# 2016-11-21

Fixing sketchy wiring on the Z-beam connector where I had to bend the Dupont connector pins at 90degrees to fit into the housing. Two pins were cracked and ready to break, and may have been the reason for flaky z-axis readings. Also re-doing the X/Y joystick connector Dupont connector to make sure there are no issues there.

Swapped the surface mount resistor on the bottom side of the R3 gain resistor mount from a 10kohm to 4.7kohm resistor to raise the gain on the Z-axis beam (1kg max beam). Re-calibrated with new resistor (along with original 6.8k precision resistor on R3 mount, giving a combined resistance of 2.78kohm), for a gain a bit above 16x. No other major changes made, so Rachel will go back to work with this version that doesn’t differ significantly from the previous version except for the altered gain on the Z-axis beam. The unit has been using the 1kg beam the whole time.

# 2015-06-20 Notes on getting RevA shield working

First off, I discovered that the AD620 amps weren’t getting the -5V supply because they were on their own net called Vneg. I soldered in an airwire between the two to get the negative supply to the AD620s. At that point they started putting out a reasonable signal.

I also discovered that I swapped the placement of the potentiometers for the X and Y axes of the joystick force meter. They still do their jobs, they just have much longer traces than necessary, and aren’t next to the associated AD620. The potentiometers exist to tweak the buffer LM324 op-amp to put out a voltage somewhere between 0V and 5V (its supply rails) that is used as an offset voltage in the AD620. That voltage is sent to the Ref pin of the associated AD620, and allows individual trimming of each AD620 signal so that it doesn’t get too near the 0V or 3V3 rail limits.

Finally, I discovered that the 2nd stage amplifier LM324 isn’t going to function in its current arrangement. It was wired as an inverting amplifier, which means that if it takes in a positive voltage signal from the AD620, it amplifies that signal AND turns it negative (inverts it). But because this LM324 only have +5V and GND supply lines, it cannot output a negative voltage, so any voltage below 0V is just output as 0V. This means it cannot be used to amplify the signal from the AD620, since we need a positive voltage to be read by the Arduino Due analog-to-digital pins. Now it would be possible to set the reference voltage of the AD620 so that it is negative, and all the voltages the AD620 outputs are negative, but the other thing we are trying to do is log the reference voltage levels for each AD620, since those determine what the baseline (no-force) voltage is on the transducer at any given time. Since this will shift with temperature, it is useful to log it. But we can’t log negative reference voltage levels. As a result, we can’t set them to negative values to make the 2nd stage amplifier work, unless we forego logging the (negative) reference voltages.

2015-06-21 testing

Probing the x-axis channel of the joystick circuit. With the joystick removed, and checking AD620 output, AD620 Ref input, and LM324 1IN+ (pin 3, coming from pot), I see that all three voltages follow each other exactly when the pot is adjusted and the voltage value from the pot is >0V. This is with the supply to the LM324 being ground and +5V. Once the 100k pot has passed the 50k ohm mark, and its output voltage is negative (recall the pot is dividing between -5V and +5V), the LM324 can no longer track it on the output of 1OUT going to the Ref pin of the AD620. As you get far enough below 0V on 1IN+ of the LM324, the AD620 eventually does some weird swing to a positive voltage and stays fixed there.

With the joystick plugged in, the bridge is fairly unbalanced, so with the Ref voltage near zero, the AD620 output (with 10k gain resistor, for 6x gain) is +2.35V, and can only be adjusted upwards from there. This is too high to be useful currently, since with only 6x amplification the swing of the transducer x-axis is small even for larger forces, and will hit +3.3V upper limit of the Due input if you try to hit it too hard. Ideally we would get this no-load voltage down to +1.65V out of the AD620, or lower even, and then amplify that value on the 2nd stage so that a minor swing in output of the transducer is turned into a larger swing around +1.65V.

Next step was to disconnect the Ground connection on the buffer LM324, and instead connect it to -5V, so that the LM324 can swing positive and negative. Probing the Ref pin on the AD620, this appears to allow a negative reference voltage of around -600mV before an weirdness begins (no joystick plugged in).

Turning potentiometers clockwise in the current configuration raises the reference voltage to the AD620s.

With the joystick plugged in, I’m seeing the Ref voltage move when force is applied to the joystick. This is problematic, since the reference voltage to the AD620 should be totally stable, at least in my mind. Tapping the center leg of the pot going to the LM324 1IN+ shows that the voltage signal on that line sags about 50mV when a force is applied to the x-axis joystick sufficient to output a 300mV signal (6x gain) on the AD620 output. This is with the LM324 powered by -5V and +5V. Switching back to GND supply on the LM324 yields the same response, of the same magnitude. I suspect this reference voltage sag existed from the beginning.

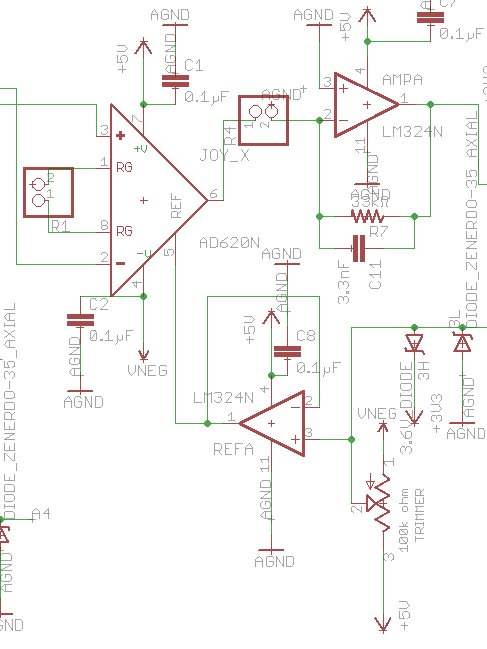
Probing the 3rd beam channel shows that its reference voltage appears to be stable when the beam has a force applied to it, while avoiding applying force to the joystick. The AD620 output moves as expected, the Ref pin on the 620 is stable. But if you simultaneously apply force to the joystick, the beam’s reference moves as well, which is bad. If the joystick is disconnected, the reference remains stable when force is applied to the beam.

Breadboarded an AD620, with adjustable reference voltage between -5V and +5V. I tried a series of different gain resistor values, and hung a 500g weight on the end of the joystick x-axis when oriented horizontally, at the end of a 4-40 screw, about 21mm of lever arm. As you increase the gain by lowering the gain resistor value, you see the baseline output voltage reading increase. If you start the output reference voltage around zero, increasing gain will drive the baseline voltage up, so that you need to start supplying a negative reference voltage to keep the output voltage in the 1-2V range. Eventually you can lower the gain resistor value to around 3400ohm (two 6.81k in parallel) and you will be about as low as the -5V supply will allow you to offset the reference voltage (it will bottom out around -5.1V). I tried a 2000 ohm resistor, but for some reason it actually lowered the output response.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Gain resistor value (ohms) | Approx. gain | Resting voltage | Voltage with 500g mass | Voltage change |
| 20k | 3.5 | 0.760 | 0.820 | 0.06 |
| 10k | 5.9 | 0.771 | 0.870 | 0.10 |
| 7.5k | 7.59 | 0.880 | 0.993 | 0.113 |
| 6.8k | 8.25 | 0.680 | 0.805 | 0.125 |
| 5.07k | 10.74 | 0.380 | 0.52 | 0.140 |
| 4.05k | 13.20 | 0.726 | 0.910 | 0.184 |
| 3.40k | 15.53 | 1.460 | 1.70 | 0.240 |

Figure . Values measured with an AD620 on a breadboard.

I went back to the circuit board and removed the buffer LM324, since it was still doing the thing where the reference voltages would shift right along with the transducer outputs when force is applied to the joystick. I soldered wires directly from the wiper of the potentiometer to the associated Ref pin of the AD620. However, after doing that, I still can’t lower the Reference voltage below -0.6V. When I try to raise the Ref voltage above 3.6V, the voltage stalls at 3.6V for a turn or two of the pot, then there is a jump from about 3.6V to 4.4V over a very short interval of the potentiometer travel, probably indicating that the diodes are up to something.



In the above portion of the RevA schematic, I’m now wondering if it was smart to try to grab the “reference” voltage from the leg of the potentiometer, rather than reading it from the output of the LM324 going to the Ref pin of the AD620, since that’s the reference voltage we are truly concerned with. I’m also wondering if the high and low diodes on the leg leaving the pot to go to the analog input of the A-D on the Due is causing my problems with trying to lower the reference voltage below about -0.6V on the circuit board. I can do this fine (going all the way down to -4.6V or so) on the breadboarded AD620, but when I attempt to lower the reference voltage on the AD620 on the circuit board, even with a line going directly from the middle leg of the pot to the Ref pin of the AD620 (no LM324 in the circuit), it still bottoms out at around -0.6V to -0.7V. I’m going to pull out the diodes next.

Removing all of the diodes and both LM324s seems to have “fixed” things. I can now adjust the reference voltages down in the negative range, which allows me to put the joystick baseline around +1.65V. Applying force to one axis of the joystick does not change the references on either joystick AD620, like it was previously doing. At this point, the circuit consists of only the AD620s, and a potentiometer attached to each AD620, with -5V and +5V legs on the pot (and supply to the AD620). With the joystick wired up so that purple = -Xin, green = +Xin, white = -Yin, orange = +Yin, supplying –5V and +5V to the Bokam 2-d joystick. Using 6.81k ohm resistors right now.



Figure . From Hahn and Denny 1989 Marine Ecology Progress Series. A typical adult Lottia scabra/digitalis has a foot area of approximately 1 cm2, usually less.

Based on Table 2 in Hahn and Denny, limpets outside of scars have tenacities that range from 2 to 174 N cm2. If the average limpet they removed was 1cm2, then removal force also ranged from 2 to 174 N. Converting Newtons to lb-f as 1N = 0.225 lbs of force. So 174N = ~40lbs of force, 2N is going to be ~0.25lbs of force.

2015-06-23

Added the LM324 buffer op-amp back into the circuit, supplied with +5V and -5V, to drive the AD620 reference pins. It looks like the buffered reference voltages now are stable when the joystick axes are pressed on. Without the buffer amp, using a reference voltage straight from the pots, applying enough force to move the AD620 output 500mV was shifting the associated Ref pin voltage by about 60mV. A smaller force would induce a smaller shift in the Reference voltage.

As a note, the peak-peak noise on the joystick amplified outputs (at the analog input pins of the A-D) is about 120mV when on AC power and about 80mV powered by the 12V battery. This is with two scope leads on the X-axis and Y-axis outputs, and the other two leads disconnected. Adding grabbers and scope leads to the two Reference pins increases that noise to 240mV, but that’s a lot of antenna hanging off the board at this point. Note that there is no filtering on the AD620 output any more because I removed the 2nd stage LM324 amp that had the filter.

Pulling the LM324 buffer amp back out, and driving the reference pins straight from the pots, the noise on the outputs is about 120mV p-p on AC power, with all 4 scope leads hooked up (this was ~240mV with the LM324 in place above). I think the repeated removal and installation of the LM324 has not been kind to the performance of the board. Having to air-wire the -5V supply to the LM324 might also be making the noise worse.

Next I put a new LM324 in the buffer amp position just to make sure the old one wasn’t the issue. The noise at the joystick AD620 outputs went back up to 200mV with all 4 leads attached on AC power, but dropped to 80mV with just the two leads attached to the X and Y outputs. So that’s a reasonable improvement. On battery power the noise is between 40mV and 80mV. The noise appears to be predominantly in the 20-60kHz range.

**Next thought:** With the buffer LM324 in place, and the AD620s doing all of the amplification, there may be a way to put the 2nd stage LM324 back in the circuit to provide for the filtering and low-impedence source to the analog pins of the Due, and act as a unity gain amplifier.

If I swap the green-purple, and orange-white pairs, it should cause the joystick channels to have a strong negative offset (currently they have a strong positive offset). The pots and LM324 buffer amp can then be used to pull those very negative values up to the -1.65V range, which will probably put the reference voltages in the upper +2-3V range. That would mean the reference voltages could then be piped over to A3+4 of the Due for recording (as long as they stay under 3.3V). Since the output of the AD620s would be centered around -1.65V, I could then potentially use the 2nd stage LM324 as a unity-gain amplifier that would also invert the signal to +1.65V, and provide the filtering it was set up for from the beginning. Then I should be able to send those positive voltage values from the joystick off to A0 and A1. In this scenario, the bending beam 3rd axis has always has a positive offset and a positive reference voltage fed into the AD620. So for the beam, I wouldn’t want to run it through the 2nd stage LM324, since that would invert it to negative (and would require a negative reference voltage, which can’t be recorded by the Due). It should be possible to add a RC pair (low ohm resistor in line with the beam’s AD620 output, and a capacitor from the output to ground) to do the filtering, and send that signal directly to pin A2 on the Due for recording.

I created an Eagle schematic force\_meter\_RevB that incorporates some of the fixes discussed above. The buffer op amp now gets -5V and +5V instead of GND and +5V. The VNEG net is removed and replaced with -5V so that it will connect to the rest of the existing -5V net. I swapped the positions of the two joystick potentiometers so that they’re next to the correct op-amps.

2015-06-24 Last night I added on the 2nd stage LM324, and swapped the polarity of the joystick X and Y axes so their baseline output voltage is negative. I can now use positive reference voltages to pull the X + Y axes into the -1.65V range, which then gets inverted by the 2nd stage LM324 to become ~+1.65V. I swapped out the 2nd stage’s original 33k ohm surface mount resistors for 10k ohm units to match the 10k ohm resistor I put in the op-amp input, creating a 1x amplification. This tweaks the filter slightly from the original target of ~200Hz cutoff and raises the cutoff point to around 482Hz. I’m still using the 0.033µF capacitor (3.3nF) for the filter. The Z-axis beam does not run through the 2nd stage LM324, since it already sits in the positive range with its reference voltage. It is wired directly from the output from the AD620 to the analog pin A2.

I also placed diodes on the 0H and 1H spots, which limit the upper voltage level of the X and Y axes to 3.8V in practice (although we got 3.6V diodes?). But it remains to be seen what happens when this system is mounted to the Due and powered up, since the 3.3V line is dead in my testing setup, but will be powered by the Due in the real setup.

I tried putting the 2H diode in place for the Z-beam, but it wasn't having any effect. Even with the diode installed I could get the output voltage up to 4V at the A2 pin. That baffles me, so I'm a bit hesitant to put the rest of the diodes in place. The 0H and 1H are the most important anyhow, since we're most in danger of having the joystick axes jump up above 3.3V. I may try reinstalling the low-side diodes, but time is always limiting

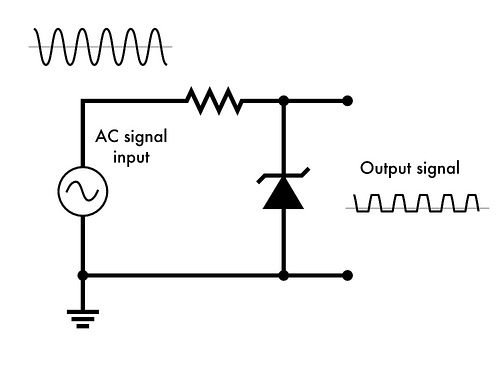
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Figure . All three axes working on 2015-06-24. The X-axis is yellow, Y-axis is blue, Z-beam is pink/purple.

# Designing the shield PCB

**SPI** – watch out with the 2x3pin SPI header from the Due. The 5V pin on the 2x3 header from the Due is 5volts, not 3V3. To power the SD card, you’ll need to send it 3V3, not 5V. So don’t go connecting that 5V\_ICSP pin to anything on the shield.

**Voltage clamps: Limiting signals with Zener diodes**

[](http://www.flickr.com/photos/oskay/6683456819/)

A varying analog signal can be constrained to a fairly narrow range of voltages with a single Zener diode. If you have a voltage that swings between + 7 V and – 7 V, you could use a single 4 V Zener, connected to ground, to ensure that the signal does not exceed 4 V or go below -0.7 V (where the diode conducts forward to ground).

**Note:** The arduino files and eagle PCB design files are now living in D:\Arduino\Limpet\_force\_meter with a git repository. That folder has a symbolic link to the D:\Miller\_projects\Electronics\Eagle\_projects\Limpet\_force\_meter folder so that Eagle can find the files.

Created the link via the windows command line (run as administrator) using the command:

mklink /j D:\Miller\_projects\Electronics\Eagle\_projects\Limpet\_force\_meter D:\Arduino\Limpet\_force\_meter\

where the /j flag says to create a symbolic “directory junction”, which makes the master directory in \Arduino\Limpet\_force\_meter appear seamlessly mirrored in \Eagle\_projects\Limpet\_force\_meter.

# 2015-05-21

Ordered the first version of the printed circuit board today from Osh Park.