Keysight U3810A Advanced IoT Teaching Solution

U3817A/18A Precision Power Measurement and MEMS Sensors

Lab 5: Evaluating Dynamic Current Drain and Battery Life

KEYSIGHT TECHNOLOGIES

Lab Sheet

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WARNING

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Objective

In the previous lab, you measured the static and dynamic power consumed by your smart sensor node using the DCPA.

In this lab, you will power the Smart Sensor Node from a battery and perform a battery drain test using the Keysight U3810A board as the device under test (DUT) while the Keysight 34465A Digital Multimeter and Keysight N6705C DC Power Analyzer with N6781A 2-Quadrant Source/Measure Unit as the measuring instruments. The XB1 or XB2 Transceiver will be used as a Zigbee Gateway which will receive the data from your smart sensor node.

In the subsequent lab, you will incorporate solar energy harvesting to power your smart sensor node.

Pre-Lab Setup Instructions

1. Prepare the required items as listed in the **Equipment** and **Accessories Required** list below.
2. Download the required software installers according to the **Software Required** list and install them on your computer.

Equipment Required

1. Keysight U3810A IoT System Design module training kit with XB1 or XB2 Module
2. Keysight 34465A Digital Multimeter (DMM)
3. Keysight N6705C DC Power Analyzer with N6781A 2-Quadrant Source/Measure Unit

Accessories Required

1. Two XBee3 Modules
2. On-board U3810A XB1 or XB2 Circuit
3. On-board U3810A DIGITAL TEMP SENSOR Module
4. On board DC-to-DC Converter / Charger Circuit
5. Jumper wires (various colors)
6. Four require (eight recommended) 4 mm banana jack to J-hook mini grabber (two red, two black)
7. Two wire end to J-hook (one red, one black)
8. 1253-6408 Terminal connector 3.5mm Phoenix Contact 1840421 https://www.phoenixcontact.com/us/products/1840421
9. (Recommended) One 3.7 V 400mAh LiPo Rechargeable battery with JST connector (https://www.adafruit.com/product/1578, connect only to P2 or P3) **or** …
    - (Optional) 9 V 200mAh NiMH Rechargeable battery (http://www.tenergy.com/10003, connect only to J1, J2 or P1
    - (Optional) 9 V 600mAh Li-ion Rechargeable battery (http://www.tenergy.com/30593, connect only to J1, J2 or P1), note that this battery's output voltage is 7.4 V.
10. 9 V battery connector to 2.1mm DIA Plug

11. (Optional) Clip leads to connect 9 V battery to DC-to-DC Converter / Charger Circuit

Software Required

1. Digi XCTU (https://www.digi.com/products/xbee-rf-solutions/xctu-software/xctu)
2. WinSCP (https://winscp.net/eng/download.php)
3. PuTTY (http://www.putty.org/)
4. (Optional) Keysight 14585 Control and Analysis Software for Advanced Power Supplies to record results
5. (Optional) BV9200B advanced power and control analysis software

Pre-Lab Battery Charging Required

IMPORTANT

Ensure that the 9 V or 3.7V rechargeable batteries are fully charged before the beginning of this lab session. The lithium battery should have its open circuit output verified to be > 4.0V to most reliably operate the Beaglebone. You may find that a packet type LiPo provides the highest voltage.

The battery is intended to be charged through the DC/DC/Charger Module. Note that directly charging the rechargeable battery with large current is dangerous. Do not connect the battery directly to a solar panel placed in direct sunlight. This may charge the battery with excessively high current. Solar panels may be rated much higher than 9V or 3.7V (Voc) and outdoors may produce current in excess of 10% of the battery capacity which will be too high for a "trickle" charging current.

The batteries may be charged with a 15mA "trickle charge" for 10 hours.

Ensure the rechargeable battery is fully charged. You will need that in Task 2. The 9 V NiMH Battery can be charged by dividing its capacity in amp-hours by 10 to obtain a 15-mA current for "trickle charging" for 10 hours. The 3.7 V LiPo Battery can be charged by dividing its capacity in amp-hours by 4 to obtain a 100-mA current for "trickle charge" for 4 hours. You may charge using the Keysight DCPA or Power Supply as a current source or begin with Task 6 and use the Charger circuit.

WARNING Verify your LiPo battery polarity visually with the DMM before connecting it. These images show correct polarity.

Task 1 – Connect Sensor Node Zigbee with Gateway Zigbee

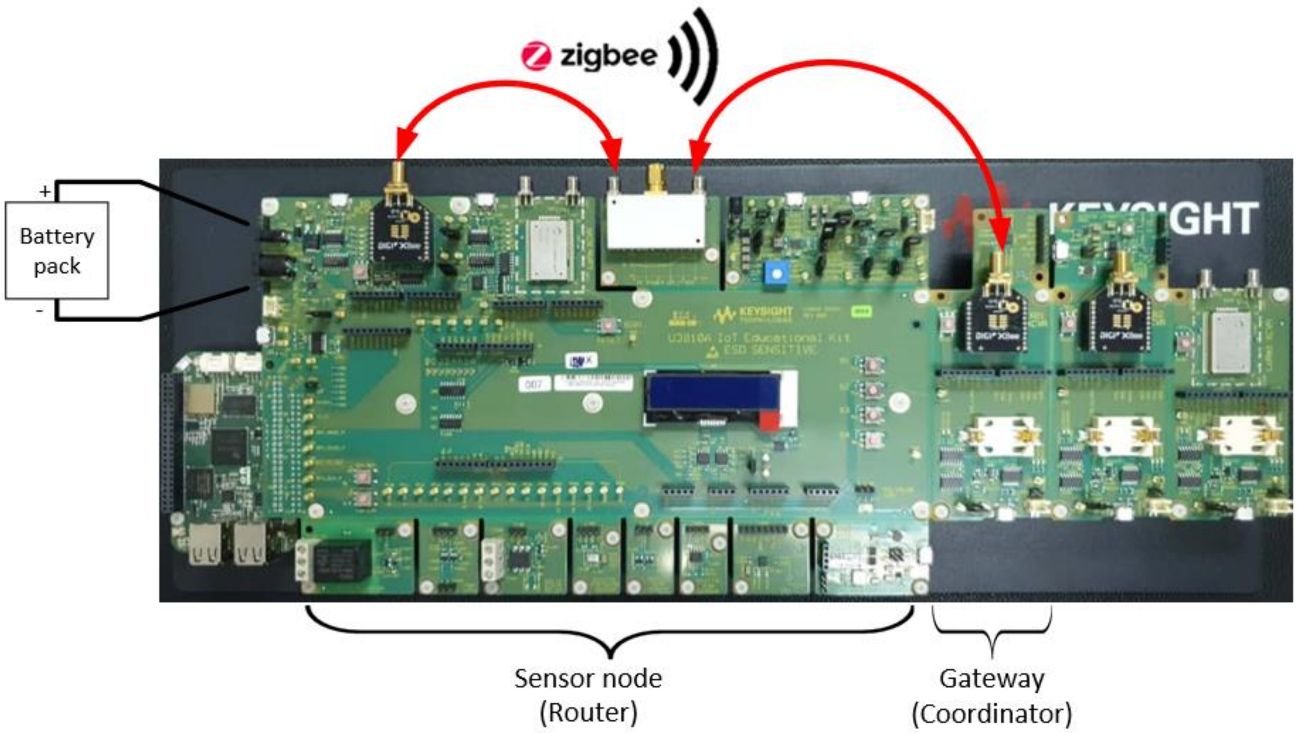
NOTE

Before you begin, please retain your measured results, measurement plots, and analyses in the next two tasks as it will be used in the next lab.

Repeating from the previous lab, the XBee3 module will be used to establish a wired (or wireless) communication between the Sensor node and the Gateway. For the wired RF connection, the splitter provides 30 dB of attenuation so that the transmitter does not overpower the receiver. The Keysight U3810A is to be mounted with one XBee3 module and together with the Beaglebone CPU act as a smart sensor node.

A second XBee3 module is mounted on the Keysight U3810A XB1 Transceiver Module. This module is connected directly to the PC and acts as a Gateway. This is the reverse configuration from prior U3810A labs that is useful to study since this new configuration incorporates a Sensor that is much more powerful but draws more energy.

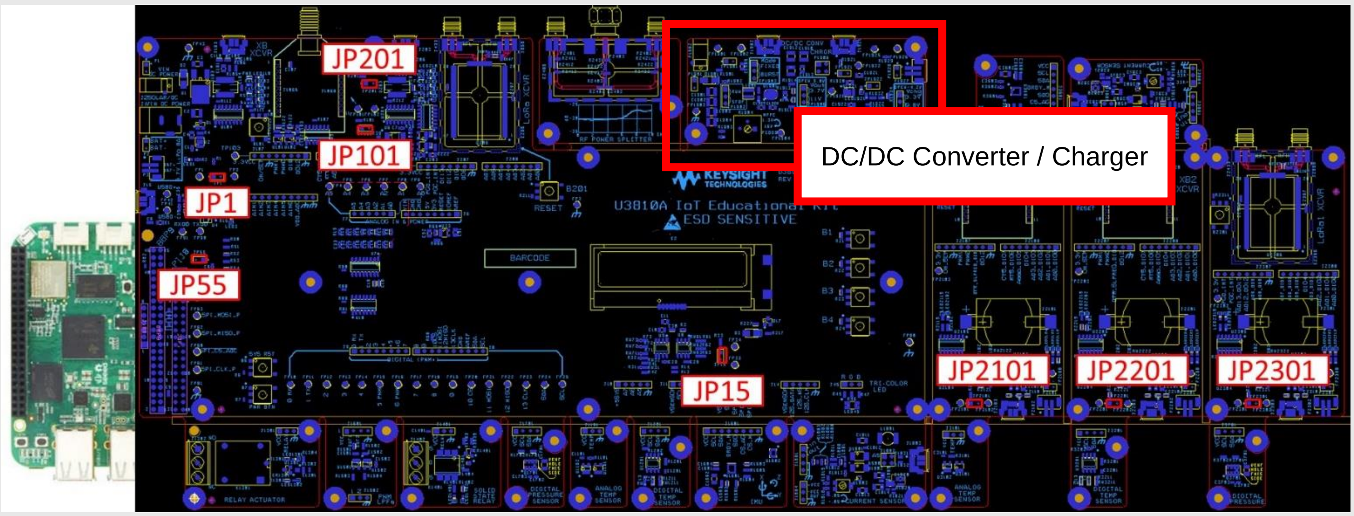
You will explore how to best accommodate the sensor’s power requirement using a battery and in the next lab, solar energy.



NOTE

Before you begin the experiment, configure the Keysight U3810A as a “cape” on top of the BeagleBone CPU and with the jumper configuration as shown below.

Jumper	JP1	JP15	JP55	JP101	JP201	JP2101	JP2201	JP2301
Name	Input Current	Sensor Current	+5VSYS +5VRAW	XB Current	LoRa Current	XB1 Current	XB2 Current	LoRa1 Current
Position	In place	In place	Removed	In place	In place	In place	In place	In place



The diagram above might appear dark in print outs. Please refer to Appendix B – Keysight U3810A Technical Documents for the searchable PDF to help you locate the locations of the jumpers, connectors and components.

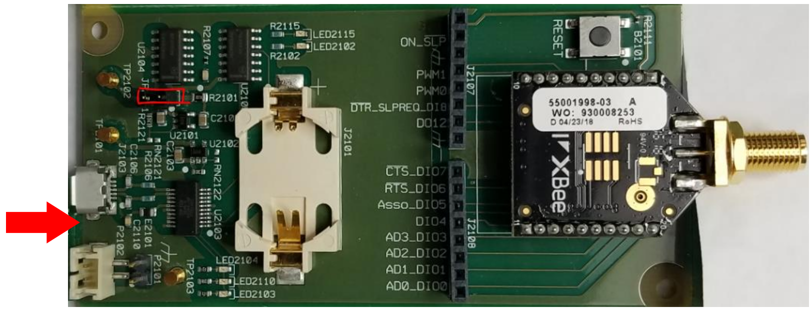
*DCDC Converter / Charger Board jumpers are not relevant in this lab but will be discussed in a later lab.

WARNING Do not connect voltages greater than 3.3 V to GPIO pins as this may damage the BeagleBone CPU. These over-voltage sources include the VIN pin on the Arduino Shield and DC Power connectors, and +5VRAW and +5VSYS on interface connectors such as J10, JP55 and TP51.

Configure the Gateway's XBee3

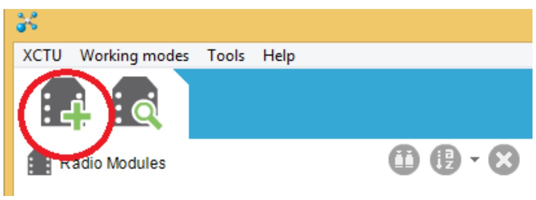
You will begin by establishing a Zigbee Coordinator (we will refer to this as the Gateway). This is done first so that the network's Extended PAN ID is established and can be entered into the configuration for other Zigbee devices on the network such as Routers and Nodes, so that they may "associate" with the network.

1. Assure the second XBee3 module (this will act as the Gateway) is mounted to the XB1 Board and connect it directly to your computer with a micro USB cable. Pay attention to the orientation of the Zigbee module. This is the cabled USB connection from the U3810A to the PC.



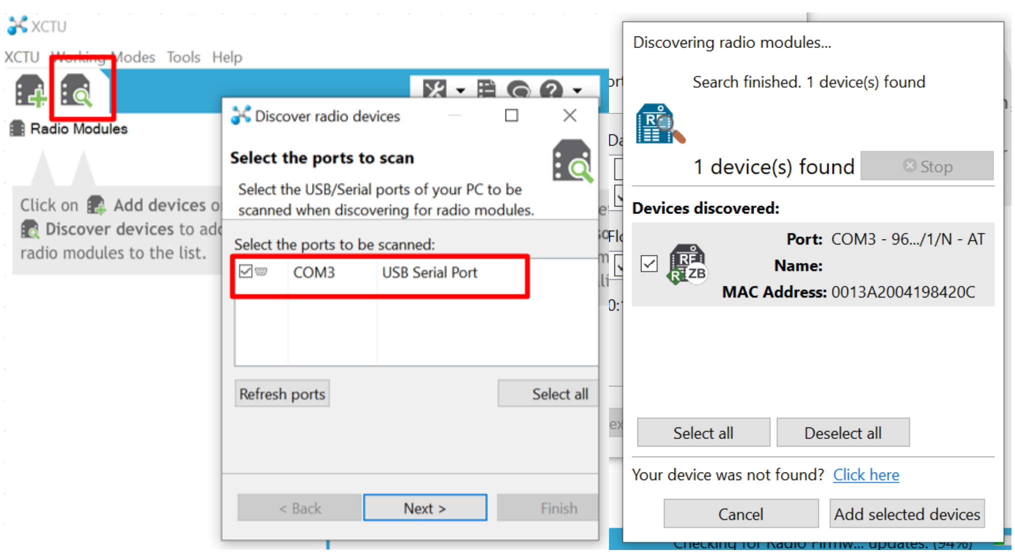
2. Launch the Digi XCTU program (version 6.3.10 and above). You are now using the XCTU software on your computer to communicate with the Zigbee module that is mounted on the Keysight U3810A.

3. Add a new device by clicking the **Add devices** icon below.



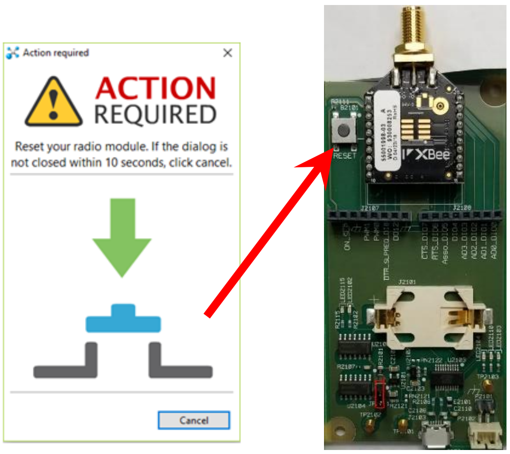
> **NOTE**
>
> If the Zigbee module is not detected when using **Add a radio module specifying the port settings (+ icon)**, use **Discover radio modules connected to your machine (search icon)**.

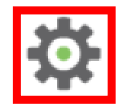
4. Select the COM port corresponding to the Zigbee device. The XCTU software will automatically detect the Zigbee device connected through USB. When you click **Finish**, watch the TX and RX LEDs flash to confirm the correct XB1 device is added.



5. Note down this COM port number (this is how you recognize your gateway in XCTU); do not change any default settings for UART connection (9600 bps, 8-bit Data, No Parity, 1 Stop bit, and No Flow Control). This will be your Zigbee Gateway.

6. If you are shown this prompt (below), press the **RESET** button B2101 located next to the Zigbee module on the XB1 XCVR board to proceed. This is because the Zigbee module might still be sleeping from the prior lab.



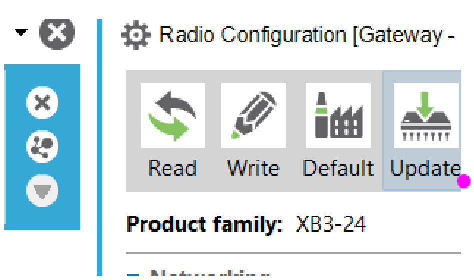


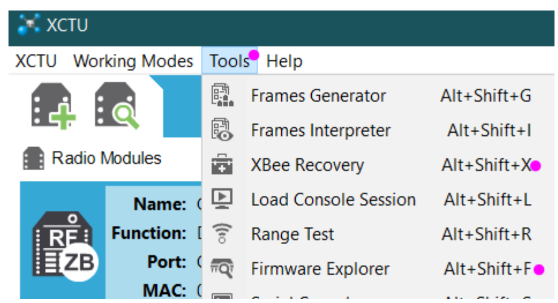
7. Click the gateway Zigbee module (XBee3 + XB1 or XB2 Transceiver board) and the Configuration working mode icon.

8. At the top of the **Configuration working mode** window, assure the latest firmware revision, 1005 or newer:

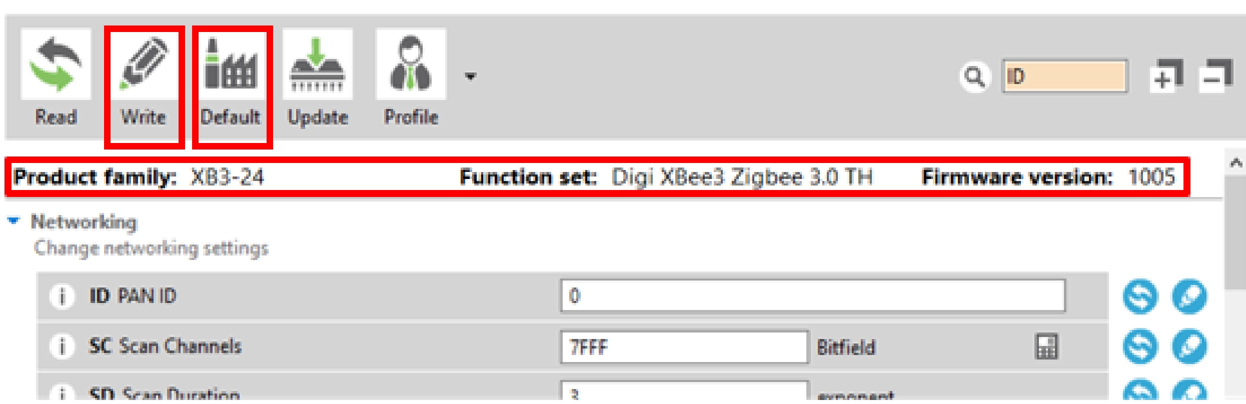
   Product family: XB3-24 **Function set:** Digi XBee3 Zigbee 3.0 TH **Firmware version:** 1005

   If necessary, update all XBee3s to this or a newer revision using **Update** or **Tools** if Recovery is required:





9. Reset the Zigbee module configuration by clicking **Default** button then **Write** button.



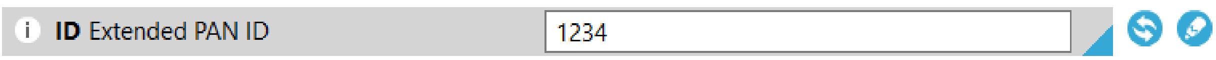
NOTE

If you see the message "**Some settings have an empty value and will not be written.**", ignore it and click **OK** to continue.

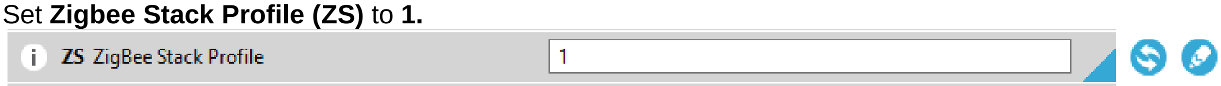
10. Click **Read** button to read back the settings from the Zigbee module.
11. Configure the following Gateway settings:

    a. Set Device Role **(CE)** to **Form Network [1]**. This will set this gateway Zigbee module as the coordinator role.

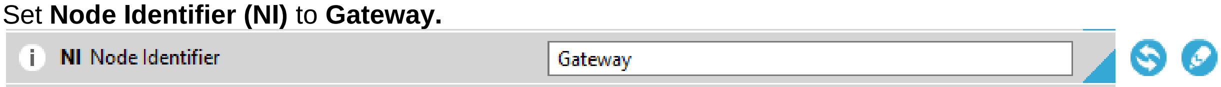
    b. Set **ID Extended PAN ID** to a unique value for your station so as not to interfere with others (for example, 1234).



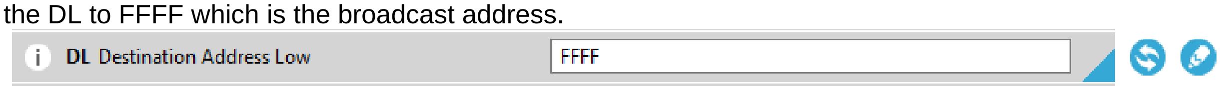
    c. Set **Zigbee Stack Profile (ZS)** to **1.**



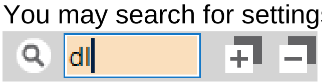
    d. Set **Node Identifier (NI)** to **Gateway.**



    e. Set **Destination Address Low (DL)** to **FFFF**. For a coordinator to communicate to other modules, set the DL to FFFF which is the broadcast address.



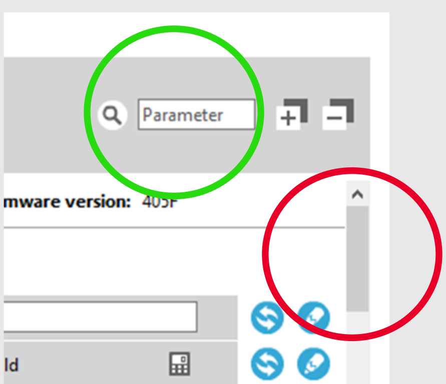
    You may search for settings by typing in the search field window in the upper right:



NOTE

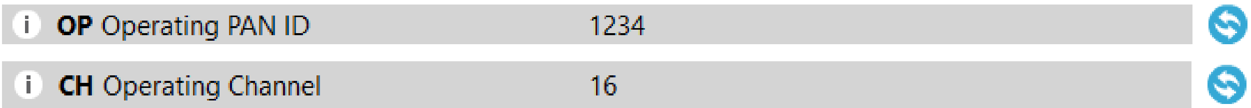
Try not to use your mouse scroll wheel when scrolling the XTCU configuration page. You will likely unintentionally change some settings. Use the GUI page scroll at the right instead.

Also, try typing **CE** in the Parameter Window to quickly find the entry cell.



12. Click **Write** button to apply the settings to the Gateway Zigbee module.
13. Click **Read** button to make sure that the settings are correctly written into the Zigbee module. You may want to click **Write** and **Read** button again, to make the changes effective.

14. Take note that the **Operating PAN ID (OP)** and **Operating Channel (CH)** are now updated.
Record the **Operating PAN ID (OP)** value. You will need this value to configure the Sensor Node Zigbee module settings.



NOTE

Also take note that **MY=0** which is the 16-bit address of the coordinator **and AI=0** which indicates a successful startup.

The Zigbee coordinator now starts its Node Join Timer to **Node Join Time (NJ)** in seconds and allows other devices to join this new PAN until its timer reaches zero. Set **NJ** to **FE** (254 sec) if it is a different value, click **Write**, then click **Read** and verify. Setting **NJ=FF** indicates the coordinator will always allow joining but is not permitted by the Zigbee 3.0 specification. **NJ=0** disables joining.

The Node Join Timer will restart if:

– A network is formed
– You change **NJ**, or a Router joins the network causing the NJ to change to the Router's NJ
– You assert **D0/Commissioning** low twice on a Router or Coordinator
– You issue a **CB** command with a parameter **2**

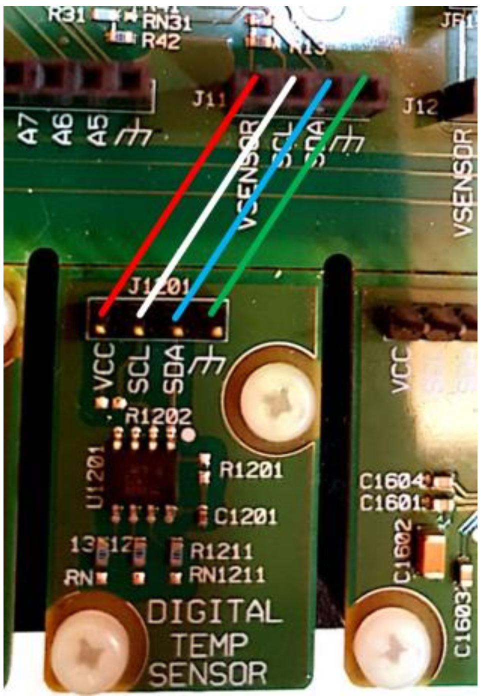
The coordinator does not re-enable joining if the device is power cycled or reset.

When a device is rejoining a network, the join window does not need to be open. However, if the rejoin attempt fails six times, the module attempts to join by association which requires an open joining window. For more information see **Permit Joining** in [2] Digi XBee3 Zigbee RF Module User Guide https://www.digi.com/resources/documentation/digidocs/pdfs/90001539.pdf

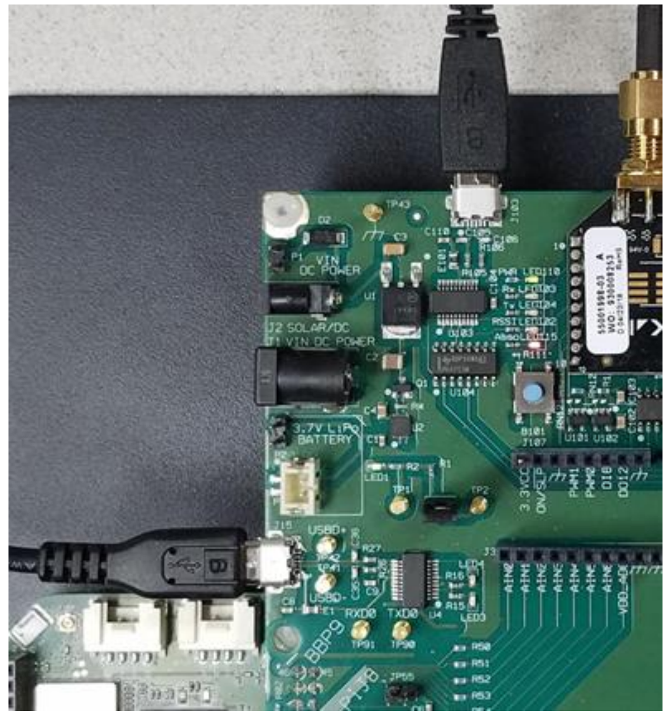
Connect the DIGITAL TEMP SENSOR to the BeagleBone

The LM75 is a digital temperature sensor that converts temperature measurements to digital form using a high-resolution, sigma-delta, analogue-to-digital converter (ADC). Therefore, you do not need an ADC to obtain the temperature reading compared with an LM35 (analogue temperature sensor).

1. Connect the DIGITAL TEMP SENSOR module to J11 on the Keysight U3810A. Connect according to the pin names: **SDA > SDA**, **SCL > SCL**, **GND > GND**, and **VCC > VSENSOR**.



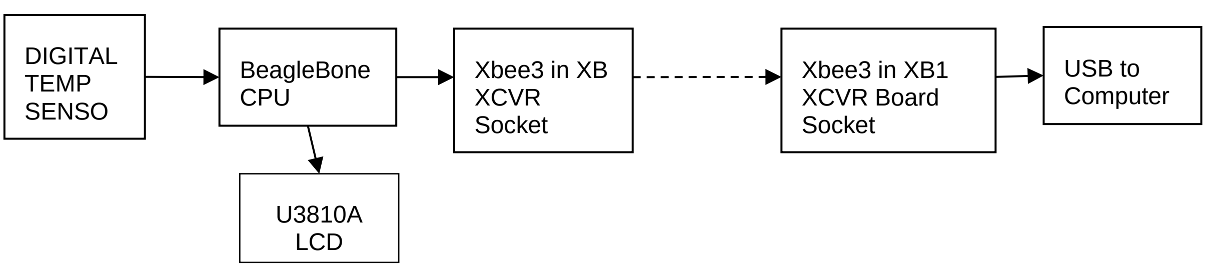
Connect the DIGITAL TEMP SENSOR

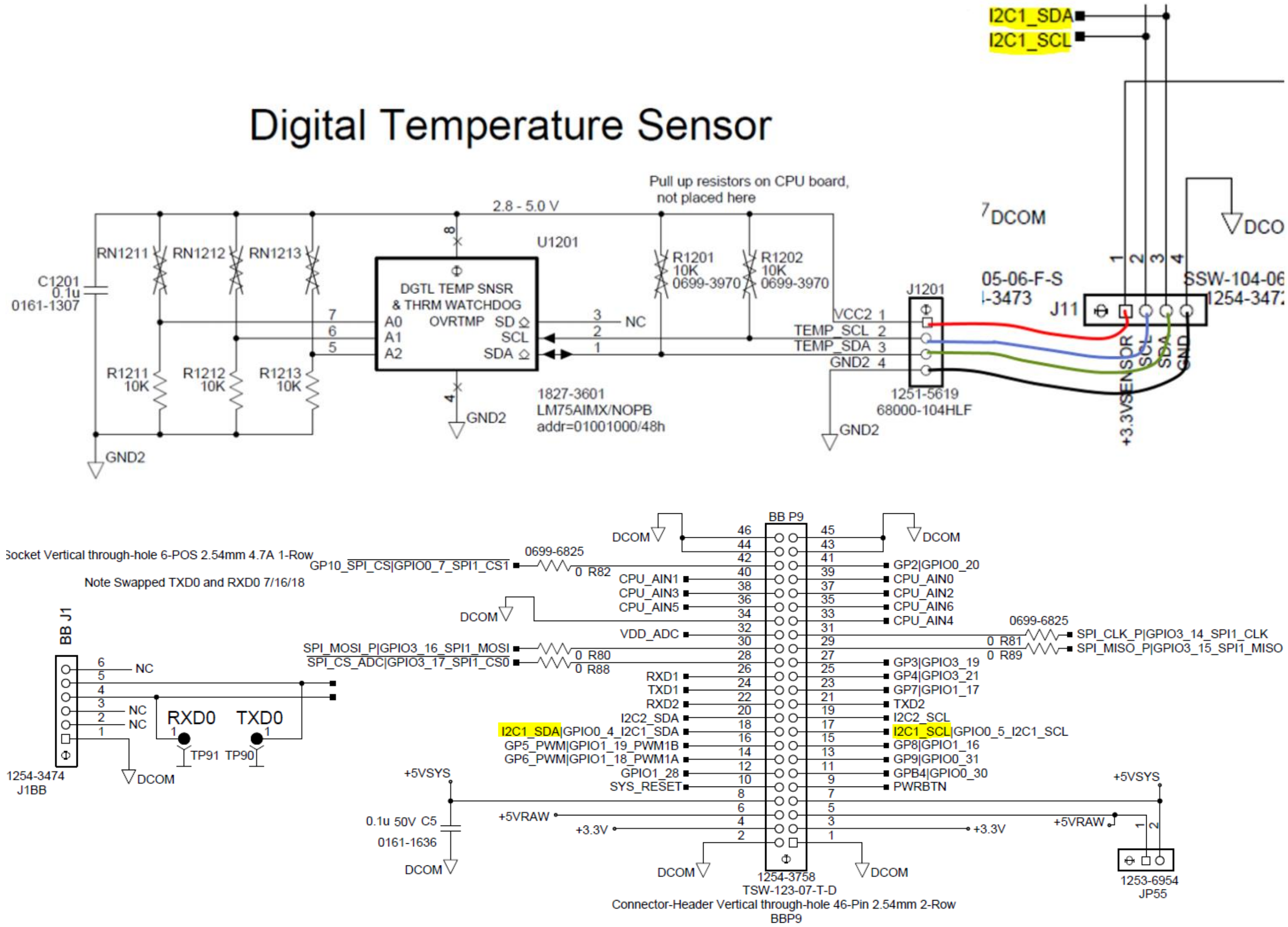


Connect both USB ports with micro USB

The LM75 operates on a 2.8 V to 5 V power supply. Pull-up resistors are needed for proper I²C communication; however, the sensor modules already contain pull-up resistors, so you do not need to connect them manually.

In this task, you will set the hardware address (A0 to A2) to 000 by connecting these three pins to ground. There is only one I²C device involved in this task.





To verify the connections to this point, you will power up the U3810 and the BeagleBone and run a test program.

2. Power the U3810A by connecting the **J15** USB port to your computer with a USB cable as shown above.
3. Open **Device Manager** on your computer and identify the USB serial port of the Keysight U3810A.

NOTE

There are many ways to open Device Manager and the procedures may vary. One way that works on all versions of Windows OS is to press the **Windows Key** + **R** and type **devmgmt.msc** in the resulting pop-up window > hit **Enter**.

4. Login to PuTTY via serial as user: **debian** and password**: temppwd**. For instructions to connect to PuTTY using serial, refer to Module 1 Lab 1.

NOTE

With the **J15** connection for the system console system messages such as

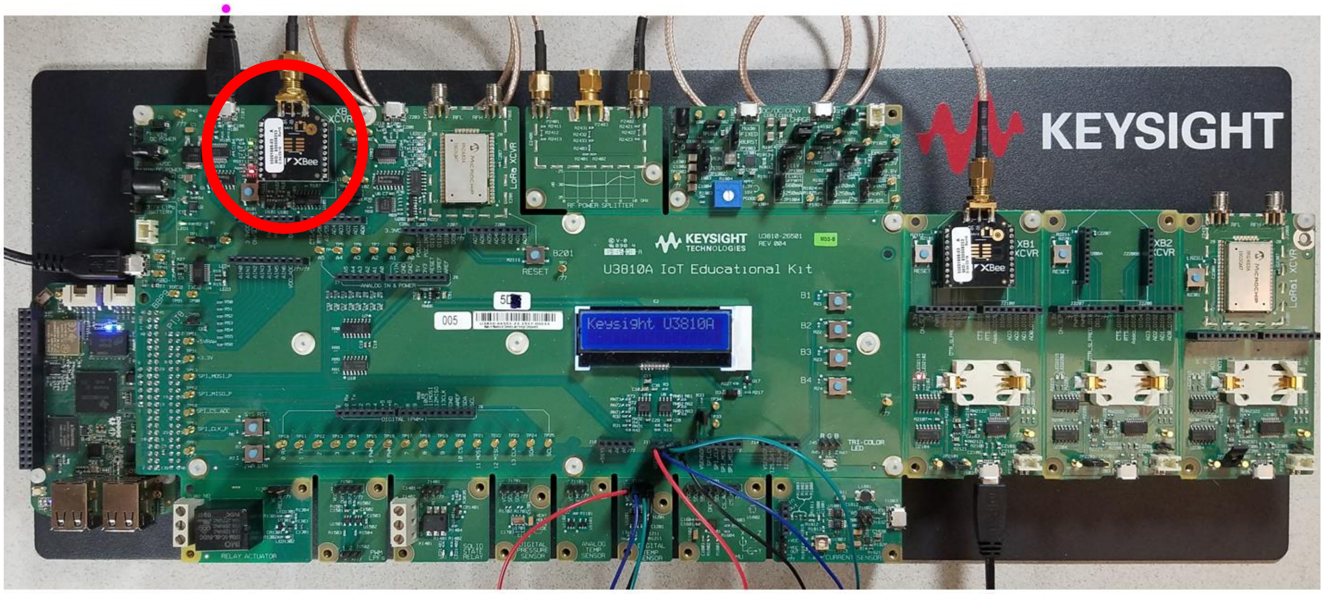
```
connmanctl> [ 2406.800674] wlcore: ERROR SW watchdog interrupt received! starting recovery.
```

…may occur. If they do, press **Enter** and beginning typing your command on a new line.

5. Run **M3_L5_T1_connectZB**. If you have not already done so, you will need to compile the file with the command **gcc M3_L5_T1_connectZB.c -l mraa -o M3_L5_T1_connectZB** and run the command by typing **./M3_L5_T1_connectZB**.
6. The LM75 temperature will appear, on the LCD display. Place your finger on the LM75 sensor to warm it. If the displayed temperature increases, your connections are correct. If there is no increase, review your connections, correct mistakes and repeat running **M3_L5_T1_connectZB**. Press **Ctrl+ C** to end the program.

Configure the Sensor's XBee3

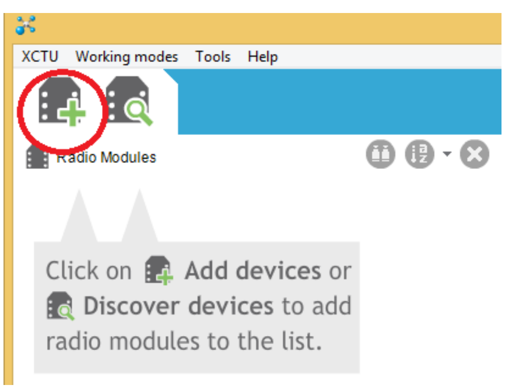
Now let's configure the XBee3 for transmission from the Sensor:



The next steps will involve making up to three USB connections to the U3810A board as shown above:

> **NOTE**
>
> – **J103** USB (upper left) allows your computer to directly communicate with the XBee3 module marked **XB**.
>
> – **J15** USB (left side) powers the BeagleBone and allows your computer to directly communicate with it.

1. Launch the Digi XCTU program (version 6.3.10 and above). You are now using the XCTU software on your computer to communicate with the Zigbee module that is mounted on the Keysight U3810A.
2. Add a new device by clicking this icon.

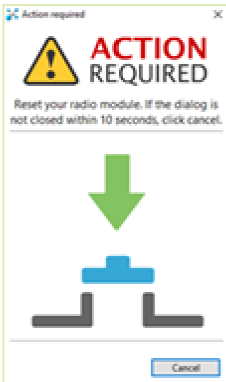


> **NOTE**
>
> If the Zigbee module is not detected when using **Add a radio module specifying the port settings** (**+** icon), use **Discover radio modules connected to your machine** (search icon).

3. Select the USB serial COM port that corresponds to the XB Transceiver on the Keysight U3810A. The XCTU software will automatically detect the XBee3 module connected through USB-Serial converter. When you click **Finish**, watch the TX and RX LEDs flash to confirm the correct XB device is added.

   Note down this COM port number (this is how you recognize your sensor node in XCTU); do not change any default settings for UART connection (9600 bps, 8-bit Data, No Parity, 1 Stop bit, and No Flow Control). This will be your Sensor Node (and Router) Zigbee.

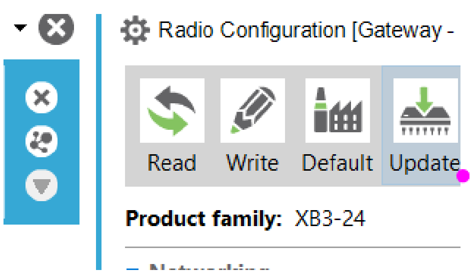
   If you see **Action Required** (below), press the **B101** button located next to the Zigbee module on the U3810A board to proceed. This is because the Zigbee module might still be sleeping from the prior lab.

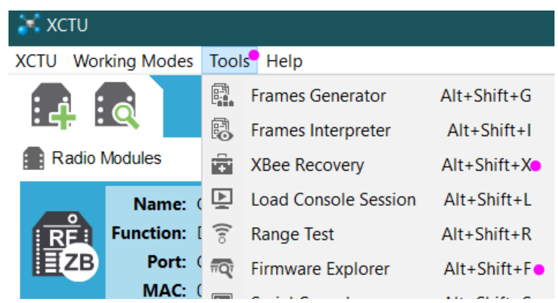


4. In XCTU click the Sensor node Zigbee module (Keysight U3810A)
5. At the top of the **Configuration working mode** window, assure the latest firmware revision, 1005 or newer:

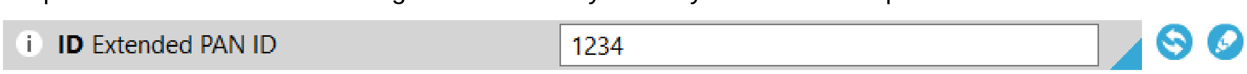
   Product family: XB3-24 **Function set:** Digi XBee3 Zigbee 3.0 TH **Firmware version:** 1005

   If necessary, update all XBee3s to this or a newer revision using **Update** or **Tools** if Recovery is required:



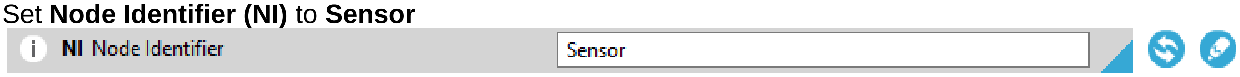


6. Reset the Zigbee module configuration by clicking **Default** button then **Write** button.
7. Click **Read** button to read back the settings from the Zigbee module.
8. Configure the following Sensor node settings:
   a. Set **Extended PAN ID (ID)** to the Gateway Zigbee module's Operating PAN ID (OP) value. Refer to Step 11 of the instruction to configure the Gateway where you chose a unique value.



   b. Set **Zigbee Stack Profile** to **1**

   c. Set **Node Identifier (NI)** to **Sensor**



9. Click the **Write** button to apply the settings to the Gateway Zigbee module. Then click the **Read** button to make sure that the settings are correctly written into the Zigbee module. You may want to click **Write** and **Read** button again, to make the changes effective.

IMPORTANT

Take note that the OP and CH are now updated (same as the OP and CH of the coordinator, respectively). Also take note that MY value is updated with the 16-bit address of the sensor node and AI=0 which indicates a successful join.

When connected, each Zigbee module should have a steady green power LED and flashing red LEDs. The Gateway/Coordinator's ASSOCIATE LED will be flashing red at 1 Hz. The Sensor/Router's (or End Device) ASSOCIATE LED will be flashing red at 2 Hz. If not, verify all procedures above, especially that the Sensor's **Extended PAN ID (ID)** to the Gateway's unique Operating PAN ID (OP), see 8a above.

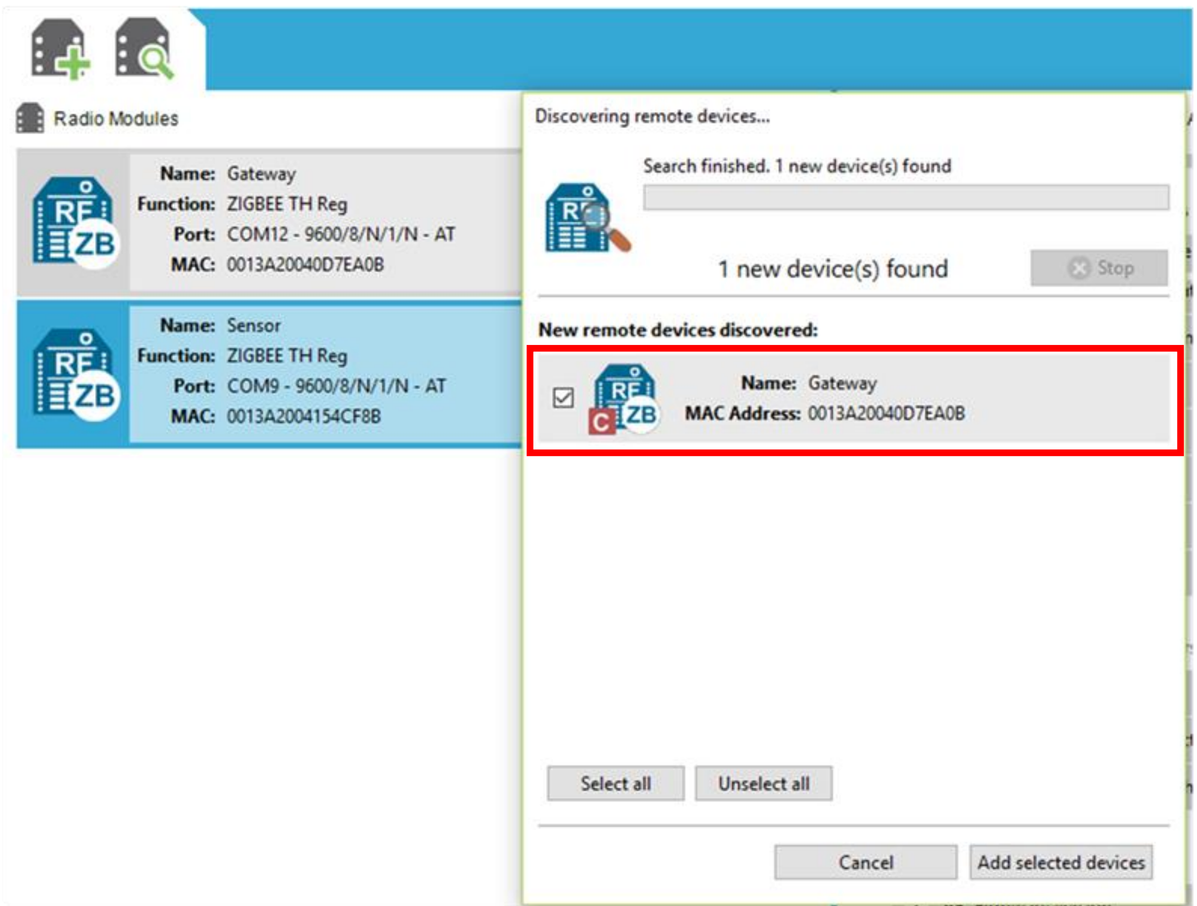
If the connection is still not established, disconnect all USB connections. Reconnect the PC to the BeagleBone USB port. Reconnect the PC to the Sensor Zigbee USB port. Reconnect the PC to the Gateway Zigbee USB port.

Verify Zigbee Configurations

1. To verify that both Zigbee modules (Sensor node and Gateway) are communicating with each other using the same wireless network, click **Discover radio nodes in the same network** button.

> **NOTE**
>
> **Discover radio** is available in all API configurations.

2. A pop-up window titled **Discovering remote devices** will appear and list the Zigbee modules discovered in the same network. Make sure that the other Zigbee module is listed:



a. On the “Discovered” Sensor node Zigbee module, verify that:

   i. The MAC Address of the Gateway Zigbee module found matches your Gateway Zigbee module MAC address.

   ii. The Gateway Zigbee module has the coordinator icon to indicate that it is a coordinator.

b. Click **Cancel** button after verification.

c. On the “Discovered” Gateway Zigbee module, verify that:

   i. The MAC Address of the Sensor node Zigbee module found matches your Sensor node Zigbee module MAC address.

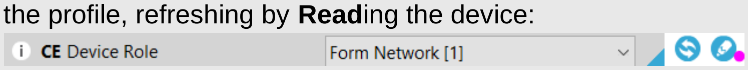
   ii. The Sensor node Zigbee module has the router icon to indicate that it is a router.

d. Click **Cancel** button after verification.

NOTE

Sometimes the C and R icons do not automatically refresh. If this happens, you can try reloading the profile, refreshing by **Read**ing the device:

or by re**Write**ing the **CE** Role with:



Do not worry if the above does not work. Simply proceed. If the next steps work, then there is no problem.

Rarely after previously successful connection is established, the Zigbee connection may not reconnect. If this is the case, try temporarily reversing the **CE** Device Role of the two devices in place, complete the connection, and then reversing again.

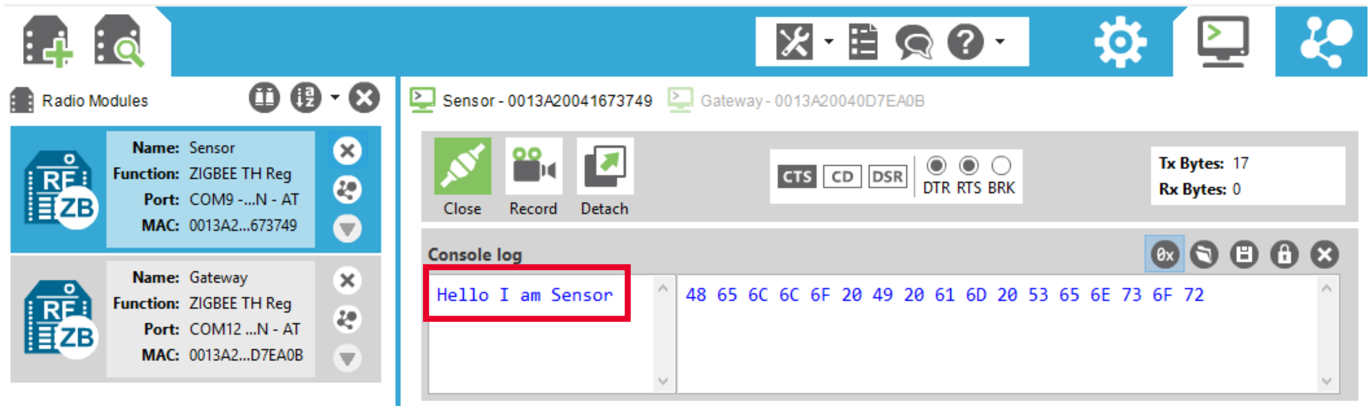
3. The Gateway’s red ASSOCIATE **LED2115** should be blinking slowly (1 Hz) and when connected to your computer via USB, the Sensor’s **LED115** should be blinking fast (2 Hz).

4. Click the sensor node Zigbee and change to the **Consoles working mode** (at the top-right corner).

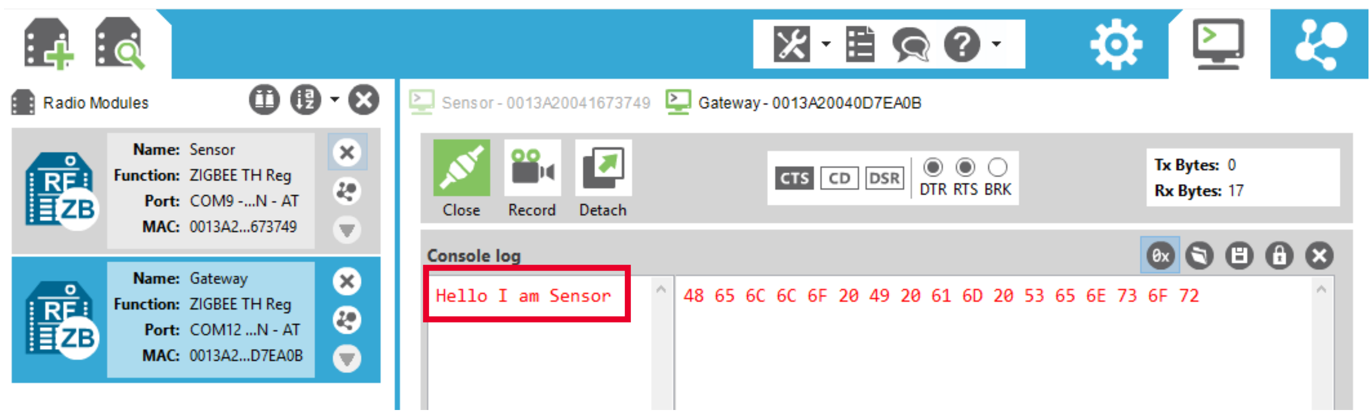
5. Click **Open** to establish communication with the sensor node Zigbee.

6. Click the gateway Zigbee which should be in Console Mode and click Open to establish communication. Both Zigbee modules can now communicate directly.
7. Type something in the **Console log** of either the gateway or sensor node Zigbee, and then do it again with the other module. You should see the same message appear in the other Zigbee module. This verifies that both Zigbee modules are communicating with each other. (HINT: No **Console Log**? Make sure parameter **AP API Enable** is set to **Transparent Mode [0]** on both XBees.)

Sensor node Zigbee console:



Gateway Zigbee console:

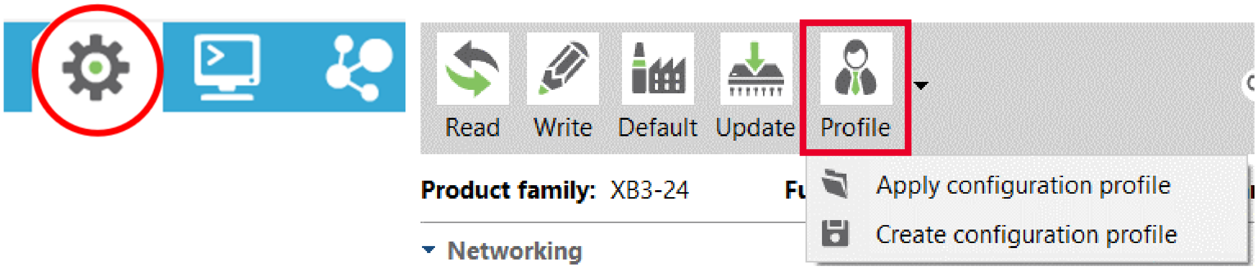


NOTE

If the Zigbee modules are not able to communicate to each other, assure that:

1. All the settings are set correctly as per the instructions.
2. The value for Zigbee Stack Profile (ZS) is the same for both Zigbee modules.
3. Assure that the Extended PAN ID (ID) of the Sensor node Zigbee is set to the Operating PAN ID (OP) of the Gateway Zigbee.
4. Rarely after previously successful connection is established, the Zigbee connection may not reconnect. If this is the case, try temporarily reversing the **CE** Device Role of the two devices in place, complete the connection, and then reversing again.

8. If you have not already done so in a previous Task, switch to **Configuration working mode** and use the **Profile** icon to **Create** and save both your Gateway and Sensor XBee configurations (a separate file for each) for use in this or subsequent labs.



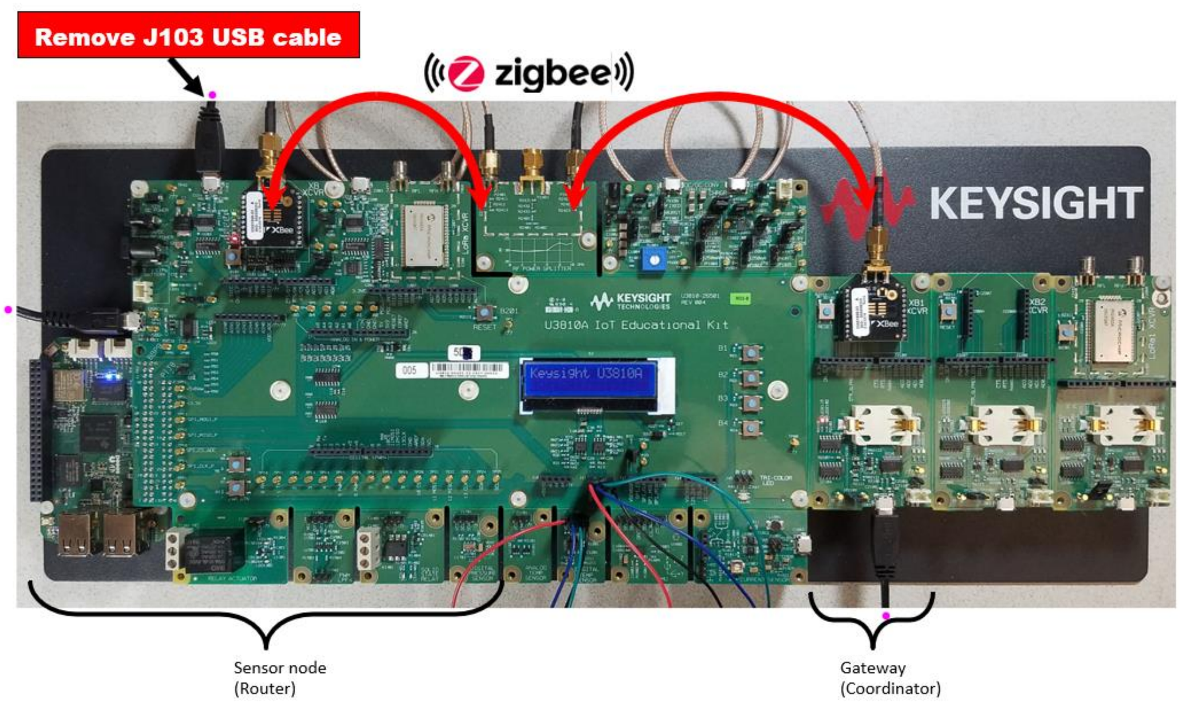
NOTE

If you have not already saved these Zigbee configurations as Profiles, you may save time and assure accurate configurations by copying the files from the **LabCode** directory on the BeagleBone to your computer. You may then use the **M3_L4567_T1_XbeeGateway_Communication.xpro** and **M3_L4567_T1_XbeeSensor_Communication.xpro** profiles for this Task.

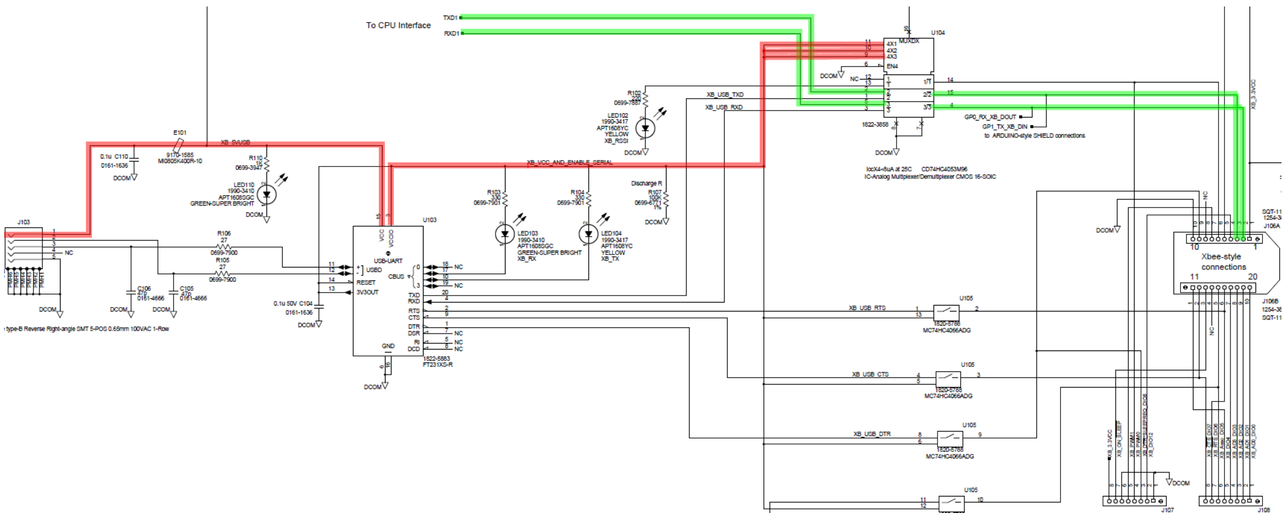
Go to "**Profile** > **Apply configuration profile**" and select the profile. For the Router (Sensor node Zigbee) please change Extended PAN ID (ID) to match the Operating PAN ID (OP) of the Coordinator (Gateway Zigbee) and re-save the profile Router profile you have customized to your network.

The **.xpro** file saved by XCTU is actually a zip format file. You can use zip software to unzip the file to examine the contents. Do not use XCTU version older than 6.3.10, the format saved is an xml format. Please read the XCTU change log (XCTU > Help > Change Log) for more details.

9. Now, move on to connect the Beaglebone to the XB in the Sensor Node (the Keysight U3810A).



10. Remove the USB connection J103 on the XB circuit. The absence of power on the USB connection J103 automatically configures the XBee3 module in the XB circuit to communicate with the BeagleBone CPU through UART1 with the signal flow shown below.

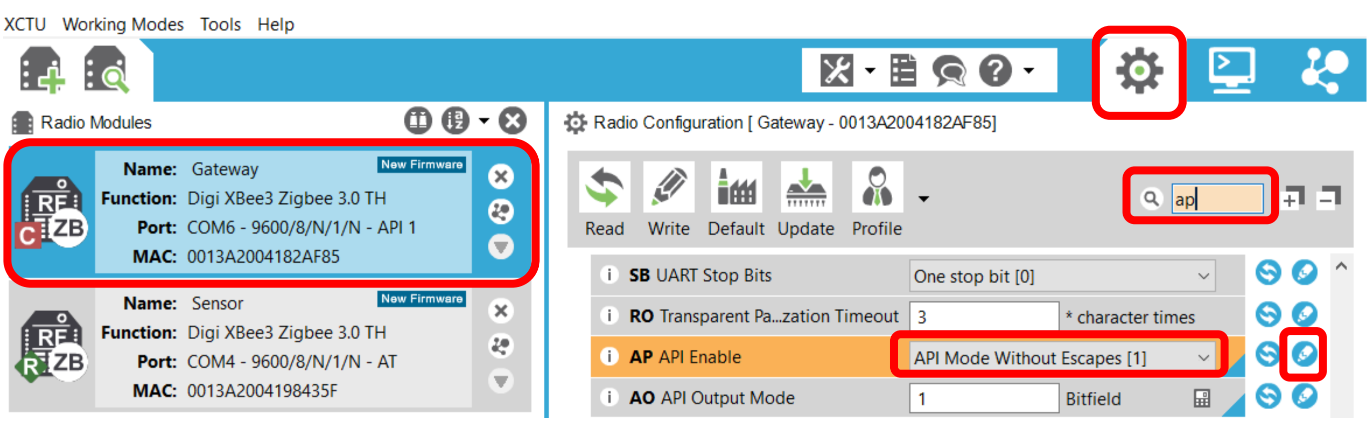


11. Confirm that the Zigbee radios are still connected using the **Network working mode** on the Gateway XBee3 on XCTU:

    a. Select the **Gateway** device, Configuration working mode, search for **AP** or **ap API Enable** and select **API Mode Without Escapes [1]**. **Write** it to the device.

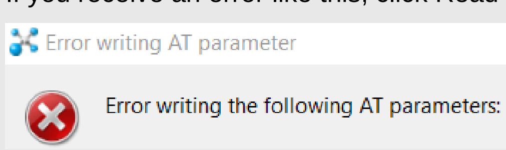
NOTE

Network working mode is not available in the default Transparent Mode [0]. In this step you will temporarily change to **API Mode Without Escapes [1]** so that you can observed the network using **Network working mode.** Then you will return to Transparent Mode[0]. (**Discover radio** is available in all API configurations)

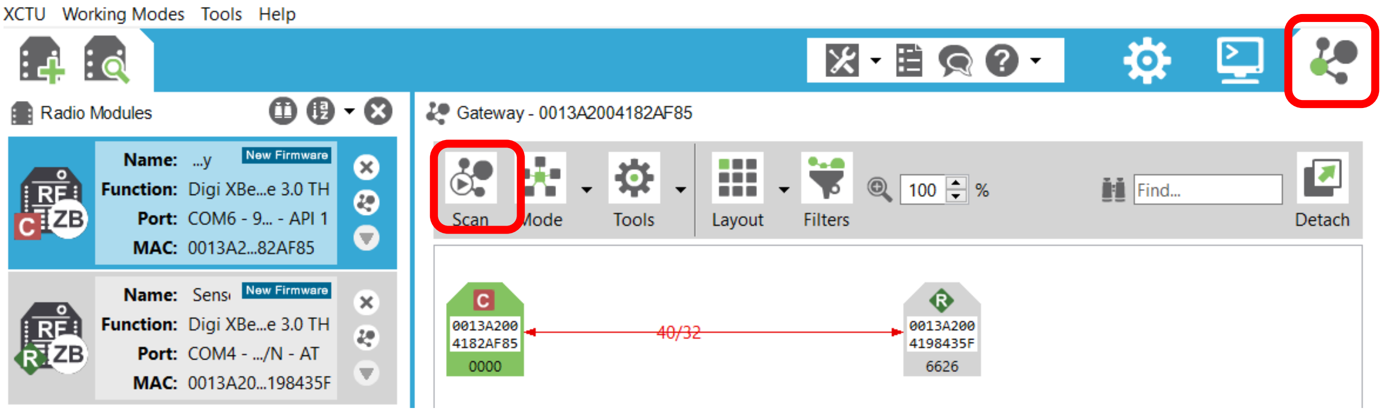


NOTE

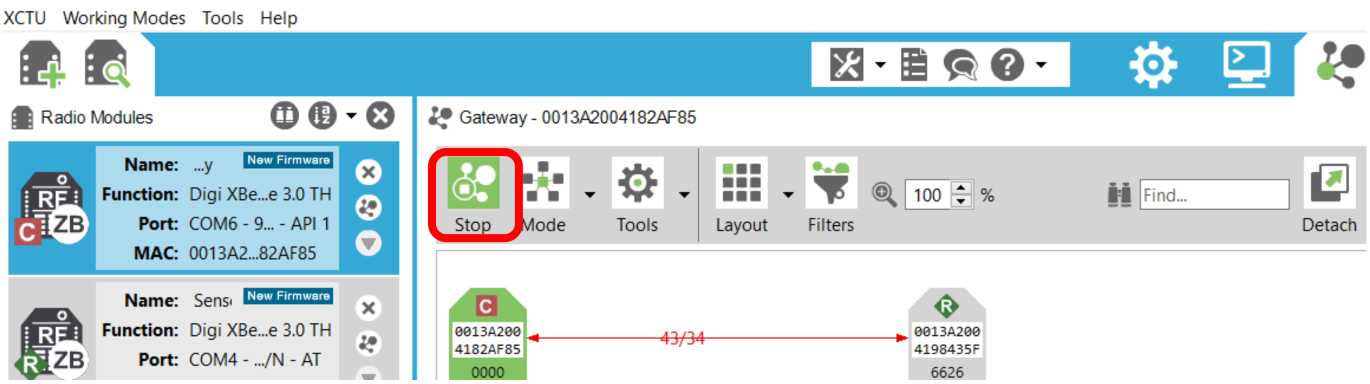
If you receive an error like this, click Read  to refresh your computer's connection to the XBee.



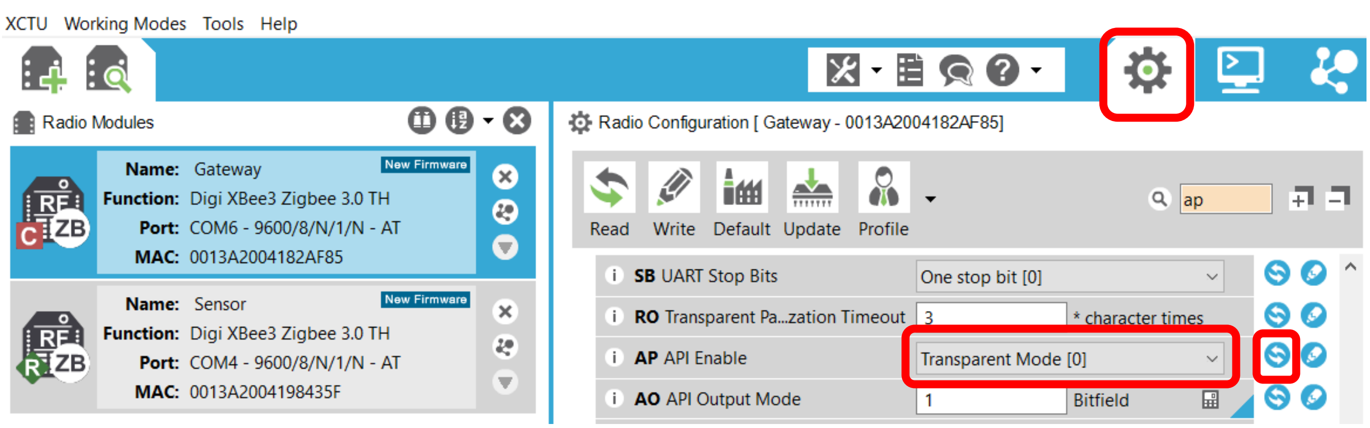
b. Now select **Network working mode** and click **Scan**. You should see the Coordinator appear connected to the sensor. You may try powering down your BeagleBone by pressing the **PWR BTN** B7. After its LEDs turn off, remove the USB cable at J15 and observe the connection disappear. Reconnect J15 and observe the XBee re=connect:



c. Now that you have confirmed the Zigbee connection, **Stop** the scan (otherwise it will continue to run in the background):



d. Select the Configuration working mode, search for **AP** or **ap API Enable and** select **Transparent Mode [0]**. **Write** it to the device:



12. Use PuTTY and log in into the BeagleBone module. Since the PC's USB cable connects through **J15**, the USB RNDIS device network is not available. Connect using **Connection type Serial**, the appropriate **Serial line COM port**, and **Speed** (baud rate**) 115200**.

13. Change directory using **cd** to **LabCode/M3-L5/** with **cd LabCode/M3-L5.** Using **ls** from the command line, verify files **M3_L5_T2_static.c** and **mraa_beaglebone_pinmap.h** are present.

> **NOTE:**
>
> Before you compile and execute the code, inspect it to understand how it works.

14. Using PuTTY, compile the **M3_L5_T2_static.c** file using this command:

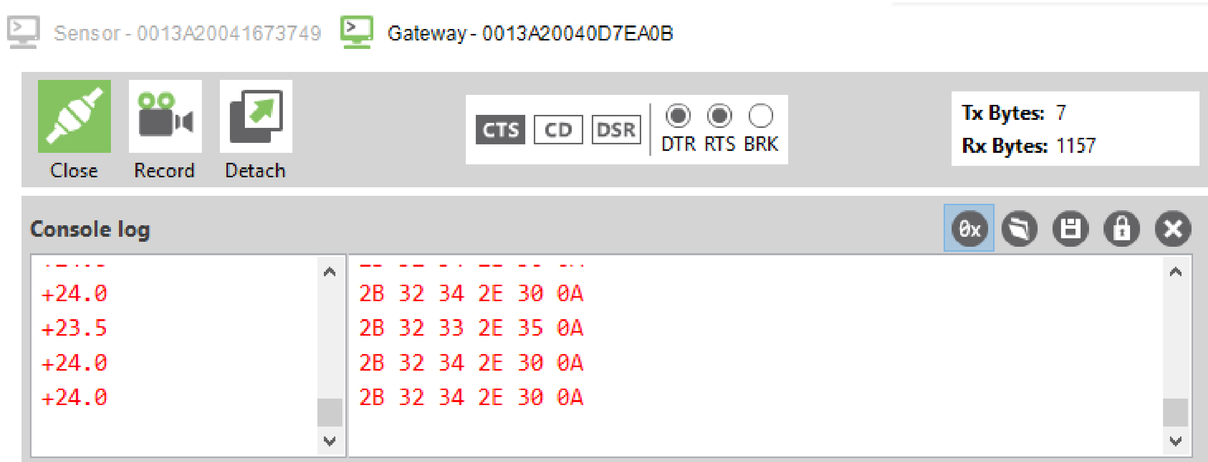
```
gcc M3_L5_T2_static.c -lmraa -o M3_L5_T2_static
```

15. Execute the compiled program using this command followed by the command **exit**:

```
nohup ./M3_L5_T2_static &
exit
```

> **NOTE**
>
> **nohup** and **&** in conjunction with **exit** (logoff) is used to assure that the program continues running after the USB cables are unplugged by ignoring terminal warnings (HangUP) and redirecting the program's output from serial **stdout** to a file named **nohup.out**. The ability to run without the USB is useful when operating from an alternate power source such as a battery. In this mode the program will continue running only if the CPU remains powered—if it powers down, the program will have to be restarted.
>
> It is normal to expect the **nohup** command to return the following message as it indicates that it is being pushed to the background and all the outputs from the command are logged in the **nohup.out** file:
>
> ```
> nohup: ignoring input and appending output to 'nohup.out'
> ```
>
> When you complete this task or wish to change what the CPU is doing, you may end the program running in the background. To show all active processes type **ps -A** or **ps -ef**. **-ef** also shows Parent Processes:
>
> ```
> UID        PID  PPID  C STIME TTY          TIME CMD
> …to save space on the page some processes have been eliminated here…
> root     20982     2  0 16:28 ?        00:00:00 [kworker/u2:0]
> root     20996     2  0 16:48 ?        00:00:00 [kworker/u2:1]
> debian   20997 19202  0 16:48 ttyS0    00:00:00 ./M3_L5_T2_static
> debian   20998 19202  5 16:49 ttyS0    00:00:00 ps -ef
> debian@beaglebone:~/LabCode/M3-L5$
> ```
>
> Find the program, e.g. **./M3_L5_T2_** , using **ps -A | grep M3_L5_T2_** or **ps -ef | grep M3_L5_T2_**). The process **PID** (not the PPID) is **20997**. To kill it, type **kill 20997**:
>
> ```
> debian@beaglebone:~/LabCode/M3-L5$ kill 20997
> debian@beaglebone:~/LabCode/M3-L5$ ps -ef
> UID        PID  PPID  C STIME TTY          TIME CMD
> …to save space on the page some processes have been eliminated here…
> root     20996     2  0 16:48 ?        00:00:00 [kworker/u2:1]
> root     21002     2  0 16:57 ?        00:00:00 [kworker/u2:0]
> debian   21005 19202  0 17:03 ttyS0    00:00:00 ps -ef
> [1]+  Terminated              nohup ./M3_L5_T2_static
> debian@beaglebone:~/LabCode/M3-L5$
> ```
>
> Then, execute **ps -A** again. You see that PID **20997** has terminated and is no longer running.

16. Observe the LCD; it should display a temperature reading from the digital temperature sensor (LM75).
    - The program reads the temperature data from LM75, and then displays and transmits the data to the LCD every one second.
    - Observe the console for the gateway Zigbee; the temperature data will be transmitted from the sensor node Zigbee (Keysight U3810A) to the gateway Zigbee (connected to the PC) every one second.



NOTE

The **M3_L5_T2_static** program is still running in the background. Exiting this session will not end or kill the program.

17. Continue to the next task while **M3_L5_T2_static** program is running in the background.

Task 2 – Measure Battery Drain Current with the DMM

NOTE

Before you begin, please retain your measured results, measurement plots, and analyses in the next two tasks as it will be used in the next lab.

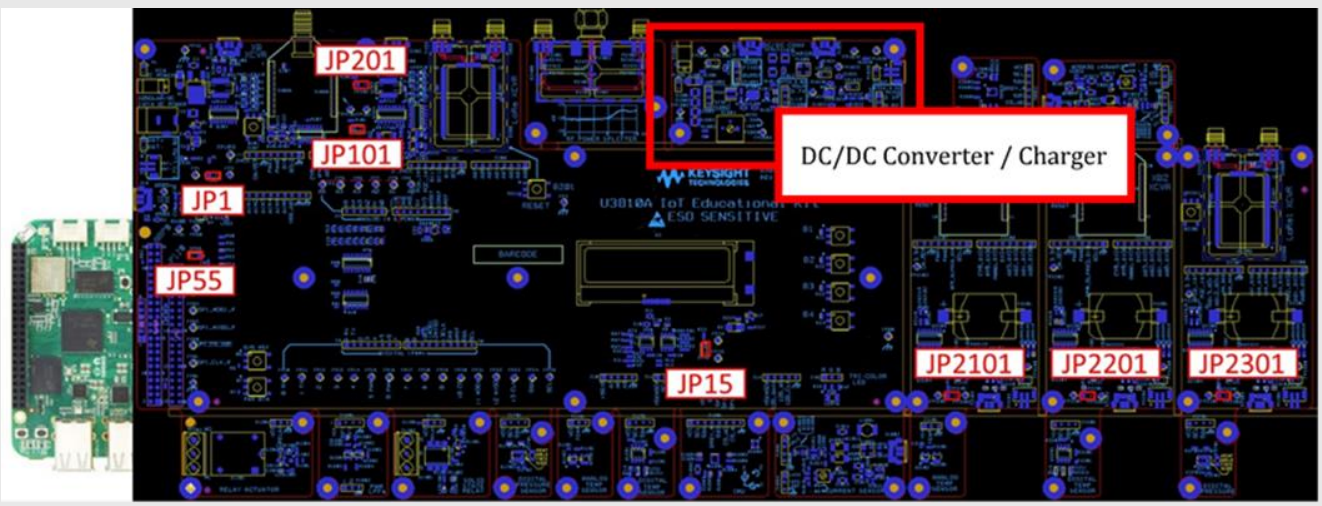
In this task, you will perform a battery drain test with the IoT sensor node (Keysight U3810A). Your battery drain measurement will depend on whether you are connected to a Wi-Fi Access Point. All measurements in this task were performed with Wi-Fi connected. Review **Appendix E – Effect of Wi-Fi Connection on Power Consumption** before beginning this task.

1. Continuing from the previous task, power down the Keysight U3810A by pressing **PWR BTN**, wait for the lights on the BeagleBone to stop flashing and disconnect the USB cables from it.

NOTE

Before you begin the experiment, assure that the Keysight U3810A has its jumpers configured as shown below.

Jumper	JP1	JP15	JP55	JP101	JP201	JP2101	JP2201	JP2301
Name	Input Current	Sensor Current	+5VSYS +5VRAW	XB Current	LoRa Current	XB1 Current	XB2 Current	LoRa1 Current
Position	In place	In place	Removed	In place	In place	In place	In place	In place



The diagram above might appear dark in print outs. Refer to Appendix B – Keysight U3810A Technical Documents for the searchable PDF to help you locate the locations of the jumpers, connectors and components.

*DCDC Converter / Charger Board jumpers are not relevant in this task but will be discussed in a later task in this lab.

WARNING Verify your LiPo battery polarity visually with the DMM before connecting it. These images show correct polarity.

NOTE

Although both 3.7 and 9 V batteries are supported, only 3.7 V battery results will be provided.

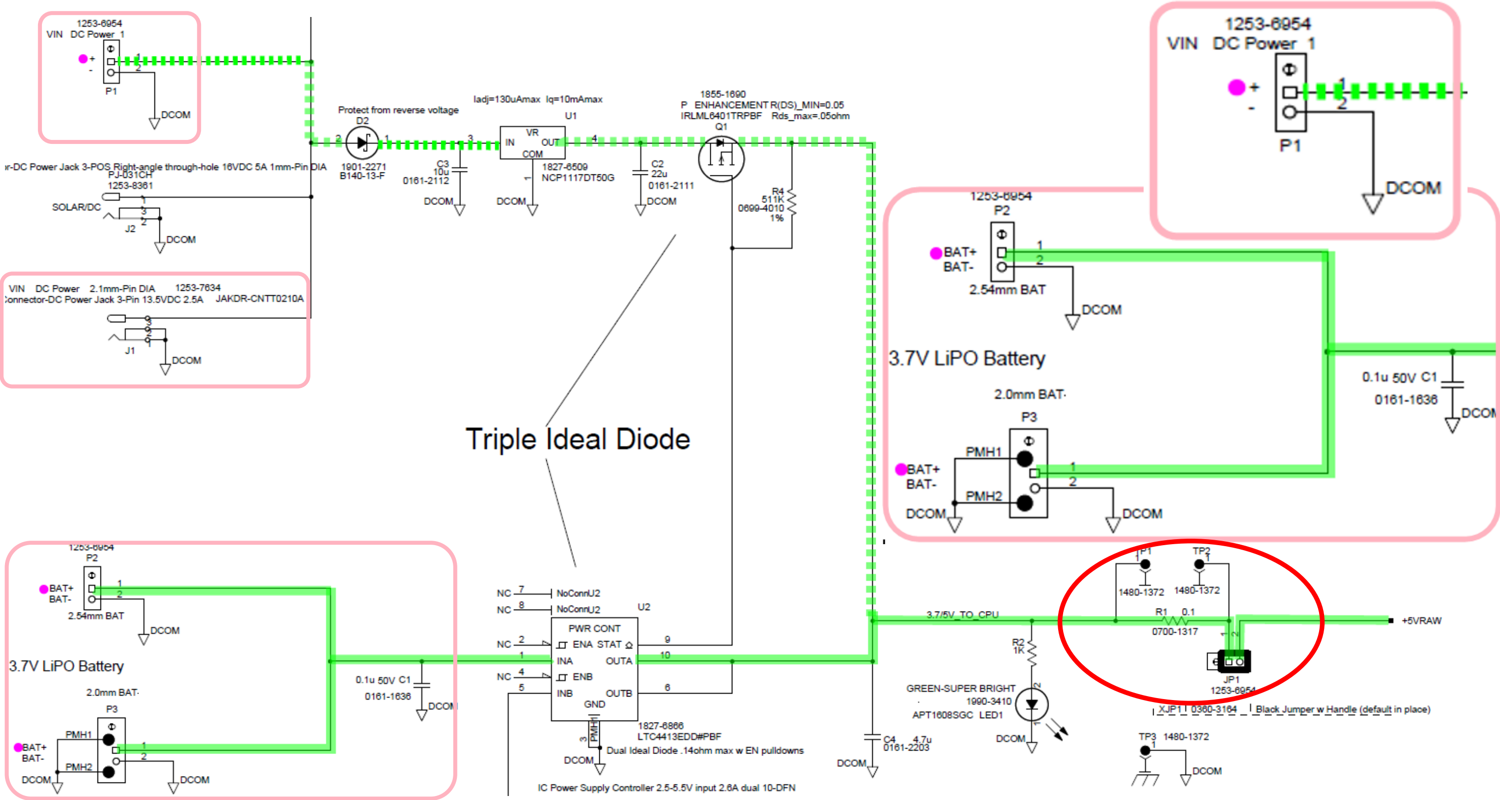
When connecting a **3.7V LiPo Battery** to **P2** or **P3**, **JP55** must be **in place** so that the BeagleBone PMIC (Power Management Integrated Circuit) will allow bootup. In all other cases **JP55** should be removed.

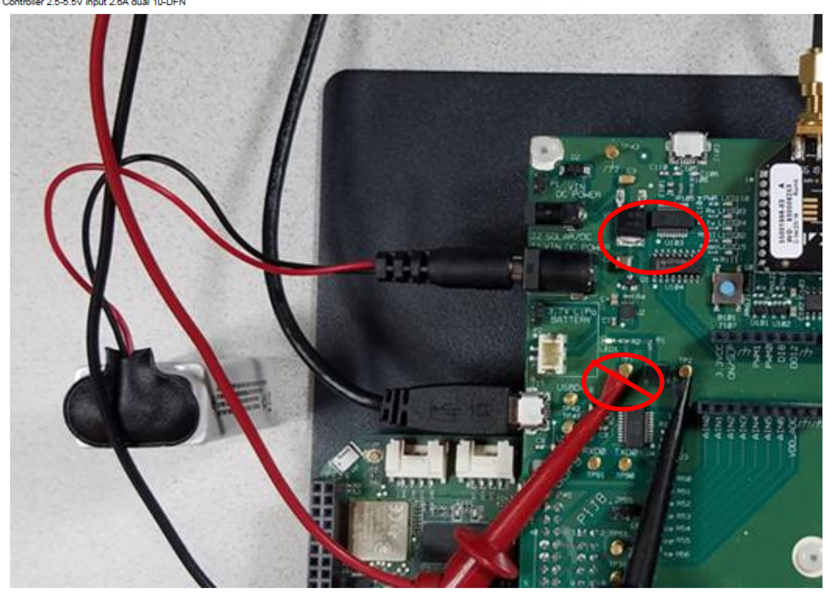
NOTE

The Triple Input Ideal Diode circuit shown below allows one of 3 sources to power the U3810A:

1. The VIN Connector Power has top priority, so be careful to not leave a 9 V Battery connected to it for too long, lest you discharge it.
2. The **3.7V LiPo Battery** Power shares the next priority with…
3. …the USB Power, although USB Power at 5 V will typically override the **3.7 to 4.2 V LiPo Battery**.

2. Connect the circuit shown below (in the circuit diagram of the Keysight U3810A input power supply) to the Keysight U3810A, including the USB connection to J15 and only one battery (a. or b., not both):
   a. **[3.7V LiPo Battery]** Connect **BAT+** to the (**+**) terminal of the **3.7 V LiPo Battery** to **P2** or **P3** ● and **BAT-** to the (**-**) terminal of the battery. If your LiPo battery has a standard 2 mm JST connector, you may plug it into directly into **P3**. **or**
   b. **[9V NiMH Battery]** The 9V rechargeable battery may be connected to **J1** or **P1** ●, but when connected will constantly power the U3810A, overriding even the USB Power. Do not leave the **9 V NiMH Battery** connected any longer than necessary.
   c. **[Solar Panel]** A **Solar Panel** may be connected to **J1** or **P1** ● (see next lab)
   d. Connect the (+) terminal of the DMM to **TP1**, one side of the 0.1-ohm shunt resistor on the U3810A.
   e. Connect the (-) terminal of the DMM to **TP2**, the other side of the shunt resistor.

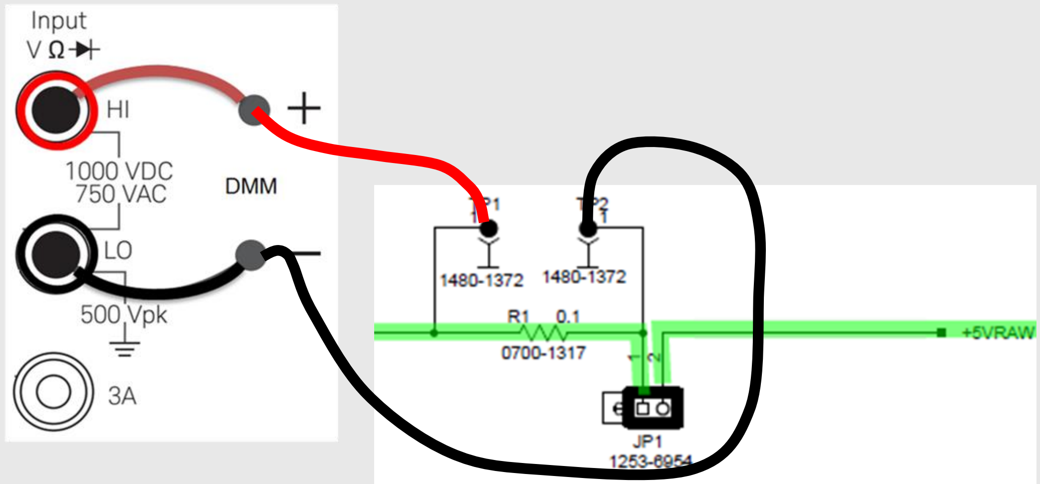




NOTE

The display may not fully light when using a 3.7VLiPo battery, or any battery producing less than 4.3V.

NOTE



As you learned in the prior lab, there are two options for current measurement and the two have different burden voltages due to current measurement resistor R1 or the DCI function and lead wires. Assuming 200 mA:

V = IR = .2A (.1Ω resistor R1) = 20mV for static current, and higher for peak currents, **<u>or</u>**
V = IR = .2A (.05Ωdmm + .1Ωleadwires) = 30mV for static current, and higher for peak currents [1]

For this lab, you will use the former, voltage across R1, since it provides lower burden voltage.

The battery is now connected in series with the Device Under Test (DUT) and the current sense resistor.

3. **[3.7V LiPo Battery] JP55** may need to be removed and re-installed to get the Beaglebone CPU to power up using a 3.7V battery.

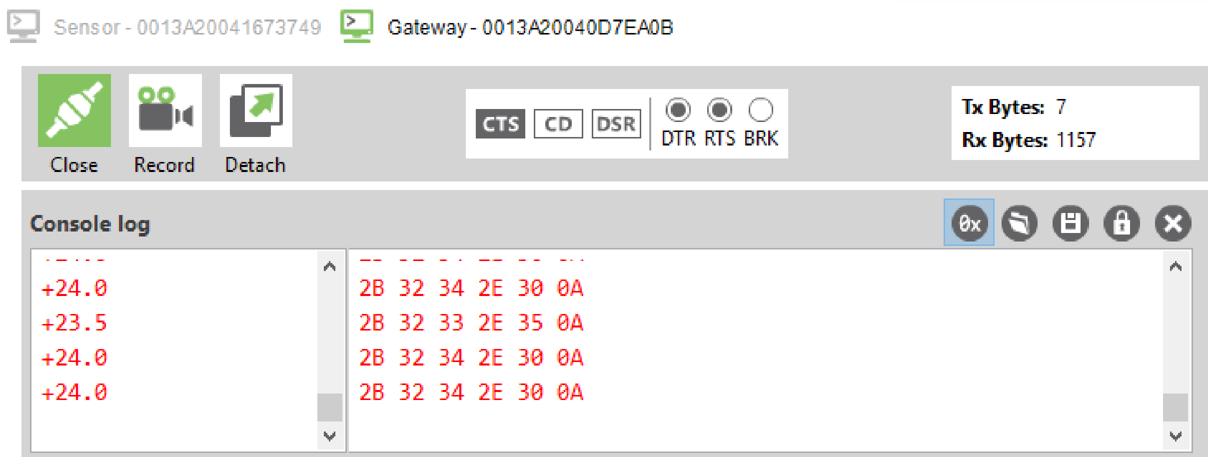
   [9V NiMH] JP55 should not be installed in any case other than using the 3.7 V LiPo battery.

4. Using PuTTY and a serial port connection through J15, execute the compiled program using this command followed by the command **exit** which takes you to logout. You will then be prompted to login, which you can ignore since the program is still running in the background:

   ```
   nohup ./M3_L5_T2_static &
   exit
   ```

   `logout . . . login:` (You can ignore this and proceed to the next step)

5. Observe the LCD; it should display a temperature reading from the digital temperature sensor (LM75) and the console for the gateway Zigbee should receive the temperature reading.
   – The program reads the temperature data from LM75 every 100 ms, and then display and transmits the data to the LCD every one second.
   – Connect a USB cable between the PC and the Gateway XBee (XB1). The XCTU to Gateway XBee serial port configuration should still be defined. Observe the console for the gateway Zigbee; the temperature data will be transmitted from the sensor node Zigbee (Keysight U3810A) to the gateway Zigbee (connected to the PC) every 100 ms.



NOTE

The **M3_L5_T2_static** program is still running in the background. Exiting this session will not end or kill the program.

6. Turn on the DMM (Keysight 34465A) and select **"DCV"** to measure the voltage drop across the shunt resistor. You should see the readings of the measured voltage. To obtain the current across, use the formula below to set the Math function of the DMM:

   $I = V / R = V / 0.1\ \Omega$

   The Keysight 34465A DMM can be configured to calculate the current across the shunt resistor in real time based on the measured voltage.

   Question: What is the accuracy of this measurement?

NOTE

By default, the per voltmeter reading integration time or NPLC setting (Shift > DCV > Aperture) is set to 10 whenever the DMM is powered up. NPLC and Aperture set the DMM's integration time and the longer the integration, the more the DMM can reject power line and other noise. However, a shorter integration will allow the DMM to better capture short spikes when precise amplitude of the spike is to be measured.

7. Press **Shift** button then **Math** button.
8. Press **Scaling** button then press **Scaling** button to toggle the scaling function to **On**.
9. Press **Function** then press **Mx-B**.

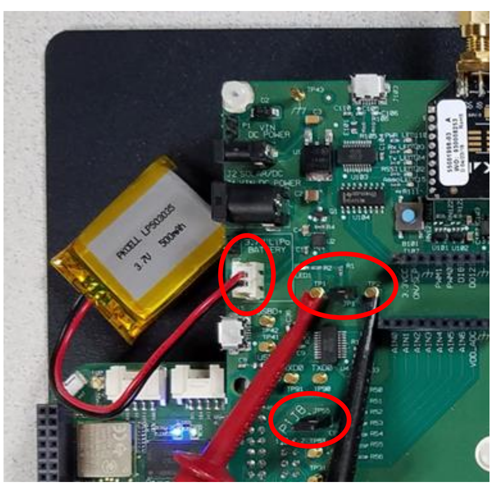
10. Adjust the gain to 10. The value of 10 is the reciprocal of 0.1 Ω (1/0.1) to be multiplied by the measured voltage.
11. Press **User Units** button then press **User Units** button to toggle it to **On**.
12. Press **Enter Units** button and set **A** as the user units.
13. Press **Done** button all the way back to apply the math function. Now you should be able to see the real time calculated current value across the shunt resistor.
14. Select **“Display” > Display > Trend Chart** to view the waveform of the measured voltage.
15. Select **“Acquire” > Acquire > Data Log**, and set **Sample Interval** to **1 sec**.
16. Turn on **Math > Statistics** on the DMM, change **Duration** to **1:30:00** (1 hour 30 min).

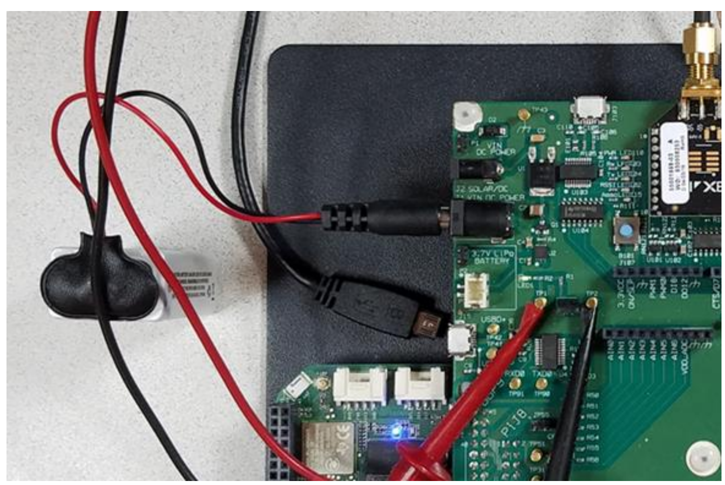
NOTE

By default, upon power up of the DMM, the NPLC is set to value of 10. Changing the sample interval of the Data Log mode will also change the NPLC value. Lower sample interval will need the NPLC to be lower for faster measurement. You can check the NPLC value after power up and check it again after you have decreased the sample interval of Data Log mode (**DCV → Aperture**).

17. Check if the Keysight U3810A is still transmitting data to the gateway (via XCTU on the PC) before we proceed to the next step.
18. Press the **“Run/Stop”** button to start DMM data logging. Note: Logged data is not shown on the display until data logging is completed. Wait and watch for a minute so that you can record the present current consumption on the graph—the 3.7 V Battery will not be discharged during this minute.
19. **Now disconnect the USB cable** to the Keysight U3810A **J15** to allow the Sensor to function on power supplied from the Battery (If a Battery is not available, the **DCPA** may be substituted in place of the **9V NiMH**. If you use the **DCPA**, slowly reduce its voltage over a period of 5 minutes until the system shuts down. Follow **9V NiMH** instructions below):

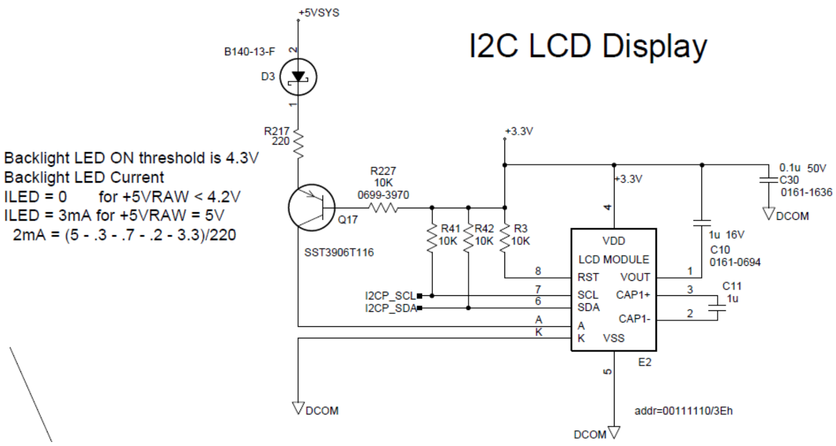
3.7 V LiPo showing USB disconnected: <u>**or**</u> **9 V NiMH** showing USB disconnected:



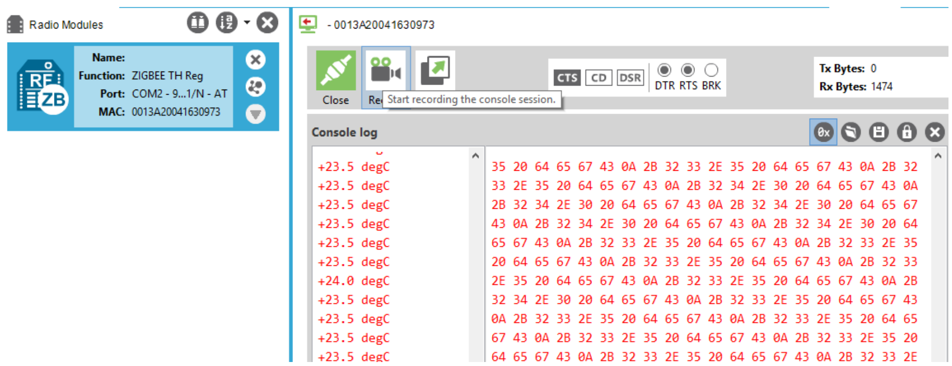


NOTE

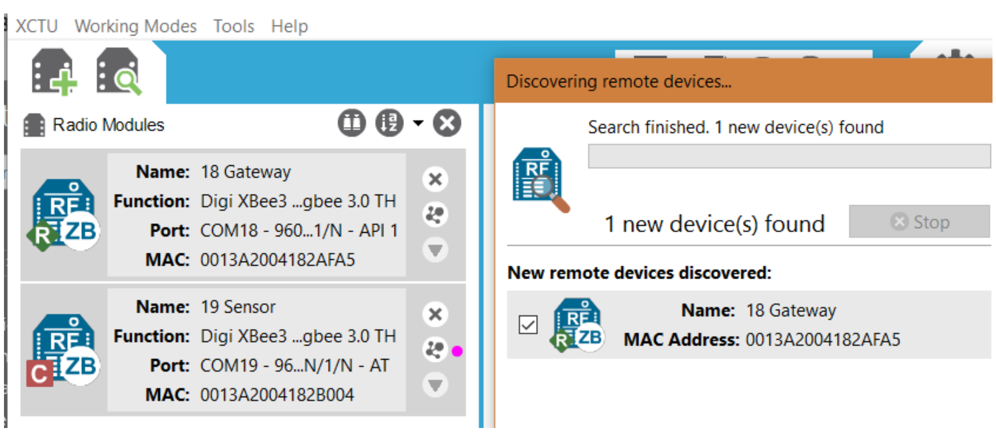
The circuit to the right here is designed to minimize current draw by shutting off the display backlight when using a **3.7V LiPo battery**, or any battery producing less than 4.3V at +5VRAW.



20. Verify that your **XB1** Gateway is still receiving DIGITAL TEMP SENSOR data from the U3810A Beaglebone CPU transmitted via the XB circuit.



If not, check that the Zigbee network is still connected. If not, repeat the procedure from the prior step to reconnect.



21. With the USB cable disconnected from the Keysight U3810A at **J15**, the sensor node (Keysight U3810A) is fully powered by the battery. While waiting for data logging to complete, occasionally verify that the Keysight U3810A is still transmitting data to the gateway.

22. During data logging, try setting your DMM's **Vertical Scale** to display values from **200mA** to **400mA**. Optional: Using a second DMM (or the DCPA's V_{AUX} DVM), perform the BeagleBone voltage measurement in step 24 simultaneously.

    Data logging should not be stopped until after BeagleBone CPU shutdown. It will be most convenient (but not required) for Average measurement in Statistics for you to stop data logging as soon as possible after shutdown.

3.7 V 400 mAhour Measurement Result using DMM and R1

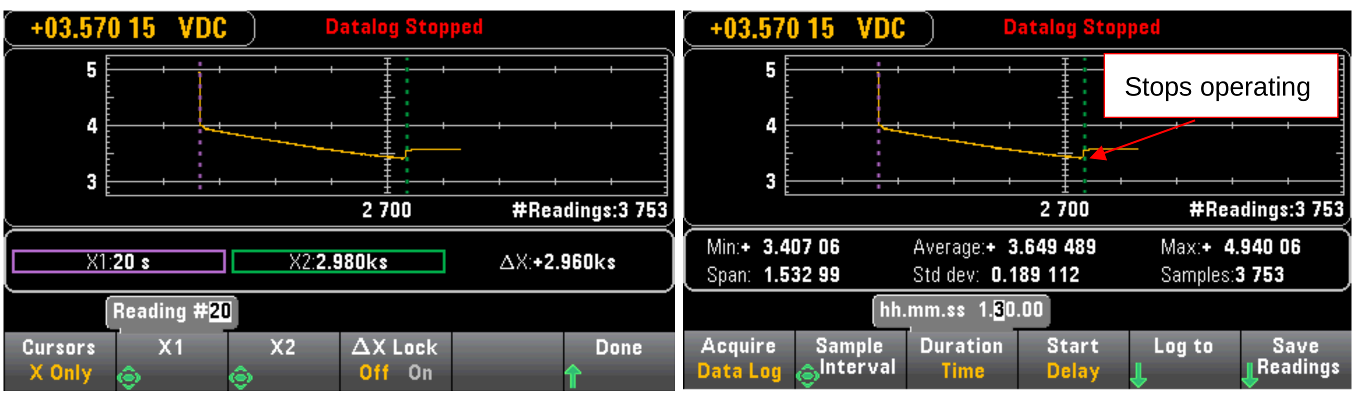
Here is an example with the 3.7 V 400 mAhour LiPo Battery. Data logging was stopped immediately after the BeagleBone CPU stopped. Note that there is no continuing yellow trend line (**red** circle in left screen) that would decrease the average current value displayed using **Math > Statistics**.

The 3.7 V 400 mAhour LiPo Battery, Wi-Fi connected – the left screen shows Cursers, right shows Statistics.

23. Use the Cursors to measure operating time and compute the charge in Coulombs consumed from the Battery. Select **"Display" > Cursors > Cursors > X Only**, and then select X1 or X2 cursor. After selecting the cursor, move the cursor using the directional buttons under the "Display" button. Calculate the charge consumed:

    ΔX = 3020samples/60samples/min = 50 min 20sec
    $Q = I_{ave} \times T$ = 302 mA x 3020 sec = 912 C

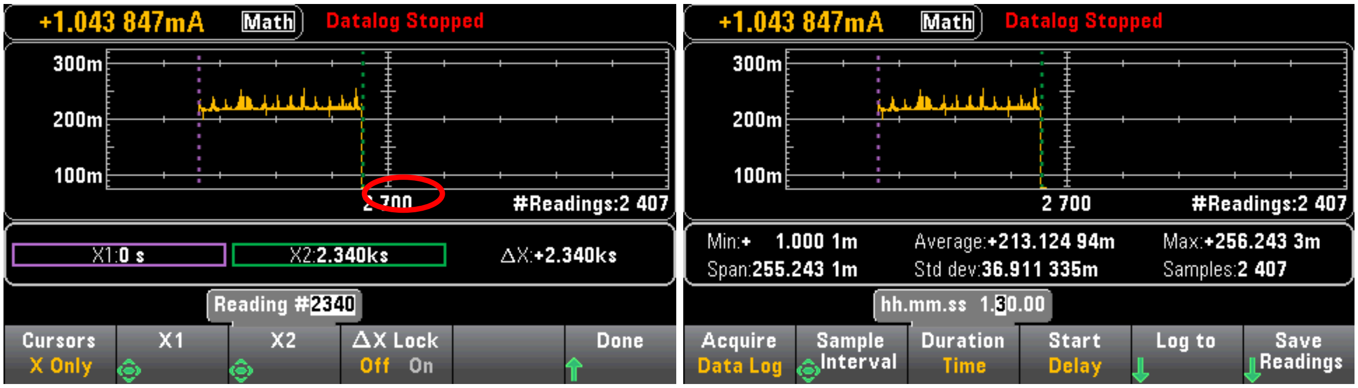
24. If using a second DMM (or the DCPA's V_{AUX} DVM) perform a simultaneous BeagleBone voltage measurement from **TP51** to **DCOM** to show the battery discharge and the voltage at which the BeagleBone CPU shuts down.



Note in the Statistics on the right screen: the starting voltage before the USB power is removed **Max 4.94 V** and the shutdown voltage when the battery current drops to zero **Min 3.407 V**. When the BeagleBone PMIC (Power Management Integrated Circuit) senses the voltage has fallen too low for operation, it shuts down the CPU. When the load current from the CPU is removed from the battery, its voltage recovers, increasing slightly.

9 V 200 mAhour Measurement Result using DMM and R1

Here is an example with the 9 V 200 mAhour NiMH Battery and **JP55 removed**. Data logging was stopped after the BeagleBone CPU stopped. Note that there is a small continuing yellow trend line (**red** circle in left screen) that suggests that the average current value displayed using **Math > Statistics** will not represent the average during operation:



The 9 V 200 mAhour NiMH Battery, Wi-Fi connected—the left screen shows Cursers, right shows Statistics

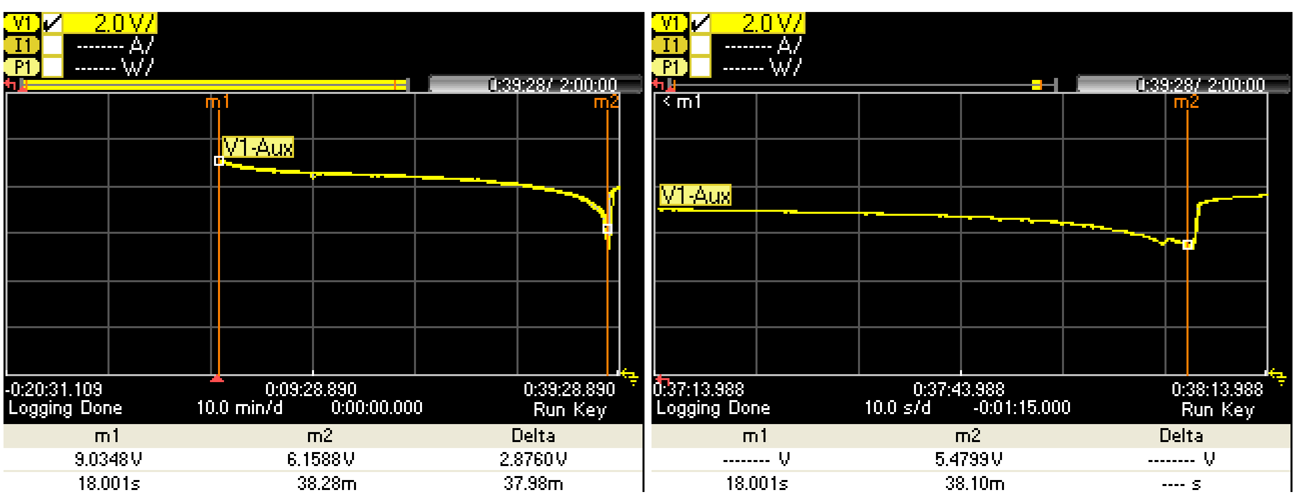
Use the Cursors to measure operating time and compute the charge in Coulombs consumed from the Battery.

Select **"Display" > Cursors > Cursors > X Only**, and then select X1 or X2 cursor. After selecting the cursor, move the cursor using the directional buttons under the "Display" button. Calculate the charge consumed:

ΔX = 2340samples/60samples/min = 39 min
Q = I_{ave} x T = 220 mA x 2340 sec = 515 C, using the "eyeballed" average operating current
Q = I_{ave} x T = 213 mA x 2407 sec = 513 C, using the statistical average of the total samples in statistics

Note that both calculations yield similar results, and that charge consumed is approximately half that of the higher capacity LiPo Battery.

If available, use a second DMM (in this case the DCPA's V_{AUX} DVM is shown here) to perform a simultaneous BeagleBone voltage measurement from **TP51** to **DCOM** to show the battery discharge and the voltage at which the BeagleBone CPU shuts down.



Note in the Markers: the starting voltage **9.0348 V** and the shutdown voltage when the battery current drops to zero **5.4799 V**.

Battery Drain Summary using DMM and R1

The following can be observed from the above screenshots when current is measured as the voltage across R1 by the DMM. Your battery drain measurement will depend on whether you are connected to a Wi-Fi Access Point. All measurements in this task were performed with Wi-Fi connected (see Appendix E for additional measurement results with Wi-Fi disconnected):

- When powered by a 3.7 V LiPo Battery the initial state of the Keysight U3810A requires less current, approximately 220mA. After a few minutes it increases to 300 mA as Wi-Fi operation stabilizes.
- With Wi-Fi disconnected from an access point, every 30 seconds the Wi-Fi radio is powered on for a scan. With Wi-Fi connected the radio remains on.
- The BeagleBone and U3810 circuits consume about 1.1 W of power or 300 mA using a **3.7 V LiPo** Battery. This energy is used to power all the modules in the sensor node (CPU, Zigbee module, LM75 sensor and other ICs and components on the board).
- The BeagleBone and U3810 circuits consume about 2 W of power or 220 mA using a **9 V NiMH** Battery.
- The voltage level on **TP51** (**+5VRAW**) is slowly decreasing. When **+5VRAW** drops below approximately **3.4 V** the Keysight U3810A will stop functioning.
- The voltage level on the 9 V NiMH Battery is slowly decreasing, but the voltage at **5VRAW** is regulated and remains at +5 V until the 9 V NiMH Battery's voltage decreases to the point that it cannot keep U1 in regulation. When the 9 V NiMH Battery's voltage drops below approximately **5.48 V** the Keysight U3810A will stop functioning.
- The current delivered by the battery increases as its voltage decreases, since the power consumed by the circuits remain the same so the input current must increase to maintain the same P = VI product.
- For the 3.7 V 400 mAH LiPo Battery a calculation shows it would take about 80 minutes (400 mAH/300mA) to drain to completely. However, the sensor node will stop functioning before the battery is fully drained because the CPU's input circuit requires a minimum voltage to maintain proper operation. The actual operating life was measured to be 50 min. Wi-Fi was connected to an access point (see Appendix E for the measurement)
- For the 9 V 200 mAH LiPo Battery a calculation shows it would take about 60 minutes (200 mAH/200mA) to drain to completely. The actual operating life was measured to be 38 min.

You will see how the DCPA can improve these measurements in the next task.

Question: Why is the U3810A operating current higher with the 3.7 V than with 9 V Battery?

NOTE

Recharge your battery for use in the next task. Appendix C provides charging procedures using USB power and the DC-to-DC Converter / Charger Circuit.

The batteries may also be charged with a 15mA "trickle charge" for 10 hours (I_{charge} < Capacity in A-hours/10).

Task 3 – Measure Battery Drain Current, Voltage and Power with the DCPA

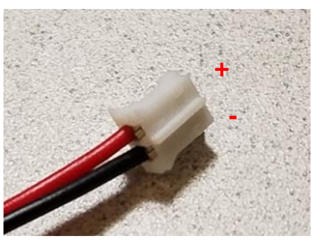
You will now perform a battery drain test using the DCPA. Improved over the single measurement DMM, the DCPA can simultaneously perform I (current), V (voltage), P (power) measurements with zero burden voltage.

1. Continue from Task 2 above, turn on the Keysight N6705C DC Power Analyzer, with **XJP1 in place.**
2. After power up, login in and run the previous program. You may find it convenient to click the **up arrow** (**Λ**) on your keyboard three times to recall the three necessary commands:

```
debian@beaglebone:~$ cd LabCode/M3-L5
debian@beaglebone:~/LabCode/M3-L5$ nohup ./M3_L5_T2_static &
[1] 886
debian@beaglebone:~/LabCode/M3-L5$ nohup: ignoring input and appending output to
'nohup.out'
exit
logout

Debian GNU/Linux 9 beaglebone ttyS0
BeagleBoard.org Debian Image 2020-03-09
Keysight U3810A Image Version 3.69 Mar 9th 2020
Support/FAQ: http://elinux.org/Beagleboard:BeagleBoneBlack_Debian
default username: password is [debian:temppwd]

beaglebone login:
```

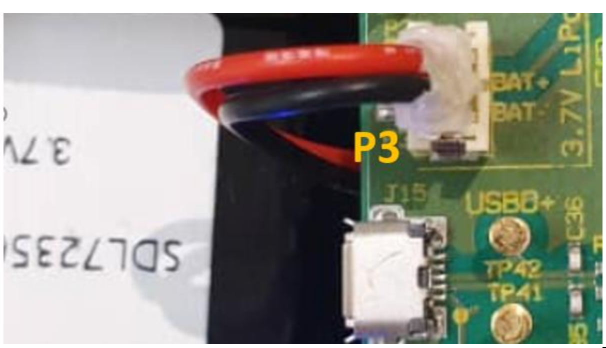
(You can ignore this and proceed to the next step)

WARNING Verify your LiPo battery polarity visually with the DMM before connecting it. These images show correct polarity.

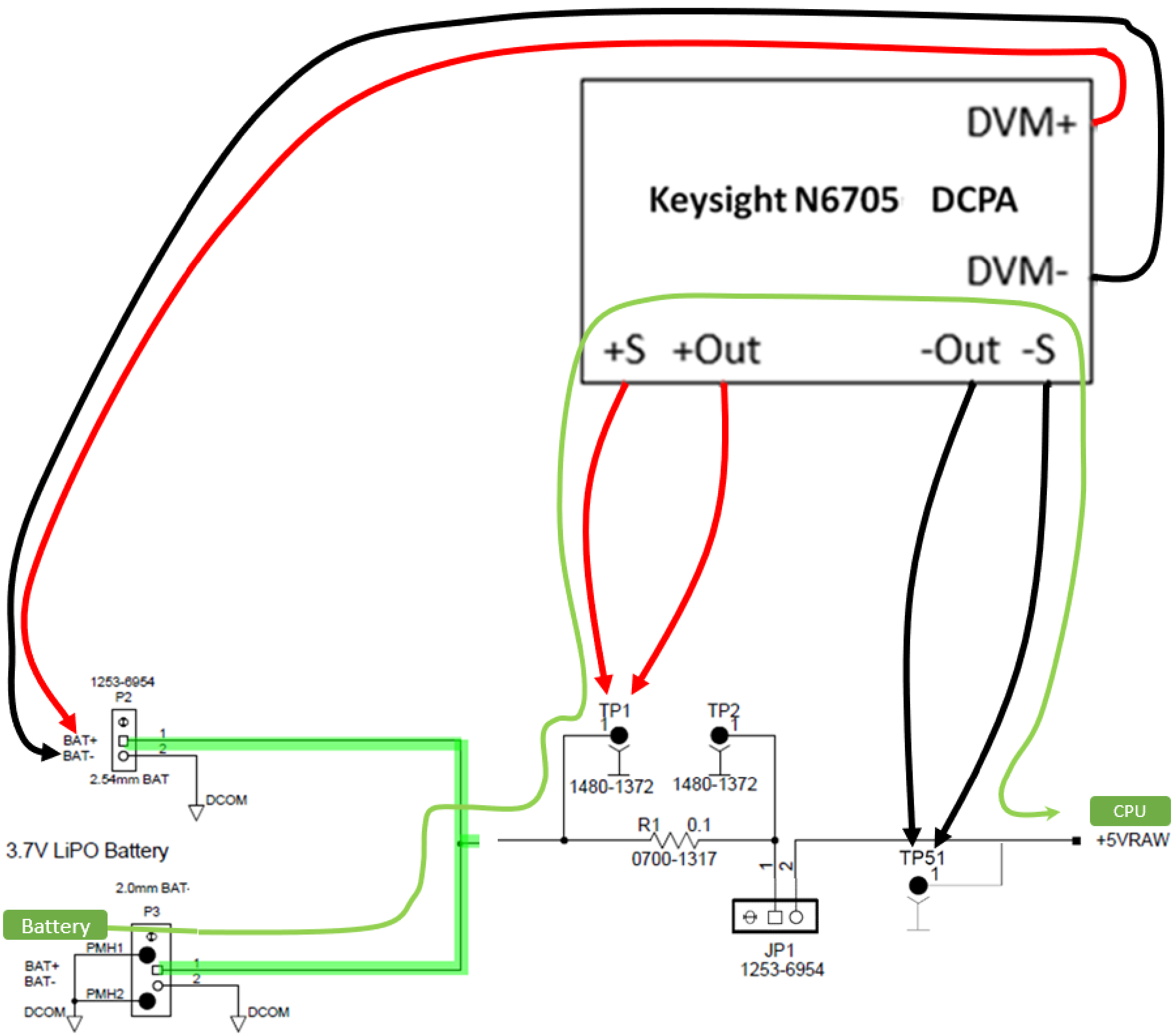


3. Assure the battery connection shown in either a. **or** b. (not both), if appropriate, retained form the previous task:

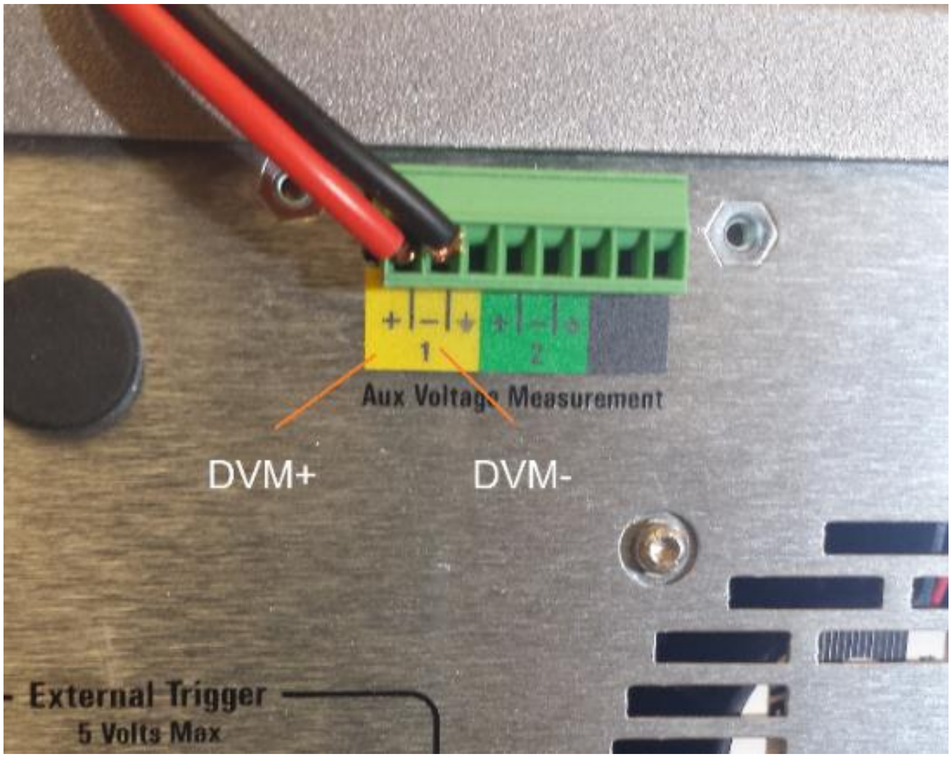
a. 3.7 V 499 mAhour LiPo Battery **or** b. 9 V 200 mAhour NiMH Battery



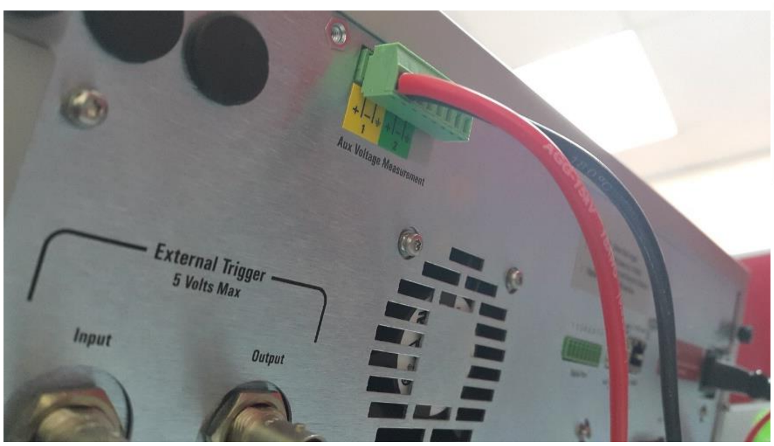
4. Reconfigure the test probe connection to the circuit shown below to the Keysight U3810A:
   a. Connect the (**+**) terminal of the DCPA's **Aux DVM+** to **BAT+** at **P2**, the (+) terminal of the battery. You will find **BAT+** and **BAT-** on the PC Board (see below) and on the schematic.
   b. Connect the (**-**) terminal of the DCPA's **Aux DVM-** to **BAT-** at **P2**, the (-) terminal of the battery, or **DCOM**.
   c. Connect **+S** (sense) and **+Out** of the **DCPA** in parallel to **TP1**.
   d. Connect **-S** (sense) and **-Out** of the **DCPA** in parallel to **TP51**.

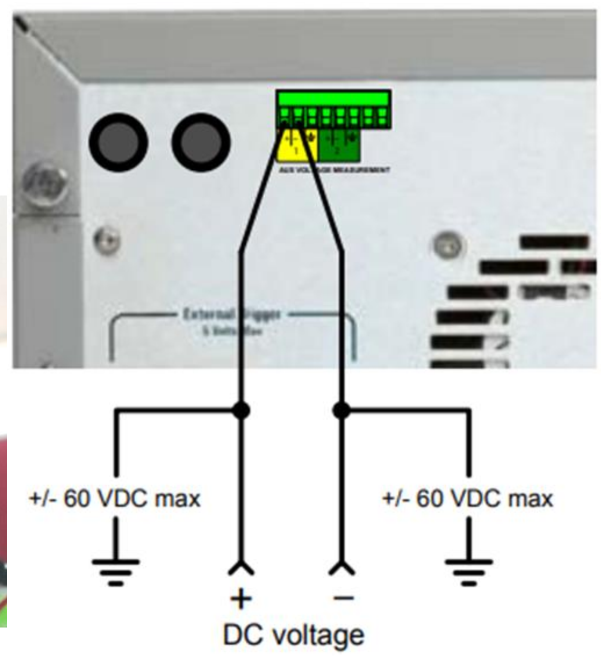


Back panel of DCPA



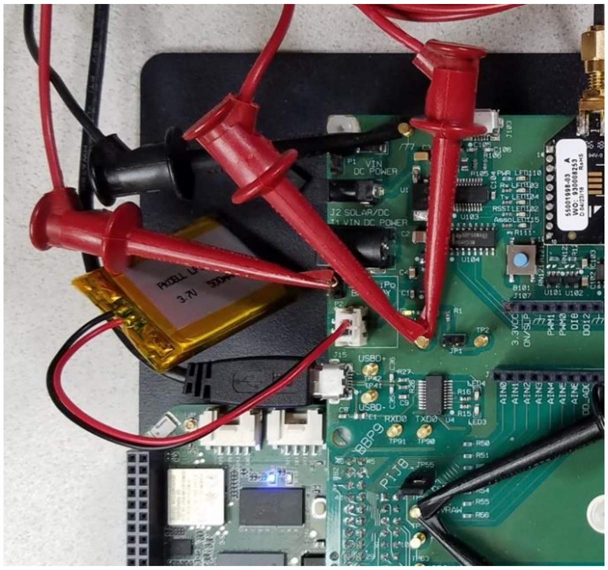
The Aux DVM has a bandwidth of about 2 kHz.
There is one input range: −20 to +20 VDC.

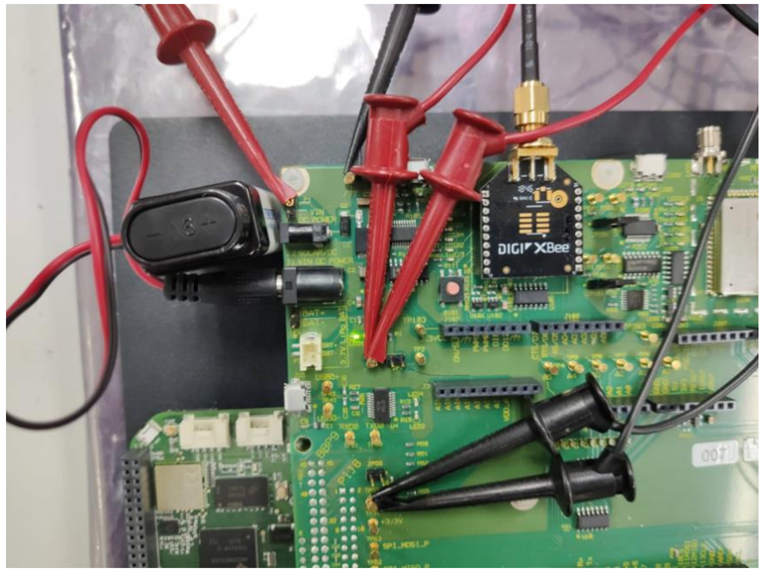




The 3.7 V LiPo connection and an alternate connection if you use a 9 V NiMH Battery are provided here.

3.7 V LiPo Connection showing USB connected: **or** **9 V NiMH** Connection showing USB discconnected:

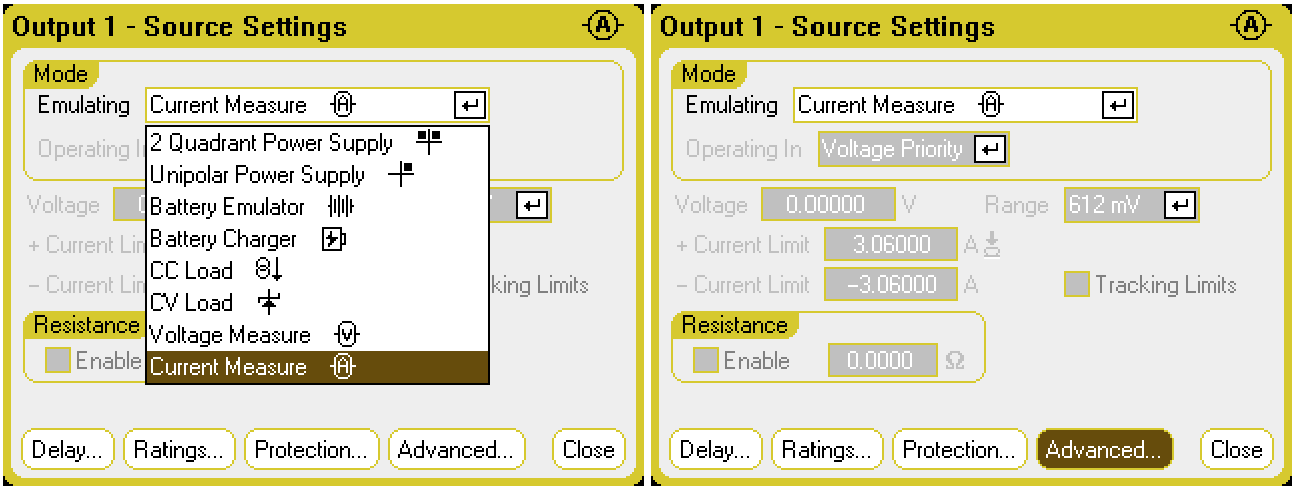




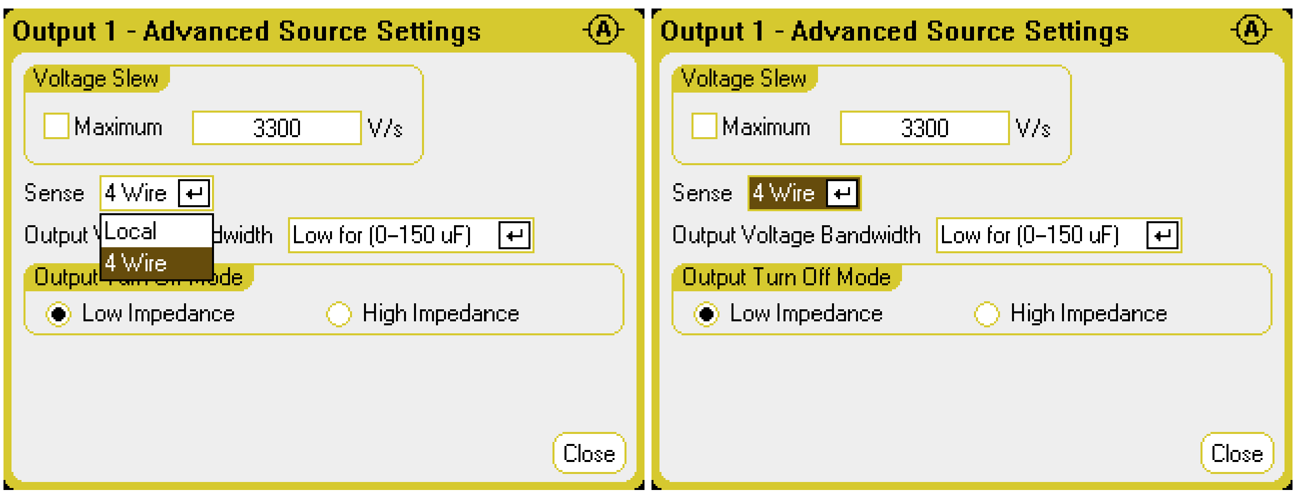
NOTE

Do not remove Jumper **XJP1** yet. First the DCPA's SMU (Source Measurement Unit) must be configured and enabled.

5. Configure the Keysight N6781A SMU in the DCPA to **Setting** □ **Current Measure,** then press the **Enter** button.



6. Now select **Advanced…** (above right screen) and below in **Advanced Source Settings** select **Sense > 4-Wire,** then press **Enter**. In this mode the sense terminals will actively drive the voltage from **+** to **–** to *zero*. This is how zero burden voltage is achieved with the DCPA. You can check this with you DMM later.



7. Verify that the **4-wire** LED is now on. At this point, do not turn on the DCPA Output yet.

NOTE

Using this connection of the DCPA, there is *zero burden voltage*, an improvement over the measurement using the DMM where the burden voltage due to current measurement resistor or the DCI function and lead wires was

V = IR = .2A (.1Ωresistor) = 20mV for static current, and higher for peak currents

V = IR = .2A (.05Ωdmm + .1Ωleadwires) = 30mV for static current, and higher for peak currents [1]

8. Once the configuration is complete double check the connections.

   The battery is now connected in series with the Device Under Test (DUT) and the sense lines of the SMU, eliminating the burden voltage associated with a sense resistor and measurement lead wires.

9. Now press **On** to turn the **DCPA** Output 1 **On**. Press **Meter View**: You should see only partial current flowing because XJP1 is still in place (please see the screen below on the left).

10. Remove Jumper **XJP1** to enable the current path shown in the above schematic in the curvy green line of the connection diagram. All the current is now flowing through the DCPA and no longer split with the XJP1 path. The DCPA now measures current delivered by the 3.7 V LiPo Battery.

11. With your DMM, verify that the voltage form **TP1** to **TP51** is near zero (**+/-** the N6781A spec of 2.5 mV).

NOTE

Since the DCPA is a power supply, positive current is defined as flowing out of the instrument's **+** terminal, so the **Current Measure** result is negative. This is the opposite of the DMM.

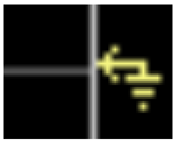
12. Remove the USB cable at **J15**. The U3810A is now running on battery power:

NOTE

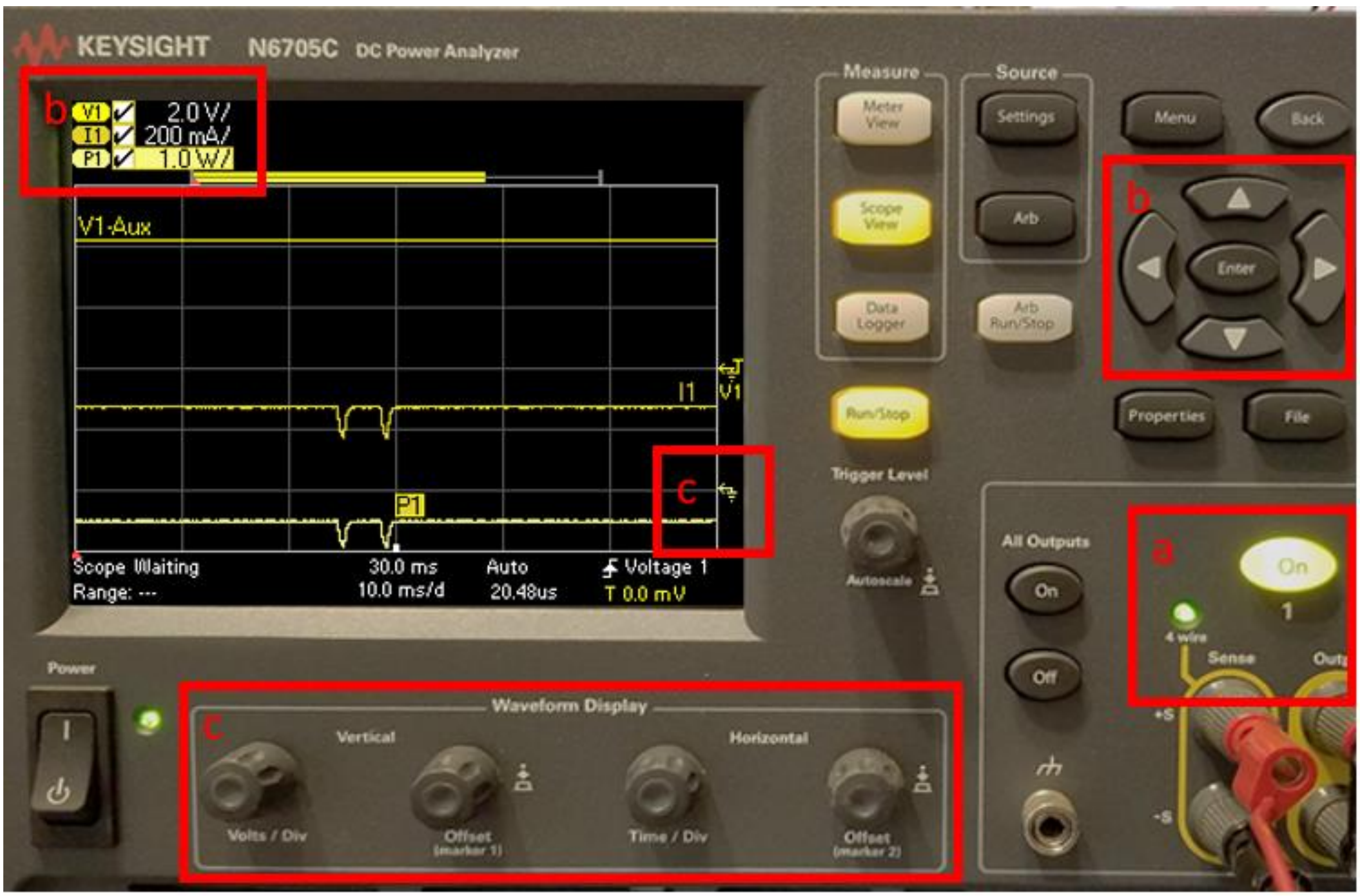
Since you are still running the program using the "**nohup**" and "**&**" option, the program should continue running the in the background after you exit the SSH session or clicking the "**X**" to terminate the PuTTY window.

A sample configuration and Meter View showing mid-cycle operating current (USB cable removed at the computer).

13. Change the view to **Scope View** by pressing that button.
14. In Scope View, you can see the waveforms of voltage, current, and power (watt).
    a. You can enable/disable the Output via the front panel button and observe 4-wire sense mode
    b. Enable/disable the voltage, current, and power measurement in the display via the navigation panel
    c. Adjust the viewing range of each measurement via the **Volts/div** and **Offset** knob. Use the up/down arrows to select the trace **V1**, **I1** or **P1** and then the Volts/Div knob to adjust vertical scale for Volts, Amps, or Watts. Use the Offset knob to adjust the offset, noting the zero value will be marked by a left-facing arrow and ground symbol on the right vertical axis:

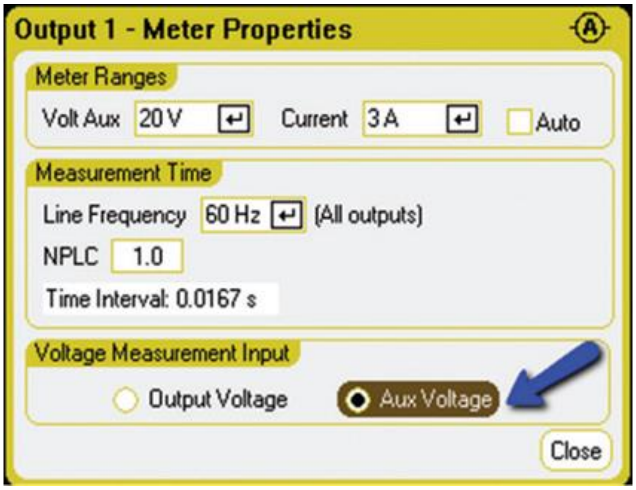


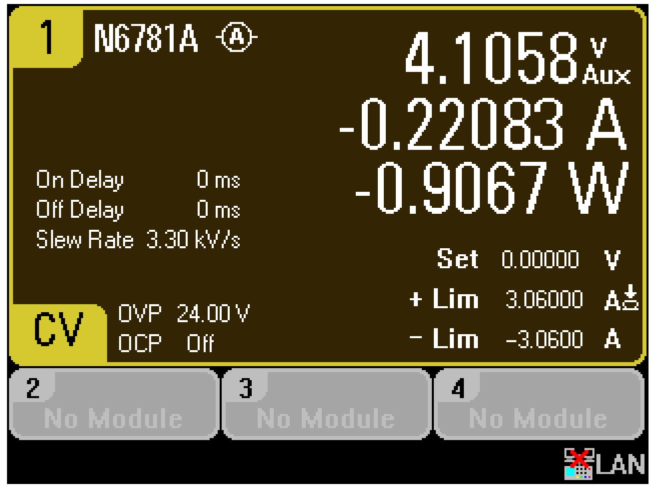
To adjust the time range, use the **Time/div** knob.



15. The Scope View let you see the current consumption of the Keysight U3810A under operation. However, the battery voltage is not shown. This can be enabled through the **Auxiliary Voltmeter** function.
16. Now switch to **Meter View**, and then press the **Properties** button (see left screen below).

17. Enable the **Aux Voltage** option and then **Close**. In either Meter View or Scope View and you should be able to see the battery voltage (right screen):

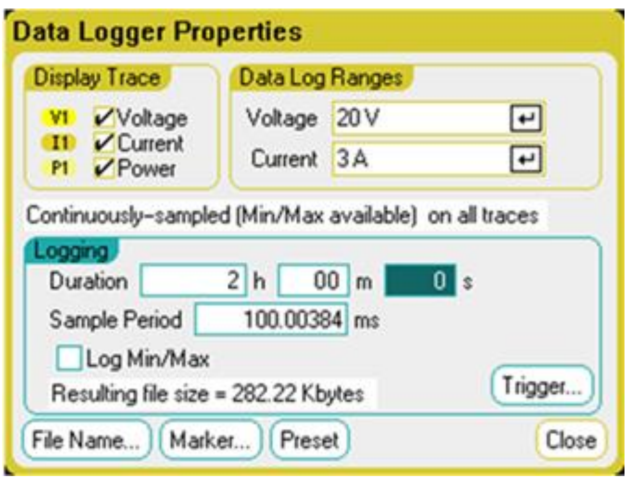




You should begin with 4.1 V - 4.2 V for a fully charged 3.7 V LiPo or 8.7 - 9.2 V for 9 V NiMH.

18. Verify in XCTU that the Keysight U3810A is still transmitting data to the gateway before you proceed.
19. Use the Data Logger to log the battery drain profile. Adjust the position of Voltage, Current, and Power measurement so they can be viewed correctly. You can use the Autoscale function on the DC Power Analyzer.

    Press the button for **Data Logger** mode, and then press the **Properties** button to change the logging **Duration** to **2:00:00** and the **Sample Period** to **100 ms**.



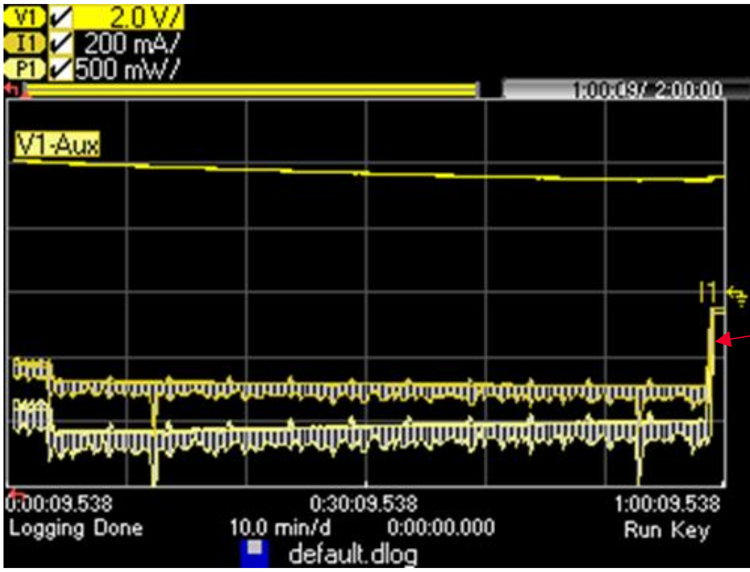
20. Ensure the USB cable is disconnected at **J15**. Now, the Keysight U3810A is fully powered by the **3.7 V LiPo** (or **9 V NiMH**) **Battery**. Again, check if the Keysight U3810A is still transmitting data to the gateway.
21. Press the **Run/Stop** button to start the data logging. You can zoom the vertical and horizontal controls during the data logging and press **Run/Stop** a second time to stop data logging when the Sensor Node stops functioning.

NOTE

Reconnecting USB to **J15** will reconnect "external" power to the U3810A and allowing the battery to stop providing current and hence its voltage may slightly increase, undesirable in your results

3.7 V 400 mAhour Measurement Result using DCPA

Here is an example for the 400mAH 3.7 V LiPo Battery, Wi-Fi Connected, **XJP55 is in place**.

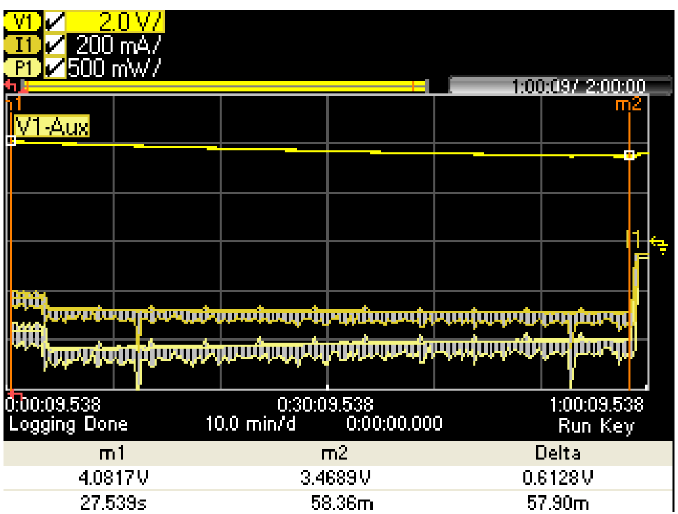


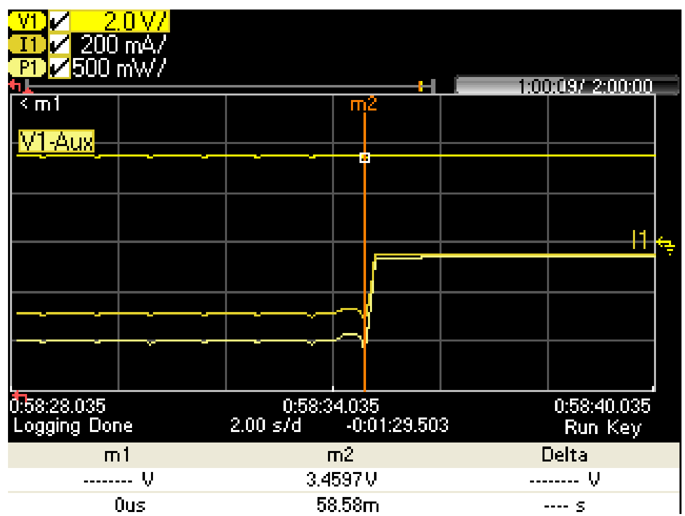
Sensor node stops functioning after 58.58 minutes.

Note also that the current is measured as negative since current out of the DCPA's **Output+** terminal, as a power supply, is defined as positive, but in this measurement the current flow into the DCPA's **Output+** terminal. Also, V1-Aux, the battery voltage, is smooth while I1 and P1 contain surges as the CPU current varies as processing load changes.

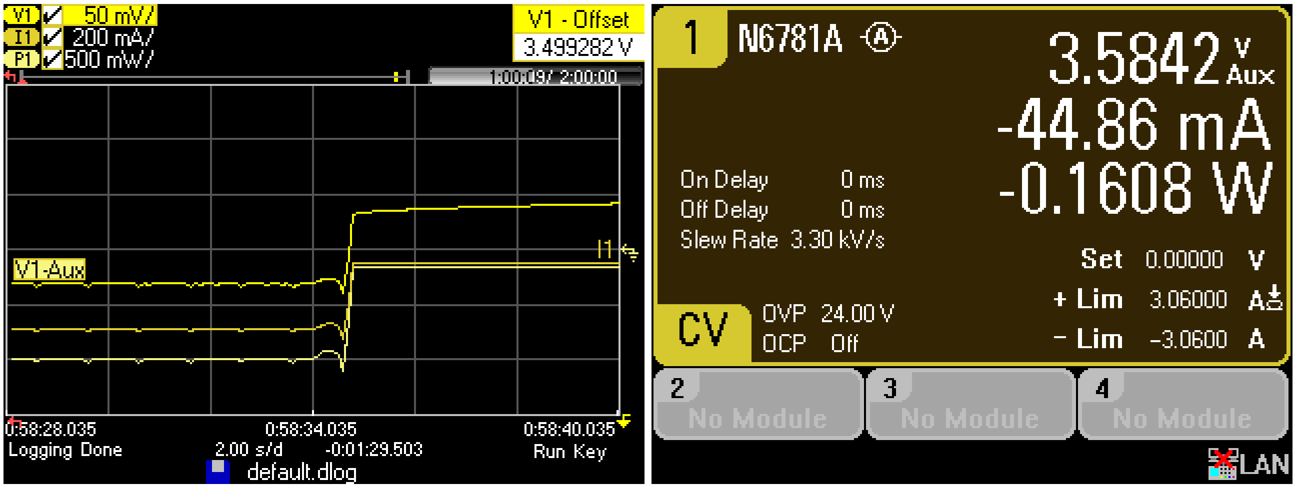
The initial state of the Keysight U3810A powered by a 3.7 V LiPo Battery requires less current, approximately 220mA. After three minutes, it increases to 280 mA as Wi-Fi operation stabilizes.

22. Press the **Data Logger** button to show **Markers** and use the knobs below the screen to measure operating time (the screen on the left below). Press the **Data Logger** button again to hide the Markers, use the knobs to zoom in and press the **Data Logger** button again to show the Marker and measure 3.4597 V at the shutdown time of 58.58 minutes.





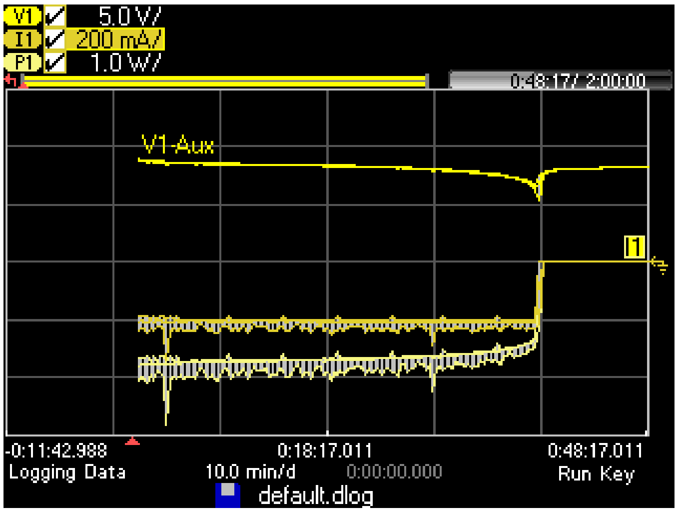
23. Press the **Data Logger** button once more to hide the Markers and expand the vertical axis for V1-Aux (using the **Volts/Div** and **Offset** knobs) and set the reference to 3.5 V at the center of the vertical axis (the zero/gnd indicator is off the bottom of the screen). View the expanded shutdown even (left screen below) and then press **Meter View** to view the pressent voltage and current (right screen below).

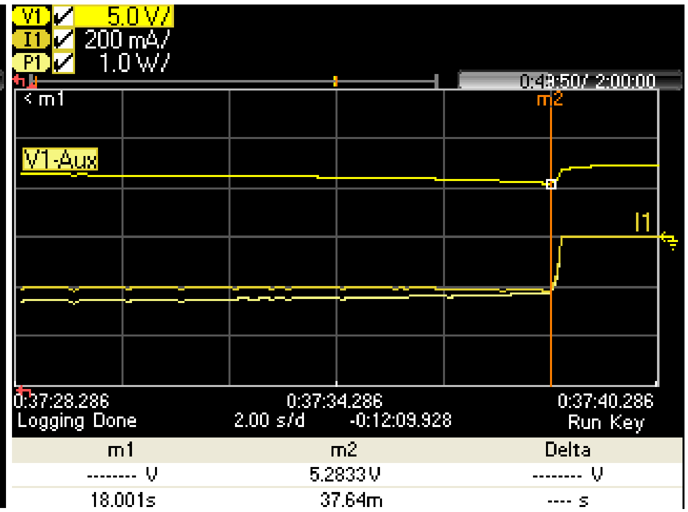


Using the DCPA instead of the DMM measuring across R1, the operating time has been extended from 50 min to almost 59 min.

9 V 200 mAhour Measurement Result using DCPA

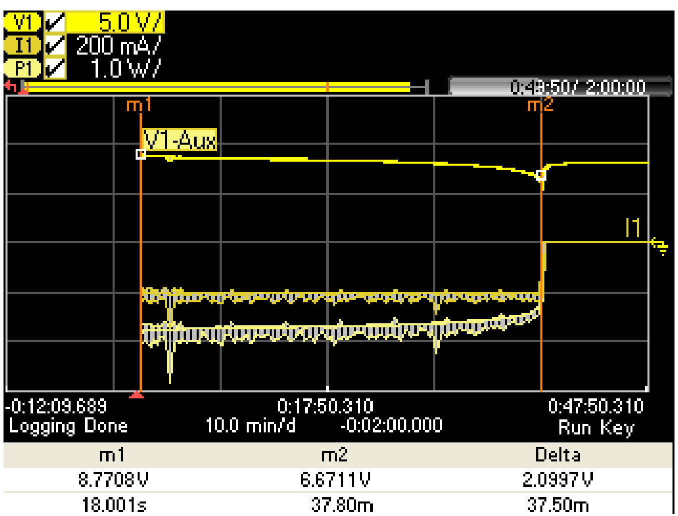
Here is an example for the 200mAH 9V NiMH, Wi-Fi Connected, XJ55 is removed:

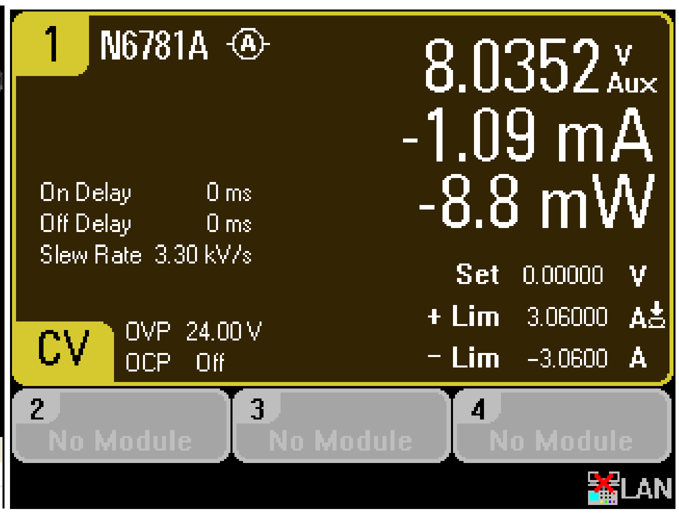




The current of 200 mA drives an operating time of 37.8 min (lower than 50 min of the 3.7 V LiPo Battery) since the 9 V NiMH Battery is lower capacity than the 3.7 V LiPo and much of its higher voltage has been wasted with voltage drops across D2 and U1. The expanded view above right shows the shutdown event at Battery voltage of 5.28 V (this is reduced by D2 and U1 to produce 3.4 V at +5VRAW).

Click the **Data Log** button once to display Markers and use the knobs to adjust them along the horizontal axis:





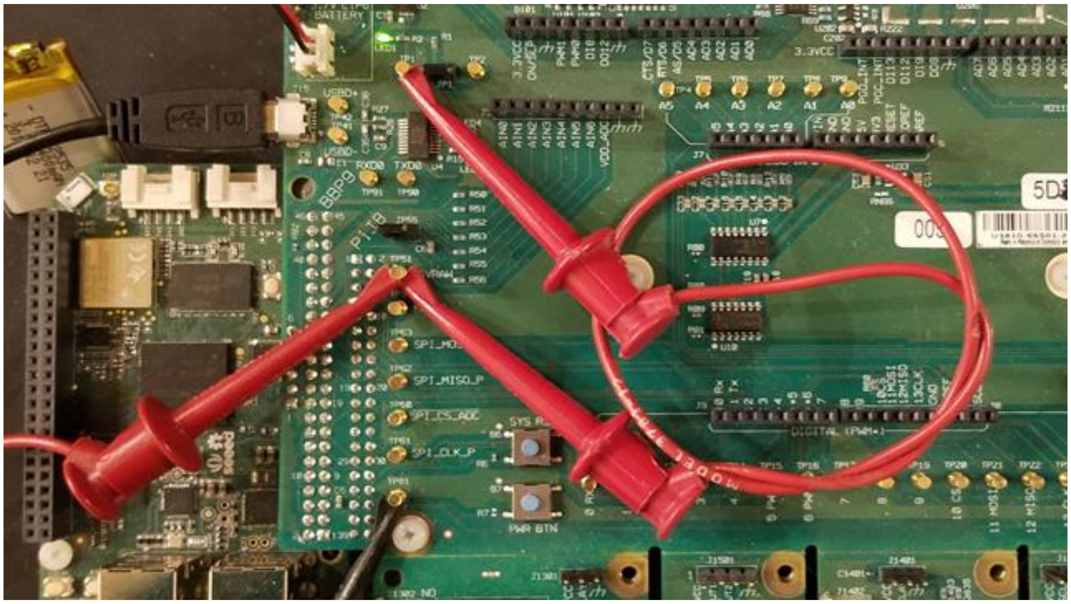
The Meter View below shows 7.9 V at 1 mA shutdown/off current after the BeagleBone has been shut down for 5 min. D2 and1 provide too much voltage drop to allow the 44.8 mA “standby current”.

Battery Drain Summary using DCPA

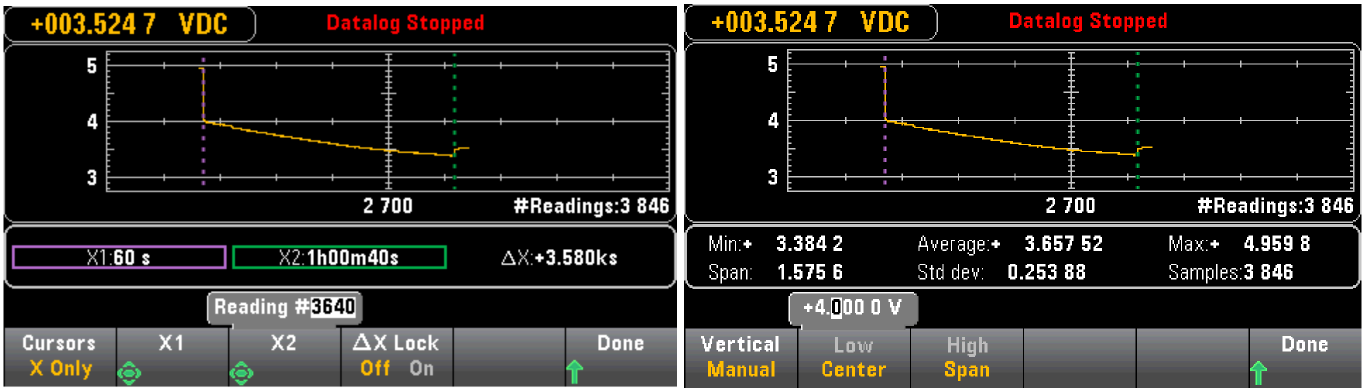
The following can be observed from the above screenshots when measuring with the zero-burden voltage DCPA:

- When powered by a 3.7 V LiPo Battery the initial state of the Keysight U3810A requires less current, approximately 220mA. After a few minutes it increases to 280 mA as Wi-Fi operation stabilizes.
- With Wi-Fi disconnected from an access point, every 30 sec the Wi-Fi radio is powered on for a scan. With Wi-Fi connected the radio remains on.
- The BeagleBone and U3810 circuits consume about 1 W of power or 280 mA using a **3.7 V LiPo** Battery. This energy is used to power all the modules in the sensor node (CPU, Zigbee module, LM75 sensor and other ICs and components on the board).
- The BeagleBone and U3810 circuits consume about 1.8 W of power or 200 mA using a **9 V NiMH** Battery.
- The voltage level on **TP51** (**+5VRAW**) is slowly decreasing. When **+5VRAW** drops below approximately **3.4 V** the Keysight U3810A will stop functioning. When powered by the 9 V Battery, shutdown occurs when the 9 V Battery's voltage drops to 5.28 V (this is reduced by D2 and U1 to produce 3.4 V at +5VRAW).
- The current delivered by the battery increases as its voltage decreases, since the power consumed by the circuits remain the same so the input current must increase to maintain the same P = VI product.
- For the 3.7 V 400 mAH LiPo Battery a calculation shows it would take about 80 minutes (400 mAH/300mA) to drain to completely. However, the sensor node will stop functioning before the battery is fully drained because the CPU's input circuit requires a minimum voltage to maintain proper operation. The actual operating life was measured to be 59 min, an improvement over the 50 min measured with the DMM and R1. Wi-Fi was connected to an access point (see Appendix E for the measurement)
- For the 9 V 200 mAH LiPo Battery a calculation shows it would take about 60 minutes (200 mAH/200mA) to drain to completely. However, the sensor node will stop functioning before the battery is fully drained because the CPU's input circuit requires a minimum voltage to maintain proper operation. The actual operating life was measured to be 38 min, nearly the same as the 38 to 39 min measured with the DMM and R1. For the 9 V battery and its regulated power system, the DCPA's zero burden voltage did not make a difference.

You can see the same effect without the DCPA by removing the burden voltage of R1 and the DMM from the circuit. Place a short clip lead from **TP1** to **TP51** performing only the voltage measurement with the DMM from **TP51** to **DCOM** (GND). XJP1 is optional – if in place it will only slightly improve lifetime:



With the clip lead, operating time is extended to 59 min 40 sec (from 50 min using R1 and without the clip lead) and shutdown occurs at 3.38 V (see **Min** in right graph). This operating time is nearly the same as with the DCPA, however there is no current measurement since R1 and the DMM had to be removed from the circuit:



Voltage discharge at **TP51 +5VRAW** for 3.7 V 400 mAhour LiPo with **XJP55** in place.

WARNING

Do not attempt to connect the clip lead directly from the 3.7 V battery terminal **P2** or **P3** to **TP51** as that will short the USB +5 V supply directly to the 3.7 V battery. The resulting overcurrent could damage the battery or cause your computer's USB to shut down.

Exercise

1. How does resistance in the battery lead affect the measurement and operating life?
2. Why not use the other option, eliminate R1 and perform a direct measurement of current using the DMM's current measurement terminals to improve operating life during the measurement?
3. Why is the operating time longer with the DCPA than with the shorting clip lead?

You are now finished using your battery. You may wish to recharge it for use by the next user of this lab. Appendix C provides charging procedures using USB power and the DC-to-DC Converter / Charger Circuit.

NOTE

- The batteries may also be charged with a 15mA "trickle charge" for 10 hours (I_{charge} < Capacity in A-hours/10).
- With **XJP55** in place after battery discharge and shutdown, you may need to restart the BeagleBone CPU by pressing **PWR BTN**.

Task 4 – Use the DCPA to Investigate the Shutdown Event

Waiting for the battery to discharge through its complete cycle can require a lot of time, so a common practice is to simulate critical events to investigate the system behavior. You will use the DCPA to investigate and directly measure the current during the “shutdown” event.

When the N6705C DCPA is used instead of a battery, it measures the current directly without the need for the DMM and shows capture events along the discharge cycle including the moment of shutdown. You will program the **N6705C/N6781A Output 2** to an arbitrary waveform that slowly drops the voltage to point where CPU shutdown occurs, log the voltage and current, and use the scope mode to capture the moment when the U3810A shuts down. This can identify the voltage level at which the BeagleBone CPU shuts down among other things.

You will set the output resistance of Output 2 to simulate that of the battery and use 4-wire output mode to assure accuracy of that output resistance eliminating the effects of the resistance in cabling. You will use the **V1-Aux DVM** to measure the internal **+5VRAW** to the CPU.

Continuing from the last DCPA measurement task and retaining the zero-burden ammeter connection of Output 1;

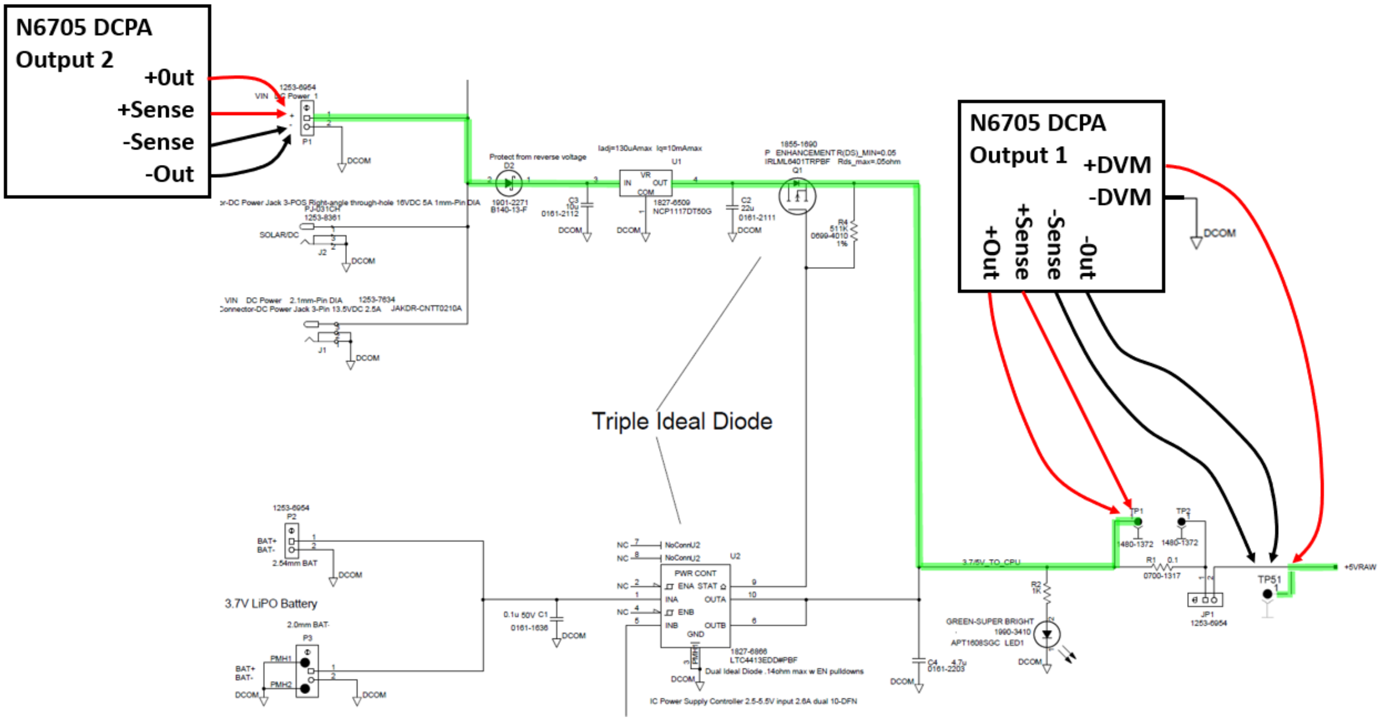
1. Turn **Off** Output 1 and assure that Output 2 is also **Off**.
2. Assure the test cables of the DCPA to the Keysight U3810 as shown as figure below:
    a. Connect the **+Sense** and **+Out** of Channel 1 of DCPA in parallel to **TP1**.
    b. Connect the **-Sense** and **-Out** of Channel 1 of DCPA in parallel to **TP51**.
    c. Connect the **(+)** terminal of the DCPA’s **Aux DVM** to **P1 (+).**
    d. Connect the **(-)** terminal of the DCPA’s **Aux DVM** to **P1 (-)** or **DCOM** (GND)**.**

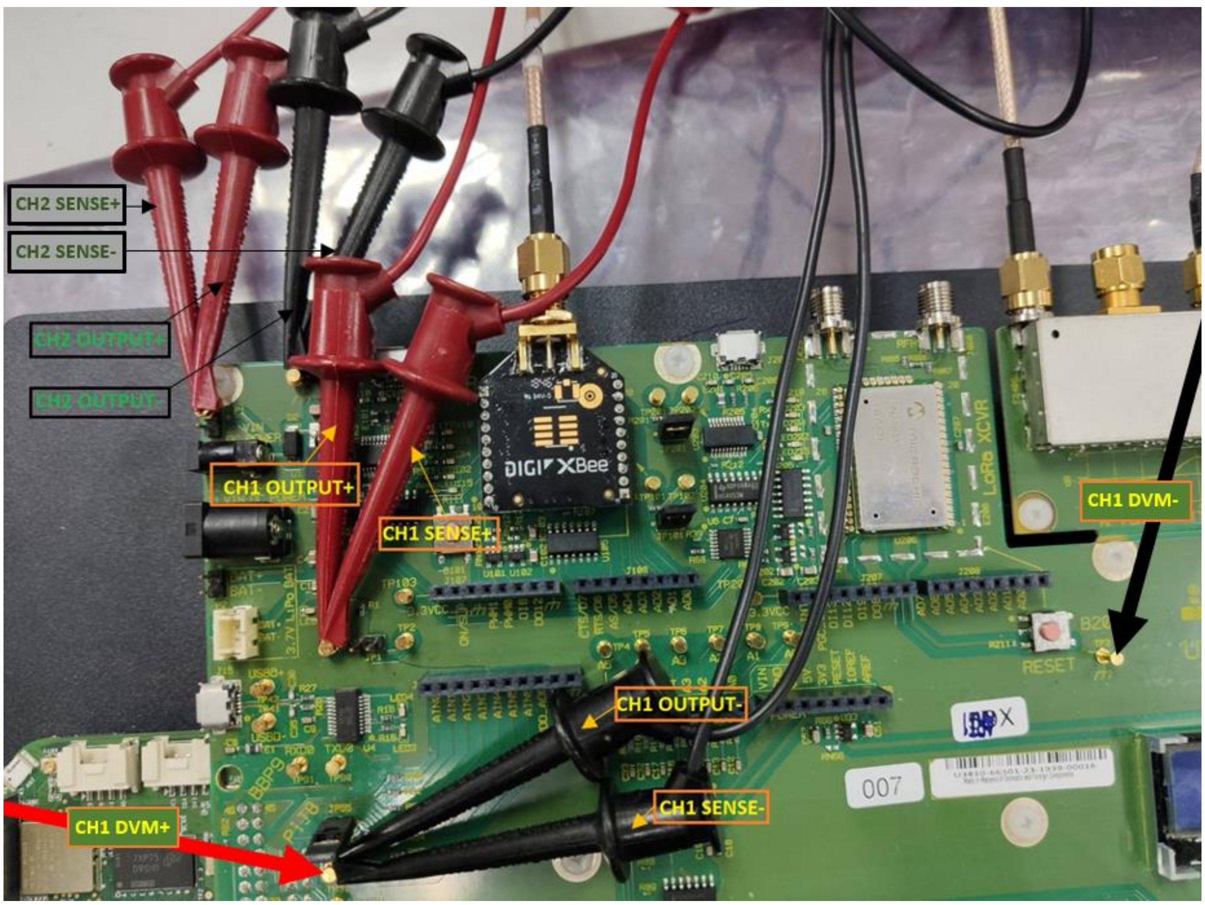
    You will use retain and use the same **Operating In Current Measure** setting as in the previous task
3. Connect DCPA **+Output 2** and **+Sense 2** to **P1(+)** and **-Output 2** and **-Sense 2** to **P1(-)**. The 4-wire sensing eliminates the effect of cable resistance and will assure this voltage will be exactly as programmed on the DCPA Output 2.

NOTE

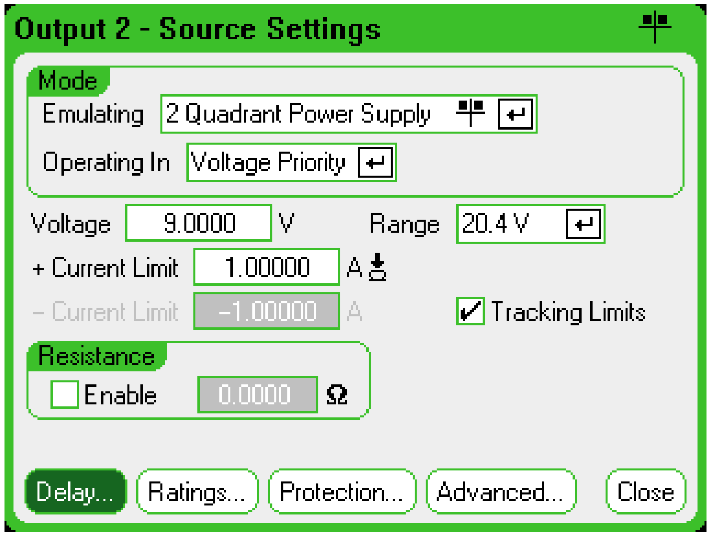
The Output 2 Connection will require you to borrow cables from a second U3810A. If you don’t have enough J-hook mini grabber cables you may substitute a 2.1mm-Pin DIA Power cable without banana plug ends and use the screw terminals on the DCPA. You may also cut a double-ended J-hook mini grabber cable in half, strip the ends, and use the screw terminals on the DCPA.

If you are only missing the one pair that connects Output 2 Sense terminals, you may ignore 4-wire sensing on Output 2 and simply use 2-wire output mode.

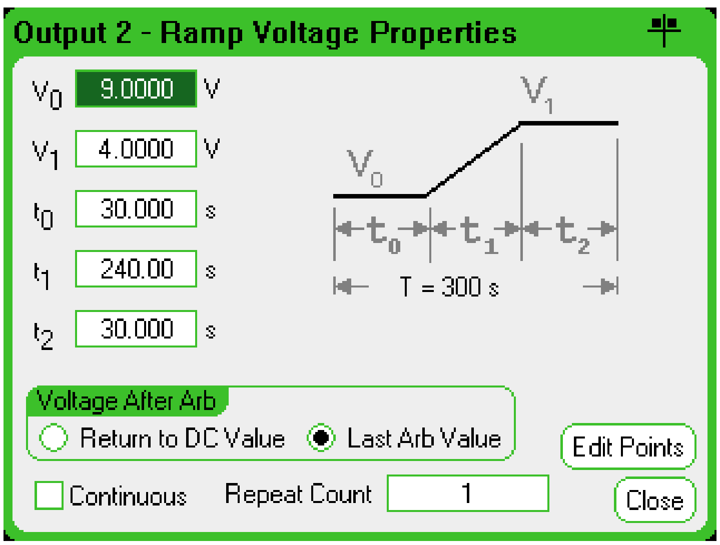

N6705 DCPA
Output 2
+Out
+Sense
-Sense
-Out
N6705 DCPA
Output 1
+DVM
-DVM
+Out
+Sense
-Sense
-Out
DCOM
Triple Ideal Diode
3.7V LiPO Battery


CH2 SENSE+
CH2 SENSE-
CH2 OUTPUT+
CH2 OUTPUT-
CH1 OUTPUT+
CH1 SENSE+
CH1 DVM-
CH1 OUTPUT-
CH1 SENSE-
CH1 DVM+

4. Select **Channel 2** at **Select Output**. After that, set the power supply of channel 2: **Settings >** set the **output range** to **20.4V**, **Voltage** to **9V** and **+Current Limit** to **1A**. If appropriate set **Advanced… > Sense > 4-wire**.

5. 

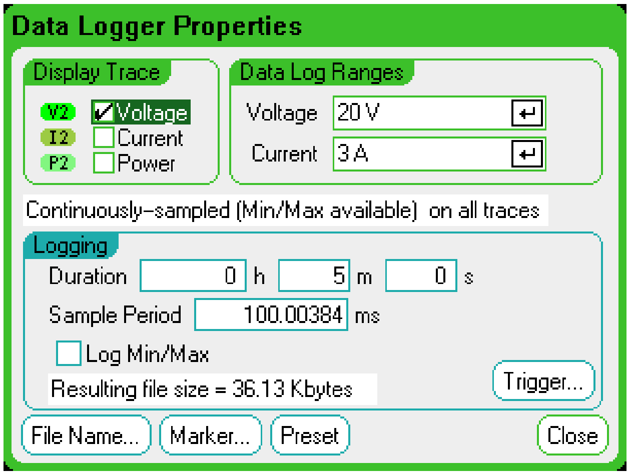
6. Create a **9V** to **4V** ramp Arbitrary waveform while using the Data Logger in the DCPA to record **V1, I1, P1** and **V2**. Create the waveform using **MenuArb > Arb Selection > Ramp + Arb Properties.**

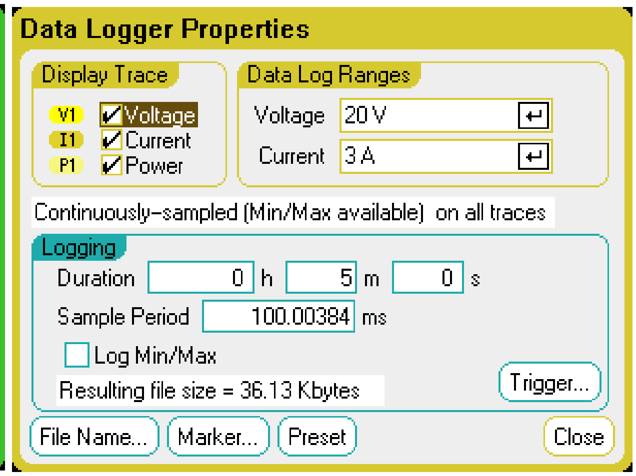


NOTE

The waveform shown on **Output 2 - Ramp Voltage Properties** is generic and will no show the negative slope of the ramp you create, even though your programmed V_1 is lower than V_0.

7. You will use the **Data Logger** to log the simulation battery drain profile. Change to **Data Logger mode**, and then press the **Properties** button to edit the **logging period** of **Channel 1** and **Channel 2**.





8. Now press "**On**" to turn **On DCPA Output 1** and **Output 2.**
9. After power up, connect **USB at J15,** login in and run the previous program. You may find it convenient to click the **up arrow** (**Λ**) on your keyboard three times to recall the three necessary commands:

```
debian@beaglebone:~$ cd LabCode/M3-L5
debian@beaglebone:~/LabCode/M3-L5$ nohup ./M3_L5_T2_static &
[1] 886
debian@beaglebone:~/LabCode/M3-L5$ nohup: ignoring input and appending output to
'nohup.out'
exit
logout

Debian GNU/Linux 9 beaglebone ttyS0
BeagleBoard.org Debian Image 2020-03-09
Keysight U3810A Image Version 3.69 Mar 9th 2020
Support/FAQ: http://elinux.org/Beagleboard:BeagleBoneBlack_Debian
default username: password is [debian:temppwd]

beaglebone login:
```

(You can ignore this and proceed to the next step)

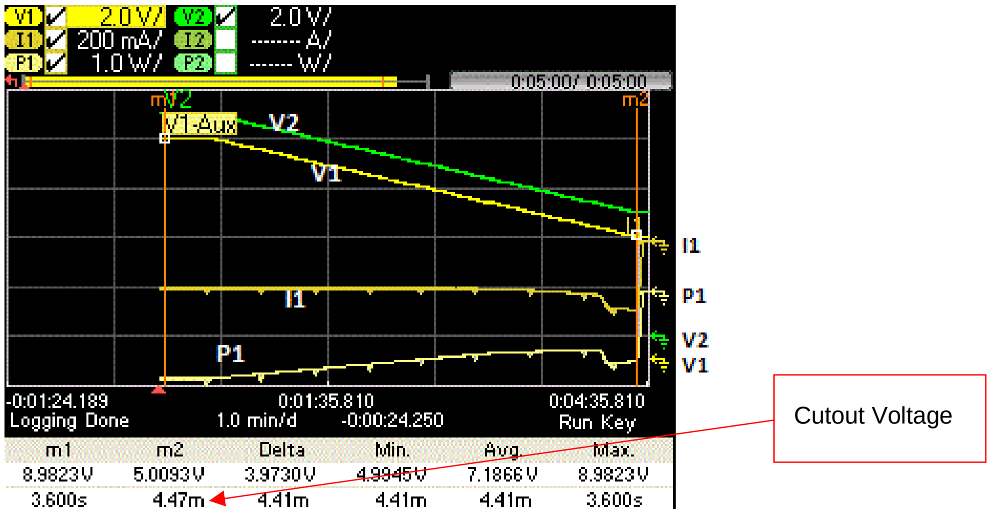
10. Verify in XCTU that the Keysight U3810A is still transmitting data to the gateway before you proceed.
11. Disconnect **USB at J15** and verify again in XCTU that the Keysight U3810A is still transmitting data to the gateway.
12. Press **Arb Run/Stop** and **Run/Stop** button to start the data logging.

A sample screenshot for 5 minutes logging is shown as figure below.

You may need to adjust the position of Voltage, Current, and Power measurement so they can be viewed correctly. You can use the Autoscale function on the DC Power Analyzer.

Press Data Logger. Select I1. Adjust the marker 2 (m2) by turning the marker 2 probe on waveform display until the current I1 is zero.

Now, select **V2**. Record the voltage of **m2** (**Marker 2**) as the **cutout voltage,** where the Keysight U3810A shuts down.



From the captured screenshot, the **power supply V2** gradually decreases from 9V to 5V. Since the DCPA is a power supply, positive current is defined as coming out of the instrument's **+** terminal, so the measurement result of current **I1** is negative.

To repeat data logging, verify Output 2 is 9.000 volts and proceed as before.

Battery Simulation using the DCPA shows that the cutout voltage is 5V, while the above 9V NiMH battery shows that 6.8V is the cutout voltage.

Question: Explain the cutout voltage condition.

Appendix A – Establish Secure Shell (SSH) Communication between BeagleBone and PC

NOTE

The following procedures are part of Lab 1 and are provided here as a reference. The connection procedure is usually to be performed only once. Do not repeat it unless necessary.

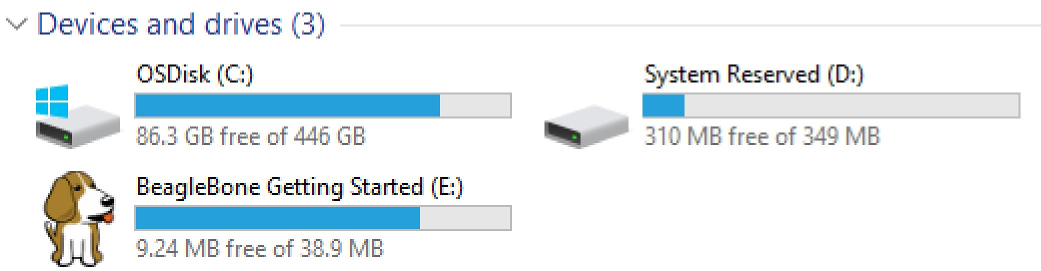
In this exercise, you will connect the PC (Host) to Beagle Bone via a USB cable and establish an RNDIS connection. RNDIS is the Remote Network Driver Interface Specification. It defines internet connection via USB, and this connection provides a virtual network to the Beagle Bone that supports various network protocols, including SSH and HTTP. Once the connection is established, a PuTTY terminal using SSH can be used. The local documentation on the webpage can also be explored. The RNDIS Network IP address of the BeagleBone will be **192.168.7.2,** while your PC will be at **192.168.7.1.**

WARNING When JP1 is in place, do not connect a USB cable to both the BeagleBone and J15 at the same time, or anomalous behavior may result.

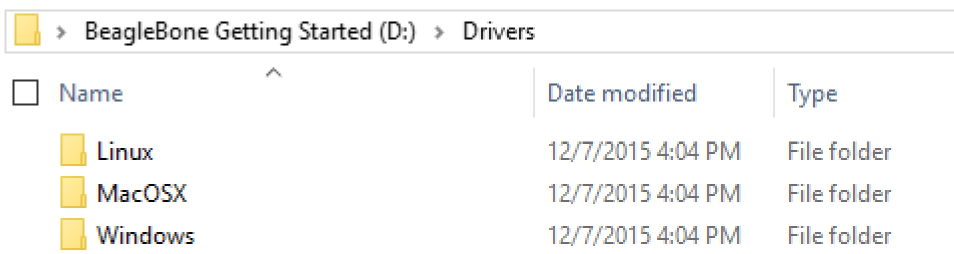
1. Remove the USB cable from J15 and connect it instead to the BeagleBone CPU USB port to your PC. This will also power up the U3810A. It may take up to 1 minute to complete the boot process:

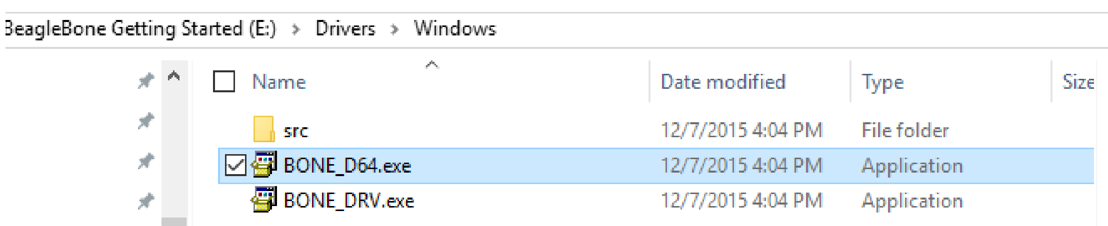
Install RNDIS drivers

2. If the drivers have not already been installed, open the **BeagleBone Getting Started** drive using a file explorer. Select the driver for your OS from the Drivers folder, and install:

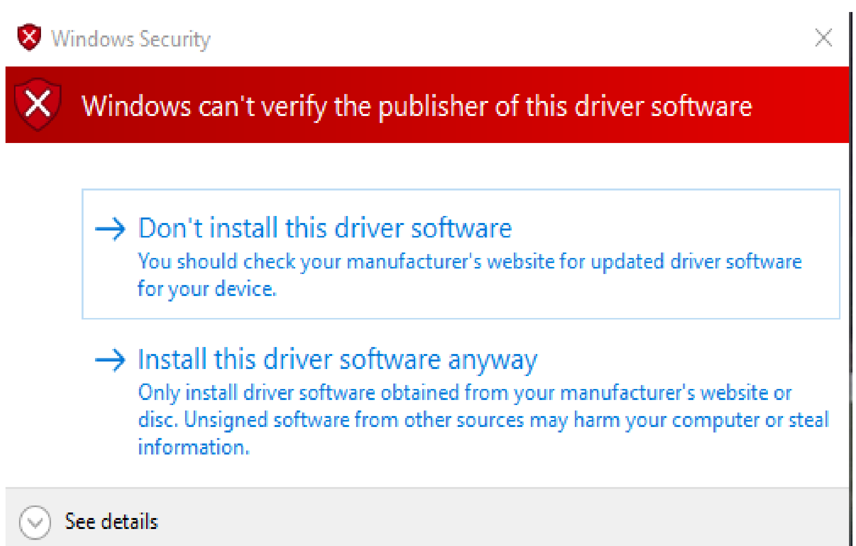


3. Select the driver for your OS from the Drivers folder and install the BONE_D64.exe file.

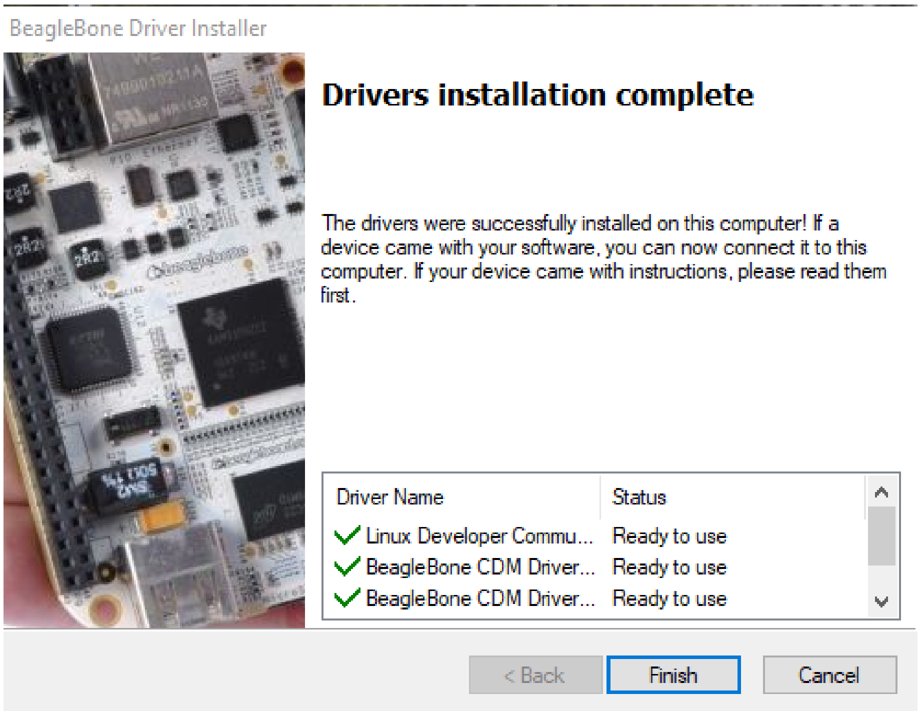




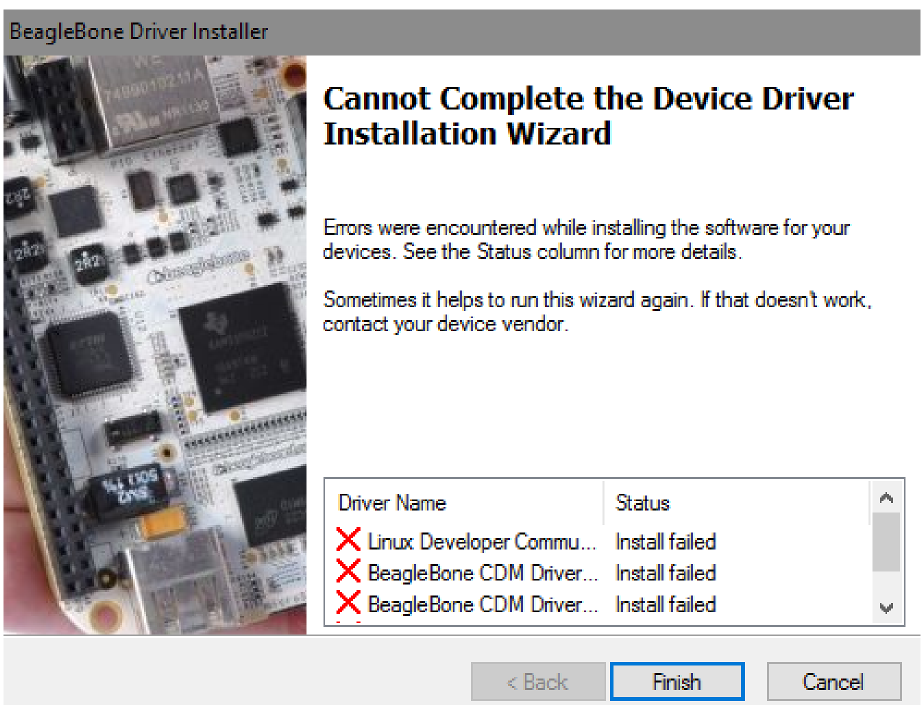
4. During the installation, Windows 10 users may see this message. Select the **Install this driver software anyway**.



Successful installation will show the message below.



Refer to Appendix C – Troubleshooting RNDIS Drivers installation for more information if you receive the error below.

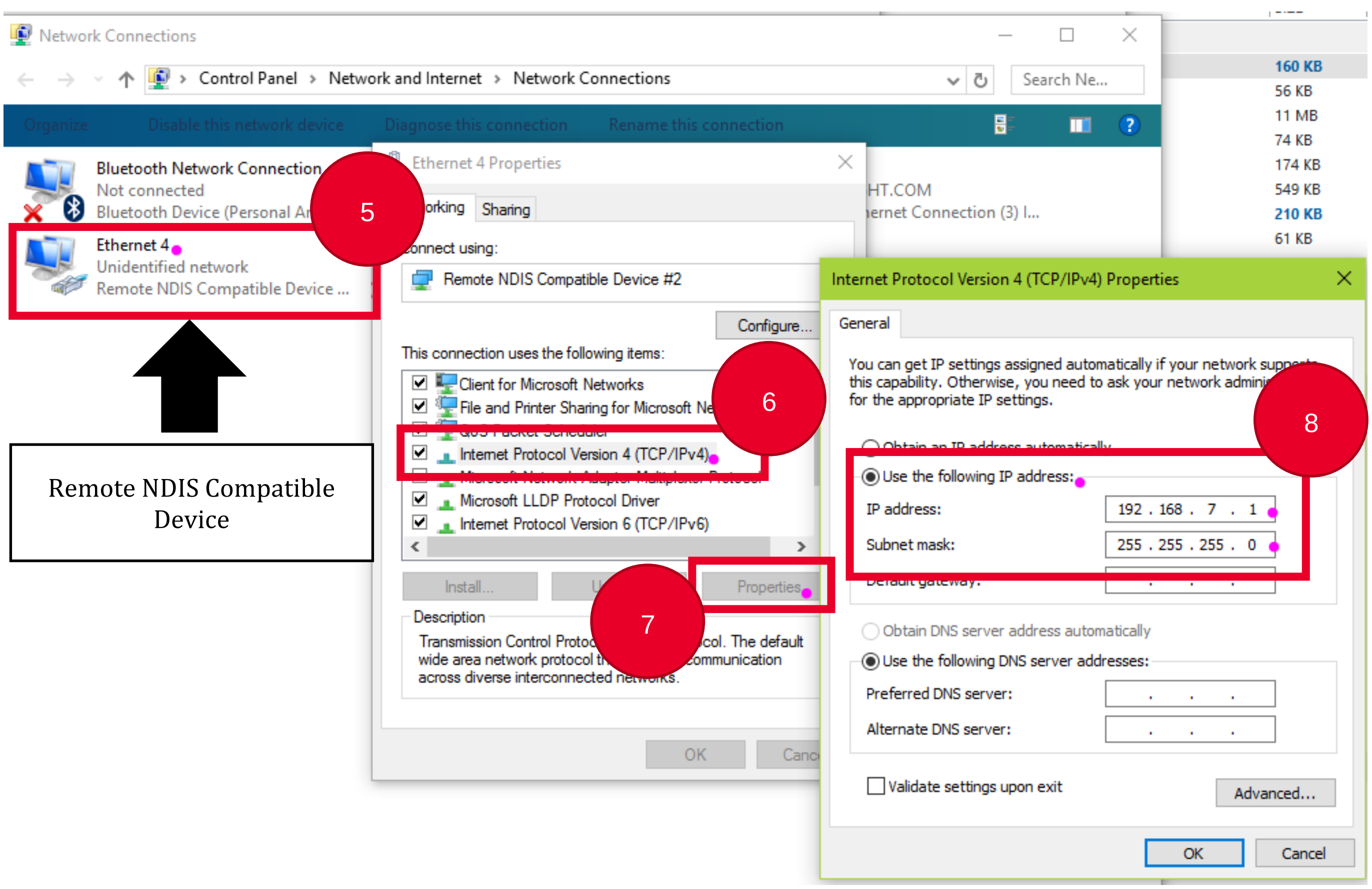


Configuring RNDIS adapter

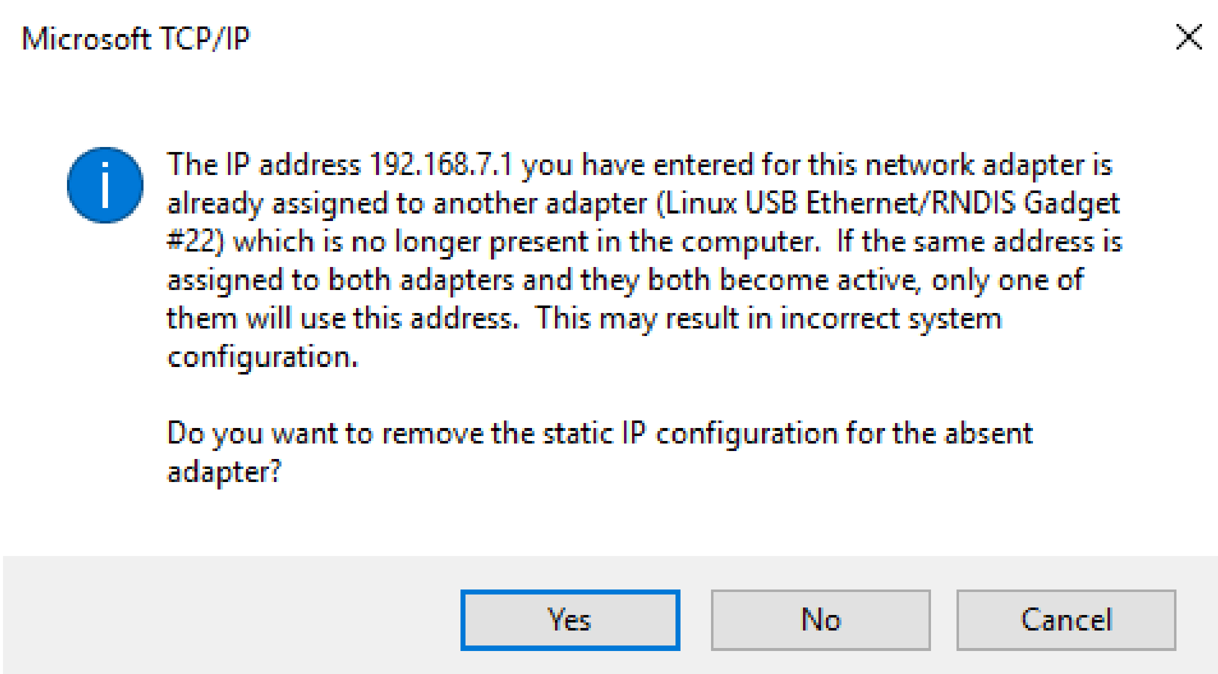
Your PC will need to be on the same subnet using the RNDIS connection. Since DHCP is not used, follow the steps below to set your PC static address to **192.168.7.1**.

> **NOTE**
>
> You may need to run this step each time you connect a different BeagleBone to your PC.

5. Go to **Network Settings**, right-click Remote NDIS Compatible device, and select Properties.
6. Click **<your Remote NDIS Adapter>** and click **Internet Protocol Version 4 (TCP/IPv4)**.
7. Click **Properties**.
8. Set up the general settings for the IP address as shown below.



If you receive the message below, it could either mean that a BeagleBone or other device was using this address previously. Select **Yes** if any of the device are not in use or select **No** as long as both devices are not present.

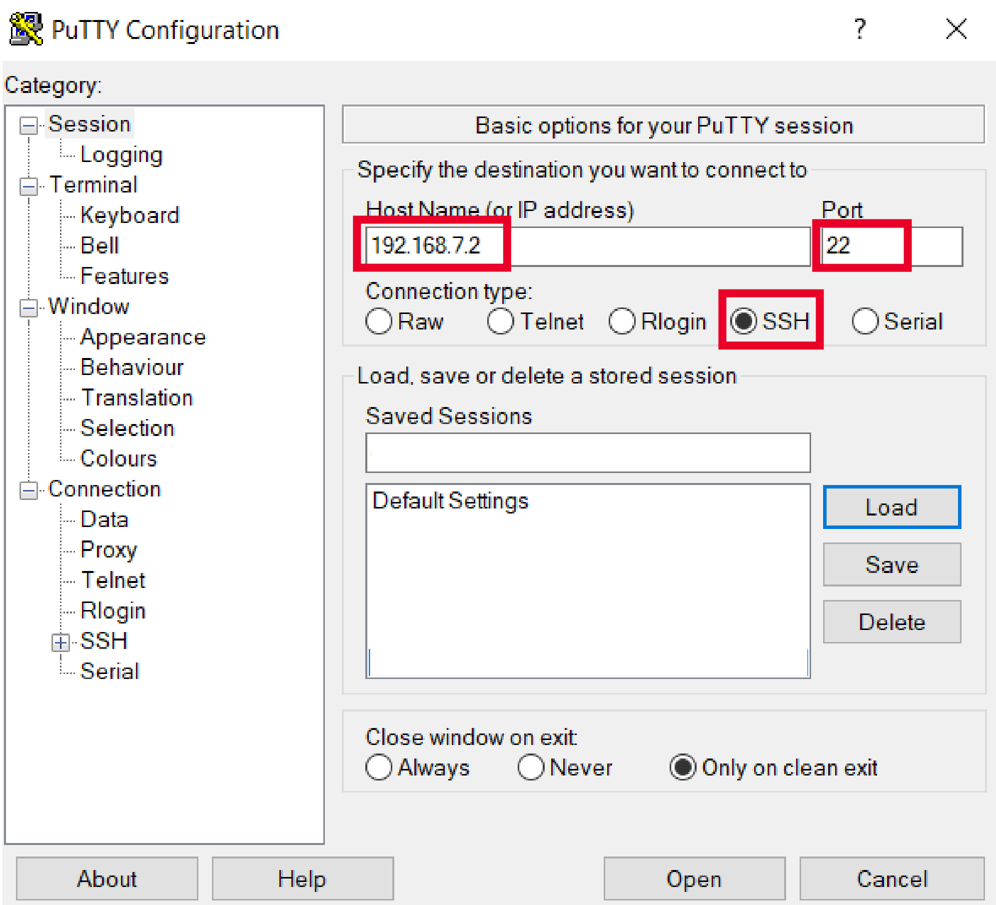


Set Up SSH connection

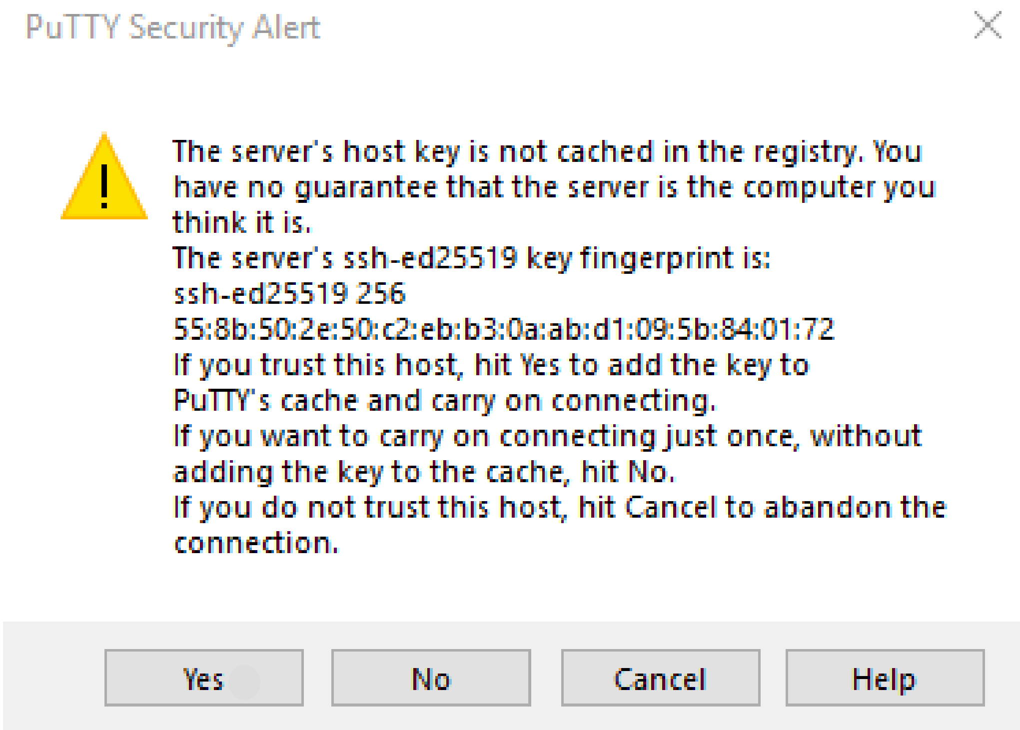
9. Once the ping command comes back with a reply and a response time, double-click PuTTY.exe to launch the PuTTY terminal program.

> **NOTE**
>
> PuTTY may also be launched from WinSCP by clicking  When launched in this manner the connection is completed automatically and the steps below are not required.

10. A PuTTY Configuration window will pop up to determine the connection type. Select **SSH** for Connection type and enter **192.168.7.2** for the IP address.



11. If this is the first time that the computer is connecting to this Beagle Bone, you will receive this message and question to which you should click **Yes**:



12. Click **Open** to open the terminal window. Press **Enter** on the PC keyboard to check and verify connectivity. Otherwise, refer to **Getting Started Guide** to upgrade the firmware.

Default username	: debian
Default password	: temppwd

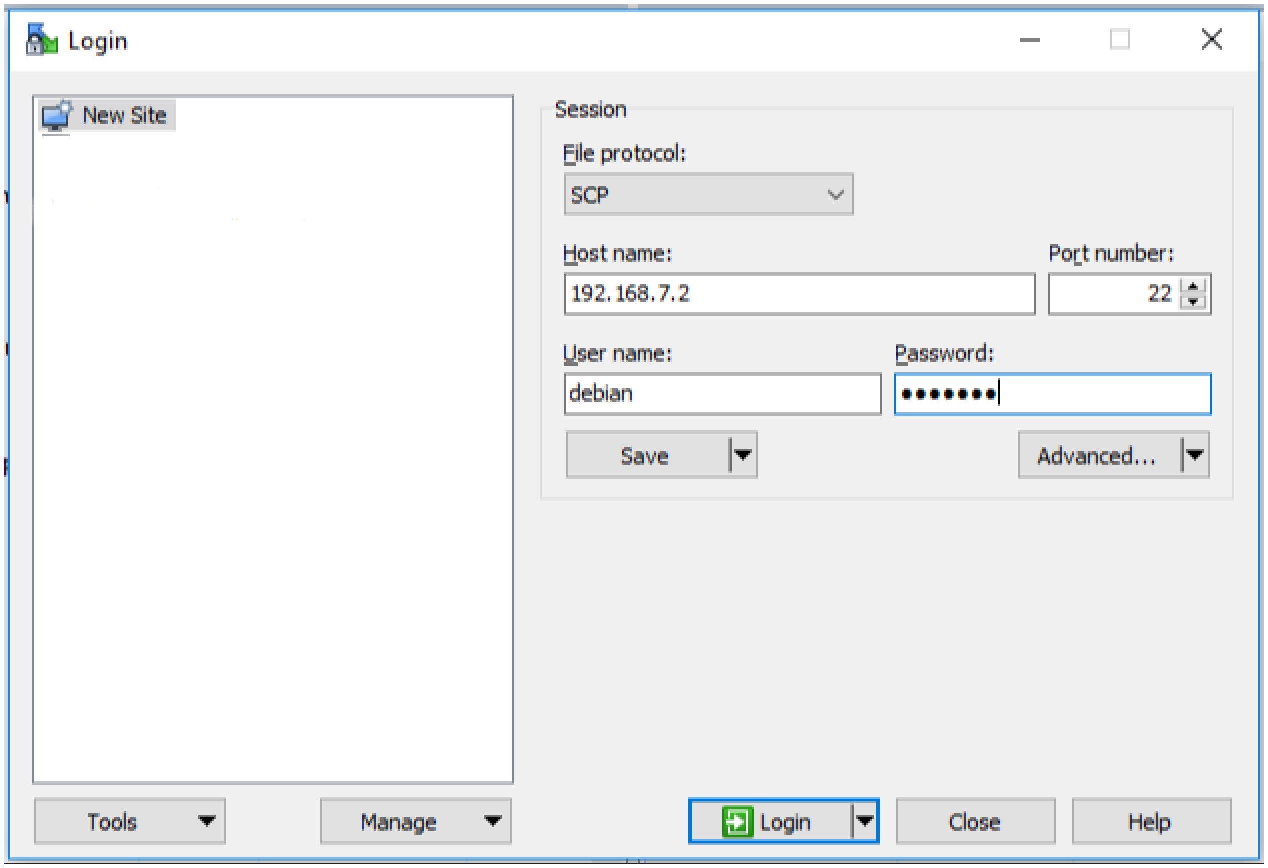
13. Enter username **debian** and the password **temppwd** to log into the BeagleBone CPU on the U3810A. Note that the password will appear as blank and unresponsive as you type.

```
login as: debian
Debian GNU/Linux 9

BeagleBoard.org Debian Image 2019-09-01

Support/FAQ: http://elinux.org/Beagleboard:BeagleBoneBlack_Debian

default username:password is [debian:temppwd]

debian@192.168.7.2's password:

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.

Keysight U3810A Image Version 3.57 Sept 20th 2019
Last login: Fri Sep 20 16:49:15 2019
debian@beaglebone:~$
```

Appendix B – Transfer Files Using WinSCP

Set Up WinSCP

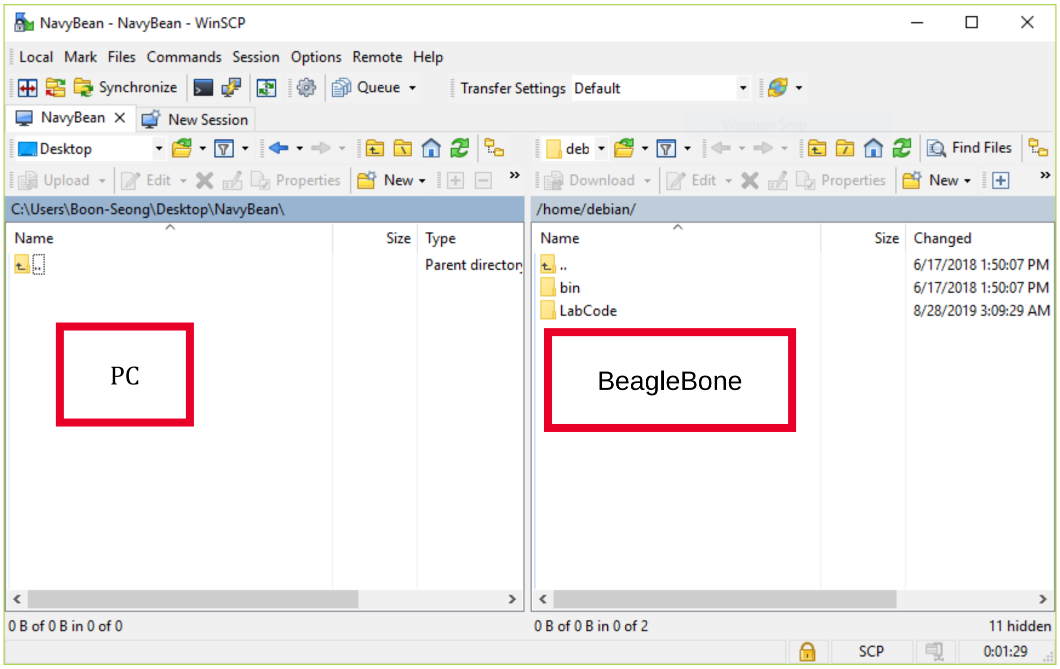
1. For Windows users download and install a copy of WinSCP from https://winscp.net/eng/download.php. You should see a WinSCP icon on your desktop.
2. Double-click to launch WinWCP and click **New Site**. Select **SCP**, enter **192.168.7.2,** Port Number **22**, Username **debian** and the password **temppwd**.



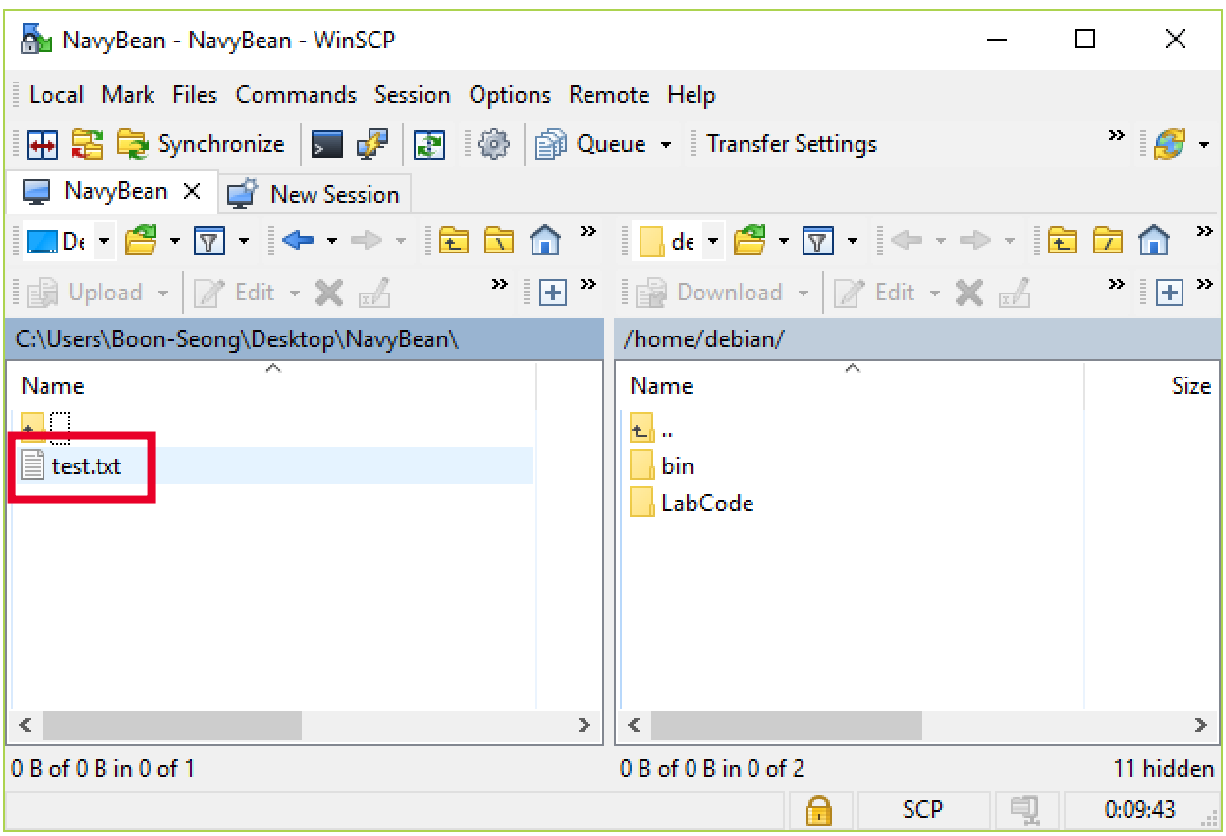
3. First time users who are connecting WinSCP to the BeagleBone, select Yes when prompted with a message about connecting to an unknown server.

Copy Files with WinSCP

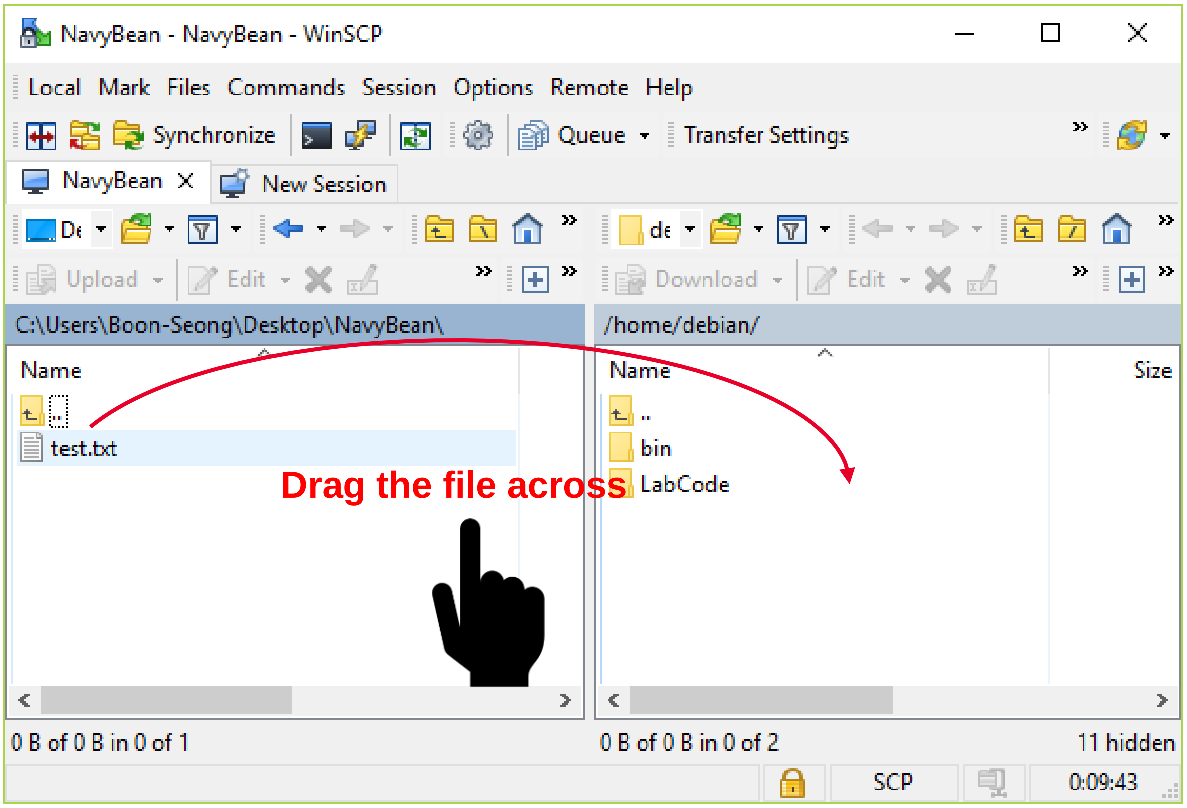
A GUI should open where files can be dragged across from the PC to the BeagleBone and vice-versa.



4. Create a text file "test.txt" in your desktop.



5. Copy the “test.txt” file over to the BeagleBone using WinSCP by dragging it across.



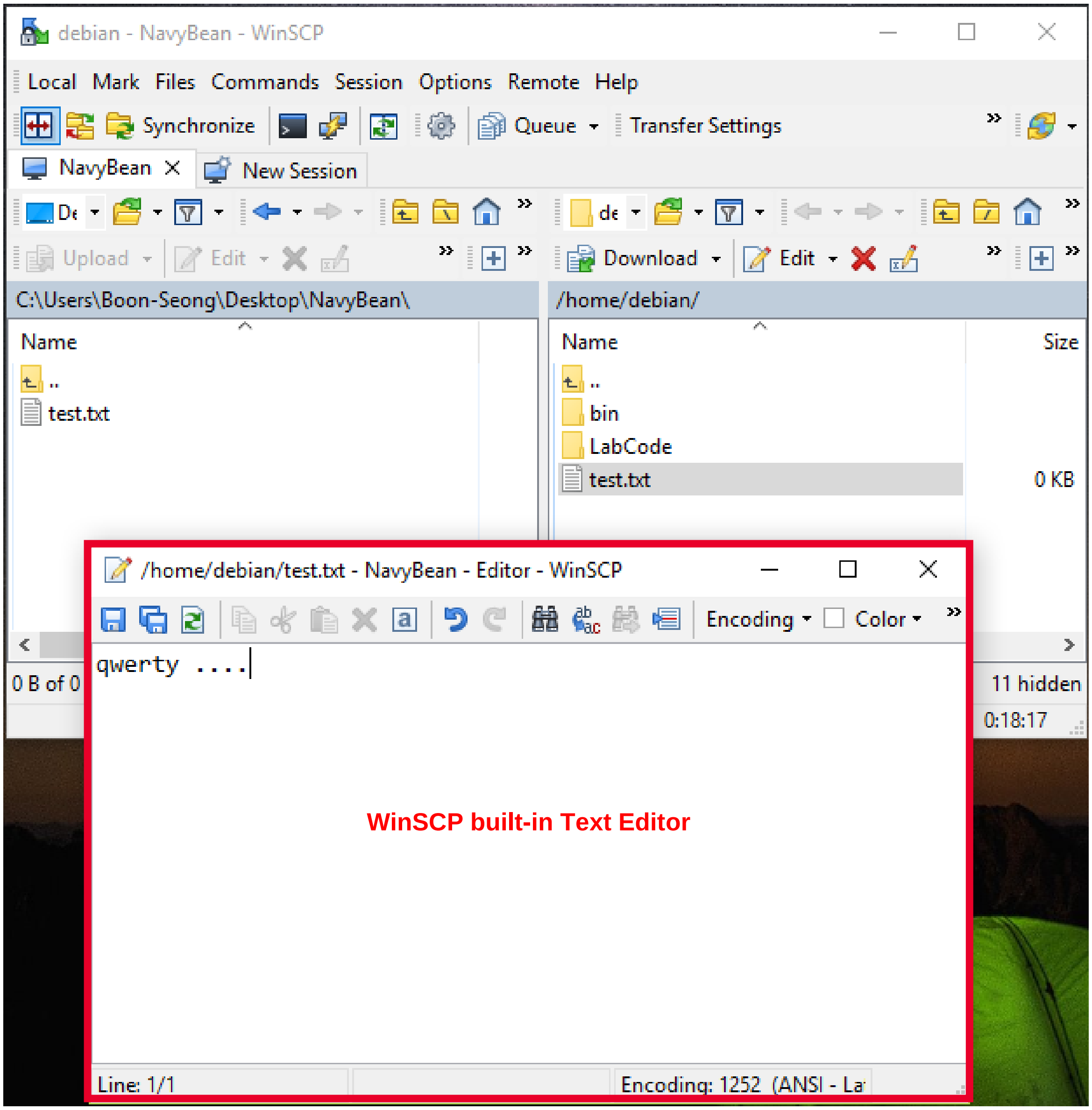
NOTE

For Linux based systems copy the file using **scp M3-L1.zip debian@192.168.7.2** command.

You may also click  to launch PuTTY from WinSCP.

Edit Files with WinSCP

6. With the copy of the test.txt file in BeagleBone, right-click the file and click **Edit**. It should prompt a built-in text editor where you will use it to edit shell scripts with a GUI text editor from PC.



7. Save your changes and close the text editor.

NOTE

You may want to frequently save your changes while editing the file due to the risk of losing your changes if there is any disconnection between your PC and BeagleBone.

Appendix C – DC-to-DC Converter and Charger Configuration for Battery Charging

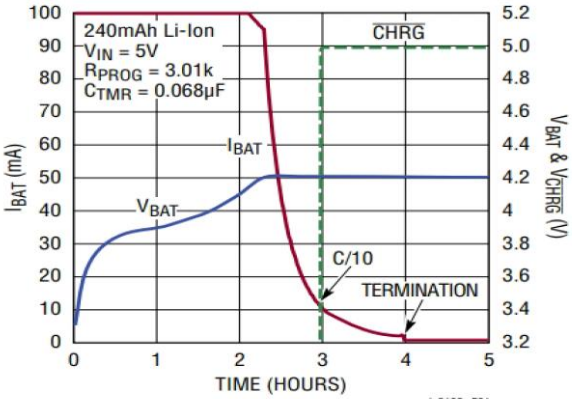
At the beginning of this lab and at the beginning of certain tasks within this lab, you may require a recently charged battery. The following table provides the proper jumper settings for certain batteries using USB power into the DC-DC Converter. Charge times from full discharge are provided. Light red shading indicates “uninstalled”:

Jumper Settings for USB Power	**3.7V LiPo (400mAhour) Time ~ 2 hours**	**9.0V NiMH (200mAhour) Time ~ 2 hours**	**9.0V LiPo (actual 7.4Vout, 600mAhour) Time ~ 3 hours**
J1901	USB Power from Computer	USB Power from Computer	USB Power from Computer
XJP1902	RUN – **up**, pin 1 to pin 2	RUN – **up**, pin 1 to pin 2	RUN – **up**, pin 1 to pin 2
XJP1903	BURST – **down**, pin 2 to 3	BURST – **down**, pin 2 to 3	BURST – **down**, pin 2 to 3
XJP1904	660mA – **up**, pin 1 to pin 2	660mA – **up**, pin 1 to pin 2	660mA – **up**, pin 1 to pin 2
XJP1906	5Vout – **uninstalled**	11Vout – **down**, pin 2 to pin 3	11Vout – **down**, pin 2 to pin 3
XP1906a,b	DCDC to Charger	DCDC to Charger	DCDC to Charger
XJP1921	Charger Power In	Charger Power In	Charger Power In
XJP1922	Charger Out	Charger Out	Charger Out
XJP1923	250mAchg - **down**, pin 2 to 3	100mAchg - **up**, pin 1 to 2	250mAchg - **down**, pin 1 to 2
XJP1924	4.2Vchg - **uninstalled**	9.8Vchg - **down**, pin 2 to 3	9.8Vchg - **down**, pin 2 to 3
XJP1925	NoNTC - **down**, pin 2 to pin 3	NoNTC - **down**, pin 2 to pin 3	NoNTC - **down**, pin 2 to pin 3
P1926 or P1927	Battery Connection	Battery Connection	Battery Connection
P1902 Solar Cell	≥ 6V, ≥ 10mA, power plug	≥ 6V, ≥ 10mA, power plug	≥ 6V, ≥ 10mA, power plug
R1904 for 6V Solar or USB	1:00 clockwise as shown	1:00 clockwise as shown	1:00 clockwise as shown

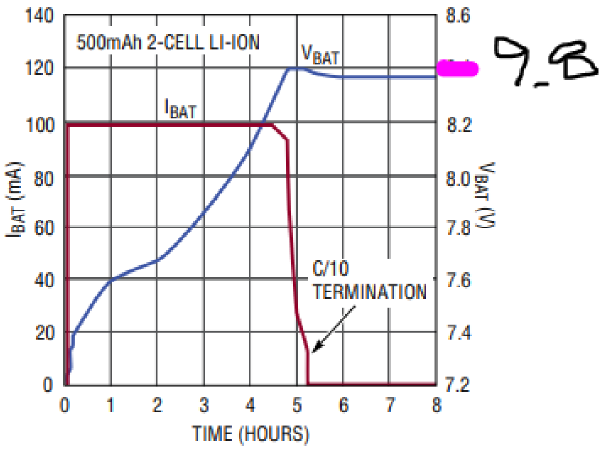
The green Charge LED (LED1921) will turn on when charging. The battery will be fully charger when the LED turns off:

For more information, see Sheet 7 of the Schematic in the next appendix. Charging is complete when the current drops to less than 10% of the initial charging current, although trickle charge continue to flow and "top off" the battery. The following graphs from show the charging profiles for various batteries and configurations:

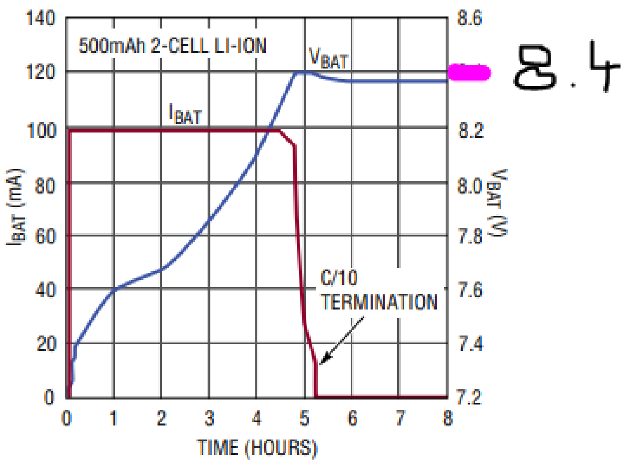
1. 3.7 V 400mAh LiPo Rechargeable battery with JST connector (Recommended, https://www.adafruit.com/product/1578, connect only to P2 or P3)



2. 9 V 200mAh NiMH Rechargeable battery (Optional, http://www.tenergy.com/10003, connect only to J1, J2 or P1)

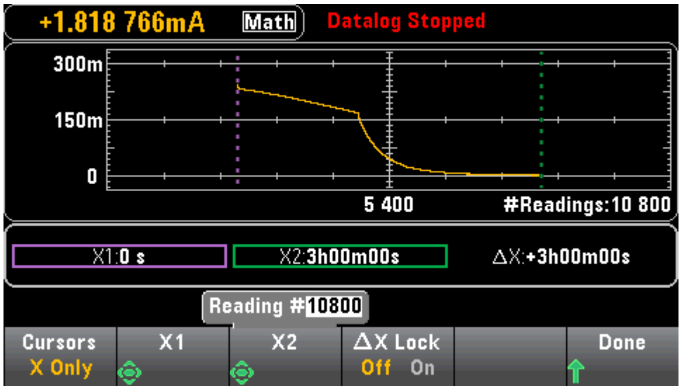


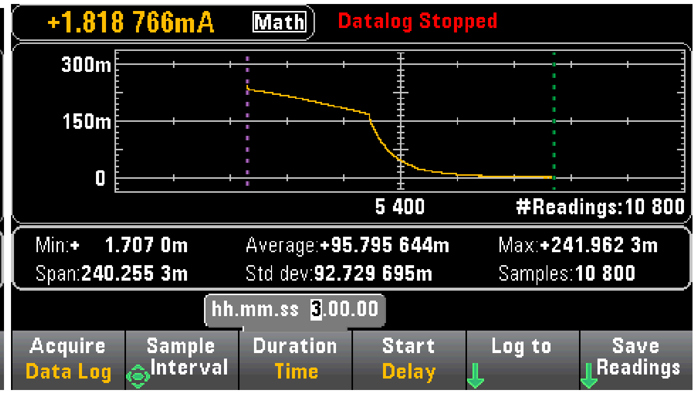
3. 9 V 600mAh Li-ion Rechargeable battery (Optional, http://www.tenergy.com/30593, connect only to J1, J2 or P1), note that this battery's output voltage is 7.4 V. This battery can be charged at 100mA and 9.8V (voltage will drop since the charger will current-limit)



3.7 V 400 mAhour LiPo Battery

The charge current for a 3:00 hour charge cycle of a 3.7 V 400 mAhour LiPo Battery is shown below.





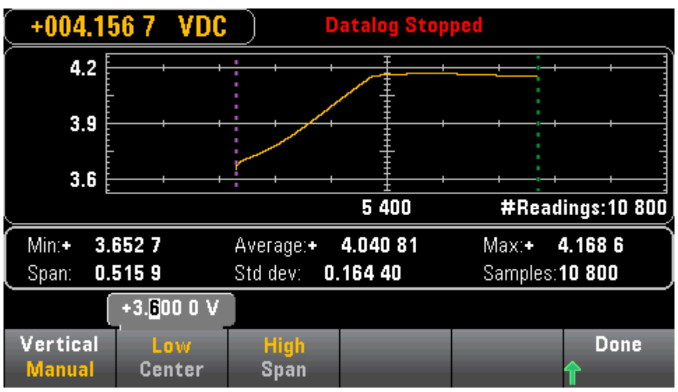
Re-charging the 3.7 V 400 mAhour NiMH Battery with $V_{OutDCDC}$ = 5 V, V_{chg} = 4.2 V and I_{chg} = 250 mA

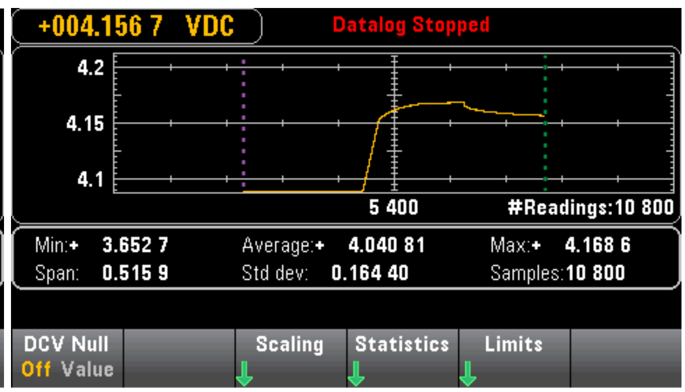
The charge LED turns off at approximately 70 min but then continues to "top off" the battery resulting in a total charge time and charge delivery of:

ΔX = 10800samples/60samples/min = 3 hour

Q = I_{ave} x T = 96 mA x 10800 sec = 1037 C

Charge voltage for a 3:00 hour charge cycle of a 3.7 V 400 mAhour LiPo Battery is show here:

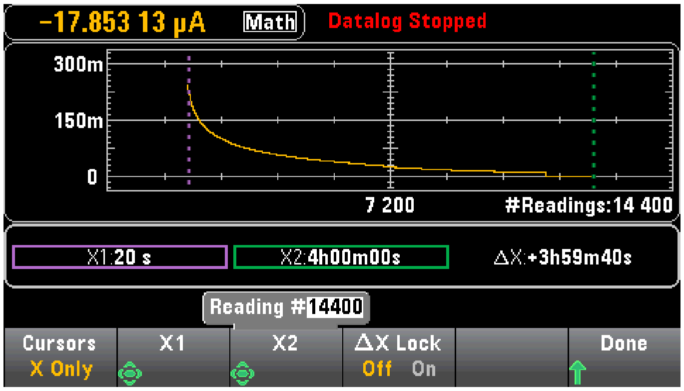


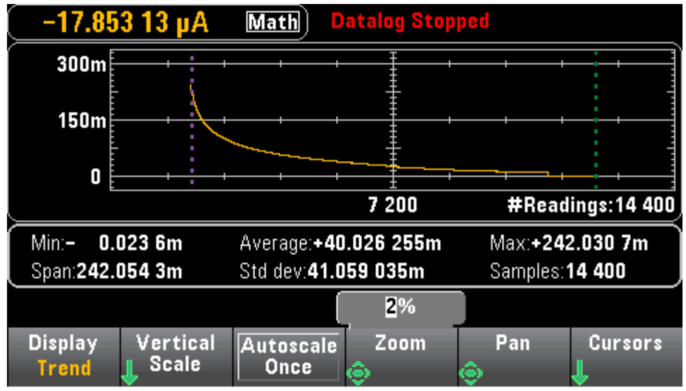


The voltage ramps up for approximately 70 minutes, then starts to level off, peaks at 4.169 V (see Max) and stabilizes near the final measurement of 4.159 V (upper left).

9 V 200 mAhour NiMH Battery

Charge current for a 4:00 hour charge cycle of a 9 V 200 mAhour NiMH Battery is shown below.





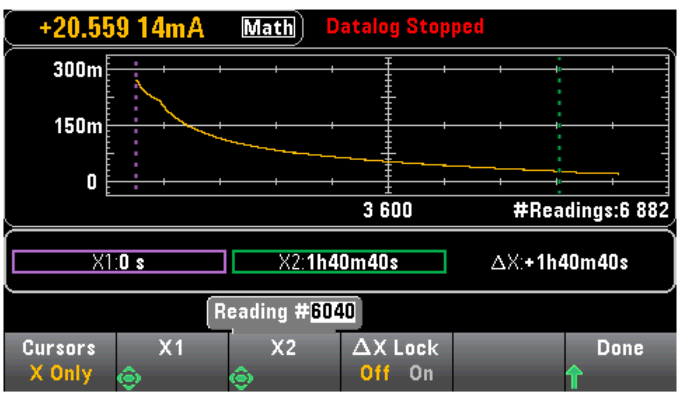
Re-charging the 9 V 200 mAhour NiMH Battery with $V_{OutDCDC}$ = 11 V, V_{chg} = 9.8 V and I_{chg} = 250 mA

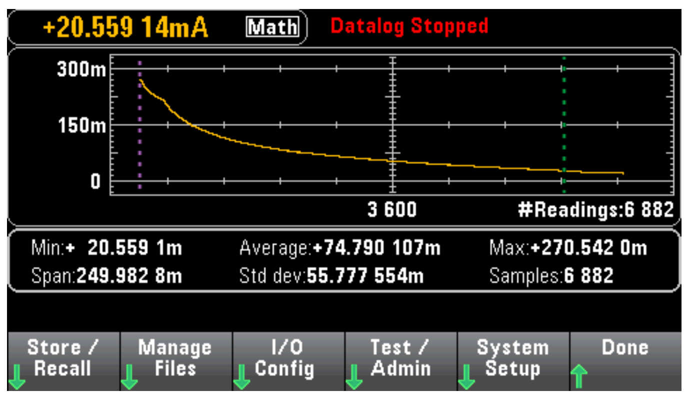
The charge LED turned off at ΔX = 6000samples/60samples/min = 1 hour 40 min:

ΔX = 14400samples/60samples/min = 4 hour

Q = I_{ave} x T = 40 mA x 14400 sec = 576 C

A quicker charge cycle of the same 9 V 200 mAhour NiMH Battery is shown here. This is the same charge cycle as above except the average current was recorded and the battery was disconnected sooner after the CHARGE LED turn off.





Re-charging the 9 V 200 mAhour NiMH Battery with $V_{OutDCDC}$ = 11 V, V_{chg} = 9.8 V and I_{chg} = 250 mA

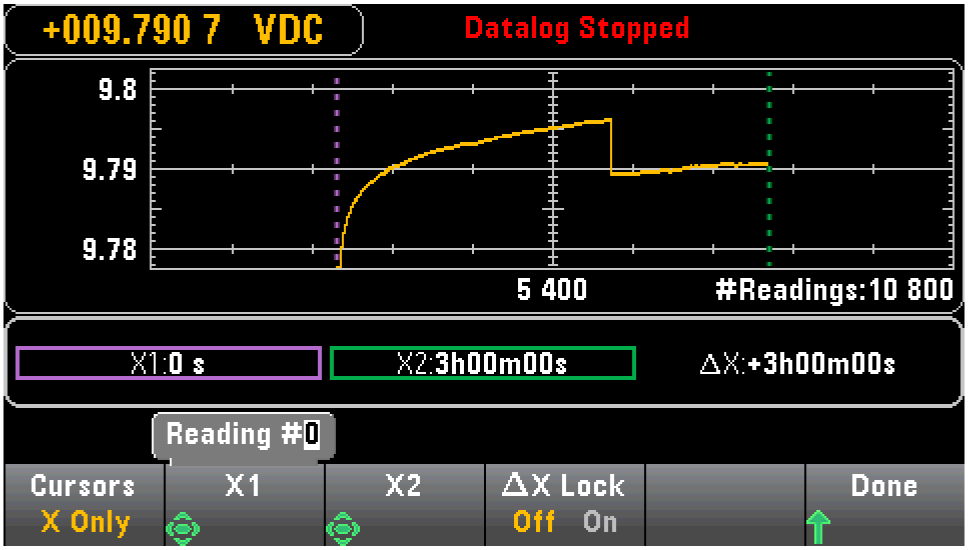
From the Average current determine the charge delivered to the Battery during charging:

You can see that 61 C less charge was delivered to the battery by not allowing is to “top off” after the LED turns off:

ΔX = 6882samples/60samples/min = 1 hour 54 min 42 sec

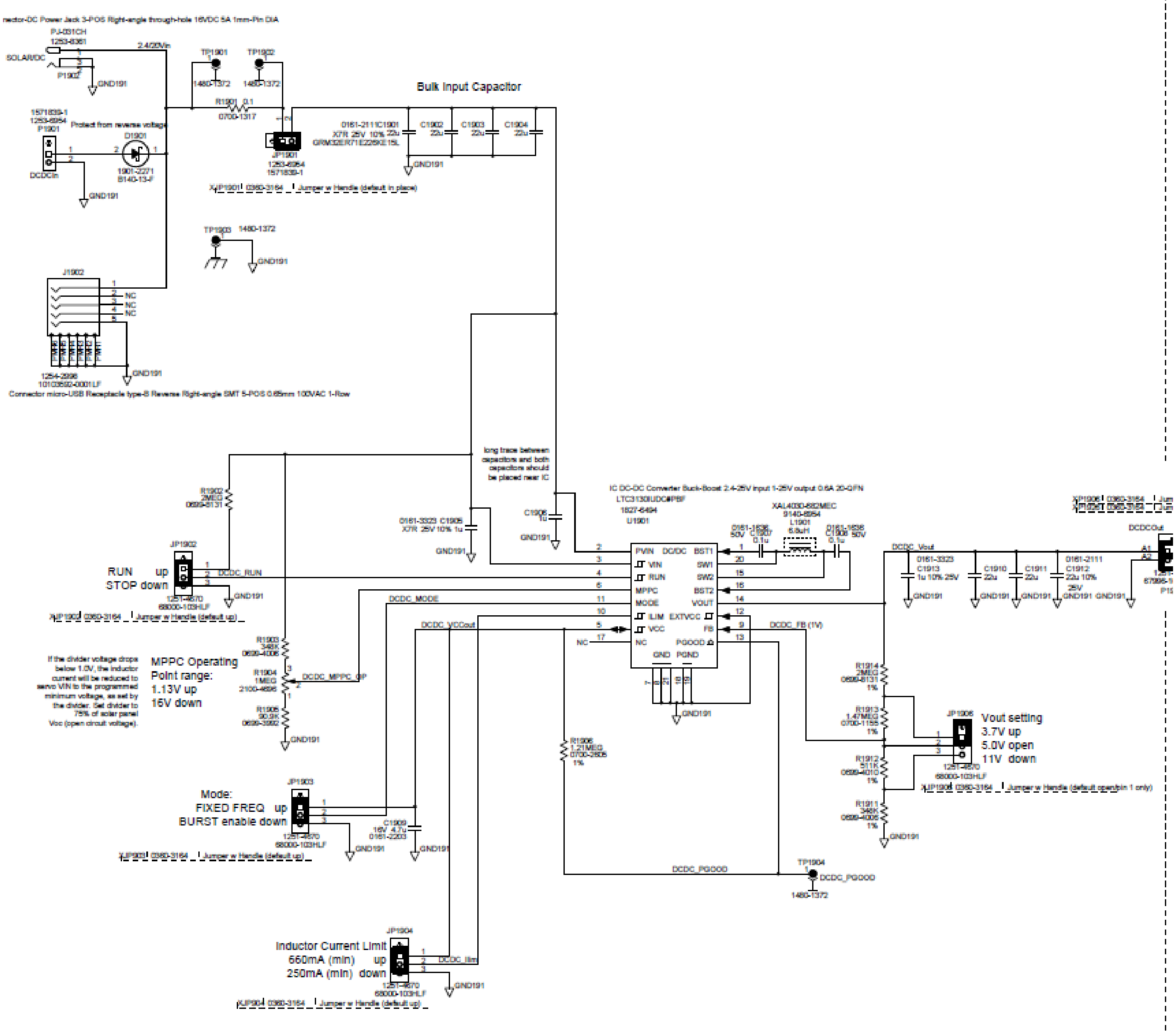
Q = I_{ave} x T = 74.8 mA x 6886 sec = 515 C

Zoomed Charge Voltage for a 3:00 hour charge cycle of a 9 V 200 mAhour NiMH Battery is shown below.



Detailed schematic of DC-to-DC Converter

2.4/20V, 600mA Buck-Boost DC/DC Converterwith 1.6µA Quiescent Current and MPPC



2.7/20V, 250mA Linear Charger with 4uA Quiescent Current

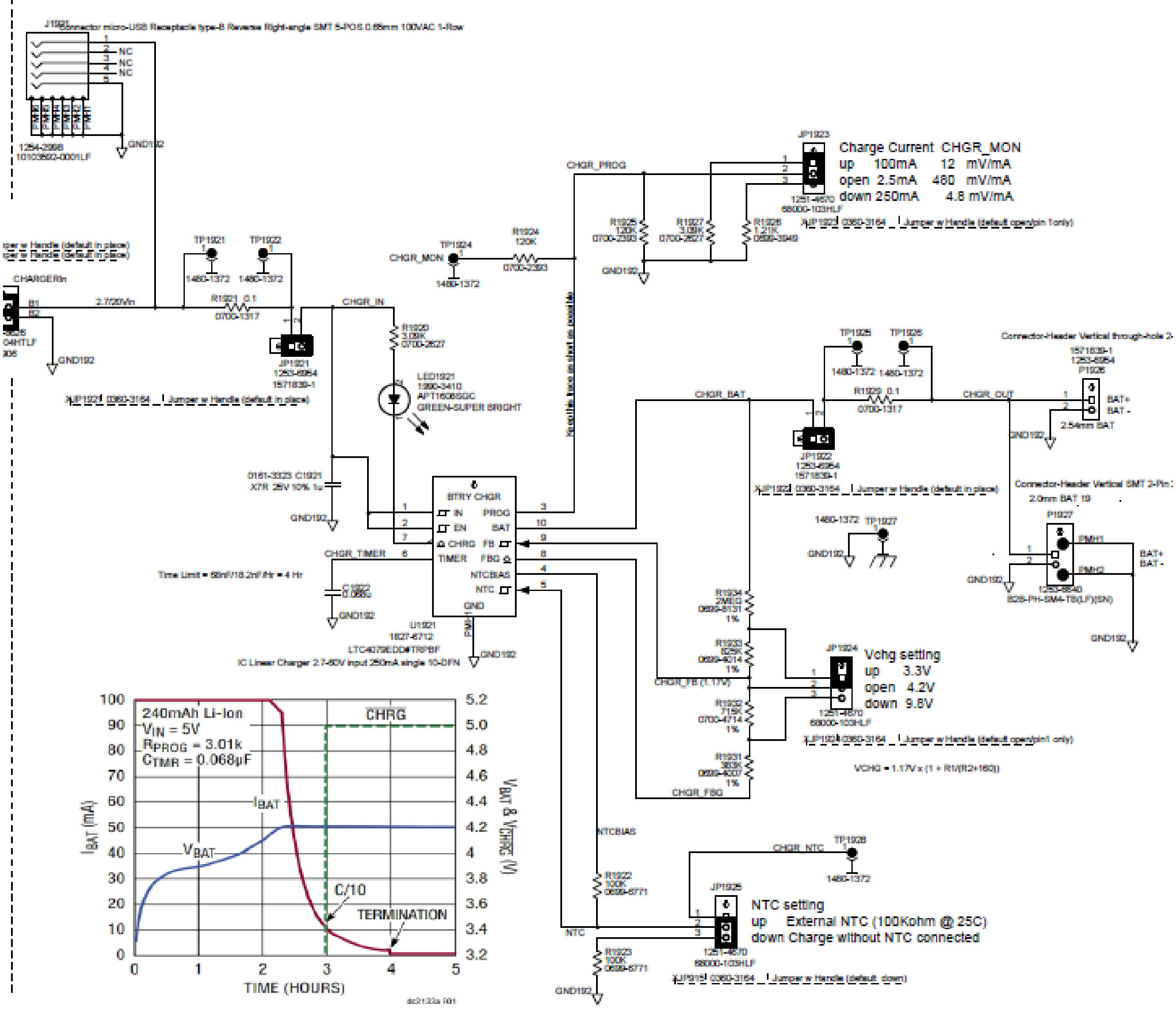


Figure 1. Typical Battery Charge Cycle

When charging the 9 V Battery, you will need to connect mini grabber leads from the charger output to the battery or the battery cable:

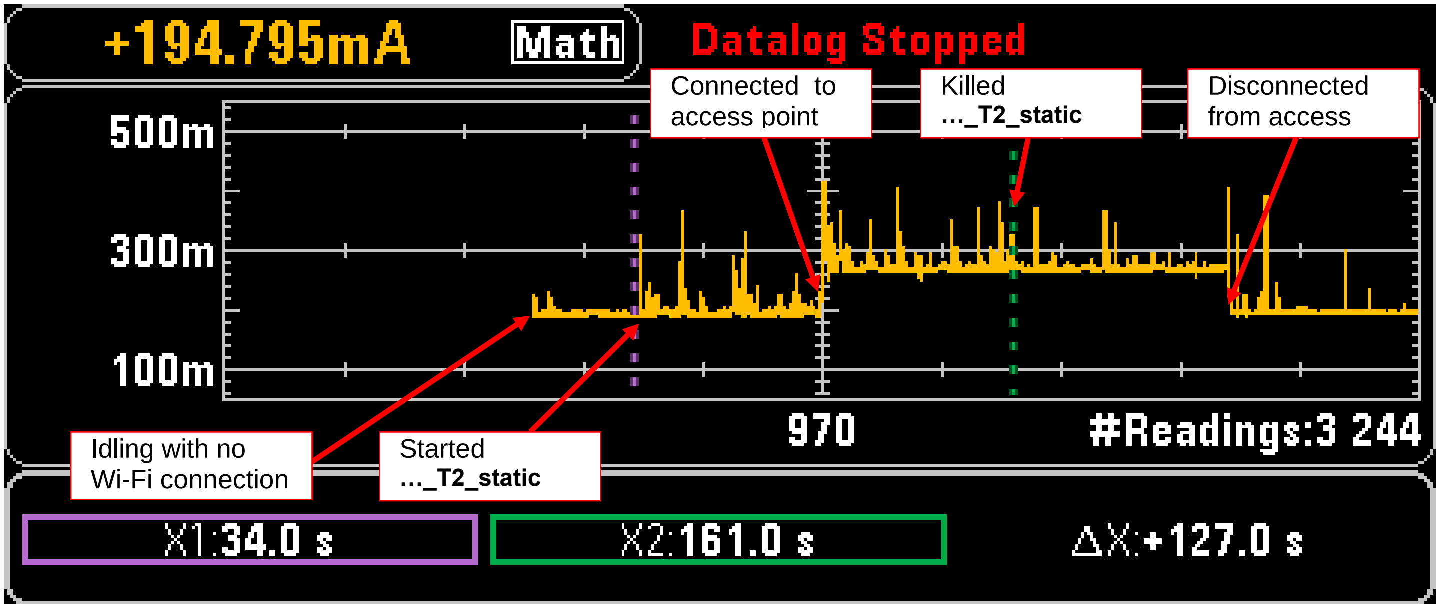
Appendix D – U3810A Full Schematic and Component Locator

The full schematic and the component locator diagrams can be found in the **./LabCode/** folder on the BeagleBone.

Appendix E – Effect of Wi-Fi Connection on Power Consumption

As you can see in the sample data log below (100ms sample rate is 10x faster than in Task 2 and 3), a connection to a Wi-Fi access point increases the BeagleBone current consumption dramatically.

- Running the program **…_T2_static** produces occasional current spikes when the XB transmits
- Connecting to an access point increases the static current nearly 100 mA



Connecting to a Wi-Fi Access Point

From Module 1 (U3813/14A) Lab 1 Task 1d – Configure BeagleBone to Connect to WLAN network:

Once this connection has been established for the first time, it will automatically connect back on subsequent reboots.

1. In the PuTTY terminal window, enter **`connmanctl`** to start the wireless connection manager.
2. Enter **`technologies`** to verify the WLAN function is available.

```
debian@beaglebone:~$ connmanctl
connmanctl> technologies
/net/connman/technology/p2p
  Name = P2P
  Type = p2p
  Powered = False
  Connected = False
  Tethering = False
/net/connman/technology/wifi
  Name = WiFi
  Type = wifi
  Powered = True
  Connected = False
  Tethering = False
/net/connman/technology/bluetooth
  Name = Bluetooth
  Type = bluetooth
  Powered = True
  Connected = False
  Tethering = False
connmanctl>
```

NOTE

– It is possible that you may see the following. This is an acceptable behavior and you may proceed:

```
debian@beaglebone:~/LabCode/M3-L7$ connmanctl
Error getting VPN connections: The name net.connman.vpn was not provided by any
connmanctl>
```

– If you see "Powered = False" for WLAN, then it means WLAN is disabled. Enter the **`enable wifi`** command to enable it.

3. Enter the **`scan wifi`** command to search the available networks.

```
connmanctl> scan wifi
Scan completed for wifi
```

4. Type the **`agent on`** command to turn on the connection agent.

```
connmanctl> agent on
Agent registered
```

5. Type the **services** command to view the available SSID’s.

```
connmanctl> services
    MRR management service wifi_#######_managed_psk
    dreamx               wifi_1234567890_managed_psk
    MRR Management 2     wifi_########_managed_psk
    PLAZZADPNG           wifi_########_managed_psk
    MRR Management       wifi_########_managed_psk
    MulhafArchitect      wifi_########_managed_psk
    GLOBAL@unifi         wifi_########_managed_psk
    ScienceExplorer      wifi_########_managed_psk
    HUAWEI-B618-1492     wifi_########_managed_psk
    TMSSB2016            wifi_########_managed_psk
    Myreka Office        wifi_########_managed_psk
    pgtopteam            wifi_########_managed_psk
```

6. Select and copy the desired SSID key, then type **connect** and paste the selected SSID key. For example:

   connect wifi_1234567890_managed_psk

   Note on Windows select the key and right-click. On Linux and MAC, you may use middle-click. Enter SSID passkeys if needed. The result should say “Connected ...”.

```
Agent RequestInput wifi_1234567890_managed_psk
  Passphrase = [ Type=psk, Requirement=mandatory, Alternates=[ WPS ] ]
  WPS = [ Type=wpspin, Requirement=alternate ]
Passphrase? w1f1p@55w0rd
Connected wifi_1234567890_managed_psk
```

   You may connect to a different Access Point using this method.

NOTE

The WLAN network id can be copy and pasted by using the mouse to highlight the section. On a Windows/PuTTY system, right-click the mouse to paste, and on a Linux system it would be middle-mouse-click. It might take two to three minutes to connect to the WLAN network.

7. Type **Ctrl + C** to exit **`connmanctl`**. Verify your connection with **`ping`** by entering **`ping www.keysight.com`** in PuTTY. Press the **Ctrl + C** on the keyboard to stop the ping process.

```
debian@beaglebone:/$ ping www.keysight.com
PING e7793.x.akamaiedge.net (23.66.248.80) 56(84) bytes of data.
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=1 ttl=52 time=102 ms
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=2 ttl=52 time=125 ms
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=3 ttl=52 time=256 ms
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=4 ttl=52 time=182 ms
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=5 ttl=52 time=102 ms
64 bytes from a23-66-248-80.deploy.static.akamaitechnologies.com (23.66.248.80):
icmp_seq=6 ttl=52 time=127 ms
^C
--- e7793.x.akamaiedge.net ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5007ms
rtt min/avg/max/mdev = 102.375/149.384/256.170/54.741 ms
^Cdebian@beaglebone:/$
```

You might see error or failure in name resolution possibly due to your local network firewall. In this case, it is recommended you use your own mobile hotspot as the internet access for BeagleBone.

NOTE

In case you run into the following problem while setting up WLAN for example

connmanctl> scan wifi

Error /net/connman/technology/wifi: Did not receive a reply.

Possible causes include: the remote application did not send a reply, the message bus security policy blocked the reply, the reply timeout expired, or the network connection was broken. Try the steps below.

connmanctl> tether wifi disable

Disabled tethering for wifi

connmanctl> enable wifi

Error wifi: Already enabled

connmanctl> scan wifi

Scan completed for wifi

Disconnecting from a Wi-Fi Access Point

Once a network connection has been established, it will automatically connect back on subsequent reboots. You may disconnect once from inside **connmanctl** using the **disconnect wifi_1234567890_managed_psk** command. However, it will reconnect when the CPU next reboots.

To permanently remove the network connection, you must delete the network file:

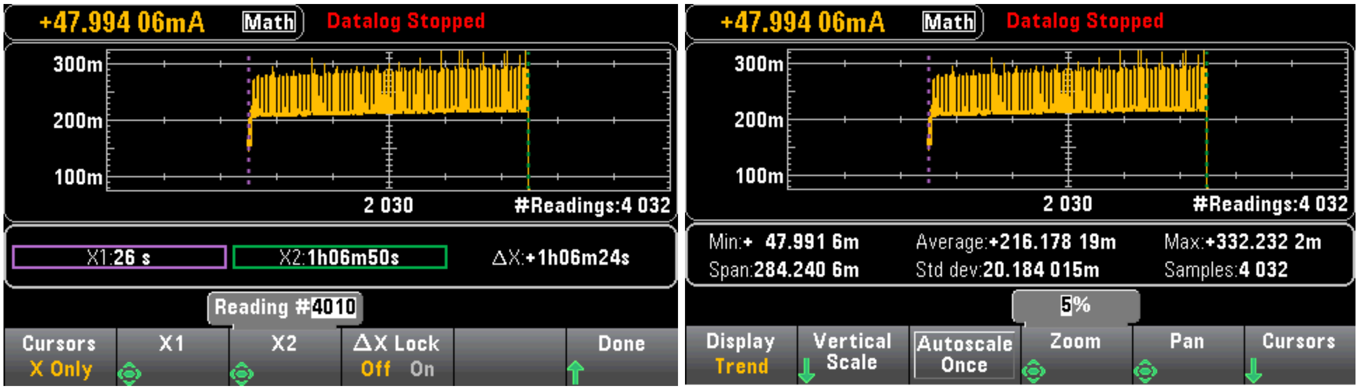
```
debian@beaglebone:/var/lib/connman$ ls
settings  wifi_1234567890_managed_psk
debian@beaglebone:/var/lib/connman$
```

```
sudo rm -Rf /var/lib/connman/wifi_1234567890_managed_psk
```

WARNING Do not remove the file named **settings**.

Measurement Examples with Wi-Fi Disconnected for Task 2 DMM / R1

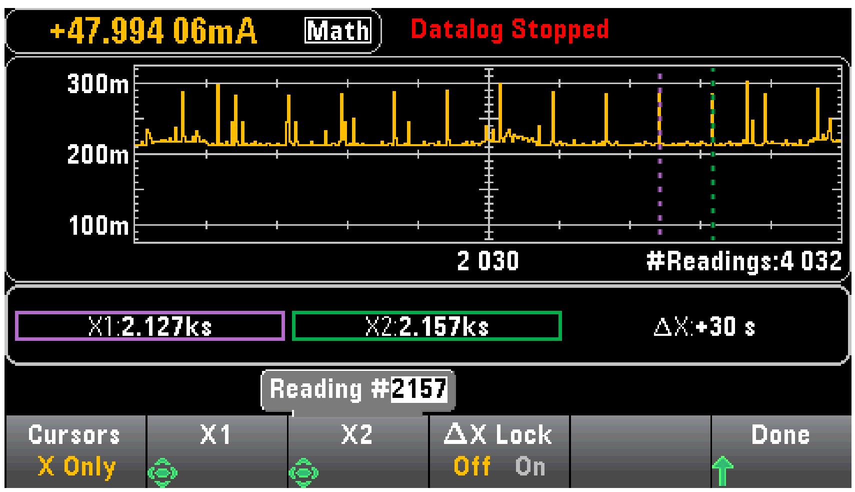
Here is an example with the 3.7 V 400 mAhour LiPo Battery with Wi-Fi disconnected, note how the average current has decreased from 300 mA with Wi-Fi connected, but note also that the peaks still reach 300 mA. Data logging was stopped immediately after the BeagleBone CPU stopped.



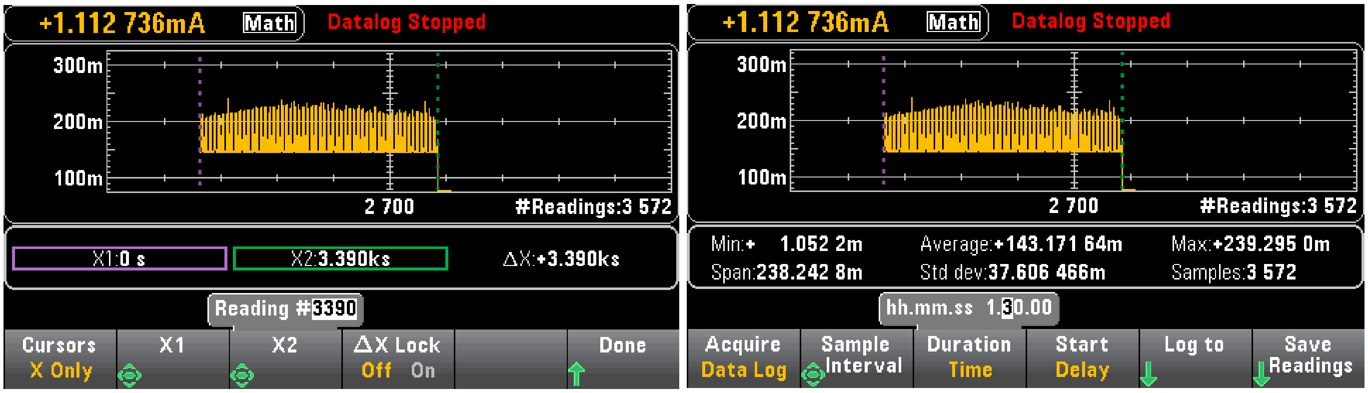
The 3.7 V 400 mAhour LiPo Battery with Wi-Fi disconnected – the left screen shows Cursers, right shows Statistics.

> ΔX = 3984samples/60samples/min = 1 hour 6 min 24 sec
> Q = I_{ave} x T = 216 mA x 3984 sec = 861 C

Here is a **Zoom**ed in and **Pan**ned trace showing the 30 sec time between Wi-Fi scans (Wi-Fi still disconnected):



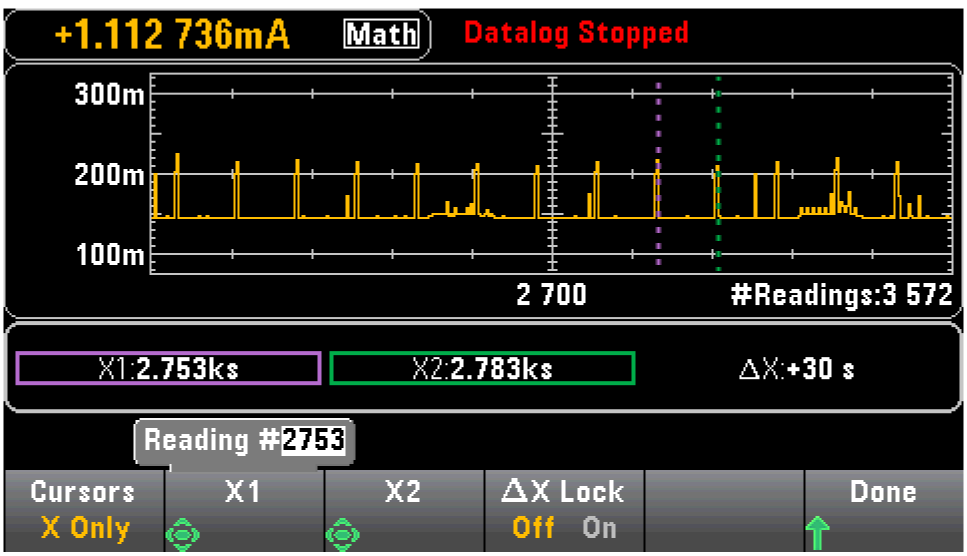
Here is an example with the 9 V 200 mAhour NiMH Battery with Wi-Fi disconnected, note how the average current has decreased from 220 mA with Wi-Fi connected, but note also that the peaks still reach 220 mA. Data logging was stopped immediately after the BeagleBone CPU stopped.



The 9 V 200 mAhour NiMH Battery with WiFi disconnected – the left screen shows Cursers, right shows Statistics.

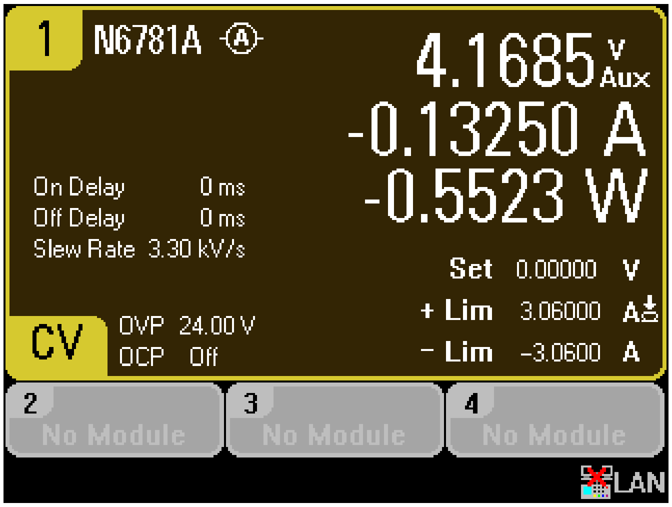
ΔX = 3390samples/60samples/min = 56 min 30 sec
Q = I_{ave} x T = 143 mA x 3572 sec = 511 C

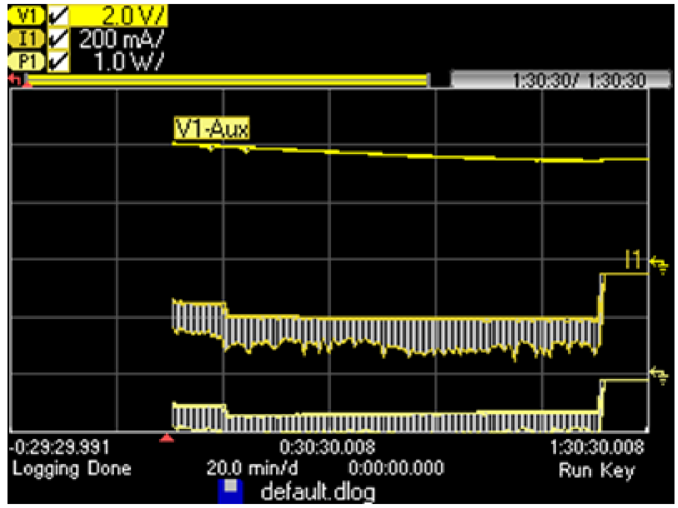
Here is a **Zoom**ed in and **Pan**ned trace showing the 30 sec time between Wi-Fi scans (Wi-Fi still disconnected):



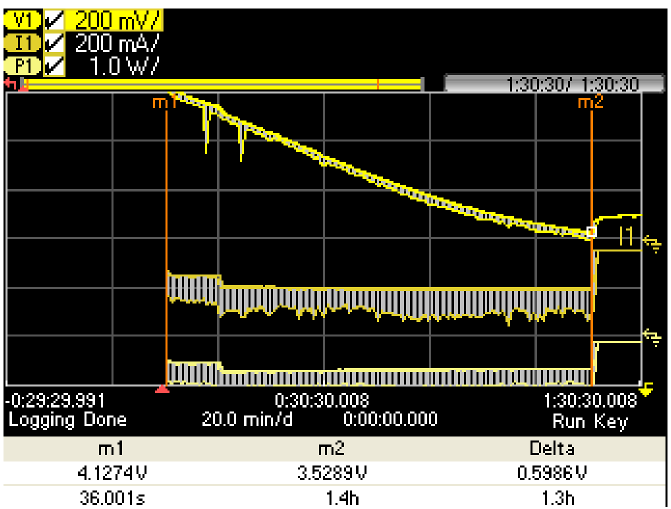
Measurement Examples with Wi-Fi Disconnected for Task 3 DCPA

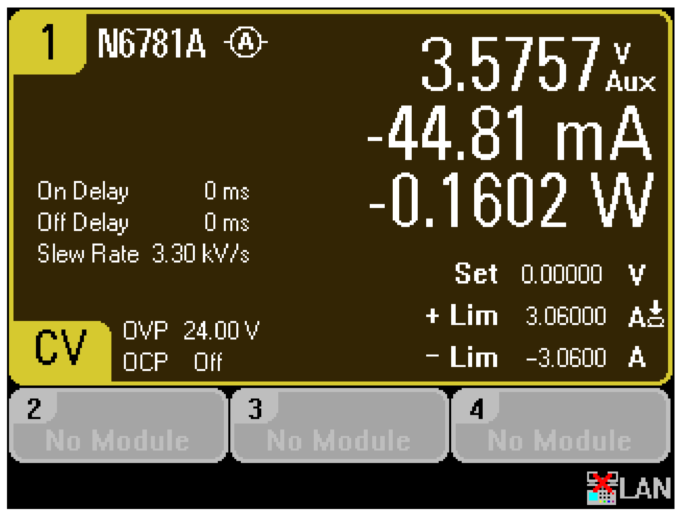
Here is an example for the **400mAH 3.7 V LiPo Battery**, Wi-Fi disconnected, **XJP55 is in place**:





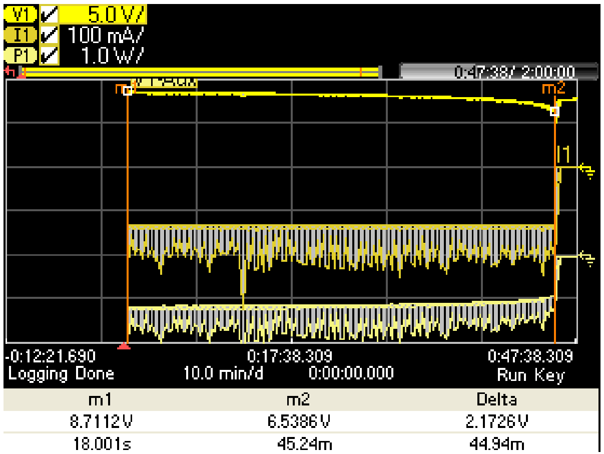
At the completion of the same data log above, here is an expanded view (using the **Volts/Div** and **Offset** knobs) of the battery voltage with 3.5 V at the center of the vertical axis (the zero/gnd indicator is off the bottom of the screen), and the static voltage and current at the end of the data log

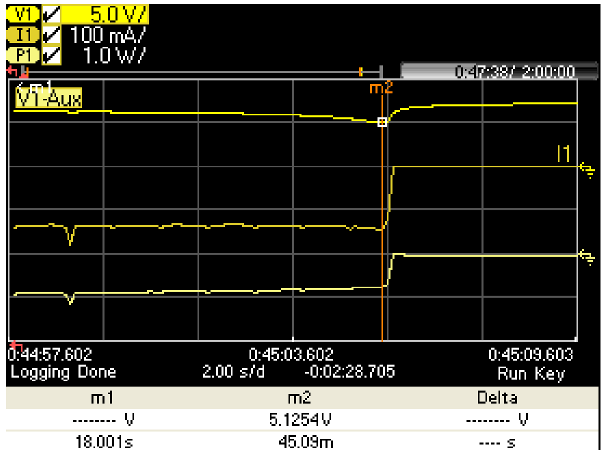




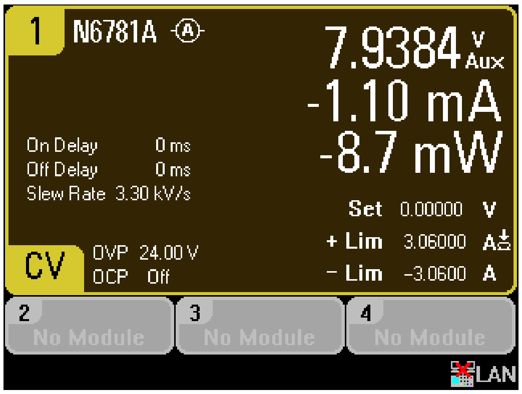
The operating time has been extended from 50 min to 80 min. The Meter View above on the right shows 3.57 V at 44.8 mA shutdown/off current after the BeagleBone has been shut down for five minutes.

Here is an example for the **200mAH 9V NiMH**, Wi-Fi disconnected, XJ55 is removed:

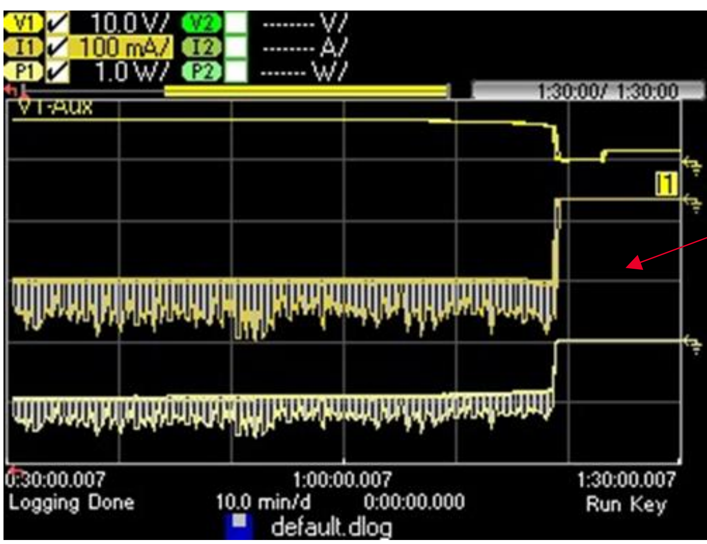




The current of 130 mA permits the operating time to be reduced to 45 minutes since the 9 V NiMH Battery is lower capacity than the 3.7 V LiPo. The expanded view above right shows the shutdown event at Battery voltage of 5.13 V (this is reduced by D2 and U1 to 3.4 V at +5VRAW). The Meter View below shows 7.9 V at 1 mA shutdown/off current after the BeagleBone has been shut down for 5 minutes. D2 and1 provide too much voltage drop to allow the 44.8 mA "standby current":



Here is an example for a **500mAH 9V LiPo**, Wi-Fi disconnected, XJ55 is removed. As this battery is composed of two series LiPo cells its actual operating voltage is 7.4 to 8.4 V. This is provided here for reference only and there is no other measured data for this battery in the lab.



Sensor node stops functioning after 79 minutes.

Note also that the current is measured as negative since current out of the DCPA's **Output+** terminal, as a power supply, is defined as positive, but in this measurement the current flow into the DCPA's **Output+** terminal. Also, V1, the battery voltage, is smooth while I1 and P1 contain surges as the CPU current varies as it processes.

The beginning of the trace has scrolled off he left side of the screen.

References

[1] Digital Multimeter Datasheet
https://www.keysight.com/us/en/assets/7018-03846/data-sheets/5991-1983.pdf

[2] Evaluating Battery Run-Down with the N6781A or N6785A 2-Quadrant Source/Measure Unit and the BV9200B Control and Analysis Software
https://www.keysight.com/us/en/assets/7018-02880/application-notes/5990-7370.pdf

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