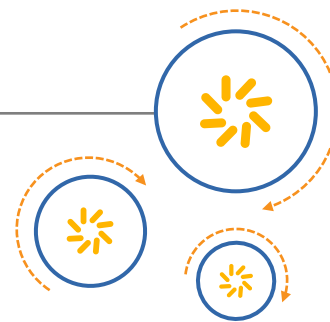




Qualcomm Technologies, Inc.



Measuring Power Consumption for DragonBoard™ 410c based on the Qualcomm® Snapdragon™ 410E processor

Application Note

LM80-P0436-48 Rev C

December 4, 2017

For additional information or to submit technical questions, go to:

<https://discuss.96boards.org/c/products/dragonboard410c>

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Revision history

Revision	Date	Description
A	February 2016	Initial release
B	September 2016	Update to 'E' part
C	December 2017	5.2 Steps to attach the energy probe to J10

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1 Introduction

1.1 Purpose

This document contains a description of the chipset capabilities. Not all features are available, nor are all features supported in the software.

NOTE: Enabling some features may require additional licensing fees.

The power consumption for modern SoC processors is dependent upon the software running on the processor. During the software development process, it is recommended to check the power consumption of the system while the actual software is running.

This application note shows several methods of measuring the power consumption of either the whole system or just a portion of the system using example of DragonBoard 410c board based on the Qualcomm® Snapdragon 410E processor.

1.2 Acronyms, abbreviations, and terms

[Table 1-1](#) provides definitions for the acronyms, abbreviations, and terms used in this document.

Table 1-1 Acronyms, abbreviations, and terms

Term	Definition
ASIC	Application specific integrated circuit
ARM	Asynchronous response mode
BT	Bluetooth
DRAM	Dynamic random-access memory
GPS	Global positioning system
HDMI	High definitions multimedia interface
I2C	Inter-integrated circuit
JPEG	Joint photographic experts group
MMC	Multimedia card
PNG	Portable network graphic
SD	Secure digital
SoC	System on a chip
USB	Universal serial bus

1.3 Basics of power measurement

The power consumption of a device can be computed by current and voltage. The power consumption of the system (in Watts) is the product of the current (in Amps) and the voltage (in Volts). Throughout this document, we use the symbols ‘P’ for Power, ‘I’ for current, and ‘V’ for voltage.

$$P = I \times V$$

Measurement of current can be done two ways; either directly with an ammeter, or indirectly by measuring the voltage drop across a shunt resistor that is in series with the power supply and the load. Voltage across the shunt resistor is called as ‘ v_s ,’ and the resistance of the shunt resistor as ‘ R_s ’. Using Ohms law, we can compute the current flowing through the shunt resistor as follows:

$$I = V_s / R_s$$

For best accuracy, measure the supply voltage at the same time as the current (because both the current and voltage are varying with time); however, an approximate power consumption of the device can be computed by simply using the known nominal value for the supply voltage.

1.4 DragonBoard 410c power distribution overview

The DragonBoard 410c power subsystem is divided into three major areas:

1. **The DC input jack:** Supplies the power to the DragonBoard 410c and to the attached peripherals (HDM Monitor, USB devices, mezzanine cards, and so on). Measuring the power consumption at this point gives an overall power consumption value.
2. **The compute core:** The power consumption of the compute core, such as the processor, DRAM memory, eMMC storage, SD card, Bluetooth/Wi-Fi, GPS can be measured independently for the overall system power. The software designer has the most control in these areas and can optimize the system power consumption.
3. **The 5 V peripherals:** The power consumption of the 5 V peripherals such as the USB ports, HDMI, mezzanine cards are dependent on the devices attached to the DragonBoard 410c. The software designer does have some control of these areas by controlling options, such as putting attached USB devices into sleep mode.

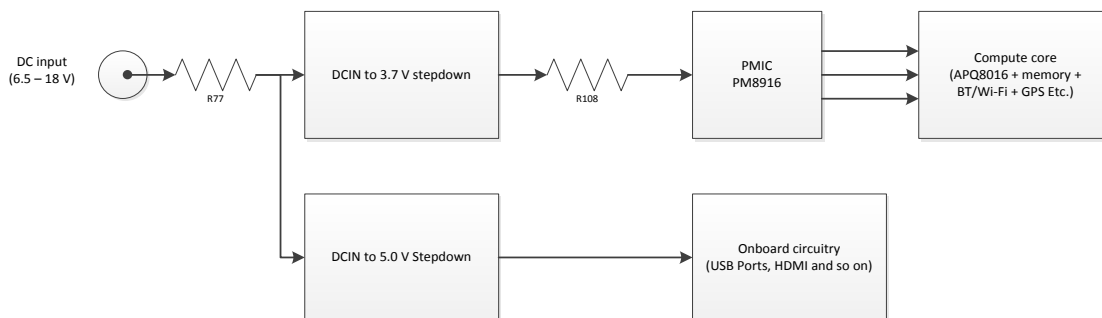


Figure 1-1 DragonBoard 410c power subsystem

The power consumption for the system can be measured at three main points:

1. **At the DC input connector:** This gives total consumption of the system including all peripherals attached.
2. **Across R77:** This gives the same values as measuring the power consumption at the DC Input connector; however, the electrical connections may be more convenient.
3. **Across R108:** This gives only the core power, which is useful for the software designers, and eliminates the influence of the attached peripherals. Eliminating the peripherals makes it easier to compare results between different system setups or between tests performed in different geographic locations.

2 Measuring power consumption with an ammeter

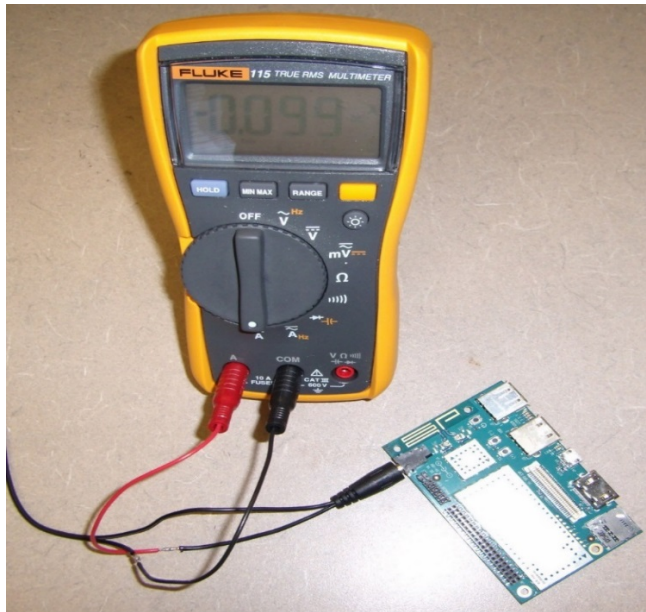
2.1 Purpose

The purpose of an ammeter is to measure the power consumption at the DC input. As the meter, cannot simultaneously measure the supply voltage, it is necessary to use the nominal supply voltage. In this case, the nominal supply voltage is 12 V from the standard power supply, in the computation of power consumption.

2.2 Steps to set up an ammeter

Perform the following steps:

1. Connect the ammeter in series with the positive supply lead and with the alligator clips or any other convenient method as shown in the figure:



NOTE: It is difficult to identify which of the two black wires is the positive voltage. It is not important to measure the current flow into the device (on the positive lead) or the current flow returning from the device (on the negative lead). The results are same, either ways.

2. Identify the positive lead wire to use the more advanced measurement techniques using an Ohmmeter.
3. The resistance between the center conductor on the power barrel connector and the wire you cut are close to 0 Ω .

For more information on the advanced measurement techniques, see the subsequent chapters in this document.

2.3 Computations

The total power consumption is: the measured current (0.099 Amps) multiplied by the nominal voltage (12 V). In this case $P = I \times V = 0.099 \times 12 = 1.188$ W. The actual consumption depends on the software being running.

The reading is a ‘negative’ number in the example. The polarity of the connections to the ammeter changes the polarity of the measurement. If there is a negative reading, ignore the sign of the reading. Else, swap the leads into the ammeter to produce a reading with the correct sign. If the ammeter cannot read negative currents, then swap the two-measurement leads.

Since this is a measurement of the total system power, in addition to the operating software and the devices attached to the system.

For example: the keyboards, HDMI monitors, mice, SDCards, and mezzanine boards all consume power from the system supply and are included in the observed measurement.

Note: Though the instant power consumption is constantly changing, the ammeter updates its readings relatively slow (one or two times per second). This is a normal behavior where the ammeter readings will likely not be stable.

3 Power measurement with INA219

3.1 Purpose

This chapter describes on how to use a readily available INA219 breakout board. The INA219 chip is a complete power measurement system on a chip. There are several more advanced ways to measure the power consumption beyond using an ammeter and voltmeter. This chapter shows how to connect the breakout board. A subsequent chapter shows how to set up the software under Debian Linux to display the power measurements. A simple test that causes the power consumption to increase is also described and can be used to verify that the INA219 is correctly connected.

3.2 Before you begin

3.2.1 Equipment required

- 96Boards sensors mezzanine card:

<https://www.96boards.org/product/sensors-mezzanine>

- I²C jumper cable:

<http://www.seeedstudio.com/depot/Grove-4-pin-Female-Jumper-to-Grove-4-pin-Conversion-Cable-5-PCs-per-PAck-p-1020.html>

- INA219 breakout board:

The INA219 breakout board is a complete power measurement system available from many suppliers at relatively low cost. In this chapter, we use the following specific implementation: <https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/overview>.

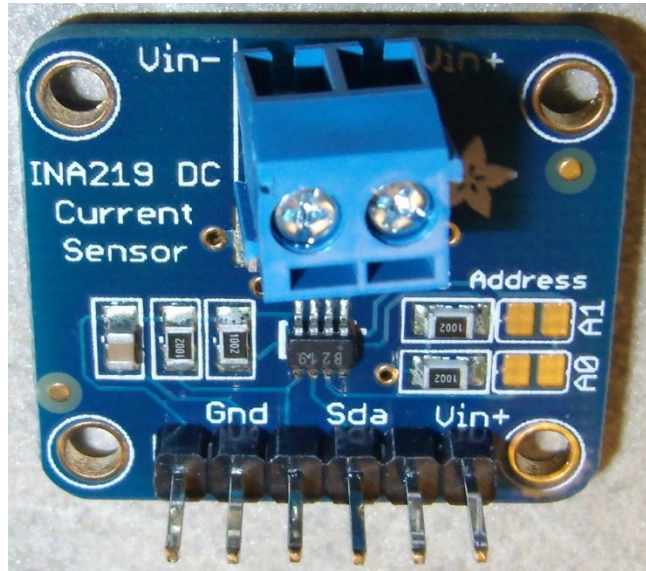
Ensure to assemble the breakout board and connect the I²C measurement port to the DragonBoard 410c.

3.3 Steps to set up a 96-boards sensors mezzanine board

Perform the following steps:

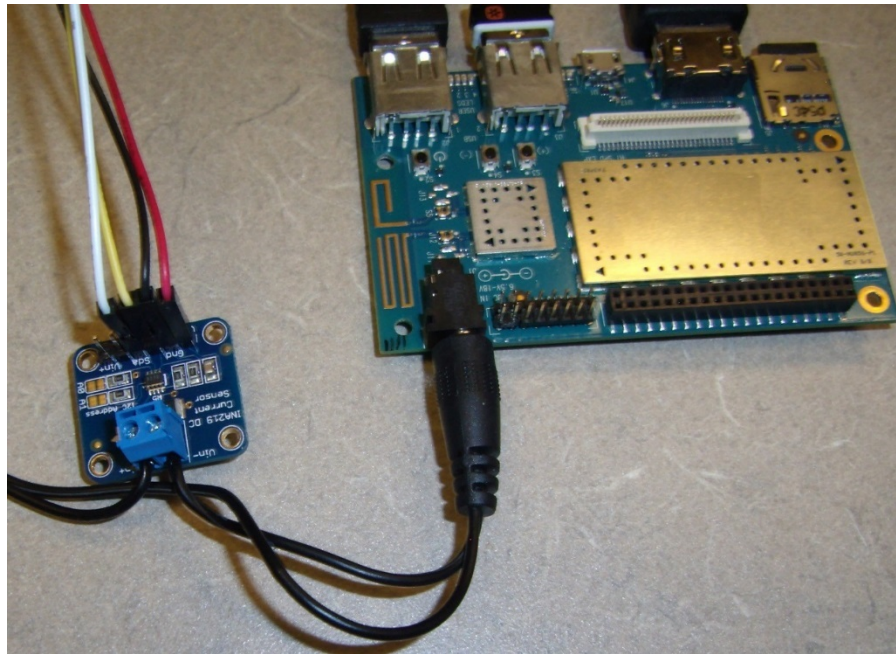
1. Attach the 96-boards sensors mezzanine board to the DragonBoard 410c.
2. Connect the I²C cable to the mezzanine board on one of the two I²C0 connectors.
3. Assemble the INA219 board as shown in the following AdaFruit instructions:
<https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/assembly>

Result: Once assembled, the board must look like as follows:



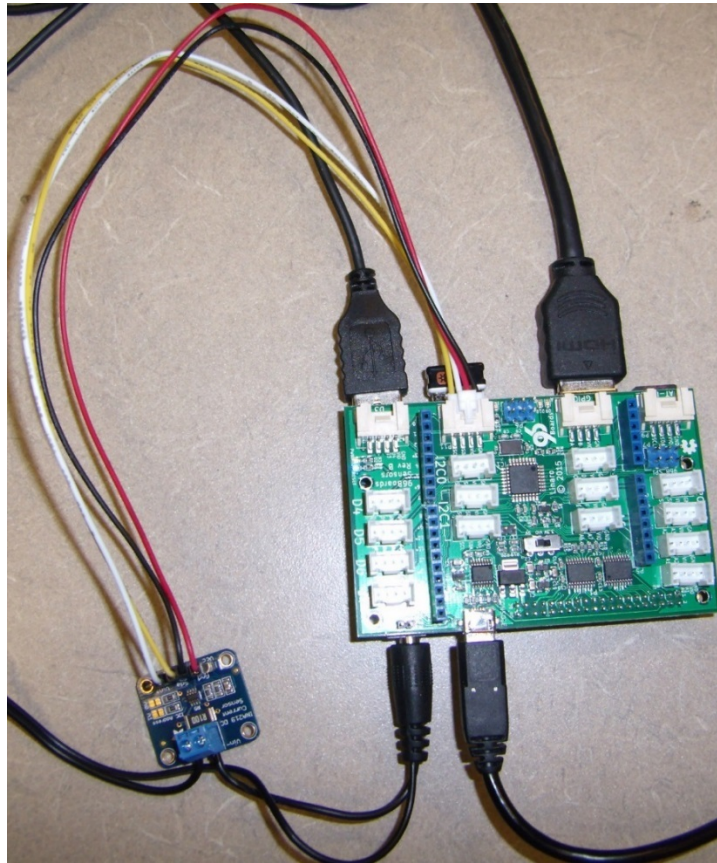
4. Connect the wires and the power supply to the INA219 current sensor breakout.

5. Connect the 12 V supply lead to the Vin+ terminal and the 12 V lead connected to the DragonBoard 410c to the Vin- terminal as shown in the following figure:



6. Connect the power and the I²C signals from the DragonBoard 410c board to the INA219 current sense breakout as follows:
 - a. +5 V (red wire)
 - b. GND (black wire)
 - c. SCL (clock, yellow wire)
 - d. SDA (data, white wire)

7. Connect the cable to the mezzanine board on the I²C0 connector.



8. Set up the software, as described in the Chapter 7.

3.4 Measure the entire system power with the onboard shunt resistor

The DragonBoard 410c has an onboard current measurement resistor R77 as shown in the schematic. It is possible to measure the voltage across this resistor and compute the current consumption. The current consumption can then be multiplied by the supply voltage to determine the system power consumption. In this section, we remove the shunt resistor from the INA219 breakout board and use R77 on the DragonBoard instead for the current measurement.

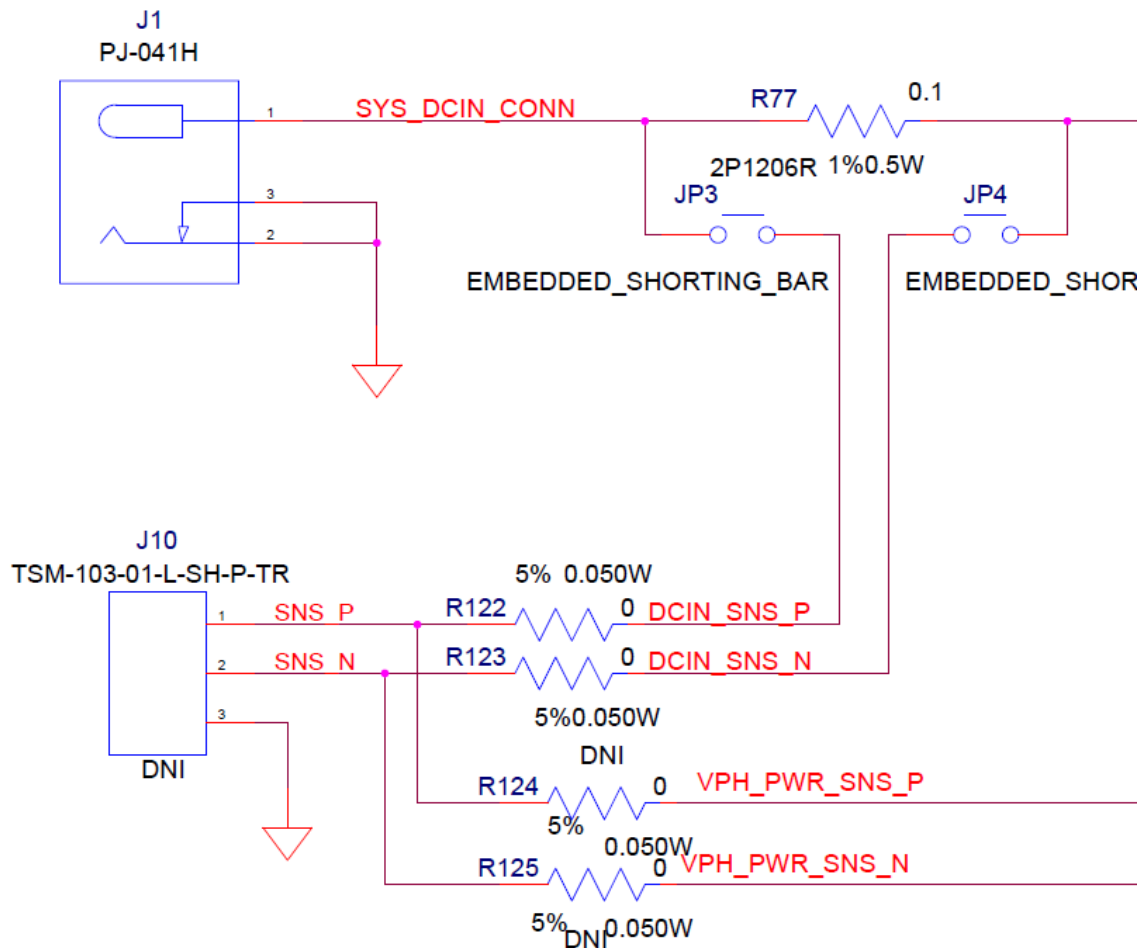


Figure 3-1 Onboard current measurement resistor (R77)

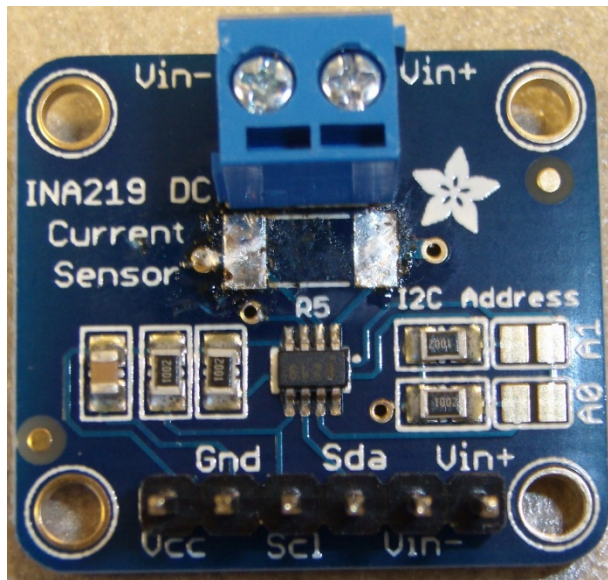
3.5 Steps to use the R77 on the DragonBoard

3.5.1 Before you begin

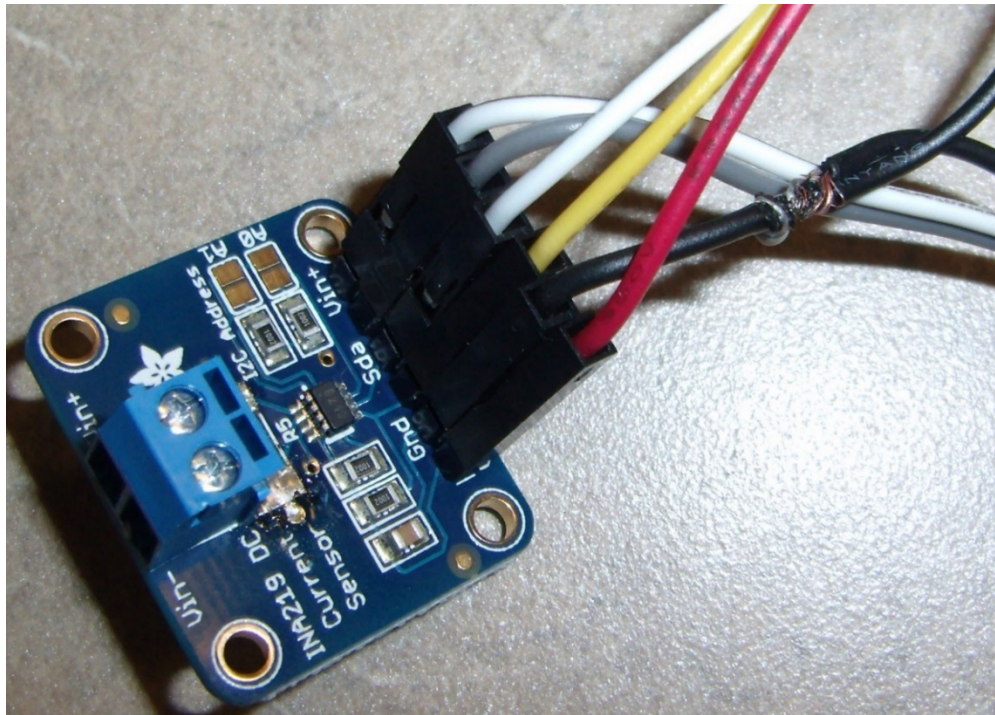
The following procedure requires basic soldering skills and the use of a soldering iron. A detailed training is beyond the scope of this document; however, the training can be found online.

Perform the following steps:

1. Remove the 0.1 Ω shunt from the INA219 current sense breakout. Note how R5 (the current shunt resistor) has been removed.

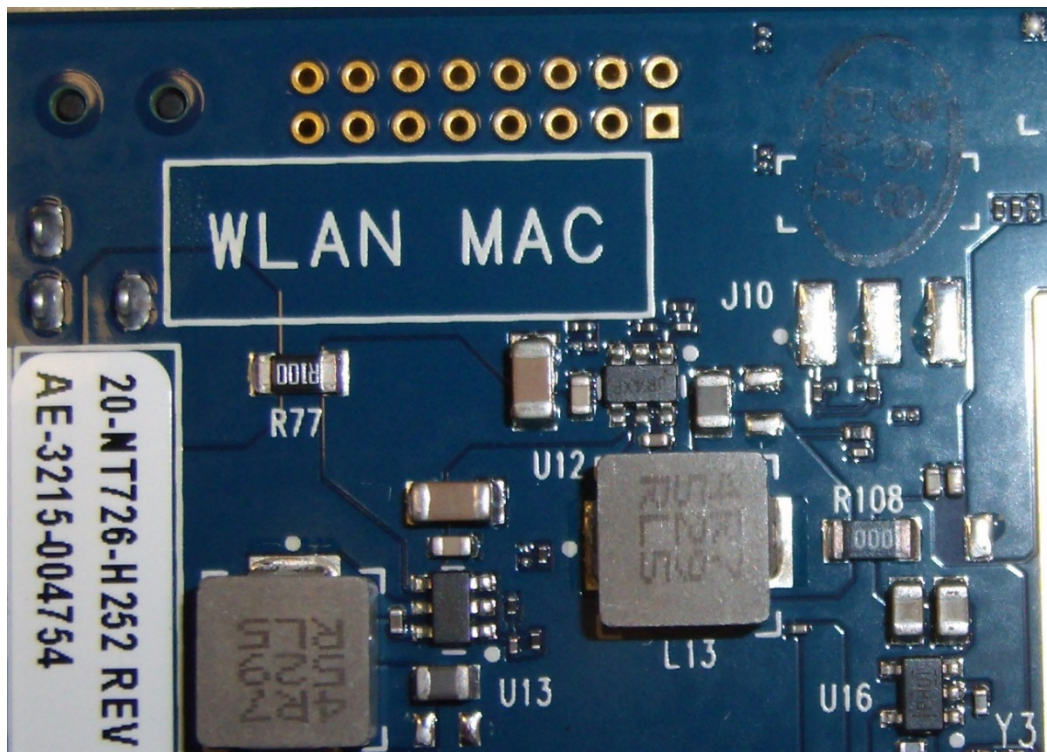


2. Attach the current and the voltage sense leads to the INA219 breakout board as shown in the following figure:

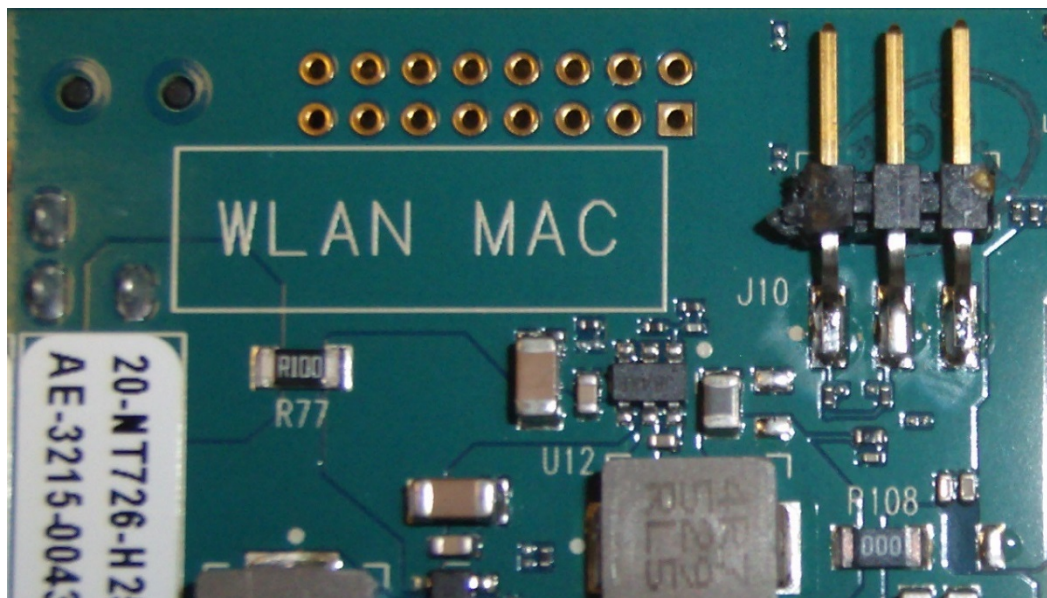


NOTE: These leads are of standard 0.1" female jumper wires. The colors of the wires are not important.

3. The DragonBoard 410c does not have J10 connector installed, as delivered from the factory.

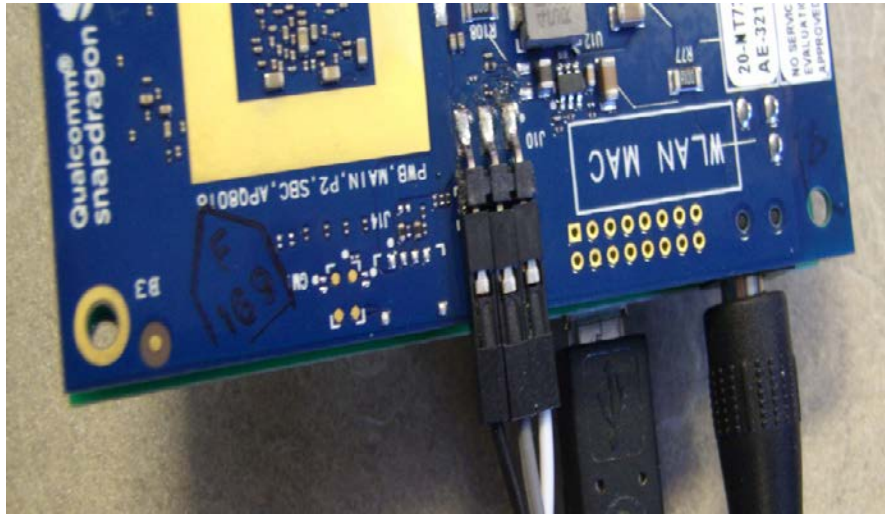


4. Install the J10 as shown in the following figure:

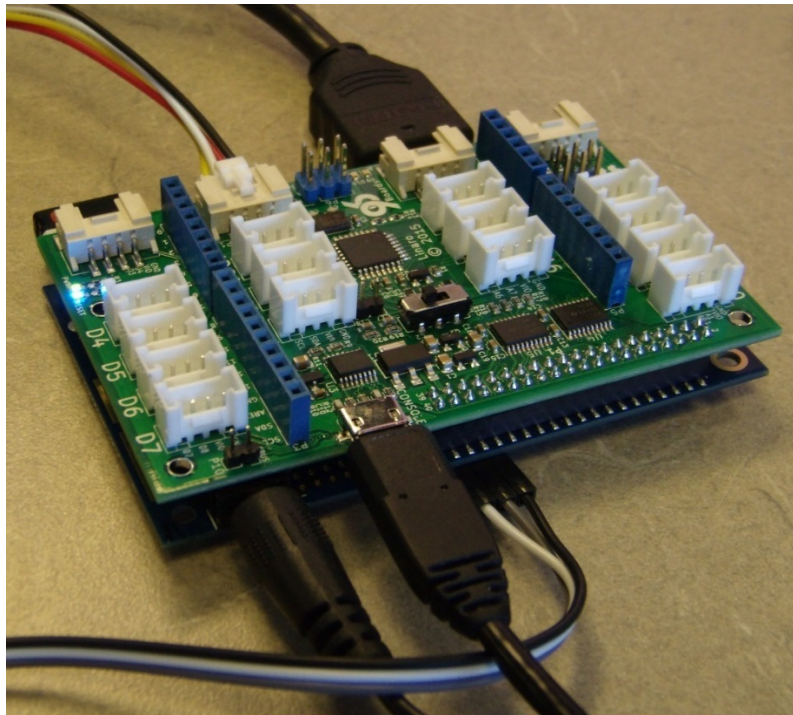


NOTE: When soldering on J10, do not disturb the tiny components on the board located near J10. This step requires basic soldering skills.

5. Connect the current monitor points to the DragonBoard 410c.



6. Connect the power and I²C signals from the DragonBoard 410c to the INA219 current sense breakout.



4 Monsoon power supply and measurement

4.1 Purpose

Measurement of the power consumption of just the core chips is possible using a monsoon power supply with measurement capability. An advantage of the monsoon is the ability to profile power across a use case. Monsoon provides software that runs on Microsoft windows that generates a nice graph.

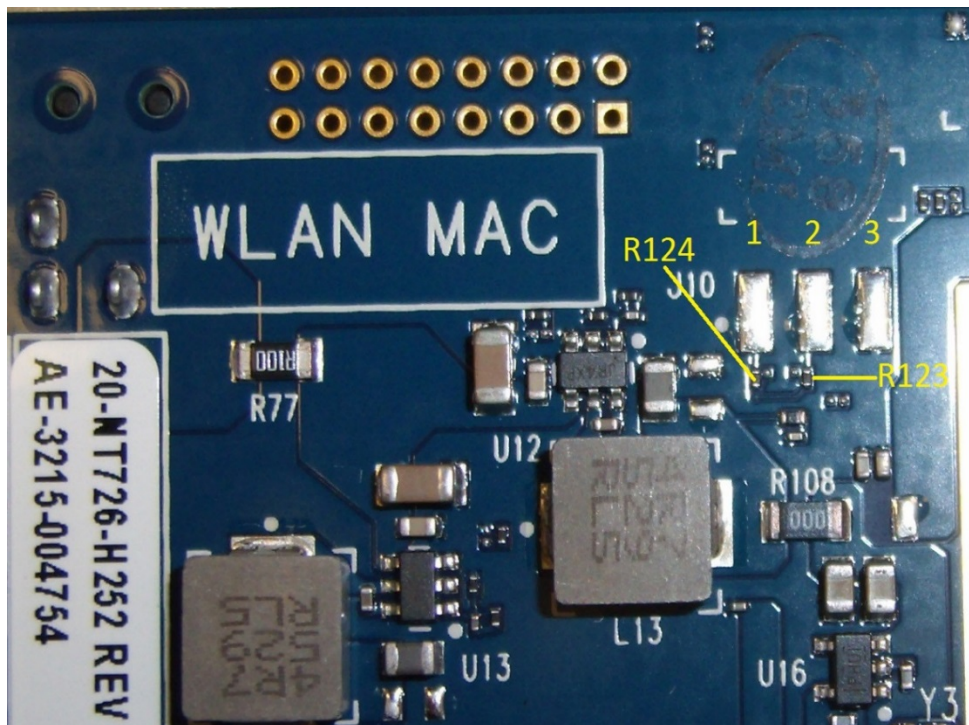
The monsoon box can only output a maximum of 4.5 V. This is not enough to operate the entire DragonBoard 410c as the DragonBoard requires 6.5 V to 18 V. Hence the monsoon box can only be used to measure the core chips.

For more information, see <https://www.monsoon.com/>

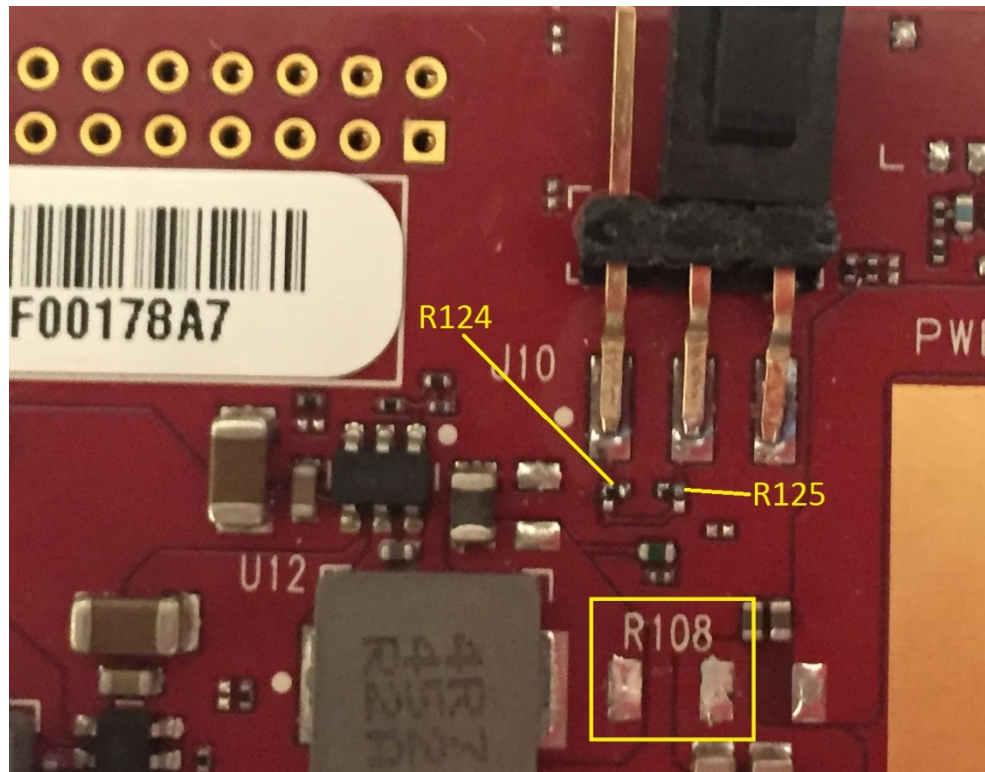
4.2 Steps to use the Monsoon box on the DragonBoard 410c

Perform the following steps:

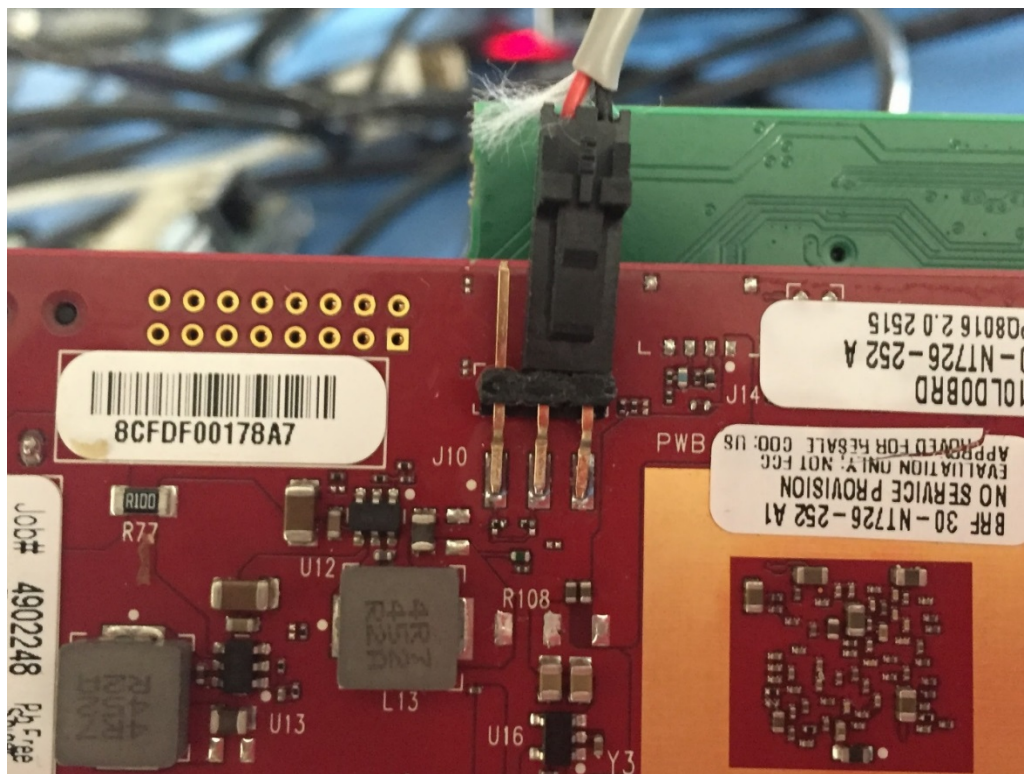
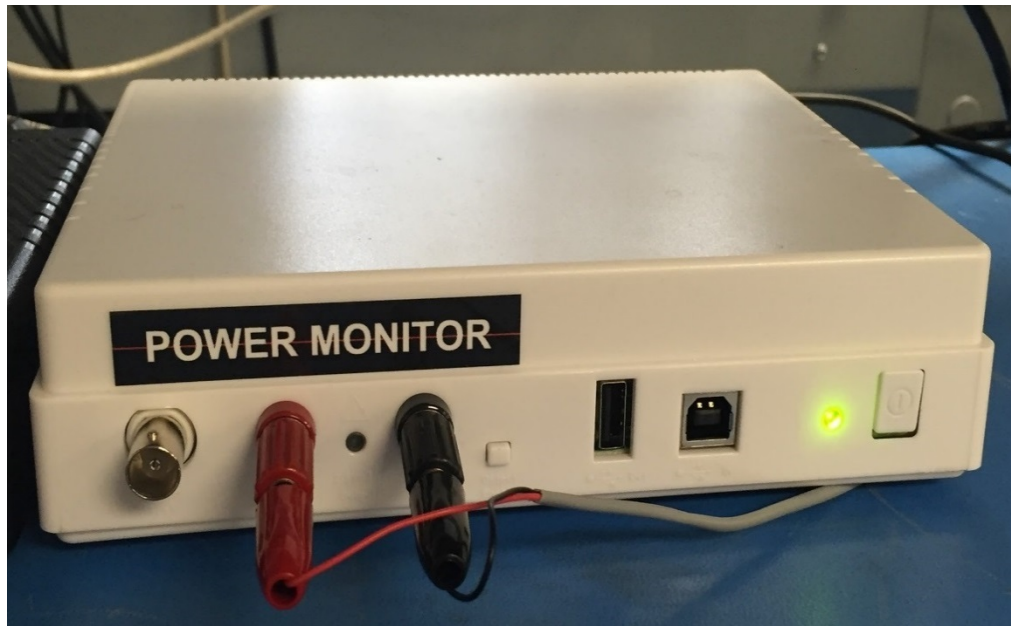
1. Install the J10 connector.
2. Remove R108, R122, and R123 resistors, respectively.



3. Install the R124 and R125 resistor (because R124 and R125 are 0 Ω resistors, a solder short works fine).



4. Connect the monsoon positive lead to J10 pin 2.
5. Connect the monsoon negative lead to J10 pin 3.
6. Ensure that the 12 V supply is also connected. The monsoon box supplies and measure the compute core circuits, but not the input/output chips; for example, the USB hub, ports, HDMI, and so on.



4.3 General description

The onboard switching supply provides the 3.7 V power to the PM8916 PMIC (power management IC). However, in the installation steps we removed R108 resistor. Once the R108 is removed, the onboard 3.7 V supply is disconnected and will no longer provide power to the PM8916. There is an option to undo the change and use the board without the monsoon by putting a jumper across J10 pins 1-2, as shown in the following figure:



The monsoon is not just a current measurement device. It is also a power supply. The monsoon takes over the task of supplying 3.7 V power to the onboard PM8916. Hence, we connect the power output of the monsoon to the J10 connector pin 2 and the return to J10 connector pin 3, which is conveniently ground.

On the DragonBoard 410c, the switching power supply provides 3.7 V. Ensure that you set the monsoon also to provide 3.7 V. However, the wires between the monsoon and the DragonBoard 410c are not ideal wires, hence have a significant voltage drop. This voltage drop causes the PMIC to brown-out when it draws much current.

Workaround

The workaround to the brown-out issue is to turn up the output of the monsoon so that the PM8916 will still see at least 3.3 V even under brown-out conditions. A fully charged lithium-ion battery of 4.2 V is programmed into the monsoon.

5 ARM energy probe

5.1 Purpose

The ARM energy probe is convenient, but not necessary. The ARM energy probe is about ¼ of the cost of the monsoon box. To use the ARM energy probe, install the J10 connector (see steps in Section 3.4.1). Once the J10 connector is installed, attach the energy probe to J10.

5.2 Steps to attach the energy probe to J10

Perform the following steps:

1. Install J10 connector.
2. Connect the ARM energy probe ground lead to J10 pin 3.
3. Connect the ARM energy probe positive lead to J10 pin 2.
4. Connect the ARM energy probe negative lead to J10 pin 1.
5. Ensure that the 12 V supply is also connected. In this set-up, the ARM energy probe measures the power consumption of the ‘compute core’ circuits and the input/output devices including the USB ports.

To measure just the core power consumption with the ARM energy probe, make the following changes to the DragonBoard 410c:

1. Install J10.
2. Remove R108, R122, and R123 resistors, respectively.
3. Install R124 and R125 (since R124 and R125 are 0 Ω resistors, a solder short works fine).
4. Install a 0.1 Ohm resistor for R108.
5. Connect the ARM energy probe ground lead to J10 pin 3.
6. Connect the ARM energy probe positive lead to J10 pin 2.
7. Connect the ARM energy probe negative lead to J10 pin 1.
8. Ensure that the 12 V supply is also connected. In this set-up, the ARM energy probe will only measure the ‘compute core’ circuits, but not the input/output chips like the USB ports.

6 Rebuild the kernel with support for the INA219

6.1 Purpose

The operating system kernel can be rebuild on the DragonBoard 410c. If it is not cross-compiling, perform the following steps to set up the DragonBoard 410c for cross-compiling.

6.2 Steps to set up the DragonBoard 410c for cross-compiling

Perform the following steps:

1. Insert a blank SDCard into the SD card slot, then partition and mount it.

2. Execute the following commands:

```
sudo gdisk /dev/mmcblk1p1
Command (? for help): o
This option deletes all partitions and creates a new protective MBR.
Proceed? (Y/N): y
#build a 8GB partition for swap
Command (? for help): n
Partition number (1-128, default 1):
First sector (34-8388574, default = 2048) or {+-}size{KMGTP}:
Last sector (2048-8388574, default = 8388574) or {+-}size{KMGTP}: 8G
Current type is 'Linux filesystem'
Hex code or GUID (L to show codes, Enter = 8300): 8200
Changed type of partition to 'Linux swap'

Command (? for help): w
Final checks complete. About to write GPT data. THIS WILL OVERWRITE
EXISTING PARTITIONS!!
Do you want to proceed? (Y/N): y
```

3. Reboot and execute the following command:

```
sudo mkswp /dev/mmcblk1p1
```

4. #edit /etc/fstab and add the following line:

```
sudo vi /etc/fstab
/dev/mmcblk1p1 none swap sw 0 0
<esc>:wq
```


5. Reboot and execute the following commands:

```
# ensure swap is mounted
free
```

Once the development system is set up, follow the instructions:

<http://builds.96boards.org/releases/dragonboard410c/linaro/debian/latest/>

After the step “make defconfig distro.config”, execute the following extra steps:

```
sudo apt-get install libncurses-dev
sudo apt-get install man-db
make menuconfig
Select "Device Drivers" then <Enter>
Select "I2C Support" followed by <Enter>
Select "I2C Support" Followed by 'Y' then <esc><esc> to move back up one
level.
Select "Hardware Monitoring support" then 'Y' followed by <Enter>
Select "Texas Instruments INA219 and compatibles" then 'Y'
Back out of the menus with <esc><esc> and at the end select 'Yes' to
save the changes.
```

Edit the file `kernel/arch/arm64/boot/dts/qcom/MSM8916.dtsi` and add the lines marked with ‘+’ as shown (do not include the ‘+’):

```
/* BLSP1 QUP2 */
blsp_i2c0: i2c@78b6000 {
    compatible = "qcom,i2c-qup-v2.2.1";
    reg = <0x78b6000 0x1000>;
    interrupts = <GIC_SPI 96 0>;
    clocks = <&gcc GCC_BLSP1_AHB_CLK>,
            <&gcc GCC_BLSP1_QUP2_I2C_APPS_CLK>;
    clock-names = "iface", "core";
    pinctrl-names = "default";
    pinctrl-0 = <&i2c0_default>;
    #address-cells = <1>;
    #size-cells = <0>;
    status = "disabled";
+
+     ina219@40 {
+         compatible = "ti,ina219";
+         reg = <0x40>;
+         shunt-resistor = <100000>;
+     };
};
```

Continue to the next step (“make -j4 Image dtbs KERNELRELEASE=4.2.4-linaro-lt-qcom” at the time this document was created) and finish building and installing the kernel as per the instructions.

Result: To view the status of the DragonBoard 410c, execute the following commands from Chapter 7 [Monitoring CPU speed and temperature](#).

7 Monitoring CPU speed and temperature

Perform the following steps:

1. Set up the required software.

```
# do this once to set up your linux system (it might already be
installed)
export PATH=$PATH:/usr/sbin
sudo apt-get update
sudo apt-get install stress i2c-tools
```

2. Under Debian, start a terminal session and execute the following command:

```
# view the core frequencies and the temperatures.
# May need slightly different paths on your system.
sudo watch cat \
/sys/devices/system/cpu/cpu*/cpufreq/cpuinfo_cur_freq \
/sys/devices/virtual/thermal/thermal_zone*/temp \
/sys/bus/i2c/drivers/ina2xx/0-0040/hwmon/hwmon0/power1_input
```

Results: This displays the speeds of the 4 CPUs, the 2-temperature monitors near the CPUs, and the power consumption as measured by the INA219 board.

3. Increase the power consumption on the board by running the following command:

```
# stress the cpu
stress -c 4 -i 4 -m 2 &
```

4. Ensure the following when executing the watch command:

```
Every 2.0s: cat /sys/devices/system/cpu/cpu0/cpufre...  Fri Dec 18
17:36:04 2015
```

```
200000
200000
200000
200000
46000
44000
1800000
```

The first four numbers are the current clock rates for the 4 A53 CPUS (in Hz, 200 MHz each). The next two numbers are the temperatures from the on chip temperature monitor points (in millidegrees C, 46C and 44C). The final number is the power consumption in micro-Watts, 1.8Watts).

8 Using glmark to stress your system

8.1 Prerequisite

- Ensure the basic tools like g++ and git and development libraries are available to download and compile the latest glmark2.

Download the glmark2 source files either with git or the source zip file from glmark GitHub website <https://github.com/glmark2/glmark2>

Perform the following steps:

1. Install required development software and development headers.

- Build a basic binary compilation environment:

```
sudo apt-get install git g++ build-essential pkg-config
```

- Build an X11 and OpenGL development environment:

```
sudo apt-get install libx11-dev libgl1-mesa-dev
```

- Install jpeg and png image development headers:

```
sudo apt-get install libjpeg-dev libpng12-dev
```

2. Download glmark2 source from git:

```
cd ~/
git clone https://github.com/glmark2/glmark2.git
cd glmark2/
```

3. glmark2 uses the Python-based WAF build system, which requires a working Python 2.x installation. And now build it with X11 and OpenGL only, no OpenGL ES, wayland, or mir support:

glmark2 uses the Python-based WAF build system, which requires a working Python 2.x installation. And now build it with X11 and openGL only, no OpenGLES, wayland, or mir support:

```
./waf configure --with-flavors=x11-gl
./waf build -j 4
sudo ./waf install
```

4. Run glmark2.

Execute the following command glmark2 to produce a high compute load on the system and measure power consumption:

```
glmark2 # test run glmark2
```

8.2 Measuring power consumption on other operating systems

It is possible to use two DragonBoard 410c boards to measure power consumption. One system performs the power measurement while the other system provides the power load. Connect the data side of the INA219 power measurement setup as directed in [Section 3](#), but connect the current sense side to the device under test. Ensure that both systems have a common ground by connecting a jumper wire from the ground on one system to the ground on the other system.

EXHIBIT 1

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1.2 **Indemnification.** You agree to indemnify and hold harmless QTI and its officers, directors, employees and successors and assigns against any and all third-party claims, demands, causes of action, losses, liabilities, damages, costs and expenses, incurred by QTI (including but not limited to costs of defense, investigation and reasonable attorney's fees) arising out of, resulting from or related to: (i) any breach of this Agreement by You; and (ii) your acts, omissions, products and services. If requested by QTI, you agree to defend QTI in connection with any third party claims, demands, or causes of action resulting from, arising out of or in connection with any of the foregoing.

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1.5 **LIMITATION OF LIABILITY.** IN NO EVENT SHALL QTI, QTI'S AFFILIATES OR ITS LICENSORS BE LIABLE TO YOU FOR ANY INCIDENTAL, CONSEQUENTIAL OR SPECIAL DAMAGES, INCLUDING BUT NOT LIMITED TO ANY LOST PROFITS, LOST SAVINGS, OR OTHER INCIDENTAL DAMAGES, ARISING OUT OF THE USE OR INABILITY TO USE, OR THE DELIVERY OR FAILURE TO DELIVER, ANY OF THE MATERIALS, OR ANY BREACH OF ANY OBLIGATION UNDER THIS AGREEMENT, EVEN IF QTI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THE FOREGOING LIMITATION OF LIABILITY SHALL REMAIN IN FULL FORCE AND EFFECT REGARDLESS OF WHETHER YOUR REMEDIES HEREUNDER ARE DETERMINED TO HAVE FAILED OF THEIR ESSENTIAL PURPOSE. THE ENTIRE LIABILITY OF QTI, QTI'S AFFILIATES AND ITS LICENSORS, AND THE SOLE AND EXCLUSIVE REMEDY OF YOU, FOR ANY CLAIM OR CAUSE OF ACTION ARISING HEREUNDER (WHETHER IN CONTRACT, TORT, OR OTHERWISE) SHALL NOT EXCEED US\$10.

2. **COMPLIANCE WITH LAWS; APPLICABLE LAW.** You agree to comply with all applicable local, international and national laws and regulations and with U.S. Export Administration Regulations, as they apply to the subject matter of this Agreement. This Agreement is governed by the laws of the State of California, excluding California's choice of law rules.

3. **CONTRACTING PARTIES.** If the Materials are downloaded on any computer owned by a corporation or other legal entity, then this Agreement is formed by and between QTI and such entity. The individual accepting the terms of this Agreement represents and warrants to QTI that they have the authority to bind such entity to the terms and conditions of this Agreement.

4. **MISCELLANEOUS PROVISIONS.** This Agreement, together with all exhibits attached hereto, which are incorporated herein by this reference, constitutes the entire agreement between QTI and You and supersedes all prior negotiations, representations and agreements between the parties with respect to the subject matter hereof. No addition or modification of this Agreement shall be effective unless made in writing and signed by the respective representatives of QTI and You. The restrictions, limitations, exclusions and conditions set forth in this Agreement shall apply even if QTI or any of its affiliates becomes aware of or fails to act in a manner to address any violation or failure to comply therewith. You hereby acknowledge and agree that the restrictions, limitations, conditions and exclusions imposed in this Agreement on the rights granted in this Agreement are not a derogation of the benefits of such rights. You further acknowledge that, in the absence of such restrictions, limitations, conditions and exclusions, QTI would not have entered into this Agreement with You. Each party shall be responsible for and shall bear its own expenses in connection with this Agreement. If any of the provisions of this Agreement are determined to be invalid, illegal, or otherwise unenforceable, the remaining provisions shall remain in full force and effect. This Agreement is entered into solely in the English language, and if for any reason any other language version is prepared by any party, it shall be solely for convenience and the English version shall govern and control all aspects. If You are located in the province of Quebec, Canada, the following applies: The Parties hereby confirm they have requested this Agreement and all related documents be prepared in English.