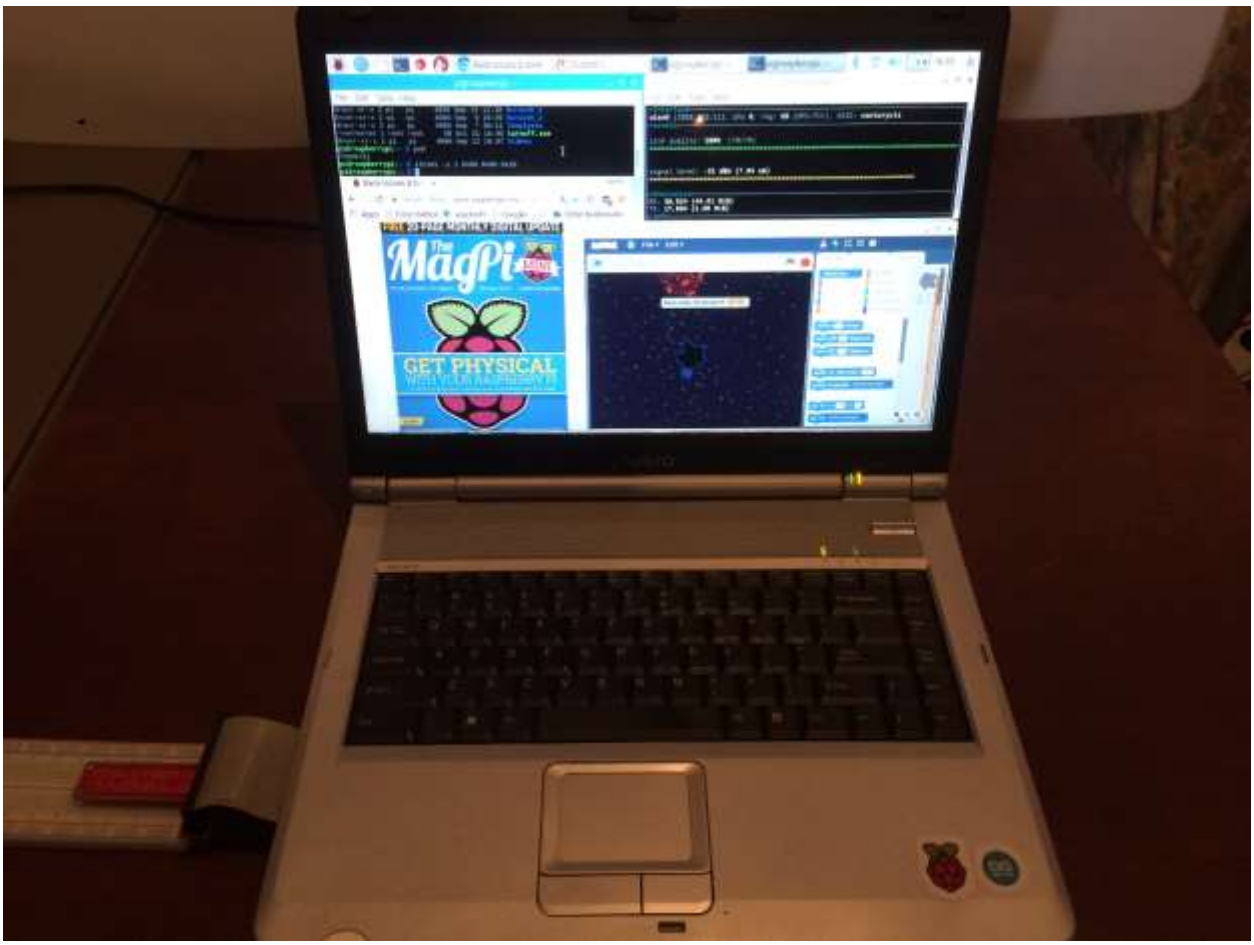
Raspberry Pi & Teensy Laptop Conversion



Now with Battery Operation

Repo at https://github.com/thedalles77/Pi_Teensy_Laptop

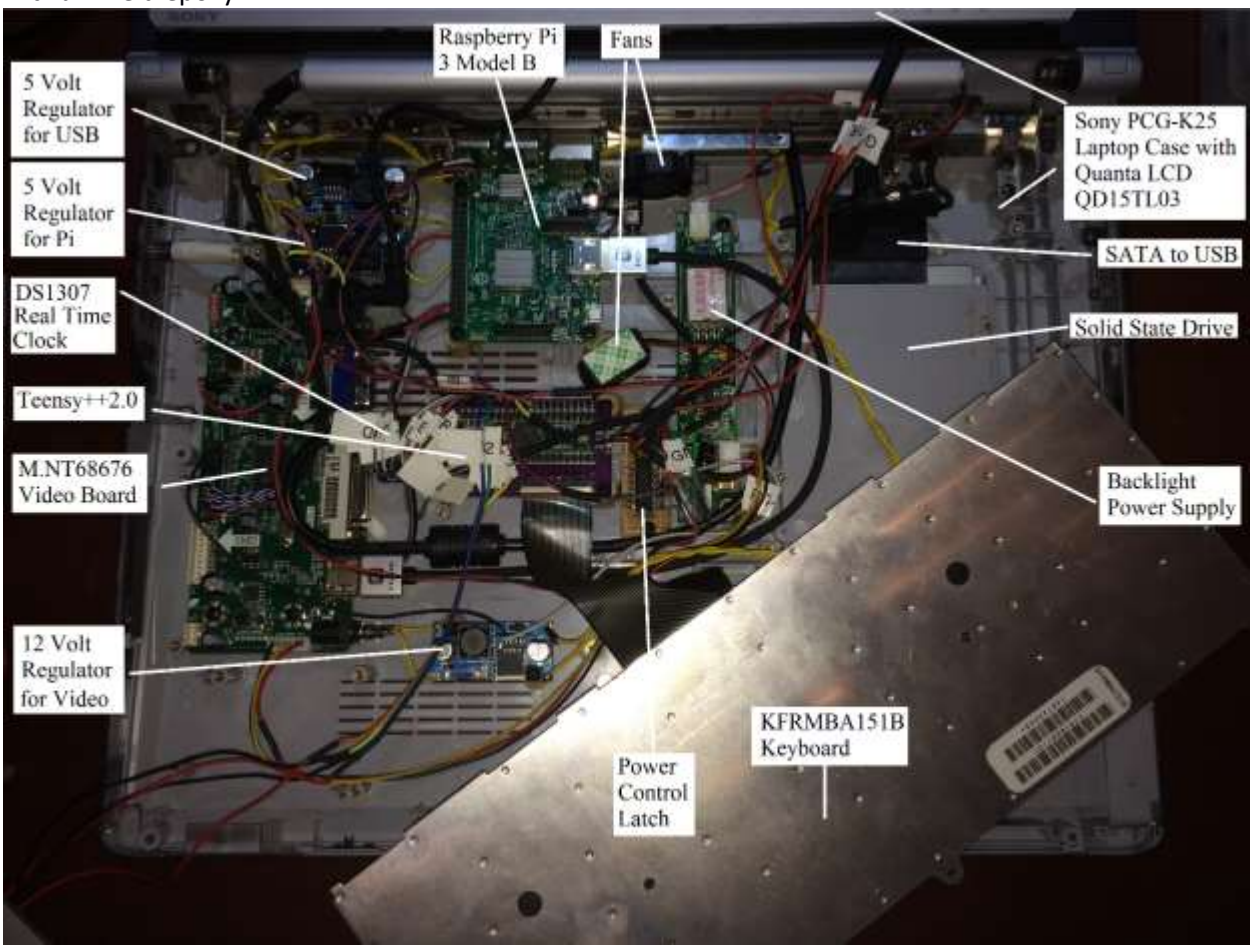
Introduction – This document will describe how I converted a Sony Vaio PCG-K25 computer into a Raspberry Pi 3B and Teensy ++2.0 laptop. Most of the circuits, software, and modifications are based on information available on the internet. The circuits in the laptop are listed below and then described in detail in the following pages:
Update: Battery operation has been added. See Item 15 Below

1. A Teensy ++2.0 is used to interface the keyboard and touchpad with the Pi via USB. This required a new circuit board to route the keyboard connector to the Teensy I/O pins. A Teensyduino sketch scans the keyboard and touchpad and sends changes to the Pi over USB.
2. The HDMI from the Pi is converted to LVDS for the display by an M.NT68676 video board. The video cable had to be lengthened to reach into the laptop base.
3. The control pad for the M.NT68676 video board was replaced by the Teensy.
4. The Pi boots from a 240GB solid state drive using a SATA to USB cable. The micro SD card has been removed.
5. The laptop Wi-Fi antenna is connected directly to the Pi for improved reception. A connector was added to the Pi that fits the laptop antenna cable.
6. A Real Time Clock and the Teensy are connected to the Pi over the I2C bus.
7. Three separate Buck regulators provide power to the M.NT68676 video board, the Pi, and the 4 USB ports. The regulators were modified so they can be enabled with a control signal.
8. The laptop power switch turns on the regulators and the Teensy turns off the regulators. This is accomplished with a NAND gate latch circuit that controls the regulator enable signal.
9. The laptop LEDs were rewired to show incoming power, regulator power, caps lock, and code debug.
10. The Teensy will reset the Pi if Control-Alt-r is typed or shut down the laptop if Control-Alt-s is typed. These actions can also be initiated by the Pi over the I2C bus.
11. The Pi GPIO signals are brought out the side of the laptop for bread boarding.
12. The Pi audio is cabled to a 3.5mm jack on the side of the laptop for headphones.
13. Audio sent to the M.NT68676 board via HDMI is connected to the laptop speakers.
14. A fan blows over the Pi and another fan blows out the back. Testing shows this gives adequate cooling to the Pi when overclocked at 1300 MHz.
15. The original laptop battery powers the laptop and is charged from the wall supply. The Pi reads the battery status registers over a bit-bang SMBus. The Teensy ADC monitors battery voltage and turns off the laptop when the battery is depleted.

A short YouTube video for this laptop project can be found here. I added battery operation after making the video. Two Hackaday articles have been written about this laptop, here and here.

A parts list with vendor links is located in the Appendix.

Board Mounting – The locations of all the boards in the laptop are shown in the following picture (except for the battery charger and ADC reference). Wood dowels were cut to make standoffs for the boards. The dowels were screwed to each board and then the dowels were attached to the laptop floor with JB Weld epoxy.



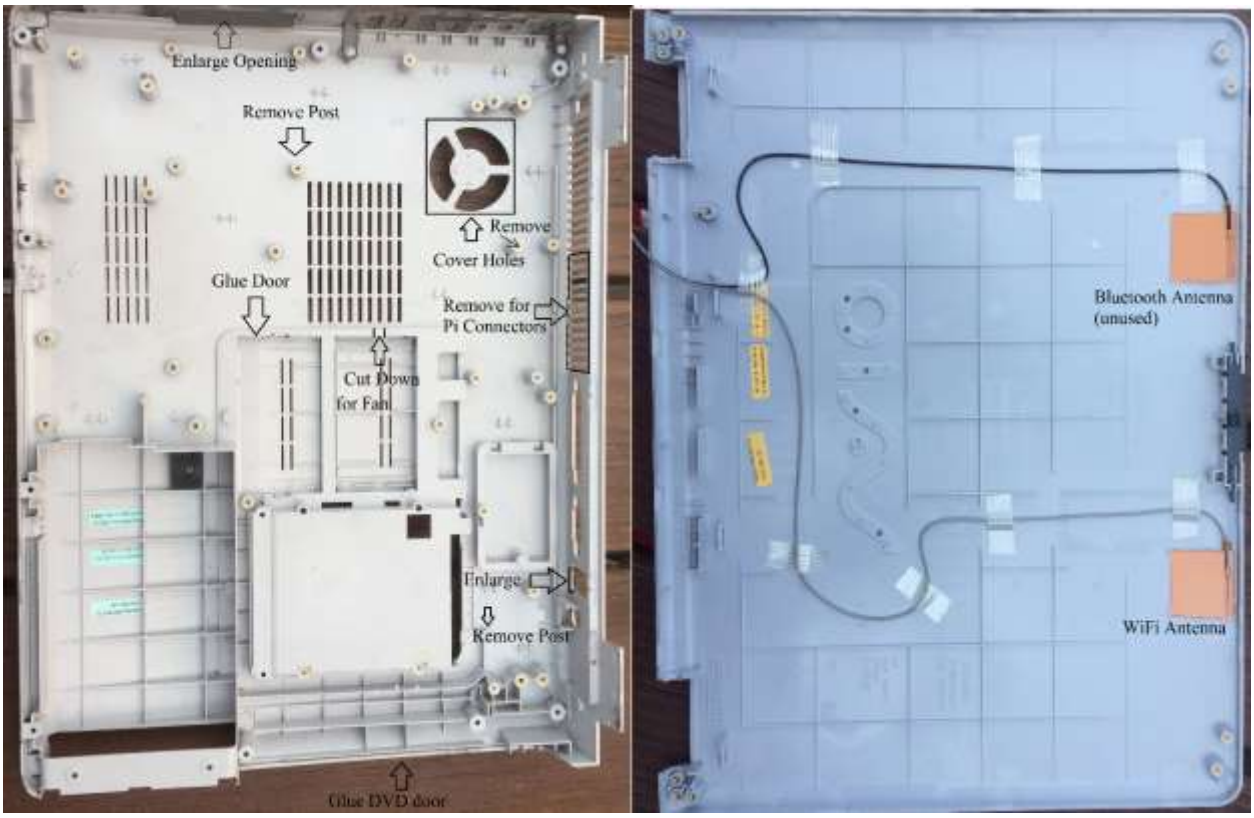
This picture shows the metal shield that helps to stiffen the keyboard.

First Steps – I was given a nonfunctional Sony laptop specifically for this project. Unlike modern ultra-thin laptops, this one has over an inch of thickness at the back so the Pi's USB and network connectors don't need to be removed to fit in the case. The laptop was in good shape but I needed to know if the LCD and keyboard were functional. After some troubleshooting, I was able to get the BIOS to boot up (there was no hard drive) and the display and keyboard worked fine. Using my Seeed DSO oscilloscope, I probed the 24 keyboard signals at the flexible printed circuit (FPC) connector. I found 16 of the signals were driven by the motherboard and pulsed low every 30 msec. The remaining 8 signals are inputs to the motherboard and were at 5 volts but would pulse low if I pressed certain keys. Powering down the laptop and switching to an ohm meter, I was able to determine the keyboard connections by systematically checking for a connection as I pressed each key. It's a long tedious process but I eventually created a matrix of the keyboard connections. I can see why people write software routines that automatically determine the matrix as each key is pressed in sequence.

I probed the touch pad connector pins with the scope but saw no clock or data pulses because the touchpad had not been initialized by the BIOS. I found the 5 volt and ground connections and two other pins that measured 5 volts but my ohm meter showed no connection to the 5 volt bus. I assumed these pins were the clock and data for the PS/2 interface and would figure which was which once I had the Teensy up and running.

This is what the laptop looked like before everything was removed:

Sony Vaio PCG-K series disassembly – I followed the “Inside my laptop” directions for disassembly of the base and LCD sections. I kept unscrewing everything and removed all metal shielding until I had a bare case as shown below. I used a Dremel tool and a file to make the cuts shown by arrows. JB Weld two part epoxy was used to glue the memory access door shut and to permanently secure the DVD Door. I blocked the 3 fan holes with Duct Tape and then poured in JB Weld. I should have removed all of the original motherboard mounting posts so I didn’t have to come back later and Dremel another one each time I tried to mount a board.



Keyboard – I chose a Teensy ++2.0 for my keyboard controller because I wanted extra I/O for controlling the touchpad, video card and anything else that might come up without adding multiplexing chips. As I expected, I've used up all 38 of the Teensy's digital I/O pins. This Teensy has been around for a while so I figured the software was stable and there would be lots of examples to follow. The Teensy developer, PJRC has created an Arduino add-on called Teensyduino that allows the controller to communicate via USB as a Human Interface Device (HID), aka keyboard and mouse. I followed the PJRC steps for installing Arduino and Teensyduino on a PC and then started experimenting with the Keyboard.set_key and Keyboard.set_modifier commands. I used PJRC's "Micro Manager" method to send the keyboard data over USB.

The finished sketch is a complete keyboard controller routine that scans the keys every 30 msec and sends the keypresses to the Pi over USB. I'm a hardware guy so don't expect pretty code but it works and can certainly be improved on. The Modifier keys (Ctrl, Alt, Shift, and GUI) can be pressed at the same time in any order and they will be sent to the Pi. The rest of the keys (called normal keys) are sent in 6 different slots so that you can have more than one key pressed at a time. The program sends the keypress in slot 1 if it's not in use, otherwise it moves on to slot 2 on up to slot 6. If the keyboard had diodes to isolate the keys, then up to 6 keys could be pressed at the same time. Unfortunately there are no diodes so ghosting causes extra keys to be sent after 3 or 4 keys are held down. Go to Geekhack and Deskthority to learn more about keyboards and check out the TMK and Soarer keyboard controllers for examples of far more sophisticated keyboard routines. For everything that I do, the keyboard has worked perfectly including playing Scratch games, typing this document, and general Linux stuff. An earlier version of my keyboard routine sent all keypresses in slot 1 and there were lots of times that I would type one key and not quite release it before typing another key which would cause the second key to be missed. And a real deal breaker was when my Scratch games wouldn't move diagonally because the up arrow and right arrow couldn't be pressed at the same time.

My Teensy code, "Keyboard_and_Touchpad.ino" is available on github.

There are two code oddities that a better coder will hopefully figure out. My guess is that I'm supposed to send some handshake messages but I've made it work by adding delays. If you know a better solution, let me know.

1. My Teensy code waits 30 seconds at startup to let the Pi boot up. I came up with this time delay by trial and error until I found what worked. If the delay isn't right, the Pi does something to the Teensy that causes the Teensy to lock up. If the Pi is re-booted, the Teensy must also be rebooted (either by cycling power or with a software reset). You can tell when the Teensy is locked up because the on-board "heartbeat" LED (that I've programmed to blink) is stuck off. When I hook the Teensy to my PC and start up the PC, I get the same error and the 30 second delay fixes the problem.

2. Whenever the Teensy code detects a key is pressed or released, it sends the information over USB but there is a special case for the Caps Lock key. When it is pressed or released, the code must wait 10 milliseconds after sending the information before proceeding to scan for other keys. Without the delay, the Teensy will lock up and the "heartbeat" LED will stop blinking. When I hook the Teensy to my PC, the Caps Lock key works fine without any delay.

The keyboard part number is KFRMBA151B and it is used on all Sony Vaio PCG K series laptops.

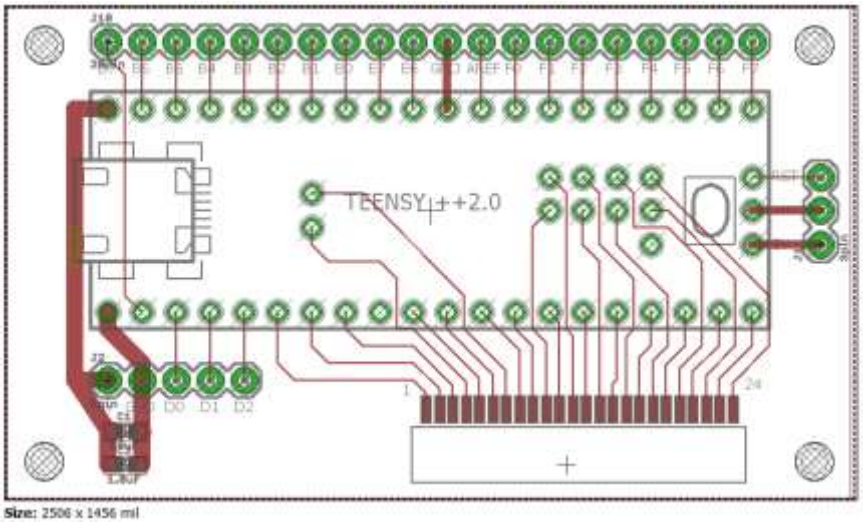
Keyboard Matrix – The 8 columns across the top of the matrix are inputs to the Teensy. The 16 rows on the left side are outputs from the Teensy. Only one row is driven low at a time and the other 15 rows are set to high impedance. The 8 columns have pull ups inside the Teensy so if a key is not pressed, it is read as a logic high. A keyboard scan is repeated at 30msec intervals and any key changes are reported over USB. I couldn't find a connection for the print screen and num lock keys on my keyboard so I'm assuming they're broke. I don't need num lock but I might want a print screen key so I use the Menu key as a print screen.

Firmware		Columns	0	1	2	3	4	5	6	7
	Teensy	Inputs	E0	E4	C1	A0	C2	A5	C4	A6
Rows	Outputs	Conn Pin#	6	7	11	12	13	14	17	18
0	D3	1			CTRL-R				CTRL-L	
1	D4	2		ARROW-L	ARROW-D	ARROW-U	PAGE-D	PAGE-U	END	ARROW-R
2	D5	3		ENTER		]		=	"	
3	E5	4	F12	MENU/PrtSc	/	;	[	P	-	BCKSPACE
4	D7	5	INSERT				\	HOME	L	DELETE
5	E1	8	F10	COMMA	PERIOD	i	ZERO	9	F	F11
6	C0	9	F8	M	B	8	U	O	J	F9
7	A4	10	F7	N	G	Y	K	7	H	6
8	C3	15	F5	V	S	T	R	5	C	F6
9	A1	16	F3	X		E	4	3	D	F4
10	C5	19	F1	Z	SPACE	Q	2	1	W	F2
11	A2	20						SHIFT-L		SHIFT-R
12	C6	21	~		A		TAB	CAPS LCK		ESC
13	A7	22		ALT-R		ALT-L				
14	C7	23					GUI			
15	A3	24	Fn							

My code doesn't report the Fn – Function (multimedia) keys to the Pi but certain Fn – Function key combinations cause the Teensy to control the video converter card. This eliminates the need for the push button keypad that comes with the video card.

Teensy Circuit Board – The 24 signals from the FPC keyboard connector are wired to the Teensy with a 2.5” x 1.5” circuit board I designed using the Freeware version of Eagle software. All signals are on the top layer with plated thru holes for pins. I found schematic and layout symbols on the web and modified those that weren’t exactly what I needed. I had never used Eagle software but I found it fairly easy to figure out with lots of information online when I got stuck. Do the schematic first and it will make a layout with air wires that guide where you need to put traces. Sparkfun has excellent tutorials for Eagle schematic and layout.

The 24 signals on the keyboard FPC cable have a 1mm pitch. I purchased compatible FPC connectors from Ali express. 24 of the Teensy digital I/O pins are routed to the FPC connector pads and the remaining Teensy I/O are routed to thru hole pads for connecting to other devices (Touchpad, Video card, LEDs, and Pi). I added pads for 5 volt bypass caps in case the Teensy or Touchpad had power problems but found they weren’t needed. The layout is shown below without the solid copper fill so you can easily see the signal traces. This is a revised layout that includes some corrections from the original that I used.



Three boards were fabricated by Oshpark in under 2 weeks. Oshpark accepts the Eagle layout file directly so you don’t have to create Gerber files or even know how to use Eagle to order the boards. I put a drop of super glue on the FPC connector and attached it to the board (just to hold it in place). Then I used my Hakko soldering iron and a T18-C05 tip to solder the 24 connector pins to the board. I definitely needed geezer goggles to see the small solder joints. Flow soldering with the toaster oven would have worked much better but my wife vetoed that plan.

I bought the Teensy without pins so I could solder my own header pins around the edge and in the interior. A standard pin won't fit in the E4 and E5 locations but a small wire from a 1/8 watt resistor will work. The finished board with Teensy and FPC connector is shown below. I included pins so I could wire a reset switch to the back of the laptop case to initiate the Teensy loader but the reset button is only needed the very first time the loader is used. After that, the loader can initiate everything over USB so I didn't bother adding a button. This worked fine until I updated the Arduino/Teensyduino software to the latest version, then I had to open up the case and push the button for the first load.

My original layout had mounting holes that were way too small. I had to drill larger holes but ended up with a power to ground short when I installed the lower left mounting screw. I've enlarged the hole size and moved the 5 volt trace to fix these problems. The schematic and revised layout files are posted in the Sony_keyboard folder at my Github repo.

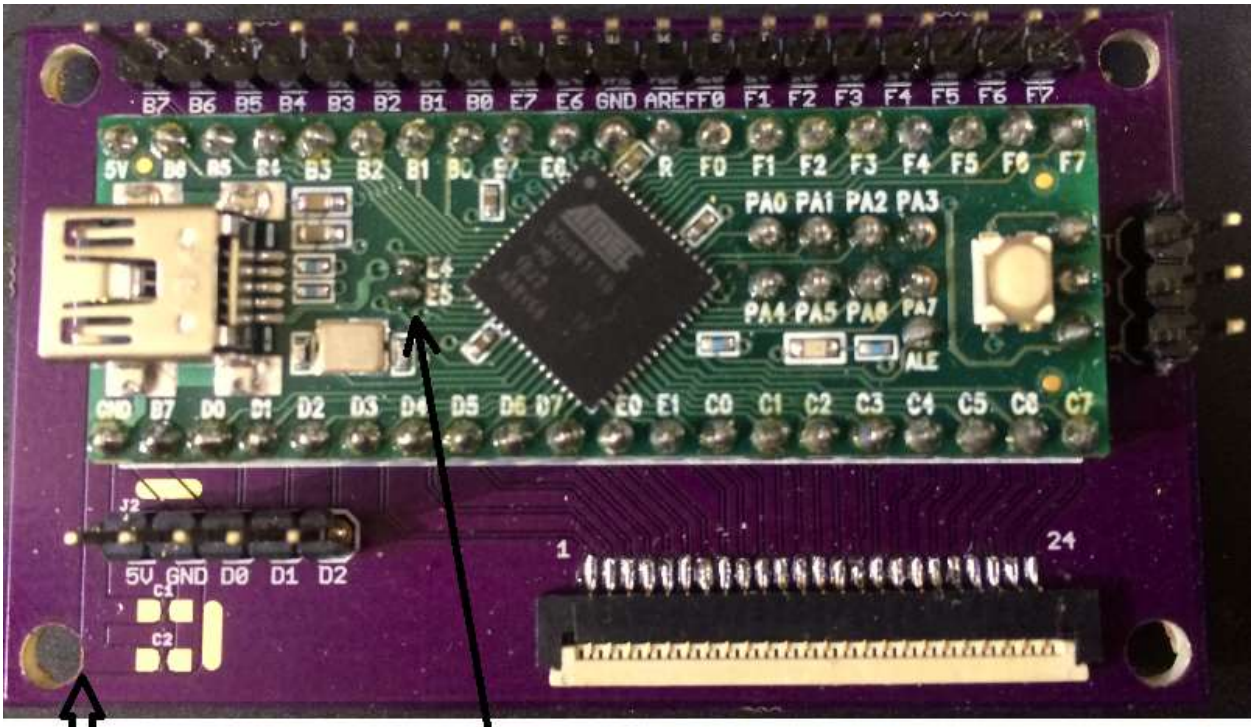
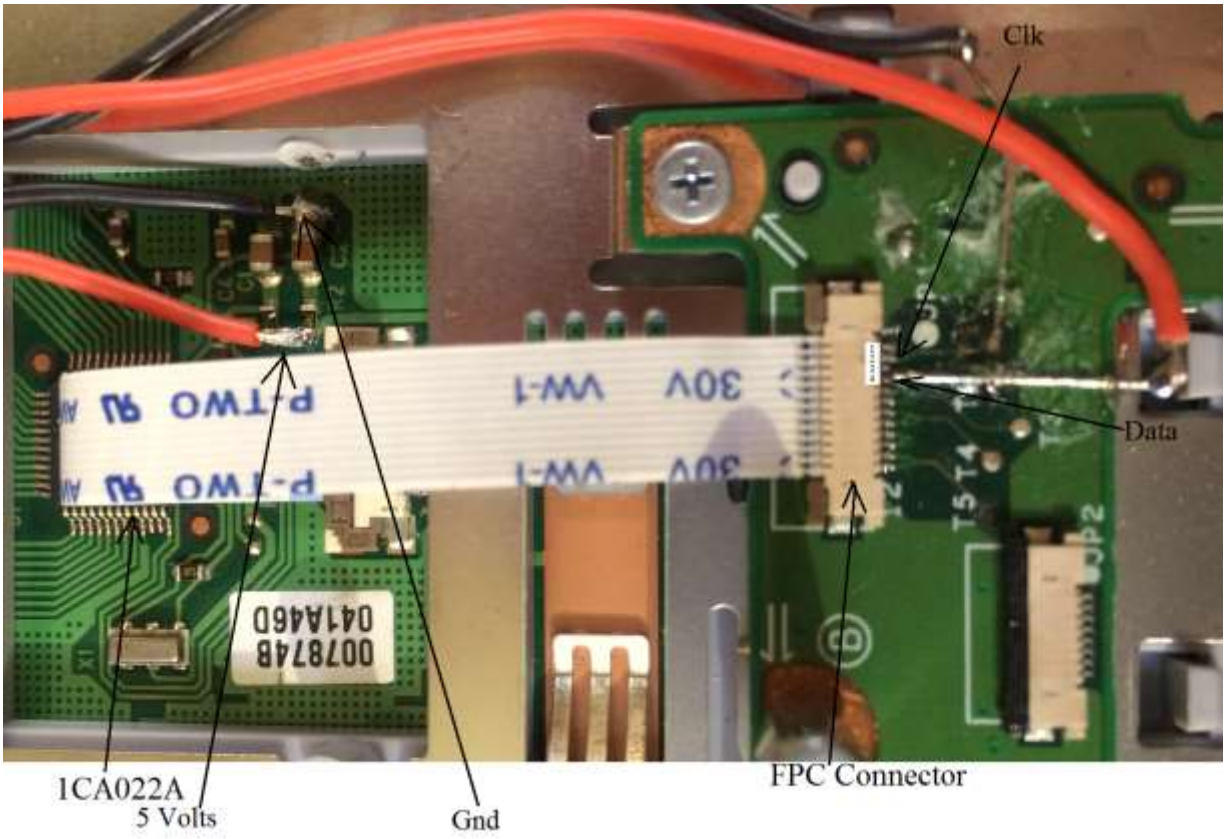


Table of FPC pins to Teensy inputs

FPC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Teensy	D3	D4	D5	E5	D7	E0	E4	E1	C0	A4	C1	A0	C2	A5	C3	A1	C4	A6	C5	A2	C6	A7	C7	A3

I used a Dremel tool to cut the air vent bars on the back of the laptop so that the Pi's network and USB connectors are accessible. The USB cables from the Teensy and from the SSD come out the back of the laptop and loop back to the connectors on the Pi as shown below. I will eventually move the USB cables inside once I'm done fooling around with the Teensy code.

Touchpad – The following picture of the Touchpad circuit boards show the connections to Clock, Data, +5 volts, and ground. The +5 volts and ground were connected on the circuit board that contains the 1CA022A touchpad chip. The Clock and Data were connected on the button board. The Clock is on pad T2 and connector pins 1 & 2, Data is on pad T3 and connector pins 3 & 4. It was difficult to attach the Clock and Data wires to the small pads. To give the solder joint some strain relief, I tinned a wire with solder and glued it to the board. After the glue dried, I soldered it to the connection point and to the jumper wire. I used super glue but I think JB Weld would work better because it's not so runny.



I started with ps/2 touchpad code from playground.arduino and modified it for USB. The touchpad uses the ps/2 mouse protocol which sends X and Y movement values as signed 9 bit values. The Teensy code converts the movement values to signed 8 bits and inverts the sign of the Y data to match the polarity of the PJRC Mouse.move USB function. The left and right buttons on the touchpad are converted from ps/2 to the PJRC Mouse.set_buttons USB function. Normally a touchpad sends position and button data in stream mode whenever a change is detected and the host runs an interrupt service routine. I needed the touchpad to send position and button data when queried by the Teensy (remote mode). In my code, after completing a keyboard scan, the Teensy requests data from the touchpad and if any movement or buttons are pressed, the information is sent to the Pi over the same USB cable as the keyboard data (known as USB Composite). The touchpad USB data can be disabled by pressing Fn and F12 on the keyboard. It can be turned back on with the same sequence. This allows a USB or Bluetooth mouse to be used instead of the touchpad.

Display - The LCD from the Sony laptop is a Quanta Display Inc. part number QD15TL03. It needs LVDS video signals so the HDMI out of the Pi must be converted by the M.NT68676 board. Several eBay companies sell the M.NT68676 board. Verify with an eBay message prior to purchase that the board is compatible with your LCD model number. The Monitor Control Board Specification gives the interface definition of the M.NT68676 board.

The board contains a 4 Megabit serial flash memory (part number Winbond 25X40CLNIG) that is programmed by the vendor for the LCD parameters. The main chip on the board is marked NOVATEK NT68676UFG but I could find no data sheet online. The board takes in 12 VDC and a 54329E buck regulator outputs 5 volts. There are two 3.3 volt linear regulators, part number 1117B 33 that feed the LCD and the NT68676UFG chip. The NT68676UFG is also fed 1.8 volts from an 1117B 18 regulator. A two watt stereo audio amplifier, part number TDA7496LG, is fed from the HDMI audio and outputs to a 3.5mm jack which I have cabled to the laptop speakers. I've tried 3 different speaker models and they all have pretty low volume. Linux commands from a terminal window are used to switch the audio to the speakers or to the headphone jack.

Speakers:

amixer cset numid=3 2

Headphone jack:

amixer cset numid=3 1

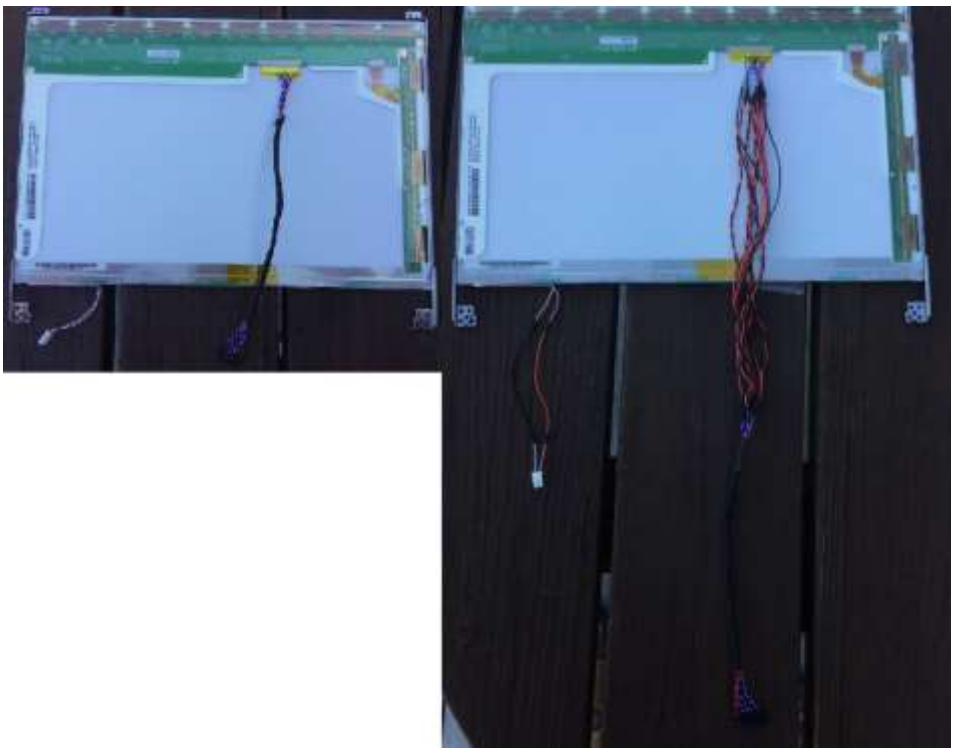
I've made aliases called "speakers" and "headphones" in .bashrc that execute the amixer commands so I don't need to remember them.

Before making any video cable modifications, I connected the M.NT68676 video board to the Pi and confirmed it correctly drove the LCD. The keypad menu items on the screen were in Chinese. Luckily I found an Alex Eames video which shows the key sequence to change the language from Chinese to English. The sequence is Menu, Right, Menu, Menu, then use the Left or Right buttons to highlight English, and then push Menu to select it.

I needed to lengthen the LVDS cable so it would reach the board when mounted in the laptop. I added 10 inches to each wire including the 4 twisted pairs using 28 gauge stranded wire. I also added 4 inches to the 2 wires that feed the backlight as shown in these before – after pictures. The display was noisy and not syncing properly with the longer cable but once I pulled the wires tight and wrapped them with electrical tape, it worked fine.

In hindsight, I should have lengthened the original laptop video cable by about 4 inches instead of the cable that came with the kit. The original cable has a shielded twisted pair clock with grounded conductive tape over all wires and is flat for the section that fits behind the LCD. My only concern with using this cable was the wire gauge is really tiny so I thought it might be fragile and hard to solder.

Before



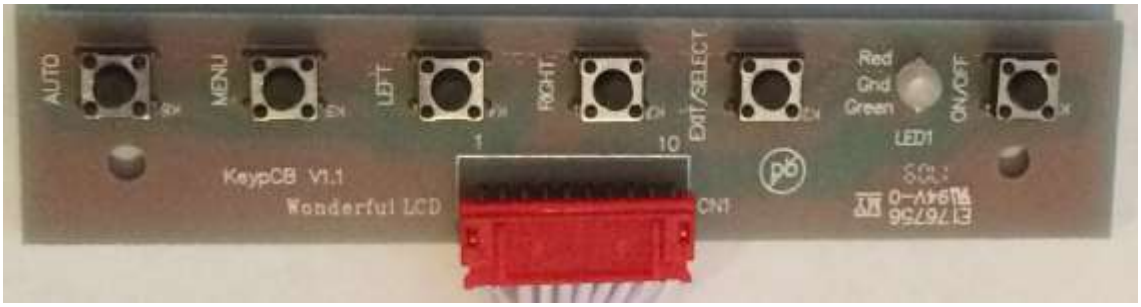
After

The pinout for the video cable is below:

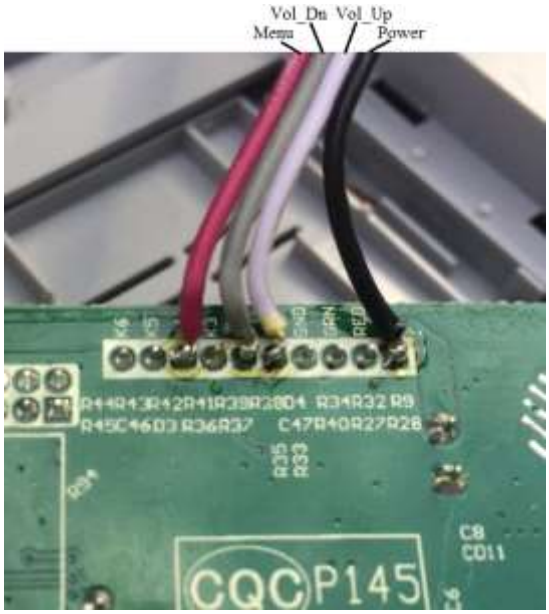
LCD Connector	Signal Name	Card Connector
1	GND	4
2	3.3V	1
3	3.3V	2
8	LVDS ODD 0-	7
9	LVDS ODD 0+	8
10	GND	5
11	LVDS ODD 1-	9
12	LVDS ODD 1+	10
13	GND	6
14	LVDS ODD 2-	11
15	LVDS ODD 2+	12
16	GND	13
17	LVDS ODD CLK-	15
18	LVDS ODD CLK+	16
19	GND	14

After lengthening my video cable, I found that 25 inch cables can be purchased from ebay. The $23 price tag is pretty steep considering I bought the converter card, backlight supply, control pad, and short LVDS cable for $25.

I replaced the key pad switch board shown below with the Teensy and Fn-Function Keys.



The only switches I wired were Left (volume down), Right (volume up), Menu, and On/Off (Power). Auto didn't seem to do anything and Exit/Select wasn't needed because the controller will exit if no keys are pressed for a couple seconds. The switches are pulled up on the video card to 3.3 volts and go to ground when pushed. The Teensy must not drive these signals to 5 volts or it could damage the control chip. The following picture shows where 4 wires were soldered to the keypad connector on the backside of the video card. The connections to the Teensy are given in the table.



Key Function	Board	Teensy
Volume Up	K1	B7
Volume Down	K2	B6
Menu	K4	B5
Power	K0	B4

The Teensy code floats the 4 control signals but sends a low when the Fn & Function keys are pressed per the following table. Menu, Volume Up, and Volume down can be sent low with manual keypresses to navigate thru the video card selections. This works for commands that are seldom changed but would get old fast if I had to do this for Mute or Brightness. For these commands, the Teensy pulses the Menu, Volume Up, and Volume Down signals in a sequence to reach the desired command. I tried speeding up the pulsing sequence but the video controller chip expects human speed or it doesn't work properly.

Key Sequence	**Result**
Fn and F1	Pulse the Menu signal low
Fn and F2	Mute/Unmute the HDMI Audio [1]
Fn and F3	Send the Volume Down signal low
Fn and F4	Send the Volume Up signal low
Fn and F5	Lower the Display Brightness [2]
Fn and F6	Raise the Display Brightness [3]
Fn and F7	Pulse the Display Power signal low

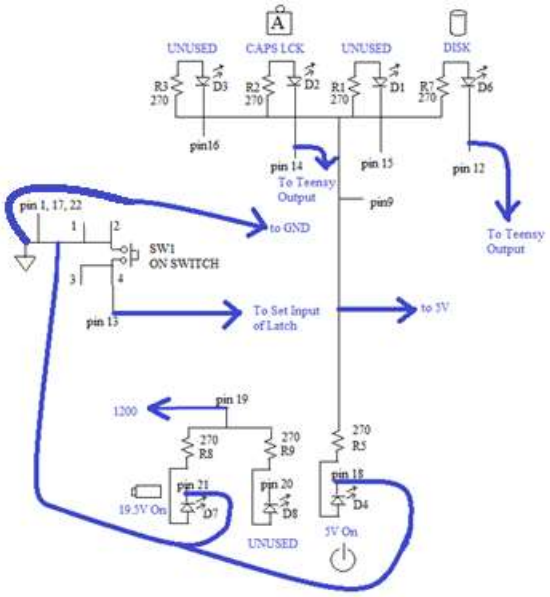
[1] Pulse Menu, Volume Up, Menu, Volume Down, Menu, Volume Down

[2] Pulse Menu, Menu, Menu, and then send Volume Down low until key is released

[3] Pulse Menu, Menu, Menu, and then send Volume Up low until key is released

The Teensy monitors the battery voltage with its ADC after each keyboard scan and if the voltage falls below a set level, the Teensy pulses the display power signal to turn off the display. After a second, the display power signal is pulsed low again to turn the display back on. Hopefully this gets my attention so I plug in the AC adapter.

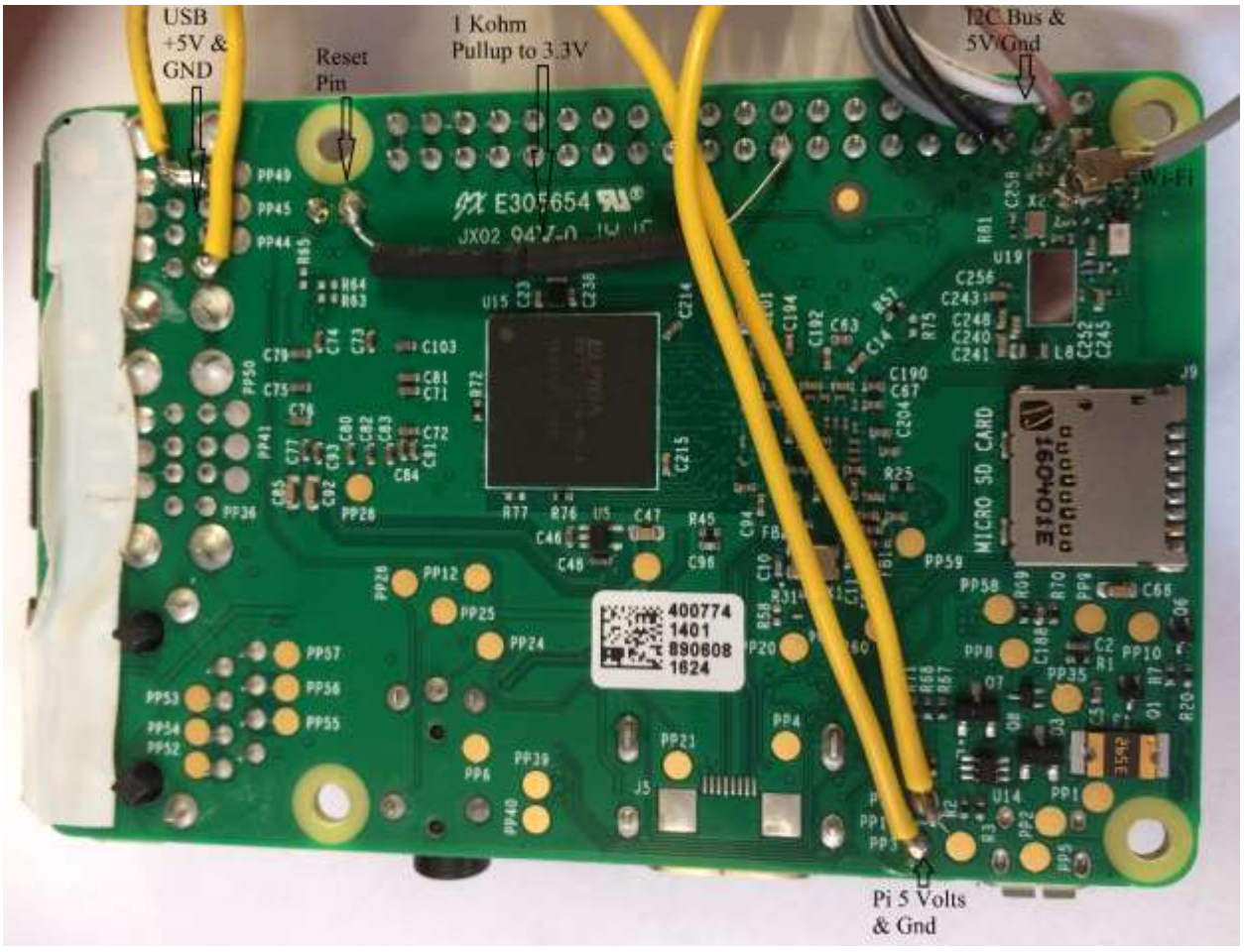
Power and LEDs – The following schematic of the Power Switch & LED Board shows blue connections where I added wires to the board. I chose to solder directly to the surface mount components instead of dealing with the ribbon cable connector. The Battery LED turns on when the 19.5 volts is connected and the Power LED lights when the Pi is powered with 5 volts. The Caps Lock LED is driven by the Teensy and is based on the "keyboard_leds" variable controlled by the Pi. The Disk LED is also driven by the Teensy and is used for code debug. The power switch is connected to the "Set" input of the Latch circuit described later.



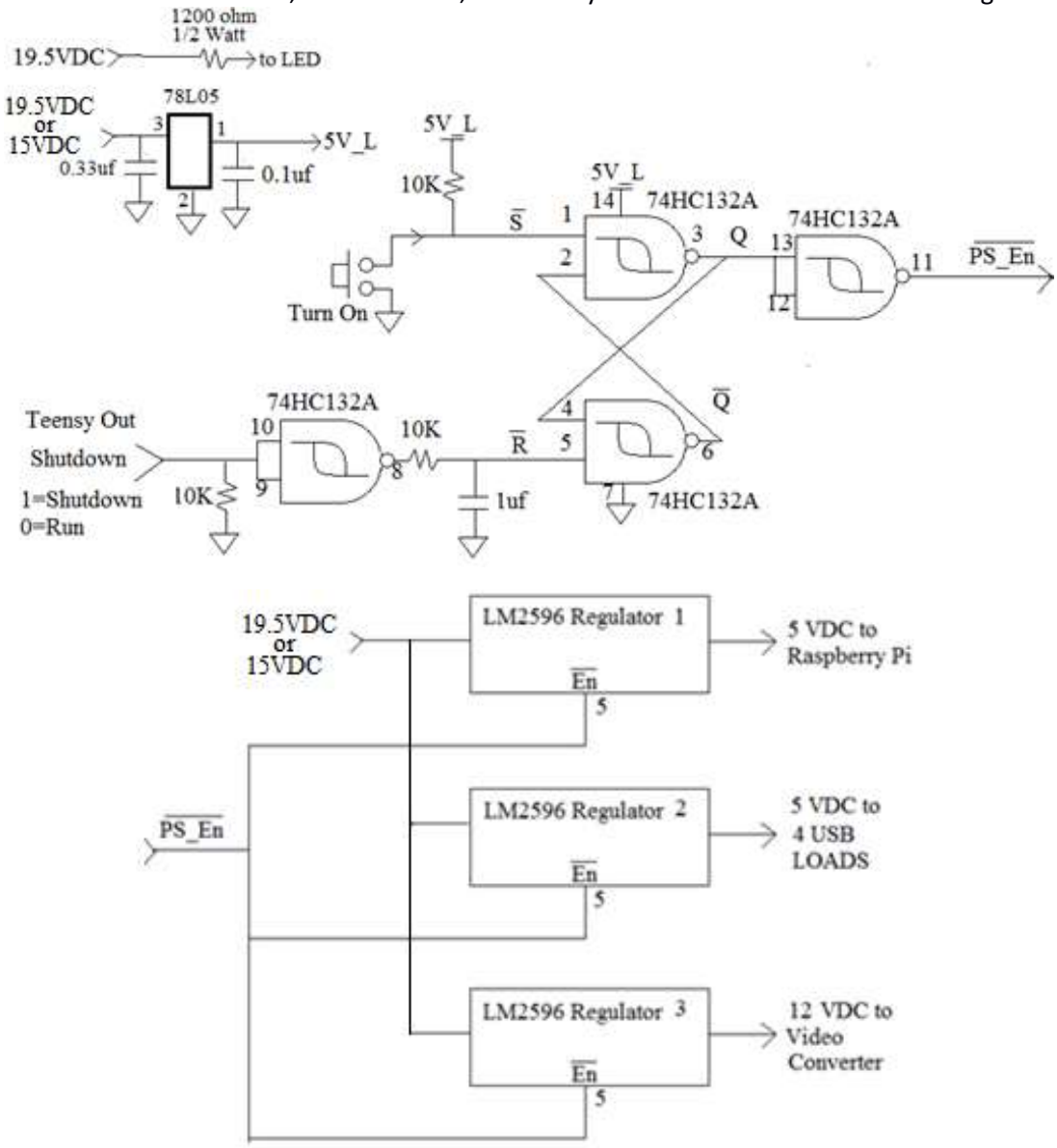
The four LEDs are all turned on in this picture.

Power Supplies – The laptop is fed 19.5 volts DC if the AC adapter is installed, otherwise the battery voltage is fed to 3 regulator boards based on the LM2596. These boards drop the voltage down to 12V for the video card, 5V for the Pi, and 5V for the USB ports. Many versions of this board can be found on Amazon and EBay. I adjusted the potentiometer on each board to give the desired voltage, then connected them to their respective loads and readjusted the voltage. The unmodified LM2596 board is shown below.

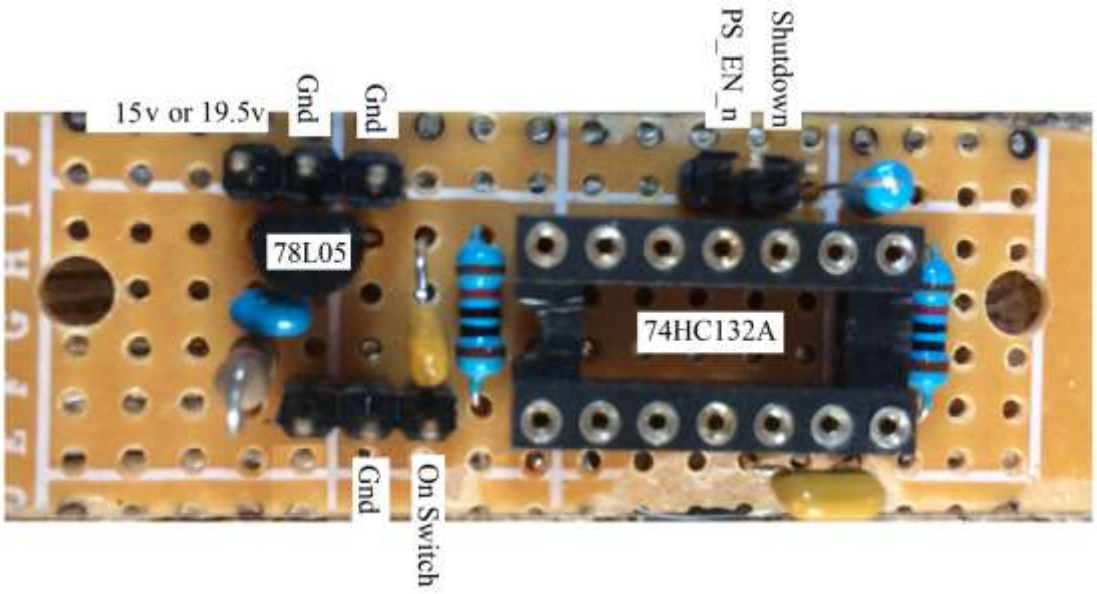
The 5 volt power from regulator #1 is soldered to the Pi (back side) at the large pad labeled PP7 near the micro USB connector. For USB power, the AP2253 at location U13 on the Pi (front side) was removed in order to separate the Pi 5 volt bus from the USB 5 volt bus. The 5 volts from regulator #2 is soldered to the power pins of the USB Connector as shown in the picture below. The power to the video card from regulator #3 uses a 2.5 x 5.5mm connector. This picture also shows the Wi-Fi connector, the reset pullup, and the four I2C wires.



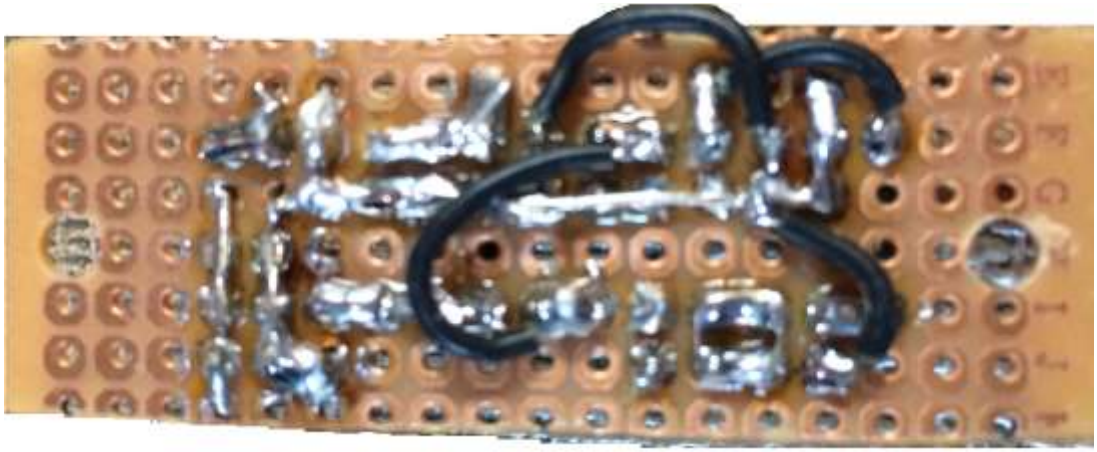
Power Latch - The enable pin of the LM2596 regulator is active low and tied to ground on the circuit board as described at raspberrypi.org forum. I cut the LM2596 enable pin (pin 5) on all 3 boards so it is no longer grounded. Then I connected an on/off control signal from the push button latch circuit shown below to pin 5 of all three LM2596 chips. The AC adapter or the battery provides power to the 78L05 linear regulator that outputs 5 volts to power the 74HC132A NAND gates, two of which are wired as an SR NAND Latch. The Set and Reset inputs to the Latch are active low. The Reset input to the Latch is fed from a NAND gate tied as an inverter to buffer the Teensy control signal. The Q output of the Latch drives another NAND gate also tied as an inverter to buffer the Latch output. The power to the NAND gates and the Set input to the latch comes up quicker than the Reset input because of the 1uf cap. This causes the latch to be reset and the power supplies disabled when power is first applied. When the Turn-On button is pushed, it sends a low to the Set input of the latch which turns on the power supply enable signal on the regulators. The Latch will continue to enable the power supplies until the Teensy is given a command to shut down, at which time, the Teensy resets the Latch to disable the regulators.



The Teensy will cause a shutdown if control-alt-s is typed on the keyboard or if a Linux shutdown is initiated with a “turnoff” alias described later. The latch circuit board shown below has a 14 pin socket for the 74HC132A and header pins for easy jumper attachment.



The components are soldered with point to point “ugly” wires on the back side.



When the laptop is turned off and not plugged into the charger, the three (disabled) LM2596 regulators, 78L05, and 74HC132A measure about 2ma from the battery. Another 4ma is drawn from the battery by the voltage divider resistors for the ADC (described later). The constant 6ma current from the battery will drain a fully charged battery in 4Ah/6mA = 667 hours = 27.8 days.

Occasionally I will lock up the Pi with a bad program but instead of cycling power, I reset the Pi with Control-Alt-r. I connected the Pi's reset pad to one of the Teensy's I/O pins. I also added a 1K pull up on the reset so I can plug and unplug USB cables and not cause a glitch that resets the Pi. This picture also shows the USB power switch that was removed at location U13 so that the Pi's 5 volt bus is separated from the USB 5 volt bus.

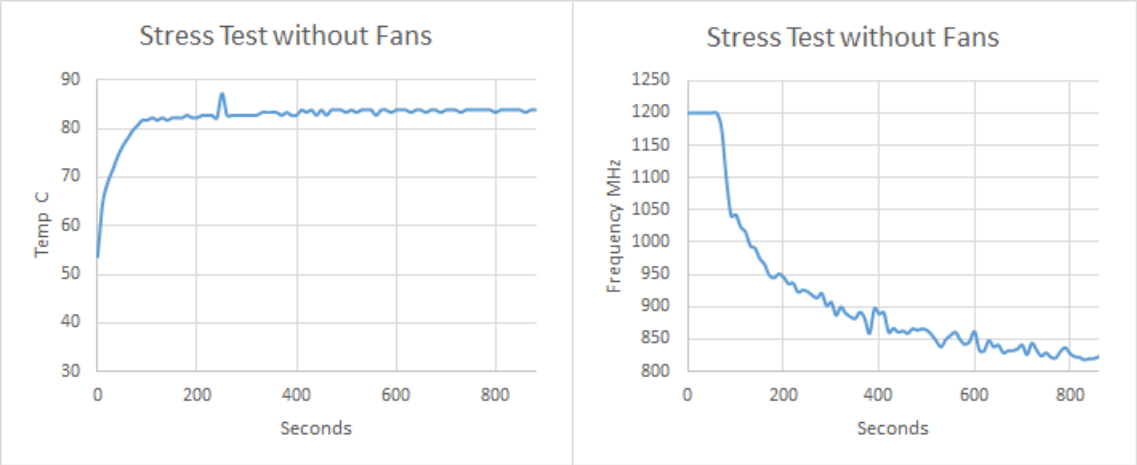
Solid State Drive – I used a standard USB to SATA cable and followed the ETA Prime procedure to boot from an external drive. I had a spare 240GB SSD which is a bit of an overkill but the price was right. Now I no longer need to worry about wearing out the micro SD card or running out of space. The micro SD card has been removed from the Pi which means I don't need to mount the Pi with the SD card connector accessible. The SSD fits in the laptop hard drive compartment (see below) but there was no mounting hardware available. To keep the drive from moving around, I used tightly rolled paper to take up the remaining space.

Wi-Fi Antenna – The laptop has a Wi-Fi antenna above the LCD fed by a coax with a U.FL connector. In order to use the laptop's Wi-Fi antenna, I had to add a matching U.FL connector to the Pi and move a zero ohm resistor. This mod was a bit difficult due to the small size of the components. The wardr instructions are very clear and include some magnified pictures. A microscope would really come in handy for this mod. I used the Wavemon program to take before and after signal strength measurements so I could tell if the new antenna was working. The following table shows a definite improvement in the Wi-Fi signal strength.

Location & distance to source	Signal Level Before Mod	Signal Level After Mod
Desk (next to Wi-Fi router)	-20dBm	-17dBm
Chair (10ft)	-40dBm	-37dBm
Bedroom (15ft)	-59dBm	-50dBm
Dining room (15ft & wall)	-68dBm	-54dBm
Kitchen (20ft & wall)	-69dBm	-62dBm

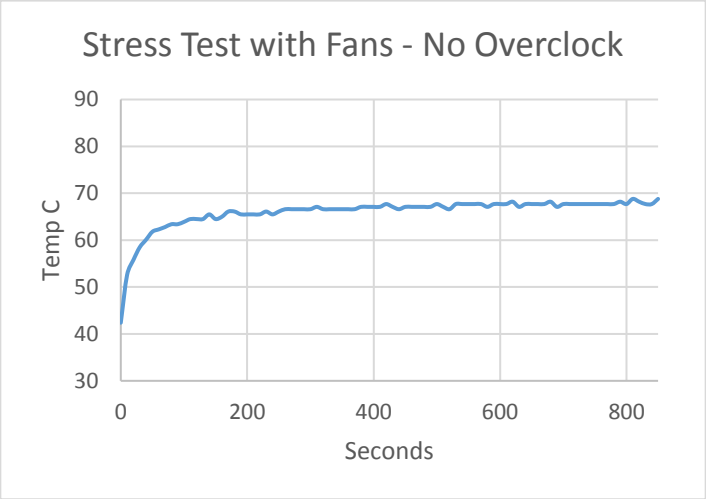
The laptop has a Bluetooth antenna with coax and a U.FL connector that I'm currently not using. I haven't found anything on the web yet for hooking this up to the Pi.

Cooling - I ran the stress test from Core Electronics on the laptop to measure the temperature of the ARM SoC and its clock speed. Core Electronics says their stress test gives “real life, high-load usage across all of the Pi's resources”. My Pi has a small aluminum heat sink on the ARM SoC chip and I wanted to see what would happen if I didn’t have any fans. The curves below show that the temperature quickly rose to 83°C and the clock speed was heavily throttled to avoid overheating.



I placed a 5 volt fan below the Pi, near the video connector but I found it didn’t help very much because the height of the video connector blocked the airflow and the SoC heat sink fins needed to be rotated 90 degrees. I moved the fan to the right away from the video connector and angled it at the processor. I also added a 12 volt fan at the rear of the case to blow the hot air out the back and draw cool air up thru the floor vents. The fans are sandwiched between the case floor and the metal shield for the keyboard. Double back foam tape keeps them from moving and vibrating (they’re still pretty loud). The fan locations are shown below.

The curve below shows the temperature not exceeding 69°C so the 1200MHz clock frequency never throttled. This is the fan configuration that I have continued to use.



I changed the /boot/config.txt file to add the “usually-safe” overclock settings given on the overclocking wiki. So far I’ve had no issues with these values.

total_mem=1024

arm_freq=1300

gpu_freq=500

core_freq=500

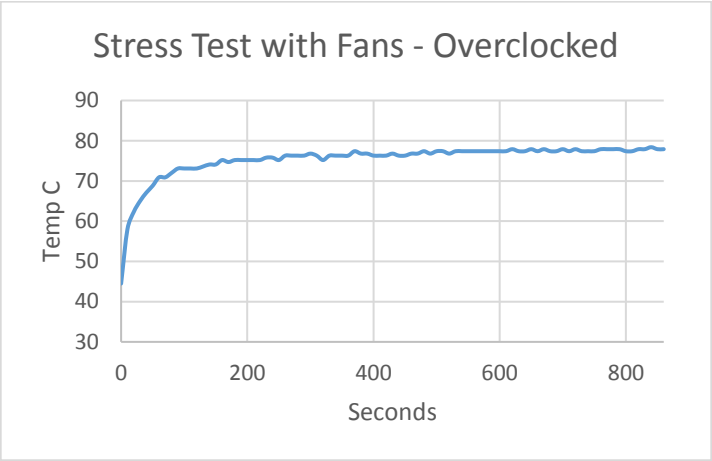
sdram_freq=500

sdram_schmoo=0x02000020

over_voltage=2

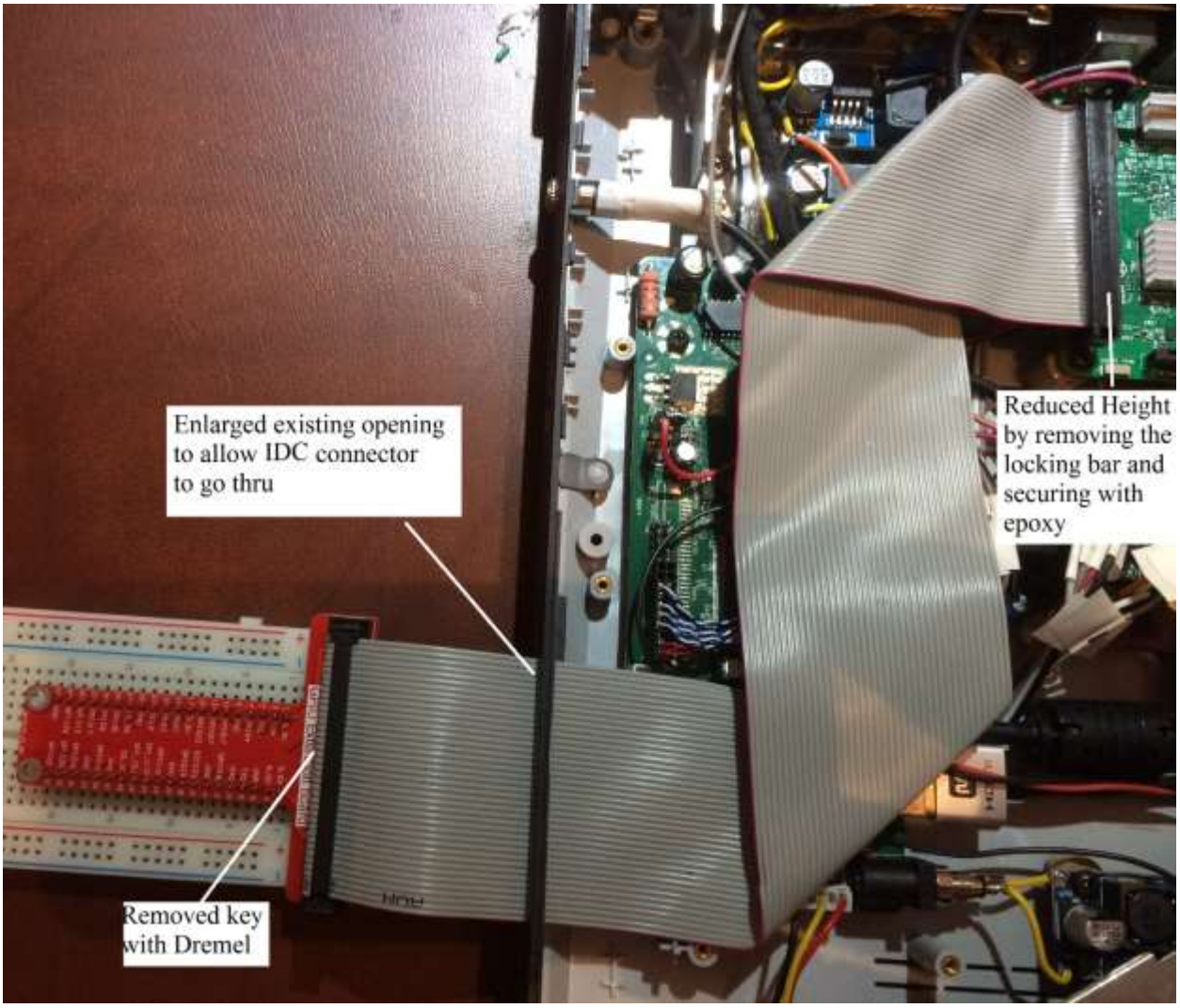
sdram_over_voltage=2

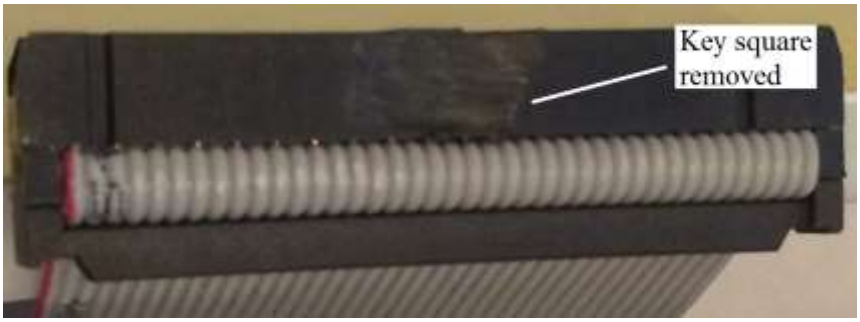
I repeated the stress test with these overclock settings. The 1300 MHz clock speed never throttled and the temperature maxed out at 78°C. I'll keep these settings unless I notice any problems.



For a final cooling test, I ran cpuburn-a53. Core Electronics says it "maxes out your Pi's CPU completely" and "is the most intense CPU stress test you can run and doesn't represent a realistic real-life scenario". The temperature quickly maxed out at 83°C and the clock speed throttled down to 820MHz. I guess I should be happy that the Pi didn't lock up (or burn up).

GPIO - A 40 pin ribbon cable is attached to the GPIO connector on the Pi and routed out the side of the laptop for bread-boarding. The IDC connector on the Pi end of the cable was too tall and touched the keyboard so I removed the locking piece from the top of the connector to reduce the height and glued it together with JB Weld. I used my Dremel tool to remove the key square on the breadboard end of the IDC connector so it can plug into the GPIO expansion board. I also used the Dremel to enlarge the existing opening in the laptop case so the IDC connector can pass thru. This opening was originally for a PCMCIA card reader.





I2C Bus - I installed the Adafruit DS1307 based real time clock (RTC) per their instructions and connected it to the Pi's I2C bus by soldering jumpers per this table. I also connected the Teensy to the I2C bus.

I2C Name	Pi GPIO & Pin Number	RTC Pin Name	Teensy Pin
Clock	GPIO 3 Pin 5	SCL	D0
Data	GPIO 2 Pin 3	SDA	D1
+5 Volts	Pin 4	5V	
Ground	Pin 6	GND	

I cut the small traces between the large pads at the locations shown below in order to disconnect the clock and data pull up resistors. These resistors are pulled to 5 volts which is not compatible with the Pi.

The 1.8K pull up resistors on the Pi are the only pull ups on the I2C bus. The Pi pull ups go to 3.3 volts but the DS1307 is a 5 volt device. The DS1307 datasheet says the minimum voltage for a logic high is 2.2 volts and all testing so far shows the RTC and Teensy work fine with 3.3 volt signals. The RTC is at I2C address 0x68.

The Teensy I2C pins are connected to the Pi along with the RTC. The Teensy is at I2C address 0x08 and if it receives a value of 0x5a, it waits six seconds to let the Pi finish and then resets the power latch to disable the regulators. I created an alias in .bashrc called turnoff that executes the turnoff.exe script. The alias in .bashrc reads:

alias turnoff='/home/pi/turnoff.exe'

The turnoff.exe script sends the shutdown value 0x5a to the Teensy, waits a second to make sure the I2C transmission is complete, then issues a shutdown command to the Pi. The turnoff.exe file is executable and reads:

i2cset –y 1 0x08 0x00 0x5a

sleep 1s

sudo shutdown –h now

The i2cset command is part of the i2c-tools that were loaded per the Adafruit instructions.

Instead of using an alias, I should be able to automatically run an executable file at shutdown but so far I have been unsuccessful. Per several websites - When a Linux shutdown command is given, all executable files in /lib/systemd/system-shutdown are run and one argument is passed to them; either “halt”, “poweroff”, “reboot” or “kexec”.

I created the following executable file that checks for “poweroff” and placed it in the system-shutdown folder.

```
If [ “$1” == “poweroff” ]; then
  i2cset –y 1 0x08 0x00 0x5a
fi
```

Unfortunately this does not work. I even tried commenting out the if and fi lines but still no luck. If you have any suggestions, let me know.

The Teensy code is watching the I2C bus for the following commands:

5a = shutdown (as described above)

b7 = reset the Pi and the Teensy

10 = turn on the “Disk” LED

11 = turn off the “Disk” LED

The Pi can read the Teensy code version and date with an i2cdump command in a terminal window.

i2cdump –y 1 0x08 i

This results in 256 bytes of ASCII text with the version & date shown 8 times. The i2cdump command converts the ASCII to text on the right hand side of each line as shown below.

```
pi@raspberrypi:~ $ i2cdump -y 1 0x08 i
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f    0123456789abcdef
00: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
10: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
20: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
30: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
40: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
50: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
60: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
70: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
80: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
90: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
a0: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
b0: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
c0: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
d0: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
e0: 56 65 72 73 69 6f 6e 20 23 30 31 2e 30 30 20 20    Version #01.00
f0: 4e 6f 76 20 31 30 2c 20 32 30 31 37 20 4d 46 41    Nov 10, 2017 MFA
```

Battery Operation - I used the laptop for a couple months with the AC adapter while I figured out battery operation. Luckily this Sony Vaio laptop has the battery charging circuit on a separate board that still fits in the case with all my new hardware. This picture shows the finished laptop (less the keyboard) with the battery charging board and battery.

The laptop battery has a 2 wire SMBus interface that I couldn't make work with the Pi's I2C bus. The Pi would not issue a repeated start which is required to read the registers in the battery. I tried all the suggestions given on the internet with no luck so I wrote a crude C program for the Pi that bit-bangs two GPIO pins to make a dedicated SMBus for the battery. The program displays the battery voltage, current, temperature, status, and state of charge. It also displays the time to full if it's charging or the time to empty if it's not charging. The "battery" alias executes the C program as shown below.

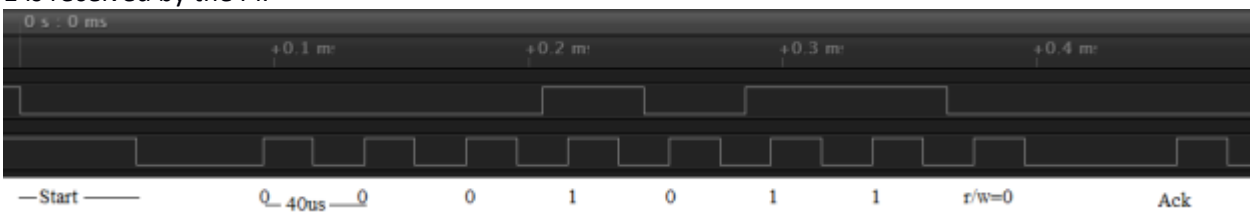
```
pi@raspberrypi:~ $ battery
Voltage = 16.791 Volts
Current = 166 mA
Temperature = 24.65 degrees C
State of Charge = 81 percent
Time to full = 30 minutes
Battery Status
   Initialized
```

I used the Sparkfun tutorial on WiringPi and the Geany IDE to write my C program. The table below gives the register names and numbers as well as the values I read from my battery. Bold items are read by the "read_battery.c" program which is available at my Github repo. See the Smart Battery Data Specification for a complete description of each register and the SMBus protocol.

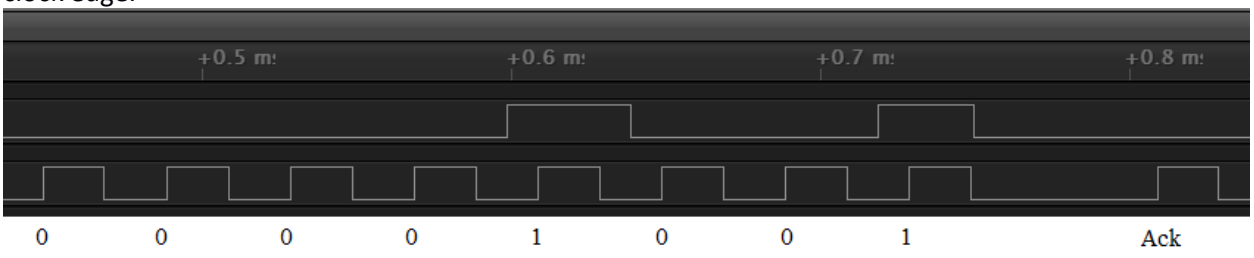
Register Name	Number	Typical Value and Description
REMAINING CAPACITY ALARM	0x01	5.92Wh (10% of 59.2Wh Design Capacity)
REMAINING TIME ALARM	0x02	10 minutes
BATTERY MODE	0x03	Report in 10mWh, Internal Charge Controller Supported
TEMPERATURE	0x08	24.25°C to 29.35°C
VOLTAGE	0x09	14.513V at 4% SoC, 16.620V at 100% SoC
CURRENT	0x0A	-1.4A w/o charger, +1.547A at 4% SoC w/ charger, 4ma@100%
AVERAGE CURRENT	0x0B	same as above except with one minute rolling average
MAX ERROR	0x0C	25% error in SoC calculation
RELATIVE SOC	0x0D	100% to 5% fully charged to nearly empty
ABSOLUTE SOC	0x0E	85% when fully charged, and drops with SoC
REMAINING CAPACITY	0x0F	50.51Wh when fully charged, and drops as SoC drops
FULL CHARGE CAPACITY	0x10	50.51Wh doesn't change with SoC
RUN TIME TO EMPTY	0x11	137 minutes at full charge, 7 minutes at 5% SoC
AVERAGE TIME TO EMPTY	0x12	same as above with 1 minute rolling average
AVERAGE TIME TO FULL	0x13	118 min when charge starts at 5% SoC (1 min rolling average)
DESIGN CHARGE CURRENT	0x14	1.5A
DESIGN CHARGE VOLTAGE	0x15	16.672V
BATTERY STATUS	0x16	0x00A0 Init & fully charged (at 100%) 0x00C0 Init & discharge (at 70%) 0x02C0 remaining cap alarm, init & discharge (at 10%) 0x03C0 remaining cap & time alarm, init & discharge (at 5%) 0x0280 remaining cap alarm, init (at 10% w/ charger) 0x0080 init (at 30% w/ charger)
CYCLE COUNT	0x17	235 charge cycles
DESIGN CAPACITY	0x18	59.20Wh
DESIGN VOLTAGE	0x19	14.8V
MFG DATE	0x1B	June 8, 2004
SERIAL NUM	0x1C	3292

Pi GPIO 26, (connector pin 37) is programmed to be the SMBus Clock with a 40 usec period. GPIO 19 (connector pin 35) is programmed to be the SMBus Data. Logic analyzer screen captures of the Clock and Data during a register read operation are given below. The battery will sink the Clock line low (known as clock stretching) to hold off the Pi from sending more clocks. I used the logic analyzer to see how long I needed to wait for the battery to release the clock after each sequence so that my code doesn't need to deal with clock stretching. The first figure shows the entire sequence needed to read the battery voltage. Each of the sequences is shown in greater detail in the subsequent figures.

The start sequence (falling clock when data is low) causes the battery to capture the next 8 data bits on the rising clock. To talk to the battery, the first 7 data bits must be 0001011 (0x0b). The 8th data bit is 0 which signifies a write will follow in the next sequence. All 8 bits together are 0x16 when writing to the battery. After the 8th clock pulse, the Pi floats the data line so the battery can sink it low to acknowledge it has received the 8 bits. The Ack/Nack bit is clocked in on the 9th rising edge and an error flag is set if a 1 is received by the Pi.

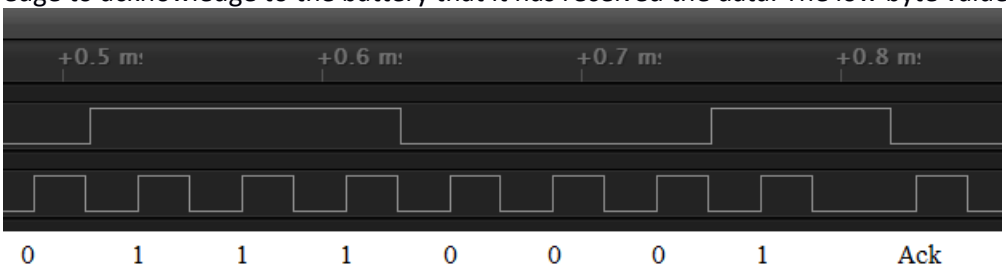


This sequence loads the register pointer in the battery so that future sequences can either read or write to the desired register. The 8 rising clock edges load 0x09 which points to the 16 bit register that contains the battery voltage in millivolts. The Ack/Nack from the battery should be low on the 9th rising clock edge.

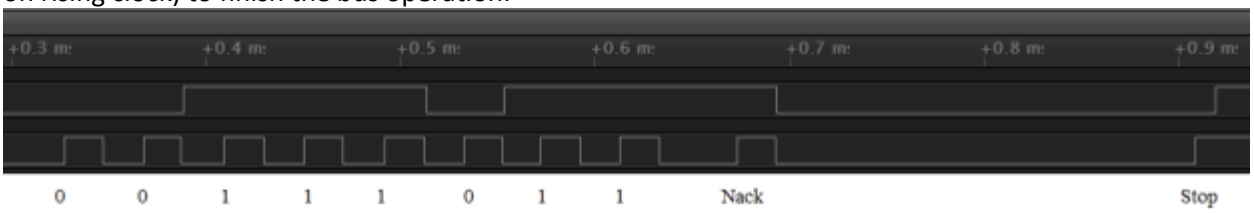


A “Repeated Start” is just like a regular start (falling clock while data is low) and it is used to keep control of the bus in a multi-master system while switching from a write to a read. This is the bus sequence that I couldn’t get the Pi’s I2C controller to implement so I had to make my own bus. After the repeated start, the battery is addressed with 7 rising clocks that capture 0001011 (just like before) but the 8th bit is a 1 this time to signify a read. The full 8 bit value is 0x17 when reading from the battery. The Ack/Nack from the battery should be low on the 9th rising clock edge.

The Pi floats the data line so the battery can send back the low 8 bits that are stored in register 0x09. The Pi captures the bits on the 8 rising clock edges and then sinks the data low for the 9th rising clock edge to acknowledge to the battery that it has received the data. The low byte value is 0x71.

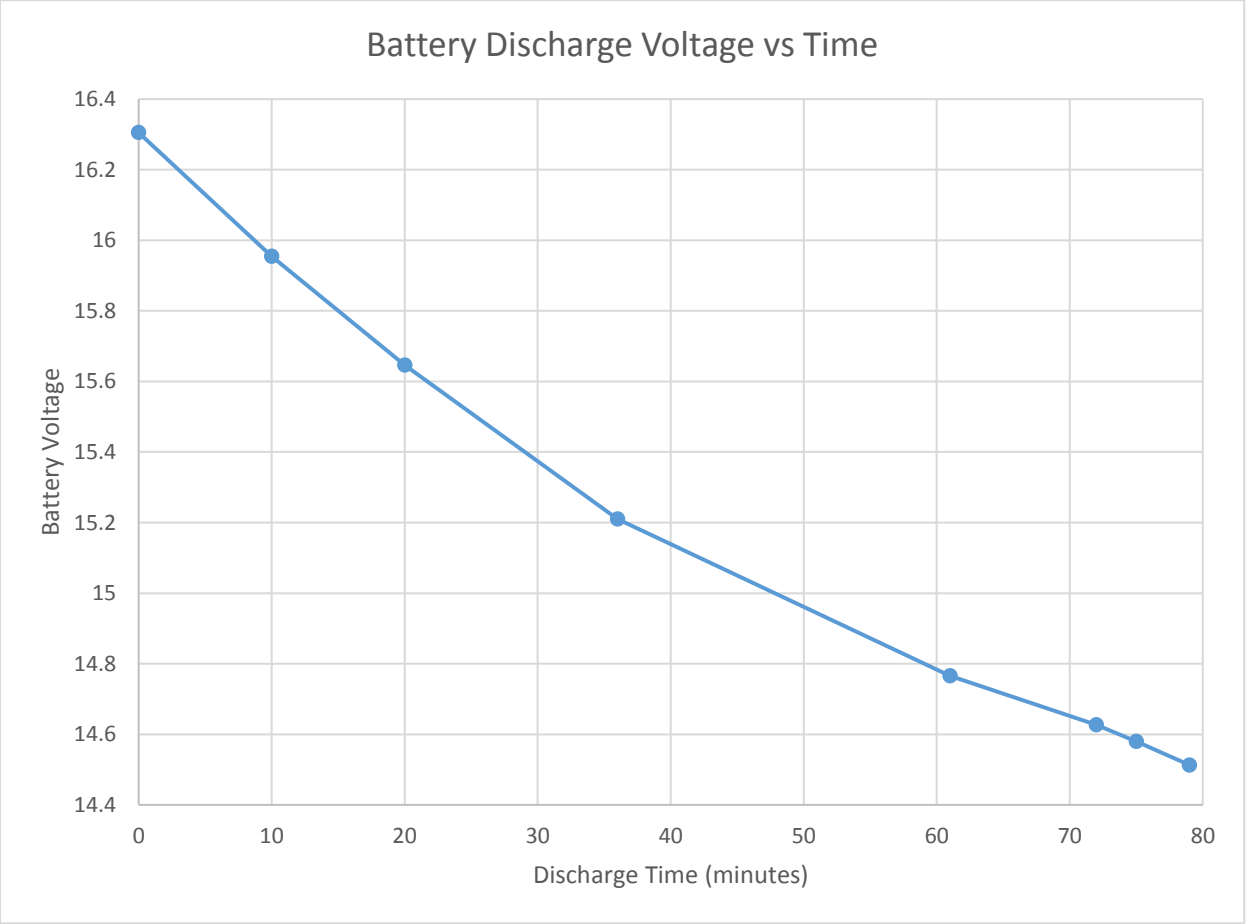


The high byte is received by the Pi in the same fashion but the Pi lets the data go high for the Ack/Nack bit to let the battery know that it is done reading the register bits. The high byte value is 0x3b. The 16 bit value of 0x3b71 is a battery voltage of 15217 mv. After a delay, the Pi gives a stop sequence (data low on rising clock) to finish the bus operation.

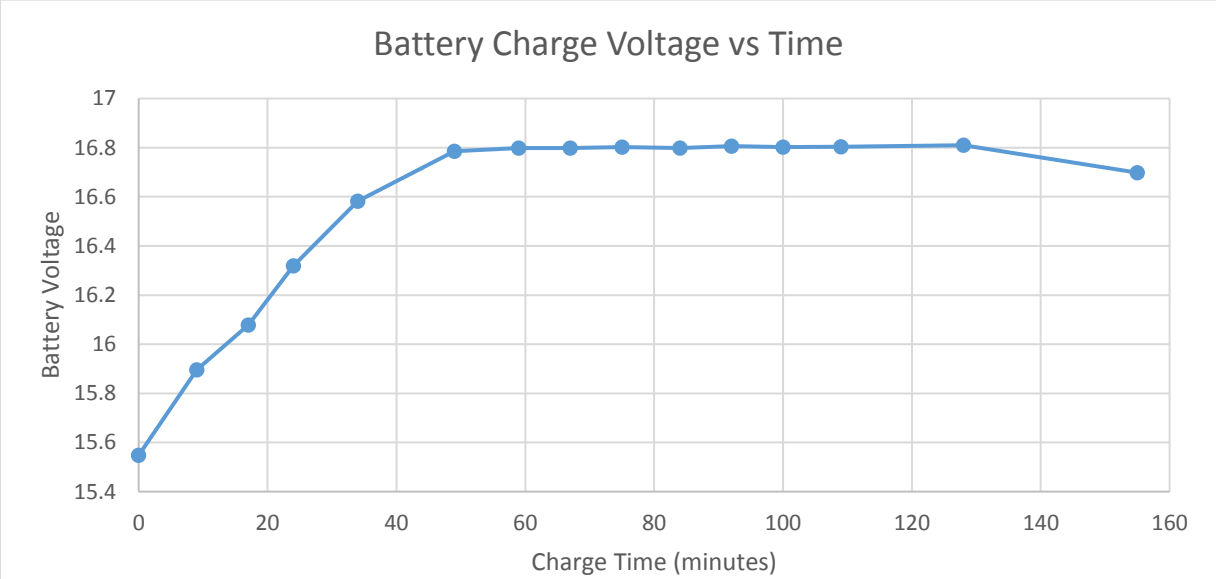


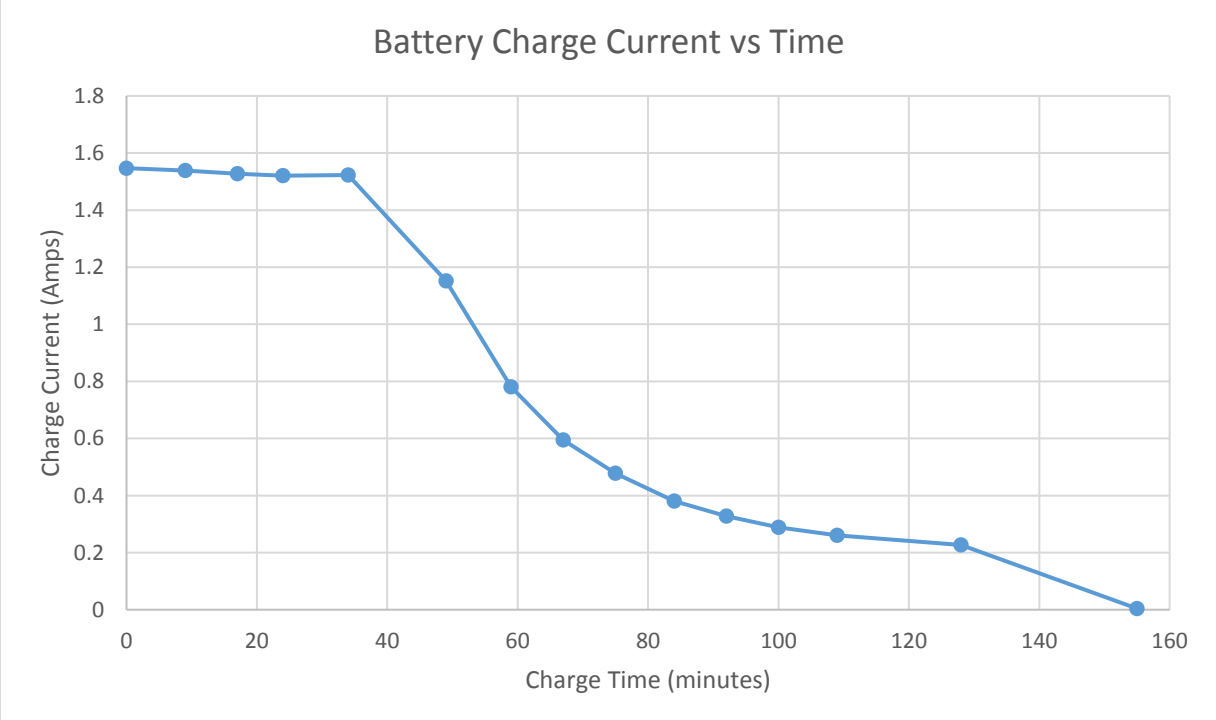
I have noticed that sometimes my code will read a bad value (usually all 1’s) back from the battery. When this occurs, the logic analyzer shows that in the middle of one of the sequences, the Pi stops clocking and then comes back after a while and proceeds with the sequence but by then the battery has timed out and gives Nack’s that set the error flag. My assumption is that Linux paused my code while it serviced some other process. I don’t know how to make Linux act like an Arduino and ignore other tasks. I even added the command piHiPri(99) to the code which is supposed to make it the highest priority process but it made no difference. My final solution detects when a bad value or a Nack is read from the battery and repeats the entire register read sequence.

The discharge voltage curve of the battery is given below. The “Time to Empty” reported by the battery was 150 minutes at the start of the discharge cycle yet it only lasted 79 minutes (to 4% SoC). The current delivered to the laptop stayed relatively constant at 1.3 amps. At time 0, the battery temperature was 24.25°C and at 79 minutes, the temperature was 29.35°C, a 5 degree rise.



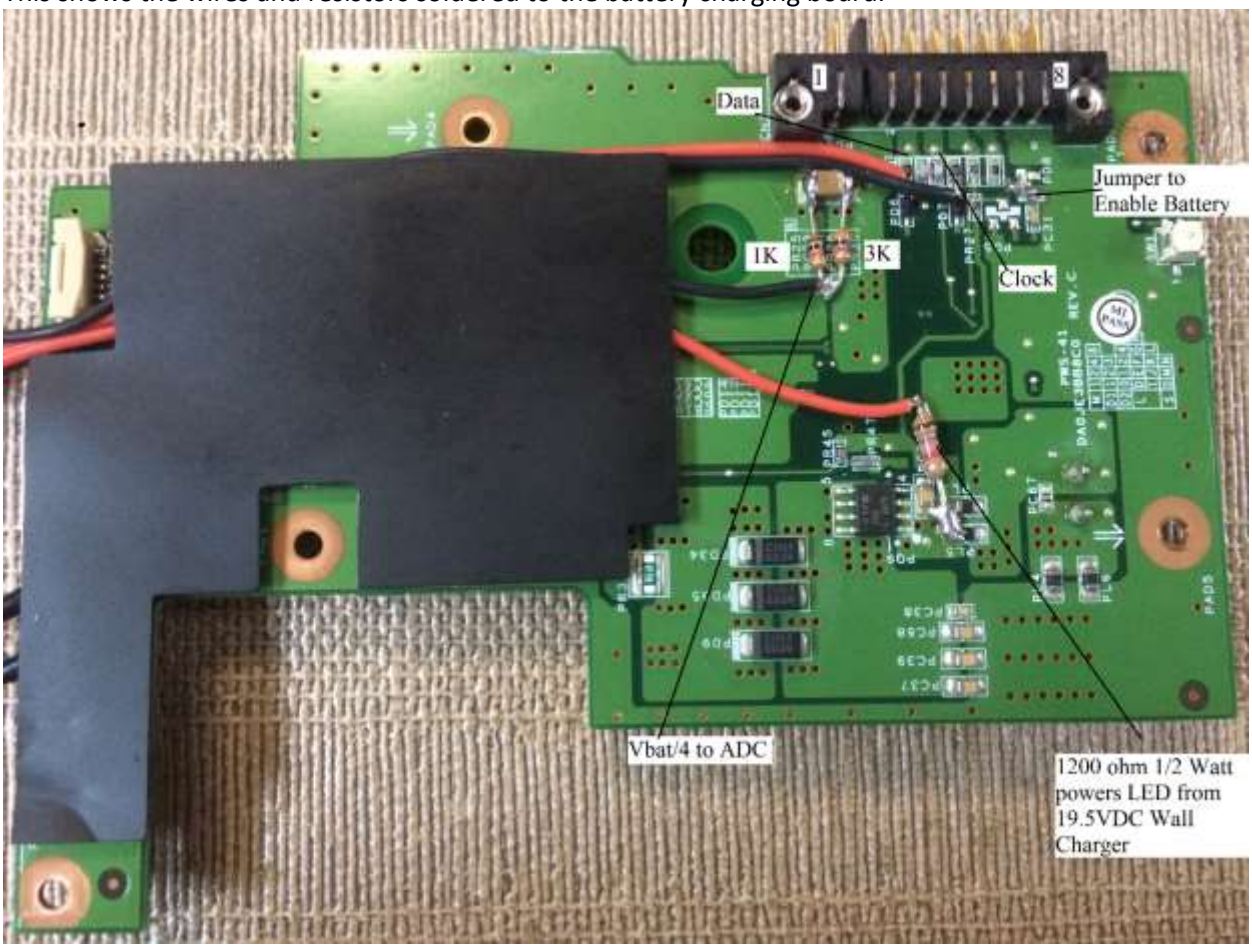
The charge voltage and current curves are given below. The different charging stages can be seen on the curves. The first ~40 minutes is a constant current of 1.5 Amps until the voltage reaches 16.8 volts. Then the voltage is held constant as the current declines, eventually reaching a trickle charge level. The "Time to Full" reported by the battery was 118 minutes at the start of the charge cycle yet it took 155 minutes. At time 0, the battery temperature was 29.35°C and at 155 minutes, the temperature was 24.25°C, a 5 degree drop.



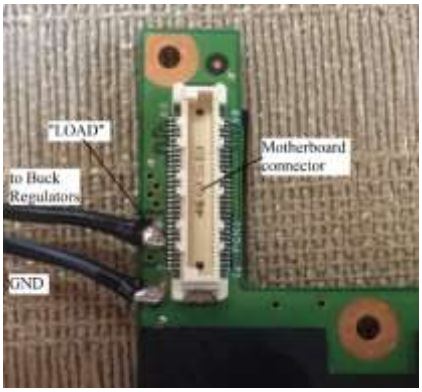


The Sony Laptop uses a 14.8V, 4Ah Li-ion battery p/n PCGA-BP2NY that plugs into the Max 1873 based circuit board part number A1061942A shown below. I haven't been able to find a schematic other than the "Typical Application" in the Max 1873 data sheet. Tracing out the connections with an ohm meter shows the incoming 19.5VDC is switched by a PFET before going to the Max 1873. There is a PFET that connects the battery to a large "Load" pad that used to feed the power supplies on the motherboard. The battery measures 0 volts on all pins except "enable" on pin 6, which measures 5 volts. To enable the battery, I soldered a jumper that ties the enable pin to ground thru a 1K resistor (PR30). When enabled, the battery voltage on pins 1 & 2 measures from 14.4 to 16.8 volts. The SMBus data and clock signals on pins 3 and 4 are at 0 volts (no pull ups in the battery). I have added 3K pullups to 3.3 volts on the data and clock signals so the Pi can interface to the battery without a level translator. I believe pin 5 is a temperature sensor and pin 6 is now tied low. Pins 7 and 8 are the ground connection. When 19.5 volts is connected to the board from the external supply, there is 19.5 volts at the Load pad. When the external supply is disconnected, the Load pad measures a diode drop below the battery voltage. Disconnecting and connecting the 19.5 volt supply causes no voltage dropouts at the Load pad. I connected the Load pad to the inputs of the 3 buck regulators and the linear regulator.

This shows the wires and resistors soldered to the battery charging board.

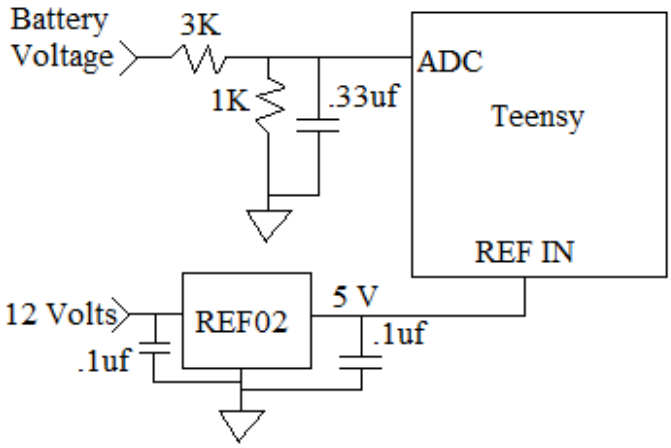


This shows the large Load pad at the motherboard connector that is wired to the 3 buck regulators and linear regulator.



The laptop battery voltage can be over 16.8 volts so a resistor divider is needed to drop the voltage to under 5 volts for the Teensy's ADC. The resistors draw about 4ma from the battery, even when the laptop is off. I may try increasing the resistor divider to 30K and 10K but for now I wanted small values for better noise immunity. The 5 volt (adjustable) buck regulator powering the Teensy would not make a good reference for the ADC so I added a REF02 5 volt reference on a small board next to the Teensy (see below).

The resistor divider and reference schematic are shown below.



Battery	ADC
17V	4.25V
16V	4.0V
15	3.75V
14	3.5V

Without the battery installed and the laptop running a YouTube video over Wi-Fi, the 19.5 volt source measures 1.06 amps. Running the "Stress" program increases the current to 1.16 amps. This equals a total laptop power of 20.7 to 22.6 watts. When running from the battery under the same two load conditions, the laptop voltage and current reported over the SMBus equate to a power range of 20.4 to 22.6 watts. Measuring the battery voltage with a multimeter gives nearly the same value as the voltage reported over the SMBus. All of this shows the voltage and current measurements made by the battery are very accurate.

The theoretical run time for a new battery is approximately (14.8V x 4Ah) / (14.8V x 1.38A) = 2.9 hours. My old battery has 235 charge cycles and gives a full charge capacity of 50.51 Wh instead of the 59.2 Wh original design capacity. It will run down to 10% in about 1 hour 10 minutes. I read an old review for this Sony laptop on the web that said the battery lasted 1.5 to 3 hours so this battery never gave a long run time. A new battery may get my run time up over 2 hours but not much more. If I don't plan on using the laptop for a while, I unplug the battery to stop the small discharge from the ADC resistors and power latch circuit. Lithium batteries scare me so just to be on the safe side, I never leave the laptop unattended while charging. To avoid running the battery down too far, the Teensy constantly monitors the battery voltage using its ADC. At the end of each keyboard scan, the Teensy reads the battery voltage 8 times and takes the average to filter out the occasional noisy read. For long term filtering, a counter keeps track of how many times the average voltage dips below 14.6 volts. The 4th time the voltage is below the trip point, the Teensy commands the video card to blink the display off for a second and the "Disk" LED is turned on to let me know it's time to plug in the charger. The 4th time the average battery voltage is below 14.4 volts, the Teensy shuts down the laptop. If the charger is plugged in prior to shutdown, the ADC will read an average battery voltage above 14.8 volts and the program turns off the "Disk" LED and clears the counter. My testing shows that 14.6 volts is when the battery is at 10% state of charge and 14.4 is at 5% state of charge. Measuring voltage to determine the state of charge is not very accurate but it's the best the Teensy can do. A future task for me will be to write a program for the Pi to read the battery status registers every minute as a background task and pop up a warning if the battery is approaching empty. If the state of charge reaches the shutdown level, the Pi can do a safe power shutdown instead of the Teensy's hard shutdown.

About the Author – I was an engineer at Boeing for 33 years, designing circuit boards, multi-chip modules, and ASICs for various systems. I built lots of Heathkits and Ham radios when I was a teenager but didn't do much electronics at home during my Boeing career. Now that I'm retired, I'm getting back into it and discovering how great the "Maker" community is. "Thank you" to all the people that helped me with your forum posts, website articles, and YouTube videos. I started writing this document to keep track of the numerous sources of information and decided I should share it in case others want to do a similar project. I'm sure I've made mistakes so feel free to send me an email (thedalles77@gmail.com) if you have any comments, improvements or questions. I'll update this document along with the Teensy and Pi code as I learn more.

Cheers

Appendix A – Parts List

Purchased Items:

Raspberry Pi 3 model B from Amazon for $35

Five FPC connectors from Ali express for $4.51 + shipping

Three boards from Oshpark for $18 (includes shipping)

Teensy ++2.0 from PJRC for $24 + shipping

M.NT68676 board from ebay for $25 + shipping

Short HDMI cable from Amazon for $8.13

Four LM2596 regulator boards from Amazon for $10

Latch components and Reference from Digikey for $17 + shipping

USB to SATA Cable from Amazon for $8

Two U.FL connectors from Amazon for $5.50

RTC & battery from Adafruit for $8.50 + shipping

Two 40 pin ribbon cables with IDC Connectors from Amazon for $10

5 volt fan from Amazon for $9

Two 12 volt fans from Amazon for $13

Total is over $225 with shipping

Parts from the junk drawer:

Donor Laptop with AC Power Supply and Battery

Solid State Drive

USB Cable – Teensy to Pi

Various gauge wire, shrink tubing, solder, mounting screws, wood dowels, and electrical tape

Header pins for Teensy and RTC

Jumpers to attach to header pins

Perf board for Latch and Ref circuit

JB Weld Epoxy

Appendix B – Alternative Power Connection

I tested another method of powering the Pi and Teensy that involved feeding the video card directly from a 12 VDC 3 amp - AC plugin adapter and then powering the Pi and USB from the 54329E 5 volt buck regulator on the video card. This would be a good approach if building a simple/low cost RetroPi gaming laptop.

The 5 volts feeding into the Pi measured 650ma to 950ma with USB loads of an SSD and a Teensy. I surfed the web, played YouTube video's and played an mp4 from the SSD with no issues

Moving the amp meter to the 12 volts feeding into the video converter card (which is powering the entire system) shows 1.2 to 1.55 amps at 12 volts, (1.55 x 12 = 18.6 watts).

The 12 volts feeding the backlight measures 450ma. To find the total load on the 5 volt buck regulator, the backlight power (12 x .45 = 5.4 watts) is subtracted from the 18.6 watt input power.

18.6W total input power - 5.4W to the backlight = 13.2W into the 5 volt buck regulator

If you assume the buck regulator is 90% efficient, then 13.2W in but only (13.2 x .9) = 11.9W out. The load current on the buck regulator is approximately 11.9W/5V=2.38 amps. The regulator is rated for 3 amps so the buck regulator on the video card seems to have enough power for the Pi, SSD, and Teensy but not much extra. After making these measurements, I learned about the "stress" test program which adds about 300ma to the 5 volt current. This puts the total 5 volt current up near 2.7 amps.

I chose to not use this method of powering the system because I wanted enough current for powering projects on the GPIO bus, plugging in one or two Passport external USB drives and still have plenty to spare. Another factor is that starting with 12 volts instead of 19.5 volts would not work with the 14 volt Sony battery.

Document Revision History

November 5, 2017 – Original release
November 10, 2017 – Added YouTube link and i2cdump command description.
December 25, 2017 – Added battery operation, SMBus bit-bang interface, and Teensy ADC reference.
January 1, 2018 – Added Hackaday links and general cleanup.
January 3, 2018 – Added Soarer's firmware link, Github file names, and ADC filtering.
January 8, 2018 – Added battery power measurements and general cleanup.