BatteryLab - A Distributed Platform for Battery Measurements
https://batterylab.dev

Updated: July 2020

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1 Introduction

Several research papers, tools, and techniques exist which propose battery saving ideas. Despite their differences, one common aspect among these works is the "evaluation struggle". While OS-based battery measurements are practical, they lack accuracy and depend too much on the capabilities of the device under test (i.e., quality of the internal battery fuel gauge). Accurate battery measurements require connecting a mobile phone's battery to an external power meter during testing. This setup is generally bulky and hard to access, making access sharing hard even between members of the same organization.

BatteryLab (https://batterylab.dev) is a distributed platform for battery measurements. It consists of both a hardware and software solution which allows easy deployment of "vantage points" for battery measurements, which can be shared across physical locations. Our vision is a platform where members contribute some hardware resources (e.g., a phone and a power monitor) in exchange for access to the hardware resources offered by other members of the platform.

Figure 1 shows a graphical overview of a BatteryLab vantage point. In the rest of this guide, we will use Figure 1 as a reference point to explain the hardware and its configuration needed to successfully host a BatteryLab vantage point.

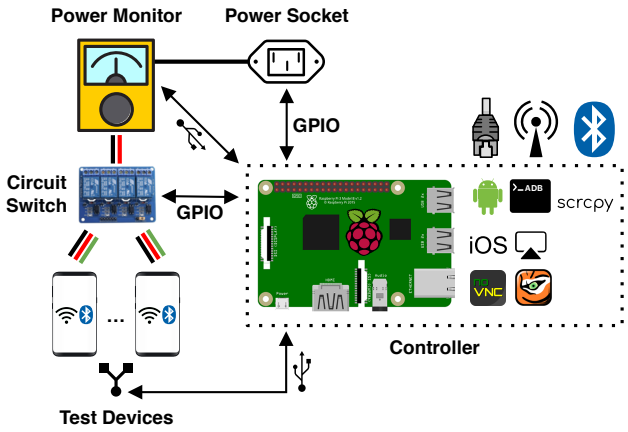

Figure 1: Graphical overview of a BatteryLab vantage point

2 Hardware Requirements

2.1 Power Monitor

We currently support the Monsoon HV [3] via its Python APIs [5]. In theory, these APIs are also supported by the Monsoon LV, but this was not tested, yet. Other power monitors can be supported, granted that they offer some APIs (e.g., set voltage, collect data, etc.) that can be integrated into BatteyLab's software suite.

2.2 Power Socket

This is a relay-based power socket that allows the controller to turn the Monsoon on and off, when needed. It connects to the controller via the GPIO port and it is controlled by our Python API.

2.3 Controller

This is the machine managing the vantage point. We use Raspberry Pi for three main reasons. 1) GPIO is used to programmatically switch between devices. 2) The Pi USB controller can be instrumented via software [10] to enable a USB connection with the vantage point controller. This is used to enable charging of a device as well as to setup adb (android debugging protocol) over WiFi. 3) It has a good tradeoff between cost and performance. We recommend a Pi 3B+ [6] with at least 16GB micro-SD card [8].

2.4 Circuit Switch

This is a relay-based circuit [9] which is controlled by the Pi's GPIO [7]. Its purpose is to programmatically switch the connection between Monsoon power monitor and the desired mobile device. It has 4 relays (supporting 4 mobile phones) but circuits with more channels do exist. The one we are using is an "ELEGOO 4 Channel DC 5V Relay Module" (Figure 2) that can be acquired, for instance, on Amazon.

The following pins from Pi's GPIO (Figure 3) need to be connected to the circuit switch, using a Jumper Wire Female to Female cable (for instance, on Amazon [1]).

- **Pin 3** (GPIO 2), connected to **In1**.
- **Pin 4** (5v - red), connected to **Vcc**.
- **Pin 5** (GPIO 3), connected to **In2**.
- **Pin 6** (Ground - black), connected to **Gnd**.
- **Pin 7** (GPIO 4), connected to **In3**.
- **Pin 8** (GPIO 14), connected to **In4**.

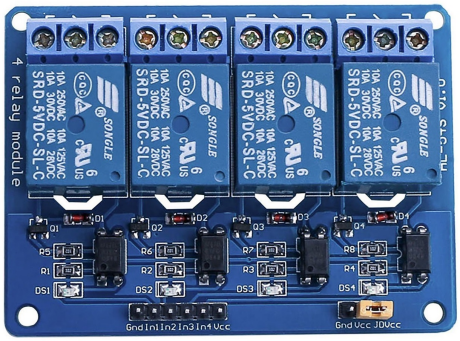

Figure 2: ELEGOO 4 Channel DC 5V Relay Module

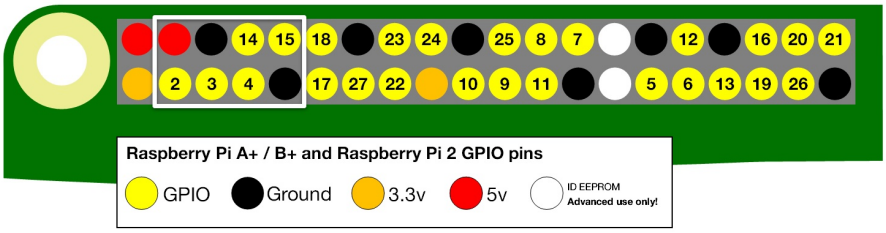

Figure 3: Raspberry Pi GPIO pins

- **Pin 9** (GPIO 15), connected to the **Power Socket In**.

Each relay is a switch. It uses the phone's Voltage (+) terminal as an input, and programmatically switches between the battery's Voltage (+) terminal and monsoon's Vout (+) connector (red cable). Monsoon's Ground (-) connector (black cable) is permanently connected to all devices' Ground (-) terminals.

2.5 Testing Devices

The full BatteyLab software suite is intended for devices running Android version >= 5.0 (Lollipop) and iOS version >= 13.0. Older devices can still be used but remote display and control of the device would not be supported. In case a testing device is to be acquired, we recommend looking for devices with a removable battery which will ease the process of connecting the power meter to the phone (see below). [2] is a great website for identifying a device with desired features such as price, removable battery, screen technology, etc.

In the following we describe how the devices should be prepared for BatteryLab integration.

Android:

1. If not a new device, perform a factory reset.
2. Boot the device and do basic setup. When asked for an account, three options are available: 1) setup a dummy account, 2) setup an account we can provide, 3) no account setup.
3. Enable developer options. The methodology might depend on the device, please check online if the following ways do not work.
   (a) Go to Settings:
      - Stock Android – go to About phone > Build number.
      - Samsung Galaxy – go to About device > Build number.
      - HTC – go to About > Software information > More > Build number.
      - LG – go to About phone > Software info > Build number.

   (b) Tap Build number seven times. After the first few taps, you should see the steps counting down until you unlock the developer options. Once activated, you will see a message that reads, "You are now a developer!"
4. Allow USB debugging from the new "Developer Options" menu entry that you have just enabled.

iOS:

1. Set orientation lock to portrait (Control Centre > tap at Lock icon).
2. Disable auto OS updates (Settings > General > Software Update > Automatic Updates).
3. Disable notifications (Settings > Notifications go through all installed apps and disable Allow Notifications).
4. Enable Airplane Mode and make sure Bluetooth and WiFi is activated (Control Centre).
5. Change screen lock time to 5 minutes (Settings > Display & Brightness > Auto-Lock).
6. Disable Auto Brightness / True Tone and manually set brightness level to 25% (Settings > Display & Brightness).
7. Disable Automatic Dark Mode appearance, and set it to Light mode (Settings > Display & Brightness).
8. Disable Night Shift (Settings > Display & Brightness).

9. Disable Automatic Downloads (Music, Apps, Books & Audiobooks, App Updates), Mobile Data Automatic Downloads, In-App Ratings & Reviews (Settings > iTunes & App Stores).

10. Disable Optimised Battery Charging (Settings > Battery > Battery Health).

11. Disable Background App Refresh (Settings > General > Background App Refresh).

3 Battery Connection Instruction

NOTE – These instructions are based on the official Monsoon's power monitor manual [4]. They have been adjusted to meet the extra requirements of BatteryLab.

To connect a phone to the circuit, the following items are required (available at any electronics store):

1. Polyimide High-Temp Tape (Kapton tape).

2. Copper tape foil (only needed in Sec. 3.1).

3. Electrical insulation tape.

4. 20 AWS stranded wire in colours Red, Black and Green.

5. Soldering iron and solder wire.

6. A voltmeter / multimeter.

7. ANSI Z87.1 compliant safety goggles.

NOTE – Wear ANSI Z87.1 compliant safety goggles (item 7) at all times while working with exposed battery terminals and wiring. When attaching the power measurement hardware to a device with a lithium battery, there is always a risk of damaging the device, or causing the device to heat-up, generate smoke, or catch fire. While this is unlikely, be extremely careful. It is recommended to work on a flame-resistant surface and have fire control equipment at the ready when performing the battery bypass and connecting the Power Monitor to the device under test. Immediately disconnect equipment that begins to exceed safe temperatures.

NOTE – It is highly recommended to discharge the battery below 20% in advance to reduce the risk of fire in the event of an accidental puncture of the battery.

Figure 4: Locate the battery's Voltage (+) and Ground (-) terminals.

3.1 Phones with Removable Battery

First locate the battery's Voltage (+) and Ground (-) terminals (Figure 4). They are usually labeled but you can also verify them using a voltmeter / multimeter.

Cover the top side of the battery with some Kapton tape (item 1), as shown below (Figure 5). This will protect the battery while using the soldering iron later.

Cut 3 pieces of copper tape (item 2) into approximately 8 cm length and 5 mm width (Figure 6). Trim the ends to match the width of the battery terminals. Note that terminal widths vary from battery to battery. Place the adhesive side of the copper tape on the Voltage (+) battery terminal, making sure it sits in securely and makes good contact (Figure 7). The copper tape should not come in contact with any other adjacent battery terminal.

Place a second strip of the adhesive side of the tape on the Ground (-) battery terminal making sure it sits in securely and makes good contact. The copper tape should not come in contact with any other adjacent battery terminal.

Fold both copper tapes over the battery on the side that will be exposed when placed into the device. Secure the copper tape with Kapton tape leaving approximately 1cm from the ends of the copper tape exposed. Cover the Voltage (+) terminal with insulating Kapton tape to isolate it from any ground connection (Figure 8).

Place the adhesive side of the 3rd copper tape on the Voltage (+) battery terminal, making sure that it does not come in contact with the Voltage (+) battery terminal or connected copper tape you placed earlier (Figure 9). Trim the low end of the copper tape so that it does not connect with the underlying

Figure 5: Cover the top side of the battery with some Kapton tape.

Figure 6: Cut 3 pieces of copper tape.

copper tape. Secure the copper tape with Kapton tape leaving approximately 1cm from the end of the copper tape exposed.

Cut a 15 centimeter length piece each of two red, one black and one green 20 AWG wires (item 4) (Figure 10). Solder the exposed end of the black test lead

Figure 7: Install the two copper tapes and secure them with Kapton tape.

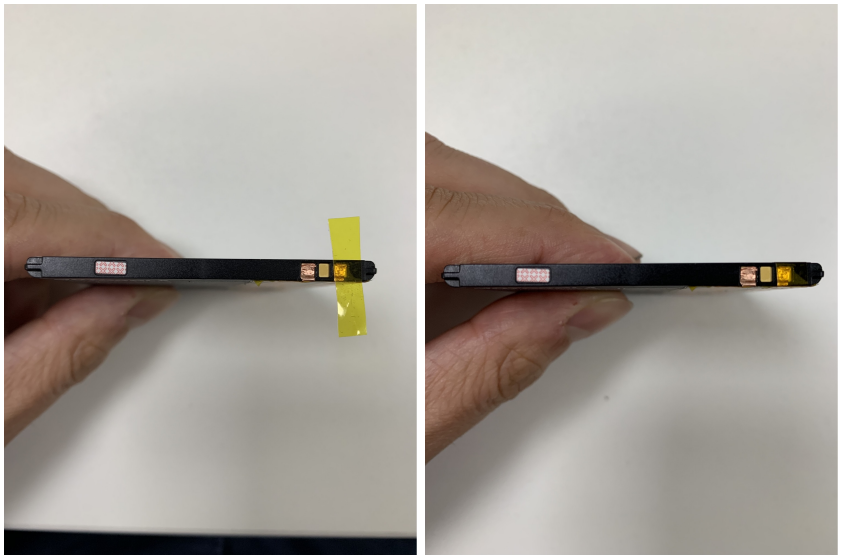

Figure 8: Cover the Voltage (+) terminal with insulating Kapton tape.

to the copper tape that connects to the Ground (-) battery terminal. Solder the exposed end of the red test lead to the copper tape that connects to the Voltage (+) battery terminal. Solder the exposed end of the green test lead to the copper tape that connects to the Voltage (+) phones terminal. Add some

Figure 9: Install the 3rd copper tape and secure it with Kapton tape.

soldering wire to the free edges of each cable to make them hard and easy to connect with the relay kit.

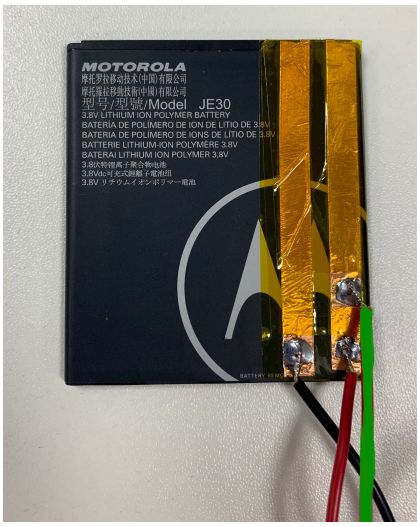

Figure 10: Solder the exposed terminals.

Use the voltmeter / multimeter to test your connections. First measure the battery's voltage by connecting the voltmeter / multimeter to the battery terminals (red and black cable). Next, check the red and green cables, they

should not make any contact. Finally, place the battery into the phone and try to power it up. It should NOT be able to power up since there is no connection between the battery's Voltage (+) and the device's (+) terminals.

Connect the black cable to monsoon's Ground (-) terminal (black) (Figure 11). Connect the green cable to the middle terminal of the relay. Connect the red cable to the right terminal of the relay. Connect monsoon's Voltage (+) terminal (red) and the right terminal of the relay with the last red cable. Finally, cover monsoon's terminals with some electrical insulation tape (item 3).

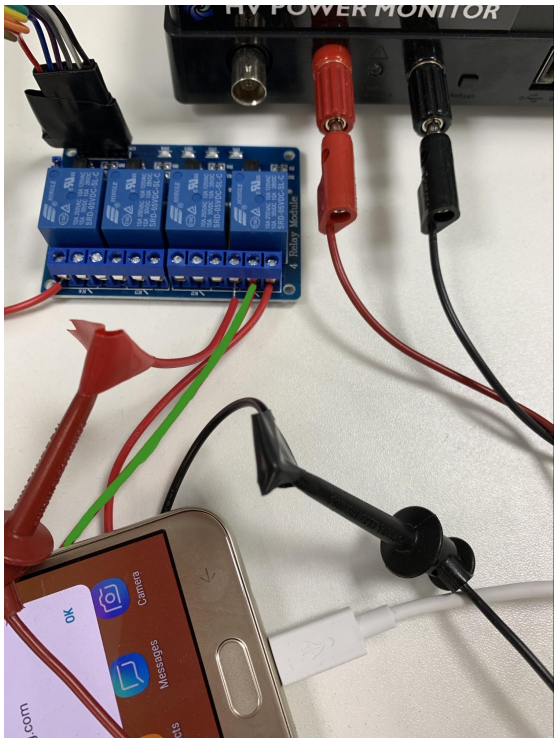

Figure 11: Connect with the vantage point.

3.2 Phones with Embedded Battery

To support devices with embedded batteries, you will first need to disassemble the device in order to extract the battery controller board and act as the intermediary between the device and Power Monitor. Phone disassembly will not be covered here, please refer to guides available online (e.g., `www.ifixit.com`) to find instructions for your device. This tutorial assumes that the battery is already removed from the device or is ready to be removed.

The board is typically held within a plastic shroud or rolled into the sleeving at the top or bottom of the battery. Open the shroud or sleeving until you can see the connection points between the battery itself and the control board. Use a voltmeter / multimeter to probe the points and identify the Voltage (+) and Ground (–) connections, make note of which connection point on the board is which for reference later. You can now cut the connections, be careful not to short the connections together, and remove the control board.

Cut a 20 centimeter length piece each of one red and one black 20 AWG wires (item 4). With the control board removed you can now solder the red wires to the Voltage (+), and the black to the Ground (–) connection points of the board. These two wires will later connect to the circuit and monsoon.

Re-connect the battery board connector to the phones power input and secure it to the chassis with Kapton tape (item 1). In order to reassemble the phone you will need to open a hole in the phone body to accommodate the power wires and reassemble the phone. Alternatively simply reattach the screen and any necessary connections and perform testing with the phone partially disassembled. It's recommended that you test the power connections prior to fully reassembling the phone.

Connect the black cable to monsoon's Ground (-) terminal (black). Connect the red cable to the middle terminal of the relay. Connect monsoon's Voltage (+) terminal (red) and the right terminal of the relay with the last red cable. Finally, cover monsoon's terminals with some electrical insulation tape (item 3).

4 How To Join?

In order to register a new vantage point to BatteryLab, please send us an email to <anonymized>. In your email please provide <vantage_point_name, public_IP>. The vantage_point_name is a human friendly name which will be used to generate a DNS entry for the new vantage point, e.g., node1.batterylab.dev. The public_IP should be the public IP from which the controller is reachable on the following (configurable) ports: 2222, 6081, and 8080. Those are BatteryLab default ports, and can be changed if needed. Note that access to port 2222 should only be restricted to 3.18.180.10 (batterylab.dev).

Next, you can proceed to physically build as described above. At this point, the controller (Raspberry Pi) should also be flashed with the latest Raspberry Pi OS. We recommend doing so via Etcher https://www.balena.io/etcher/. The next step consists of installing BatteryLab's software at the controller. This step is realized automatically by BatteryLab's access server and it is the first job to be deployed at the new vantage point. After the above step, the controller is turned into an "access point"' where the test devices will connect to. By default, the access point spins a new SSID (BatteryLab) with a pre-set password operating on 2.4GHz. However, BatteryLab automatically switches to 5GHz for devices that support it. This "switch" is required since the Raspberry Pi does not mount two WiFi antennas and thus both frequencies cannot be active at the same time.

If successful, you should now have a local wireless network available (ssid="BatteryLab", ssid_pwd="BatteryLab2019") where the testing devices should be connected. Please setup such connectivity as needed per device. Next, please connect the testing devices to the controller via USB. At this point each device should ask you to grant access to the Pi (see Figure 12 – note that the RSA key will be different). Please tick the box "Always allow from this computer" and press OK.

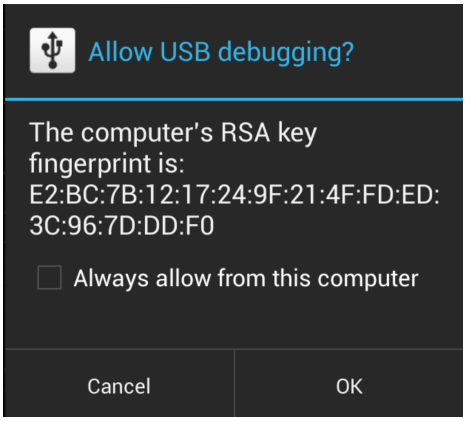

Figure 12: Grant USB access to the Raspberry Pi.

References

[1] Aukru. Aukru 40x 20cm Female-Female Dupont Jumper Wire Jumpers Cables for Arduino Raspberry Pi. https://www.amazon.co.uk/Aukru-20cm-Female-Female-Jumpers-Raspberry/dp/B00OL6JZ3C/.

[2] GSM Arena. GSM Arena. https://www.gsmarena.com.

[3] Monsoon Solutions Inc. High Voltage Power Monitor. https://www.msoon.com/online-store.

[4] Monsoon Solutions Inc. Mobile Device Power Monitor Manual. https://msoon.github.io/powermonitor/PowerTool/doc/Power%20Monitor%20Manual.pdf.

[5] Monsoon Solutions Inc. PyMonsoon. https://github.com/msoon/PyMonsoon.

[6] Raspberry Pi Foundation. Raspberry Pi 3 B+. https://www.raspberrypi.org/products/.

[7] Raspberry Pi Foundation. Raspberry Pi Documentation: GPIO. https://www.raspberrypi.org/documentation/usage/gpio/.

[8] SanDisk. SanDisk 32GB X2 (64GB) MicroSD HC Ultra Uhs-1 Memory Card. https://www.amazon.com/gp/product/B00CNYV942.

[9] Shenzhen Elegoo Technology Co. ,Ltd. ELEGOO 4 Channel DC 5V Relay Module with Optocoupler. https://www.elegoo.com/product/elegoo-4-channel-dc-5v-relay-module-with-optocoupler/.

[10] Vadim Mikhailov. uhubctl. https://github.com/mvp/uhubctl.