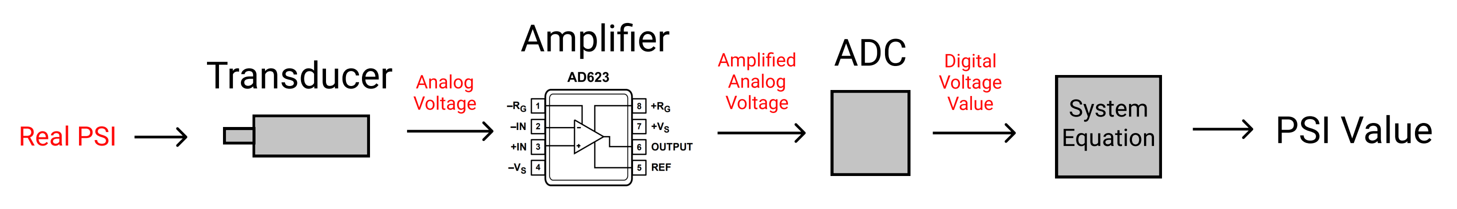
Transducer-To-ADC System Design



Our goal is to be able to convert the Real PSI pressure the transducer sees into a digital PSI Value our computers can read. You will see that the main steps to acheiving that goal are to figure out how to properly configure the amplifier and also to find the System Equation to convert that Digital Voltage Value back into a PSI Value.

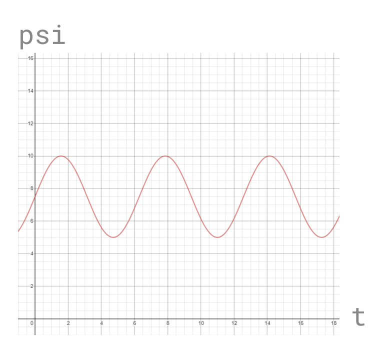
The first step is to find how to convert Real PSI into the Analog Voltage. Then we will find the capabilities of the ADC (the range and number of bits or “resolution”). Then, we bridge the gap in the middle with an amplifier. Lastly, this process will help us create a System Equation which we can use in our programs to finally get a PSI Value.

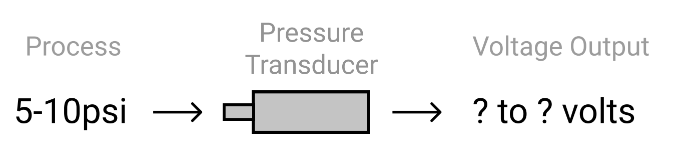
System Specs

Transducer: **PX409-015GV Pressure Transducer**
Amplifier: **AD623 Instrumentation Amplifier**
ADC: **USB-6000 (Range +/- 10 V, 12 Bit ADC)**
Process: **5-10 psi Sinusoidal @ 10 Hz**

The Transducer

Goal: Find min and max voltage output for min and max psi input.





Model: PX409-015GV

(datasheet found in lab doc)

RANGE psi	RANGE bar	2 m (6') CABLE TERMINATION	MINI-DIN TERMINATION	TWIST-LOCK TERMINATION
mV/V OUTPUT, GAGE PRESSURE RANGES				
10 in-H_2O	25 mb	PX409-10WGV	PX419-10WGV	PX429-10WGV
1	69 mb	PX409-001GV	PX419-001GV	PX429-001GV
2.5	172 mb	PX409-2.5GV	PX419-2.5GV	PX429-2.5GV
5	345 mb	PX409-005GV	PX419-005GV	PX429-005GV
15	1.0	PX409-015GV	PX419-015GV	PX429-015GV
30	2.1	PX409-030GV	PX419-030GV	PX429-030GV
50	3.4	PX409-050GV	PX419-050GV	PX429-050GV
100	6.9	PX409-100GV	PX419-100GV	PX429-100GV

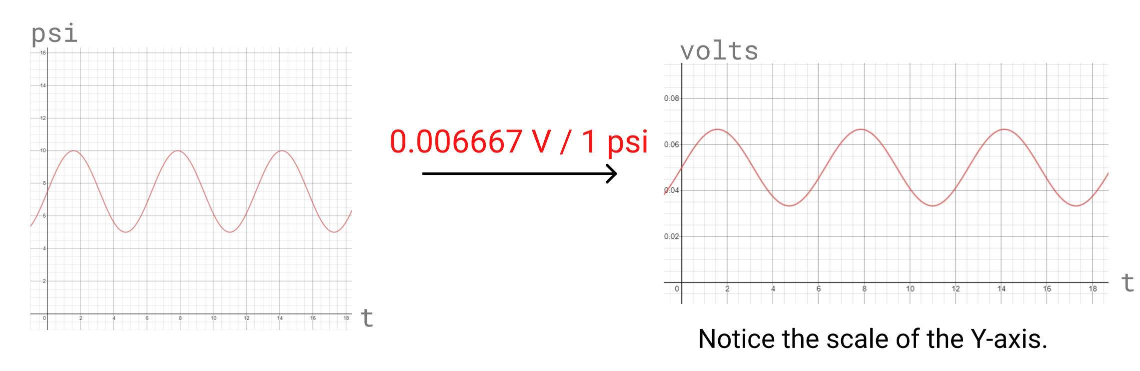
15 psi full range

mV/V Specifications
Output: mV/V, 100 mV @ 10 Vdc (Ratiometric 5 to 10 Vdc)
Supply Voltage: 10 Vdc (5 mA @ 10 Vdc)
Input/Output Resistance: 5000 Ω ±20% typical
Accuracy (Combined Linearity, Hysteresis and Repeatability): ±0.08% BSL maximum
Zero Balance: ±0.5% FS typical 1% max (1% typical, 2% maximum for 2.5 psi and below)
Span Setting: ±0.5% FS typical 1% maximum (1% typical, 2% maximum for 2.5 psi and below) Calibrated in vertical direction with fitting down

You supply 10 volts to the transducer and, at it’s full range of 15 psi, it will output 100mV

Therefore, the ratio of psi to voltage is:
15 psi / 0.100 V
or
0.006667 V / 1 psi

So our min and max output voltage for the inputs of 5 - 10 psi is
0.033335 V - 0.06667 V



Notice the scale of the Y-axis.

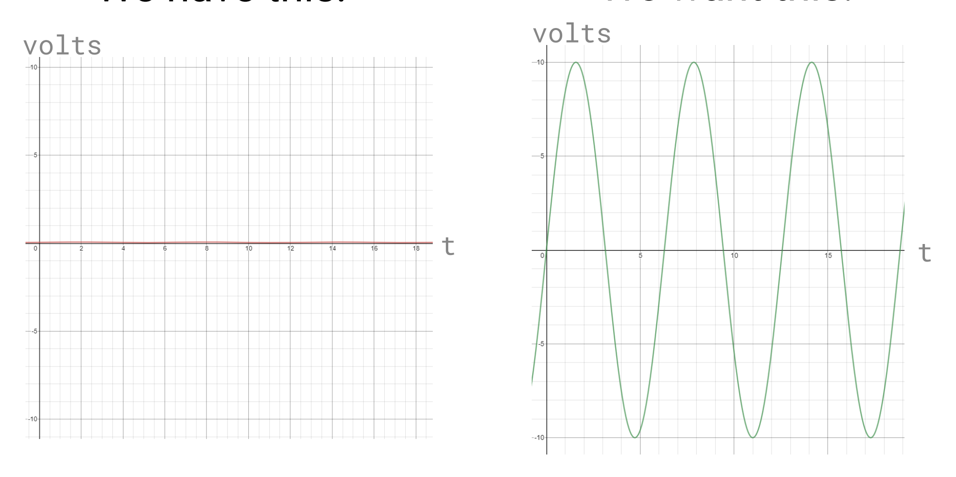
Amplification

Goal: Figure out how much we need to amplify the signal by.

Why? Because the Analog To Digital Converter has a fixed range of voltages it can read (+/- 10V) and it has a specific number of voltage steps it can read (12 bits = 4096 steps) (Quantization). That gives us 20 / 4096 = 0.00488 V per step. If we input these meesly 0.033 - 0.066 volts, we will be using only six steps out of the possible 4096.

If we can amplify the voltage before it goes into the ADC so that is spans the entire +/- 10 volt range, we can use almost all of the steps which gives us much better resolution.

We have this: | We want this:

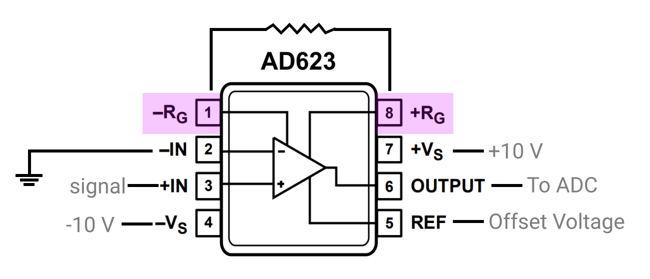


Our voltage output is 0.03335 V - 0.06667 V. We want that to span between -10 and +10 V. The way to do that is to take the range you want (+/- 10 V = 20V range) and divide it by the range you have (0.033335 - 0.06667 V = 0.033335 V range).

So: 20 / 0.033335 = 599.97

That is the amplifier gain we need.

Enter the AD623 Instrumentation Amplifier.
(In part 2 you’ll be using the AD627 but it’s the same process)



The terminals -RG and +RG are what controls the gain of the amplifier. You just need to connect the right resistor between those terminals. How do you figure out what the right resistor is?

RG = 100,000 / (G - 1)

This equation can be found in the datasheet.

Note: The AD627 in part 2 uses a different gain equation!

So we want our gain to be 599.97. That gives us an RG value of 166.953 ohms. Unfortunately, there is no standard resistor size that is 166.953 ohms. So we need to choose the next largest value.

Why the largest? Because 599.97 is the gain that will get us to span the entire range of the ADC. If we choose the next smallest resistor, it will increase the gain above what we need and will caus the signal to max out past the range of the ADC causing saturation. It’s better that we have a slightly smaller gain and don’t use the full ADC range than to saturate the signal and lose that information.

You can google “Standard Resistor Sizes” and find the next largest standard value to 166.953 ohms. It looks like 180 ohms is the next largest value.

Now that we have our actual resistor we will use, we must now go back and calculate the ACTUAL gain we will multiply the signal by. Using the gain equation from earlier, our new gain value is 556.555

So our new range of output voltages after amplification is
0.033335 V x 556.555 = 18.5527 V
This is still within our +/- 10 volt range of the ADC.

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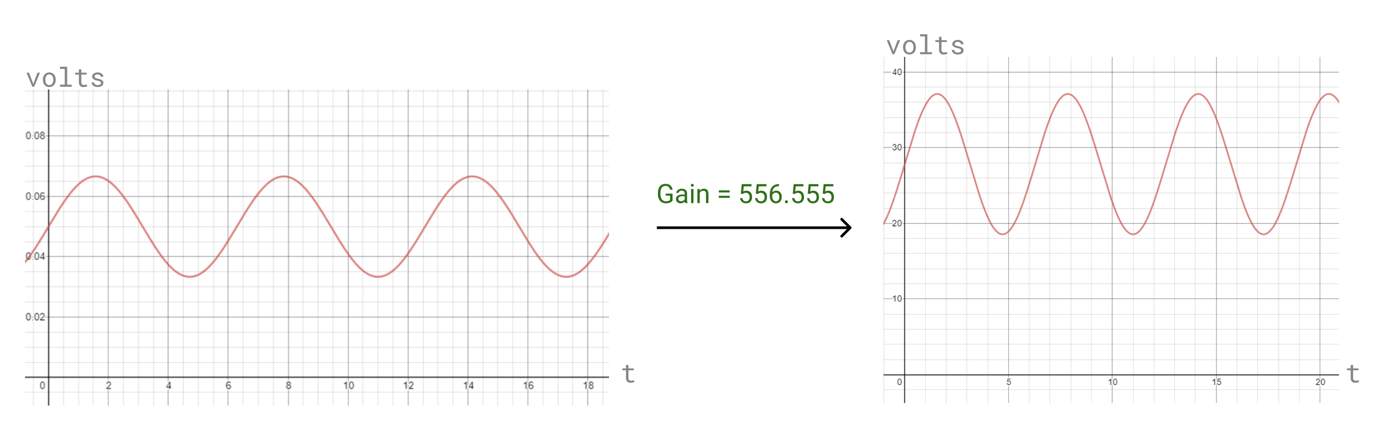
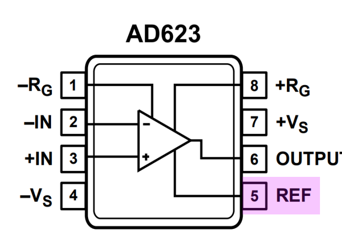
But there is a problem...
We’ve managed to amplify the signal but it’s still offset from 0.



Our output is now going above 10 volts. It is offset from where we want it. We want the center of this waveform to be at 0 volts.

This happened because the input voltage range was from 0.033335 V - 0.06667 V . If we multiply both those values by our gain of 556.555, we get a minimum value of 18.55 V and a maximum of 37.10 V. Our original input voltage was already offset. It was not centered around zero volts.

So what is the fix?



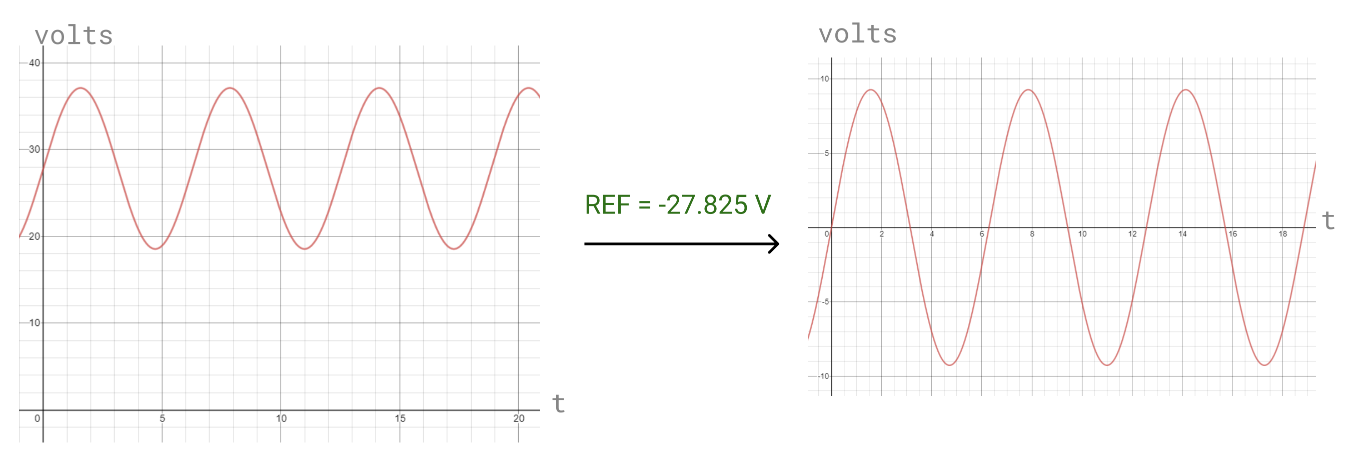
Enter the REF pin.

Whatever voltage we feed into the REF pin will act as an offset for the output signal. If the amplified signal is 1 volt and we feed in + 2 volts to the REF pin, the output will be 3 volts.

Think of an amplifier like so:
Output = Input * Gain + REF

The REF pin can also have a negative voltage applied to it. This is exactly what we want to do in our case.

The center of our amplified signal is (37.10 + 18.55) / 2 = 27.825 V
We want it to be centered at 0 volts.
So let’s apply - 27.825 volts to the REF pin..



We have now succesfully amplified the signal.

You’ll notice that we are now not going exactly up to + / - 10 volts. This is because we had to choose the next largest standard resistor value. This reduced our gain a little bit. That’s fine because we’re limited by the standard resistor sizes.

So say we now want to back-calculate the pressure value from this new graph of amplified voltage. To do that, we just need to take these steps backwards:

1) Add +27.825 V
2) Divide by the gain of 556.555
3) Multiply by 15 psi / 0.100 V

PSI = ((OutputVolts + 27.825) / 556.555) * (1 psi / 0.006667 V)

Or in a general equation:
PSI = ((OutputVolts - OffsetVolts) / Gain) * (x PSI / volts)

Where “x” is PSI / volts. And OffsetVolts is the voltage you apply to the REF pin.

Once we’ve amplified the signal properly and offset it, we can now hook it up to our ADC and get a digital value out of it. For now, we don’t need to go any farther since the ADC will handle the conversion for us. No need to configure it or calculate anything. In the end, you will get a digital value that represents your output voltage from your amplifier and then you can use the above equation to back-calculate to find the PSI.

Calculating Errors

Each of the components in this chain can add some level of uncertainty to their outputs. We care about what these errors do to our final calculated PSI.

The signal travels from the transducer and is converted to a voltage. This conversion can have errors as specified in the datasheet. Then, this voltage is fed to the amplifier which also has inaccuracies. The output voltage is now not exactly what you thought you calculated. The resistor you used for the amplifier also has a tolerance. For example, it could be anywhere from 175 - 185 ohms. Lastly, the ADC itself has errors that it introduces to the output value.

You need to take into account all of these errors so that at the end of the day you can say “This system can measure pressure in PSI with an accuracy of “tolerance” of +- 0.20 PSI for example. We want to know that when the system says 4 PSI, we also know that it could be 3.8 PSI or 4.2 PSI. All of the errors in your system contribute to that final accuracy.

The exact process to calculate the errors will be left up to you. If you understand the steps above, you should be able to calculate the various errors without too much problem. One thing to note:

When calculating errors, convert all of the errors into a PSI value. Then, at the end, you’ll have a bunch of error values with the units of PSI. There are two ways we can calculate the total error. One way is to assume all of the errors will happen at once. So this would be the max worst case scenario. To get that, you just add up all of the errors.

The more realistic error value you should calculate is the Root Sum Squared error. This is a statistical calculation which assumes that not all errors are at their worst case.

The formula looks like this:

RSS-Error = sqrt(E1^2 + E2^2 + E3^2 + ...)