Qualcomm Technologies, Inc.

Measuring Power Consumption for DragonBoard™ 410c

Application Note

February 2016

Questions or comments: https://www.96boards.org/DragonBoard410c/forum

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Revision history

Revision	Date	Description
A	February 1, 2016	Initial release.

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1 Introduction

1.1 Purpose

The power consumption for modern SOC processors is highly dependent upon the software running on the processor. During the software development process it is often a good idea 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.

1.2 Basics of power measurement

Power consumption of a device can be computed by taking two measurements: 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 will 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. We will call the voltage across the shunt resistor ‘V_s’ and the resistance of the shunt resistor is ‘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, the supply voltage should be measured at the same time as the current (because both the current and voltage are varying with time); however, a reasonably good approximation of the power consumption of the device can be computed by simply using the known nominal value for the supply voltage.

1.3 DragonBoard 410c power distribution overview

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

1. The DC Input. All power to the DragonBoard 410c and any attached peripherals (HDM Monitor, USB devices, mezzanine cards, etc.) are supplied from the DC input jack. Measuring the power consumption at this point will give an overall power consumption value.
2. The Compute Core (Processor, DRAM memory, eMMC storage, SDCard, BT/WiFi, GPS, etc.) consumption can be measured independently of the overall system power. These are the areas where the software designer has the most control and can optimize the system power consumption.

3. The 5V peripherals (USB Ports, HDMI, mezzanine cards). The power consumption in this area is very 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.

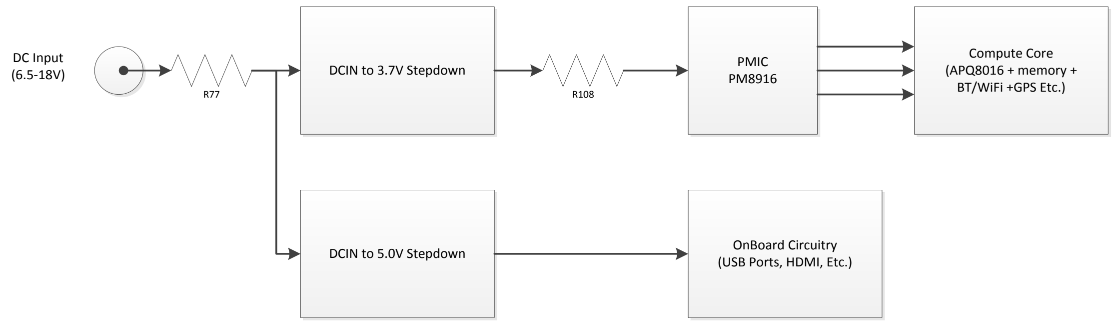


Figure 1-1 DragonBoard 410c power subsystem

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

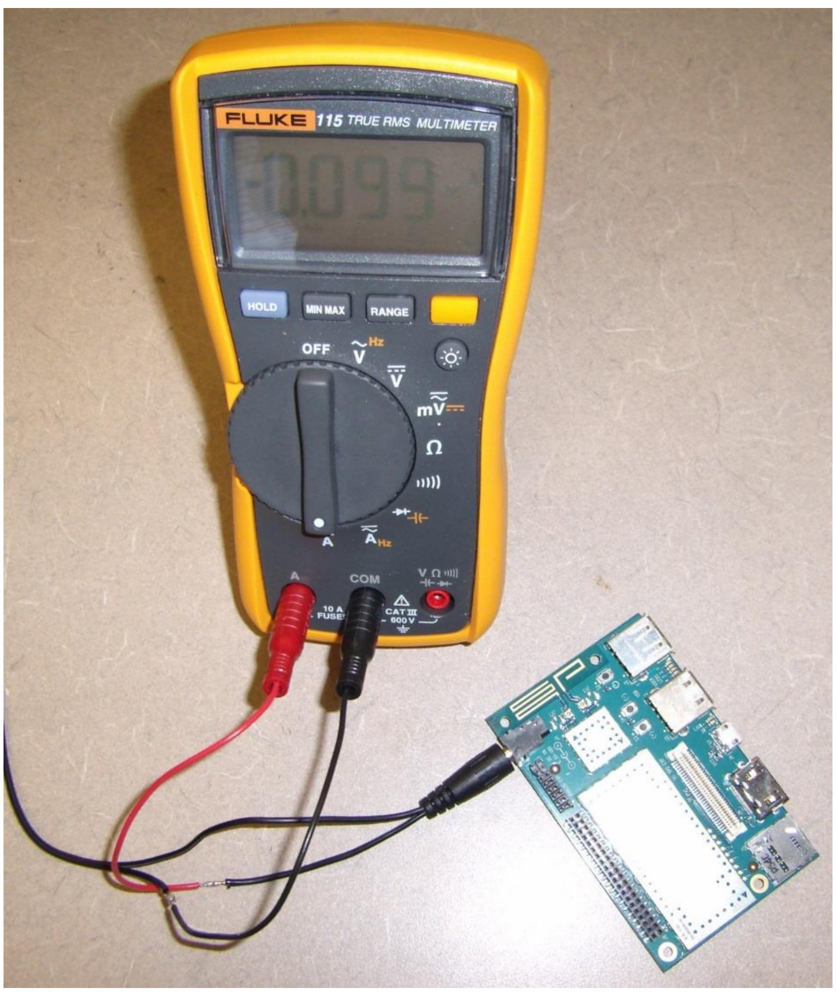
1. At the DC input connector. This givers total consumption of the system including all peripherals attached.
2. Across R77. This gives exactly the same values as measuring the power consumption at the DC Input connector; however, the electrical connections may be more convenient.
3. Across R108. This gives only the core power, which may be more 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

A common handheld ammeter can be used to measure the power consumption at the DC input. Since the meter cannot simultaneously measure the supply voltage, it will be necessary to use the nominal supply voltage, in this case the nominal supply voltage is 12V from the standard power supply, in the computation of power consumption.

2.1 Setup

Connect the ammeter in series with the positive supply lead as shown in the picture below. The connections can be made with ‘alligator clips’ or any other convenient method.



The most difficult part of this connection is identifying which of the two black wires is the positive voltage. If you are only measuring the current as shown above, it is not important if you are measuring the current flowing into the device (on the positive lead) or the current returning from the device (on the negative lead). The results will be the same either way.

If you plan to use one of the more advanced measurement techniques described in subsequent chapters, then you will need to identify which wire is the positive lead. This can be done with an Ohmmeter. The resistance between the center conductor on the power barrel connector and the wire you cut should be close to zero ohms.

2.2 Computations

The total power consumption is: the measured current (0.099Amps) multiplied by the nominal Voltage (12Volts). In this case P = I x V = 0.099 x 12 = 1.188 Watts. Your actual consumption will be dependent on what software is actually running.

In the example above, you will note that the reading is a ‘negative’ number. The polarity of the connections to the ammeter will change the polarity of the measurement. If you have a negative reading you can simply ignore the sign of the reading, or you can swap the leads into the ammeter to produce a reading with the correct sign. If you have an ammeter that cannot read negative currents, then it will be necessary to swap the two measurement leads.

Since this is a measurement of the total system power, in addition to being dependent on the operating software, it will also be dependent on the devices attached to the system. Keyboards, HDMI monitors, mice, SDCards, and mezzanine boards all consume power from the system supply and will be included in the observed measurement.

The instantaneous power consumption is constantly changing; however, the ammeter updates its readings relatively slowly (one or two times per second). The ammeter readings will likely not be very stable; this is normal behavior.

3 Power Measurement with INA219

There are several more advanced ways to measure power consumption beyond using an ammeter and voltmeter. In this chapter we will describe how to use a readily available INA219 breakout board. The INA219 chip is a complete power measurement system on a chip. 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.

3.1 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 will use this specific implementation: https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/overview.

First, it is necessary to assemble the breakout board and connect the I2C measurement port to the DragonBoard 410c.

3.1.1 Equipment required

- 96Boards sensors mezzanine card:

  https://www.96boards.org/products/mezzanine/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

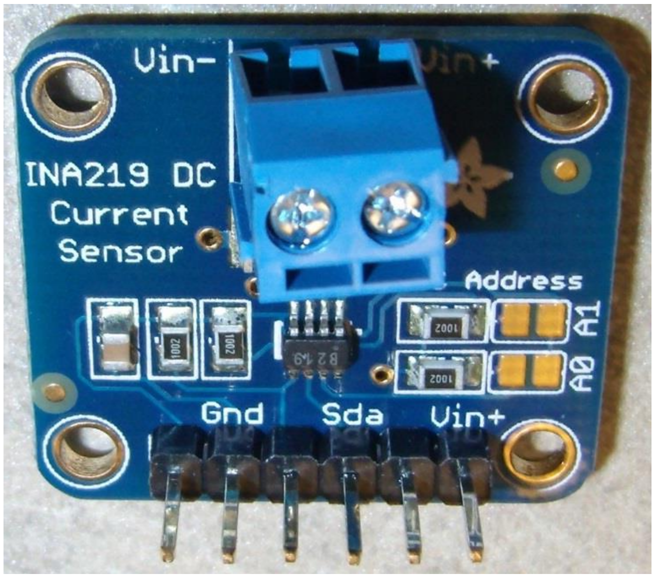
- INA219 breakout board:

  https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/overview

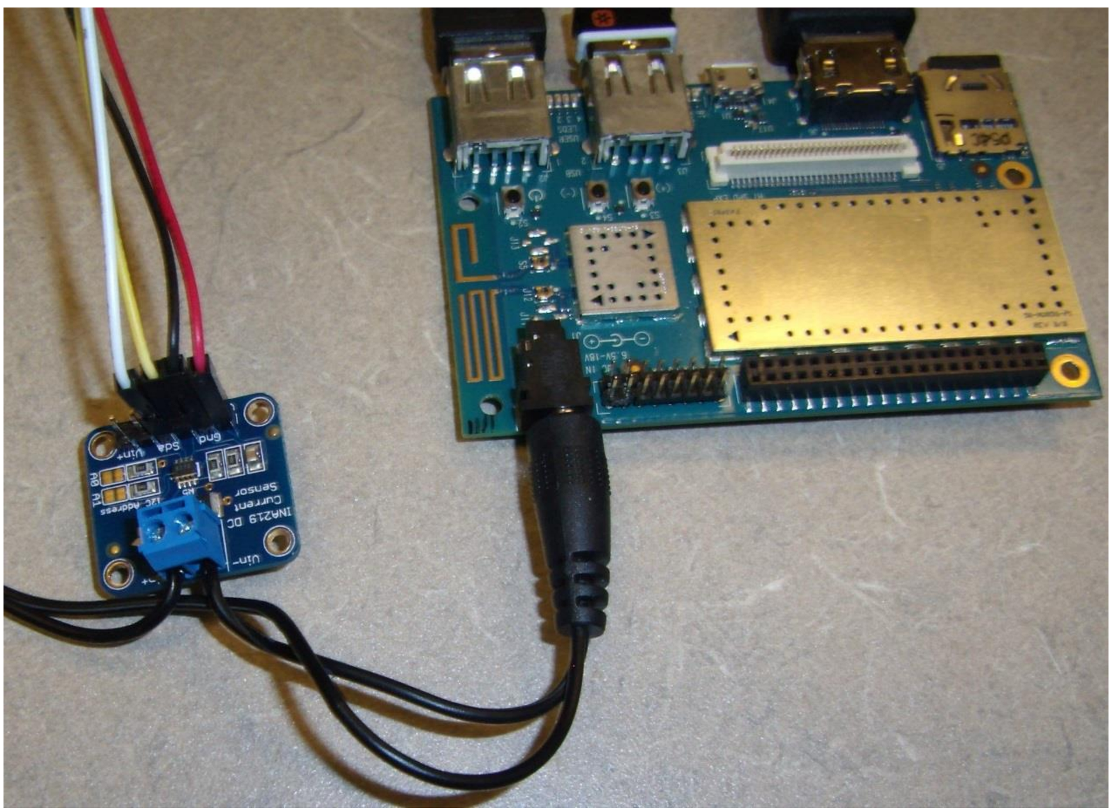
3.1.2 Steps

1. Attach the 96Boards 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 following the AdaFruit instructions here: https://learn.adafruit.com/adafruit-ina219-current-sensor-breakout/assembly

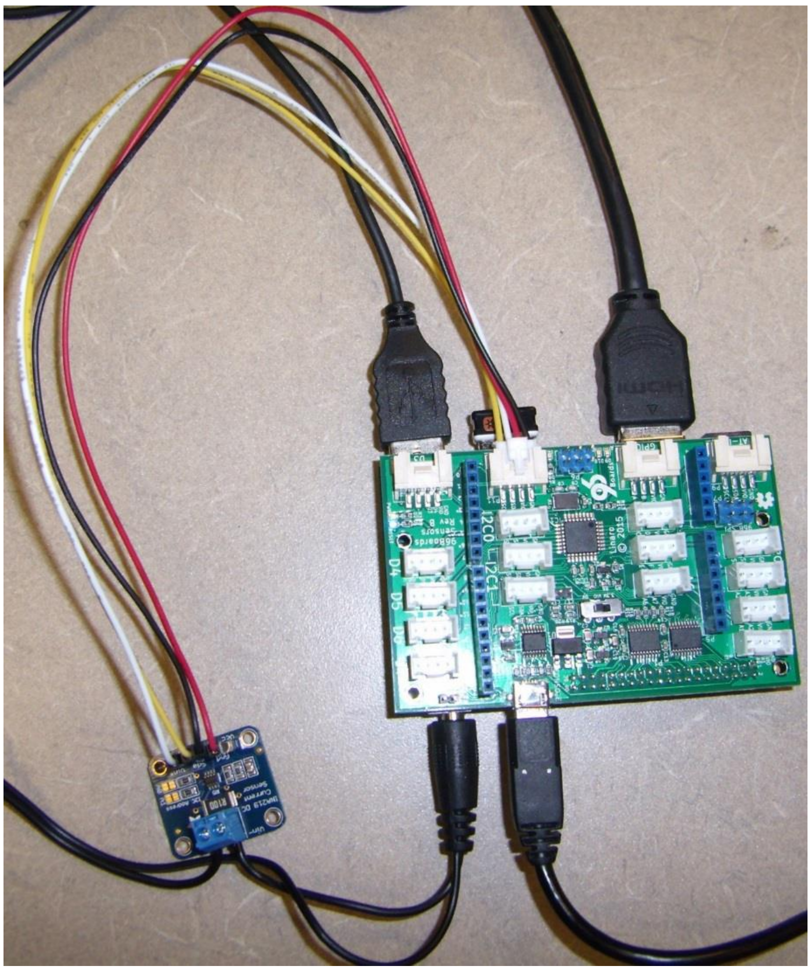
When assembly is complete your board should look like this:



4. Cut the positive lead to your power supply, strip the wires, and connect them to the INA219 Current Sensor breakout. The 12V supply lead should connect to the Vin+ terminal. The 12V lead going to the DragonBoard 410c should be connected to the Vin- terminal. Like this:



5. Connect the power and I2C signals from the DragonBoard 410c board to the INA219 current sense breakout.
   a. +5V (red wire)
   b. GND (black wire)
   c. SCL (clock, yellow wire)
   d. SDA (data, white wire)
6. Connect the cable to the mezzanine board on the I2C0 connector.



7. Set up the software as described in Section 7.

3.2 Measure the entire system power with the onboard shunt resistor

The DragonBoard 410c has an onboard current measurement resistor (R77 in the schematic below). 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 will remove the shunt resistor from the INA219 breakout board and use R77 on the DragonBoard instead for current measurement.

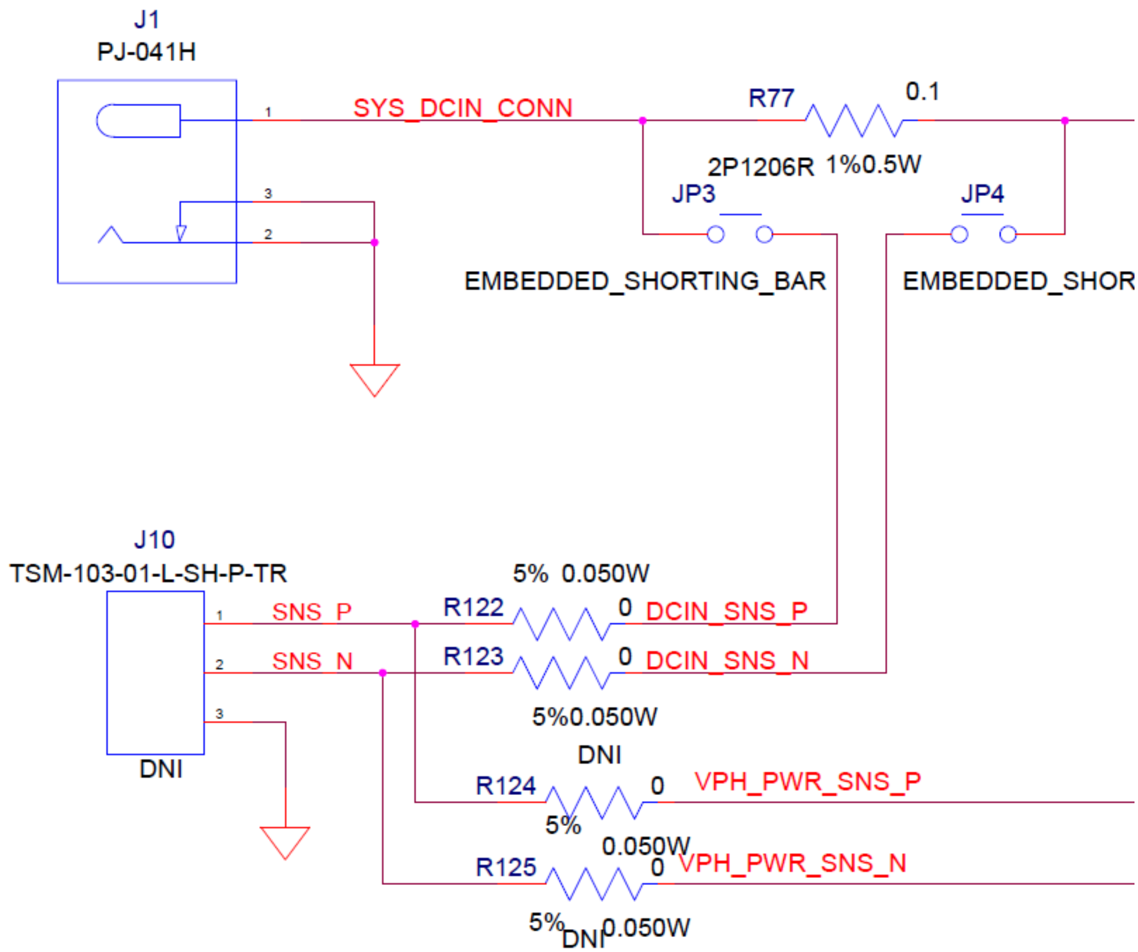
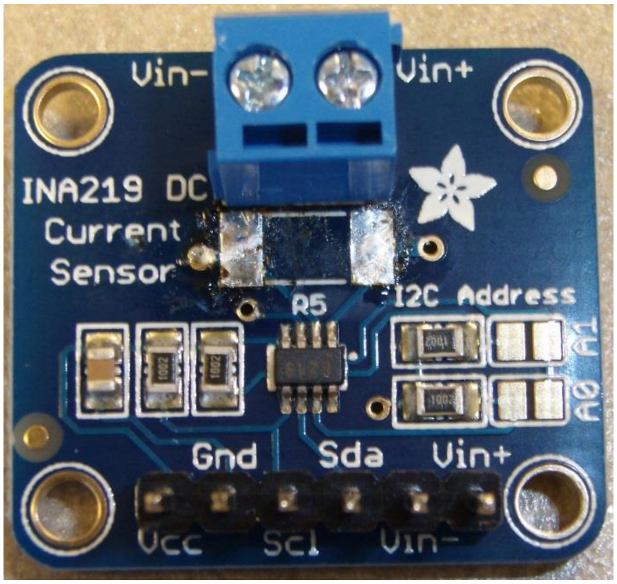


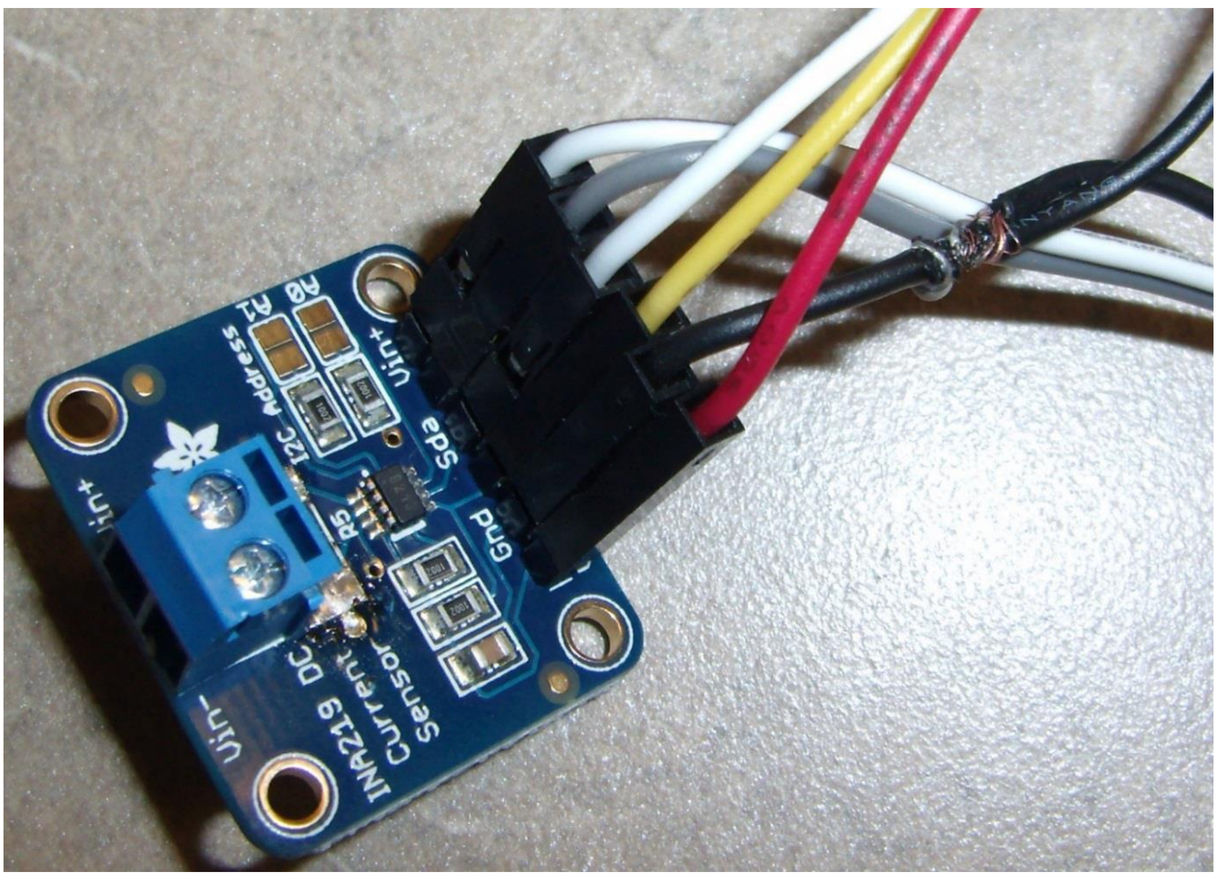
Figure 3-1 Onboard current measurement resistor (R77)

3.2.1 Steps

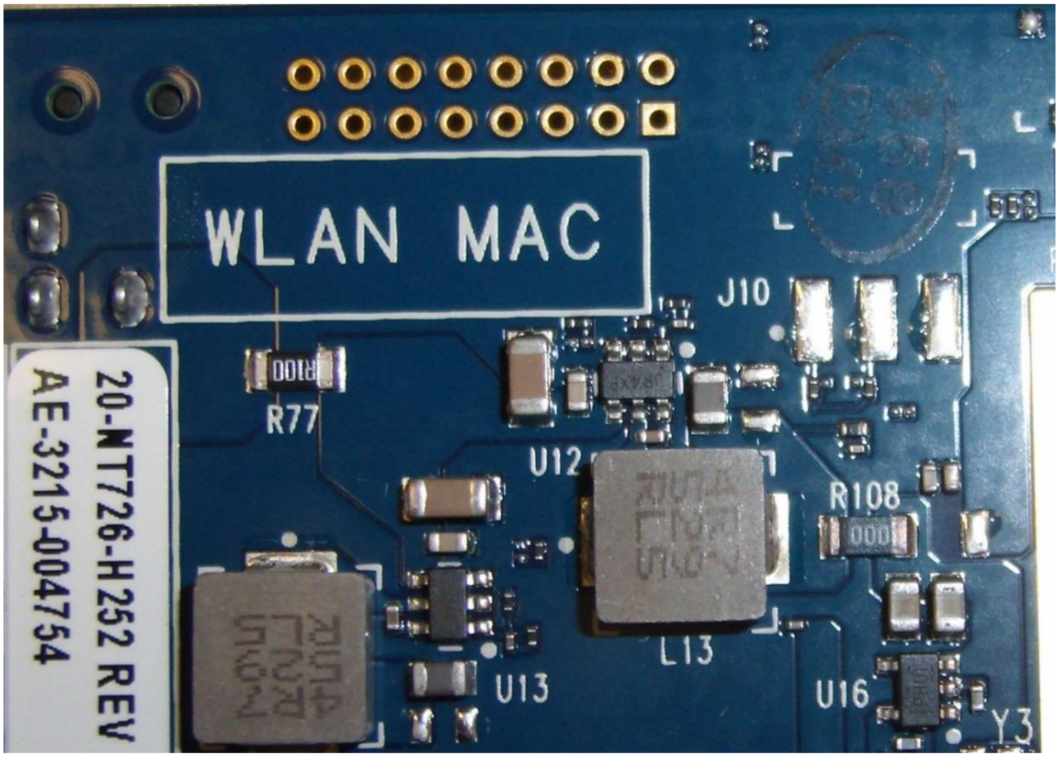
1. Remove the 0.1 Ohm shunt from the INA219 current sense breakout. This step requires basic soldering skills and the use of a soldering iron. Detailed training is beyond the scope of this document, but can be found in many places online. Note how R5 (the current shunt resistor) has been removed.



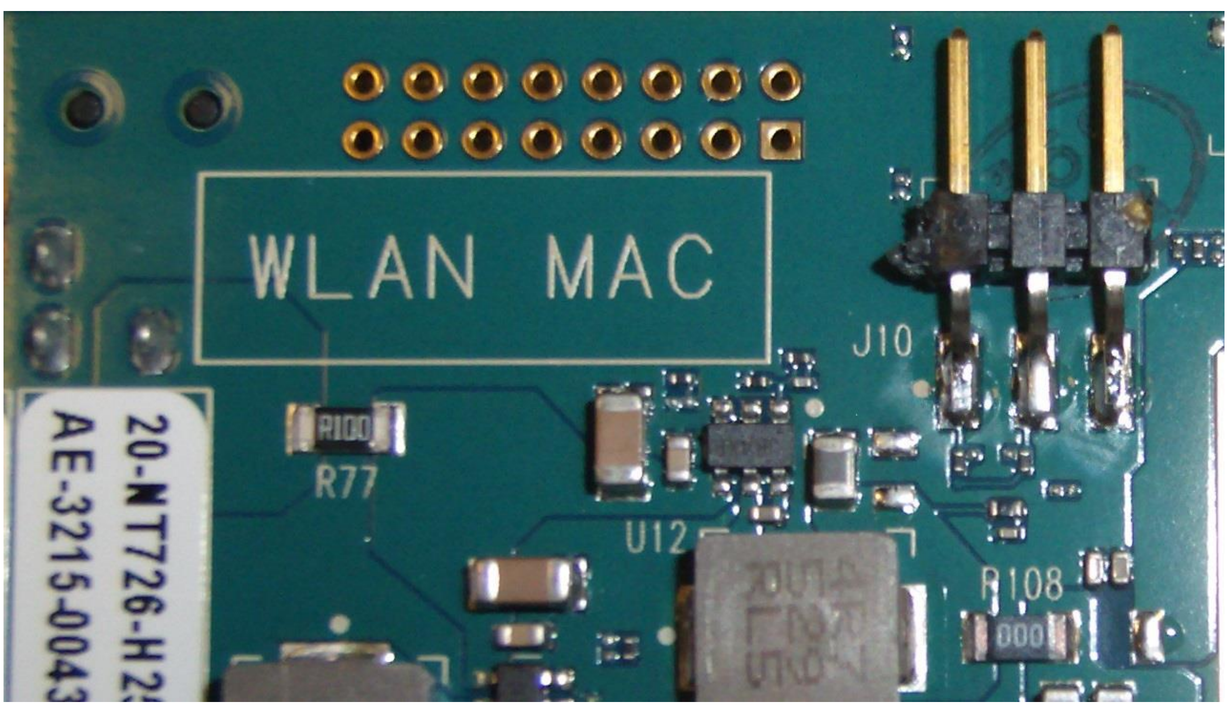
2. Attach current and voltage sense leads to the INA219 breakout board as shown. These leads are standard 0.1” female jumper wires. The colors of the wires are not important.



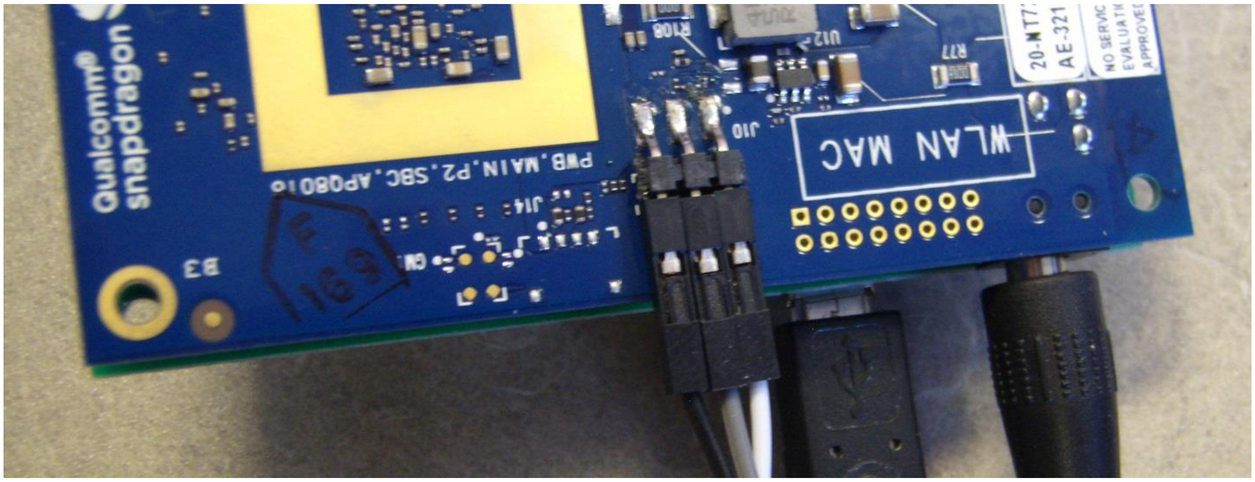
3. As delivered from the factory, the DragonBoard 410c does not have J10 installed:



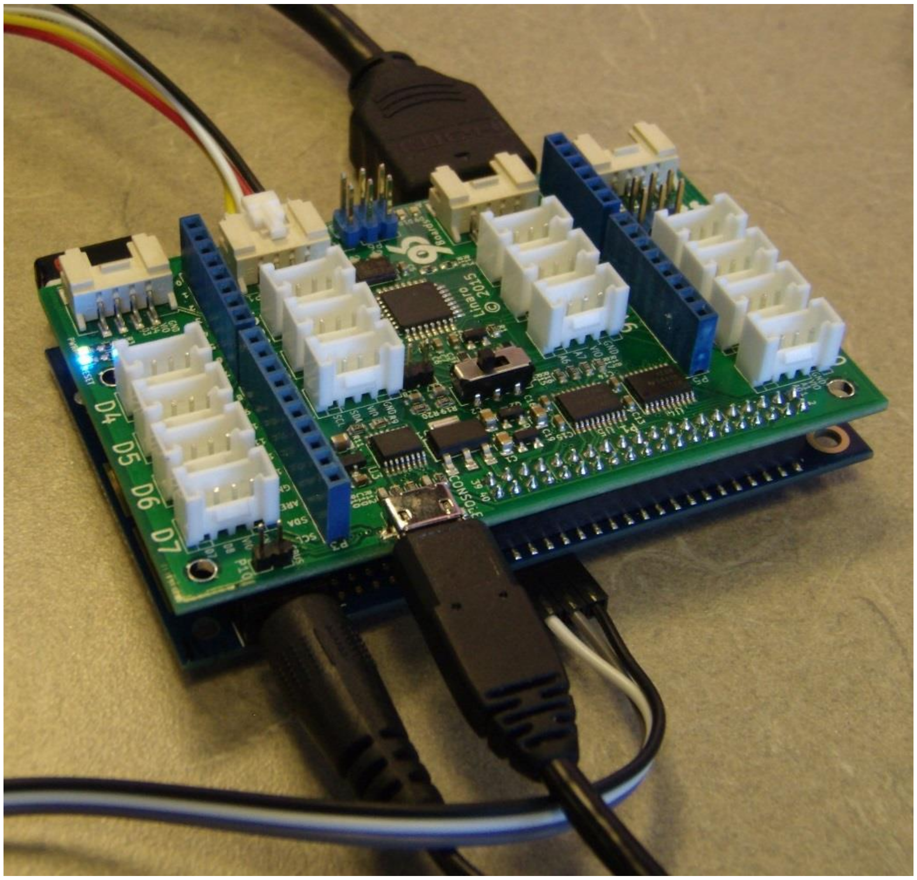
Install J10 as shown. Again this step requires basic soldering skills. When soldering on J10, be careful to not disturb the tiny components on the board located near J10.



4. Connect the current monitor points to the 410c.



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



4 Monsoon Power Supply and Measurement

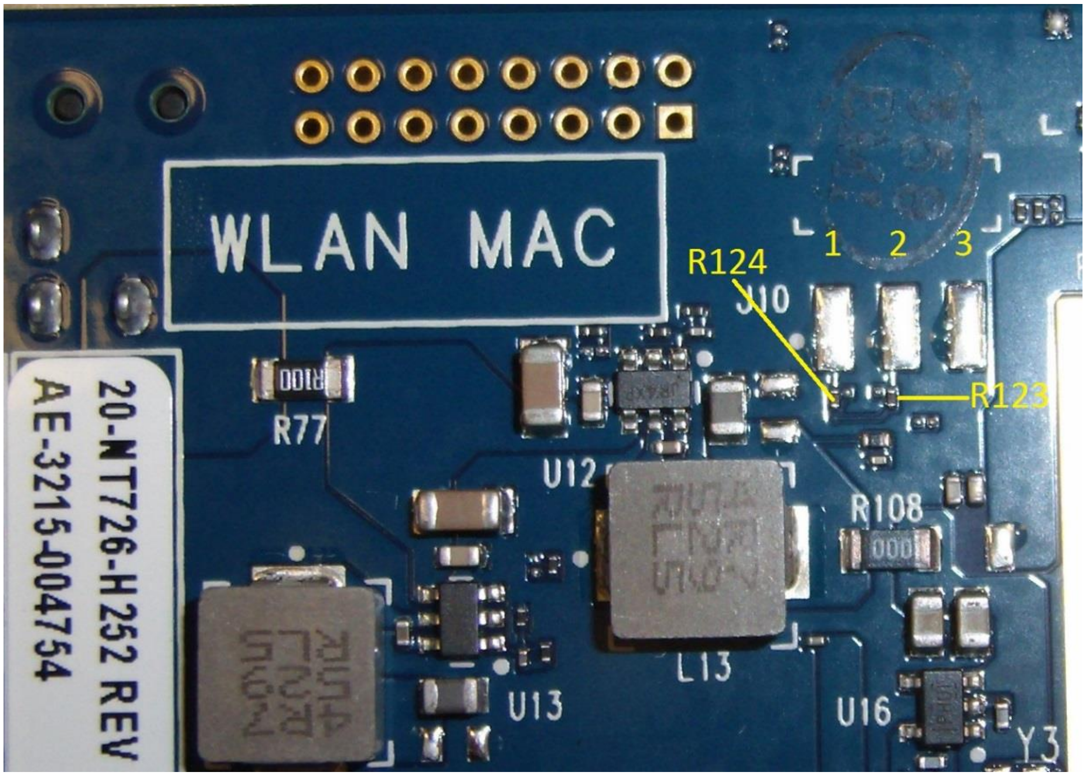
Measurement of the power consumption of just the core chips is possible using a Monsoon power supply with measurement capability. An advantage of the Monsoon is the ability to profile power across a use case. Monsoon provides software that runs on Microsoft Windows that generates a nice graph.

The Monsoon box can only output a maximum of 4.5V. This is not enough to operate the entire DragonBoard 410c (requires 6.5V to 18V), hence this can only be used to measure the 'core' chips. (https://www.msoon.com/LabEquipment/PowerMonitor/)

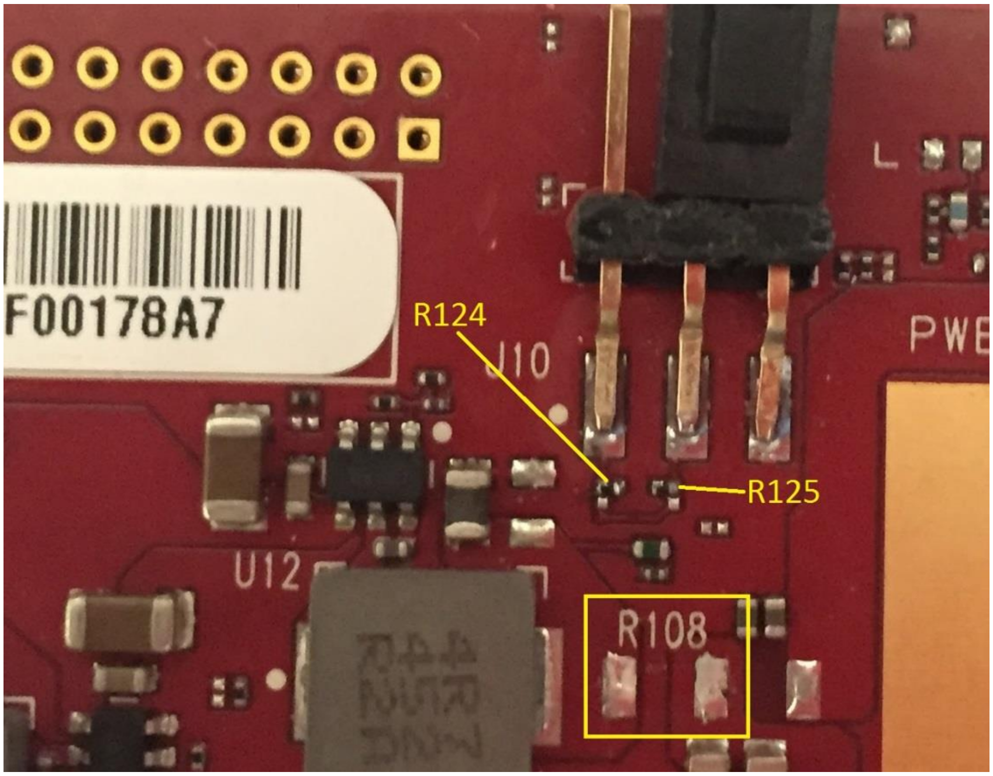
To use the Monsoon box you need to do a little rework on the DragonBoard 410c.

4.1 Steps

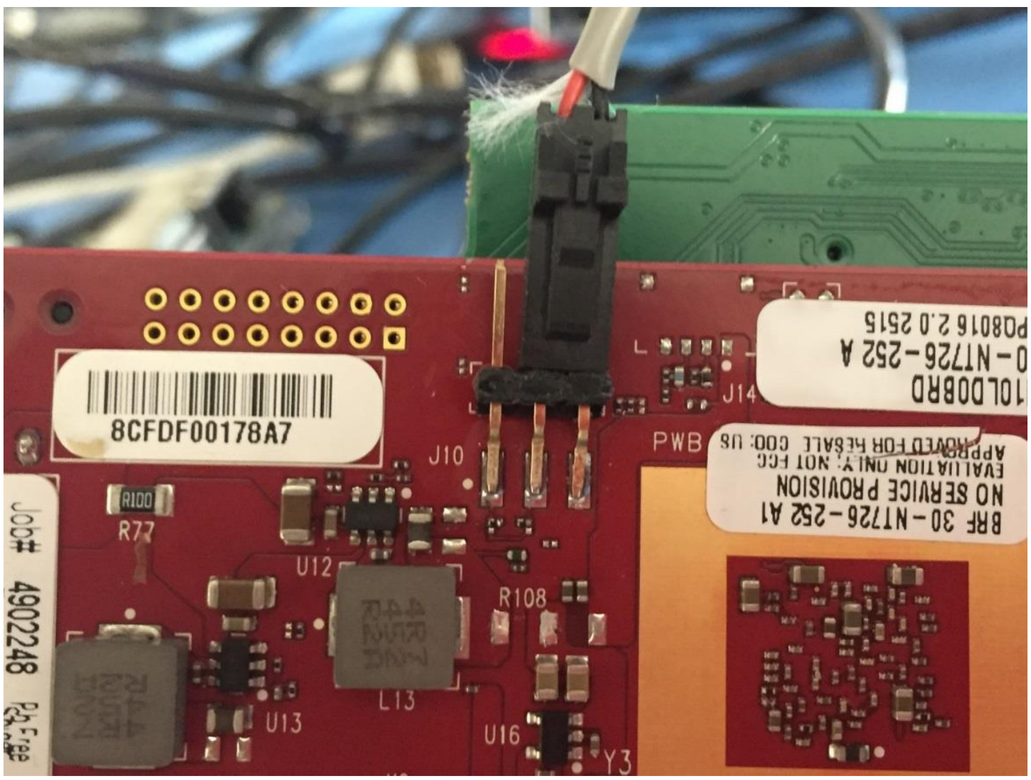
1. Install J10.
2. Remove R108, R122, and R123.



3. Install R124 and R125 (since R124 and R125 are zero Ohm resistors, a solder short will work fine).

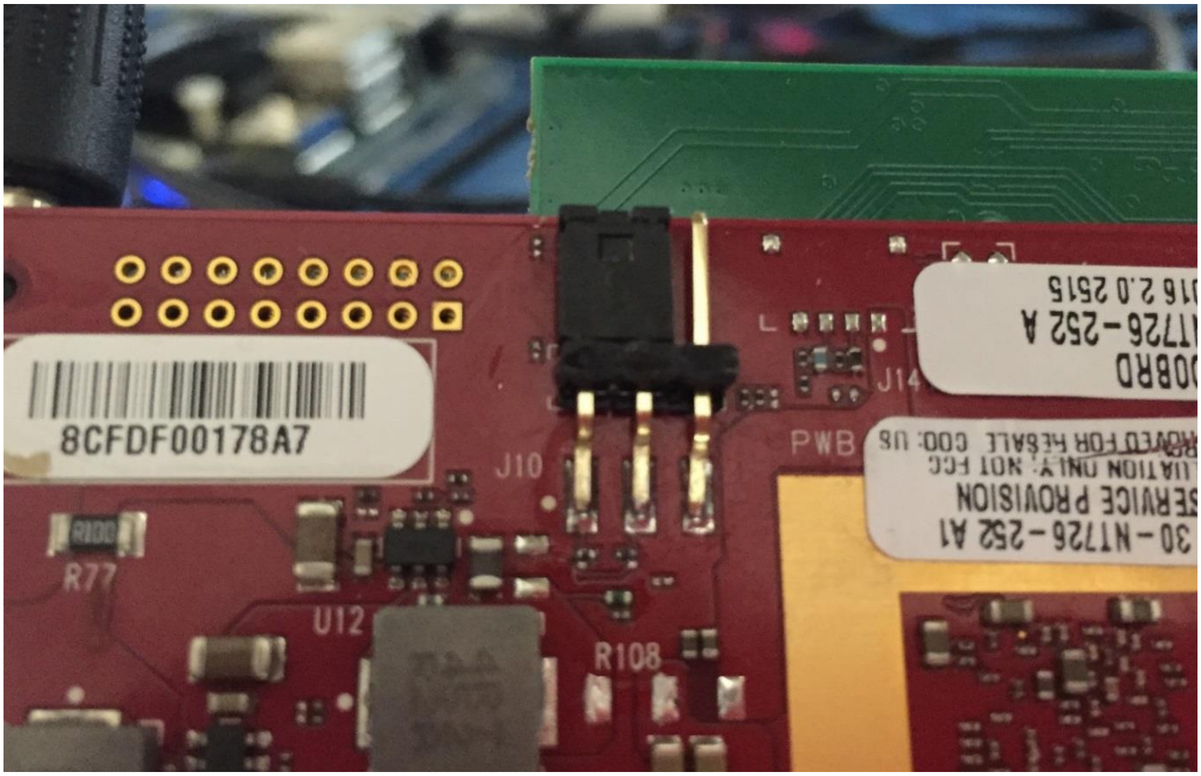


4. Connect the Monsoon positive lead to J10 pin 2.
5. Connect the Monsoon negative lead to J10 pin 3.
6. Ensure that the 12V supply is also connected. The Monsoon will only supply and measure the 'compute core' circuits, but not the IO chips (USB hub and ports, HDMI, etc.).



4.2 Further explanation

Normally the onboard switching supply would provide the 3.7V power to the PM8916 PMIC; however, in the installation steps above we removed R108. Once R108 is removed the onboard 3.7V supply is disconnected and will no longer provide power to the PM8916. You can "undo" this change so you can use the board without the Monsoon by simply putting a jumper across J10 pins 1-2 like this:



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

On the DragonBoard 410c the switching power supply provided 3.7V. Ideally you should set the Monsoon to also provide 3.7V, unfortunately the wires between the Monsoon and the DragonBoard 410c are not ideal wires, and, in fact, have a significant voltage drop. This voltage drop causes the PMIC to ‘brown-out’ when it draws a lot of current. 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 3.3V even under brown-out conditions. Typically the voltage that a fully charged lithium-ion battery would supply is programmed into the Monsoon, 4.2V.

5 ARM Energy Probe

The ARM energy probe is ‘convenient’ but not necessary. The ARM energy probe is about ¼ of the cost of the Monsoon box. In order to use the ARM energy probe it is necessary to install J10 (see steps in previous section), then attach the energy probe to J10, and follow the instructions provided with the probe.

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

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

6 Rebuild the Kernel with Support for the INA219

It is possible to rebuild the operating system kernel right on the DragonBoard 410c. If you are not cross-compiling you need to do a few minor steps to set up the DragonBoard 410c for cross-compiling, after which you can follow the instructions below.

6.1 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 run 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 run the following commands:

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

Once your development system is set up, follow the instructions at 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.

To view the status of the DragonBoard 410c, run commands from Section 7 Monitoring CPU Speed and Temperature.

7 Monitoring CPU Speed and Temperature

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
   ```

This will display the speeds of the 4 CPUs, the 2 temperature monitors near the CPUs, and the power consumption as measured by the INA219 board.

You can increase power consumption on the board by running the following command:

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

You should see this when you are running 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 milli-degrees C, 46C and 44C). The final number is the power consumption in micro-Watts, 1.8Watts).

8 Using glmark to Stress Your System

1. Install required development software and development headers.

   To download and compile latest glmark2, we need some basic tools like g++ and git and development libraries.

   a. Build a basic binary compilation environment.

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

   b. Build an X11 and OpenGL development environment.

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

   c. Install jpeg and png image development headers.

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

2. Download glmark2 source from git.

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

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

3. Configure, compile, and install glmark2.

   glmark2 uses the Python-based WAF build system, which requires a working Python 2.x installation. Now we are going to 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.

   Finally, run the glmark2 program to produce a high compute load on the system and measure power consumption.

   ```
   glmark2 # test run glmark2
   ```

8.1 Measuring power consumption on other operating systems

It is possible to use two DragonBoard 410c boards to measure power consumption. One system will perform the power measurement while the other system will provide the power load. Connect the data side of the INA219 power measurement set up as directed in Section 3, but connect the current sense side to the device under test. Make sure 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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1.4 **WARRANTY DISCLAIMER.** YOU EXPRESSLY ACKNOWLEDGE AND AGREE THAT THE USE OF THE MATERIALS IS AT YOUR SOLE RISK. THE MATERIALS AND TECHNICAL SUPPORT, IF ANY, ARE PROVIDED "AS IS" AND WITHOUT WARRANTY OF ANY KIND, WHETHER EXPRESS OR IMPLIED. QTI ITS LICENSORS AND AFFILIATES MAKE NO WARRANTIES, EXPRESS OR IMPLIED, WITH RESPECT TO THE MATERIALS OR ANY OTHER INFORMATION OR DOCUMENTATION PROVIDED UNDER THIS AGREEMENT, INCLUDING BUT NOT LIMITED TO ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR AGAINST INFRINGEMENT, OR ANY EXPRESS OR IMPLIED WARRANTY ARISING OUT OF TRADE USAGE OR OUT OF A COURSE OF DEALING OR COURSE OF PERFORMANCE. NOTHING CONTAINED IN THIS AGREEMENT SHALL BE CONSTRUED AS (I) A WARRANTY OR REPRESENTATION BY QTI, ITS LICENSORS OR AFFILIATES AS TO THE VALIDITY OR SCOPE OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT OR (II) A WARRANTY OR REPRESENTATION BY QTI THAT ANY MANUFACTURE OR USE WILL BE FREE FROM INFRINGEMENT OF PATENTS, COPYRIGHTS OR OTHER INTELLECTUAL PROPERTY RIGHTS OF OTHERS, AND IT SHALL BE THE SOLE RESPONSIBILITY OF YOU TO MAKE SUCH DETERMINATION AS IS NECESSARY WITH RESPECT TO THE ACQUISITION OF LICENSES UNDER PATENTS AND OTHER INTELLECTUAL PROPERTY OF THIRD PARTIES.

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 acknowledges 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.