- Power Down mode – In this mode end device can be woken up only by external pin change interrupt [1]. Detailed description and measurement for wakeup by pin change interrupt is given in Section 5.3.

The deep sleep current profile will be same for devices that are not associated with any network (Factory New) and operational devices that are joined to a network.

Table 4-1. Current Consumption in Power Save/Power Down

Description	Result at 8MHz	Result at 16MHz
Average current – Power Save [mA]	0.002	0.00169
Average current – Power Down [mA]	0.0007	0.00064

5 Device Wake-up

This chapter characterizes the power consumption when the device is woken up by the sleep timer, application timer and external interrupt.

5.1 Wake-up by Sleep Timer Overflow

When end device is configured in power save mode it will wake up every eight seconds due to sleep (asynchronous) timer overflow, which is clocked by external 32.768kHz crystal. On waking up the device updates this timer module and goes to power save mode again.

Note: In Factory New (FN) state, asynchronous timer should not be running, though currently BitCloud 3.0.0 has a known issue that asynchronous timer will be running in FN state.

Table 5-1. Current Consumption During Sleep Timer Overflow

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	0.35	1.93
Average current [mA]	2.41	1.70
Charge consumed [mA x ms]	0.85	3.29
Peak Current [mA]	3.60	4.72
Current Profile	Figure 5-1	Figure 5-2

Figure 5-1. Current Consumption Profile of Sleep Timer Overflow at 8MHz

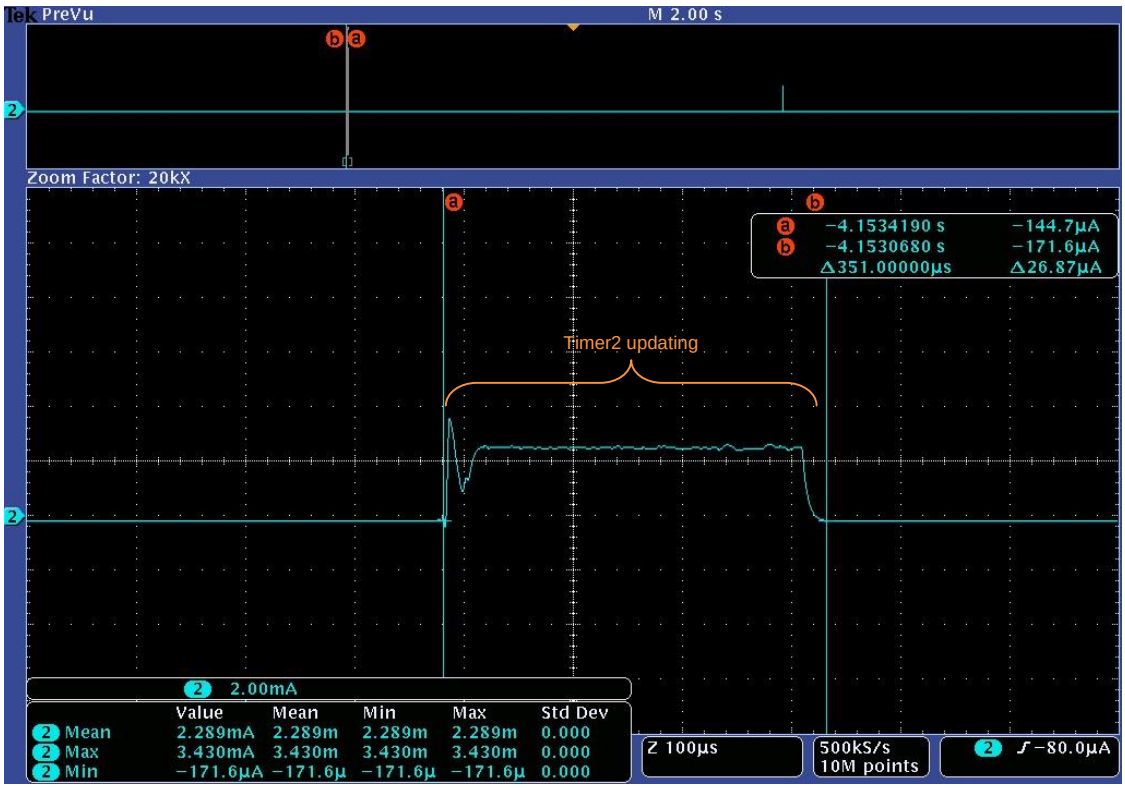
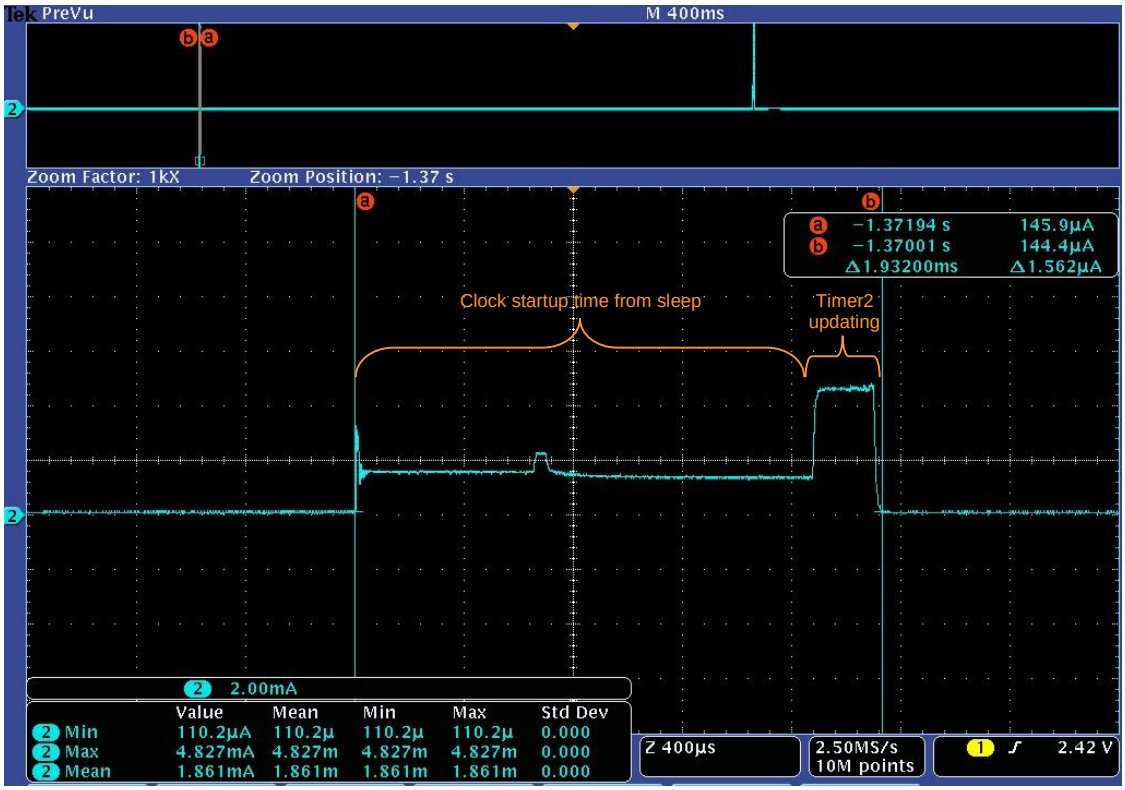


Figure 5-2. Current Consumption Profile of Sleep Timer Overflow at 16MHz



5.2 Wake-up by Application Timer

An end device can be configured to go to power save mode for a finite duration by the application using the API HAL_StartAppTimer() [4].

Table 5-2. Current Consumption During Application Timer Wake Up

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	4.15	3.44
Average current [mA]	1.21	3.47
Charge consumed [mA x ms]	5.06	11.94
Peak Current [mA]	17.58	19.79
Current Profile	Figure 5-3	Figure 5-4

Figure 5-3. Current Consumption Profile of Application Timer Wake Up at 8MHz

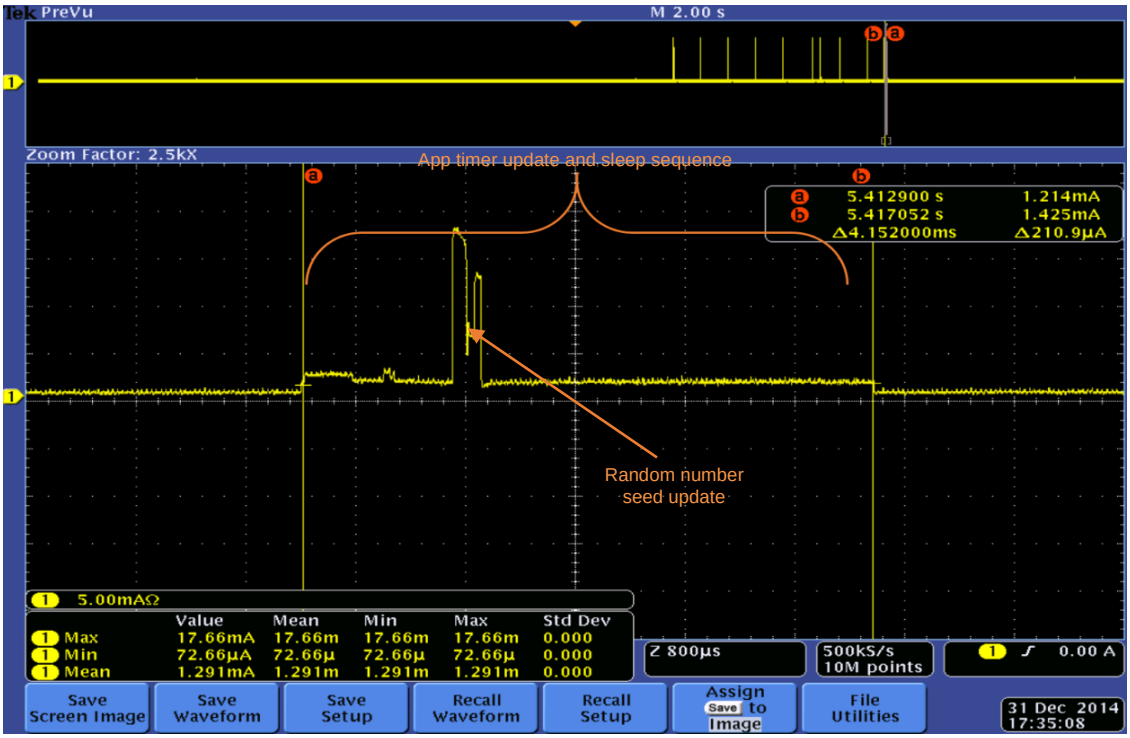
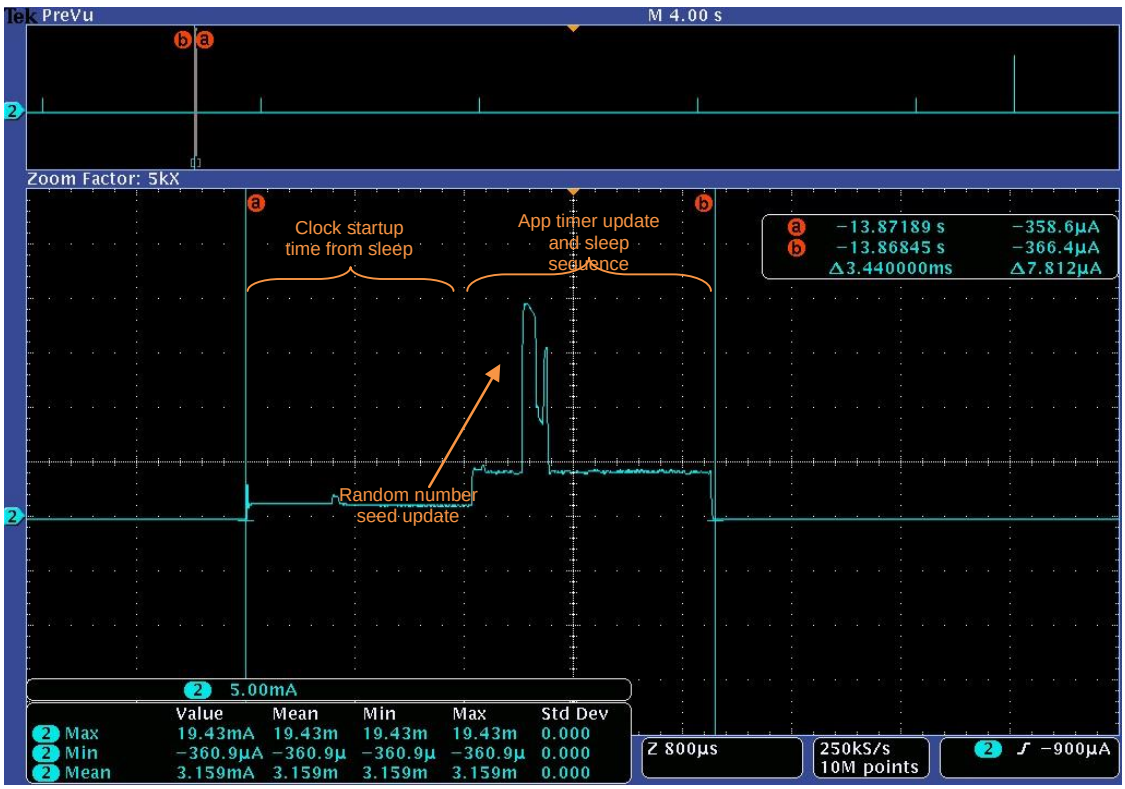


Figure 5-4. Current Consumption Profile of Application Timer Wake Up at 16MHz



5.3 Wake-up by External Interrupt

This section characterizes the power consumption when the device is woken up by an interrupt like button press etc. The pin change interrupt is enabled on the GPIO pin connected to a button so that the device will wake up from deep sleep on button press.

Table 5-3. Current Consumption During External Interrupt Wake Up

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	4.10	3.84
Average current [mA]	3.81	3.77
Charge consumed [mA x ms]	15.62	14.46
Peak Current [mA]	21.60	21.36
Current Profile	Figure 5-5	Figure 5-6

Figure 5-5. Current Consumption Profile of External Interrupt Wake Up at 8MHz

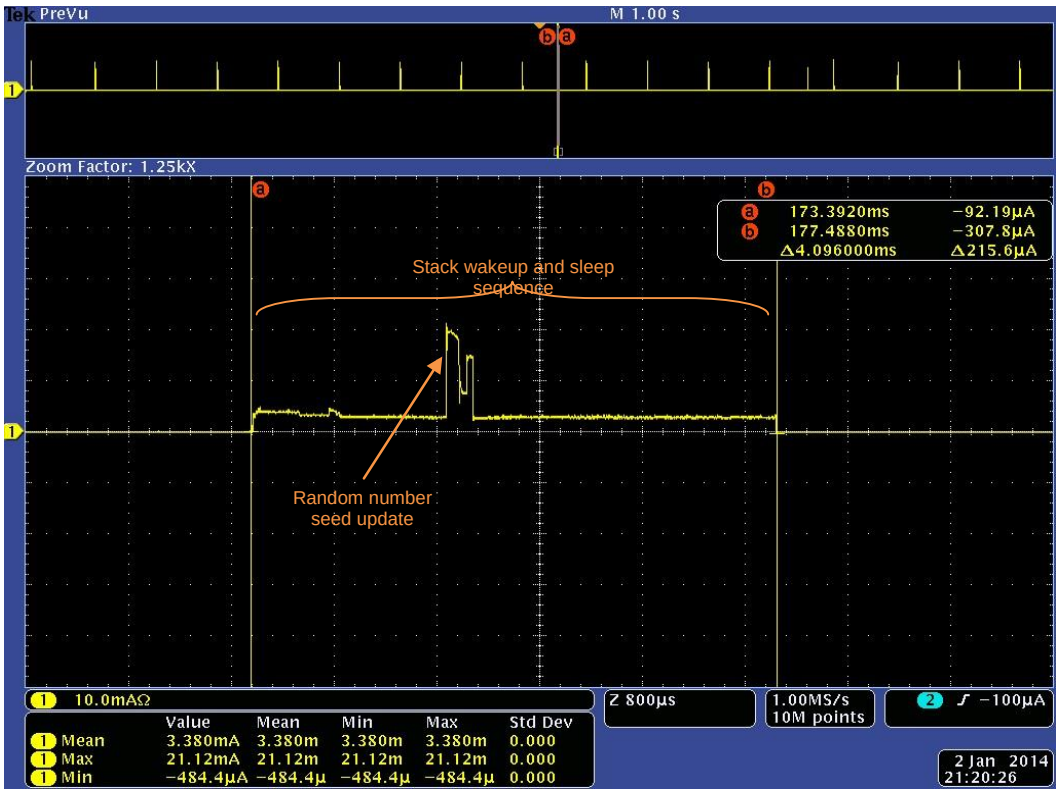
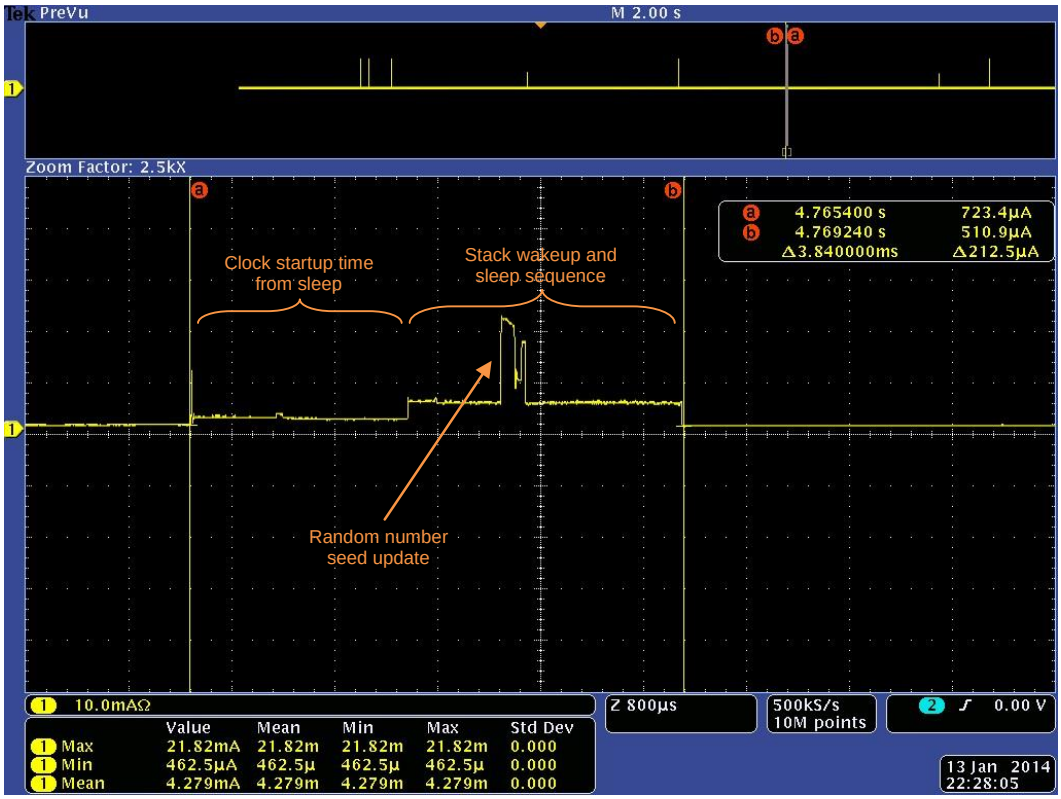


Figure 5-6. Current Consumption Profile of External Interrupt Wake Up at 16MHz



6 Parent Polling

Parent polling is done by sending MAC Data Request to the parent node. Figure 6-1 shows sniffer log for the periodic data polling. Current consumption during Data polling is given in Table 6-1.

Figure 6-1. MAC Data Request Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	06:05:02.187	MAC: Mac Data Request			0x1b90	0x0008
1	06:05:02.188	Ack				

Table 6-1. Current Consumption During Parent Polling

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	8.82	6.95
Average current [mA]	1.49	6.17
Charge consumed [mA x ms]	13.15	42.85
Peak Current [mA]	19.53	19.81
Current Profile	Figure 6-2	Figure 6-3

Figure 6-2. Current Consumption Profile of Parent Polling at 8MHz

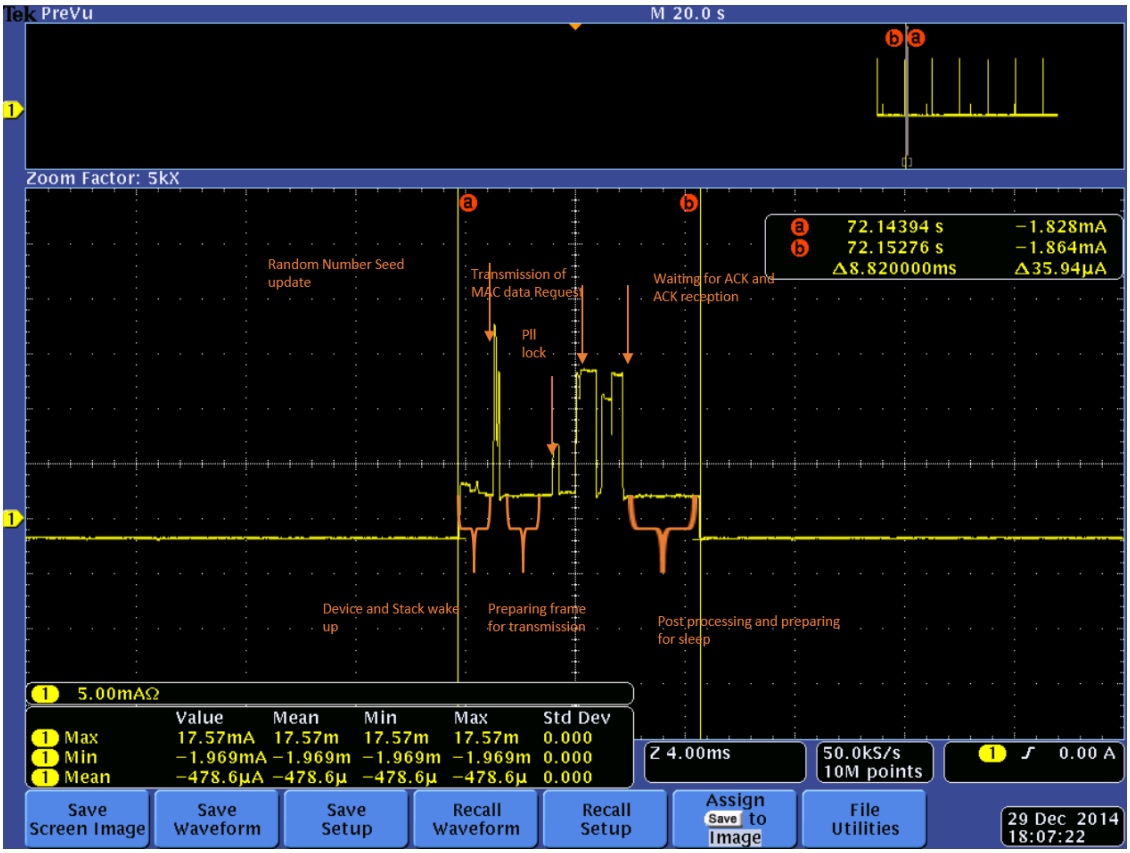
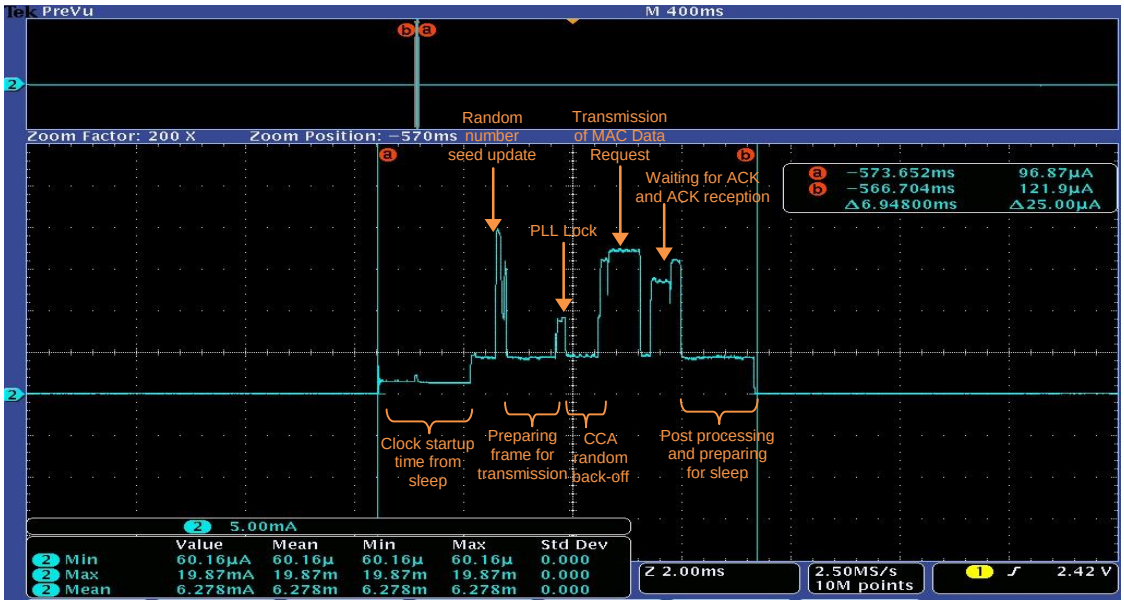


Figure 6-3. Current Consumption Profile of Parent Polling at 16MHz



Note: The total duration will vary from packet to packet and is dependent on the random back-off period.

7 Data Transmission

7.1 Without APS ACK (Typical Environment)

APS Data transmission without APS ACK from an end device in a typical environment is characterized in this section. Figure 7-1 shows the sniffer log for the data transmission without APS ACK. The total size of the APS data frame is 46 bytes in this example.

Note: APS (i.e. ZCL: On) frames in this example are sent using Application timer overflow event [4].

Figure 7-1. Data Transmission without APS ACK Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	11:55:51.249	ZCL: On	0x0001	0x0002	0x0001	0x0002
1	11:55:51.388	Ack				
2	11:55:51.894	MAC: Mac Data Request			0x0001	0x0002
3	11:55:52.033	Ack				

Table 7-1. Current Consumption During Data Transmission without APS ACK

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	24.4	17.38
Average current [mA]	2.50	6.89
Charge consumed [mA x ms]	61.04	119.71
Peak Current [mA]	17.70	19.82
Current Profile	Figure 7-2	Figure 7-3

Figure 7-2. Current Consumption Profile of Data Transmission without APS ACK at 8MHz

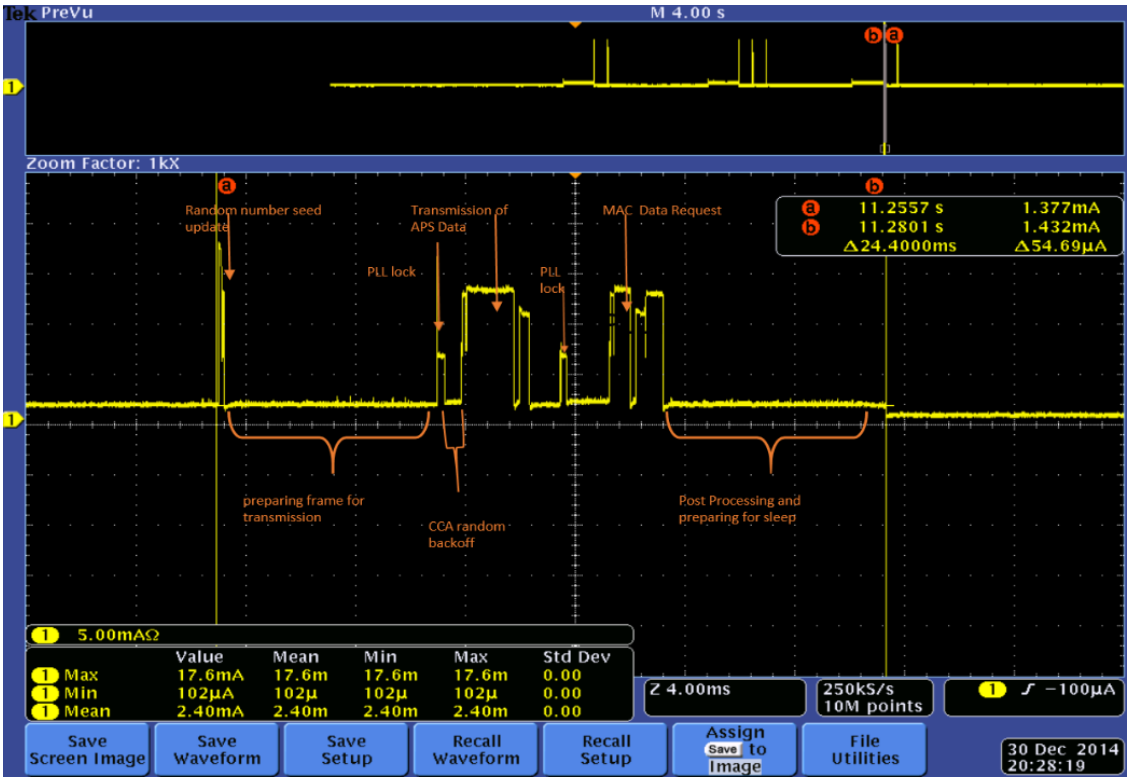
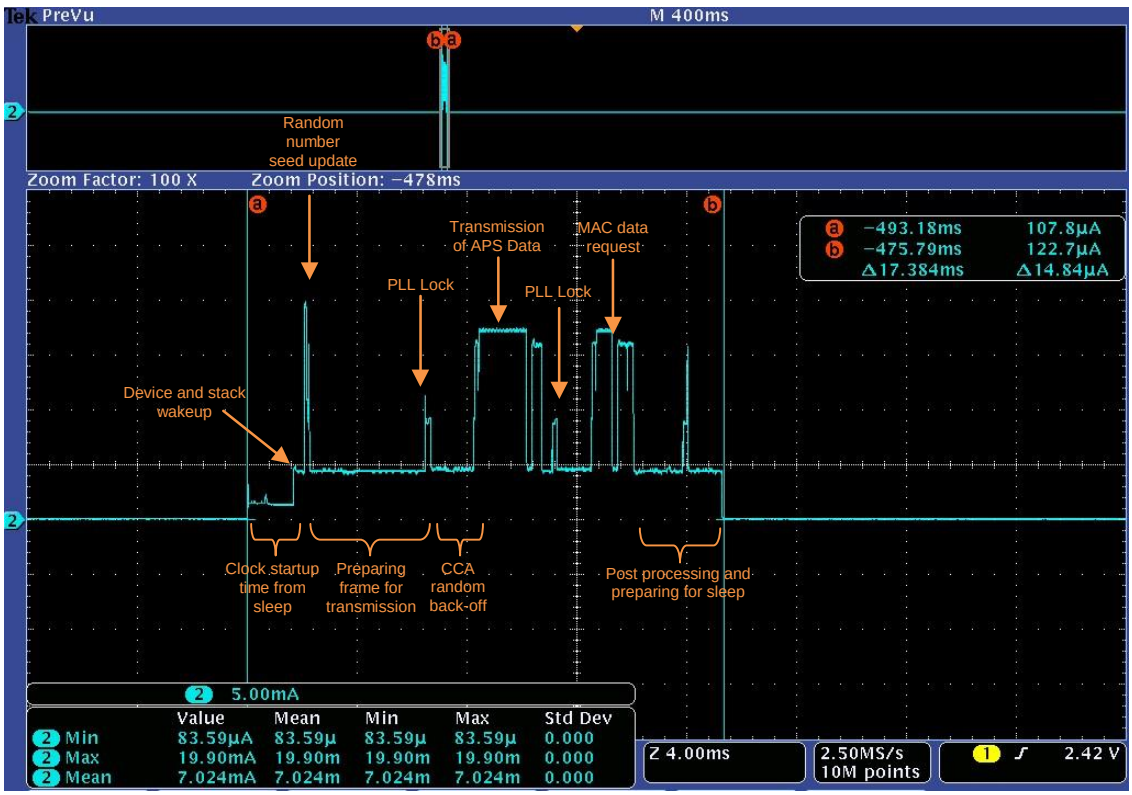


Figure 7-3. Current Consumption Profile of Data Transmission without APS ACK at 16MHz



7.2 With APS ACK (Typical Environment)

Transmission of APS data with APS ACK of a ZigBee End Device in a typical environment is characterized in this section. Figure 7-4 shows the sniffer log for the data transmission with APS ack. The total size of the APS data frame is 46 bytes.

Note: APS (i.e. ZCL: On) frames in this example are sent using Application timer overflow event [4].

Figure 7-4. Data Transmission with APS ACK Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	11:19:16.908	ZCL: On	0x0001	0x0002	0x0001	0x0002
1	11:19:17.047	Ack				
2	11:19:17.931	MAC: Mac Data Request			0x0001	0x0002
3	11:19:18.070	Ack				
4	11:21:22.887	MAC: Mac Data Request			0x0001	0x0002
5	11:21:23.026	Ack				
6	11:21:24.300	APS: Ack 0x0006	0x0002	0x0001	0x0002	0x0001
7	11:21:24.439	Ack				
8	11:21:25.666	MAC: Mac Data Request			0x0001	0x0002
9	11:21:25.805	Ack				

Table 7-2. Current Consumption During Data Transmission with APS ACK

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	540.00	519.00
Average current [mA]	0.67	0.58
Charge consumed [mA x ms]	361.8	299.31
Peak Current [mA]	20.25	19.99
Current Profile – Data Transmission with APS ACK	Figure 7-5	Figure 7-8
Current Profile – Data Transmission	Figure 7-6	Figure 7-9
Current Profile	Figure 7-7	Figure 7-10

Figure 7-5. Current Consumption Profile of Data Transmission with APS ACK at 8MHz

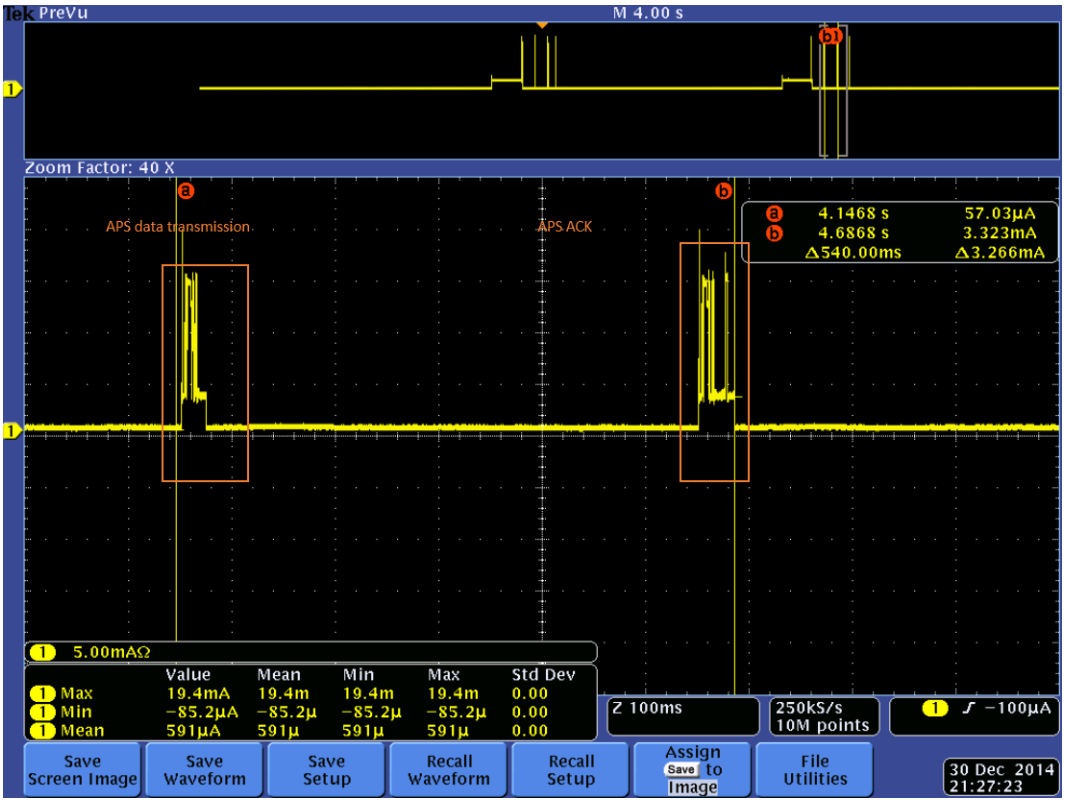


Figure 7-6. Current Consumption Profile of Data Transmission at 8MHz

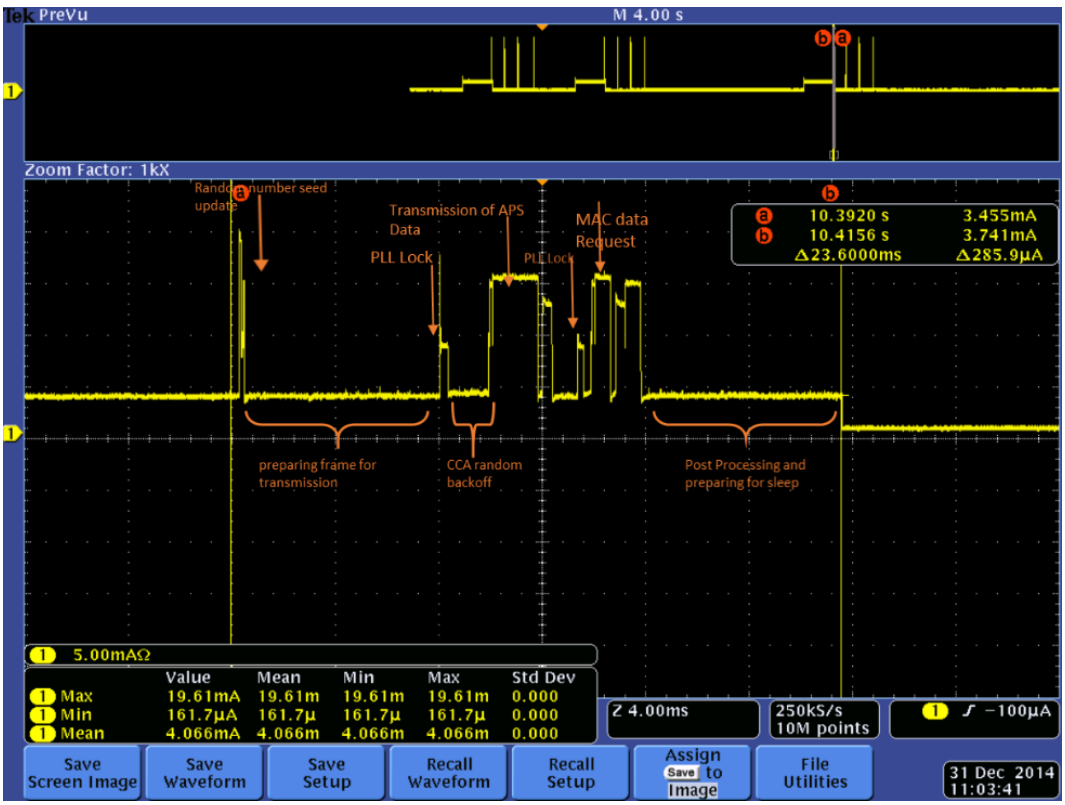


Figure 7-7. Current Consumption Profile of APS ACK Reception at 8MHz

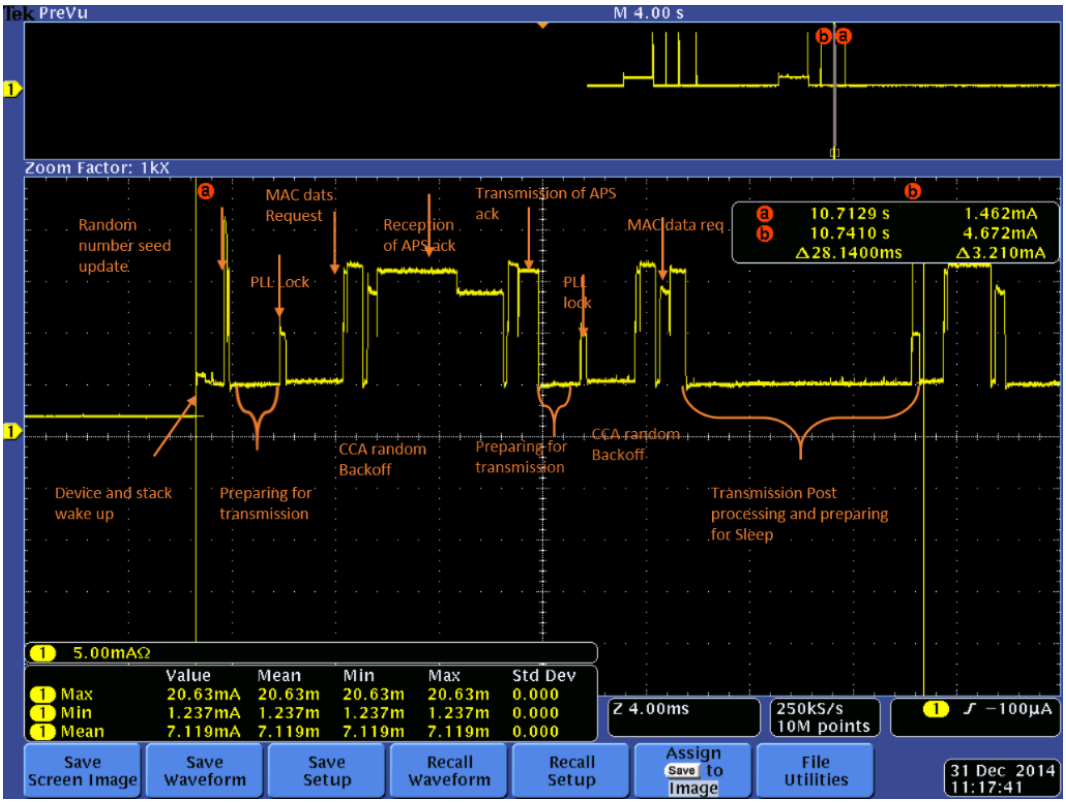


Figure 7-8. Current Consumption Profile of Data Transmission with APS ACK at 16MHz

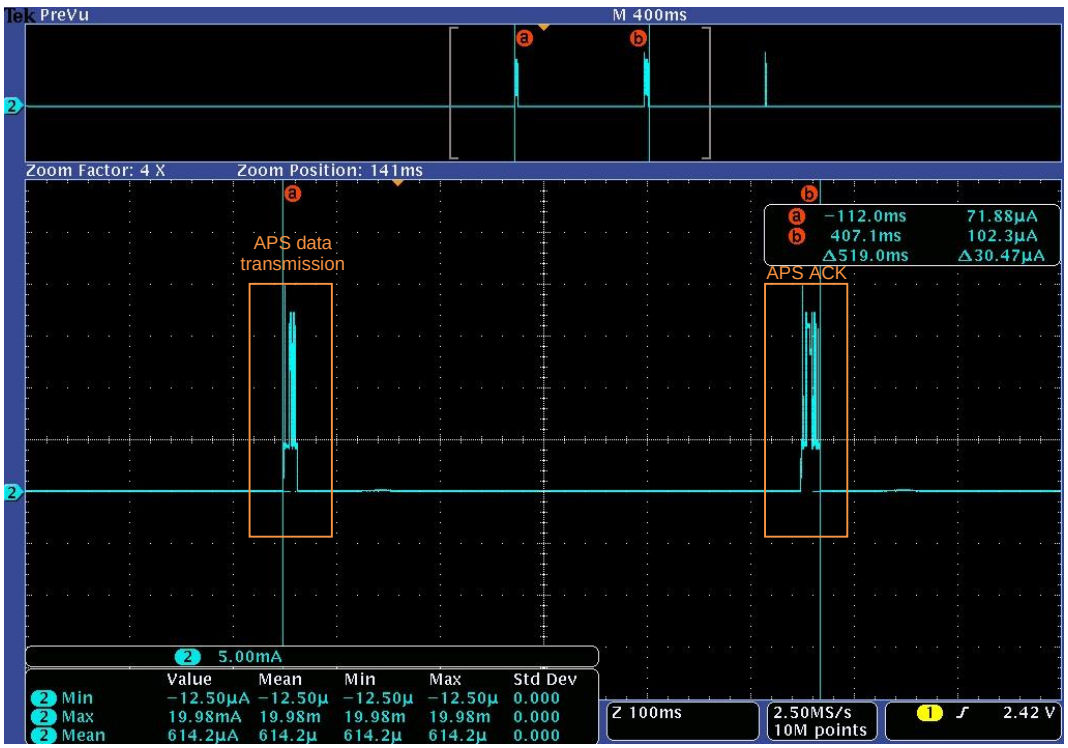


Figure 7-9. Current Consumption Profile of Data Transmission at 16MHz

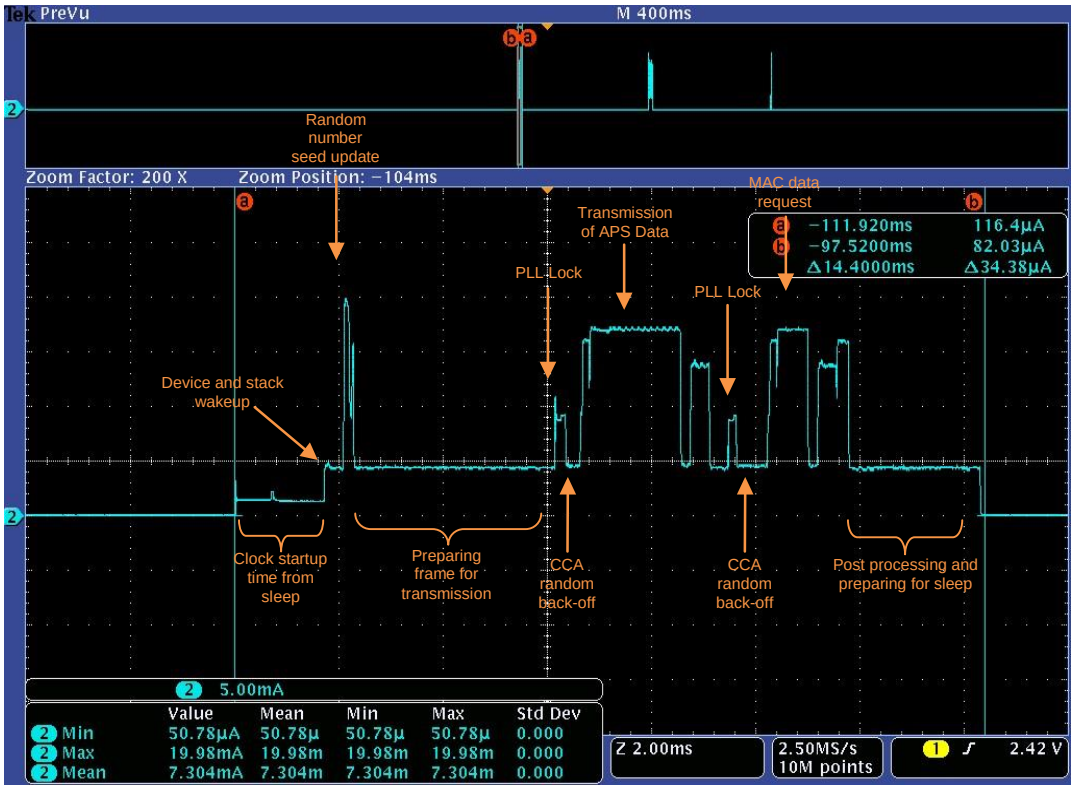
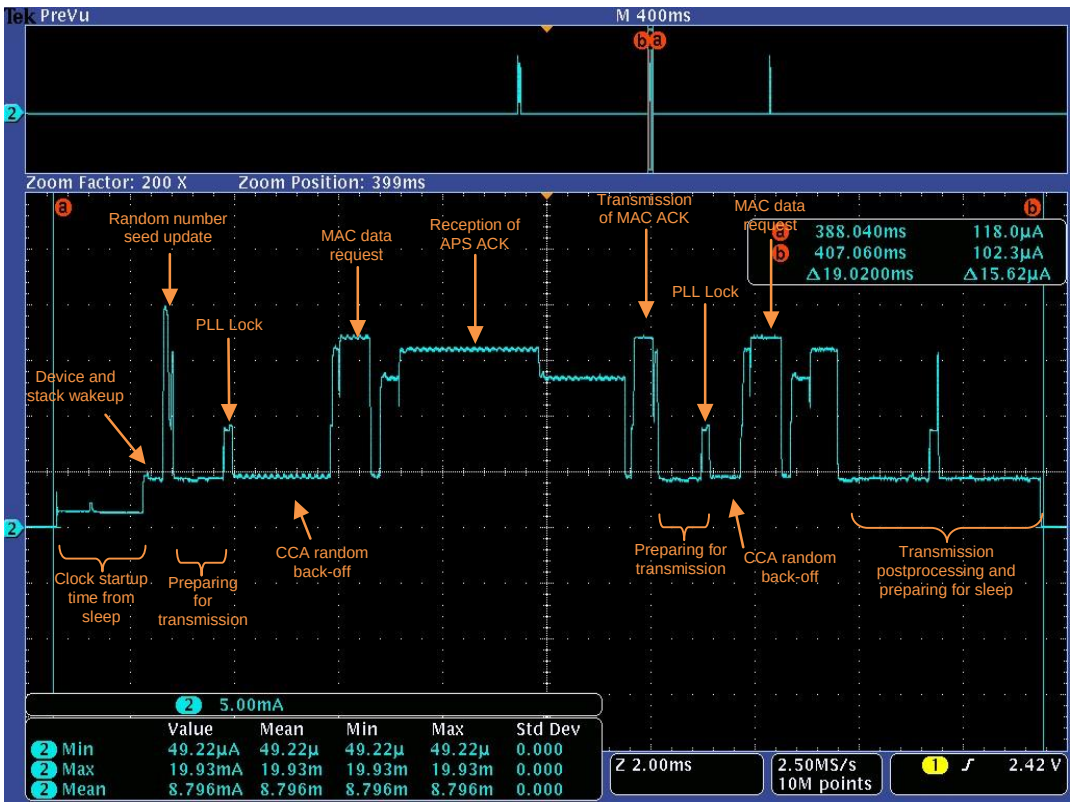


Figure 7-10. Current Consumption Profile of APS ACK Reception at 16MHz



8 MAC Beacon Scanning

This chapter characterizes the power consumption during the MAC Beacon Scanning when there are no networks available. Figure 8-1 shows the sniffer log where the devices requests beacon and waits for them. Here, the CS_CHANNEL_MASK [4] is configured for one channel so the device will scan on that channel only and goes to deep sleep.

Figure 8-1. MAC Beacon Request Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
1	12:45:46.234	MAC: MacBeaconReq				0xffff

If the CS_CHANNEL_MASK is configured for scanning more than one channel, then the total power consumption for beacon scanning will be power consumed for one channel multiplied with the number of channels scanned.

For example if channel mask is configured for enabling channels 11, 15, 20, and 25, the total current consumption will be four times the average current consumed for one channel.

Table 8-1. Current Consumption During MAC Beacon Scanning

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	73.8	111.10
Average current [mA]	14.42	18.14
Charge consumed [mA x ms]	1064.34	2015.69
Peak Current [mA]	17.32	22.65
Current Profile	Figure 8-2	Figure 8-3

Figure 8-2. Current Consumption Profile of MAC Beacon Scanning at 8MHz

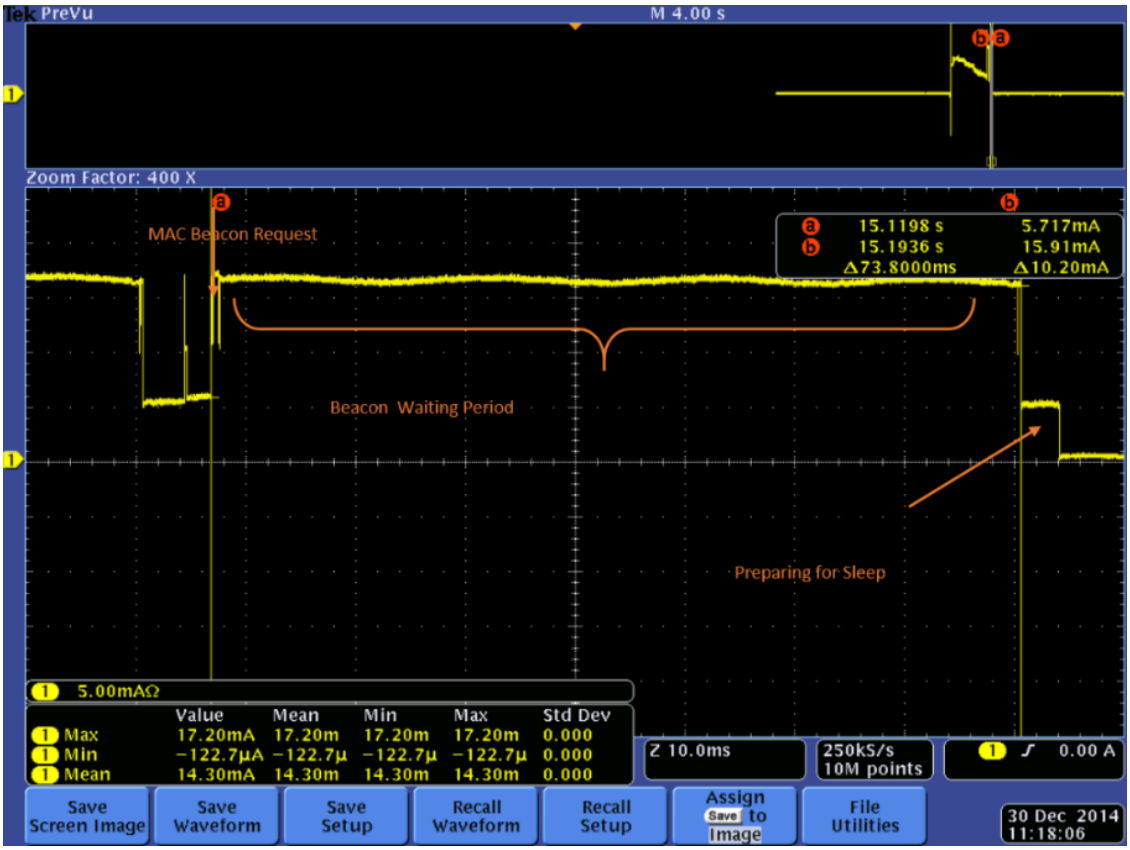
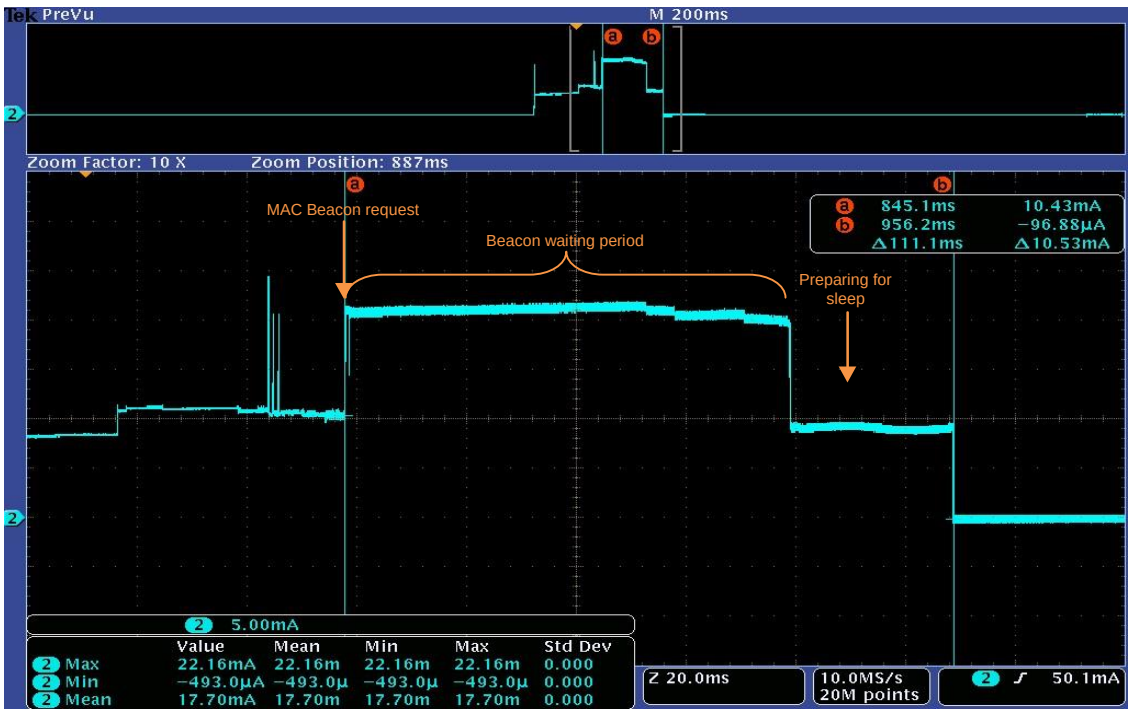


Figure 8-3. Current Consumption Profile of MAC Beacon Scanning at 16MHz

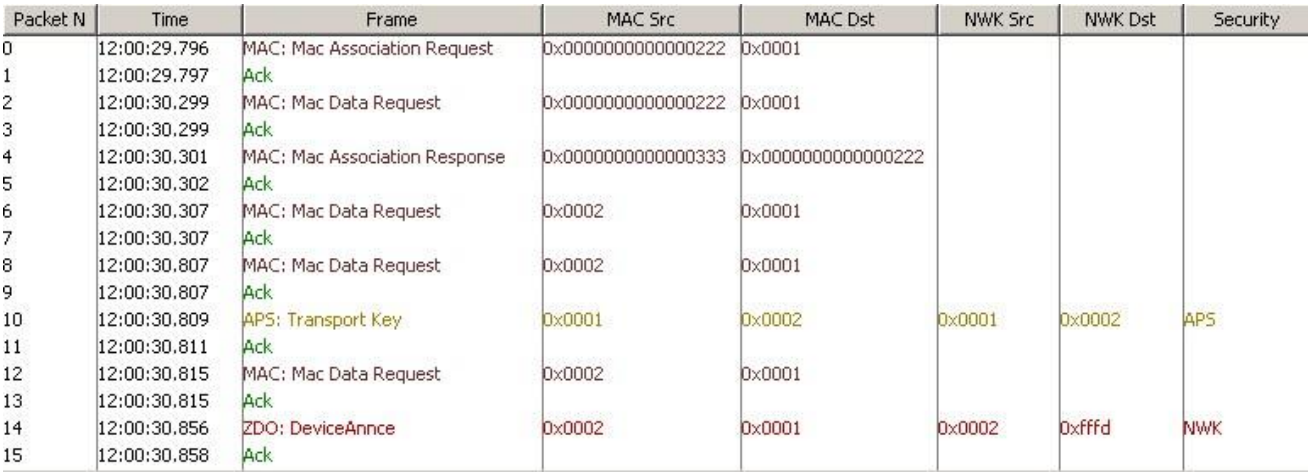


9 Network Association – Classical Join

Power consumption of ZigBee End Device during Classical Join procedure in factory new condition is described in this chapter. Figure 9-1 shows the sniffer log where;

- End Devices sends a MAC Association Request to its parent and polls for the Association Response
- If the status of Association Response is success
- If security is enabled, then End Device will poll the parent for Transport Key
- After getting Transport Key, the End Device will transmit Device Announcement frame

Figure 9-1. Classical Join Sniffer Log



Packet N	Time	Frame	MAC Src	MAC Dst	NWK Src	NWK Dst	Security
0	12:00:29.796	MAC: Mac Association Request	0x0000000000000222	0x0001			
1	12:00:29.797	Ack					
2	12:00:30.299	MAC: Mac Data Request	0x0000000000000222	0x0001			
3	12:00:30.299	Ack					
4	12:00:30.301	MAC: Mac Association Response	0x0000000000000333	0x0000000000000222			
5	12:00:30.302	Ack					
6	12:00:30.307	MAC: Mac Data Request	0x0002	0x0001			
7	12:00:30.307	Ack					
8	12:00:30.807	MAC: Mac Data Request	0x0002	0x0001			
9	12:00:30.807	Ack					
10	12:00:30.809	APS: Transport Key	0x0001	0x0002	0x0001	0x0002	APS
11	12:00:30.811	Ack					
12	12:00:30.815	MAC: Mac Data Request	0x0002	0x0001			
13	12:00:30.815	Ack					
14	12:00:30.856	ZDO: DeviceAnnce	0x0002	0x0001	0x0002	0xfffd	NWK
15	12:00:30.858	Ack					

Table 9-1. Current Consumption During Classical Join

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	1243.00	1228.00
Average current [mA]	6.40	9.95
Charge consumed [mA x ms]	7963.90	12221.92
Peak Current [mA]	19.60	19.71
Current Profile – Classical Join	Figure 9-2	Figure 9-7
Current Profile - Association request transmission	Figure 9-3	Figure 9-8
Current Profile - Association response reception	Figure 9-4	Figure 9-9
Current Profile - Transport Key reception	Figure 9-5	Figure 9-10
Current Profile - Device Announcement transmission	Figure 9-6	Figure 9-11

Figure 9-2. Current Consumption Profile of Classical Join at 8MHz

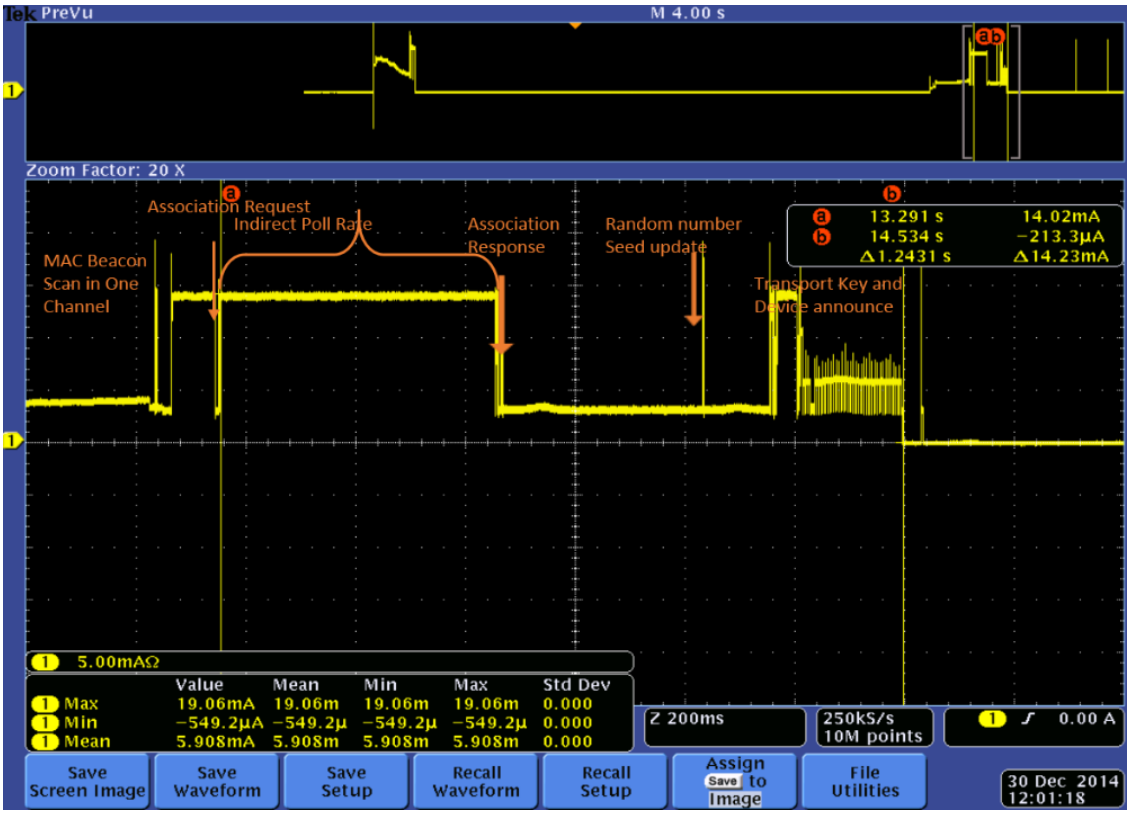


Figure 9-3. Current Consumption Profile of Association Request Transmission at 8MHz

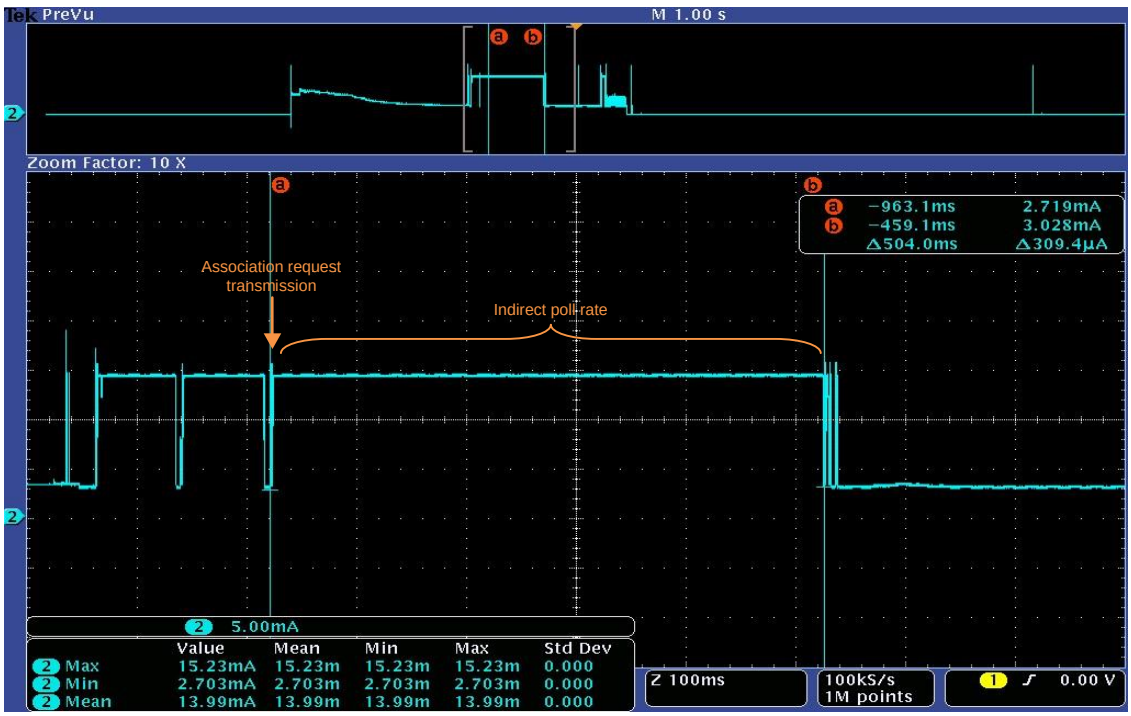


Figure 9-4. Current Consumption Profile of Association Response Reception at 8MHz

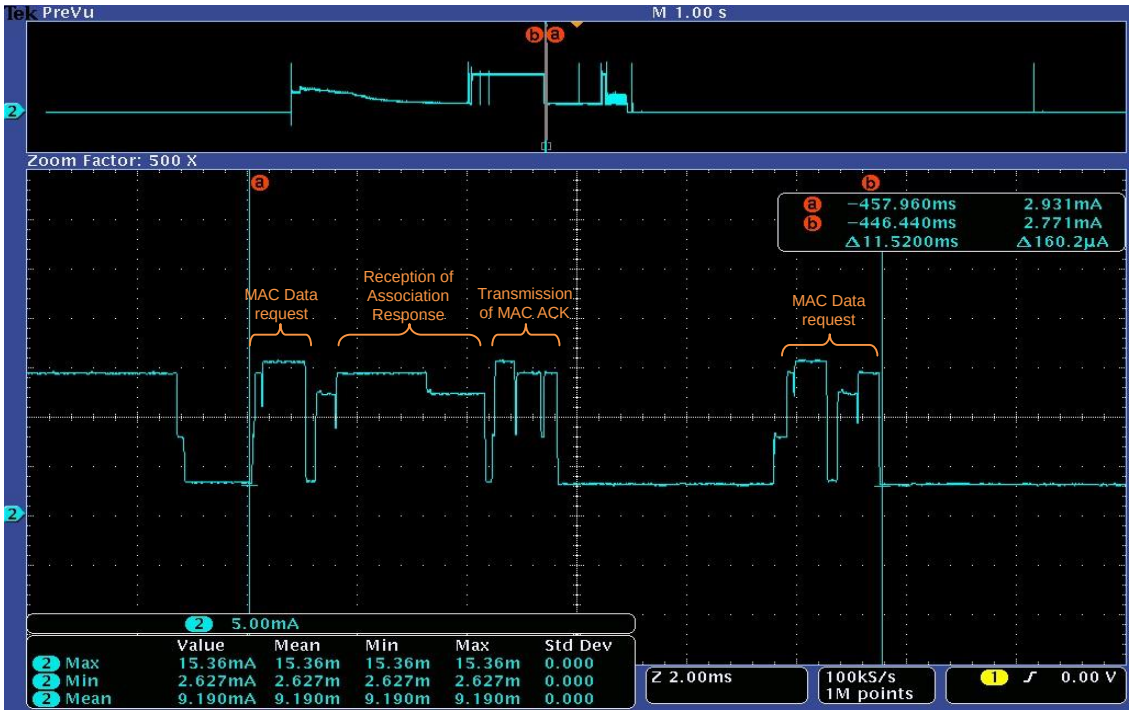


Figure 9-5. Current Consumption Profile of Transport Key Reception at 8MHz

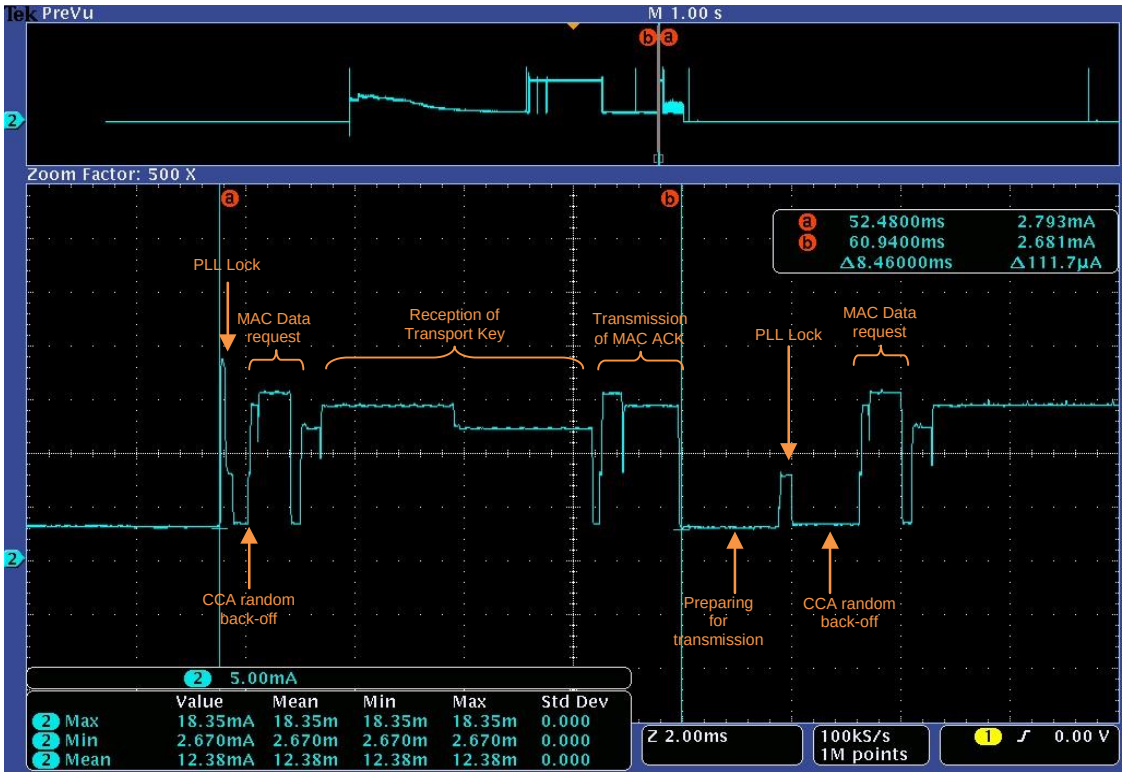


Figure 9-6. Current Consumption Profile of Device Announce Transmission at 8MHz

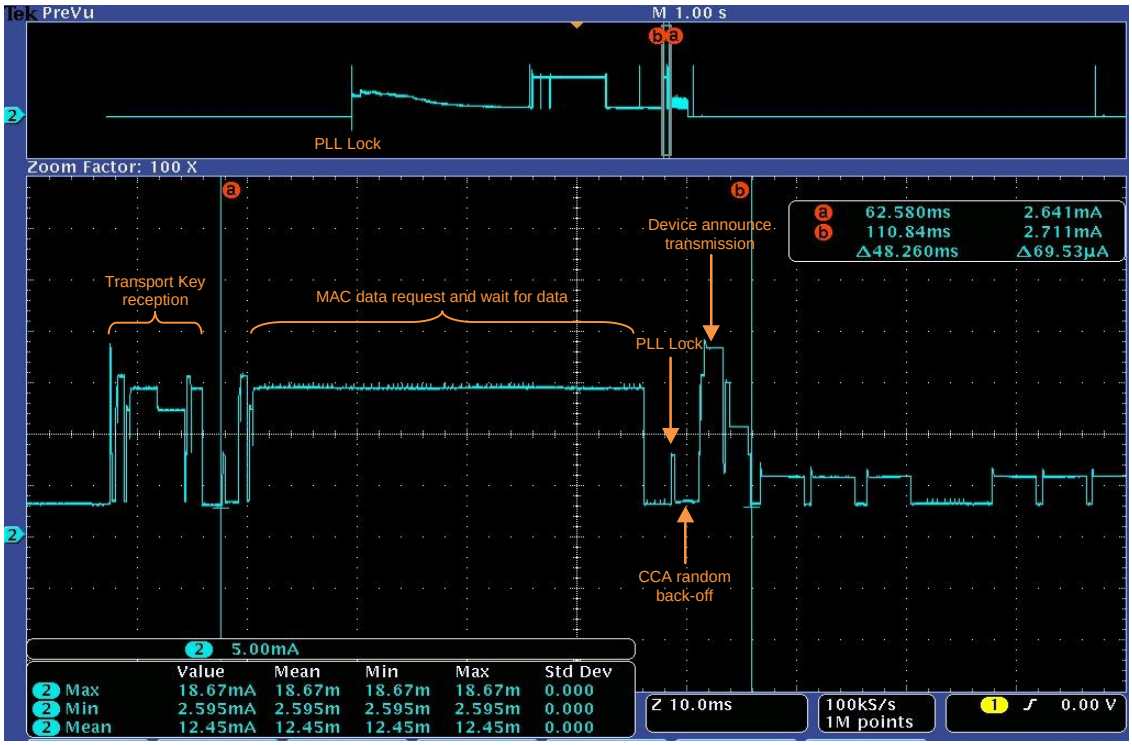


Figure 9-7. Current Consumption Profile of Classical Join at 16MHz

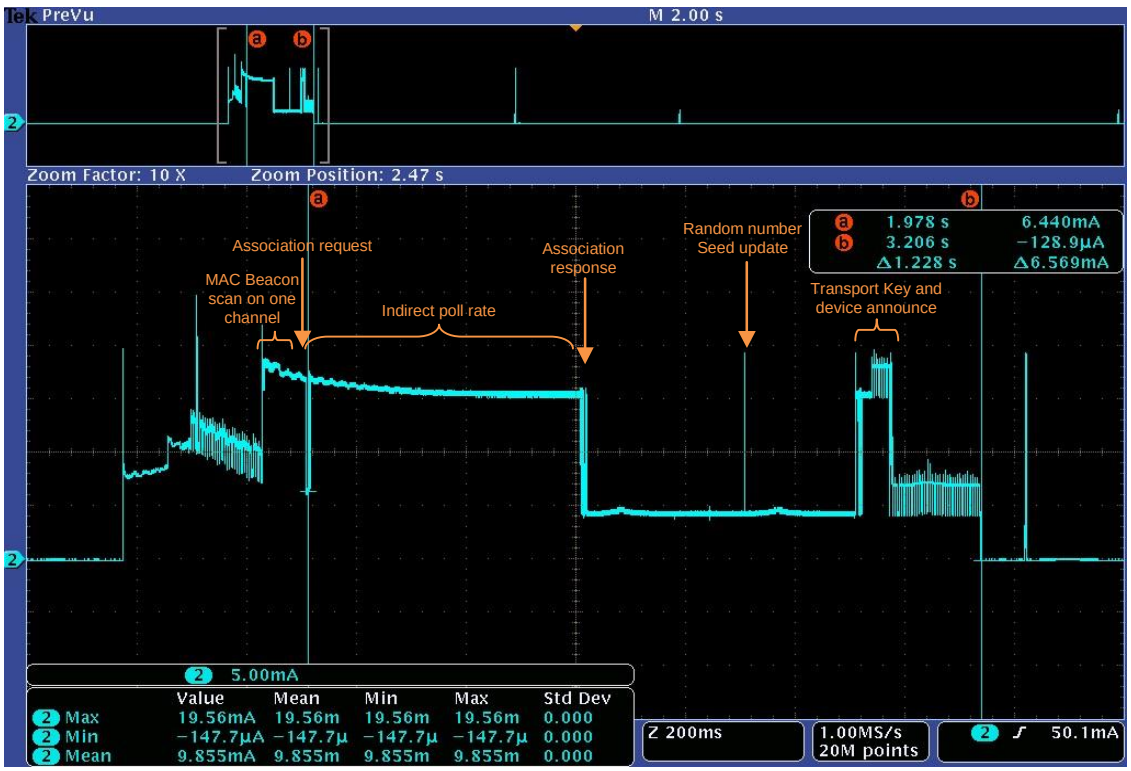


Figure 9-8. Current Consumption Profile of Association Request Transmission at 16MHz

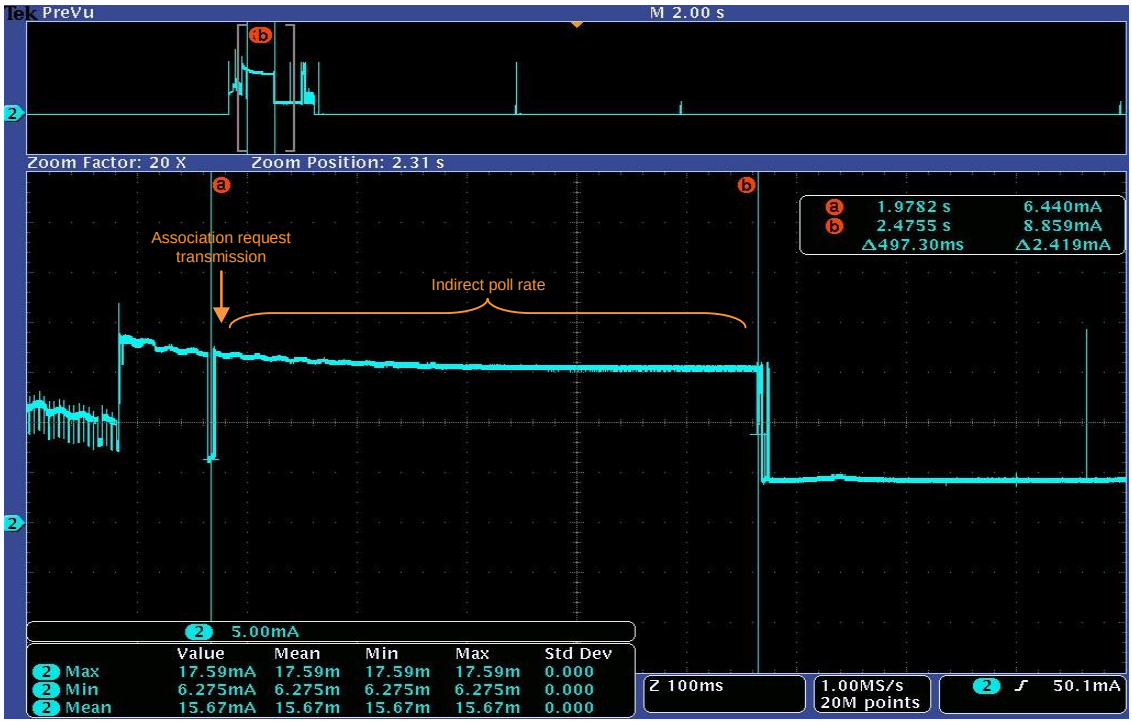


Figure 9-9. Current Consumption Profile of Association Response Reception at 16MHz

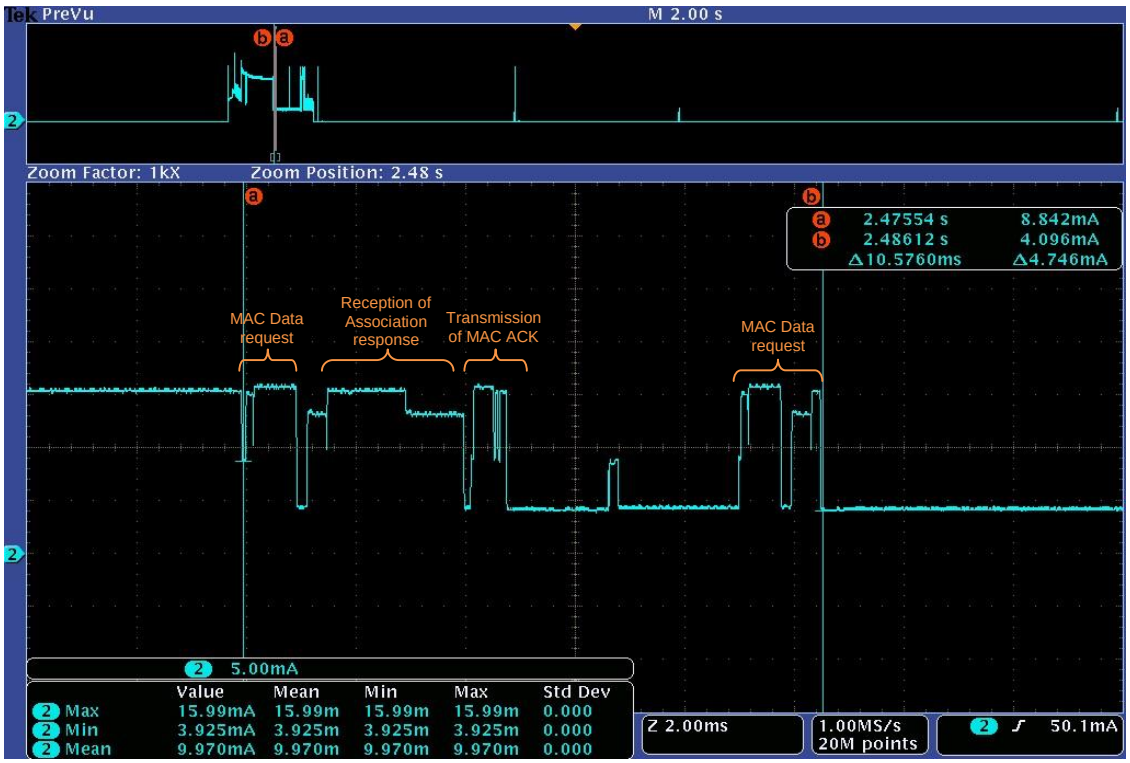


Figure 9-10. Current Consumption Profile of Transport Key Reception at 16MHz

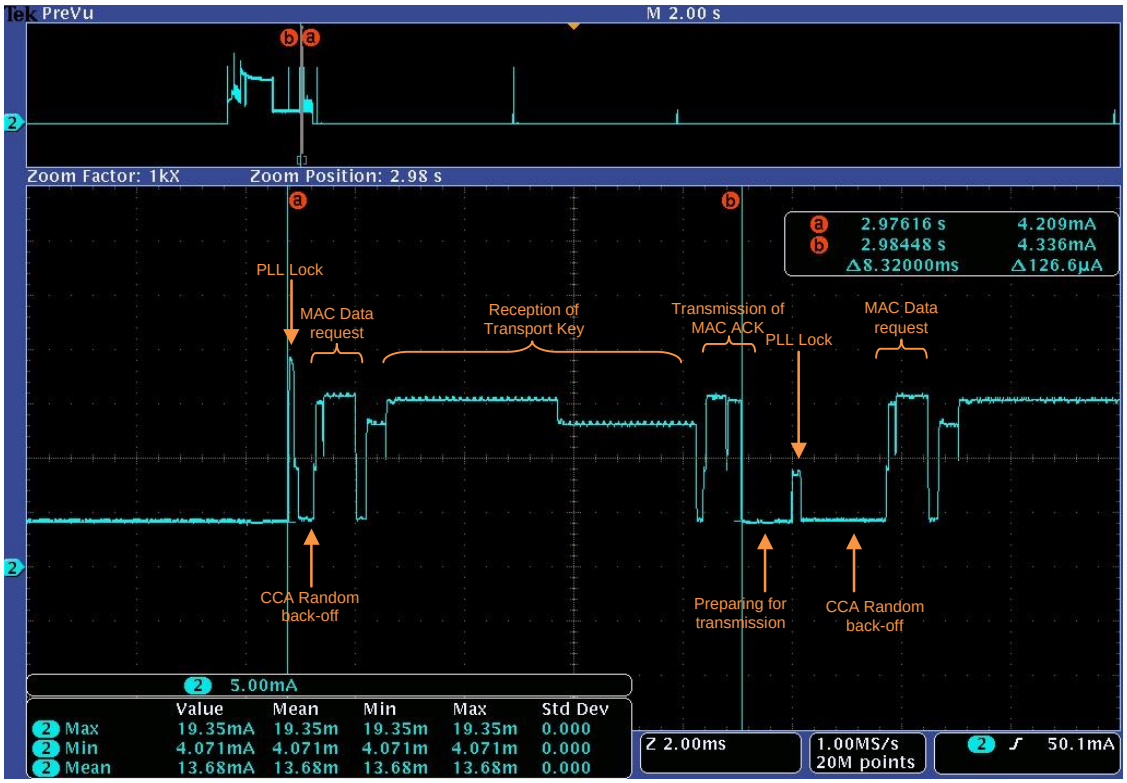
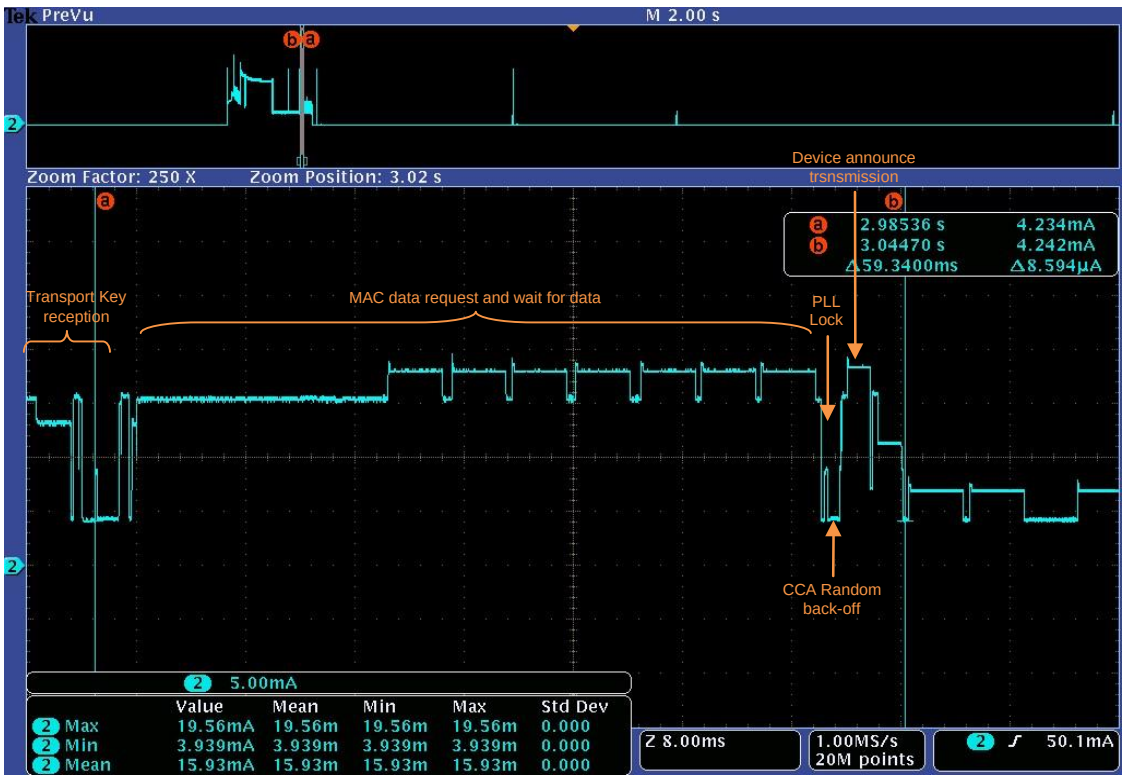


Figure 9-11. Current Consumption Profile of Device Announce Transmission at 16MHz



10 Rejoin to the Parent without Beacon Scanning

This chapter characterizes the power consumption of ZigBee End Device when it tries to rejoin the parent without beacon scanning. Figure 10-1 shows the sniffer log where the device sends a rejoin request to its parent and polls for rejoin response command from the parent device.

Note: The scenario is created by power cycling the End Device.

Figure 10-1. Rejoin to the Parent Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst	Security
0	05:22:25.502	NWK: Rejoin Request	0x0002	0x0001	0x0002	0x0001	NWK
1	05:22:25.503	Ack					
2	05:22:26.091	MAC: Mac Data Request			0x0002	0x0001	
3	05:22:26.091	Ack					
4	05:22:26.093	NWK: Rejoin Response	0x0001	0x0002	0x0001	0x0002	NWK
5	05:22:26.095	Ack					
6	05:22:26.106	MAC: Mac Data Request			0x0002	0x0001	
7	05:22:26.106	Ack					
8	05:22:26.115	ZDO: DeviceAnnce	0x0002	0xfffd	0x0002	0x0001	NWK
9	05:22:26.117	Ack					
10	05:22:26.136	MAC: Mac Data Request			0x0002	0x0001	
11	05:22:26.136	Ack					

Table 10-1. Current Consumption During Rejoin to Parent

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	579.6	1120.00
Average current [mA]	2.67	6.32
Charge consumed [mA x ms]	1551.70	7078.40
Peak Current [mA]	17.96	24.41
Current Profile – Rejoin to Parent	Figure 10-2	Figure 10-5
Current Profile – Rejoin Request transmission	Figure 10-3	Figure 10-6
Current Profile – Rejoin Response reception	Figure 10-4	Figure 10-7
Current Profile – Device Announce transmission	Figure 10-4	Figure 10-8

Figure 10-2. Current Consumption Profile of Rejoin to Parent at 8MHz

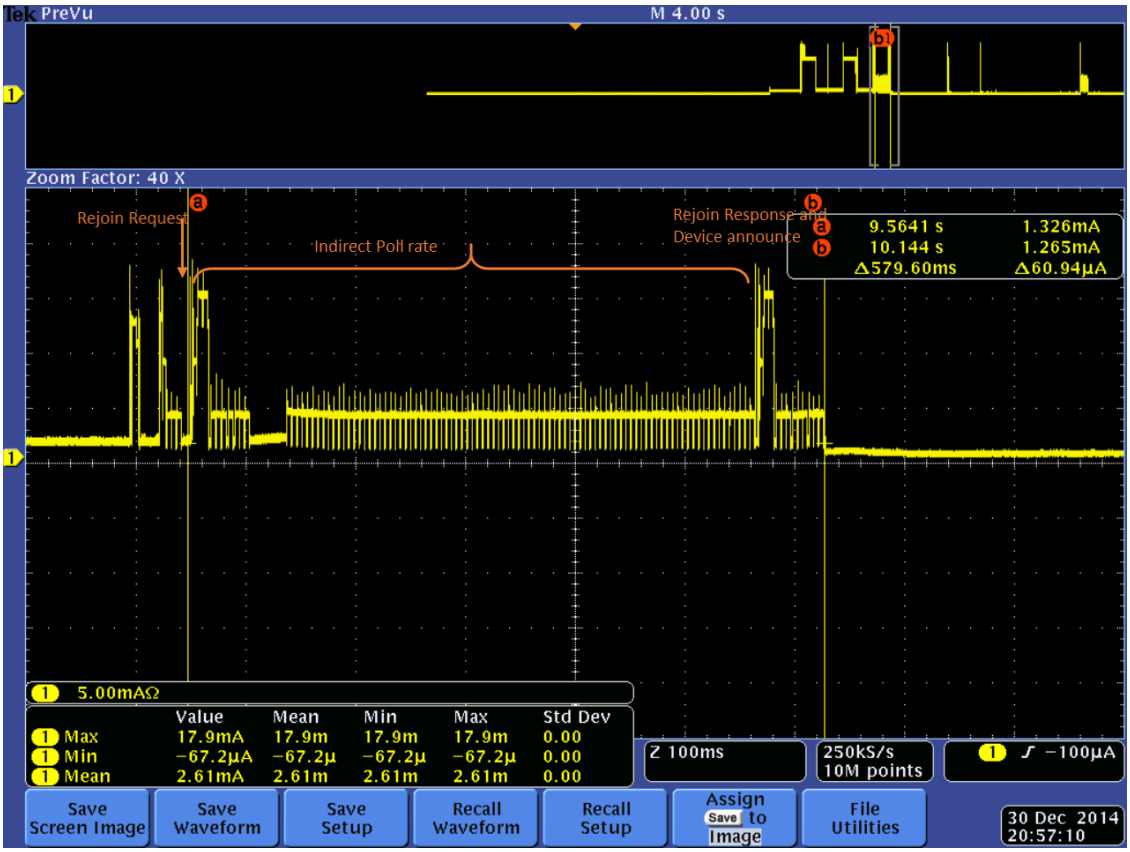


Figure 10-3. Current Consumption Profile of Rejoin Request Transmission at 8MHz

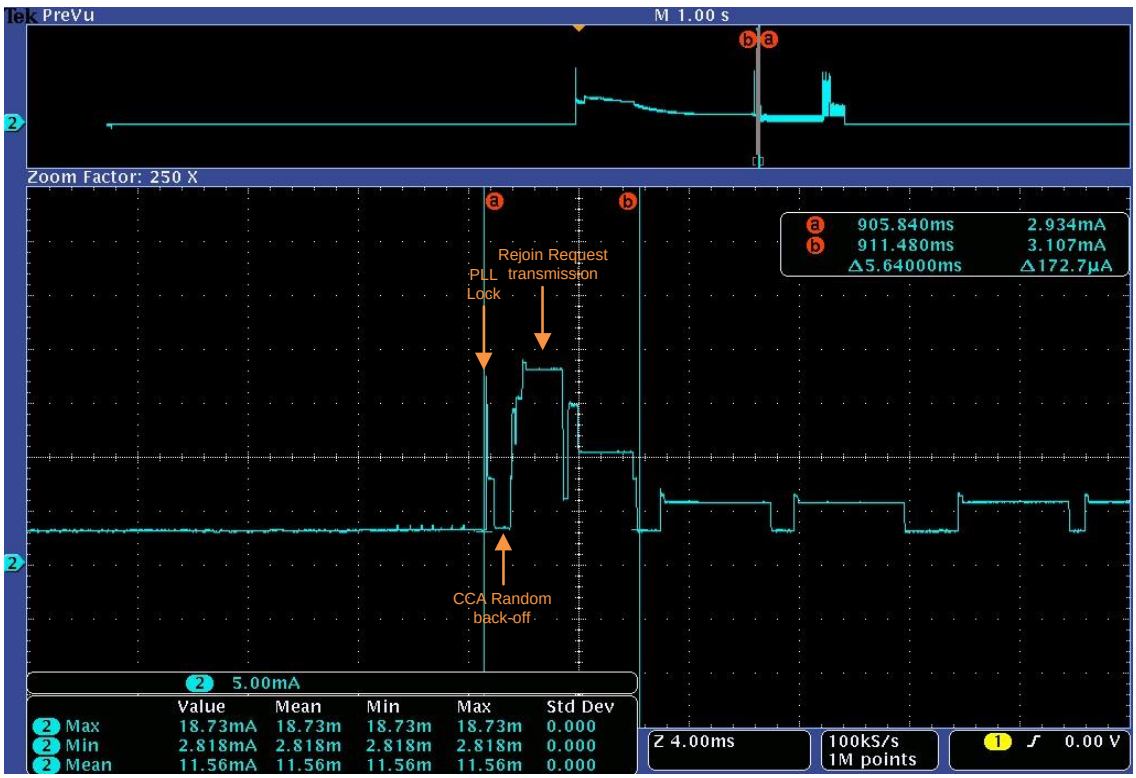


Figure 10-4. Current Consumption Profile of Rejoin Response and Device Announce at 8MHz

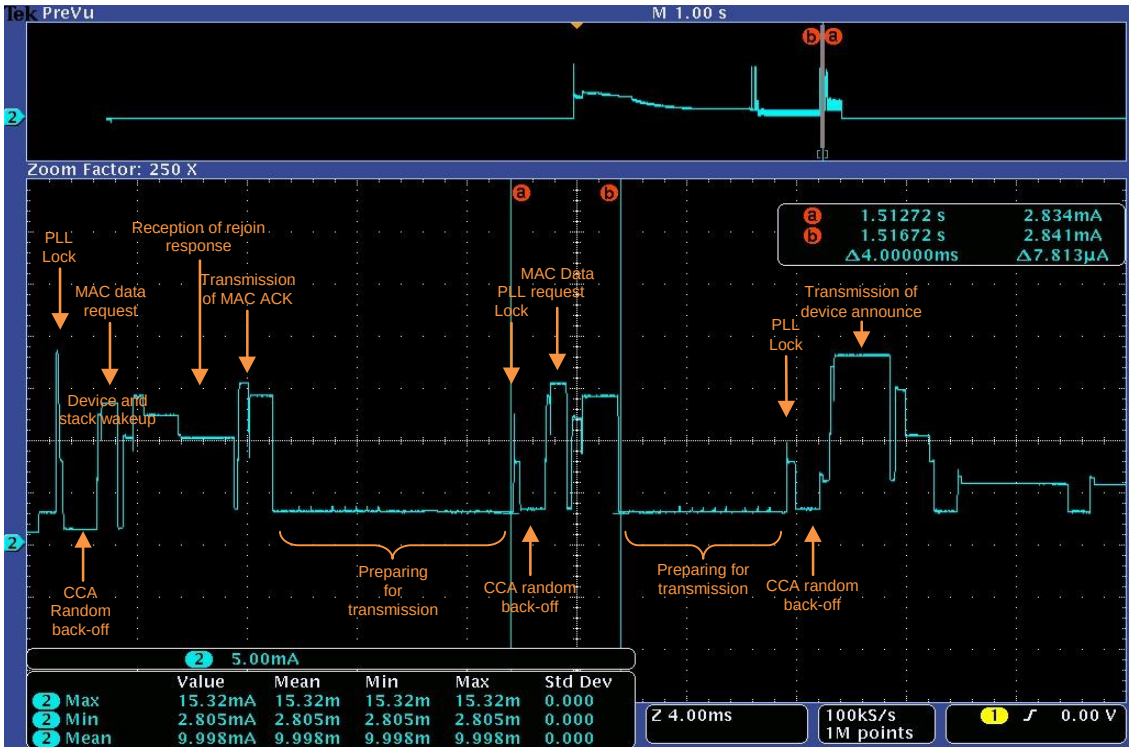


Figure 10-5. Current Consumption Profile of Rejoin to Parent at 16MHz

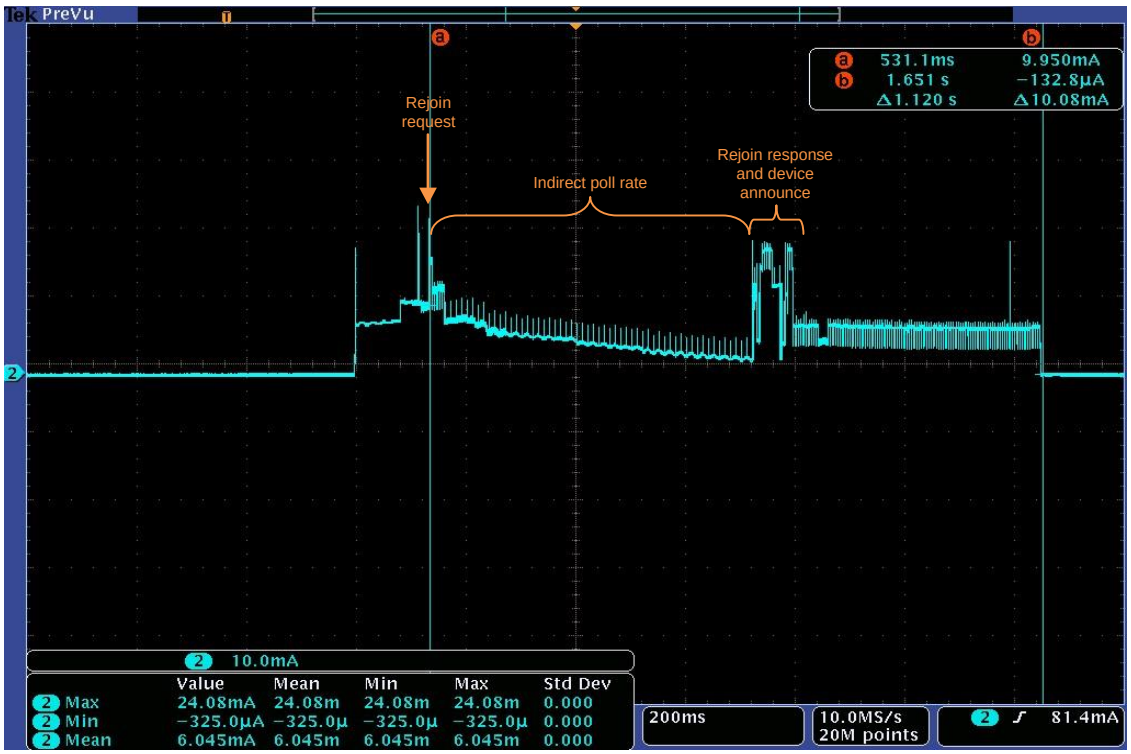


Figure 10-6. Current Consumption Profile of Rejoin Request Transmission at 16MHz

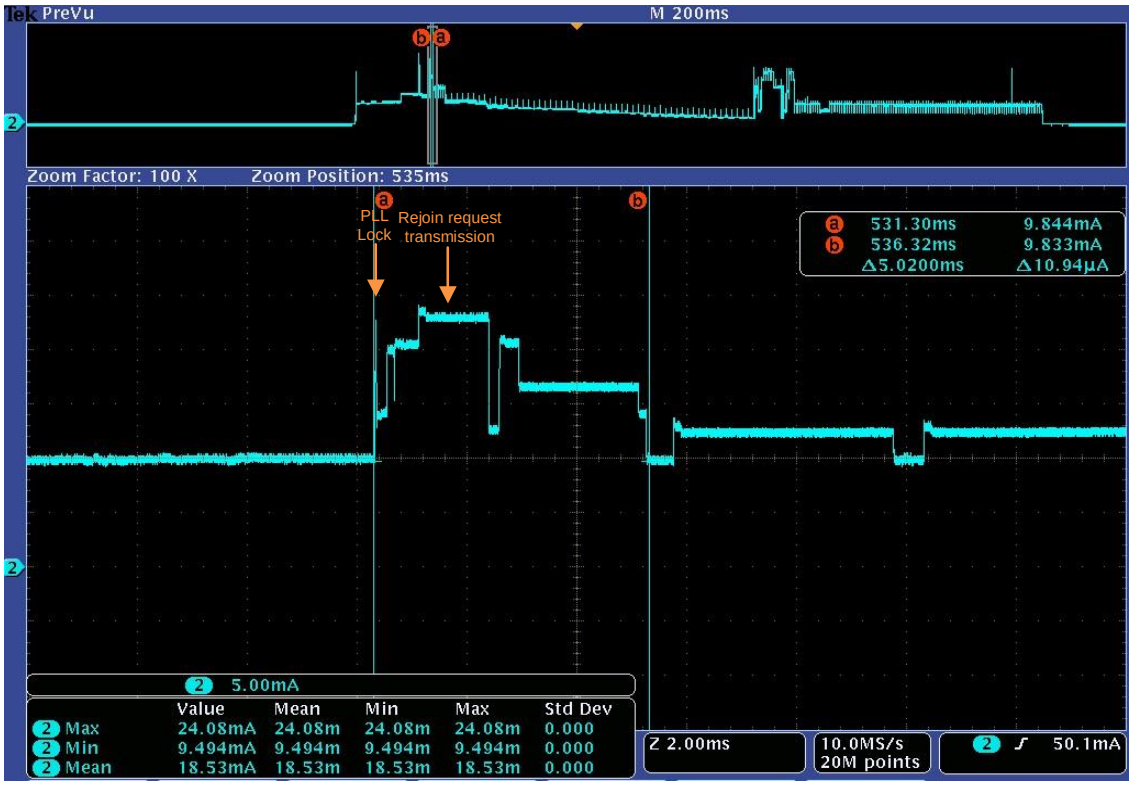


Figure 10-7. Current Consumption Profile of Rejoin Response at 16MHz

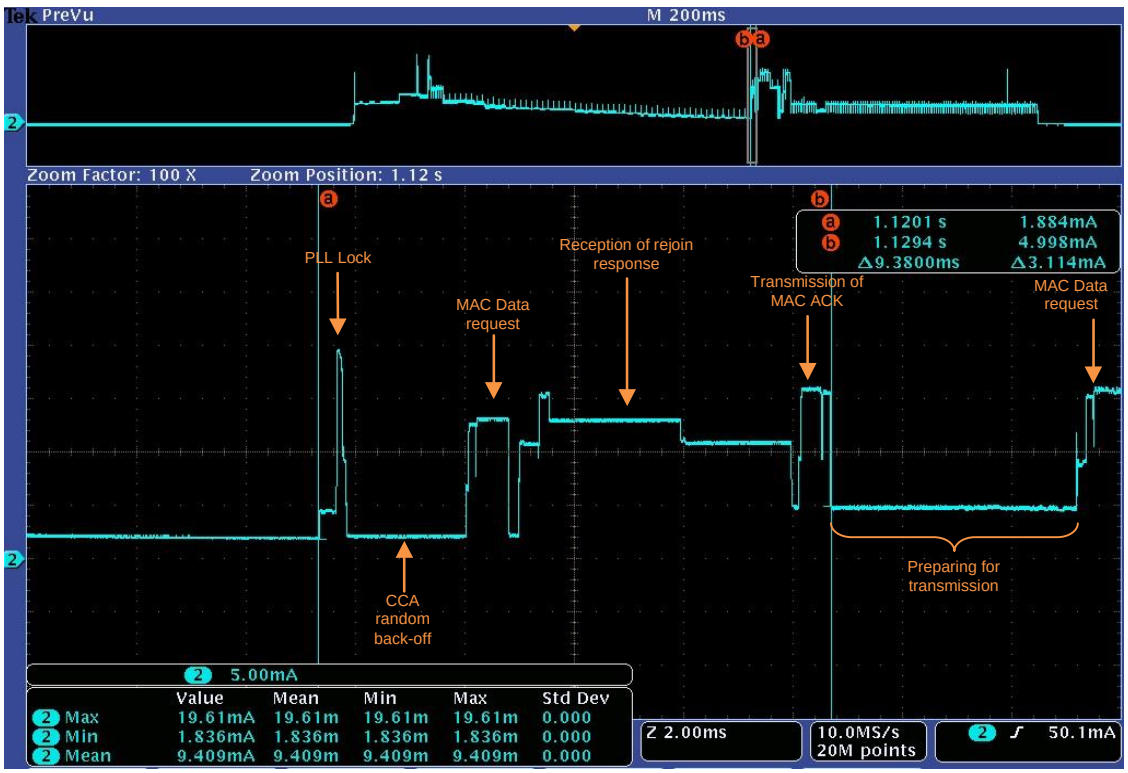
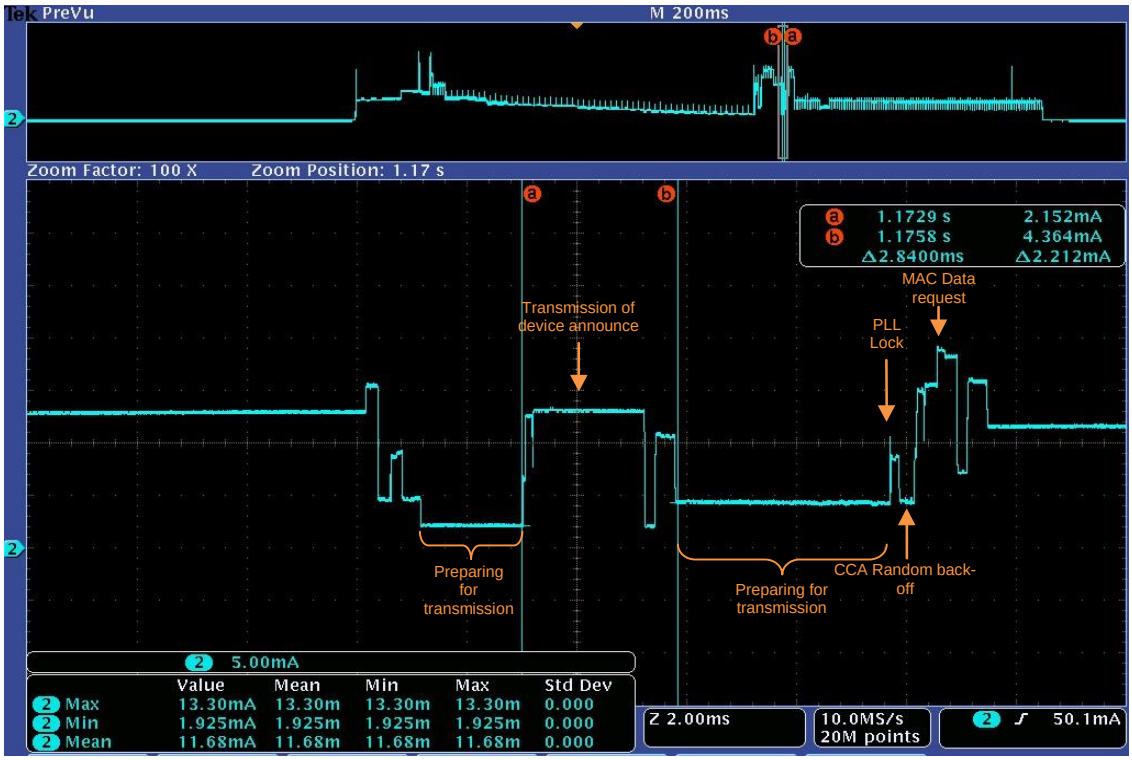


Figure 10-8. Current Consumption Profile of Device Announce at 16MHz



11 Parent Loss Detection and Rejoin to another Parent

This chapter characterizes the power consumption of ZigBee End Device when it detects parent loss and tries to rejoin another parent in the network. Figure 11-1 shows the sniffer log where the device detects the parent loss, performs beacon scanning and thereby finding a new parent and rejoin to the same network.

Note: ZigBee End Device is configured to send periodic polling of parent (refer Chapter 6).

- Number of retries before indicating parent loss is controlled by CS_ZDO_MAX_SYNC_FAIL_AMOUNT or N_END_DEVICE_ROBUSTNESS_MAX_POLL_FAILURES parameter [4]
- After Parent loss detection, End Device does a Beacon Scanning (section) on the current channel
- Other Full Function Device (FFD) in the same network responds with a Beacon frame, then the End Device joins the network with that FFD as its parent

Figure 11-1. Parent Loss Detection and Rejoining to another Parent Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst	Security
0	07:18:14.475	MAC: Mac Data Request			0x0003	0x0001	
1	07:18:14.483	MAC: Mac Data Request			0x0003	0x0001	
2	07:18:14.491	MAC: Mac Data Request			0x0003	0x0001	
3	07:18:14.499	MAC: Mac Data Request			0x0003	0x0001	
4	07:18:19.473	MAC: Mac Data Request			0x0003	0x0001	
5	07:18:19.480	MAC: Mac Data Request			0x0003	0x0001	
6	07:18:19.487	MAC: Mac Data Request			0x0003	0x0001	
7	07:18:19.495	MAC: Mac Data Request			0x0003	0x0001	
8	07:18:23.662	NWK: Link Status	0x0002	0xfffc	0x0002	0xffff	NWK
9	07:18:24.533	MAC: Mac Data Request			0x0003	0x0001	
10	07:18:24.537	MAC: Mac Data Request			0x0003	0x0001	
11	07:18:24.544	MAC: Mac Data Request			0x0003	0x0001	
12	07:18:24.551	MAC: Mac Data Request			0x0003	0x0001	
13	07:18:24.558	MAC: MacBeaconReq				0xffff	
14	07:18:24.561	Beacon			0x0002		
15	07:18:24.668	NWK: Rejoin Request	0x0003	0x0002	0x0003	0x0002	NWK
16	07:18:24.669	Ack					
17	07:18:25.252	MAC: Mac Data Request			0x0003	0x0002	
18	07:18:25.252	Ack					
19	07:18:25.254	NWK: Rejoin Response	0x0002	0x0003	0x0002	0x0003	NWK
20	07:18:25.256	Ack					
21	07:18:25.266	MAC: Mac Data Request			0x0003	0x0002	
22	07:18:25.266	Ack					
23	07:18:25.300	ZDO: DeviceAnnce	0x0003	0xfffd	0x0003	0x0002	NWK
24	07:18:25.302	Ack					

Table 11-1. Current Consumption During Parent Loss Detection and Rejoining to Another Parent

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	21900.00	10950.00
Average current [mA]	0.755	0.62
Charge consumed [mA x ms]	16534.0	6798.86
Peak Current [mA]	17.87	19.61
Current Profile - Parent loss detection and rejoining to another parent	Figure 11-2	Figure 11-9
Current Profile - MAC Data Request retry 1 and 2	Figure 11-3	Figure 11-10
Current Profile - MAC Data Request retry with Beacon request	Figure 11-4	Figure 11-11
Current Profile - Beacon scanning	Figure 11-5	Figure 11-11
Current Profile - Rejoin Request transmission	Figure 11-6	Figure 11-11
Current Profile - Reception of Rejoin response	Figure 11-7	Figure 11-12
Current Profile - Device Announce	Figure 11-8	Figure 11-13

Figure 11-2. Current Consumption Profile of Parent Loss Detection and Rejoin to another Parent at 8MHz

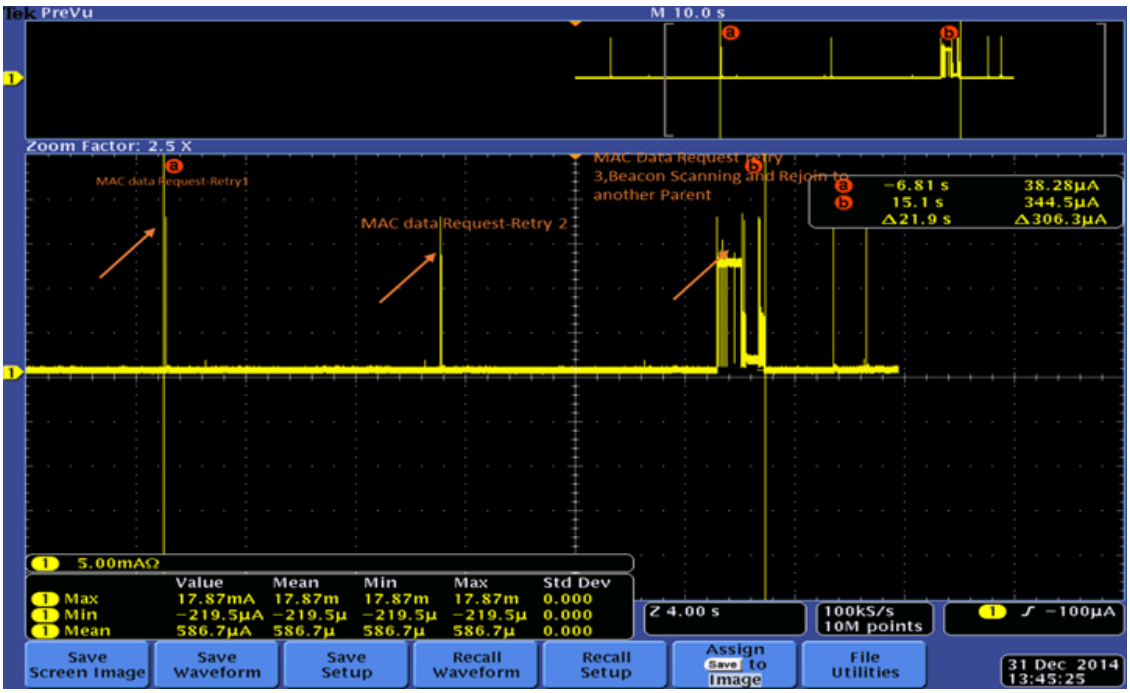


Figure 11-3. Current Consumption Profile of MAC Layer Retries at 8MHz

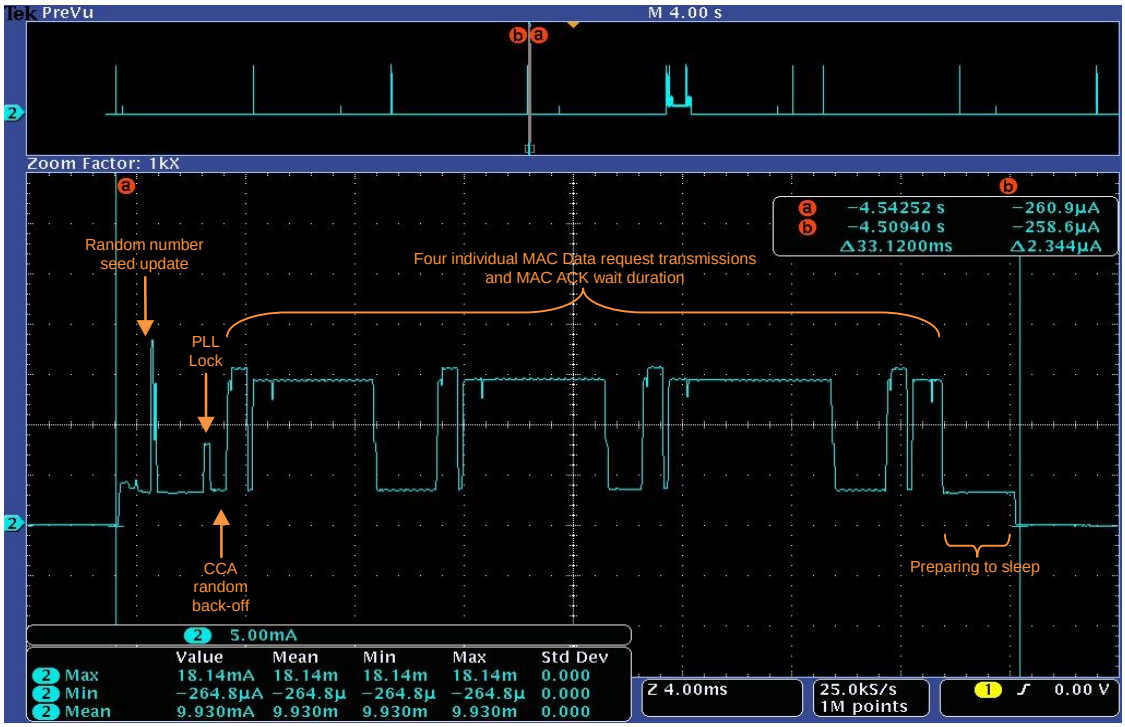


Figure 11-4. Current Consumption Profile of MAC Layer Retries with MAC Beacon Request at 8MHz

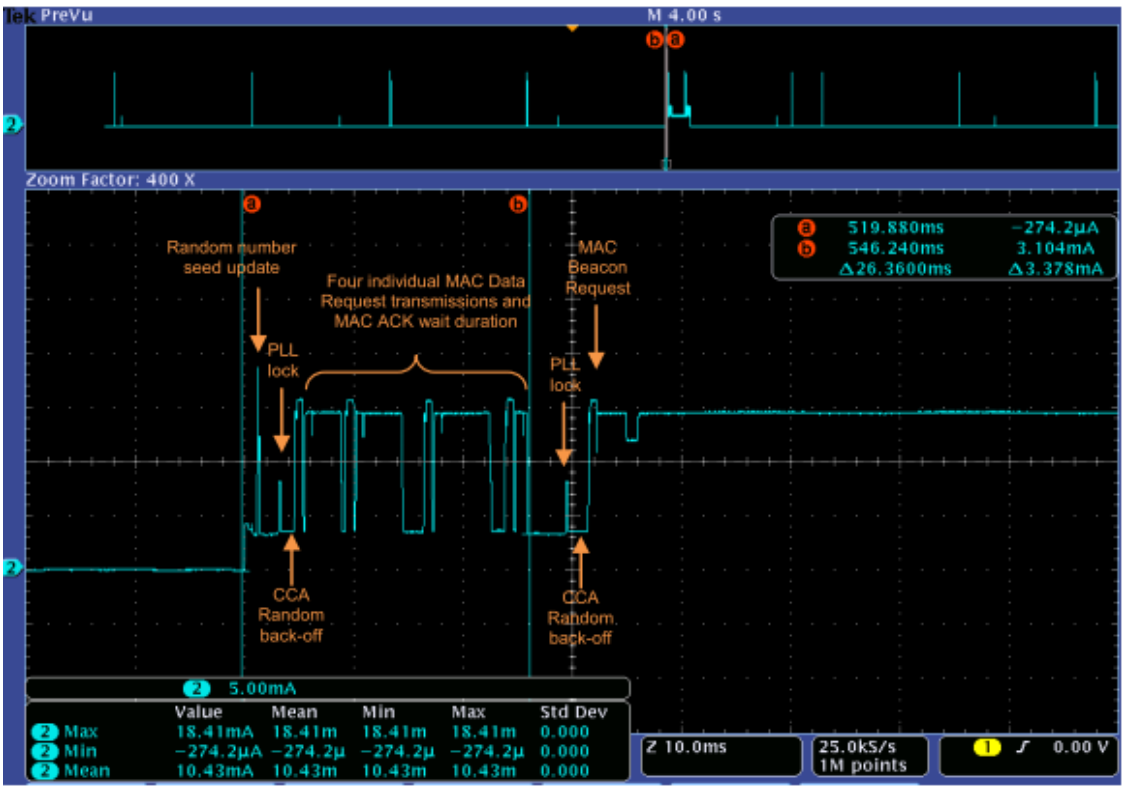


Figure 11-5. Current Consumption Profile of MAC Beacon Scanning at 8MHz

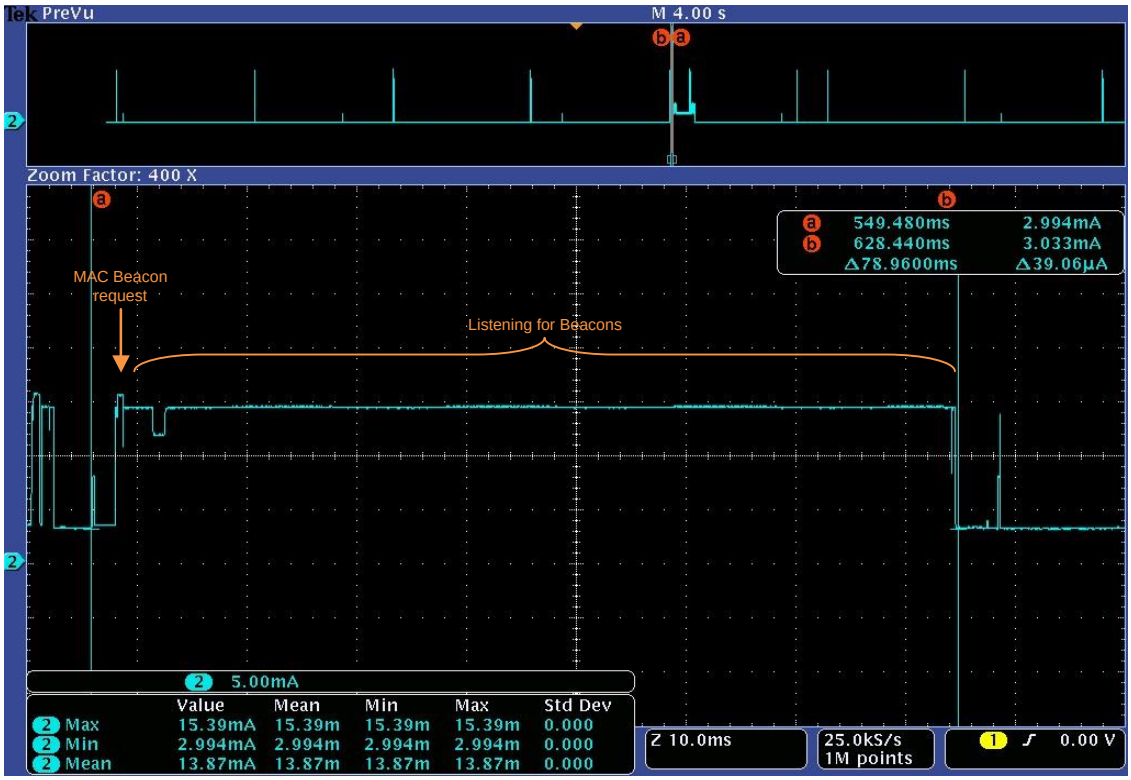


Figure 11-6. Current Consumption Profile of Rejoin Request at 8MHz

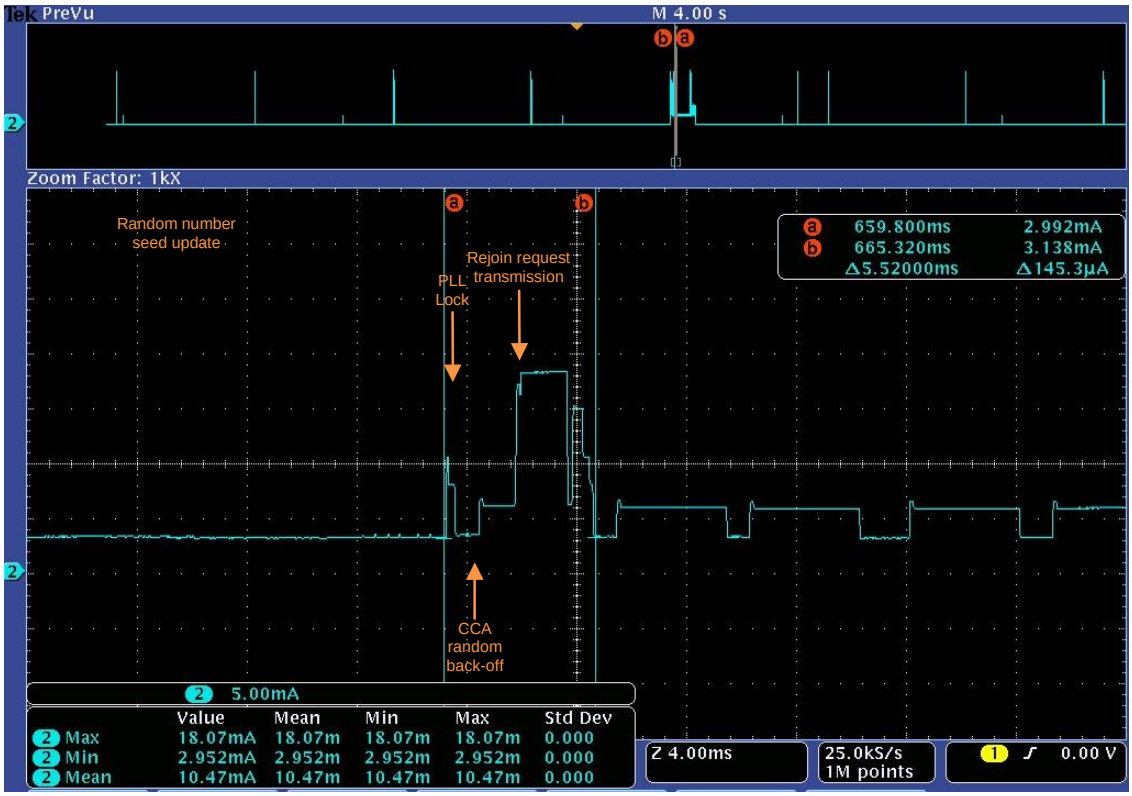


Figure 11-7. Current Consumption Profile of Rejoin Response at 8MHz

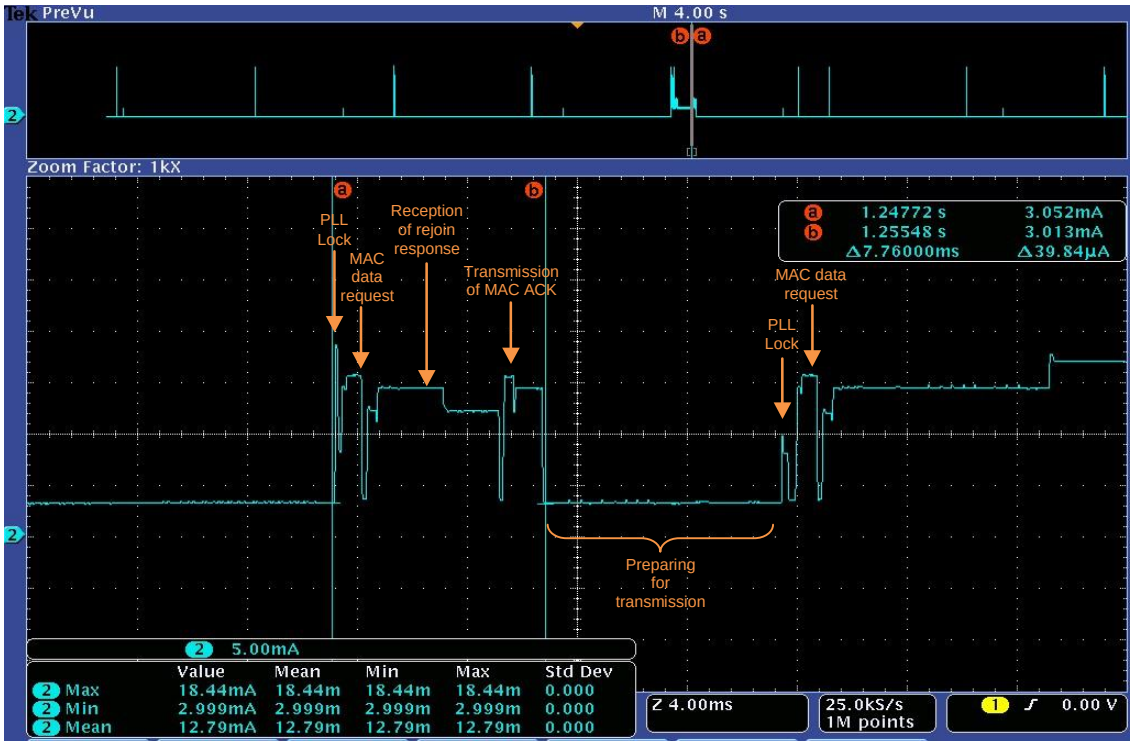


Figure 11-8. Current Consumption Profile of Device Announce at 8MHz

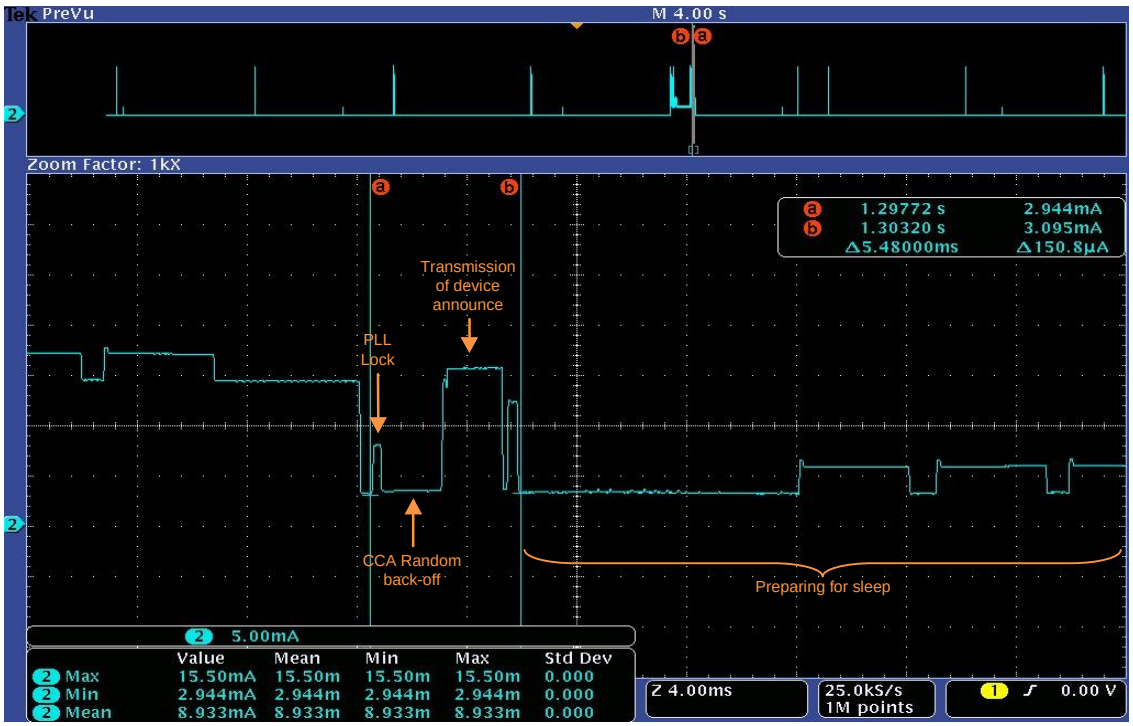


Figure 11-9. Current Consumption Profile of Parent Loss Detection and Rejoin to another Parent at 16MHz

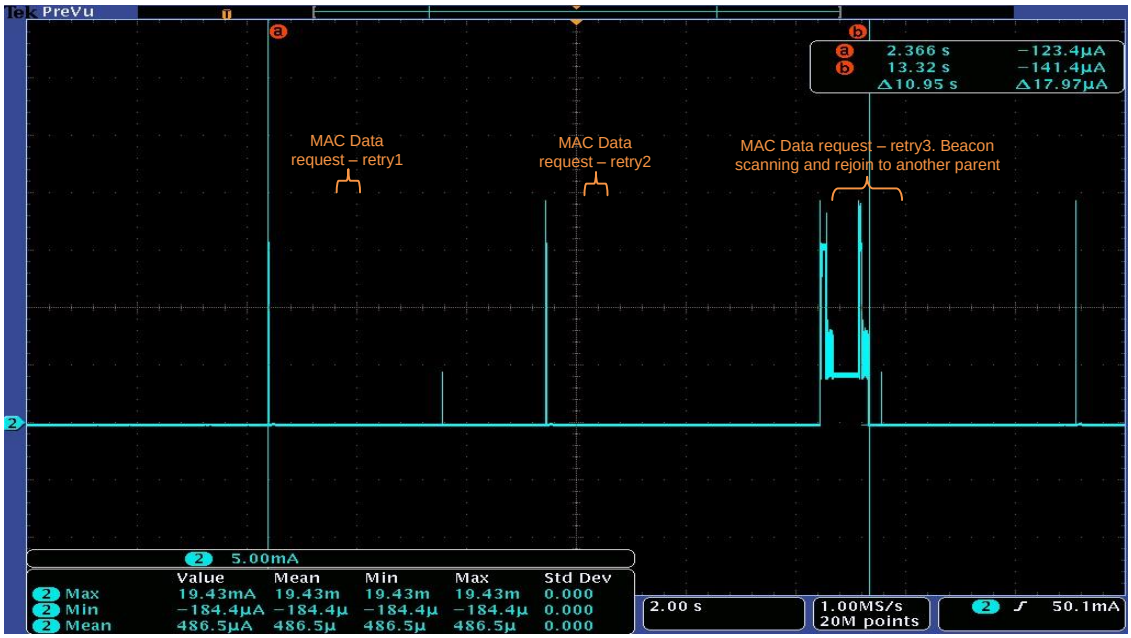


Figure 11-10. Current Consumption Profile of MAC Layer Retries at 16MHz

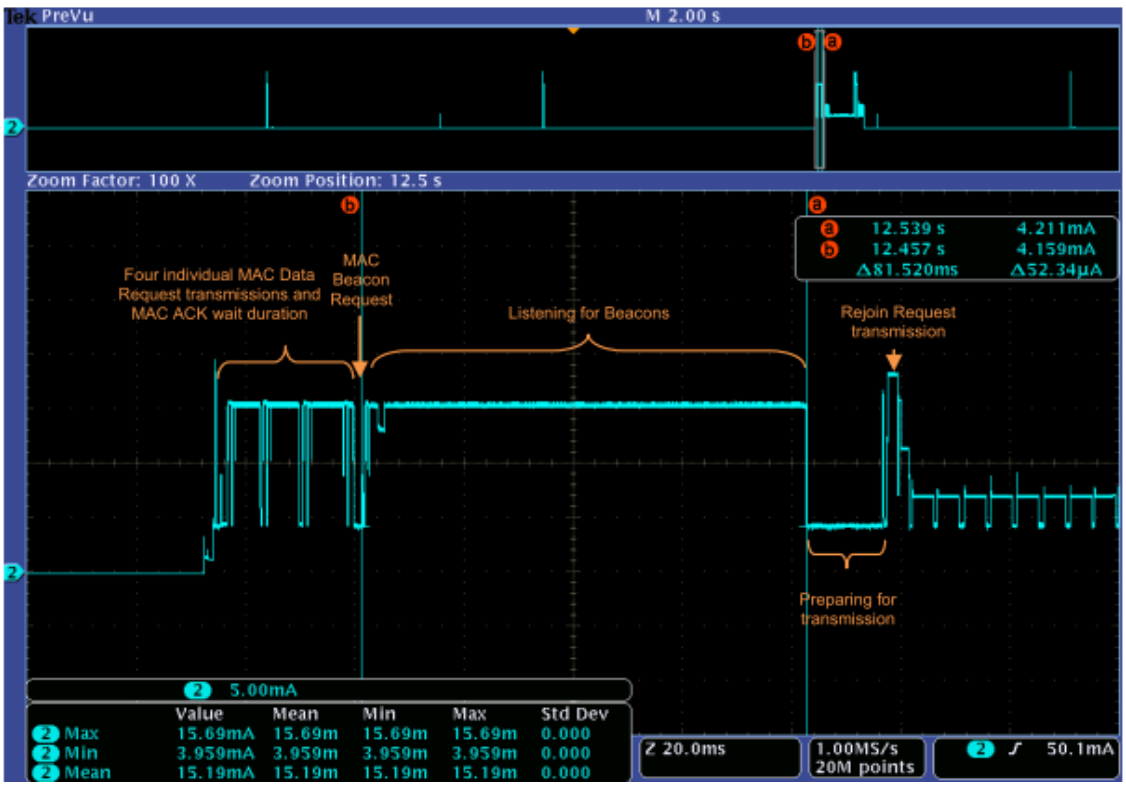


Figure 11-11. Current Consumption Profile of MAC Layer Retries, Beacon Scanning, and Rejoin Request at 16MHz

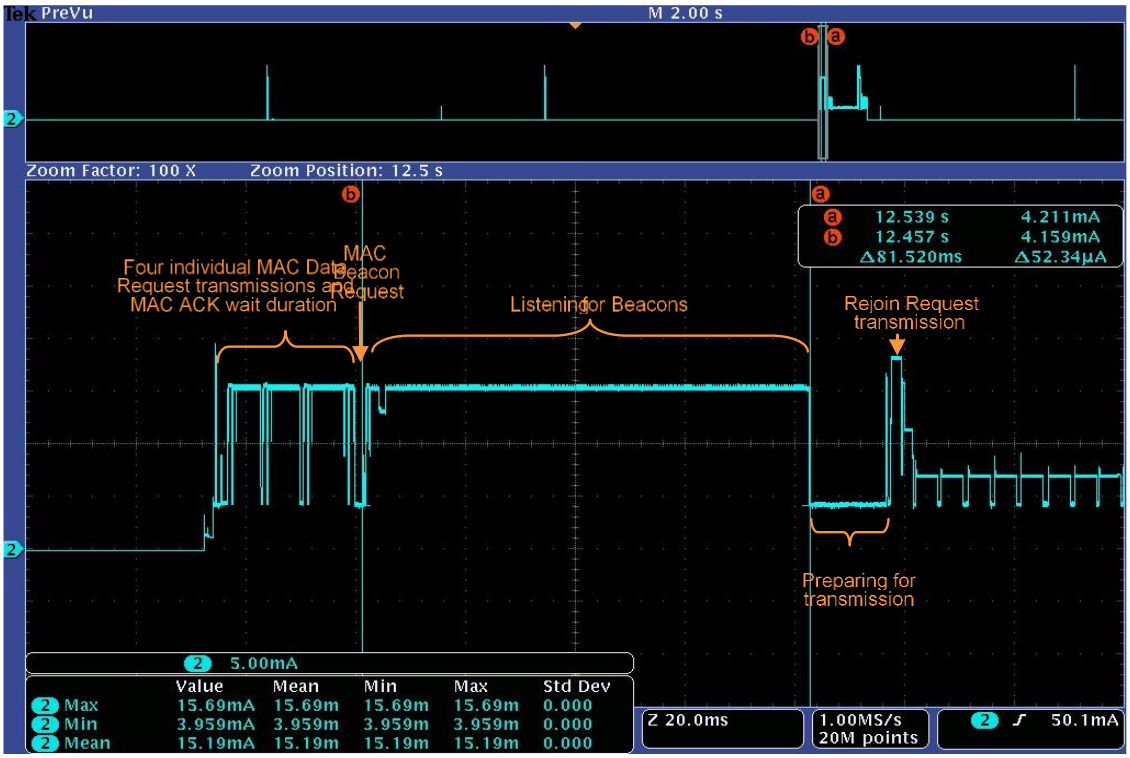


Figure 11-12. Current Consumption Profile of Rejoin Response at 16MHz

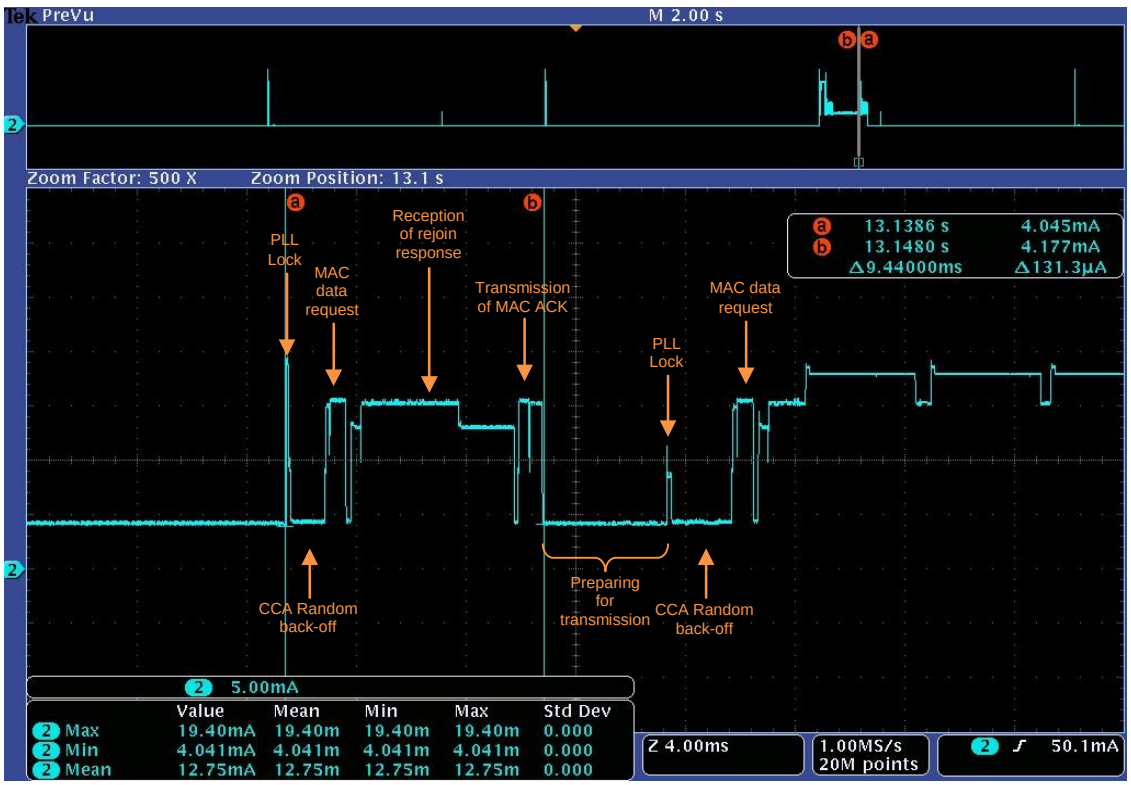
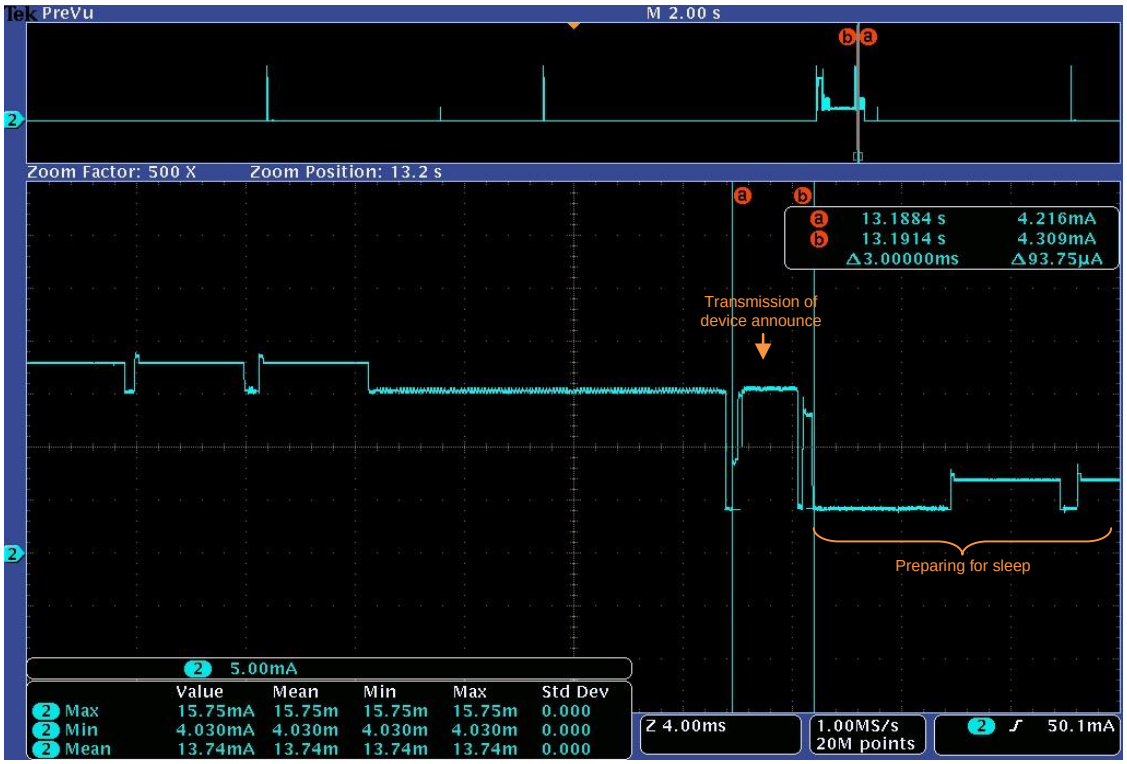


Figure 11-13. Current Consumption Profile of Device Announce at 16MHz



12 Touchlinking

Touchlinking is the procedure followed to associate a ZigBee Light Link (ZLL) remote to a particular ZLL light. During touchlinking we observe:

- Touchlinking - Five scan request frames on the first primary channel and one scan request on other primary channels will be sent
- ZLL remote will send Identify Request to that particular ZLL light, which sends Scan Response
- Following this we will observe sequence of communications (like Network Start Request/Response, Rejoin Request/Response, IEEE® Address Request/Response, Add Group/Response, End Point Registration, etc) as shown in the sniffer log Figure 12-1

Note: Default primary channel mask is used, where channels 11, 15, 20, and 25 are enabled.

Figure 12-1. Touchlinking Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	12:37:30.196	ZSL: Scan request			0x0000000000000222	0xffff
1	12:37:30.261	ZSL: Scan response			0x00042519140020a9	0x0000000000000222
2	12:37:30.263	Ack				
3	12:37:30.442	ZSL: Scan request			0x0000000000000222	0xffff
4	12:37:30.692	ZSL: Scan request			0x0000000000000222	0xffff
5	12:37:30.940	ZSL: Scan request			0x0000000000000222	0xffff
6	12:37:31.190	ZSL: Scan request			0x0000000000000222	0xffff
7	12:37:31.447	ZSL: Identify request			0x0000000000000222	0x00042519140020a9
8	12:37:31.448	Ack				
9	12:37:33.596	ZSL: Network start request			0x0000000000000222	0x00042519140020a9
10	12:37:33.599	Ack				
11	12:37:33.629	MAC: MacBeaconReq				0xffff
12	12:37:33.683	ZSL: Network start response			0x00042519140020a9	0x0000000000000222
13	12:37:33.685	Ack				
14	12:37:33.869	ZDO: DeviceAnnce	0x0002	0xfffd	0x0002	0xffff
15	12:37:34.528	ZDO: DeviceAnnce	0x0002	0xfffd	0x0002	0xffff
16	12:37:35.738	MAC: MacBeaconReq				0xffff
17	12:37:35.740	Beacon			0x0002	
18	12:37:36.013	NWK: Rejoin Request	0x0001	0x0002	0x0001	0x0002
19	12:37:36.014	Ack				
20	12:37:36.602	MAC: Mac Data Request			0x0001	0x0002
21	12:37:36.602	Ack				
22	12:37:36.604	NWK: Rejoin Response	0x0002	0x0001	0x0002	0x0001
23	12:37:36.606	Ack				
24	12:37:36.618	MAC: Mac Data Request			0x0001	0x0002
25	12:37:36.618	Ack				
26	12:37:36.627	ZDO: DeviceAnnce	0x0001	0xfffd	0x0001	0x0002
27	12:37:36.629	Ack				
28	12:37:36.650	MAC: Mac Data Request			0x0001	0x0002
29	12:37:36.650	Ack				
30	12:37:36.656	ZDO: IeeeAddrReq	0x0001	0x0002	0x0001	0x0002
31	12:37:36.657	Ack				
32	12:37:36.677	ZDO: DeviceAnnce	0x0001	0xfffd	0x0002	0xffff
33	12:37:36.735	ZDO: IeeeAddrReq	0x0001	0x0002	0x0001	0x0002
34	12:37:36.736	Ack				
35	12:37:36.957	MAC: Mac Data Request			0x0001	0x0002
36	12:37:36.957	Ack				
37	12:37:36.960	ZDO: IeeeAddrRsp	0x0002	0x0001	0x0002	0x0001
38	12:37:36.962	Ack				
39	12:37:36.967	MAC: Mac Data Request			0x0001	0x0002
40	12:37:36.967	Ack				

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
40	12:37:36.967	Ack				
41	12:37:36.969	ZDO: IeeeAddrRsp	0x0002	0x0001	0x0002	0x0001
42	12:37:36.971	Ack				
43	12:37:36.975	APS: Ack IeeeAddrRsp	0x0001	0x0002	0x0001	0x0002
44	12:37:36.976	Ack				
45	12:37:36.983	MAC: Mac Data Request			0x0001	0x0002
46	12:37:36.983	Ack				
47	12:37:36.991	APS: Ack IeeeAddrRsp	0x0001	0x0002	0x0001	0x0002
48	12:37:36.992	Ack				
49	12:37:37.006	ZCL: Add group	0x0001	0x0002	0x0001	0x0002
50	12:37:37.008	Ack				
51	12:37:37.150	NWK: Link Status	0x0002	0xfffc	0x0002	0xffff
52	12:37:37.293	MAC: Mac Data Request			0x0001	0x0002
53	12:37:37.293	Ack				
54	12:37:37.294	APS: Ack 0x0004	0x0002	0x0001	0x0002	0x0001
55	12:37:37.295	Ack				
56	12:37:37.298	MAC: Mac Data Request			0x0001	0x0002
57	12:37:37.298	Ack				
58	12:37:37.318	ZDO: DeviceAnnce	0x0001	0xfffd	0x0002	0xffff
59	12:37:37.568	MAC: Mac Data Request			0x0001	0x0002
60	12:37:37.568	Ack				
61	12:37:37.569	ZCL: Add group response	0x0002	0x0001	0x0002	0x0001
62	12:37:37.571	Ack				
63	12:37:37.574	MAC: Mac Data Request			0x0001	0x0002
64	12:37:37.574	Ack				
65	12:37:37.589	APS: Ack 0x0004	0x0001	0x0002	0x0001	0x0002
66	12:37:37.590	Ack				
67	12:37:37.872	MAC: Mac Data Request			0x0001	0x0002
68	12:37:37.872	Ack				
69	12:37:37.874	ZCL: Endpoint information	0x0002	0x0001	0x0002	0x0001
70	12:37:37.876	Ack				
71	12:37:37.881	MAC: Mac Data Request			0x0001	0x0002
72	12:37:37.881	Ack				
73	12:37:37.893	APS: Ack 0x1000	0x0001	0x0002	0x0001	0x0002
74	12:37:37.894	Ack				
75	12:37:37.905	ZCL: Default response	0x0001	0x0002	0x0001	0x0002
76	12:37:37.906	Ack				
77	12:37:38.174	MAC: Mac Data Request			0x0001	0x0002
78	12:37:38.174	Ack				
79	12:37:38.175	APS: Ack 0x1000	0x0002	0x0001	0x0002	0x0001
80	12:37:38.176	Ack				

Table 12-1. Current Consumption During Touchlinking

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	10190.00	12900.00
Average current [mA]	2.42	4.52
Charge consumed [mA x ms]	24690.37	58296.39
Peak Current [mA]	19.86	20.37
Current Profile	Figure 12-2	Figure 12-3

Figure 12-2. Current Consumption Profile of Touchlinking at 8MHz

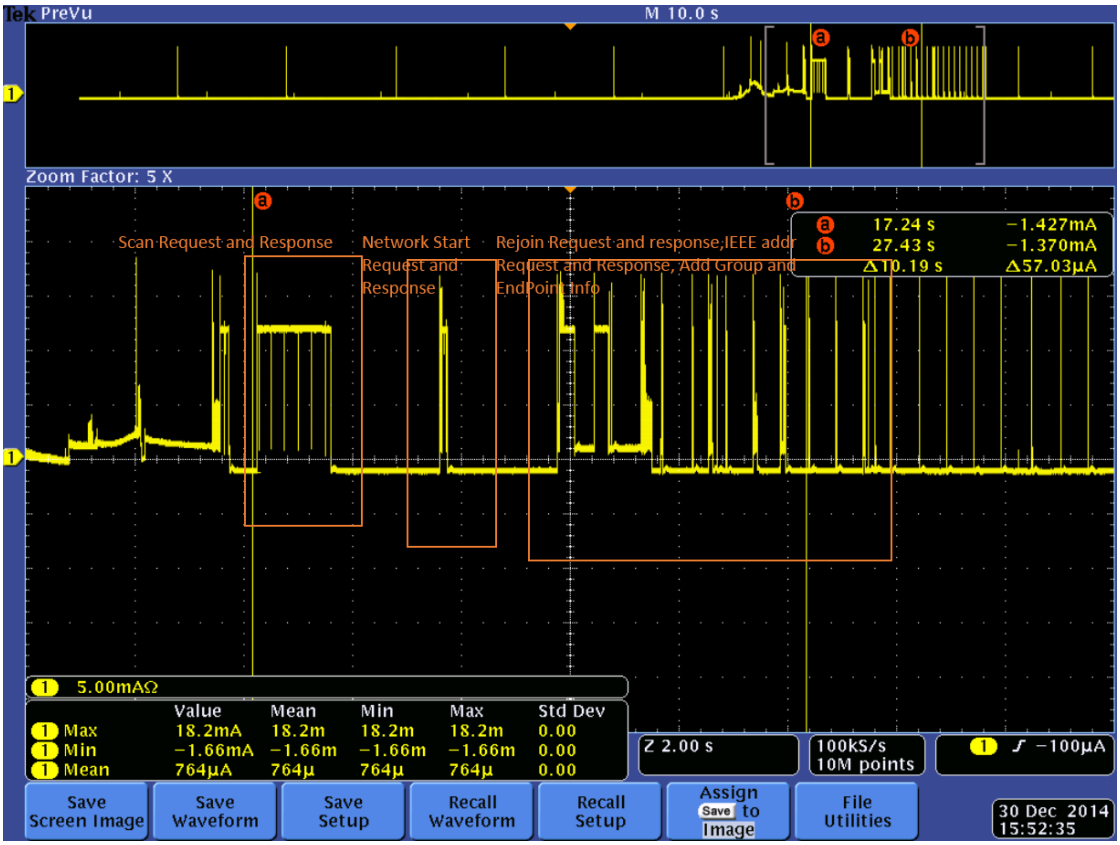
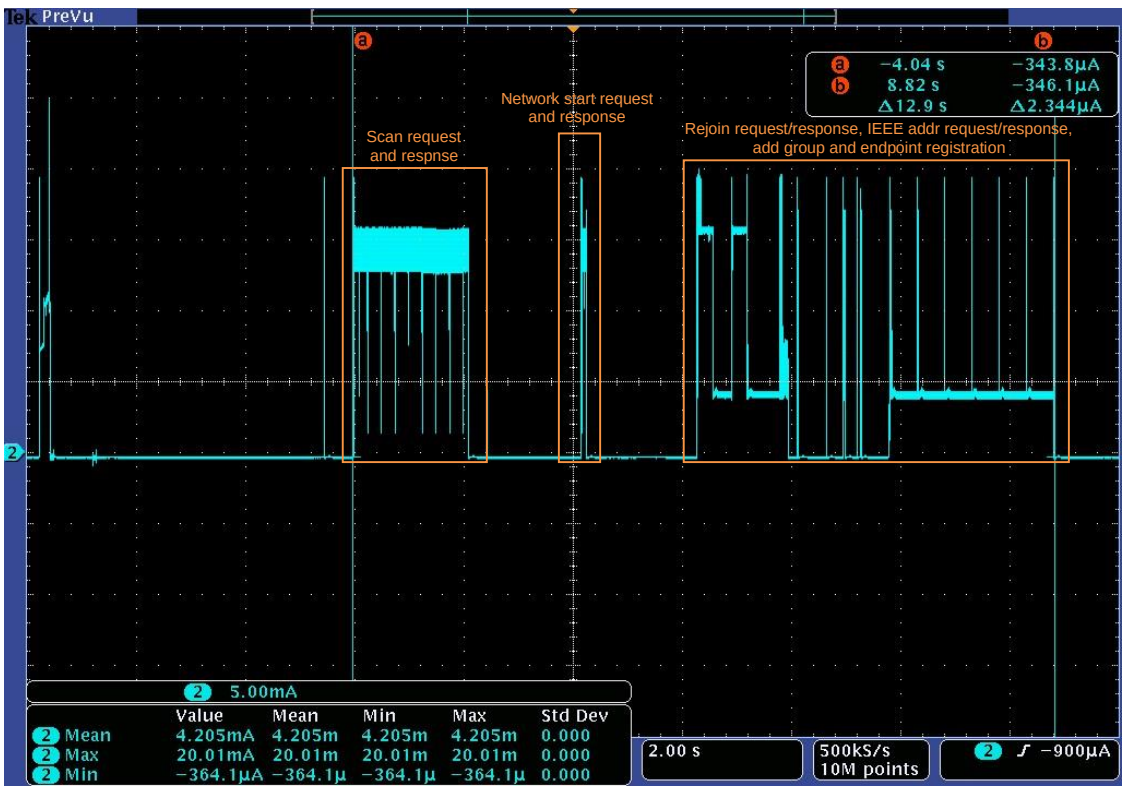


Figure 12-3. Current Consumption Profile of Touchlinking at 16MHz



13 Over-the-Air Upgrade (OTAU)

13.1 OTAU Server Discovery with no Response

This section characterizes the power consumption when a device (OTAU client) initiates a server discovery (Query next image). Figure 13-1 shows the sniffer log of the complete sequence where an OTAU client finds an OTA server but there is no response for the Query next Image request frame.

Figure 13-1. OTAU Server Discovery with no Response Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst	Security	SecStatus
53	06:05:00.498	ZDO: MatchDescReq	0x1b90	0xfffd	0x0008	0xffff	NWK	OK
54	06:05:00.655	MAC: Mac Data Request			0x1b90	0x0008		
55	06:05:00.656	Ack						
56	06:05:00.658	ZDO: MatchDescRsp	0x0008	0x1b90	0x0008	0x1b90	NWK	OK
57	06:05:00.660	Ack						
58	06:05:00.665	MAC: Mac Data Request			0x1b90	0x0008		
59	06:05:00.665	Ack						
60	06:05:00.679	APS: Ack MatchDescRsp	0x1b90	0x0008	0x1b90	0x0008	NWK	OK
61	06:05:00.681	Ack						
62	06:05:01.144	ZDO: MatchDescReq	0x1b90	0xfffd	0x0008	0xffff	NWK	OK
63	06:05:01.186	MAC: Mac Data Request			0x1b90	0x0008		
64	06:05:01.187	Ack						
65	06:05:01.687	MAC: Mac Data Request			0x1b90	0x0008		
66	06:05:01.688	Ack						
67	06:05:02.187	MAC: Mac Data Request			0x1b90	0x0008		
68	06:05:02.188	Ack						
69	06:05:02.719	MAC: Mac Data Request			0x1b90	0x0008		
70	06:05:02.720	Ack						
71	06:05:03.218	MAC: Mac Data Request			0x1b90	0x0008		
72	06:05:03.219	Ack						
73	06:05:03.720	MAC: Mac Data Request			0x1b90	0x0008		
74	06:05:03.721	Ack						
75	06:05:04.218	MAC: Mac Data Request			0x1b90	0x0008		
76	06:05:04.219	Ack						
77	06:05:04.318	ZDO: IeeeAddrReq	0x1b90	0x0008	0x1b90	0x0008	NWK	OK
78	06:05:04.320	Ack						
79	06:05:04.718	MAC: Mac Data Request			0x1b90	0x0008		
80	06:05:04.718	Ack						
81	06:05:04.722	ZDO: IeeeAddrRsp	0x0008	0x1b90	0x0008	0x1b90	NWK	OK
82	06:05:04.724	Ack						
83	06:05:04.729	MAC: Mac Data Request			0x1b90	0x0008		
84	06:05:04.730	Ack						
85	06:05:04.744	APS: Ack IeeeAddrRsp	0x1b90	0x0008	0x1b90	0x0008	NWK	OK
86	06:05:04.746	Ack						
87	06:05:04.759	ZCL: Query Next Image Request	0x1b90	0x0008	0x1b90	0x0008	NWK	OK
88	06:05:04.761	Ack						
89	06:05:05.218	MAC: Mac Data Request			0x1b90	0x0008		
90	06:05:05.219	Ack						
91	06:05:05.222	APS: Ack 0x0019	0x0008	0x1b90	0x0008	0x1b90	NWK	OK
92	06:05:05.224	Ack						
93	06:05:05.228	MAC: Mac Data Request			0x1b90	0x0008		
94	06:05:05.229	Ack						
95	06:05:05.749	MAC: Mac Data Request			0x1b90	0x0008		
96	06:05:05.750	Ack						
97	06:05:06.282	MAC: Mac Data Request			0x1b90	0x0008		
98	06:05:06.283	Ack						

The OTAU Client device periodically does OTAU server discovery depending on the interval configured in CS_ZCL_OTAU_SERVER_DISCOVERY_PERIOD parameter until it gets a Query next image response.

Note: Fuse Settings used for this scenario is with bootloader, refer Chapter 2.

Table 13-1. Current Consumption During OTAU Server Discovery with no Response

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	4882.00	5664.00
Average current [mA]	2.59	0.44
Charge consumed [mA x ms]	12649.04	2503.49
Peak Current [mA]	19.68	19.10
Current Profile	Figure 13-2	Figure 13-3

Figure 13-2. Current Consumption Profile of OTAU Server with no Response at 8MHz

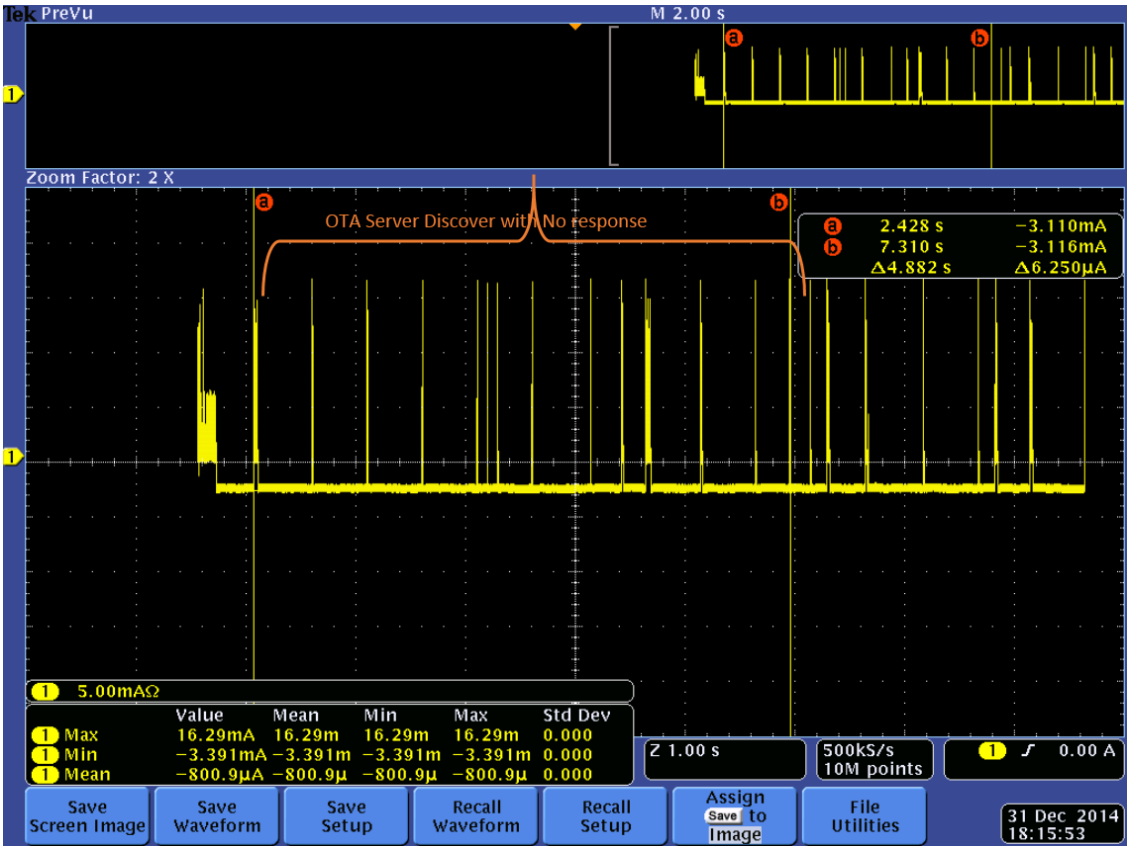
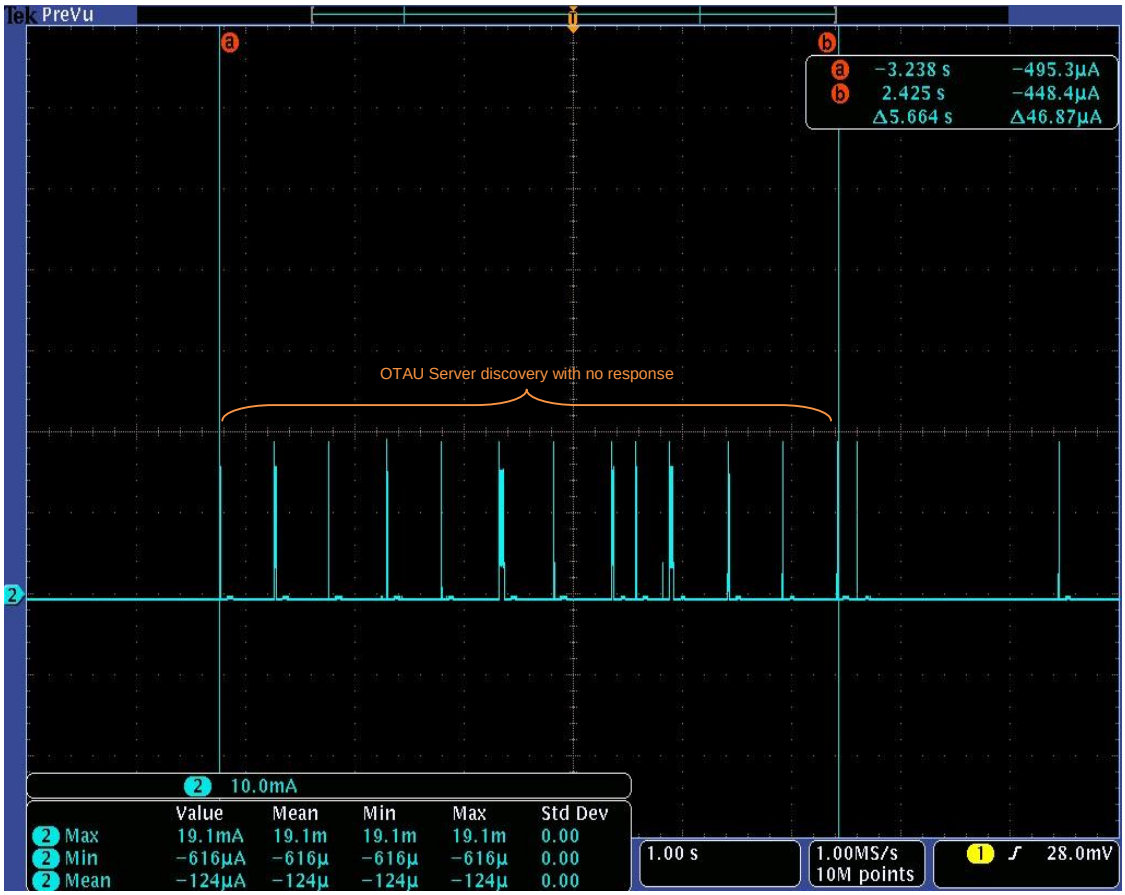


Figure 13-3. Current Consumption Profile of OTAU Server Discovery with no Response at 16MHz



13.2 OTAU Server Discovery with no New Image

This section characterizes the power consumption when OTA Client receives the Query Next Image Response from the server.

Query Next Image Request happens continuously for every five second until we get a Query Next Image Response indicating the availability of new firmware at the OTA server.

Interval of Query Next Image Request can be modified using parameter QUERY_NEXT_IMAGE_PERIOD.

Figure 13-4. OTAU Server Discovery with no New Image Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst	
0	06:06:09.533	ZCL: Query Next Image Request	0x1b90	0x0008	0x1b90	0x0008	NWK
1	06:06:09.535	Ack					
2	06:06:09.999	MAC: Mac Data Request			0x1b90	0x0008	
3	06:06:10.000	Ack					
4	06:06:10.002	APS: Ack 0x0019	0x0008	0x1b90	0x0008	0x1b90	NWK
5	06:06:10.004	Ack					
6	06:06:10.008	MAC: Mac Data Request			0x1b90	0x0008	
7	06:06:10.008	Ack					
8	06:06:10.499	MAC: Mac Data Request			0x1b90	0x0008	
9	06:06:10.500	Ack					
10	06:06:10.501	ZCL: Query Next Image Response	0x0008	0x1b90	0x0008	0x1b90	NWK
11	06:06:10.503	Ack					
12	06:06:10.508	MAC: Mac Data Request			0x1b90	0x0008	
13	06:06:10.509	Ack					
14	06:06:10.522	APS: Ack 0x0019	0x1b90	0x0008	0x1b90	0x0008	NWK
15	06:06:10.524	Ack					

Table 13-2. Current Consumption During OTAU Server Discovery with no New Image

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	1070.00	1025.00
Average current [mA]	1.33	0.60
Charge consumed [mA x ms]	1423.1	603.73
Peak Current [mA]	19.57	19.10
Current Profile -Query Next Image	Figure 13-5	Figure 13-9
Current Profile - Query Next Image and MAC Data Request	Figure 13-6	Figure 13-10
Current Profile - MAC data request, APS ACK frame for the image request	Figure 13-7	Figure 13-11
Current Profile - Query Next Image Response	Figure 13-8	Figure 13-12

Note: Fuse settings used for this scenario is with bootloader, refer Chapter 2.

Figure 13-5. Current Consumption Profile of OTAU Server Discovery with no New Image at 8MHz

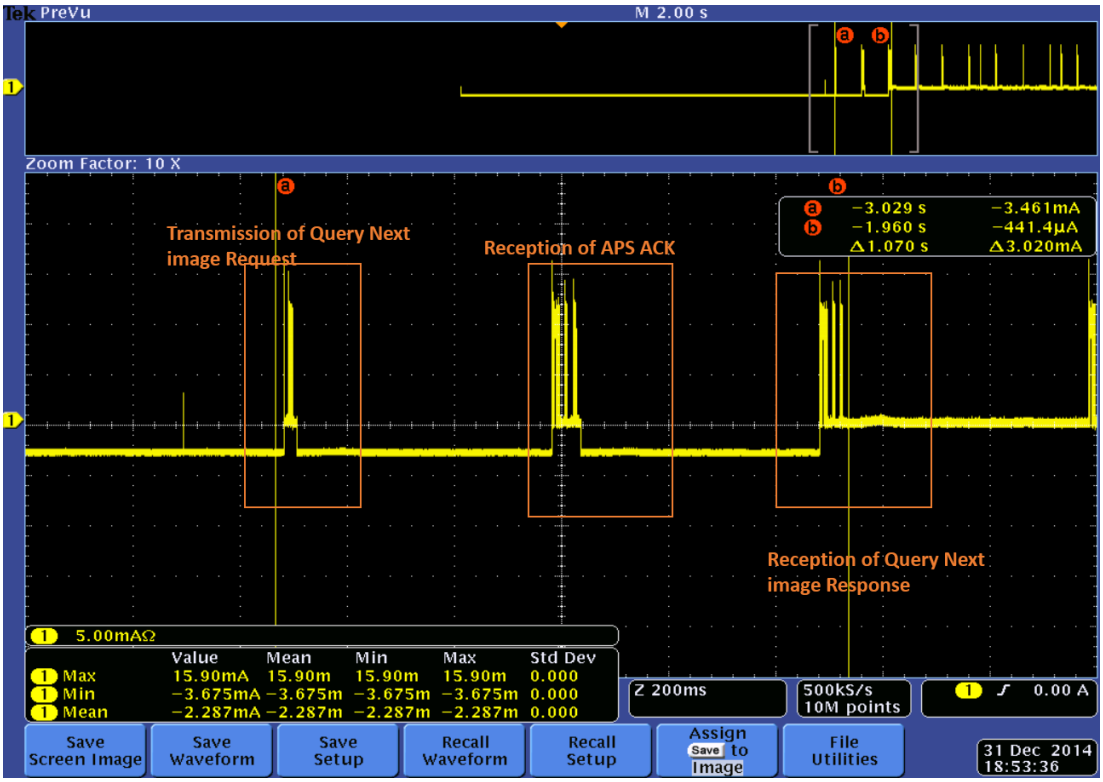


Figure 13-6. Current Consumption Profile of Query Next Image Request at 8MHz

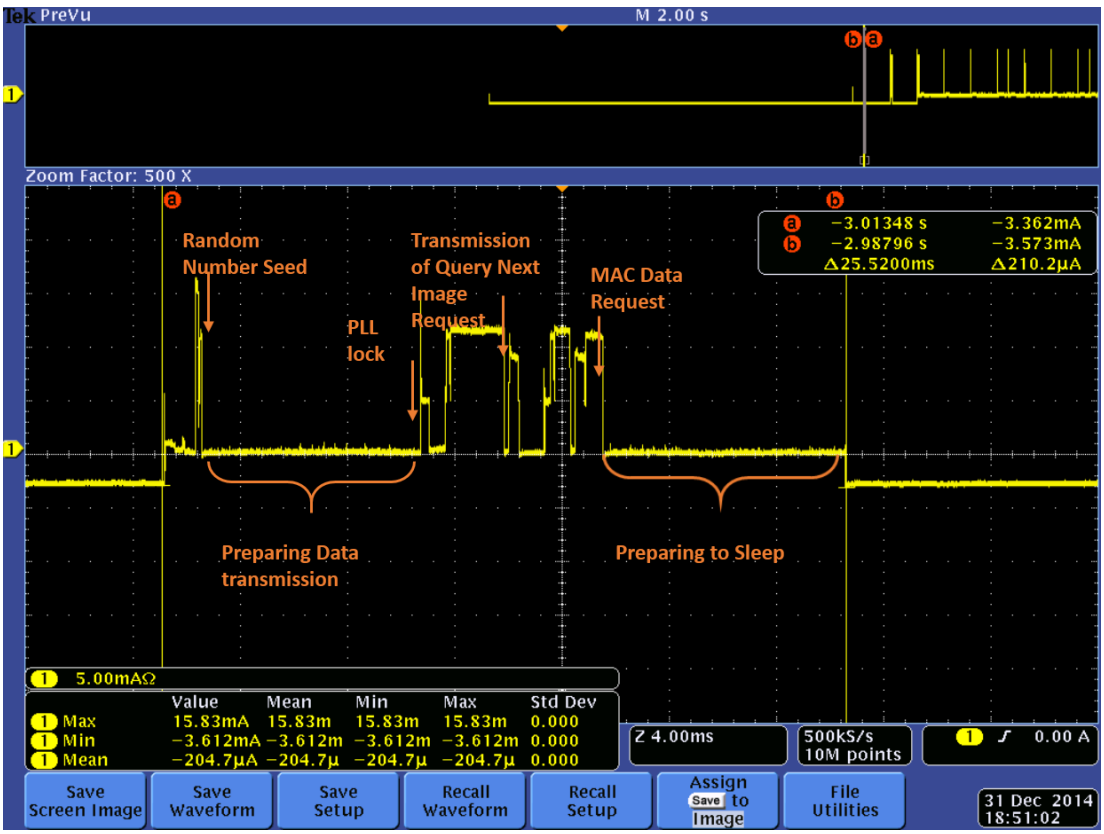


Figure 13-7. Current Consumption Profile of APS ACK at 8MHz

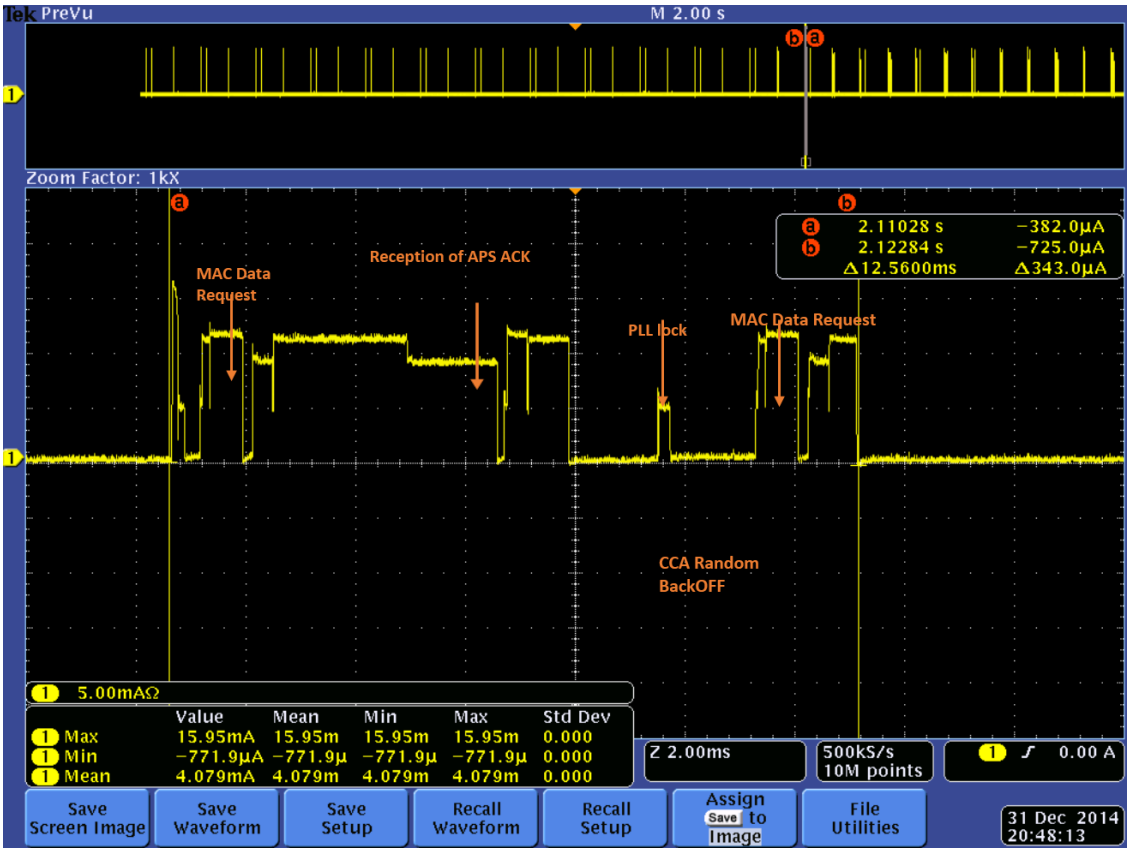


Figure 13-8. Current Consumption profile of Query Next Image Response at 8MHz

Figure 13-9. Current Consumption Profile of OTAU Server Discovery with no New Image at 16MHz

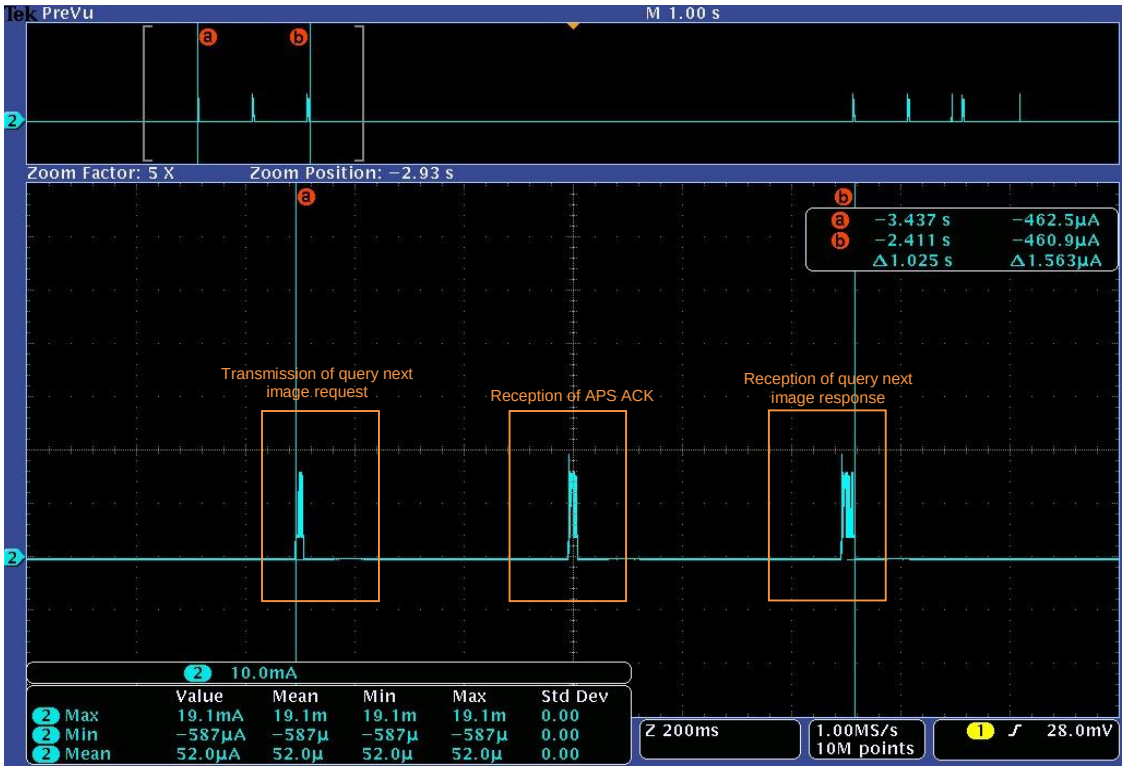


Figure 13-10. Current Consumption Profile of Query Next Image Request at 16MHz

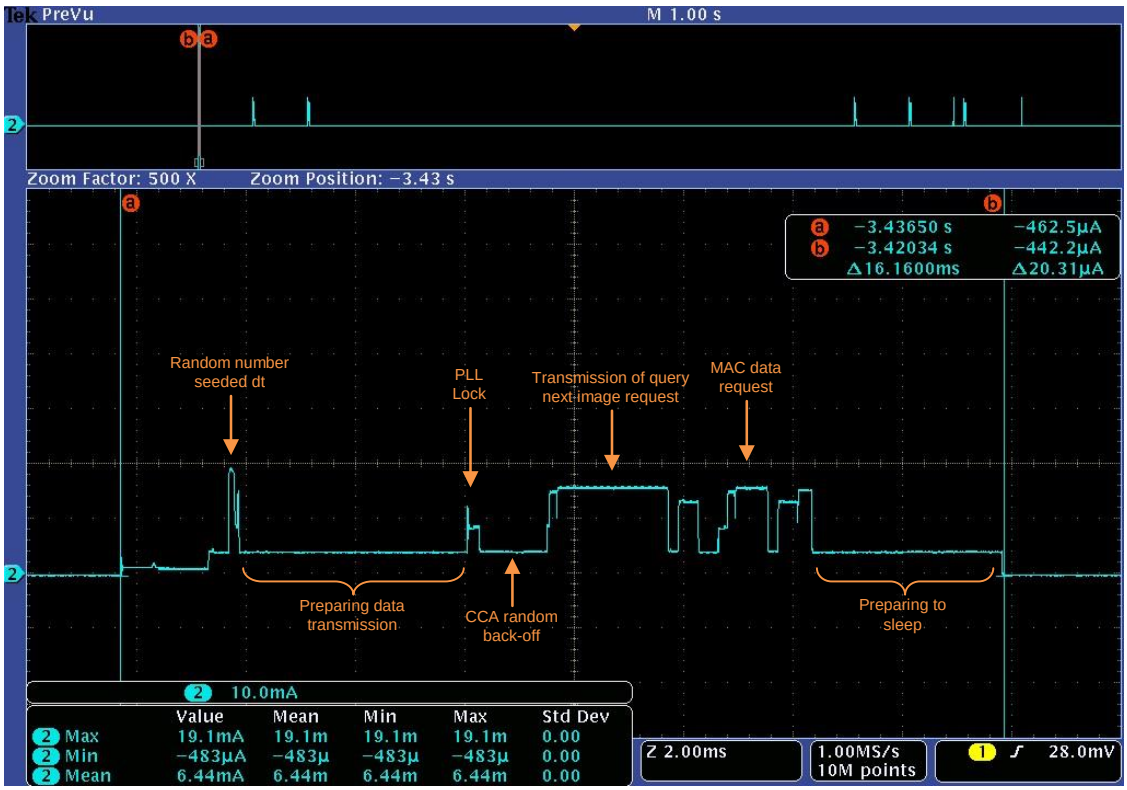


Figure 13-11. Current Consumption Profile of APS ACK at 16MHz

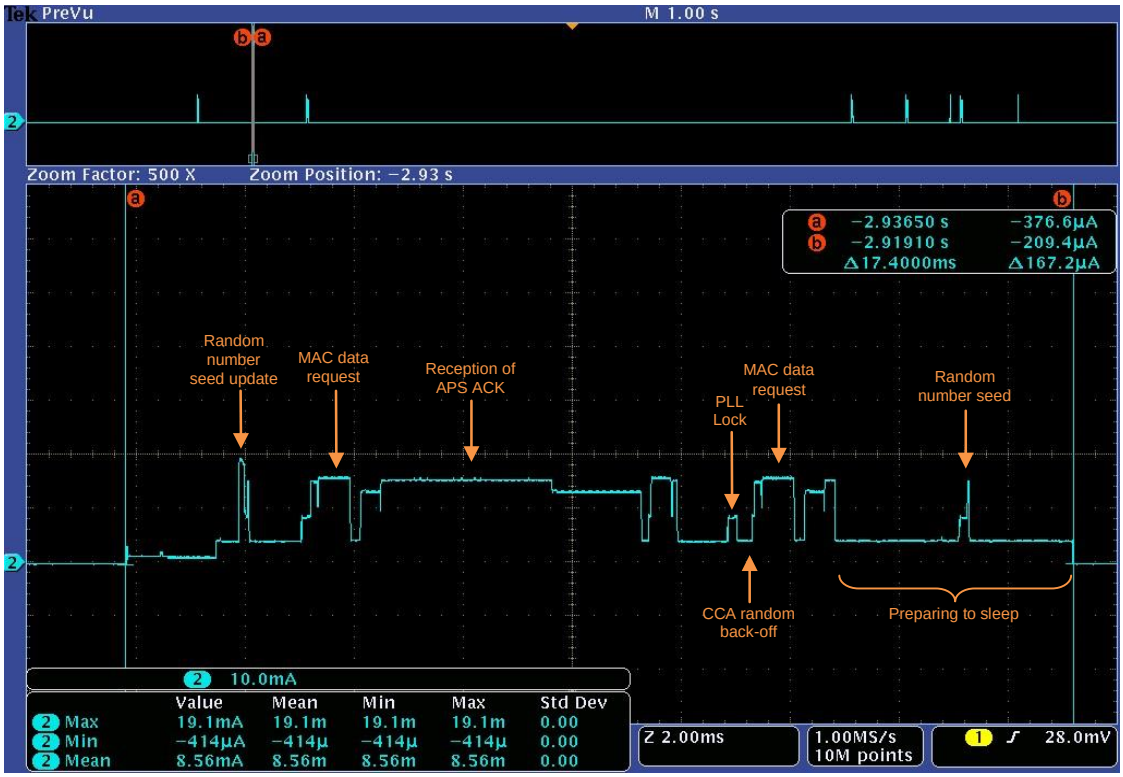
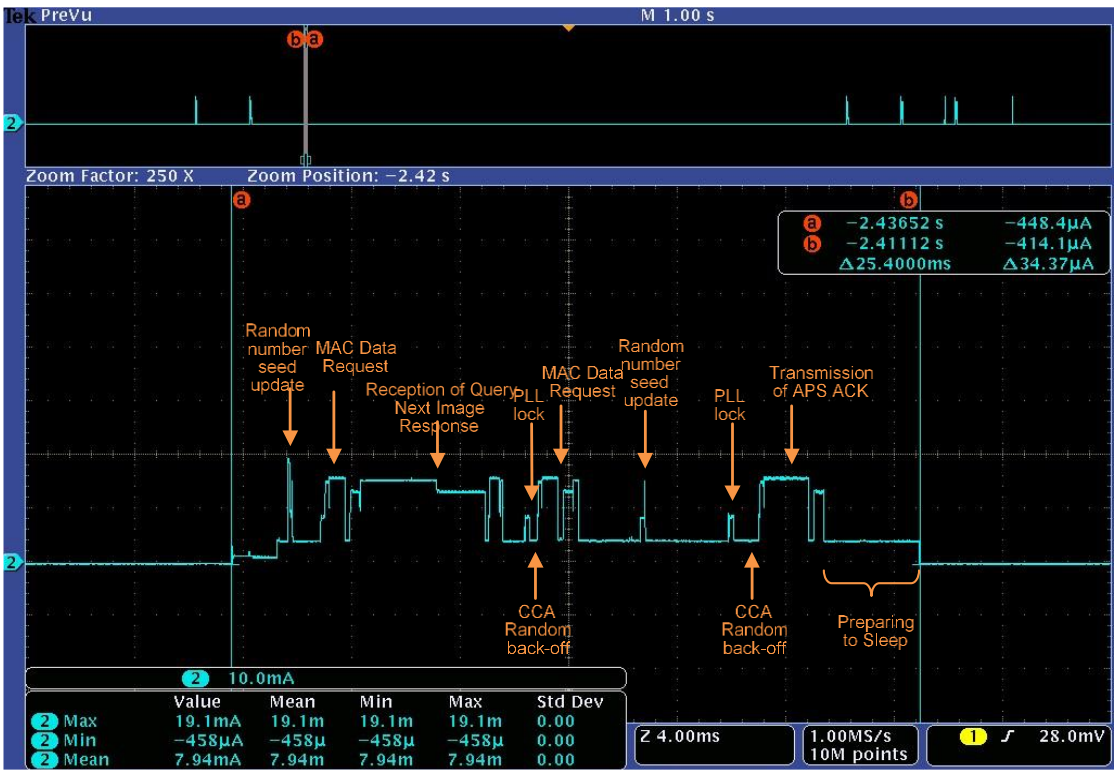


Figure 13-12. Current Consumption Profile of Query Next Image Response at 16MHz



13.3 Image Block Request and Response

This section characterizes the power consumption during single OTAU block request and response. Figure 13-3 shows the sniffer log of block response.

In single block request/response communication transfers 33 bytes of new firmware is transferred. So based on the new application firmware size the user needs to calculate the approximate number of block request/response communications required for transferring the complete firmware.

Note: Fuse Settings used for this scenario is with bootloader, refer Chapter 2.

Figure 13-13. Image Block Request and Response Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	06:01:51.360	ZCL: Image Block Response	0x0008	0x3faa	0x0008	0x3faa
1	06:01:51.364	Ack				
2	06:01:51.369	MAC: Mac Data Request			0x3faa	0x0008
3	06:01:51.370	Ack				
4	06:01:51.384	APS: Ack 0x0019	0x3faa	0x0008	0x3faa	0x0008
5	06:01:51.386	Ack				

Table 13-3. Current Consumption During Block Request and Response

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	1092.00	1031.00
Average current [mA]	0.701	0.63
Charge consumed [mA x ms]	765.49	648.50
Peak Current [mA]	16.54	19.40
Current Profile – Image block request and response	Figure 13-14	Figure 13-18
Current Profile - Image block request	Figure 13-15	Figure 13-19
Current Profile – APS ACK for image block request	Figure 13-16	Figure 13-20
Current Profile – Image block response	Figure 13-17	Figure 13-21

Figure 13-14. Current Consumption Profile of Image Block Request and Response at 8MHz

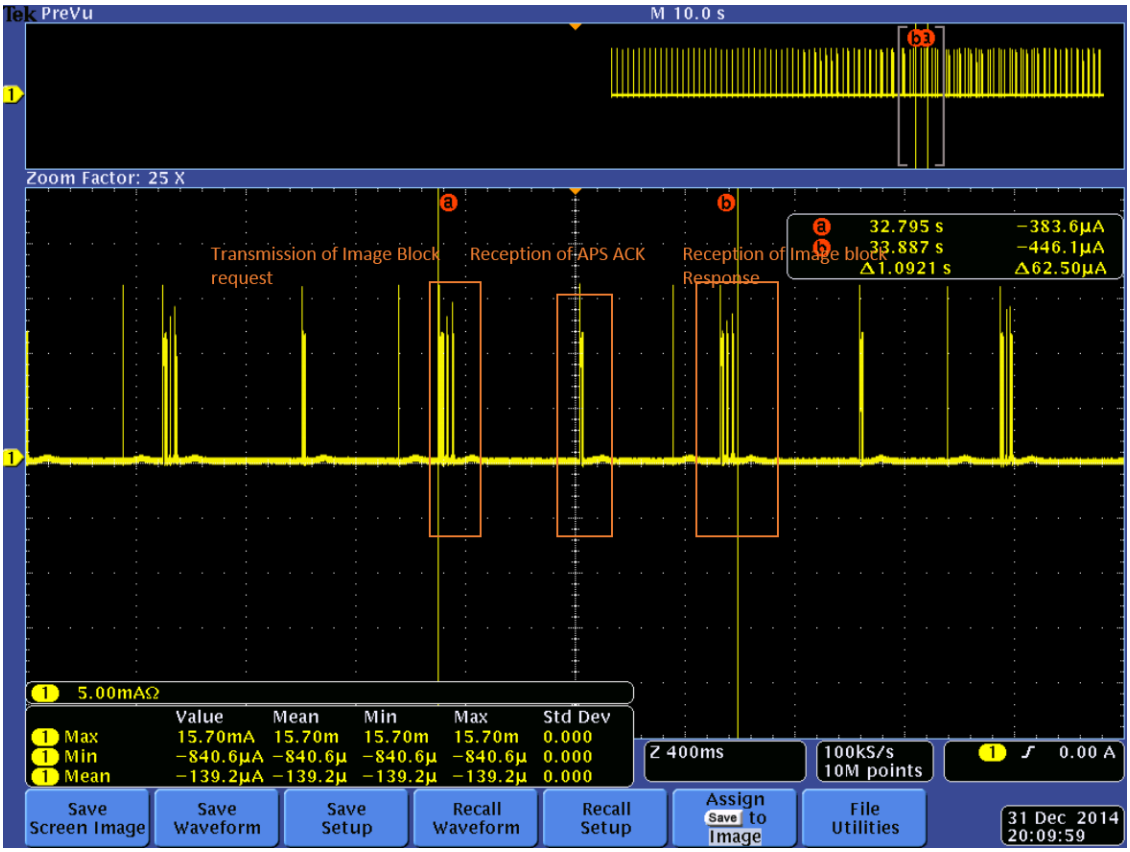


Figure 13-15. Current Consumption Profile of Image Block Request at 8MHz

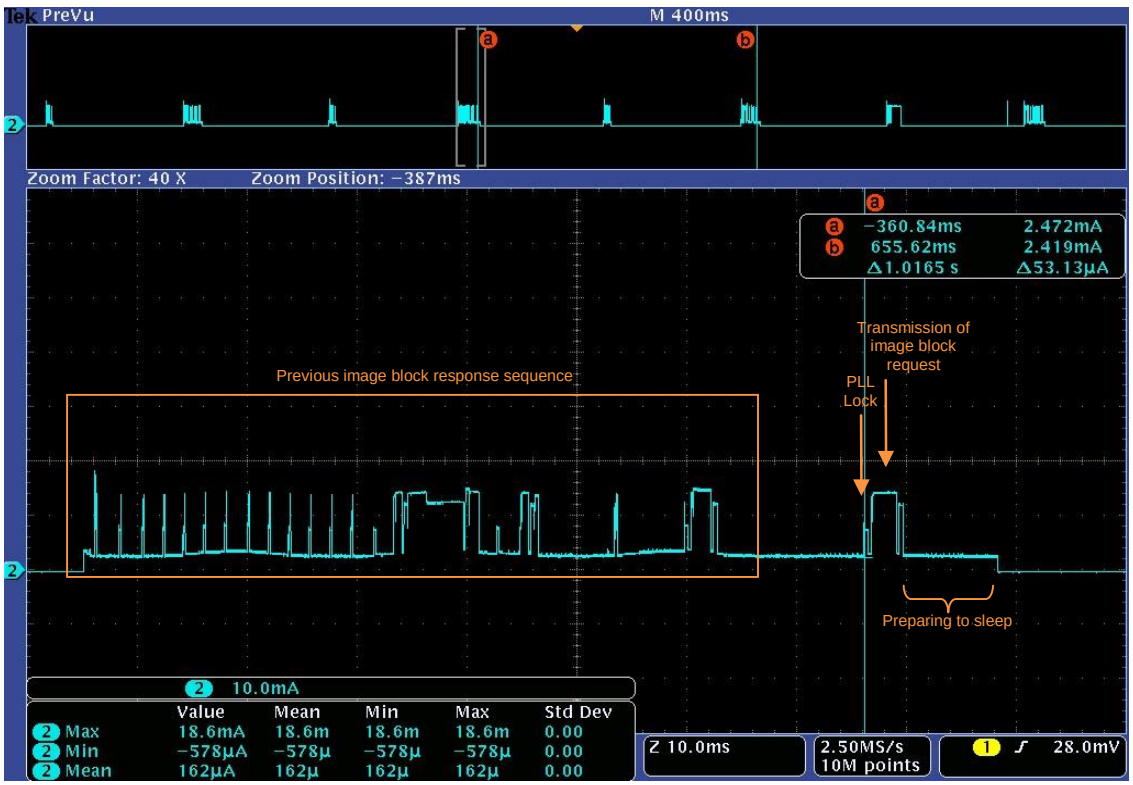


Figure 13-16. Current Consumption Profile of APS ACK at 8MHz

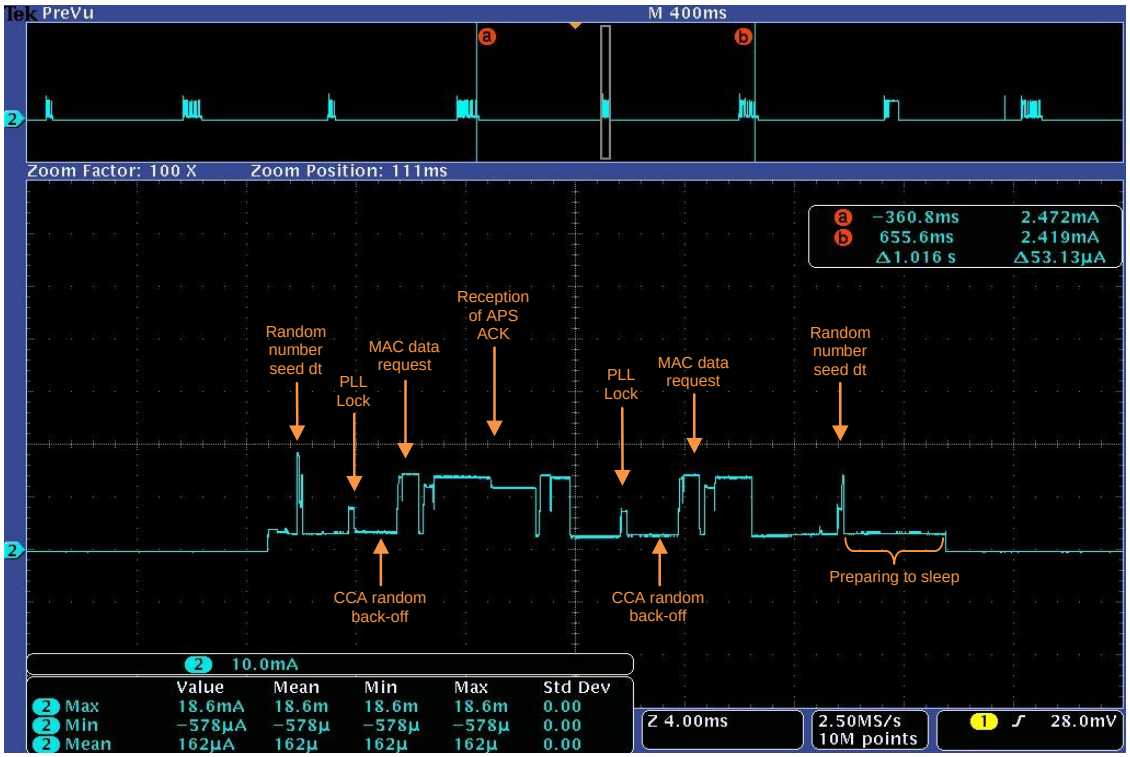


Figure 13-17. Current Consumption Profile of Image Block Response at 8MHz

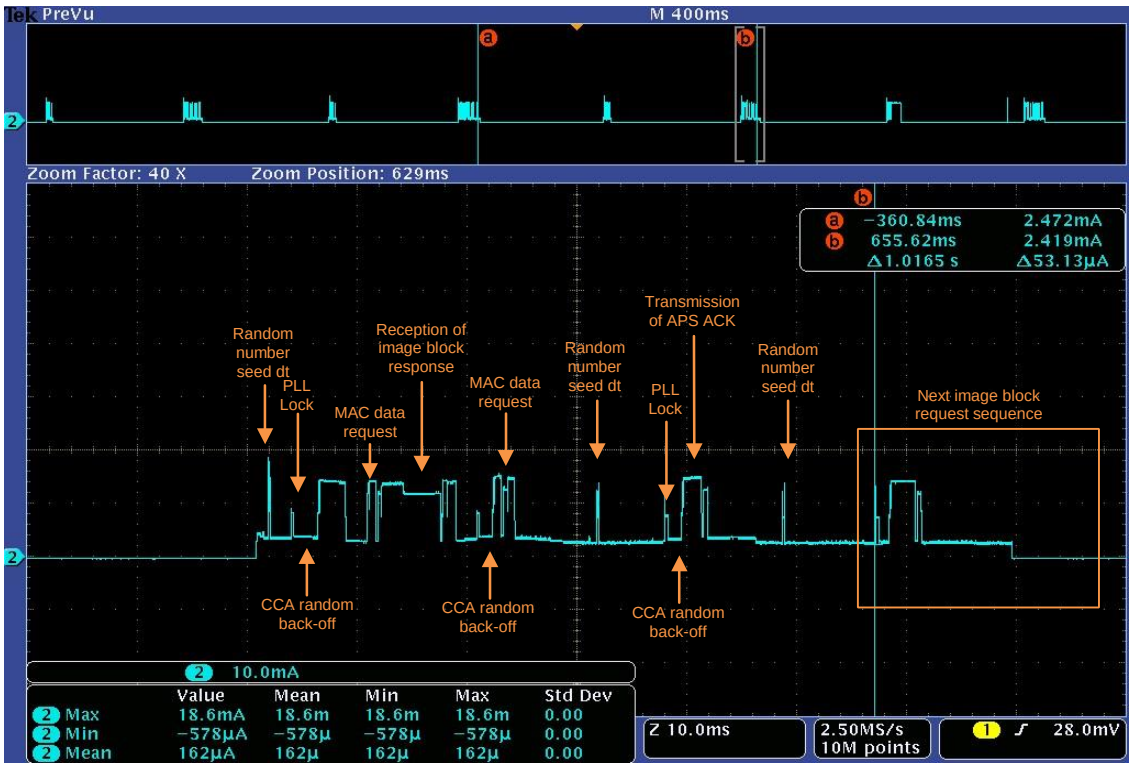


Figure 13-18. Current Consumption Profile of Image Block Request and Response at 16MHz

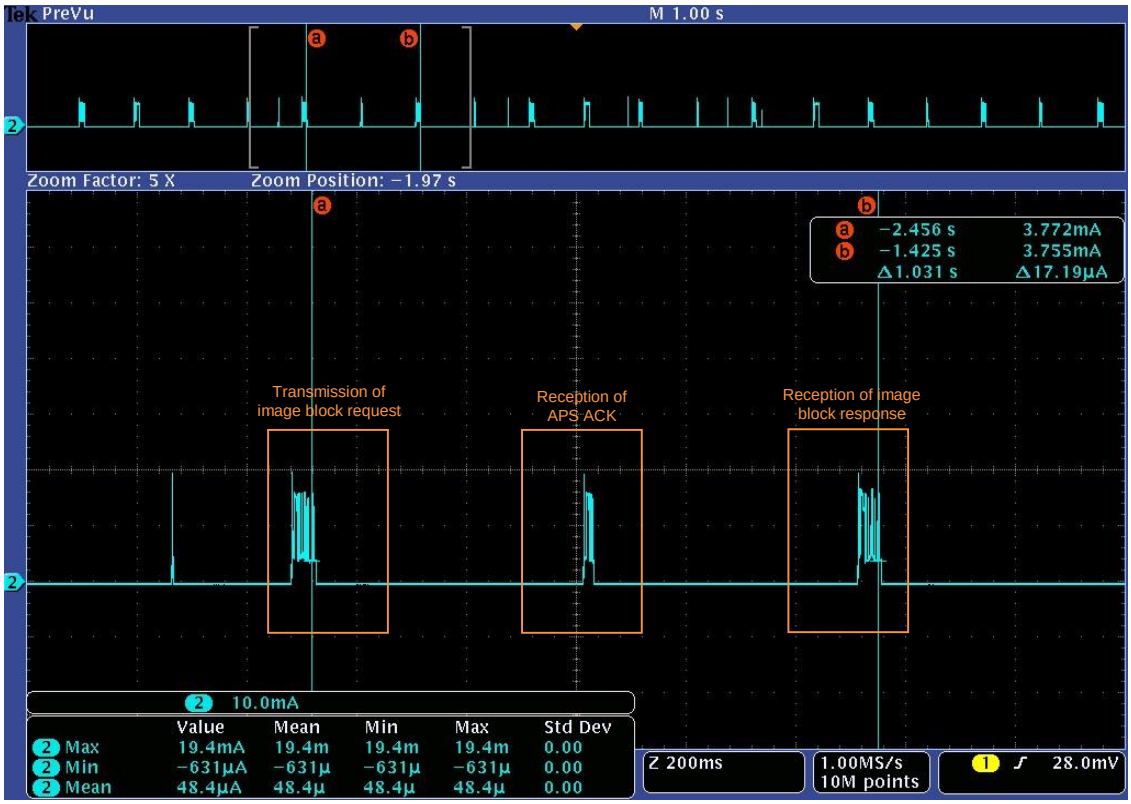


Figure 13-19. Current Consumption Profile of Image Block Request at 16MHz

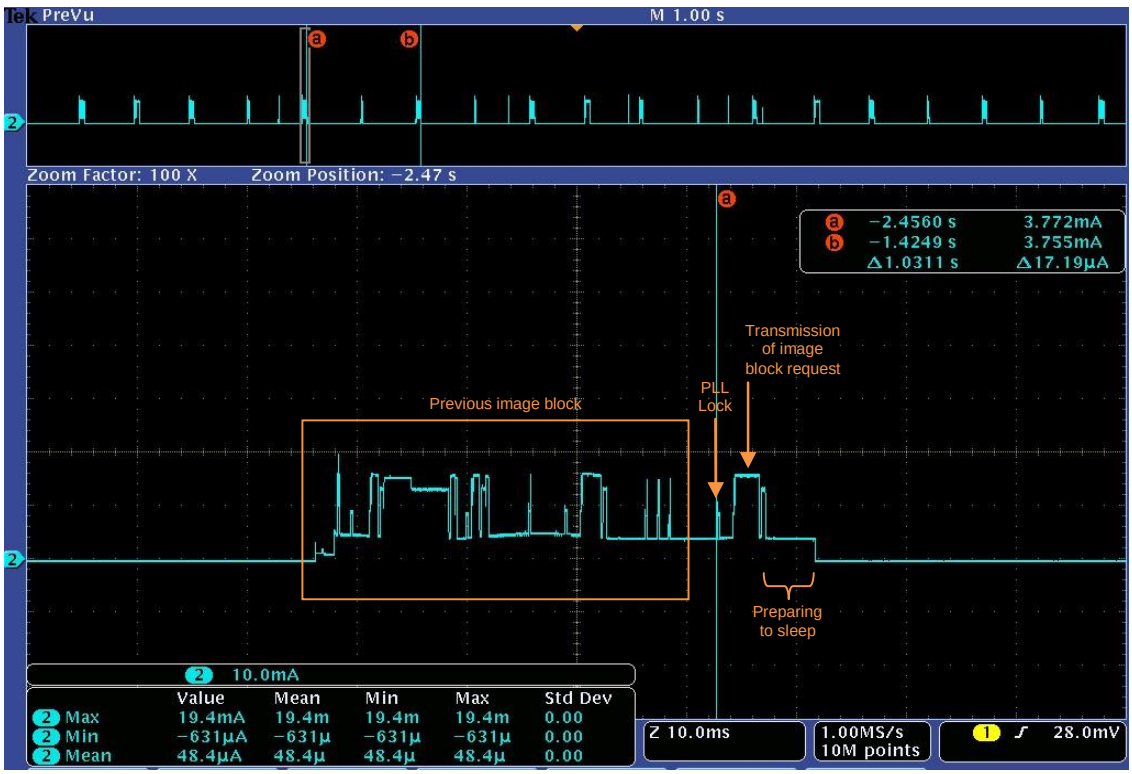


Figure 13-20. Current Consumption Profile of APS ACK at 16MHz

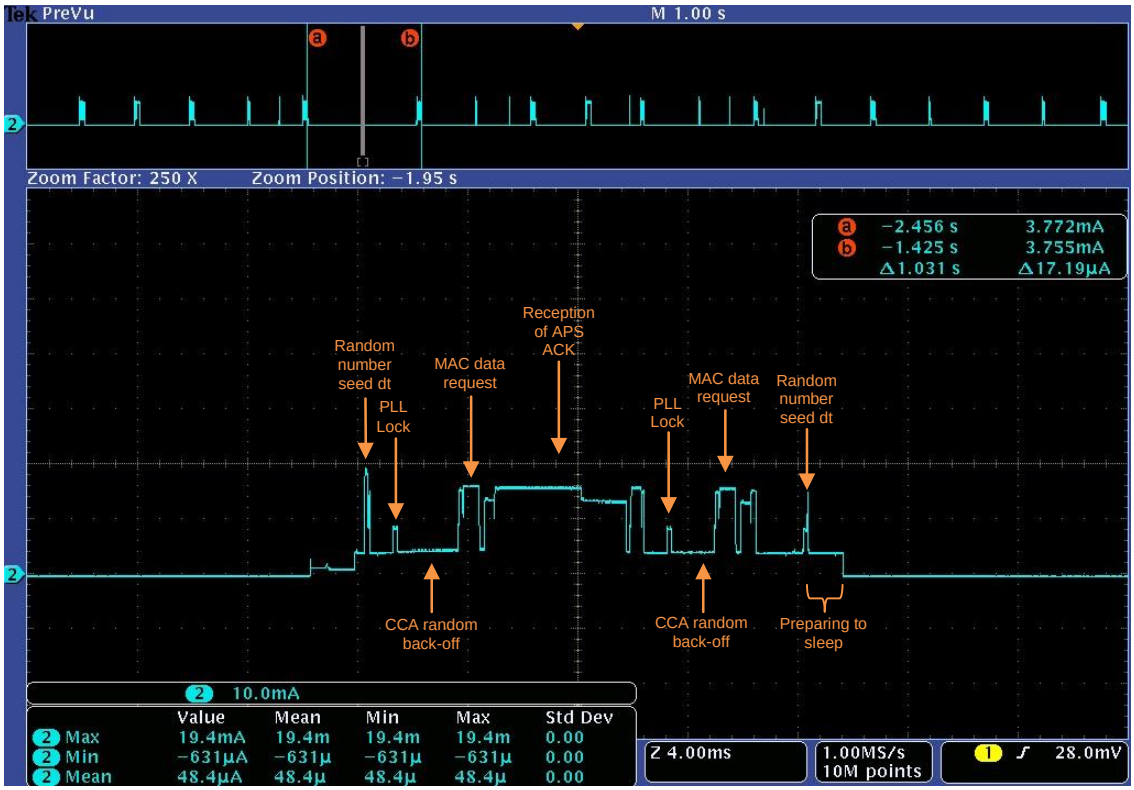
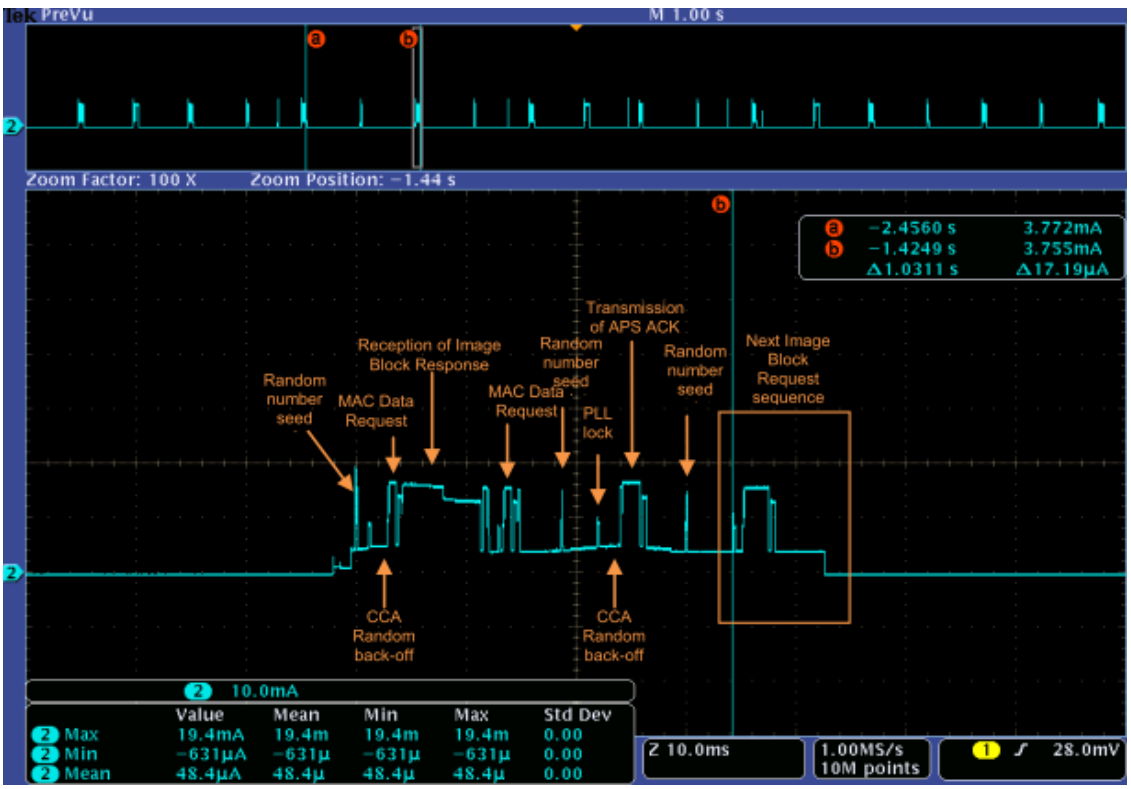


Figure 13-21. Current Consumption Profile of Image Block Response at 16MHz



13.4 Scenario - Upgrade End Response and Reset

This section characterizes the power consumption during an OTAU upgrade end response and bootloader reset. Figure 13-22 shows the sniffer log of upgrade end response.

OTA device waits for this Upgrade End Response frame from the OTA Server. After receiving this frame OTA device switches to the new firmware image.

After receiving Upgrade End Response device resets, then clock stabilization happens followed by bootloader initialization and flash read/write process.

Note: Fuse Settings used for this scenario is with bootloader, refer Chapter 2.

Figure 13-22. OTAU Update End Response Sniffer Log

Packet N	Time	Frame	NWK Src	NWK Dst	MAC Src	MAC Dst
0	06:05:07.299	ZCL: Upgrade End Response	0x0008	0x3faa	0x0008	0x3faa
1	06:05:07.302	Ack				
2	06:05:07.307	MAC: Mac Data Request			0x3faa	0x0008
3	06:05:07.308	Ack				
4	06:05:07.321	APS: Ack 0x0019	0x3faa	0x0008	0x3faa	0x0008
5	06:05:07.323	Ack				

Table 13-4. Current Consumption During Upgrade End Response

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	63.30	57.10
Average current [mA]	4.85	6.31
Charge consumed [mA x ms]	307.19	360.47
Peak Current [mA]	18.20	19.10
Current Profile	Figure 13-23	Figure 13-24

Figure 13-23. Current Consumption Profile of Upgrade End Response at 8MHz

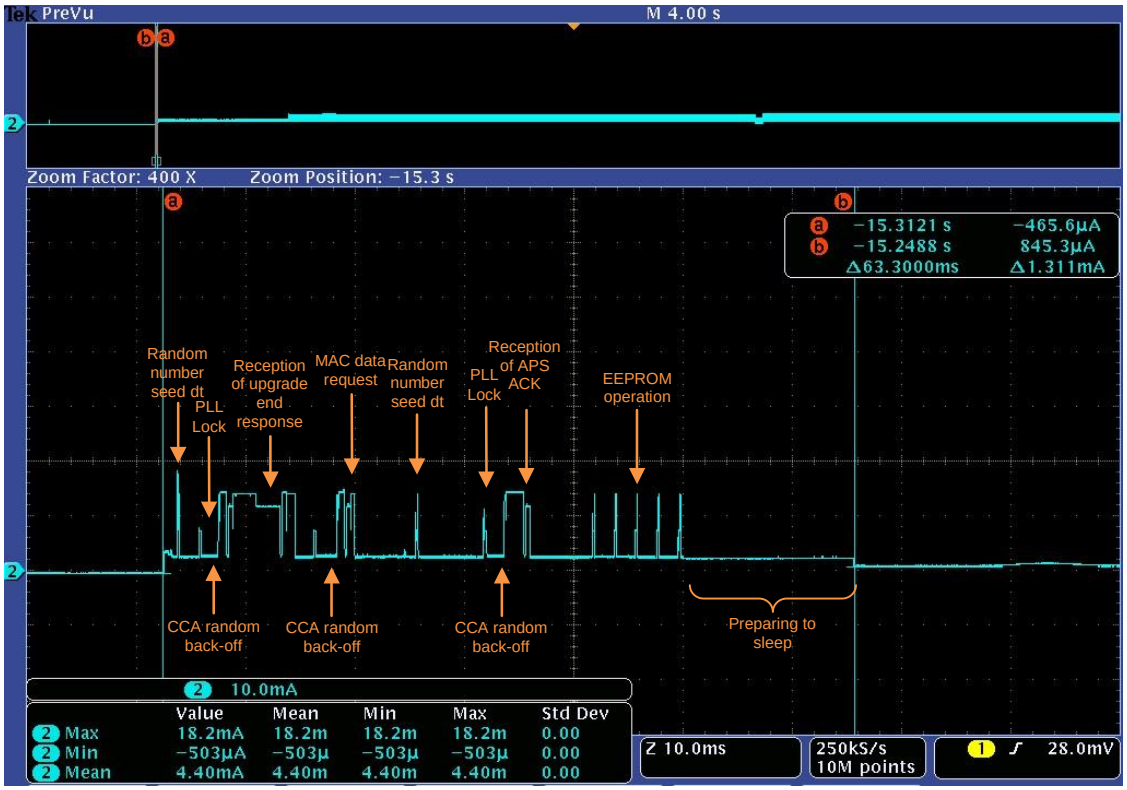


Figure 13-24. Current Consumption Profile of Upgrade End Response at 16MHz

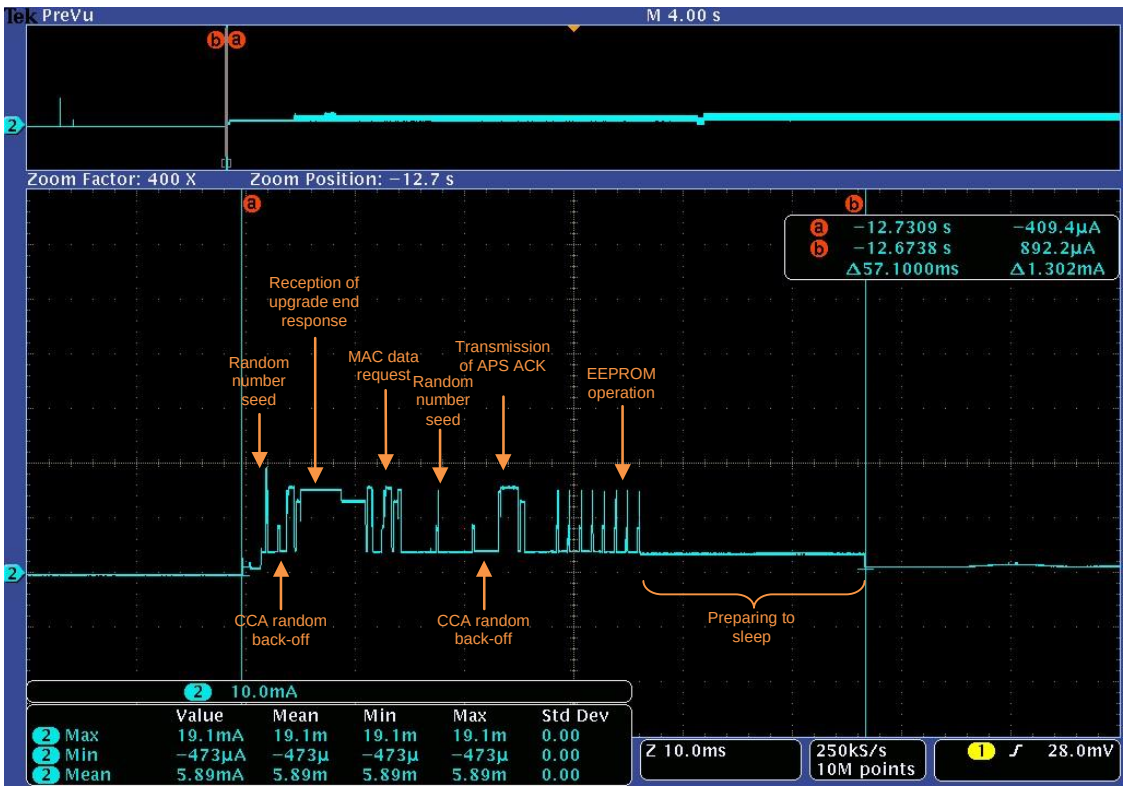


Table 13-5. Current Consumption During Clock Stabilization after Reset

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	62.20	82.20
Average current [mA]	1.63	1.83
Charge consumed [mA x ms]	101.57	150.67
Peak Current [mA]	1.92	2.12
Current Profile	Figure 13-25	Figure 13-26

Figure 13-25. Current Consumption Profile of Clock Stabilization after Reset at 8MHz

Figure 13-26. Current Consumption Profile of Clock Stabilization after Reset at 16MHz

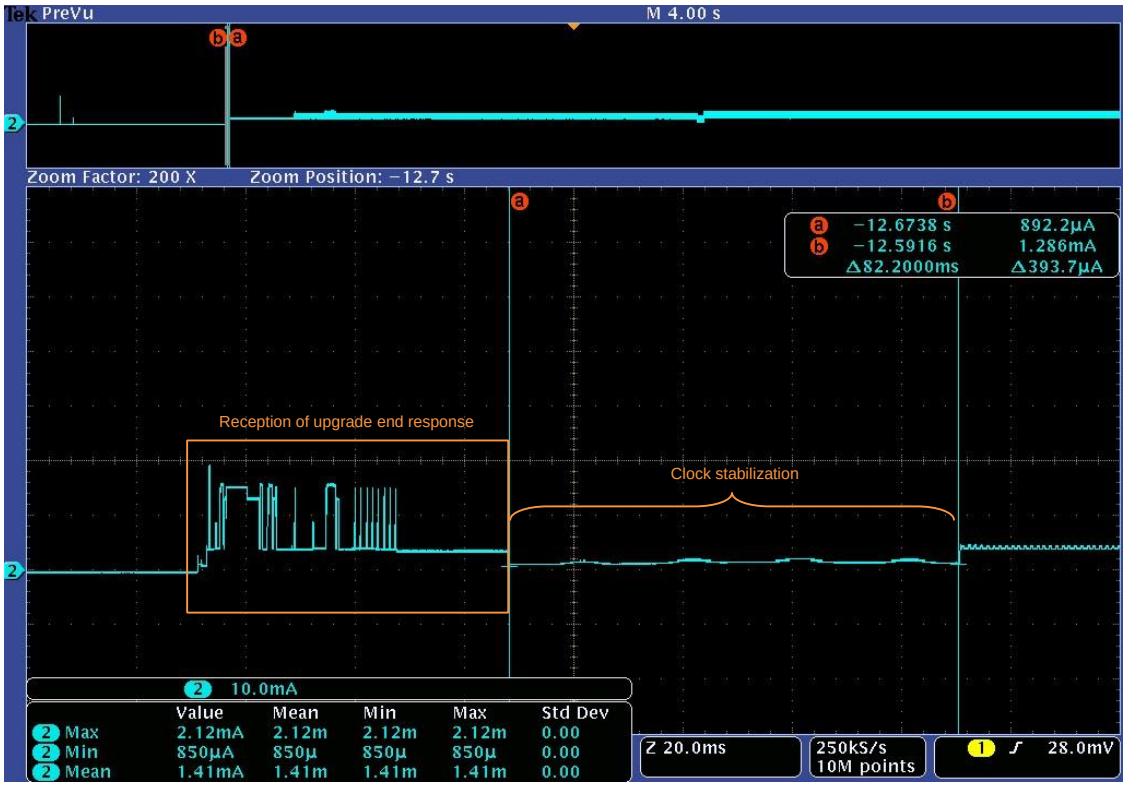


Table 13-6. Current Consumption During Bootloader Initialization

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	4754.00	2390.00
Average current [mA]	3.14	4.44
Charge consumed [mA x ms]	14941.82	10618.77
Peak Current [mA]	2.69	4.02
Current Profile	Figure 13-27	Figure 13-28

Figure 13-27. Current Consumption Profile of Bootloader Initialization at 8MHz

Figure 13-28. Current Consumption Profile of Bootloader Initialization at 16MHz

Table 13-7. Current Consumption During Flash Read and Write

Description	Result at 8MHz	Result at 16MHz
Duration [ms]	17350.00	14980.00
Average current [mA]	4.98	6.60
Charge consumed [mA x ms]	86455.05	98912.94
Peak Current [mA]	7.67	9.00
Current Profile	Figure 13-29	Figure 13-30

Figure 13-29. Current Consumption Profile of Flash Read and Write at 8MHz

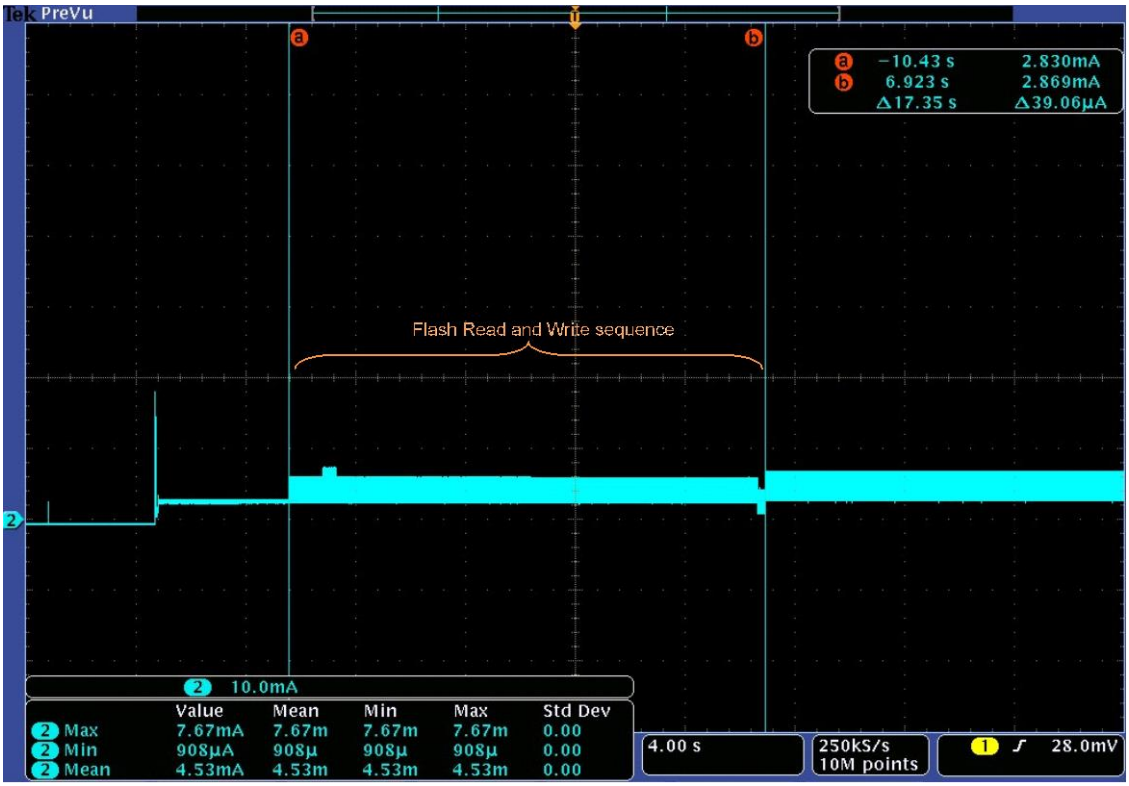
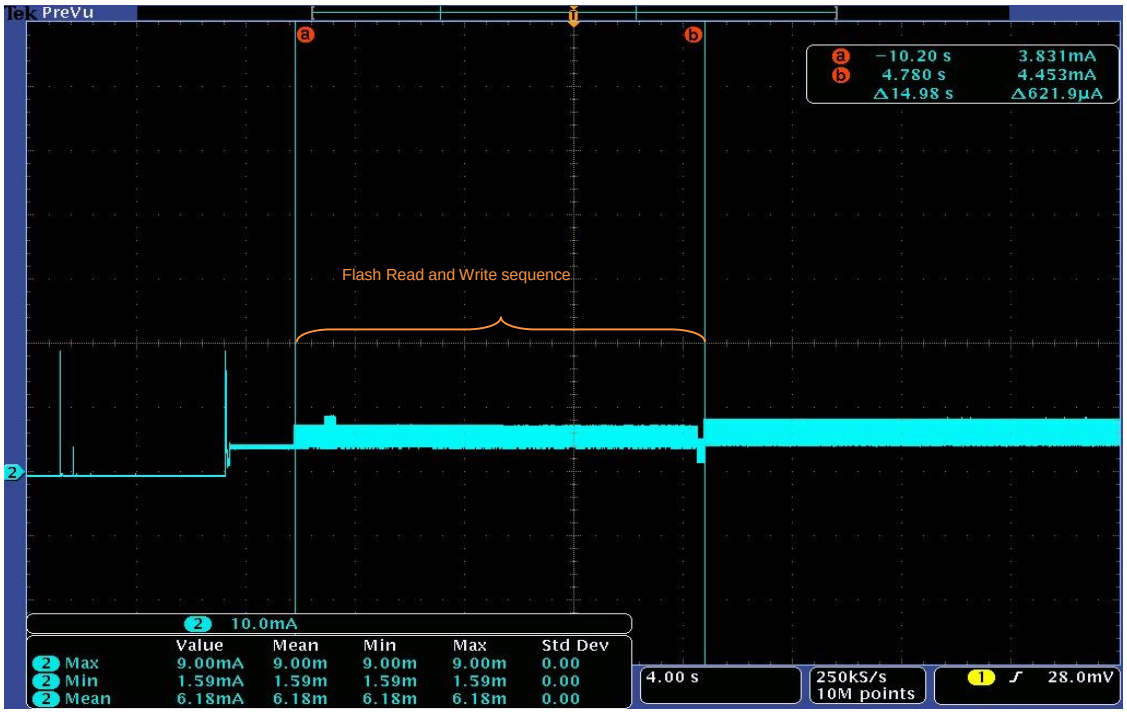


Figure 13-30. Current Consumption Profile of Flash Read and Write at 16MHz



14 Reference

[1] Atmel ATmega256RFR2 Datasheet

[2] Atmel ATmega256RFR2 Xplained Pro User Guide

[3] Atmel AVR®2054: Serial Bootloader

[4] Atmel AVR2050: BitCloud Developer Guide

15 Revision History

Doc Rev.	Date	Comments
42321B	02/2015	Updated for BC 3.2 release for 8MHz on RFR2.
42321A	06/2014	Initial document release.

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