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Harris Cold Plate Test Rig

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1.0 Executive Summary

Anyone with a STEM mindset knows that there is one major hurdle one must cross before progress and eventually results can be achieved; variables. We try to control them as best as we possibly can as too many variables left unchecked can very easily have a negative impact on a project and in many cases lead to skewed and inaccurate results. In an ideal world we would be able to control every variable and our results would always turn out perfect, but obviously that is very much not the case. Unaccounted for variables can and often do slip past even the best of us and make their way to the final product, leading to bugs, glitches, and unexpected results. One may think that large engineering corporations with years of experience and countless brilliant people working toward a common goal would be able to squash any rogue variables before they could get that far, but in rare cases even they let something through. With the massive projects these companies undertake the amount of variables present are just unimaginable, and some are bound to go unchecked.

This is where specialty teams such as our group come in. The Harris cold plate test rig is a tool created to help possibly find a solution to a known issue. Harris creates a multitude of different products, including electronics for various applications. In order to cool these electronics heat exchangers are used to draw heat from the sensitive electronics and transfer them to the surrounding air through forced convection. In static airflow cases these heat exchangers work just as expected but in other cases those pesky variables make their way back into the picture and cause havoc. Under pulsating airflow Harris engineers are seeing abnormal results and are not quite sure what the issue is. In an attempt to try and locate the exact source of the abnormality and find a possible solution, we are creating a test rig for Harris that simulates the conditions the skewed results are found in order to recreate them in a controlled lab environment. Our test rig consists of an airflow source that is capable of creating not only a steady flow of air but more importantly a pulsating airflow of a very specific given frequency and amplitude. This airflow is drawn through a box which houses interchangeable plates that replicate the heat exchangers found in rigs currently out in the field.

Because the phenomenon is not fully understood and we do not know exactly what it is we are looking for we have to cover all of our bases. This means the box houses a slew of extremely sensitive electronics capable of testing precise airflow, air velocity, pressure differentials, and rate of heat exchange. But all of these sensitive electronics are worthless without something to control them and collect the data they provide. In order to remedy this situation a powerful DAQ must be used to adjust the airflow source, collect massive amount of data at extremely high rates, and transfer all of it to a computer where it can be interpreted to values that help us better understand the problem we are encountering. To add to that the heat exchangers must also be heated to simulate a heat source like would be typical for a product in the field and this source must also be controlled as well. A power supply must then be capable of powering all of the various units of differing voltages and current draws.

2.0 Project Description

2.1 Product Motivation

The main motivation for this product comes from a need to control as many variables as possible in a very complex system. Harris created their product and have been putting it into use for some time now but have seen the issues and abnormal results mentioned before. In order to preserve their resources and bring a fresh set of eyes into the mix they called upon us to give them a hand.

Another motivation for this project is one of personal gain. Although our main objective is that outlined by Harris and we are always working toward that goal, there is no reason why we can not push ourselves to better our understanding of the various systems and use the time spent to further our knowledge. While we could do the bare minimum required to get the passing grade and make Harris happy, we plan to push ourselves a little farther by stepping up various subsystems in order to gain more experience with products we have never worked with before. For example, while it would be trivial and the obvious choice to simply buy a power supply unit off the shelf to supply power to various components, we are choosing to instead build the power supply ourselves to gain some experience in that field. By going above and beyond what is explicitly asked of us we are able to try new things are learn even more.

Our last motivation was to be able to use as much of the knowledge in specialized fields we have studied over the course of our time here at UCF. We not only have two computer engineers and two electrical engineers, but we are also working with mechanical engineers of varying specialties. Utilizing our combined experiences from classes, labs, experiments, and extracurricular activities we are able to create an extremely well rounded group capable of tackling virtually any hurdle that may come our way. We can rely on each other if we get stuck as one of the other will most likely have experienced that problem before or at the very least provide a fresh set of eyes on the issue. With such a complex system of heat transfer, air turbulence, fluid dynamics, computer programming, control systems, feedback design, and sensor implementation having such a well rounded group is an absolute must.

2.2 Goals and Objectives

Our primary goal for this project is to attempt to find the source of the abnormal test results Harris is seeing in their equipment. In order to do this we must create a pulsating air flow with the precise characteristics outlined by Harris through a box of a very specific size. We will heat a plate and monitor the change in temperature at very precise locations in order to attempt to observe the phenomenon in precise detail. The following are design characteristics that we hope to achieve with our testing rig.

One of the most important secondary goals is durability. Because this a test rig in a lab environment it will be pushed to its absolute maximum capacity for a long period of time and will go through countless cycles of this process. The fan will be cycled at a very high rate for hours on end with varying voltages flowing through it. This puts stress on not only the fan but also our power supply and DAQ which must power and control the fan. The heaters will be run for extended amounts of time at variable temperatures and must be able to stand up to the abuse. Because the heat exchangers are interchangeable there will be numerous plugs and wiring needed to swap the plates which will be bent, pulled, and clipped countless times. All of these components need to provide reliable service for a reasonable amount of time and so must be chosen and engineered accordingly.

Another important goal is expandability. Because this is a test rig for a phenomenon that has not yet even been observed closely in these systems, we can not give exact specifications on how powerful each of our subsystems must be in order to observe it. Harris gave us a range of values for air flow and heaters that they think we would have the best shot at seeing something at but that's all. Our system will be designed to meet these requirements, as well as a little more, but will also be designed such that should we still not get a result we are happy with, the project could be expanded with different components to test a different range.

Controllability is a major goal set by Harris for this project. Many aspects, namely the airflow and heaters, need to be adjustable over a wide range and therefore will require some kind of control systems. With the help of DAQs, feedback loops, rheostats, and variacs we will be able to precisely control the fan rpm and cycle rate for pulsating airflow based off of the output obtained from our various sensor. We will also be able to ramp up or dial down the heaters in order to simulate different loads and see their effect on the system. One of the most important goals we must achieve is accuracy and speed. Because the phenomenon we are trying to observe is suspected to be very difficult to observe we must employ extremely powerful sensors that can not only reliably gather data very precisely, but must also do it incredibly fast. This means our temperature sensors, pressure sensors, and air velocity sensors must sense very minute and fast changes and pass that info on to the DAQ which will send it to a PC to be logged and studied in detail later.

2.3 Users

Because this project was brought to us by Harris and will be used in a test environment by Harris engineers, it will not be directly employed in technology that many people will use. However, this is a bonus in some aspects for us as it allows us to focus less on usability and more on the performance of the system. That is not to say we will create a poorly designed, difficult-to-use product by any means though. The product will be designed for the skill level of the people using it which in this case is incredibly knowledgeable engineers with significantly more experience using systems such as this one than any of us do. We just need ensure that nothing is confusing or poorly built which allows us to put our efforts toward making it faster, more precise, more efficient, and overall better performing.

2.4 Requirements and Specifications

2.4.1 Main Functions

The main functions of our project are as follows:

- Create a steady-state as well as a pulsating airflow
- Measure the temperature of the heat exchanger
- Measure the air velocity
- Measure the pressure differential at the inlet and outlet
- Provide heat the heat exchangers
- Control the heaters and fans
- Power the various components
- Collect all of the data for later review

A very important function of this project is that it must create not only a steady flow of air but also a pulsating air flow of a specific amplitude and frequency. Steady flow is not an issue as we can simply purchase any fan with the correct flow rate and it will do the job just fine. The problem arises when we want to turn that steady flow in to a very specific pulsation of air as measured by its velocity. We must utilize various control systems and feedback loops to very accurately adjust the fan speed and cycling rate while accounting for a multitude of factors.

Perhaps the most critical function of this project is to measure the temperature of the heat exchanger. While this is typically a fairly simple task of slapping a heat probe where you want it and getting a reading out, ours is much more complex. We are attempting to observe a very minute change in temperature that only happens at very specific locations on the heat exchanger that will change position based on a host of variables such as air flow, heat generation, and time. In order to accurately adjust the airflow we must measure its precise velocity at a very high rate. This information is sent back to the controller by way of a feedback loop and the controller will automatically adjust the fan accordingly in order to keep it within the range we are aiming for.

2.4.2 Target Performance

Target performance boils down to a few main factors which will be broken down as temperature readings, velocity readings, fan control, and power supply efficiency. Temperature readings are the most critical requirement for this project and so we have put a significant portion of time in to making sure they will be their absolute best. We are implementing dozens of the highest performing sensors in very precise, calculated position on the heat exchanger in order to get the most optimal readings. While accuracy is very important, speed is the real deciding factor here as the phenomenon we are trying to see is believed to be extremely brief and thus requires extremely fast sensors. We are shooting for upwards of 10 Hz with a +- 1 degree of accuracy. Velocity readings are also very important for various reasons. The main reason is that velocity must be kept at very specific levels for each different test we want to run. The speed of the air changes the way the fluid mechanics and heat transfer works which has all been meticulously calculated out by the mechanical team. If our velocity sensor is not fast or accurate enough the airflow and heat will develop at rates different than what we were expecting and throw off our results. Secondly, we use the velocity readings in our feedback loop in order to automatically adjust our fan to keep our air speed in check. Multiple other subsystems rely on its readings and it must therefore be very accurate and extremely fast. Once again we are looking for the 10 Hz range with a high degree of accuracy.

Fan control is another critical subsystem and we must therefore shoot for the absolute best performance possible. Initially our requirements were to cycle the airflow at up to 10 Hz but when we brought up the complications and additional complexity necessary to obtain that we were told a 1 Hz cycle would suffice. After careful calculations done by the mechanical team, based on numerous factors, we came to the conclusion that we need at most 24 CFM of airflow to achieve the results we are looking for in the worst case. Initial calculations and testing looks like the CFM requirement will be met with no issue and the minimum cycle rate will be possible with the possibility of higher. Lastly, we would like to achieve superb power supply efficiency. While this is not a direct requirement for Harris, we chose to push ourselves a little further and explore territory we were not familiar with. By creating the power supply ourselves we can have full control over all aspects including power output as well as efficiency. We will strive to achieve a greater than 85% efficiency from our PSU.

3.0 Research

3.1 Existing Similar Projects and Products

Because this is an experimental test rig designed specifically to find one issue that Harris is having, there are not any other projects exactly like it. However, the general concept of a wind tunnel has been explored countless times over the years. Everything from aerodynamic testing to HVAC has used methods similar to what we plan to do by creating a duct with air flowing through it and measuring a host of different variables. The pulsating airflow condition is a bit more obscure as other projects that involve airflow pulsation rarely require it to be a sinusoidal wave but rather a step response of simply off and on. Because Harris' requirement was much different than that we could not use much of the data or ideas obtained from those projects. Overall we were able to gather a host of relevant data from previous research projects and apply it to our system.

3.2 Relevant Technologies

3.2.1 Temperature sensors

3.2.1.1 Resistive Thermal Devices (RTD)

RTD is called resistance temperature detector, a sensor to measure to measure the temperature by varying the resistance value of RTD elements as temperature changed. They have been used in many fields, and can be measured in air, liquid and solid temperatures. The RTD elements are made by pure material, mostly platinum, nickel and copper.

Many common RTD materials can last stable operation characters for many years, and it has repeatable R vs. T linear relationship in the operating temperature range. The resistance vs. temperature is defined as the amount of resistance change of sensor per degree of temperature change. In order to have good sensor sensitivity, we need to choose the material that have large temperature coefficient of resistance, which is called α,

$$\alpha = \frac{R100 - R0}{100R0}$$

Where R100 is the resistance of the sensor at 0 degree C.
And R0 is the resistance of the sensor at 100 degree C.

Material	Temperature coefficient of resistance Ω/Ω/°C)
Iron	5.6*10^-3
Steel	3*10^-3
Platinum	3.7*10^-3
Molybdenum	4.4*10^-3
Tungsten	4.4*10^-3
Zinc	3.8*10^-3
Nickel-iron	3.3*10^-3

Figure 3-1 TCR of different materials

Due to the safety, cost, environmental issues, Platinum is commonly used for RTD material. Measure the temperature by using the RTD is simple, supply it with the excitation current, and read the voltage across the terminals.

Advantage and Disadvantage

The RTD has gain it reputation for accuracy, stability and sensitivity. It has high accuracy and maintain stability for many years. It can be operate from the range of -200 °C to 500 °C, ideally linear change the resistance through the temperature.The down side is the size is not compatible to both RTD and Thermocouple sensor, it relative large for our application. The response time is slower than 1 second, and our design requirement require the time constant have to be much lower than 1 sec, so finding other option to replace the RTD is necessary and can be useful to compare different technologies, and in the research period finding the best temperature sensor is required. Unlike other sens or, it require relative large amount of input power source.

3.2.1.2 Thermocouples

Thermocouple is temperature sensor which two wires made of different materials joined at one point. It generate the voltage when the temperature is different from sensing point to reference point. Thermocouple is widely used for control system, it can convert a temperature gradient to electricity. The voltage change is linear change through the temperature difference between two materials, $\Delta V = a_z \times \Delta T$ where ΔT = the temperature difference between reference point and sensing point.

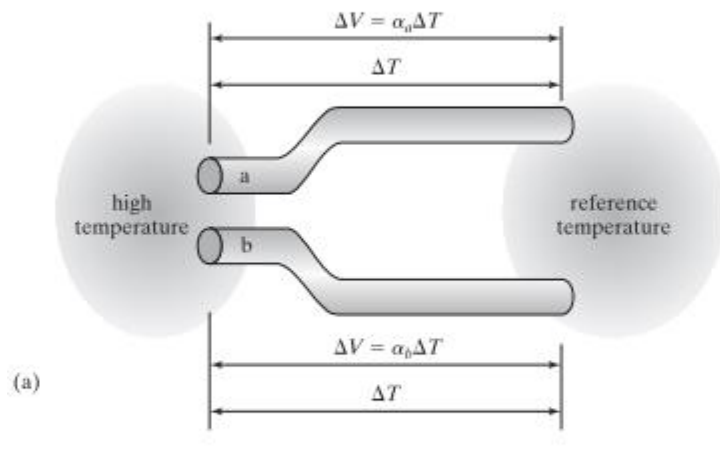


Figure 3-2 Thermocouple diagram

α_z =the Seebeck coefficient, is combined with two materials, which defined the amount of voltage change due to the change of the temperature.
There are a lot of materials combination to give us large Seebeck coefficient, then we can pick the best one which depend by our application.

Type	Metal 1	Metal 2	Temperature Range(℃)	Sensitivity(µV/℃); comment
E	Chromel	Constantan	-270-900	68;high sensitivity; nonmagnetic
J	Iron	Constantan	-210-1200	55;low temperature range
K	Chromel	Alumel	-270-1250	41;low cost,general purpose
T	Copper	Constantan	-270-400	55;low temperature range
R	Platinum	Rhodium 13% Rhodium	-50-1450	10;low sensitivity.high cost;suitable for high temperature measurement
S	Platinum	Rhodium 6% Rhodium	-50 -1450	10;same as R type

Table 3-1: calibrations types of thermocouple

The table shown above introduced the Seebeck coefficient and different operating temperature. The measurement is simple for thermocouple. It create voltage without power supply, we would measure the output voltage directly by using ADC, so digital device able to read it. Since output voltage is so small, it require amplifier to increase the voltage amplitude.

Advantage and Disadvantage

It does not require power supply for the sensor itself, but only generate small amount of output voltage, so it require amplifier and should bias by power source, which is 5V; Wide range operating temperature, it can be as low as -267 degree C, and can be reach to 2400 degree C; good interchangeability and fast response time. The huge bad impact by using the thermocouple is low accuracy; Low voltage output and nonlinear at operate range. it require a lot of thermocouple, but the cost of them still inexpensive. we can select two types of material which give us large difference of Seebeck coefficient, Chromel and Alumel is mainly used, then follow the configuration below to build the thermocouple.

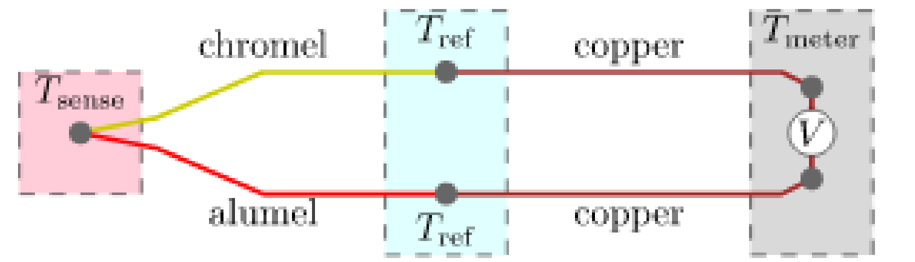


Figure 3-3: Thermocouple configuration
(Pending Permission)

Unfortunately, the output voltage generated by this particular circuit is going to be small, it require the small sized amplifier to boost up the voltage in order to be read by the DAQ.For a most thermocouple sensor, the stability is a big issue too, it require to calibrate once per every few weeks to maintain the constant temperature reading for the controller.

3.2.1.3 Thermistors

A thermistor is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistor. Widely used for temperature sensor.Thermistor is different compare to RTD in that the material used in a thermistor is generally a ceramic or polymer, while RTD just the pure metals. The temperature is different, the RTD are useful for large temperature range, while the Thermistor is only work for narrow bandwidth, but it achieve a higher accurate temperature. There is two types of Theristor, One is called Negative temperature Coefficient(NTC), when the temperature increased, the resistance decreased. they other type is opposite, which called the positive temperature Coefficient(PTC), when the temperature decreased, the resistance increases. Thermistor are easy to use, inexpensive, and response accuracy to changes in temperature while they do not work with extremely cold and hot temperature, they are mainly work for the application that in a desire based temperature, need high accuracy but do not require the best response time. Which doesn’t meet the specification for our project. The figure shown below illustrate the characteristic of Thermistor, advantage and disadvantage of this type of sensor.

Parameter	Within 50 ℃of a given temperature
Temperature Range	Within 50 ℃of a given temperature
Relative cost	Very inexpensive
time constant	6 to 14 seconds
Stability	Very stable
Sensitivity	High
Advantage	• Durable • long lasting • High sensitive • small size • low cost • Best for measuring a single point temperature
Disadvantage	• Nonlinear output • Slow response time • Limited temperature range

Table 3-2: Thermistor specifications

Temperature range: The approximate overall range of temperature in which a sensor type can be used. In this project, it cover from 0 to 100 degree C.for different material, it can have better result. Relative cost: The cost of this sensor are compared to one another. For example, Thermistor is inexpensive compared to RTD. Time constant: Approximate time required to change from one temperature value to another. This is the time, in seconds, the 63.2% of the temperature difference from the initial reading to the final one. Stability: the ability of a controller to maintain a constant temperature based on the sensor's temperature feedback.

Advantage: it has higher sensitivity, high stability, small size, and it best for measuring single point temperature, and it has big disadvantage, so that we can't choose the thermoresistor. It perform non-linear output, limited temperature range which is only 50 degree C, and slow response time.The response time is the big factor of the consideration of this design

3.2.2 Pressure Sensors

3.2.2.1 Measurement Types

For pressure sensors, there are various types of measurements that are needed for different applications. The three main types of pressure sensors are absolute, gage, and differential.

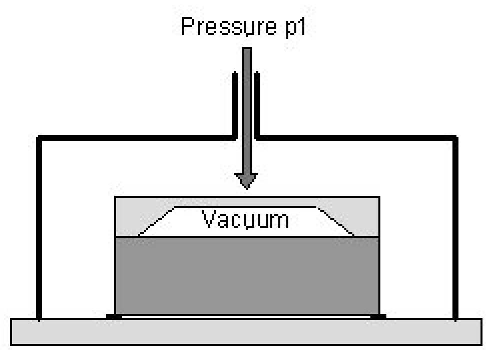


Figure 3-4 Absolute Pressure Sensor

Absolute pressure is the measurement of pressure relative to a vacuum reference. Only one port is used in this measurement. Some applications of absolute sensors include measurement of atmospheric pressure in barometers or altimeters or verification for the sealing done in vacuum packing machines.

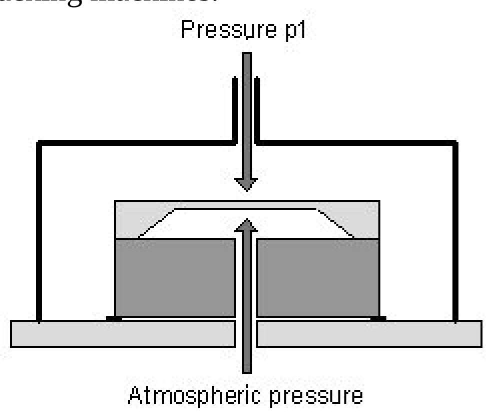


Figure 3-5 Gage Pressure Sensor

Gage (or Gauge) pressure is the measurement of pressure relative to the ambient atmospheric pressure reference. Again only one port is used in this measurement, as the air pressure is usually vented into the sensor through a hole or a reference air pressure may be sealed in. Applications include measurement of tire pressure, liquid level, and suction in medical equipment.

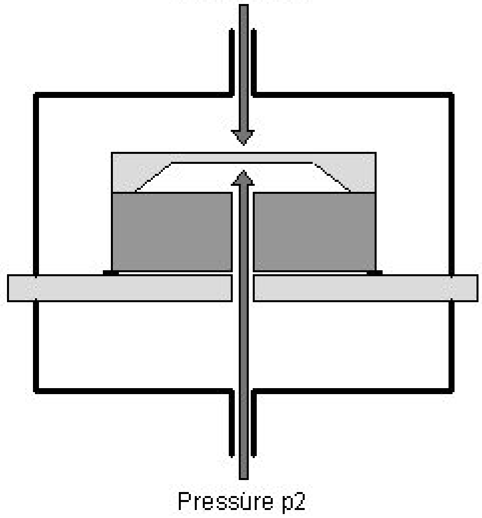


Figure 3-6 Differential Pressure Sensor

Differential pressure is the measurement of the difference between two pressures. These sensors have two ports. They can be unidirectional or bidirectional depending on the use. Applications for such sensors include measurement of respiratory flow, HVAC air flow, and filter flow resistance.

3.2.2.2 Sensor Types

Because of the wide array of applications for pressure sensors, they can be exposed to various different types of media. Therefore sensors come in many levels of compatibility with media. In an application of air pressure measurement, not much compatibility is needed, whereas an application involving a volatile environment for the pressure measurement of high temperature liquids might need something a little more flexible.

Figure 3-7 Pressure sensor types (a) board mounted, (b) industrial wall mounted (Pending Permission)

The environment does matter when choosing a sensor. There are various types of sensors for different environments. Board mounted sensors are compact and economical and are meant to be integrated into a certain type of product. General purpose transducers can be used or reused for a large set of applications and are generally recommended because of their flexibility. Industrial pressure sensors more heavy duty and are fit for tough industrial environments while providing certain levels of durability and protection from noise. There are also high accuracy and special purpose sensors available. Another factor that comes into consideration with pressure sensors is their output. Usually for most sensors, it is the low mV analog output. Then there is the corrected or amplified V analog output. And finally there is digital output which is usually only available on board mounted sensors. Each output type has its advantages for particular applications. There is also the differing ranges in pressure sensors. There are ultra-low pressure sensors which can reference anything from 0.25 mbar to 5 mbar. And on the other side of the spectrum there are ultra-high pressure sensors which can measure up to 6.9 kbar.

3.2.2.3 Mounting

As with any measurement sensor, pressure sensors have different mounting styles. The purpose of the difference in mounting styles is largely application and environment specific. These styles include but are not limited to wall mounted sensors and board mounted sensors.

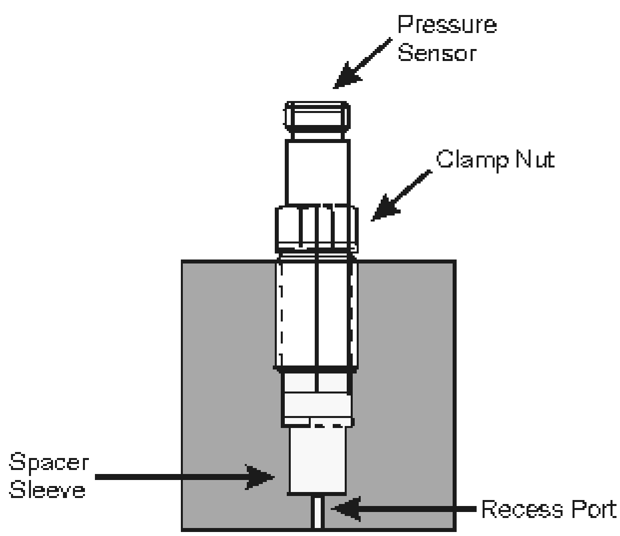


Figure 3-8 Wall mounted industrial sensor

The wall mounted style is used when the sensor needs to be extremely close to the system for more accuracy in measurements. Figure 3-8 above illustrates an example configuration for the wall mounted style. In this configuration the sensor is embedded into the system wall and is connected to the system by a recess port. It is fitted into the wall so as to eliminate turbulence and so that the wall can provide stability of the sensor. The recess port protects the sensor from volatile media. Other configurations include sensor mounting outside of the wall for easy removal or sensor mounting flush with the system's inner walls if a recess is not needed. The difference between a flush and recess mount is that a flush mount is used when turbulence, cavity effects, or volume differentials are undesired, whereas a recess mount is used when thermal shock or temperature changes are undesired. Standardized mounting adaptors can be used for easy mounting or replacement of pressure sensors.

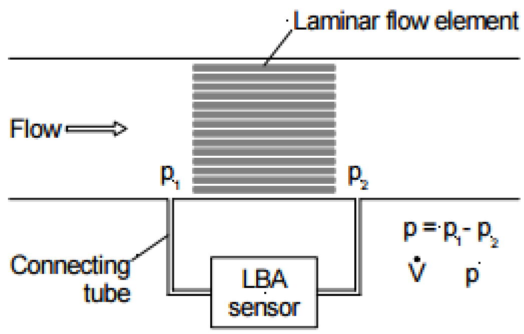


Figure 3-9 Board mounted pressure sensor

The board mounted style is used when the sensor can or needs to be mounted on a PCB. This is usually done in smaller embedded systems. Figure 3-9 above illustrates an example configuration for the board mounted style. This style is used primarily for smaller applications where the sensor is included as an internal module of a closed system or the PCB is close enough to the point(s) of measurement in the system where the length does not affect the results.

Response Time	0.2ms
Total Accuracy	± 2%
Operating Temperature	-20 ... +80 °C
Power Consumption	< 1mW
Cost	~$20-500

Table 3-2 Piezoelectric sensor specs

3.2.3 Mass Flow Sensors

3.2.3.1 Hot Wire Probes

Theory of Operation:

The hot wire air flow sensor is very simple in concept. At the tip of a probe there is a small, thin wire. This wire is heated to a constant temperature. This is achieved with use of a control circuit that maintains a constant voltage across the wire. Because the resistance of the wire is a function of temperature the control circuit can adjust the current supplied to the wire to obtain a specific voltage across the wire and thus a specific temperature. As air moves across this wire heat is stolen from it. This heat loss is a function of the amount of air flowing over the wire as well as the temperature and humidity of the air. The humidity of the air has small effect of the heat loss if it is below

80% and so the humidity measurement is ignored in many applications. The temperature of the air has a much larger effect on the heat loss of the wire and so knowledge of the air temperature is paramount to accurate readings. With a known air temperature the current through the wire is just a function of airflow.

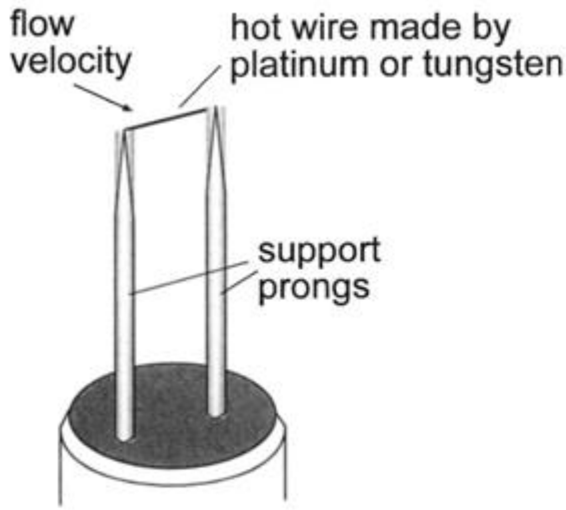


Figure 3-10 Hotwire Probe Diagram
(permission pending)

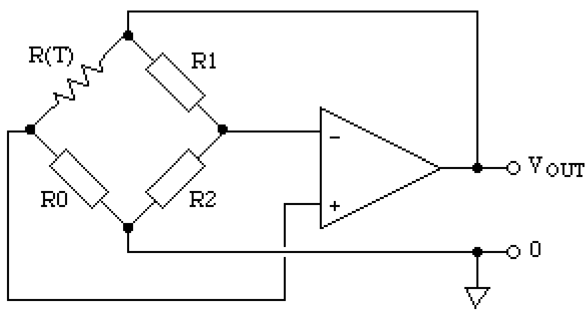


Figure 3-11 Simple hotwire sensor circuit. R(T) is the hot wire.

Advantages and disadvantages:

The hot wire air flow sensor is extremely accurate and can measure airflow as light as a human breath 5 feet away. It also has a very fast response time (less than 50uS in some cases) because the wire that makes the measurement is so small and thus has very little mass and can gain or lose heat quickly. It has the disadvantage that its reading must be compensated for air temperature. Also because of the small wire (small resistance) the system requires calibration to account for drift caused by aging electronics.

Response Time	20kHz
Accuracy	± 0.01%
Calibration Requirements	Weekly Calibration for steady state
Power Consumption	< 1mW
Cost	~$6,000

Table 3-3 Hotwire Specs

3.2.3.2 Insertion Probe

Theory of operation:

The insertion probe works on a very similar concept to the hot wire sensor but with a slightly different twist. It has two RTD (Resistive Thermal Device) thermometers. The RTD measures its temperature by measuring the resistance of an internal resistor. One of these RTDs is connectected to a heated element and the other remains at ambient temperature. The heated element radiates a constant known amount of heat. The device then compares the temperature of the heated element to the temperature of the ambient element. By knowing the temperature of the air (from the ambient sensor) and the temperature of the heated element it can calculate the amount of air flowing over it.

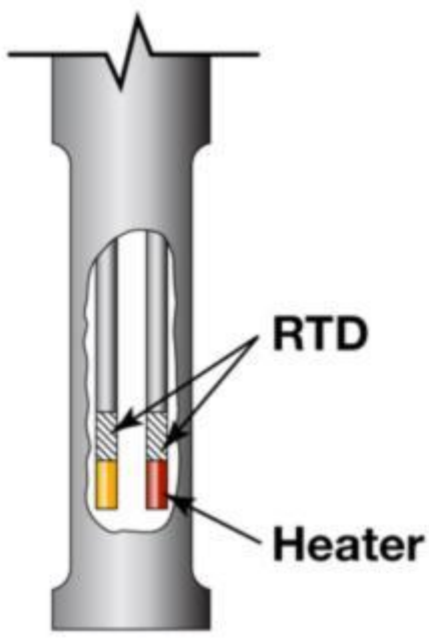


Figure 3-12 Inside an RTD mass-flow probe
(permission pending)

Advantages and disadvantages:

This type of probe is very accurate and relatively cheap. Because it uses larger sturdier parts it is also more durable and thus suited for more industrial environments and requires less often calibration. But because it uses RTDs, which are slow to respond to temperature change, its response time is slow. And because of its extra size and thus mass it does not change temperature as fast as a hot wire probe and often requires a start up period to warm the heated element.

Response Time	2 seconds
Accuracy	± 1%
Calibration Requirements	Self calibrating
Power Consumption	1 - 20 W
Cost	~$500

Table 3-4 RTB mass flow specs

3.2.3.3 Orifice Plate

Theory of operation:

The orifice plate operates on a very different concept than the hot wire or insertion probes. Where the hot wire and insertion probes use heat loss to measure air flow the orifice plate uses pressure drop. The concept behind the orifice plate is simple and efficient. A plate is installed across the inside of the duct which contain the air flow. In the center of the plate there is a hole to allow airflow to pass through. The diameter of this hole is on average about 70% the diameter of the duct. When the air encounters this plate it is forced through this hole. Because the hole is smaller than the diameter of the plate the air builds up on the upstream side of the plate. A pressure differential is created across the plate that is proportional to the amount of air moving through the plate as well as the ambient pressure and temperature of the air. If these factors are known the calculation of airflow becomes straightforward.

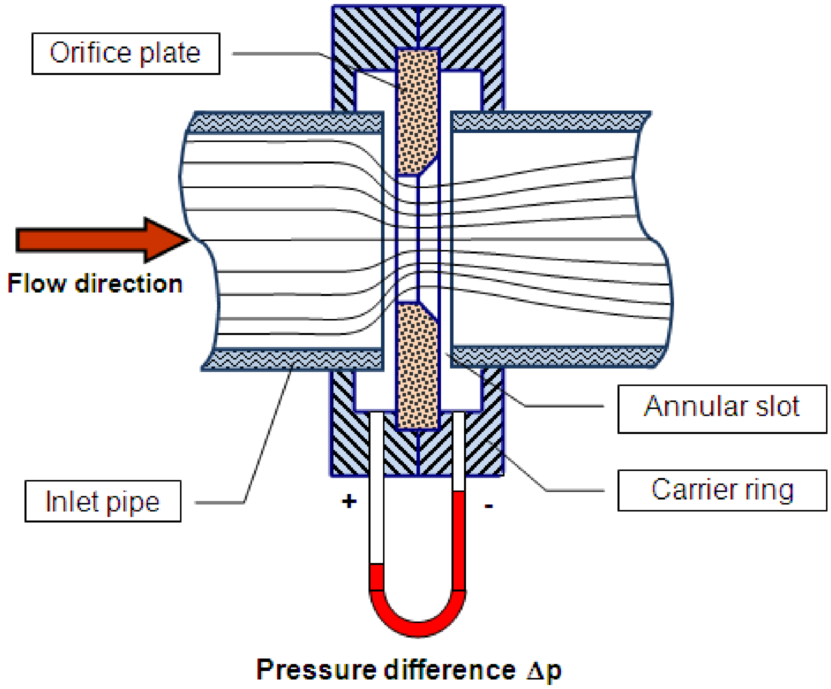


Figure 3-13 Orifice plate diagram
(permission pending)

Advantages and disadvantages:

The orifice plate uses a differential pressure sensor to obtain the airflow. This type of sensor is generally very fast and thus the response time of the orifice plate as a whole is very fast. It also requires less power to operate because it has no heated parts and is generally less expensive then heated elements. It does have its drawback though. Because the air has to be compressed through a hole the orifice plate adds resistance to the duct. Also the orifice plate requires that the air in the duct must not be turbulent and that there must be an uninterrupted space up and downstream of the plate.

Response Time	10ms
Accuracy	± 3%
Calibration Requirements	Milled to specifications; Verification needed
Power Consumption	< 1mW
Cost	~$500-700

Table 3-5 Orifice plate spec

3.2.4 Airflow

We have multiple different options when it comes to airflow. The obvious choice are fans as offer high flow rates, ease-of-operation, and cost efficiency. However there are many other ways of producing the flow we are looking to achieve. The two that we chose to focus on aside from fans were compressed air and vacuum. All options are very different and offer unique benefits and drawbacks, as we will see below.

3.2.4.1 Fans

Theory of operation:

Fans are the obvious choice and what we initially thought would be the end-all. They work by spinning precisely shaped blades at a high rate of speed to displace air in a relatively high volume. They operate on DC voltage, generally up to 12 volts, and draw varying amounts of amps, generally around 1A for the high performance fans we require. We initially planned on having the fan push the air through the box but after consideration from the mechanical team on how this would affect the fluid dynamics within the box we decided to have the fans pull air through.

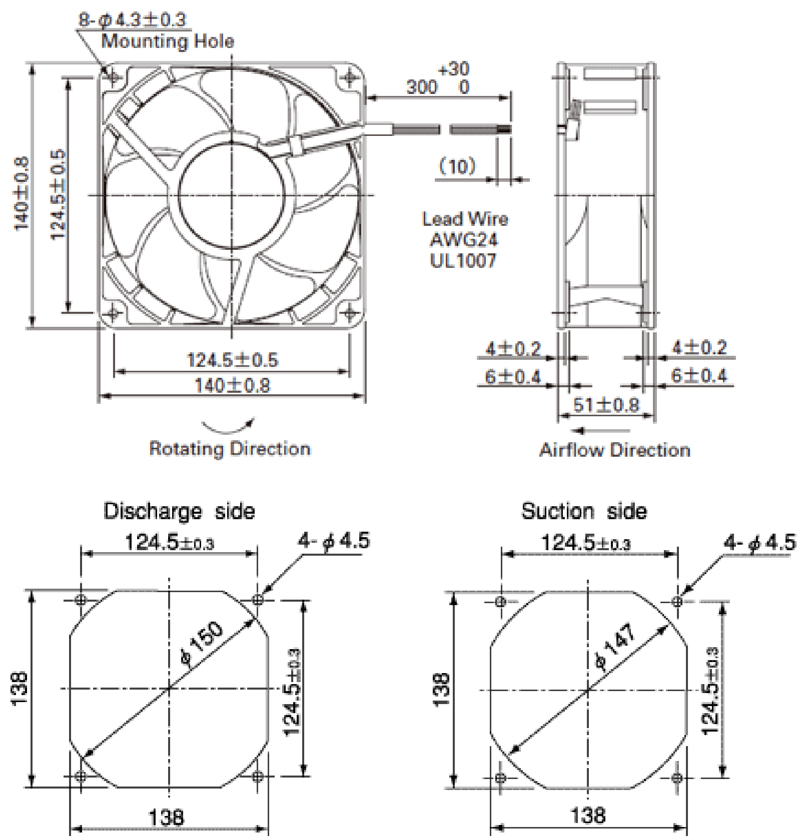


Figure 3-14 Sanyo 140mm computer fan
(Pending Permission)

Advantages and disadvantages:

Fans offer a number of advantage, namely that they are easy to control, offer high CFM, are simple to implement, are widely available, and are highly modular. Because fans run off of just DC voltage and the amount and duration of that voltage determines how fast the fan will spin and therefore how much air it will flow, controlling the airflow and cycling rate will be fairly straightforward. They also offer very high CFM for their size, with fans just 40mm across capable of providing the 24 CFM we are shooting for and fans 80mm or more offering upwards of 100 CFM. They are also very simple to implement because they are just a small box shaped object with thin wires running out of them. They don't require and other supporting components aside from a voltage source to run. Fans are also widely available which is important for us since we under a time crunch and don't have time to wait on specialty manufacture to build and ship out a piece that may end up not even working for what we need. They are also highly modular which is an important concept we are considering in the box since it is a test rig for a phenomenon that we are not familiar with and don't even know if it will show up at the given specifications. A larger, more powerful fan can fairly easily be swapped in with very little redesign. For these reasons we decided to use fans as our air flow source.

Response Time	~1-3 Hz
Flow Rate	30-150+ CFM
Voltage	0-12 VDC
Power Consumption	Up to 15W
Total Cost	~$20

Table 3-6 Fan specifications

The main disadvantage is the relatively slow response times. Because we must rely on a physical fan to spin up and slow down there is quite a bit of inertia involved and that limits our cycling rate. The initial proposed rate of 10 Hz will most likely not be achievable with fans but the amended rate of 1 Hz should be very possible. We are trying to limit this inertia as much as possible by using smaller, extremely powerful fans that will hopefully cycle faster than larger, heavier fans. Extensive testing on the exact fan size will be completed and documented.

3.2.4.2 Compressed Air

Theory of operation:

Compressed air works by compressing air and bringing it to a high pressure, typically somewhere around the 90 PSI area. When a valve is hooked up to a compressed air tank and opened the air will escape with a very high velocity. Because the air moves at such a high velocity, it achieves it maximum air flow nearly instantly meaning we can cycle it very fast and still reach our airflow goal. An electronically controlled proportioning valve would be hooked up to modulate the rate at which the air cycles and a pressure regulator would be attached to control how much air will flow through, as seen in the figure below.

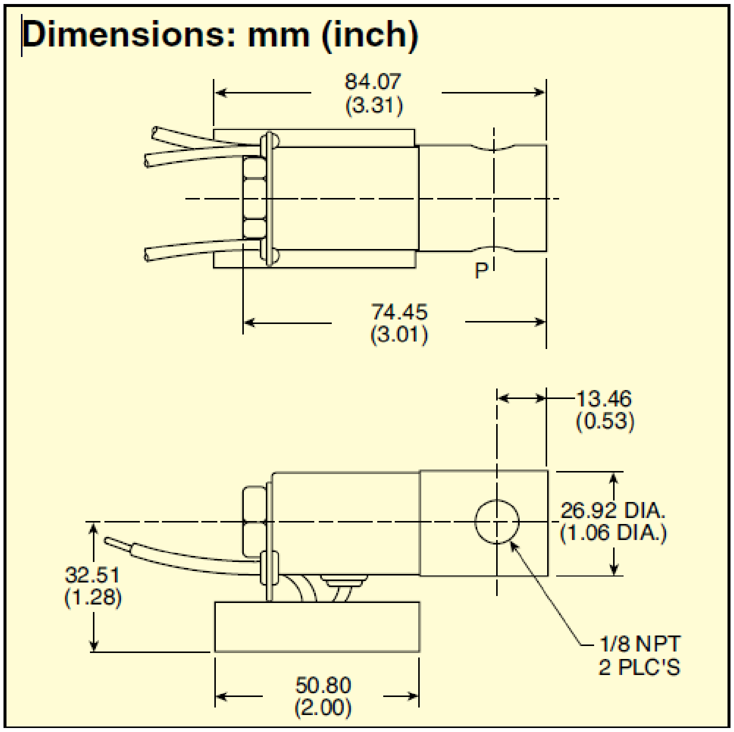


Figure 3-15 Omega air compressor proportional valve
(Pending Permission)

Advantages and disadvantages:

The advantages of compressed air are short but critical. The number one advantage is the incredibly fast response times. From the valves we researched, we would be able to achieve up to 10 Hz which is the maximum amount required for the project. It's also easy to control since the proportioning valve would simply require an input voltage and will open a set percentage based on that voltage. The amount of airflow would also be simple to adjust as we would just need to lower or raise the PSI of the air coming from the tank using the regulator.

While the advantages of compressed air are great, the disadvantages are too numerous to utilize it. The biggest disadvantage is definitely the complexity it would add to the entire system. Compressed air requires an air tank, hoses, fittings, nozzles, a regulator, a proportioning valve, and some way to fill the tank up, whether that is an onboard compressor or external. It also adds significant size to the entire system, with a fairly large tank being required to run for any reasonable amount of time. The pressure also drops as the volume in the tank dips below a certain level which would be detrimental for our airflow. The final nail in the coffin for compressed air is that the valve required to cycle the air is not able to provide the amount of airflow that we require, pushing around 3 CFM rather than the necessary 24 CFM. For these reasons we were able to rule out compressed air.

Response Time	10 Hz
Flow Rate	2.82 CFM
Voltage	0-5 VDC
Power Consumption	7W (valve); 300-500W (compressor motor)
Total Cost	~$700 for tank, valve, lines, fittings, etc

Table 3-7 Compressed air specs

3.2.4.3 Vacuum

Theory of operation:
A vacuum based system would work very similar to a compressed air system but rather than using a compressed air tank and pushing air through the system, a vacuum would be used to pull air through. The same valve system would be used so the response time and flow rate would be similar to compressed air.

Advantages and disadvantages:
The advantages of a vacuum based system are very similar to a compressed air system in that we would be able to achieve excellent cycle rates and easy controllability. The main advantage a vacuum system has over a compressed air system is that because the air is pulled rather than pushed at a high velocity, the need for diffusers to even out the airflow would be reduced or removed altogether.

Response Time	10 Hz
Flow Rate	2.82 CFM
Voltage	0-5 VDC
Power Consumption	Up to 7W
Total Cost	~$800 for pump, valve, lines, fittings, etc

Table 3-8 Vacuum specs

The disadvantages of vacuum, like compressed air, are just too hard to ignore however. Complexity, physical size, low airflow, and an extremely high cost make it so that going with a vacuum system is just not a valid option.

3.2.5 Heaters

3.2.5.1 Strip Heaters

Theory of operation:

The ceramic strip heater is basically a resistor. When a voltage is applied across the resistor the resistor heats up. This resistor is wound up inside of a metal strip. This metal strip can then be mounted to whatever needs to be heated. This type of heater offers a uniform distribution of heat and comes in a hard metal strip.

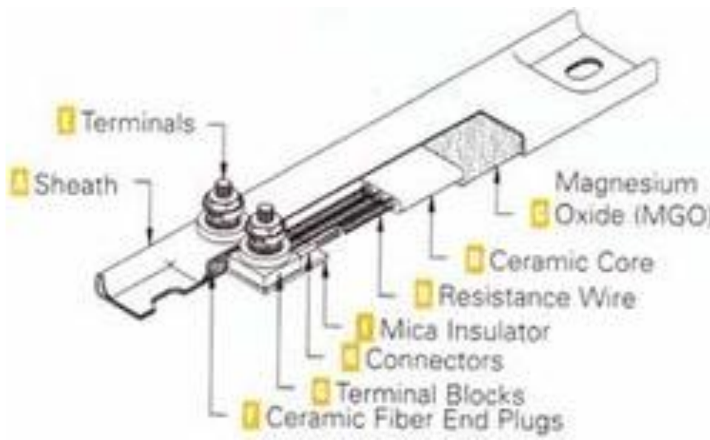


Figure 3-16 Ceramic heater diagram
(permission pending)

Advantages and disadvantages:

This heater is very durable and offers a uniform distribution of heat. It comes in many shapes and can be made to fit in a variety of areas. But is stiff and cannot be bent.

Power Output	~ 13 W/in^2
Installation Restrictions	Not flexible; Room for fasteners required
Cost	~$55 per 8in^2

Table 3-9 Strip heater specs

3.2.5.2 Coil Heaters

Theory of operation:

The coil heater is also basically just a resistor. When a voltage is applied across the resistor the resistor heats up. It is shaped like a flat coil and offers very uniform heat distribution. It is better suited for applications that need a circular heater.

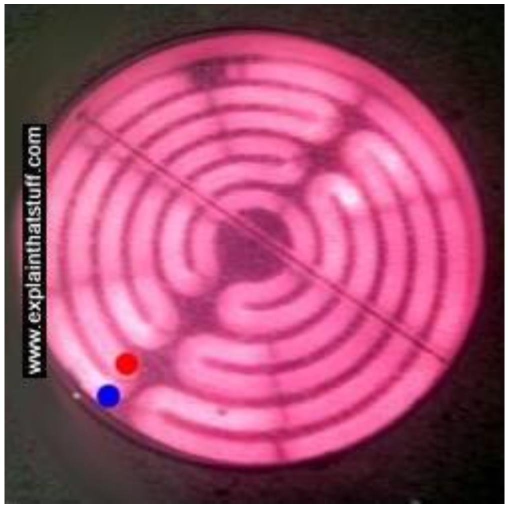


Figure 3-17 Example of a coil heater used in a household stove (permission pending)

Advantages and disadvantages:

The coil heater is durable and can fit is round areas. But is not flexible.

Power Output	~ 13W/in^2
Installation Restrictions	Not flexible; Round
Cost	~$70 per 8in^2

Table 3-10 Coil heater specs

3.2.5.3 Rubber Mat Heaters

Theory of operation:

The rubber mat heater is also basically just a resistor. When a voltage is applied across the resistor the resistor heats up. It is flexible and can be wrapped around things that need to be heated.

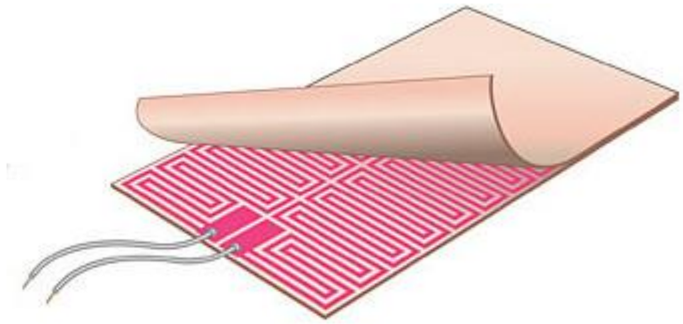


Figure 3-18 Inside a silicon rubber heater

Advantages and disadvantages:

This heater can be fit into odd shaped places and bent or wrapped around the things it needs to heat. But it cannot supply as much heat as the ceramic heaters.

Power Output	~ 10W/in^2
Installation Restrictions	None
Cost	~$25 per 8in^2

Table 3-11 Rubber mat heater specs

3.2.6 Data Acquisition and Control

Data acquisition is used extensively in industrial processing systems, assembly lines in factories, various types of machinery, research test systems, and vehicle control systems. All of these systems contain physical, mechanical, or electrical phenomena may need to be measured in order to further understand the behavior of a system or control other variables within the same system or other systems. Data acquisition takes the role of measuring that variable phenomena, processing it, and converting it into a human-readable form. The variables being recorded by the data acquisition system vary in characteristics such as temperature, radiation, force, volume, speed, pressure, quantity, time, motion, chemical, or electrical. Some important factors that need to be taken into consideration for the measurement of signals in a data acquisition system are the types of measurement devices used to convert the variable attributes into measurement signals and data acquisition input handling. Modern data acquisition systems can record data accurately, reliably, and fast. This is provided the appropriate practices of choosing the correct application compatible sensors, making sure signal wires are housed, shielded, and insulated properly, and matching the accuracy, frequency, and range requirements are all adhered to. Environmental and reliability concerns must also be considered.

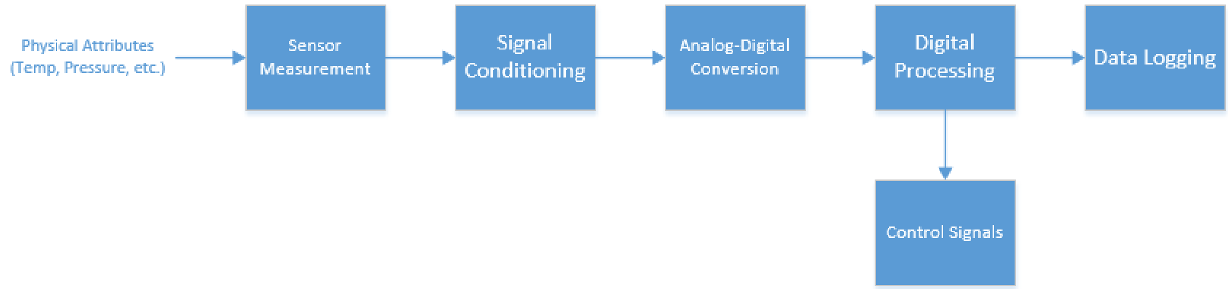


Figure 3-19 Data Acquisition general flow chart

The data acquisition process can be described as being done in a sequence of modules. An example configuration of a data acquisition system is detailed in the flowchart shown in Figure 3-19 above. The physical variable attribute is measured by a sensor of some sort. The sensor converts that measurement into a voltage. The signal conditioning circuit handles the normalization of that output voltage into a more useable form and manageable form. That signal is then fed into an analog to digital converter which, given its name, converts an analog voltage into a multi bit digital signal. That digital data is then handled by a processor and stored somehow and may also be used to change control signals. Every entity in the system needs to be configured or come compatible with all of the others. That way the data that is being acquired can be logged in an efficient and accurate manner.

3.2.6.1 Signal Processing

Signal processing or conditioning is a key step in all data acquisition systems. Signal conditioning is done in the analog domain before the signal is fed into the adc. The incoming signal from the sensor will probably not be in the correct, most desirable, or compatible form for the rest of system. Accurate measurements depend on the good connections to avoid noise from unshielded leads and circuits with improper grounds. One of the major points of signal conditioning is amplification of the signal data into a usable form that is compatible with the adc. Although some sensors provide amplified output, those signals may still not be in the correct format or range for the adcs. Therefore in most cases amplification in some form is needed. The way the signal is amplified depends on the output of the sensor and the input of the adc.

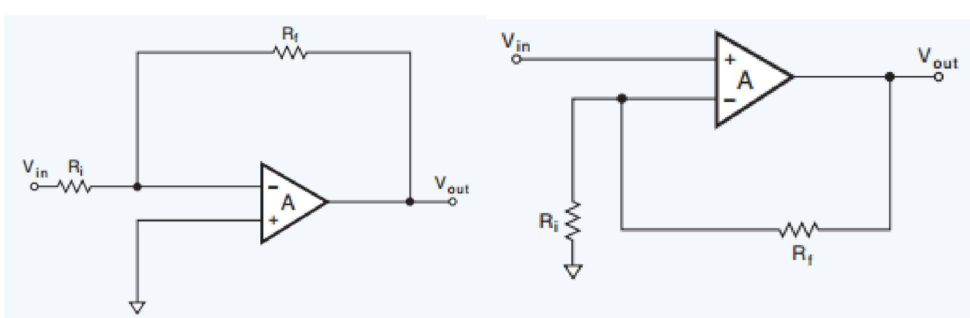


Figure 3-20 (a) Inverting op-amp (b) Non-inverting op-amp

Amplification of a signal is easily accomplished with operational amplifiers (op-amps). Shown above are two different configurations for opamp gain circuits. The first is an inverting op-amp and the gain achieved by the circuit is described by the equation □□□□ = −□□/□□. The other is a non-inverting op-amp circuit and the gain its gain is given by the equation □□□□ = □□/□□ + 1. This gain value can be used to calculate the output voltage value of the amplifier by the equation □□ = □□□ ∗ □□□□. This allows us to easily configure and design amplifiers for each of our signals.

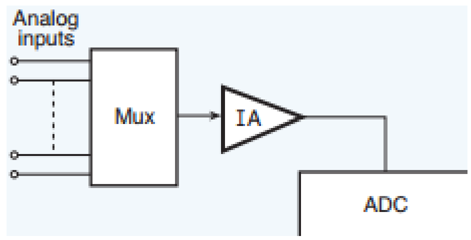


Figure 3-21 Instrumentation amplifier placed after an analog multiplexer

In a multiplexed multi-channel system as shown in Figure 3-21 above, the amplification unit may be positioned between the multiplexer and the adc. This configuration is only possible where every one of the incoming multiplexed analog inputs require the same amplification. That means that they have to be coming from the same kind of sensor or have the same range of output. This configuration also saves on space and cost; where the number of amplifiers that were going to be used to condition each input is now handled by a single unit.

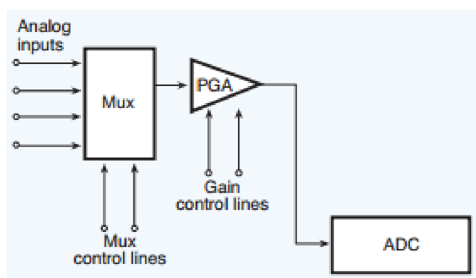


Figure 3-22 Programmable amplifier placed after an analog multiplexer

This is not true in a case where the amplifier being used is a programmable amplifier (PGA). A programmable amplifier is one that can be controlled by digital control signals from a processing unit. These signals modify the level of amplification done by the programmable amplifier. That way a multitude of different analog signals can go through the same unit. A diagram of a programmable amplifier showing the effect of control signals is shown below in Figure 3-22.

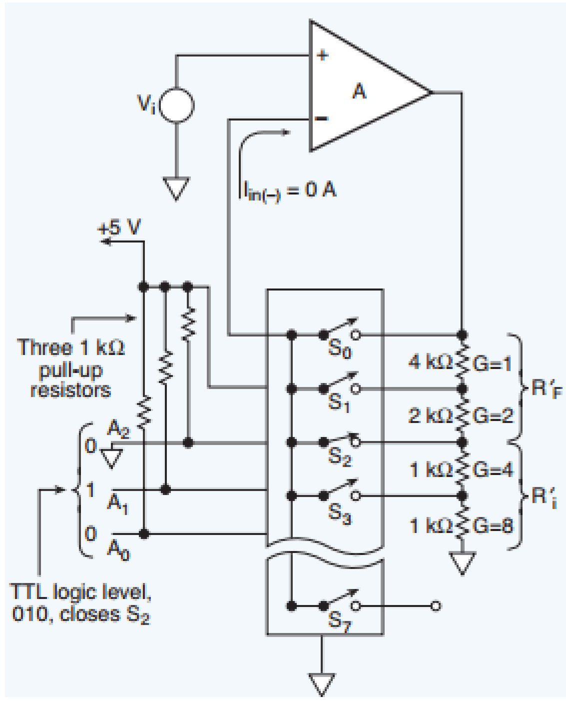


Figure 3-23 Programmable amplifier diagram

The synchronization of these control signals are done by the digital processor by means of sequencing and clock matching. An advantage of individual signal conditioning is to include filtering on each channel individually in the signal path for each sensor. Filtering is needed to filter out unwanted ranges of frequencies in order to reduce noise.

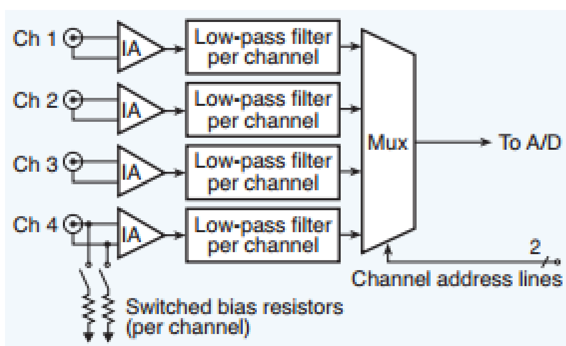


Figure 3-24 Filter positioned between amplifier and mux

Depending on the way the sensor configures its output, the signal may need filtering. This decision is also application dependent. In the configuration shown above in Figure 3-24, a low-pass filter is attached to each signal going into the multiplexer, which then sends that signal to the ADC.

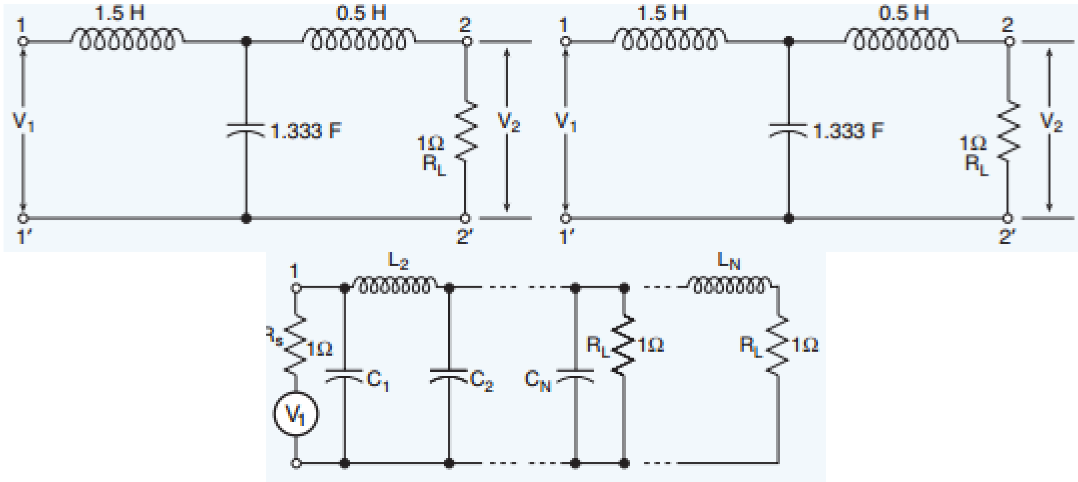


Figure 3-25 (a) Butterworth filter (b) Chebyshev filter (c) Bessel Filter

Passive filters are made up of basic electronic components including capacitors, inductors, and resistors. There are three main types of passive filters that can be used: the Butterworth filter, the Chebyshev filter, and the Bessel Filter. These three configurations are shown in Figure 3-25 above. Passive filters do pose a problem as the signals propagate through them. They may inadvertently reduce the value of the signal coming in. The filter's configuration characteristics may change when attached to a load.

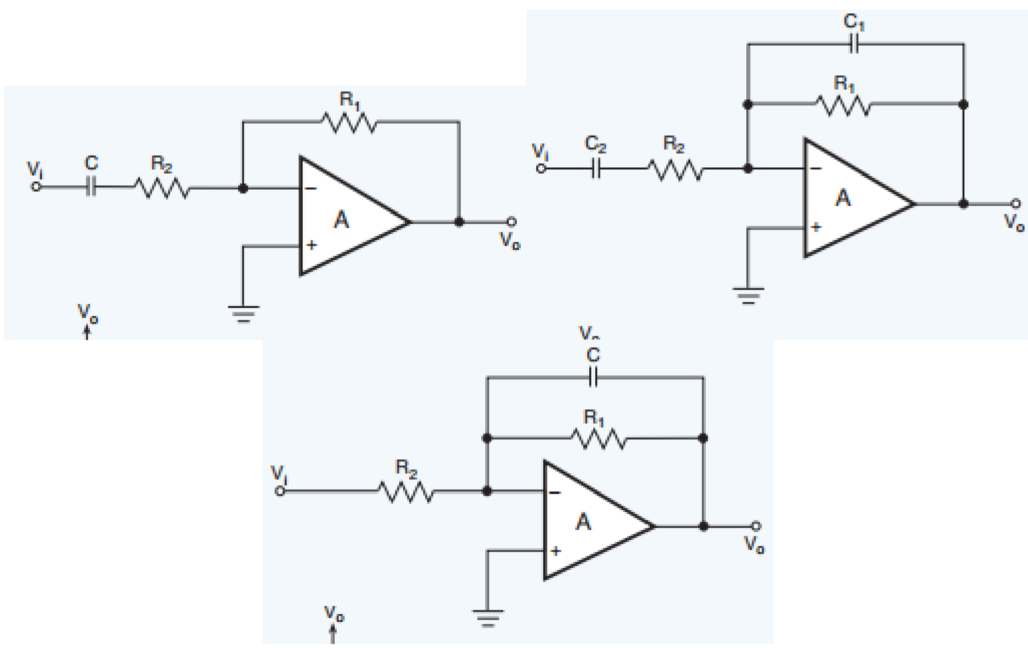


Figure 3-26 (a) Active high-pass filter (b) Active low-pass filter (c) Active band-pass filter

Active filters on the other hand can bypass the issues associated with the passive filters. They are made up of op-amps, resistors, capacitors, and inductors. They provide accurate pass-band filtering without the shortfalls of passive filters like contributing to the circuit load and changing the circuit. These also easier to design and can be tuned more accurately to the application. The three possible filter configurations are high-pass (a), which allow the passing of signals of frequencies higher than a minimum set value, lowpass (b), which allow the passing of signals of frequencies lower than a maximum set value, and band-pass (c), which allow the passing of signals of frequencies between a certain range.

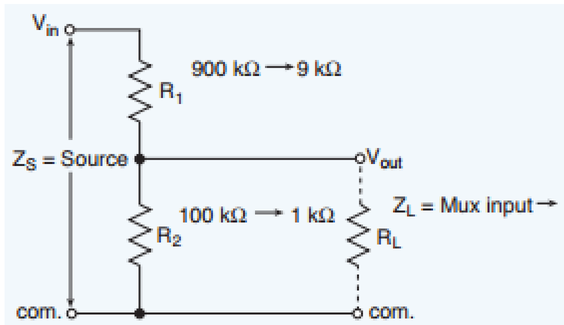


Figure 3-27 Voltage divider

In some cases the voltage may be to high for conversion in the ADC section of the data acquisition system. The solution to this problem is the inclusion of a voltage divider or attenuator. An example configuration of such a circuit is drawn above in Figure 3-27. This circuit reduces the voltage value into a workable scale.

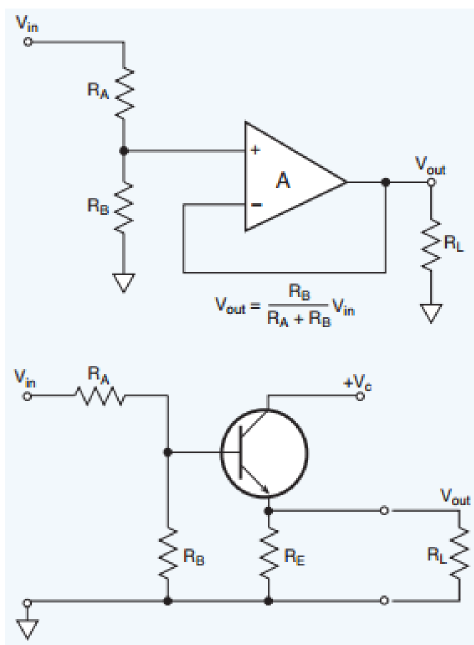


Figure 3-28 Buffered voltage dividers

There is a problem with using simple voltage dividers. They present a low impedance loading effect which can change the configuration of the circuit unintendedly. This effect can be overcome by the use of a buffered voltage divider instead. Above in Figure 3-28 are depicted two example configurations. The first is using a op-amp and the other uses a transistor. These inclusions are done to serve as impedance matching buffers. This prevents the load changing the resultant output voltage. The equation that relates the output of the op-amp is □□□□ = □□/(□□ + □□) ∗ □□□.

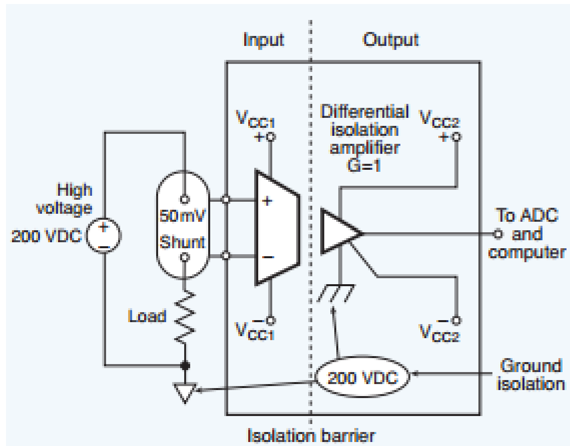


Figure 3-29 Galvanic Isolation Amplifier

Isolation may also be required in some situations. An example situation is one where the data being acquired is measured from low-level signals also have relatively high voltages. In the real world this occurs in motor controllers/winders and transformers. Above in Figure 3-29 is a diagram of a galvanic isolation amplifier. The purpose of this amplifier is to allow the device to withstand a large common voltage between input/output and the grounds.

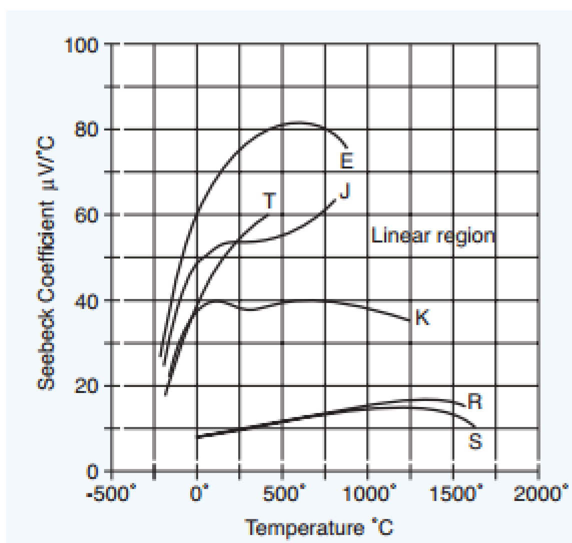


Figure 3-30 Thermocouple non-linear outputs

Depending on the output of the sensors or transducers that are being used in the data acquisition system, linearization of the output may be needed to allow for easier processing or more accurate and relevant results. Shown above, Figure 3-30 is a graph of Seebeck coefficient mapped against temperature for different thermocouple types. As displayed, the output for each of these sensors is not entirely linear and in some cases may give entirely inaccurate results without proper linearization. This situation occurs when the transfer function that relates the input of the sensor to the output is in a nonlinear configuration for design reasons. This nonlinearity may be so minute that it is irrelevant to the accurate measurement in the system. But in some cases a fix may be needed from either a hardware or software subsystem to compensate for the discrepancy. Usually this is done in software, using polynomials that relate voltage values to physical attributes. But this can also be done in the signal conditioning stage with hardware but the circuitry may be too complex and expensive when compensating for error possibility, noise, and attribute variability.

3.2.6.2 Analog to Digital Conversion

The ADC is the point between the analog domain and digitized domain. The job of the ADC is, obviously, to convert an analog signal into a digital signal or binary number that can be handled by a digital processor and then later displayed as a numbered representation that can be read by a human. This can be done in a multitude of ways. The main factors that should be considered in ADCs in data acquisition systems are bit resolution and sampling rate. Other factors come into further consideration in application specific systems. Below is a table that details a general representation of expected specifications for ADCs in the market today. This excludes specialty ADCs and is only meant to analyze regular low power, low cost modules.

Sampling Rate	10kHz to 1MHz
Resolution	10-24 bits
Cost	~$1-3

Table 3-12 Typical ADC specifications

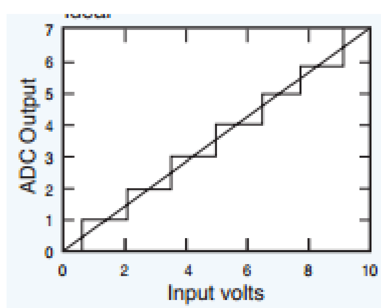


Figure 3-31 Graphical representation of ideal ADC resolution

ADCs have a certain bit size and therefore resolution associated with them. The mathematical equation that relates the number of bits to the resolution is $\square\square\square\square\square\square\square\square\square\square\square = 1/2^{\square}$. This means that for the nominal bit size of 12, the adc will have a bit resolution of 1/4096. Therefore the voltage resolution is the same as the bit resolution multiplied by the maximum input voltage of the ADC. We can develop the final equation by including the voltages and attribute range like so: $\square\square\square\square\square\square\square\square\square\square\square = \square\square\square\square/(\square\square * 2^{\square}) * \square$. Vref is equal to the maximum input voltage of the ADC, Vs is the maximum voltage from the signal conditioning circuit, and

E is the range of the physical attribute being measured by the sensor. ADCs have a variety of different architectures. They differ in technology, power, rate, and resolution.

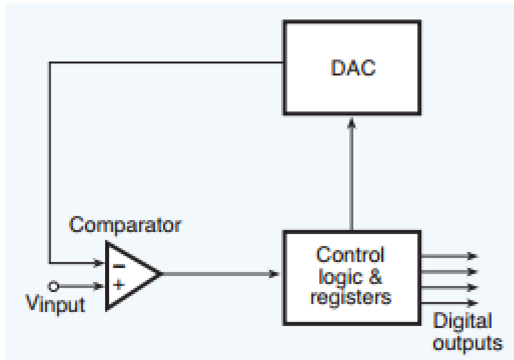


Figure 3-32 Successive approximation ADC

A diagram of the successive approximation ADC shown in Figure 3-32. It is made up of a comparator, a control logic block, and a digital to analog converter. The value sent to the DAC is instantiated at half of the full range. The input value is then compared with that value and if it is greater, the value from the logic block is increased to ¾ the range, and if it is lower, the value is decreased to ¼ the range. This process goes on until all of the bits in the register are used in the comparison. Because of the nature of the device, each of the bit comparisons are run serially. This causes the rate to be relatively slow because the ADC needs to wait for each comparison to be made before the next one can begin. Given that, the rates can still be relatively high and the costs for such devices are fairly low, and are therefore pretty widely used in the industry, especially in integration into data acquisition systems.

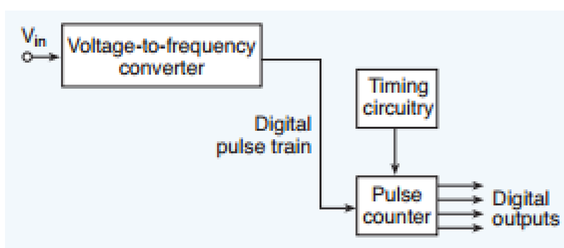


Figure 3-33 Voltage-Frequency ADC

A diagram of the voltage-frequency ADC is shown in Figure 3-33. It is made up of a voltage to frequency converter, a pulse counter, and some timing circuitry. The voltage is converted to a pulse sequence which is counted during a fixed time period by the counter and then finally converted into a digital output. Voltage-frequency ADCs are great for noise mitigation and therefore are commonly used to convert slow or noisy signals.

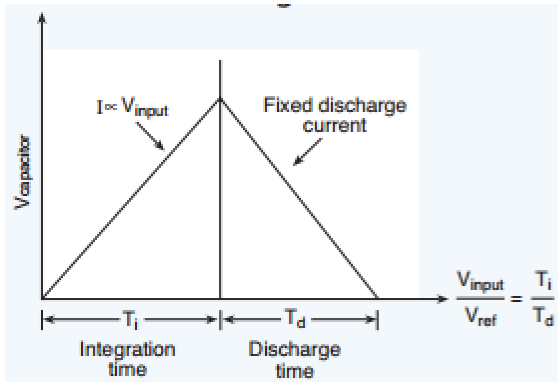


Figure 3-34 Integrating ADC time slope graph

A graphical representation of the dual slope integrating ADC is shown in Figure 3-34. The integrating ADC uses a capacitor to determine its conversion. It does this by measuring the time needed to charge or discharge the capacitor. This in turn allows the time values measured to determine the value of the input voltage using the equation □□□/□□□□ = □□/□□. This technique provides improved accuracy and stability compared to other architectures. It is also good at reducing noise. These ADCs usually have a relatively slow conversion rate though because of their nature.

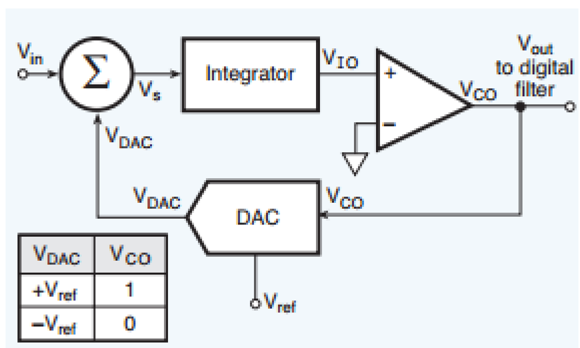


Figure 3-35 Sigma-Delta ADC

Sigma-delta ADCs are one of the most common types of integrating ADCs. A diagram of the circuit is shown in Figure 3-35. It contains an summator, integrator, comparator, and DAC. These ADCs are relatively cost effective and can do high resolution measurements easily. The way they work is that the input voltage sums with the output voltage from the DAC, then the integrator adds the summation to a previous value that was stored previously. The comparator output goes through a couple cycles until it reaches the desired final comparison for the circuit.

Architecture	Sampling Rate	Resolution
SAR	1 Msps	8-16 bits
Sigma-Delta	50 Ksps	16-24 bits
Voltage-Frequency	100 Ksps	8-14 bits
Integrating	500 sps	12-24 bits

Table 3-13 Comparison of ADC architectures

ADCs, like any other device, contain unavoidable errors that may affect the accuracy of the converted measurements. The total error can be described by the equation $□□□□□□ = \sqrt{□□ * □□^{2}}$ where σi is a single independent error. Possible errors that may occur include gain error, linearity error, missing code, and offset error. An ADCs accuracy must be tested before implementation in a data acquisition system. Otherwise the values being measured may be unknowingly inaccurate and may provide faulty data to work with.

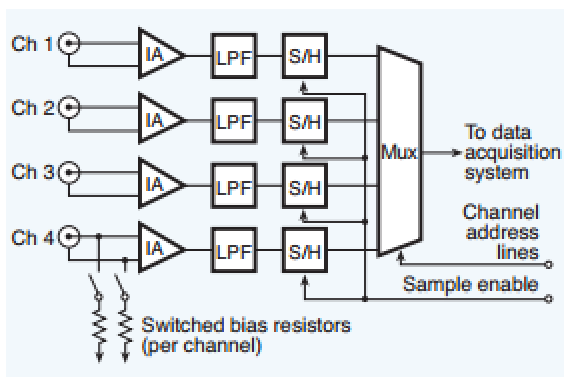


Figure 3-36 Sample and hold circuit

Because the ADC converts a single voltage value that is only completed after certain amount of time, the incoming signal must be steady-state. Otherwise changes in the input will prevent the adc from converting accurately. There is an exception for the case where the rate at which the incoming signal changes is relatively slow compared to the ADC's sampling rate. This whole problem is solved by the use of sample and hold (S/H) circuits. Figure 3-36 above displays the diagram for such a circuit. A sample and hold circuit acts takes a signal from a specified moment in time and holds that value until it is finished being read. This prevents changes in the incoming analog signal from affecting the ADC output. This also allows for conversion and acquisition of simultaneously sampled measurements in multi-channel systems that require it. The sample and hold circuit can be included in the signal conditioning circuit or more commonly in an adc that does it internally.

3.2.6.3 Digital Processing and Control

In the digital realm of data acquisition we have processing of and transmission (and sometimes display) of data and the control of peripherals such as sensors or ADCs. This is handled by either a microcontroller, an FPGA, a DSP, or some other ASIC device. The processor is the main handling unit for the transmission of data from the ADCs or sensors to some peripheral, storage, or communication output. The processing module is may be in charge of linearizing the data, but this is typically done at the highest level of software stages.

3.2.6.4 Interfacing

Digital signals are the common mode of communication between processors and peripherals. These digital signals can be inputs, outputs, clocks, or controls. The way the processor interacts with a peripheral, ie an ADC, is usually through a standardized serial communication interface. Some peripherals may use non-standardized interfaces that need custom hardware or processing techniques. This may require the utilization of custom developed hardware or logic blocks that need consideration during the development process. At the low level of communication interface protocols are SPI and I^2C. These two protocols are suited for relatively slow communication in embedded integrated circuit systems and their peripherals.

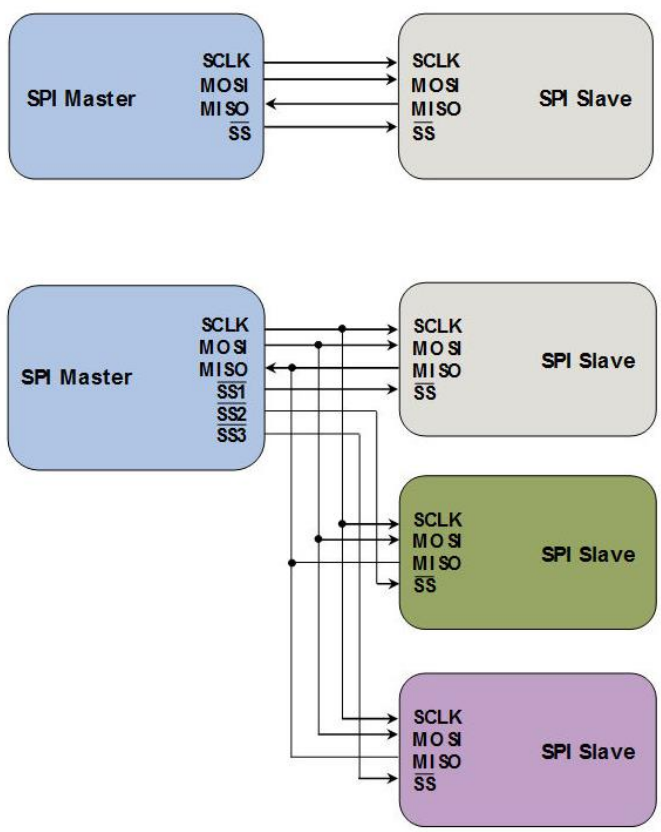


Figure 3-37 SPI block diagram

The serial peripheral interface or SPI bus is one of the most used and useful interfaces for interacting with peripherals. It is a synchronous serial communication interface that is primarily utilized in short distance communications in embedded systems. The bottom of Figure 3-37 displays a block diagram of an example configuration where there is one SPI master or host that is connected and able to communicate with and control three individual and separate SPI slaves. The master sends control signals and the clock in order to configure, control, and synchronize its slaves. This interface uses four signals:

- SCLK: Serial clock from master sent to slaves. All SPI signals are synchronous to the clock.
- MOSI: Master output, slave input data line
- MISO: Master input, slave output data line
- SS: Slave select; individual signals for each slave.

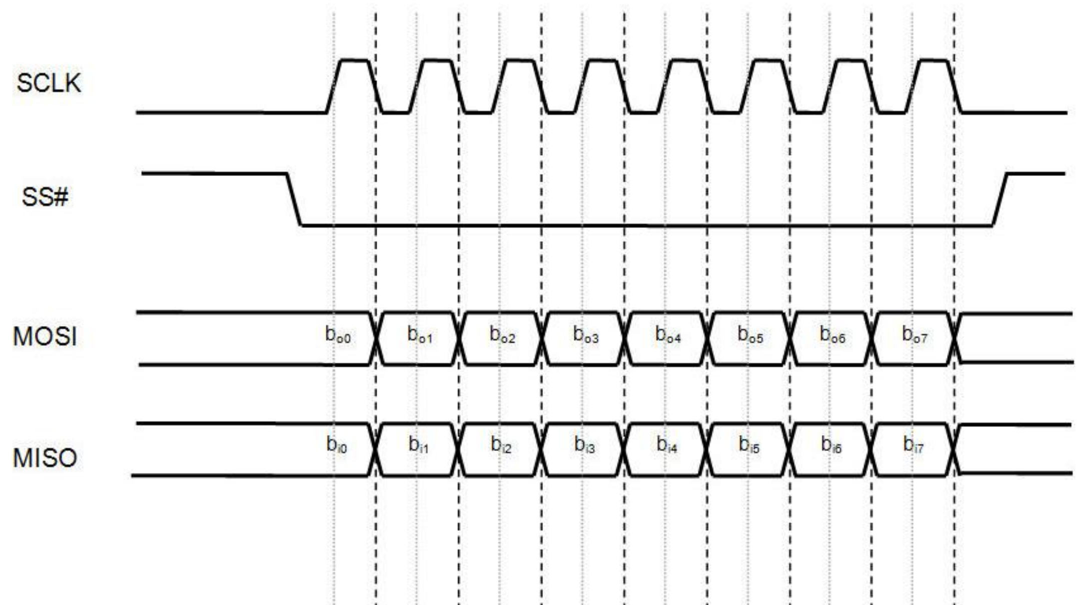


Figure 3-38 SPI transmission waveform

Transmission works by the master first configuring its clock and logic and selecting the slave it needs to communicate with. The master then shifts mosi bits into the slave while the slave shifts miso bits into the master. This occurs during each clock cycle. The clock cycle may need certain delay for the completion of analog to digital conversion. The process is finished when the complete transmission of one word size is accomplished. The process is the same whether the communication is one directional or two directional. SPI is the most commonly used interface in ADCs as it is simple and the communication system fits well with the nature of the devices.

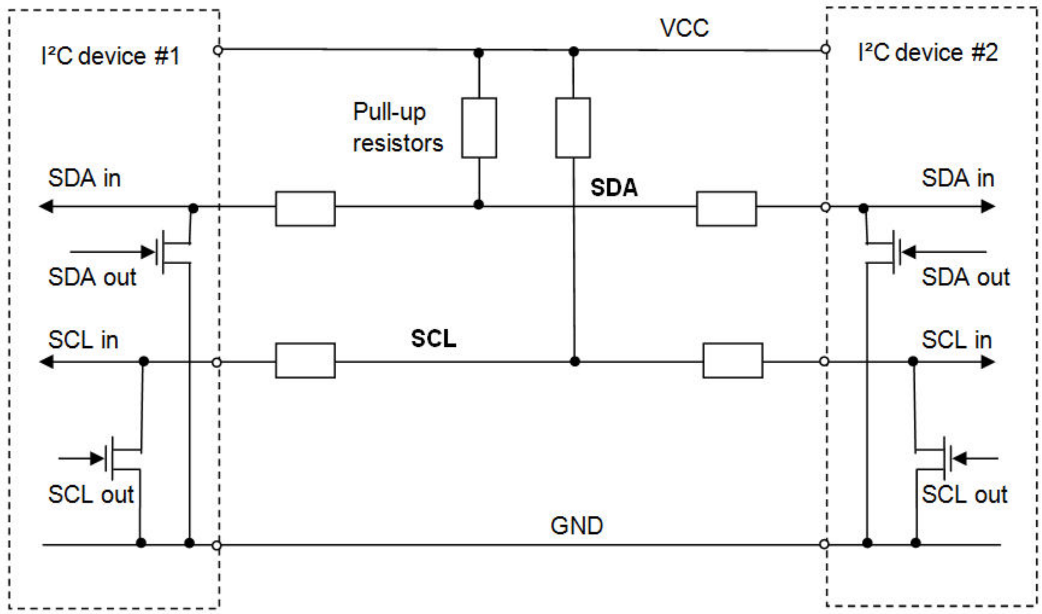


Figure 3-39 I²C block diagram

I²C is a low level communication interface protocol that uses only 2 wires. These two wires transmit data signals signals across the two devices. Figure 3-39 above depicts the connections between the two devices. The two signals are:

- SDA: serial data
- SCL: serial clock

There are no select lines for multiple slaves in this interface. A single wire is shared and used to transmit data from one device to the other. The bits from data define the slave addresses, data, and control for the communication start, end, direction, and acknowledgement. The master takes care of the handling of all communications and slave interfacing. A typical communication consists of a start bit, followed by a slave address, followed by a read/write control, followed by a 8 bits of data and an ack bit, followed by that pattern for however long the word is, and then finally ended with a stop bit.

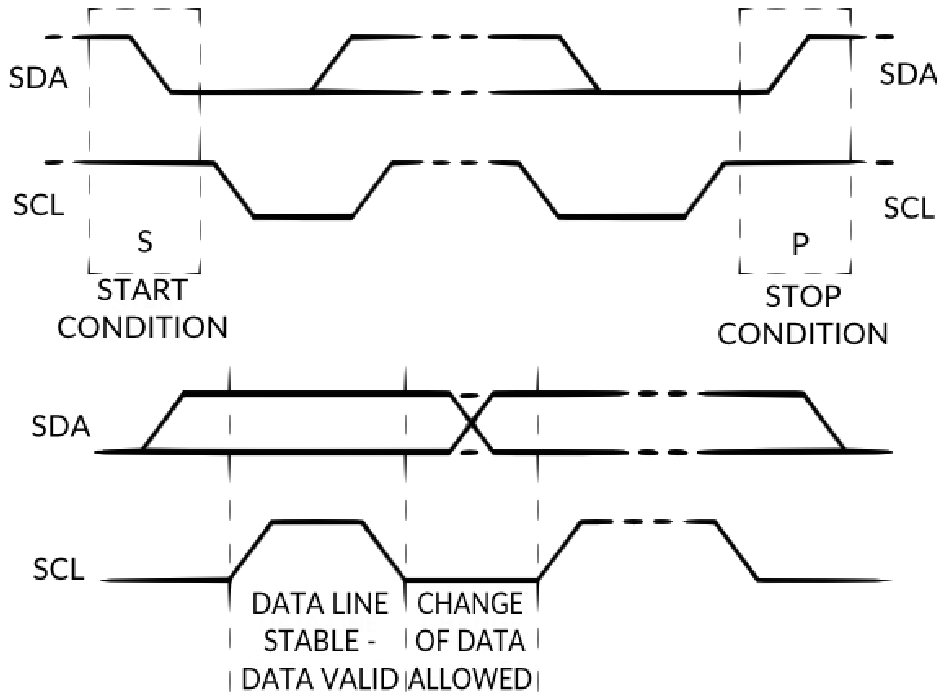


Figure 3-40 I²C transmission waveform

The clock signal determines when data is being read, and when it is allowed to change on the transmitter. This system allows for optimal communication between any number of devices while using only two physical wires. Comparing the two protocols is a matter of distinguishing what advantages each brings to the table.

	SPI	I²C
Bus Routing / Size	> 4 wires (3 + # of slaves)	2 wires
Speed	> 10Mbps (full duplex)	< 1Mbps or < 3.4Mbps (highspeed)
Utility	Widely used for peripherals including ADCs; easy to implement	Lacks performance; difficult to implement

Table 3-14 Comparison of SPI and I²C

3.2.6.5 System Rate

The system sampling rate is equivalent to the highest channel rate multiplied by the number of channels being sampled. A high frequency sampling rate is required for accurate measurements of time-transient events occurring on sensors. One consideration that for sensors that is often overlooked is the redundancy of data from a high sampling rate in a multichannel system. If one channel requires a high sampling rate, that the other does not, then the other sensor will be oversampled. Therefore in such a case, the channels must be sampled at different rates in order to avoid unnecessary data.

Multiplexing reduces the sampling rate of a multichannel ADC. This is because each channel needs to timeshare with the other channels being multiplexed. For an ADC running at 1ksps, the individual rate for each channel if the ADC was running with 8 channels is 125 sps.

Since the number of channels can exceed that of which a single adc may have the capabilities to handle, the design needs to contain some form of multi channel synchronization and processing.

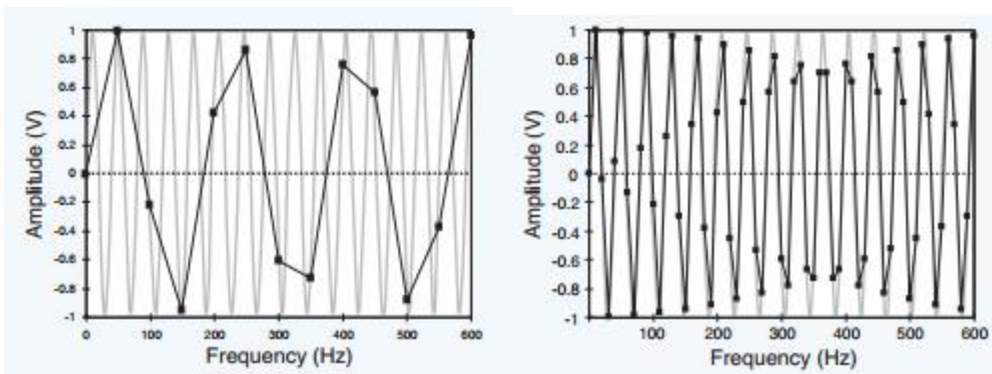


Figure 3-41 Nyquist sampling rate example (a) inadequate (b) acceptable

The sampling rate needed to accurate sample the an incoming analog signal is described by the Nyquist theorem. It states that given a cutoff frequency that describes the highest possible frequency given by a signal, the sampling rate that is needed to accurately reconstruct the input signal is at least two times the cutoff frequency. Figure 3-41 shows the need and application of the Nyquist sampling theorem. The first image displays an inadequate sampling rate being used, and the effect that rate has on the accuracy of the measurements, while the second image shows an acceptable range based on the theorem in use.

3.2.6.6 Data Logging

Logging the data is the crucial process of organizing it into an acceptable form before transmitting it through a communication system or storing it into a peripheral. The reason we log data is so that we can have access to it after or during the testing process. Large quantities of data at a very high rate are difficult for a human to process. There needs to be a way to collect, pool, and format the data for easy reading and use in data diagrams or displays. Data logging is usually done by storing the data into some non-volatile storage. An SD card would be a great example of this as it can receive and store large amounts of data fairly quickly, all while keeping the data safe from the threats of power down wipes.

3.2.6.7 Analog Control

The system will be further controlled by a linear control system. By using a LSC system our device can compensate on-the-fly for disturbances and system characteristics. To design a LCS system that can give us the performance we need we have to obtain a model of our fan duct system that is accurate within the operating ranges of our device. Once we have obtained the mathematical model we can use it and the specifications of the output required by our project to decide what type of controller is needed. Even after our model and controller are obtained additional tweaking of the controller will be necessary to compensate for unknowns in the model of the system and controller. The general design of our controller is shown below.

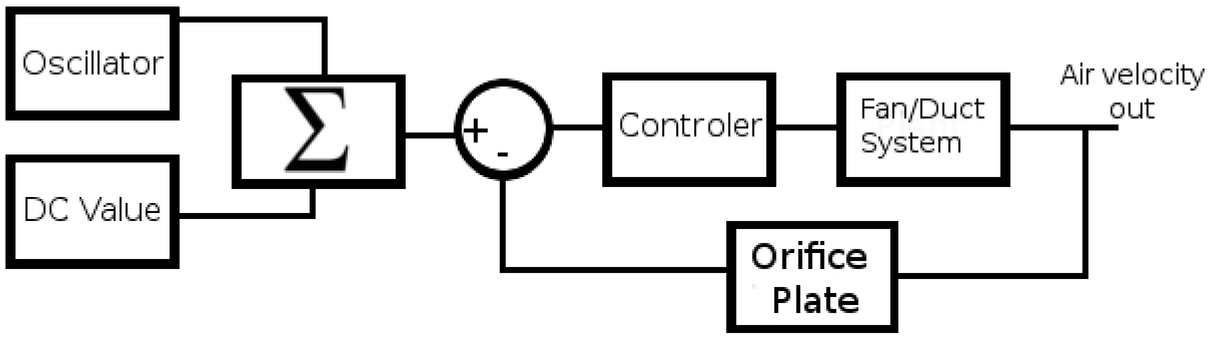


Figure 3-42 Generalized LCS

3.2.7 Power Supply Units

Supplying power to our multitude of components is a critical and often overlooked step. The different units within the system require different types of power supplies. Though there is not a lot of room for different types of supplies here, we have taken a look at a few different options for our varying tasks.

3.2.7.1 DC Power Supply

Theory of operation:

The DC power supply converts alternating current to direct current. It is usually designed to convert the power available in a household socket to a low voltage DC power source. It is very useful because most digital logic devices run on low voltage DC. The DC power supply operates by first rectifying the AC signal so that it becomes a DC signal with the same voltage as the input AC signal. The power supply then converts the DC to a lower voltage using a regulator. DC power supplies come in many shapes,sizes,voltages and power ratings. A simple example of a DC power supply is a cell phone charger.

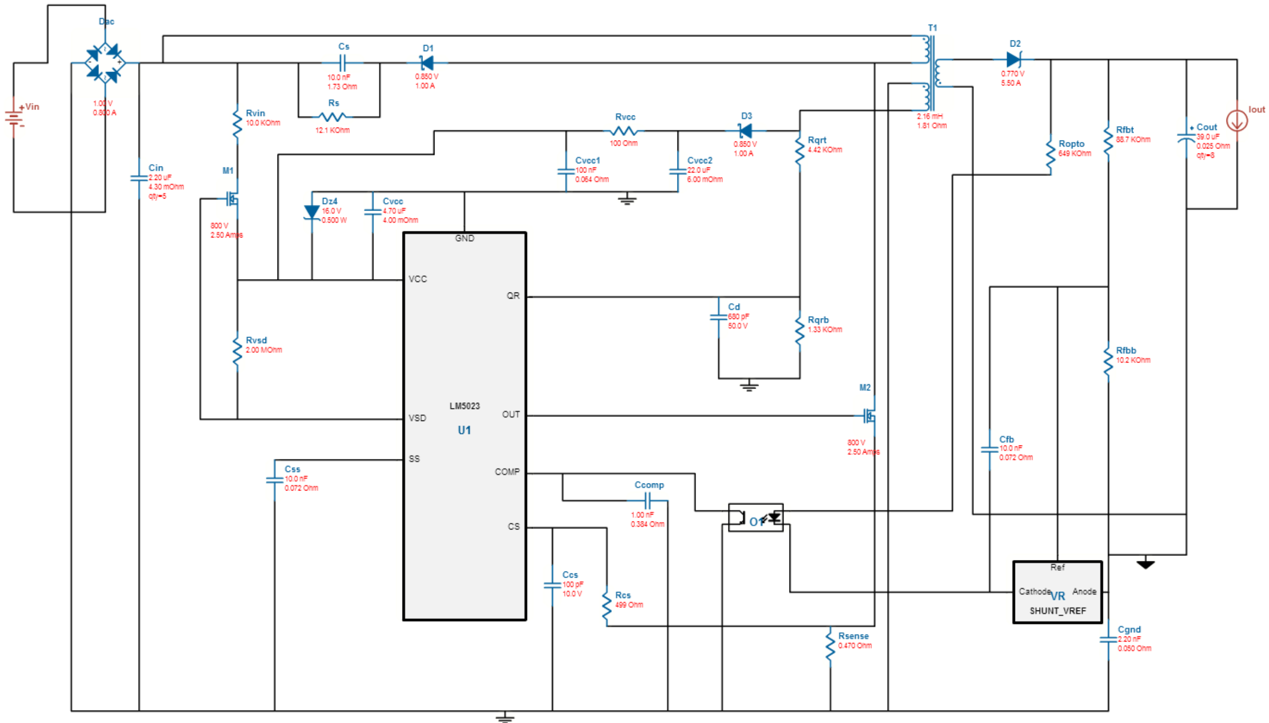


Figure 3-43 DC power supply 12V rail

Advantages and disadvantages:

In many cases a DC power supply is essential and can not be substituted. While batteries can supply DC power they have to be recharged and have limited recharge cycles. And while the power company could supply you with DC power it is extremely inefficient for them to use DC instead of AC. So if you need constant DC power in a home or office environment the DC power supply is essential. DC power supplies are not perfect though. They waste energy when converting the power and dissipate that energy as heat. Converting large amounts of power can require very large power supplies. And while DC power is radiates less noise than AC the power supply itself can radiate noise.

Output Voltages	+12V, -12V, +5V DC
Output Power	4A, 0.5A, 0.5A Respectively
Input Voltage	120V AC @ 60Hz

Table 3-15 DC power supply specs

3.2.7.2 Transformers

Theory of operation:

The transformer is a transforms alternating current to another alternating current of another voltage. It does this through magnetic coupling. The transformer consists of two wire coils wrapped around the same metal bar. This metal bar is often made of iron or steel but can be any other material that has desirable magnetic properties. As the current changes it creates a magnetic field in the bar. This magnetic field then creates a current in the second coil. The ratio of the number of winding on the first coil vs the second determines the voltage of the output ac signal to the input one.

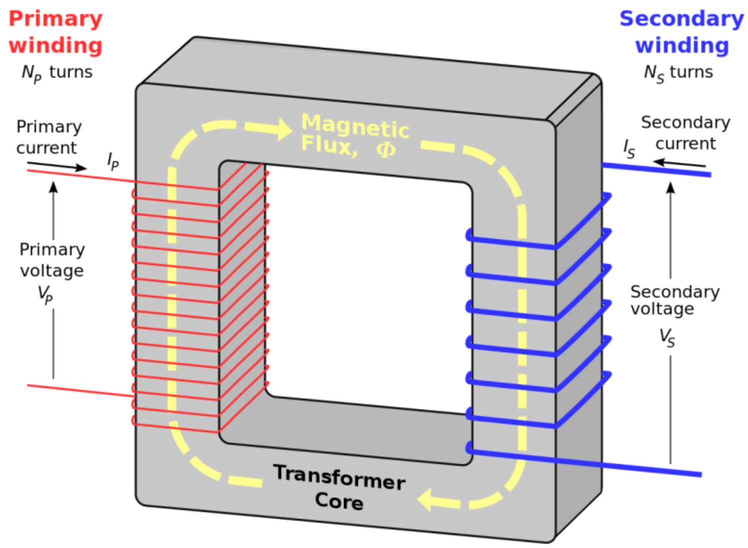


Figure 3-44 Transformer diagram

Advantages and disadvantages:

The transformer is very simple and cheap and thus popular. It is very useful, especially to power companies. This is because it it more efficient to send power long distances at high voltages. And because the transformer is a simple, reliable and cheap method of converting AC power it makes sense to use AC to distribute power.

Output Voltages	(Np/Ns)*Vin AC volts out
Output Power	0-200W needed (high power transformer exist)
Input Voltage	120V AC @ 60Hz

Table 3-16 Transformer specs

3.2.7.3 Variac

Theory of operation:

The variac is literally a variable transformer. By adjusting the number of windings on the second and or first coil the variac can vary the output voltage relative to the input voltage. It achieves this by adjusting the location of the lead that connects to the coil. By using a large coil and then moving the connection to one end of that coil the variac can adjust the effective number of coils.

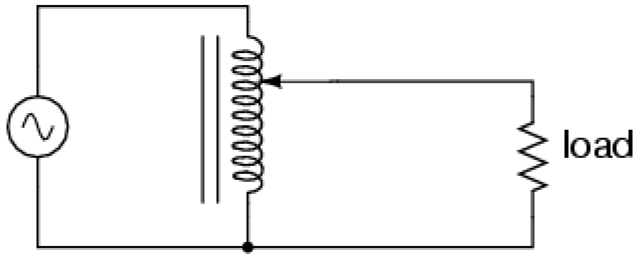


Figure 3-45 Variac circuit diagram

Advantages and disadvantages:

The variac makes variable conversion of AC power easy. Just plug it in and adjust the dial to your desired output voltage. It has the disadvantage of not being able to handle as much power as a standard transformer and has less durability.

Output Voltages	Variable AC out
Output Power	0-200W needed (high power variacs exist)
Input Voltages	120V AC @ 60Hz

Table 3-17 Variac Specs

3.3 Strategic Components

After carefully considering every option we looked in to and weighing the pros and cons by utilizing a weighted selection matrices for each, we were able to come to a conclusion on the type of part we would like to use in each subsystem.

3.3.1 Heater Choice

The rubber mat heater comes out as the winner in this selection process. All of the heaters are able to meet our power requirements and both the rubber and fiberglass heaters are equally easy to install. The rubber mat heater is cheaper and thus the best choice in this case. The ceramic strip heater is not as good of a choice for this project because we would have to build the plates to accommodate the fitting on it. While this is not a huge deal it is certainly an advantage to just have a couple wires extending from the side of the silicon heater then accommodating the fittings on the ceramic heater

	Power Output (20%)	Ease of Install (50%)	Cost (30%)	Total
Ceramic Strip	10	8	7	**8.1**
Silicon Rubber	10	10	10	**10**
Silicon Fiberglass	10	10	7	**9.1**

Table 3-18 Heater selection matrices

Power Output	**Ease of Installation**	**Cost (per 8in2)**
10: > 2 w/in2	10: No Design Changes nessasary	10: < $30
9: 1.8-2.0 w/in2	9: No design changes but wire position needs to be worked around	9: $30-45
8: 1.6-1.79 w/in2	8: Easy but fittings may need to be specially acounted for	8: $45-60
7: 1.4-1.59 w/in2	7: Usable but only in one way	7: $60-75
6: 1.2-1.39 w/in2	6: Extra work required to install	6: $75-90
5: 1.0-1.19 w/in2	5: Awkward fit	5: $90-115
4: 0.8-0.99 w/in2	4: Inproper fit	4: $115-130
3: 0.6-0.79 w/in2	3: Unusable fit	3: $130-145
2: 0.4-0.59 w/in2	2: Unusable fit and awkward wiring	2: $145-160
1: 0.2-0.39 w/in2	1: Completely unusable	1: > $160

Table 3-19 Heater matrices explanation

3.3.2 Mass Flow Sensor Choice

The winner of this selection process is the orifice plate. The hot wire probe has the fastest response time and the best accuracy but requires calibration to often and costs way too much. The insertion probe has good accuracy but unacceptable response time. The orifice plate is able to meet our requirements for response time because it uses pressure sensors that have acceptable response times. It is also much cheaper than the hotwire sensor and requires minimal calibration is milled by a manufacturer. It was important that the mass flow sensor be able to resolve a sinusoidal variation with a frequency of ten hertz in the velocity of the air moving through the duct. By Nyquist’s sampling theorem the minimum sampling rate to resolve a sine wave is two times its frequency. In practice a higher sampling rate is usually required and so a sampling rate of 50Hz is required. Because of this we knew that we needed to find a sensor with a response time better than 20ms. This immediately ruled out the RTD probe.

	Response Time (40%)	Accuracy (30%)	Calibration (10%)	Cost (20%)	Total
RTD Insertion Probe	1	8	10	7	**5.2**
Hotwire Probe	10	10	3	1	**7.5**
Oriface Plate	9	8	7	7	**8.1**

Table 3-20 Mass flow sensor selection matrices

Responce Time	Accuracy	Calibration	Cost
10: < 1 ms	10: < ± 3%	10: Self calibrating	10: < $50
9: 1-5 ms	9: ± 3%	9: Pre calibrated	9: $50-199
8: 5-10 ms	8: ± 4%	8: Once	8: $200-499
7: 10-20 ms	7: ± 5%	7: Once + data compensation for enviroment	7: $500-699
6: 20-40 ms	6: ± 6%	6: Monthly	6: $700-899
5: 40-60 ms	5: ± 7%	5: Monthly + data compensation for enviroment	5: $900-1099
4: 60-80 ms	4: ± 8%	4: Weekly	4: $1100-1299
3: 80-100 ms	3: ± 9%	3: Weekly + data compensation for enviroment	3: $1300-1499
2: 100-200 ms	2: ± 10%	2: Daily	2: $1500-1699
1: > 200 ms	1: ± > 10%	1: Daily + + data compensation for enviroment	1: > $1700

Table 3-21 Mass flow sensor selection matrices explanation

3.3.3 Pressure Sensor Choice

The selection process for the pressure sensor was based on many factors. Included are:

- Pressure range
- Stability
- Accuracy
- Sensitivity
- Response time
- Linearity
- Size
- Mounting options
- Type of output

The most important of which is conformity to the requirements. The requirements stated a need for finding the average change in pressure along the entire system. This can be done one of two ways. The first is to use two absolute or gauge sensors at two different points on test apparatus (front and end). The other, more obvious way is to use a differential pressure sensor. Again a differential sensor measures the difference between pressure at two distinct points in the system. A differential sensor's connections are done by extending cables to the two points and can be either mounted near the wall or on the PCB. This conforms to our requirements.

The main issue with part picking was the range. The calculations done by the ME team defined a need for an ultra-low range sensor. The expected average pressure difference was calculated to be 0.4 Pa. This is an extremely low value that needs to be measured accurately. The regular ranges for most of the industry low range differential pressure sensors are still much too high for our application. There was a need to branch out and search for specialized ultra low range sensors that would be capable of measuring the values desired. What was found was a special ultra low sensor.

Pressure range	0 - 25 Pa
Accuracy	2.75% FSS
Output	0.5 - 4.5 V (amplified, linear)
Size	17.7 x 18.0 x 5.6 mm (board mounted)
Cost	$136

Table 3-22: Pressure sensor specs

In the table below is detailed a comparison chart for the types of technologies considered for the pressure sensors. The table helped identify which of the sensor architecture provided the best balance of the most needed factors that decided our selection.

	Range	Accuracy	Cost	Avg
Ceramic	6	7	5	**6**
Thin-Film	3	7	7	**6**
Piezoresistive	8	9	5	**7**

Table 3-23 Pressure sensor technology comparison

3.3.4 Temperature Sensor Choice

There is many characteristic we have to considered when choosing the thermocouple, and each characteristic is weight differently based on the importance toward our project. It come down to the seven following characteristics:

1. Temperature range
2. Stability
3. Accuracy
4. Sensitivity
5. Time constant
6. Linearity
7. Size

The figure shown below is illustrated how each characteristic weight, and the total score of each type of temperature gained.

	Temp.Range (5%)	Stability (5%)	Accuracy (15%)	Sensitivity (10%)	Time Constant (35%)	Linearlity (15%)	Size (15%)	Total
Thermocouple	10	8	7	8	10	9	10	**9.1**
RTD	10	10	10	9	7	10	9	**8.7**
Thermistor	10	7	10	10	8	7	10	**8.7**

Table 3-24

In the original Harris' specification, the temperature sensor for this particular senior project should have the response time larger than 10 Hz, and it is one of the major condition for this project.Thermocouple sensor can reach this requirement without any issues, smaller size can get the faster time constant. the rest of the two type temperature sensor have slightly larger time constant, but still considering those two because of other advantages. All type of temperature sensor that I am considering that meet the temperature rage requirement. Both RTD and Thermistor have good accuracy compared to thermocouple, but due to the importance of response time, we have to sacrifice the accuracy of the thermocouple. Because this project require large amount of temperature sensor,24 pieces for each of the plate, the size of senor become big consideration, but fortunately, most of the sensors can reach as small as 0.1 mm diameter. After consider all the characteristic of temperature sensor, Thermocouple rate 9.1 out of 10, which become the winner. The cost of each thermocouple is inexpensive,for the project, there is the way to build the thermocouple sensor by ourselves. The stability issue, which means how long it can maintain a constant temperature based on the sensor;s temperature feedback. For RTD, it able to maintain the same temperature up to years, For both thermocouple and the Thermistor, it require to be calibrated every few weeks by using different type of calibration technique. The table shown under illustrate the numerical value of each type temperature sensor.

Sensor type	Thermocouple	RTD	Thermistor
Temperature range(℃)	-200 to 2320	200 to 700	-200 to 260
Stability	medium	good	poor
Linearity	medium	good	poor
Accuracy	+/-(1to 2.2℃) or +/-(0.25%to 0.75%)	+/-(.3℃) or +/-(0.12%)	+/1(0.1 to 0.2%)
Sensitivity	Low	Medium	
time response	<0.1 sec	>1 sec	<.5 sec
size	<0.063 in	0.125 to 0.25in	

Table 3-25 Temperature sensor evaluation

Even though the thermocouple is the winner of this selection, it still need a lot of work to do to improve the performance. shield each thermocouple sensor, so that is not not interrupt with each other. The response time is not depend sensor itself, it has a lot of factors that we have to consider in order to get the best performance.

3.3.5 Airflow Source Choice

Choosing our airflow source came down to the five following characteristics:

- Controllability
- Response time
- Complexity
- Airflow
- Cost

Each characteristic was weighted differently depending on its importance to the project. Controllability is one of the biggest considerations we had for choosing an airflow source. We needed whatever we chose to be easily controllable and adjustable so that we could deliver the airflow in exactly the way Harris is requesting. In this category the fan, compressed air, and vacuum all scored perfect because they are all very easy to control, requiring only a voltage input from the controller to tell them when to turn on. Response time was also a major consideration for this project. Initially Harris requested that the airflow cycle at up to 10 Hz. Compressed air and vacuum were able to meet this requirement due to the extremely fast proportioning valve they would utilize. Fans however were not able to meet this requirement. After talking to our representative about the problem he agreed to lower the requirement down from 10 Hz cycling rate to just 1 Hz. Fans are able to reach this rate without issue and should be able to go beyond. Because of this we rated the compressed air and vacuum a perfect score and fans only a 5 out of 10.

	Controllability (25%)	Response Time (25%)	Complexity (20%)	Air Flow (20%)	Cost (10%)	Total
Fan	10	5	8	10	10	**8.9**
Compressed Air	10	10	4	0	5	**6.3**
Vacuum	10	10	4	0	3	**6.1**

Table 3-26 Airflow source selection matrices

Complexity, though not a specific requirement set by Harris, is very important to us as we always are looking for ways to achieve the desired results with less complexity. Keeping the subsystems as simple as possible helps to reduce the possibility of errors that could be caused by an overly complex project. Compressed air and vacuum scored quite low in this category due to the multitude of parts that would be required to use them as well as the inherent finicky nature of the systems. Using these systems would require valves, regulators, outside power sources, fittings, hoses, tanks, and more, adding to the cost and complexity of the system as a whole. Fans on the other hand require just the fan itself and a low amperage 12V source, making them much easier to implement into our already complex system. Airflow is also a critical component of this project. In order to meet the requirements set in place for the mechanical students, we must meet a maximum airflow of 24 CFM. For fans, this is no issue as all of the server-grade high performance units we are considering can easily reach over 100 CFM. This is more of a problem for compressed air and vacuum however. For compressed air, the raw output capabilities of the tank and hose is enough to meet the requirement but the electronic proportioning valve that it must flow through in order to achieve our sinusoidal airflow has a very limiting flow rate of less than 3 CFM. The same issue arises for vacuum as well as it requires the same valve to function. For these reasons fans received a perfect score and the other systems received nothing. Although we have a very generous budget allocated to us by Harris, cost was also taken into consideration for each choice. Fans are extremely cheap, coming in at $15 to $30 even for the performance models we are looking at. For this reason they were given 10 points. Compressed air and vacuum however do not share this same benefit as both would require the use of a $500 valve and hundreds of dollars worth of tanks, pumps, fittings, regulators, and hoses. For this reason they were given much lower scores of 5 and 3.

3.3.6 DAQ Choice

For the data acquisition system our group has come up with two viable options. Our senior design coordinator requires the design and utilization of a custom PCB in our project. This will provide us with much needed embedded design experience. In this PCB we could include a customly designed DAQ made up of signal processing circuits, adcs, digital processing units, and communication modules. Because the design of the DAQ is not as of yet finalized, and there is a need for a backup system that could be used if the designed system were to not function properly or fail, a pre built DAQ system could be bought online. These systems come with a certain, sometimes limited set of features at a high price. But they do provide a big advantage in the ease of use and time to market factors. Because LabVIEW allows for easy interfacing with DAQs and provides simple, intuitive creation of data processing systems in software it makes sense to use a pre-made LabVIEW compatible DAQ to collect the data we need.

3.3.6.1 DAQ Requirements

- 48 amplified analog inputs
- 5 digital outputs
- Minimum sampling rate of 500 sps for thermocouples
- Minimum sampling rate of 10 ksps for pressure sensors
- Resolution must fit sensor measure requirements (detailed in 3.2.6.2)
- USB communication
- LabVIEW compatible

3.3.6.2 Custom DAQ

There are many components that need to be considered in the custom designed data acquisition unit. There are the ADCs, the digital processing modules, and communication modules. As for ADCs some of the factors that were considered included:

- Resolution
- Channel width
- Accuracy
- Sampling rate
- S/H functionality
- SE analog inputs
- Size
- Interface

Although all factors were considered during deliberations, the main factors that were taken into account are resolution, sampling rate, and interface. The ADC model was also chosen to conform to the requirements of the system. That is there is a need for simultaneous sampling through store and hold functionality, a large enough bit resolution to not affect the accuracy, and an interface compatible and easy to work with when being connected to the digital processing unit. The product that was found was the AD7689.

Number of channels	8
Resolution	16 bit
Sampling rate	250 ksps
Output / Interface	SPI
S/H	No
Cost	$5.99

Table 3-27 ADC choice specs

As for digital processing unit the factors that were considered included:

- Processing speed
- Ease of use
- Flexibility
- Built in functionality
- Performance
- Internal ram
- Size
- Programming interface
- Cost

Although all of these factors were considered the main ones that were taken into account are performance and flexibility. The two main options for a digital processing unit are an FPGA and a microcontroller.

	Flexibility (25%)	Performance (25%)	Ease of Use (25%)	Cost (25%)	Total
Microcontroller	5	6	10	10	7.75
FPGA	10	10	7	7	8.5

Table 3-28 Comparison of digital processing units

The microcontroller comes with included functionality that would assist in development. Microcontrollers cost next to nothing and provide many desirable features. A microcontroller excels in ease of use because of this. Microcontrollers can also be easily reprogrammed very easily in a language that is commonly known amongst all members of the project, C. All members would be able to participate and contribute to the development of the embedded software system and make changes pertaining to their section of the project. The pitfall of the microcontroller is its limited functionality and its subsequent inability to interface properly with all other sub-systems of the embedded system. It also lacks in total performance rating because of processing speed and lack of parallelization. So in summary, microcontroller pros include:

- Built in interfaces and functionality
- Ease of use
- Low cost

An FPGA on the other hand provides many more benefits to a data acquisition system. It comes with the ability to create standardized interfaces like I2S, I2C, SPI, and also other custom non standardized serial interfaces that the pins can allow. Microcontrollers have a limited number built in hardware interfaces and may be insufficient or may make it impossible to interact with other module in the system. FPGAs provide the ability for high speed interfacing as well making it a prime choice for high rate applications. FPGAs have the ability to process multiple streams of data all in parallel. Each point of data entry can go through its own processing channel so it can all be done simultaneously and independent of the rest of the incoming data. This allows for handling of different process and control of external interfaces to be done at different rates. This is useful for when you have one type of sensor with a high response time and another with a low one or when one stream of data needs to be more logged more frequently than the others. This can be achieved by designing clock dividers in the logic. Because the FPGA can process different sets of data independently and not in a sequence, this opens up the possibility for precise timing of data events. A microcontroller needs to wait for a process to finish or an interrupt to be processed in order to time an event and therefore it would end up being imprecise. FPGAs can create a number custom counters whereas a microcontroller may only come with three built in hardware counters. An FPGA can actually implement and instantiate different instances of independent microcontrollers to perform custom tasks. FPGAs are also much faster in speed and can typically exceed speeds of 100 MHz. I/O flexibility is another area FPGAs shine in. An FPGA I/O pin can be configured to over 25 different types of standards whereas a microcontroller may only be limited to one or two. The fact that FPGAs can implement hardware designs opens them up to the providing of a multitude of advantages over the microcontroller. These advantages are especially relevant in data acquisition systems. A summary of the advantages an FPGA has to offer:

- Interface ability
- Parallel processing
- Event timing
- Customized hardware implementation
- High speed
- Complex I/O
- Relatively low cost

Building an FPGA board from scratch without some amount of experience in embedded PCB design is risky and counterproductive. The process would take far too long and the outcome may very well be inefficient useless. Buying a prebuilt experimental or development board is a much more sane option. This will provide a massive advantage in ease of use as all of the interfaces for programming the board and configuring all of the individual modules and pins on the board are documented. There is a massive amount of support available online for any problem or application associated with any of the FPGA boards available today. The question that is left is which board to use. There are a couple of options when it comes to picking an FPGA. The two main players in the game are Xilinx and Altera. Their products mostly differ in performance, size, and application. The member from our group who will be developing the data acquisition system is comfortable working with Xilinx products. Xilinx's low/mid-range FPGA that is used pretty widely for a variety of different projects because of its performance, cost, and I/O capabilities is the Atrix 7 series.

	Basys3	Nexys4
FPGA IC	XC7A35T-1CPG236C	XC7A100T-1CSG324C
Logic Slices	5200 (4 6-input LUTs, 8 flip-flops)	15850 (4 6-input LUTs, 8 flip-flops)
Clock Speeds	> 450 MHz	> 450 MHz
SDRAM		128Mbit Cellular
FLASH	32Mbit Serial	128Mbit Serial
ETHERNET		SMSC 10/100 Ethernet PHY LAN8720A
USB JTAG Bridge	Micro-AB High Speed	Micro-AB High Speed
USB UART	Micro-USB FT2232	Micro-USB FT2232
USB Host	Type A USB PIC24FJ128	Type A USB PIC24FJ128
Oscillator	100 MHz oscillator	100MHz crystal oscillator
I/O	4x 12-pin PMOD	5x 12-pin PMOD MicroSD card connector
User Interface	16 switches, 16 LEDs, 5 pushbuttons, 4-digit 7-segment display	16 switches, 16 LEDs, 2 tricolor LEDs, PWM audio output, 2 4-digit 7-segment displays
Cost	$79	$179

Table 3-29 Atrix-7 FPGA board comparison

We can compare the specifications for some different Atrix-7 boards available from Digilent in Table 3-29. The Basys3 and Nexys4 are the two boards that are under consideration. The Basys 3 is based on the Atrix-7 35T and is optimized for low power, low cost applications. It features USB, VGA, user interfaces, and 4x PMOD connectors. The Nexys4 is based on the Atrix-7 100T and is optimized for the same things except it includes everything the Basys does plus a few extra features. The Nexys4 is optimal for for expansion development with its 5x PMOD connectors. The Basys3 is basically a simpler version of the Nexys4, or we could also say that the Nexys4 is a version of Basys3 with all the bells and whistles. Included in these are:

- Ethernet port
- Extra PMOD connector
- Audio output
- Accelerometer
- Microphone
- More flash ram
- Inclusion of external SDRAM
- More displays and user interfaces (buttons, LEDs)

The added flexibility and resources provided by the Nexys4 are not all beneficial to the application. Most may actually be considered quite useless. The main thing the Nexys has going for it though is the extended RAM and number of logic slices in the IC. These features, although they are appealing, are not essential for the project at hand. Therefore the Basys3 will make a solid choice.

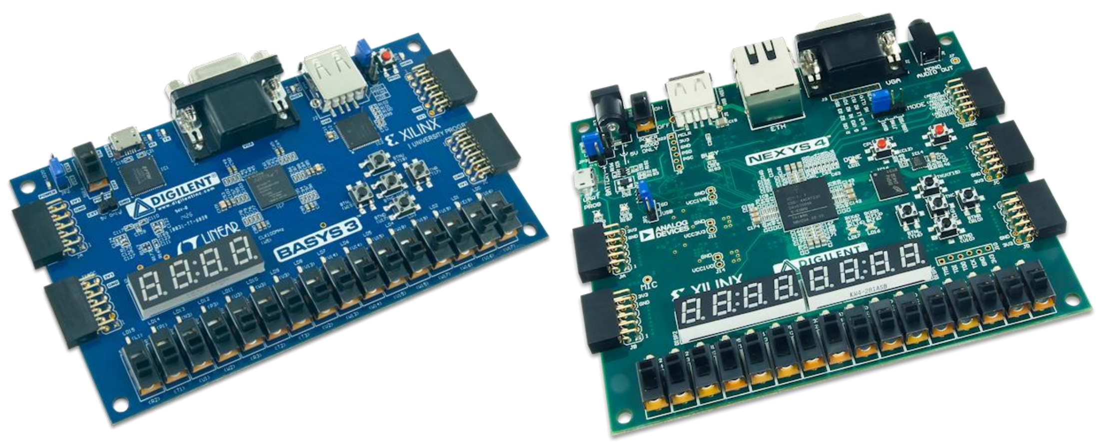


Figure 3-46 (a) Basys3 (b) Nexys4
(permission pending)

3.3.6.3 Pre-Built DAQ

While there are a lot of advantages to creating our own data acquisition device such as price and the experience of creating one it is also important to have a pre-built option to assure that the project can be complete in the event we are unable to build our own. Data acquisition devices can be obtained from a many distributors and have anywhere from one or two inputs to over sixty four. Data acquisition devices are generally somewhat expensive but have the added advantage of being reusable. The goal when picking a data acquisition device was to find one that was compatible with LabVIEW. While not all data acquisition devices can do this it is essential to our project because we have decided to use LabVIEW as our data processing software.

USB-2633 ($1099)

- 64-SE analog inputs
- 16-bit resolution
- 1 Msps sampling rate
- 24 digital I/O
- USB powered
- Software support

DT9813-10V Series – Low Cost DAQ ($445 * 3 = $1335)

- 16 analog inputs
- 12-bit resolution
- 6 ksps sampling rate
- 8 digital I/O lines
- Software support
- Simultaneous sampling

Figure 3-47 (a) USB-2633 (b) DT9813-10V
(permission pending)

3.3.7 Power Supply Choice

For the power supply we decided to use AC and DC power. We need DC power to run the fan, feedback controller, and possibly the data acquisition device, if it needs more than USB power. Because were asked to create our own power DC power supply for this project we thought that is would be advantageous to use AC to power our heaters. This is because the heaters use a lot more power than the other items and by running them on AC we could build a lower power DC power supply and save ourselves a hassle. The AC power does introduce a small issue in the form of extra electric noise but proper shielding can rectify this problem. By using a variac we can adjust the power output of the heaters without needing to put a large load on a DC power supply. We may need to step down the voltage even further with a second fix transformer to get the required power output.

3.3.7.1 DC Power Supply Choice

For the DC power supply we have opted to attempt to design and build one ourselves. It will meet the requirements set in place in section 3.2.7.1 which are:

Output Voltages	+12V, -12V, +5V DC
Output Power	4A, 0.5A, 0.5A Respectively
Input Voltage	120V AC @ 60Hz

Table 3-30 DC power supply specs

The design of the unit is gone into further detail in section 6.1.1.2 but essentialy it will consist of 5 rails total. The 120V AC will be converted and stepped down to 24V DC and 10V DC. These will be stepped down to positive 12V and negative 12V from the 24V rail and 5V from the 10V rail. Going about it this way allows us to achieve the required output voltages as well as increase the efficiency from a more simplified system. Although we have every intention of attempting to create this power supply, we are well aware that there are countless alternatives available that would meet every requirement we have and beyond and do so cheaper, smaller, and more efficiently. We are choosing to create our own for the experience but should all of our attempts fail and it comes down to the wire, we can always fall back on a pre-built unit to complete the project.

3.3.7.2 AC Power Supply Choice

The choice for the AC power supply was pretty simple. We initially thought about having multiple different transformers that would allow the user to step between a few set heat outputs. But once we learned of variacs that idea got slashed and the obvious choice was to go with the variac based design. The variac essentially did exactly what we planned to do but much more elegantly and with significantly more adjustability potential. The specific variac we plan to buy will give us adjustability over a very large range and we will do the calculations to convert the voltage output to wattage of the heater in order to create a custom label that we will place on the dial. We go more into detail about the variac in the design section.

3.4 Possible Architectures and Related Diagrams

3.4.1 System Diagrams

Our system diagrams fall into two categories, external and internal. Externally the test rig is fairly unassuming. A large rectangular box, about 36 inches long, connects to an exhaust duct which will taper from the wide, short rectangle of the exhaust port to the large circular cross-section of the exhaust pipe. This exhaust pipe will run onobstructed for 6-12 inches before reaching the mass flow sensors, than another 6-12 inches before reaching the fan. A DC and AC power supply will reside on the top of the box to power the various components.

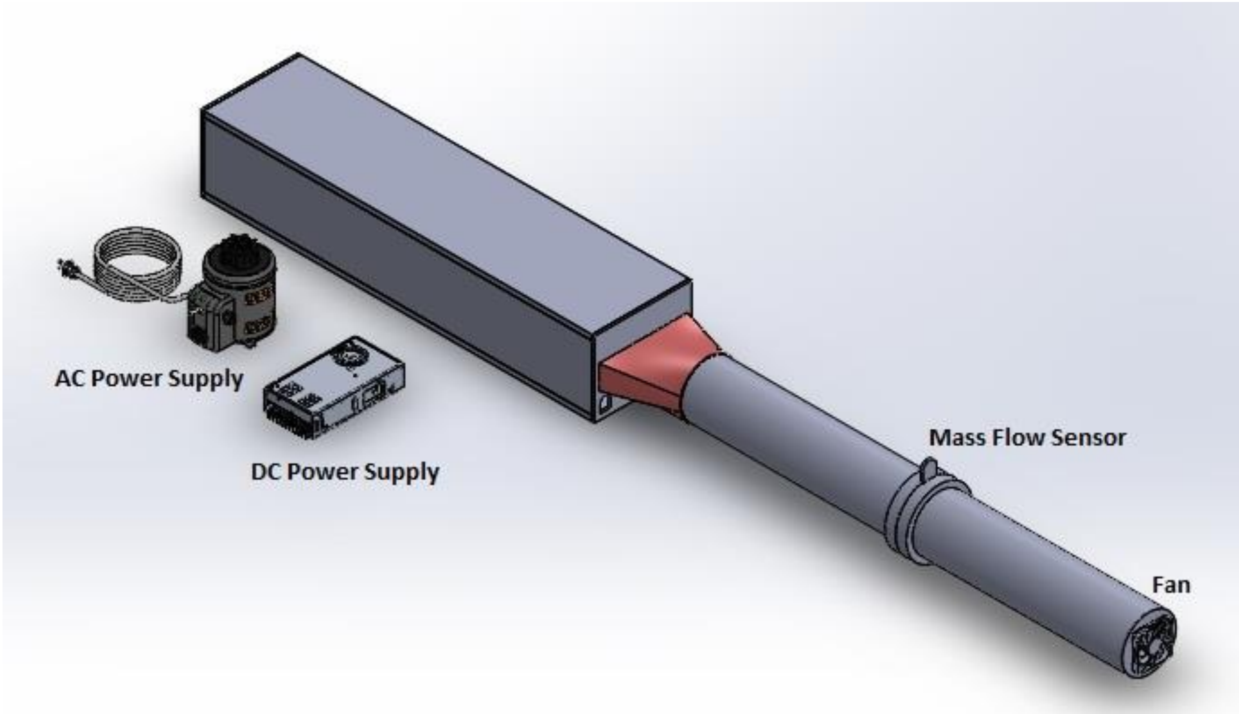


Figure 3-48 External system diagram

Internally the system will consist of two heat exchangers we have labeled as endplates. Directly above that is the heating pad which is sandwiched directly between the endplates and an insulating material to help keep the heat in. Cables will run directly above the insulating plate in the cable channel before finally getting to the outer housing. Because the distance between the endplates must be adjustable an adjuster will be engineered for the top plate so that the bottom stays fixed while the top is free to move up and down. Thermocouples will be spread across the endplates and pressure sensors will be placed at the inlet and outlet to measure pressure drop. More details on the exact design can be found later in section 6.

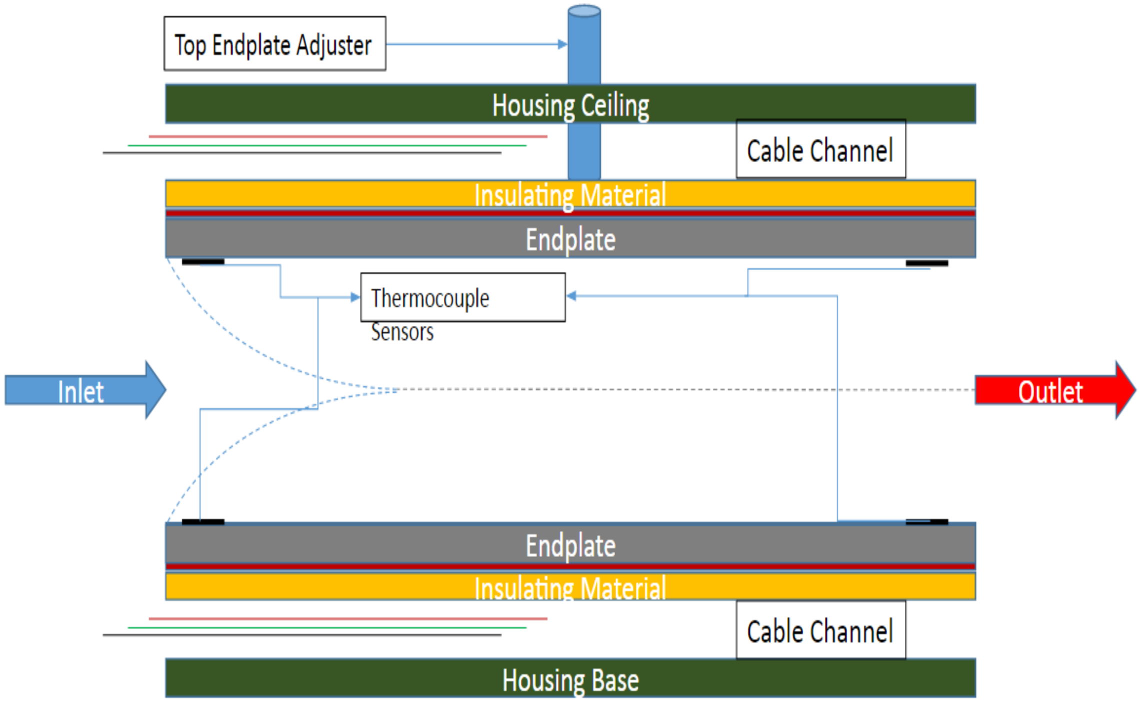


Figure 3-49 Internal system diagram

3.4.2 Block Diagrams

The block diagram helps us to better visual the connections within the system. We have split the block diagram into two distinct sections, mechanical components and electrical components. On the mechanical side of things we have only two blocks, the housing and the endplates. These two components, while obviously very critical to the project, are really just to hold the electronics (housing) and have work done to them (endplates being heated and measured). The bulk of the connections in the block diagram come on the electronic components side. We chose to split this down into two sections, electrical devices and sensors. Electrical devices include the fans, heater, power supply, and microcontroller/DAQ. These items are what control as well as do work within the system. The other brand is sensors which is broken down into thermal sensor, flow sensor, and pressure sensor (not pictured). The sensors are what will actually collecting the data from the test rig and feeding it to our electrical devices.

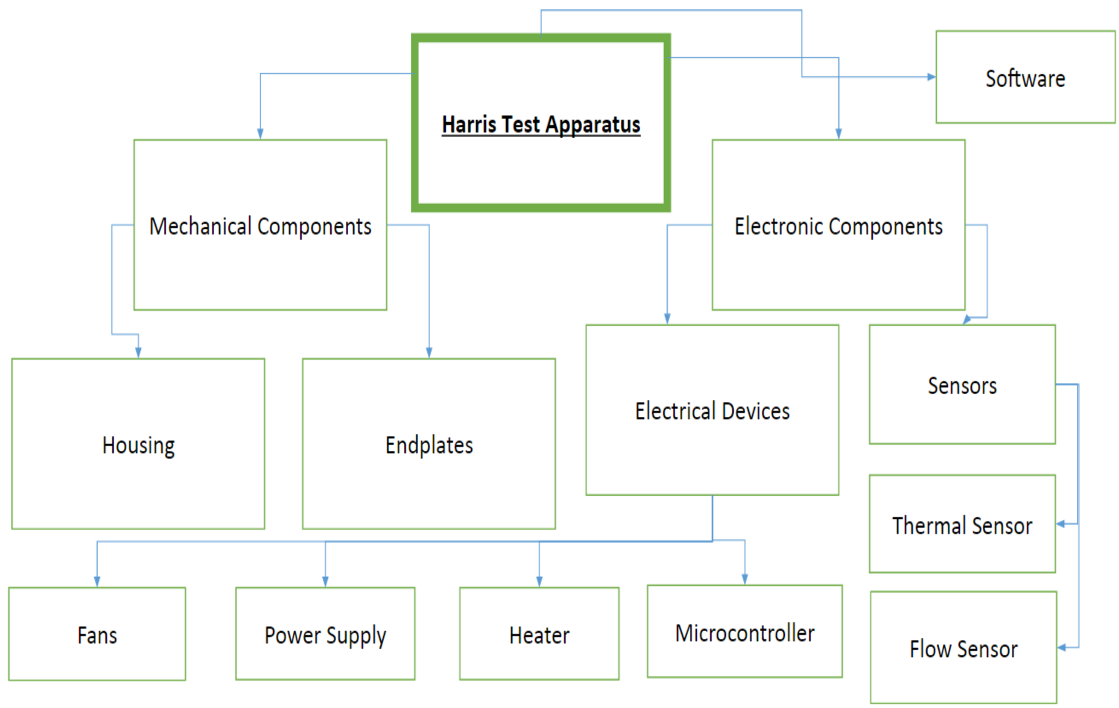


Figure 3-50 System block diagram

3.4.3 Schematic Diagrams

Our schematic diagram shows the physical connection between the various subsystems within our test rig. Because there are so many electronics within the box a schematic is important in order to visualize exactly how the devices will interface. Starting off with the sensors we can see that the pressure sensors located at the inlet and outlet will connect to the DAQ in order to transfer their finding to the computer. The temperature sensors will also connect to the DAQ as will the mass flow sensor. The DAQ will then be connected to a computer where it will offload the data that the sensors have all sent to it as well as draw its power from. The mass flow sensor does double duty however as it also is a part of the logic control system that controls the fan. In the steady state case the fan will be set to a predetermined flow rate and left alone but in the pulsating airflow case the fan must be run in a sinusoidal fashion in order to produce a smooth pulsating airflow. The mass flow sensor reports its flow data to the logic control system which will then adjust the power supplied to the fan to meet whatever pulsating case we are attempting to run at the time. The fan obviously will be connected to the logic control system as well in order to receive this pulsating power and the logic control system will be connected to the DAQ to pass on data and receive its commands. The logic control system will be power directly by the DC power supply and the heaters will be powered by the AC power supply.

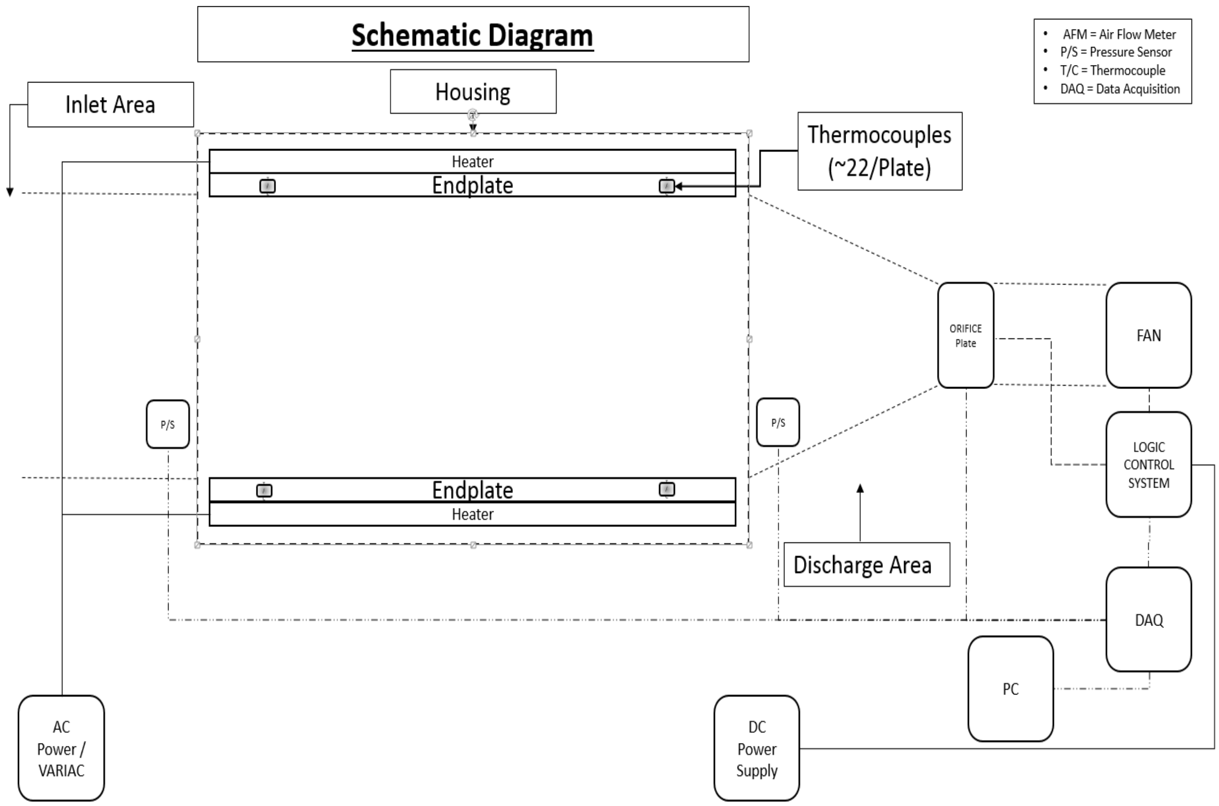


Figure 3-51 System schematic diagram

3.4.4 Heat Flow Diagrams

The purpose of this project was to create a device that could measure the reynolds number and friction factors in a duct under a thermally and hydrolytically developing flow. To achieve this goal a duct that met the requirements for measuring these coefficients needed to be designed. Our client originally specified that the flow in the duct needed to have a reynolds number between 100 and 2000. It was also specified that the temperature of the air moving through the duct should increase in temperature by 10 degrees celsius. To meet these requirements analytical solutions had to be calculated to get general ball park numbers. The analytical solutions were calculated for the upper and lower end of the reynolds number range.

	Case 1	Case 2
Re_{Dh}	100	2000
u(ft/s)	0.110	2.202
u(m/s)	0.03379	0.6758
$\dot{m}(\frac{kg}{s})$	$2.089\text{x}10^{-4}$	$4.178\text{x}10^{-3}$
$\dot{Q}(W)$	2.099	52.496
$q''(\frac{W}{m^2})$	5.651	113.02
$\Delta p(Pa)$	0.0243	0.4166

Table 3-31 Results of the analytical solutions

Once the analytical solutions we found it was time to test them against computer simulations. The first step in computer simulation was to test a two dimensional model of the system. A representation of flow over a flat plate was constructed. This model was created with a larger length than the actual specifications found by the analytical solutions with the assumption that the distance required to achieve completely developed flow might be longer than what the analytical solutions predicted.

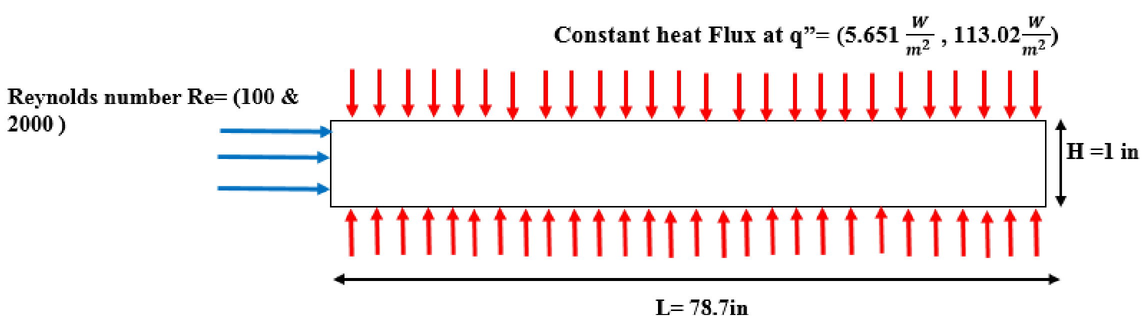


Figure 3-52 2D simulation setup

After the simulation was rendered we noticed some irregular changes in the flow of the air. This was uncharacteristic of the phenomena we were simulating and so the question was brought to our Harris representative Don. Don suggested that the results may not be caused by actually caused by the phenomenon we were studying but instead by the setup of our simulation. He suggested that the simulation was not high resolution enough and that the results we saw were a result of making the data discrete. So a study was conducted to find the optimal number of grid cells in the simulation. To find the optimal number of grid cells the simulation was run and the grid cell increased until the results of the data no longer changed with increased grid cells. At this point is was decided that the results of the simulation were no longer dependent of the density of the grid cells.

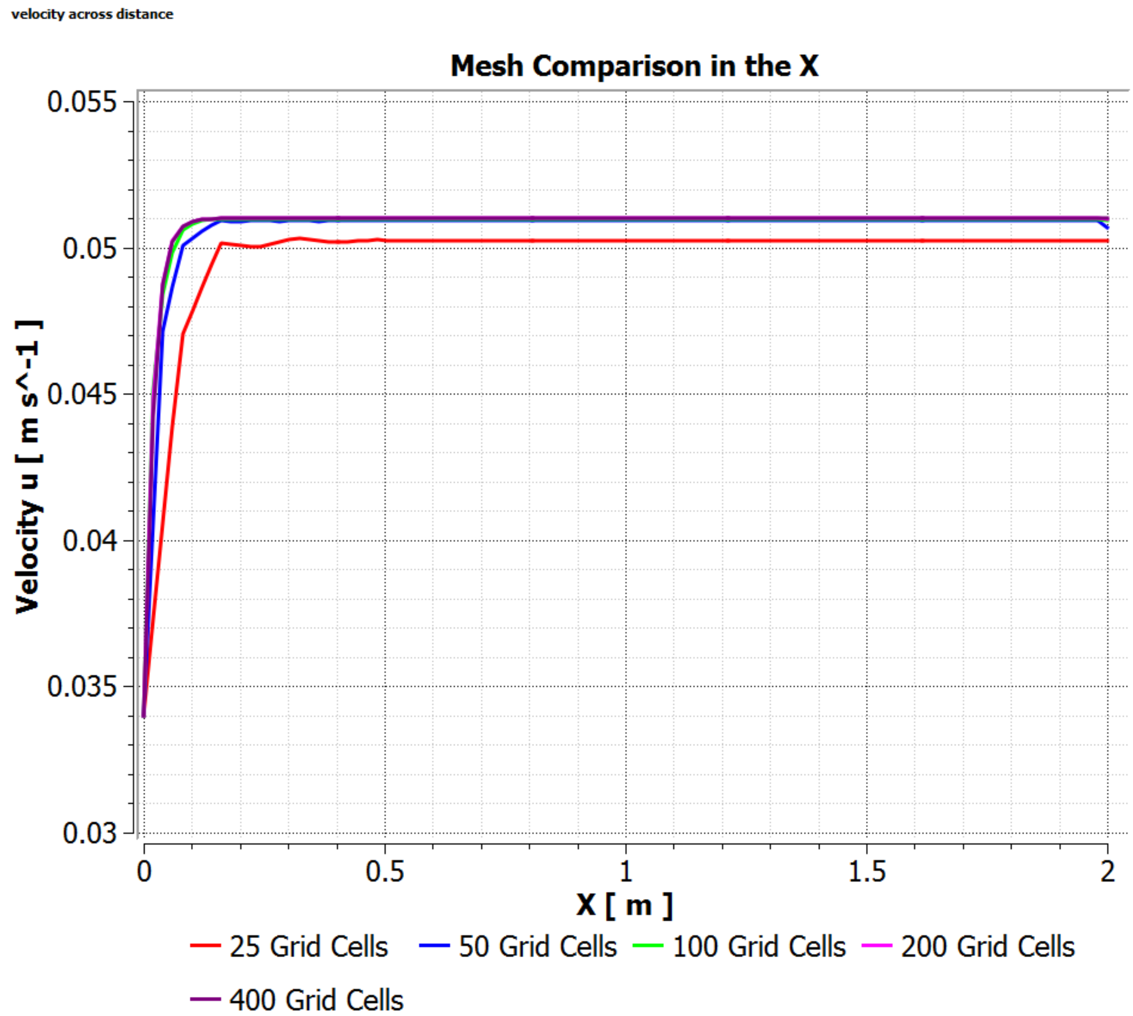


Figure 3-53 Comparison of centerline velocity for different grid densities

After the optimal number of grid cells was found the simulation was run and the results were compared to the analytical results. The results were satisfactory. This allowed us to feel more comfortable with the validity of our results. The figures below show the velocity of the air moving through the duct. One image depicts the velocity contour at a reynolds number of 100 and the other at a reynolds number of 2000. You can see that the flow starts to develop quickly but takes a lot longer to reach a fully developed state.

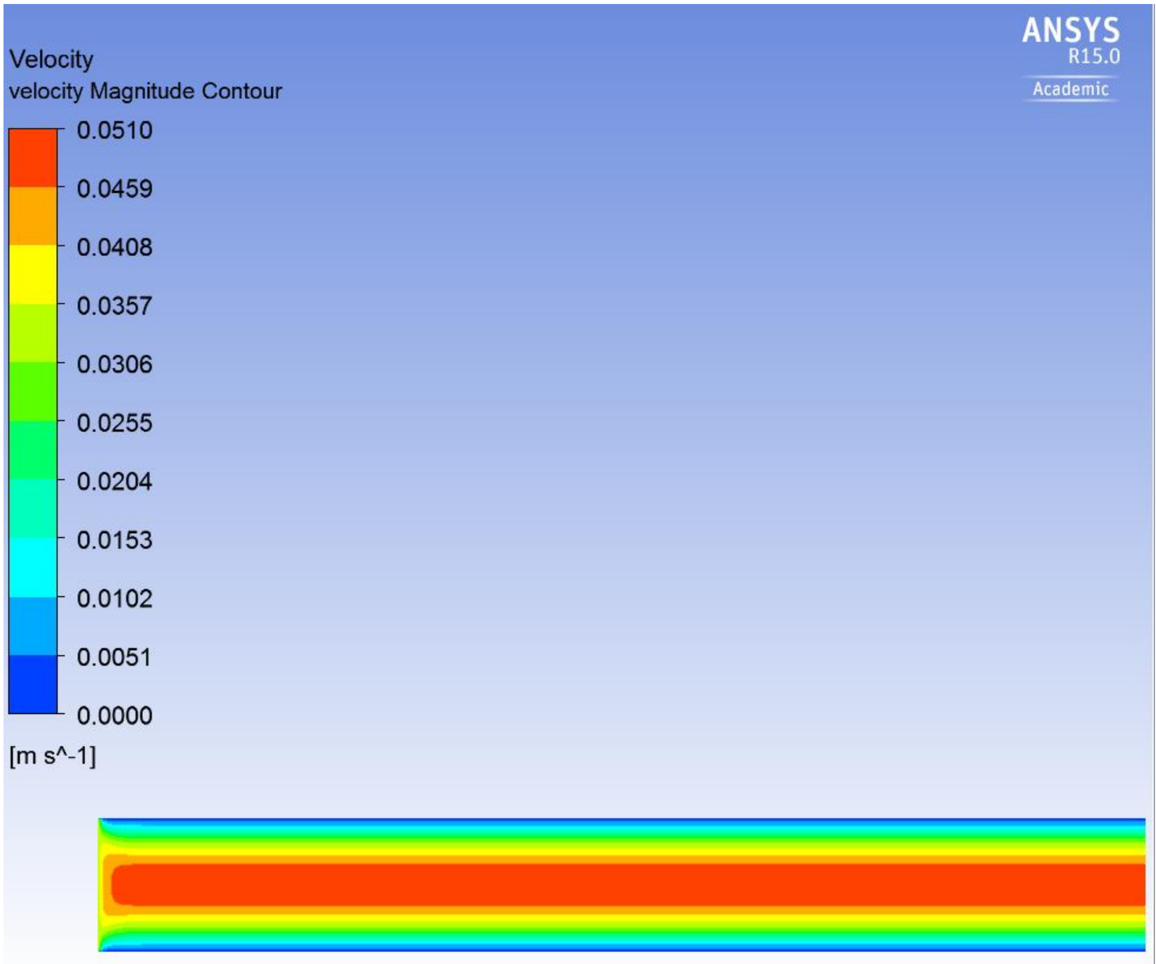


Figure 3-54 Velocity at a reynolds number of 100

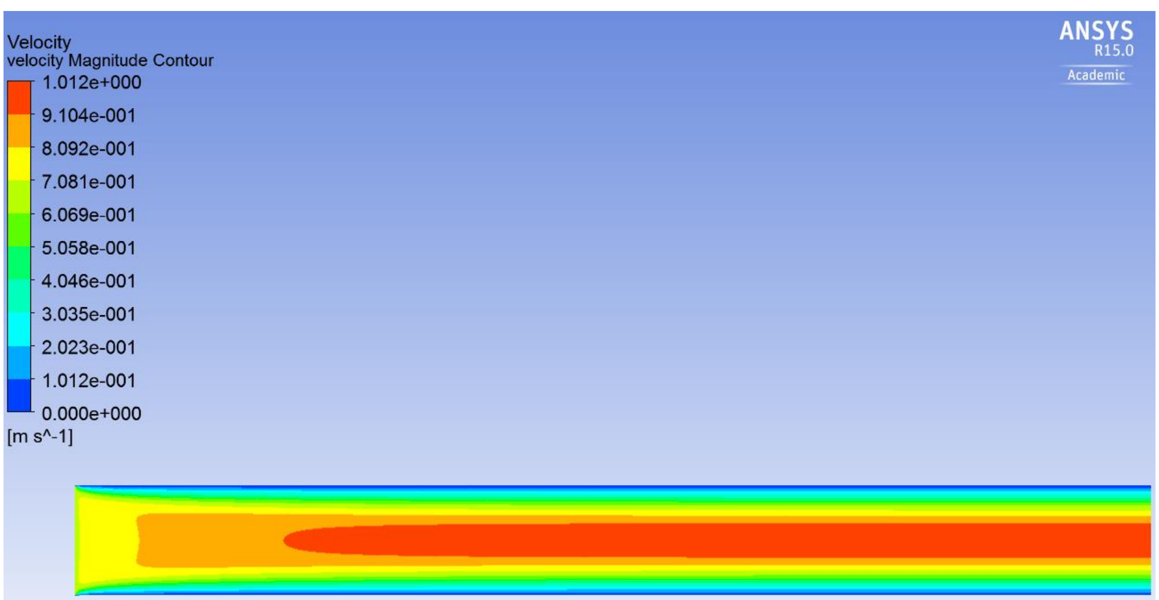


Figure 3-55 Velocity at a reynolds number of 2000

The following image depicts the the temperature change across the duct as calculated by the 2D simulation. You can see the the temperature change across the duct is 22 degrees celsius. This is a little over double what was required for the device. This is not due to an error in calculation. It is because the setup of the simulation specified the duct as being a lot longer than it actually was. The results matched nicely with the analytical solution. This temperature simulation was calculated for a reynolds number of 100.

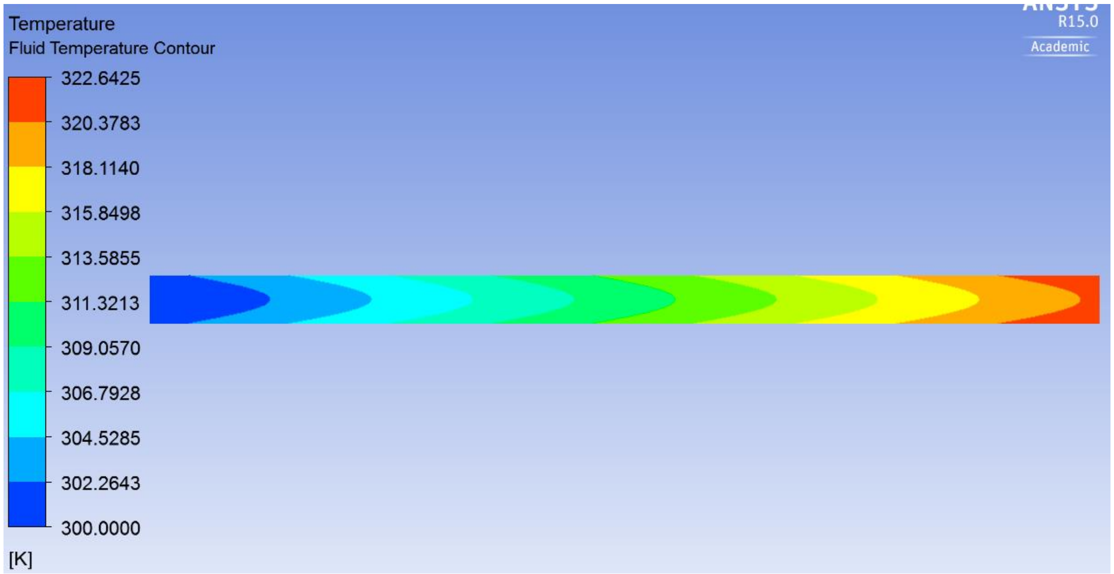


Figure 3-56 Temperature across the plate at a reynolds number of 100

The next figure depicts the pressure drop across the duct. As you can see in the figure the pressure drop is very small. This is because the duct is very smooth and does not create much resistance. While this is as predicted the actual pressure drop in the duct will be much higher once harris installs a heatsink in it.

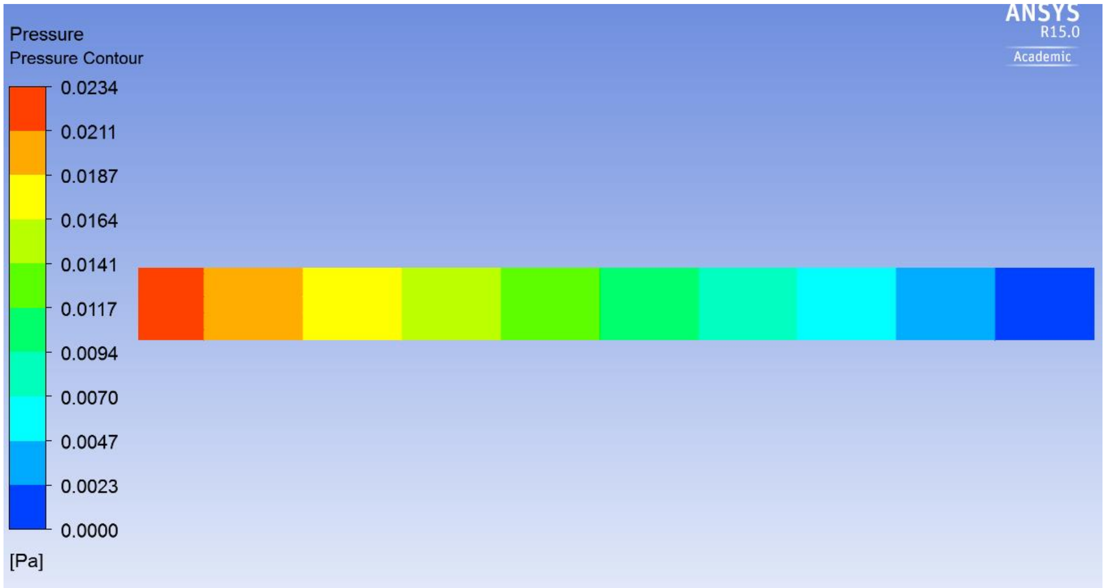


Figure 3-57 Pressure drop across duct

After the 2D simulation verified the analytical solutions a 3D simulation needed to be done. The 3D simulation is more accurate because it accounts for the top plate as well as the bottom plate. The following figure show the 3D simulation results for the velocity, temperature as calculated by the 3D simulation.

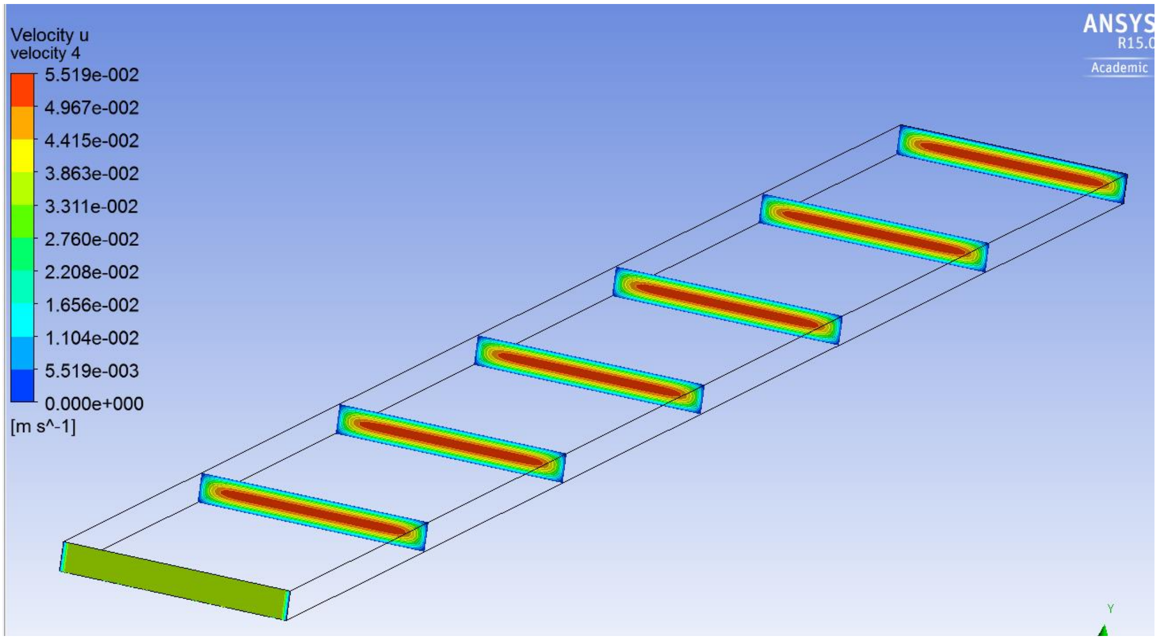


Figure 3-58 Velocity at a reynolds number of 100

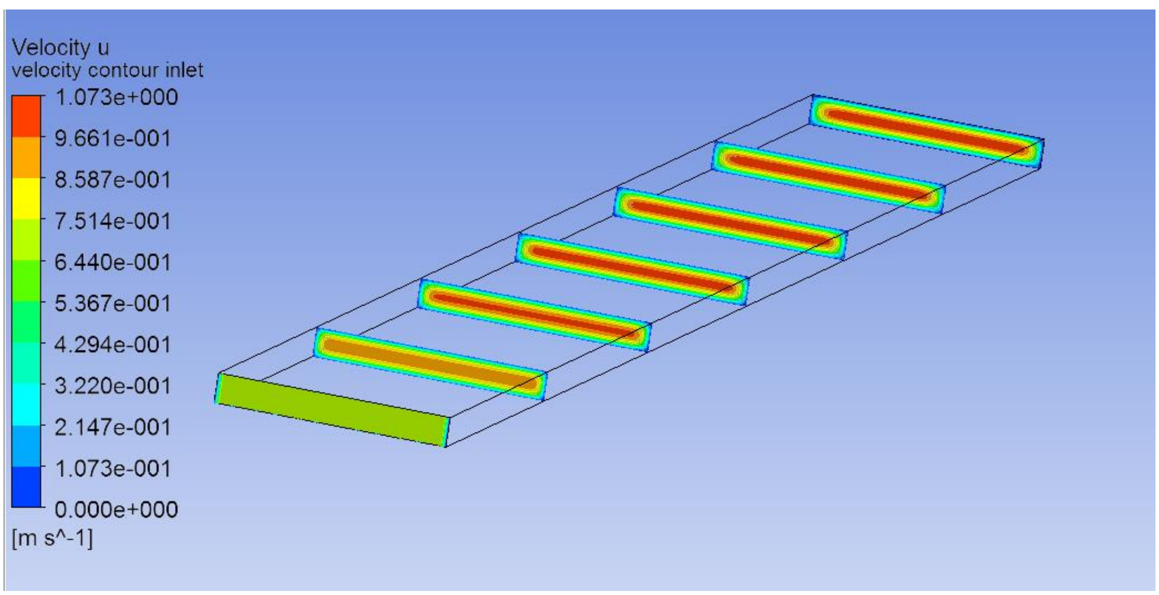


Figure 3-59 Velocity at reynolds number of 2000

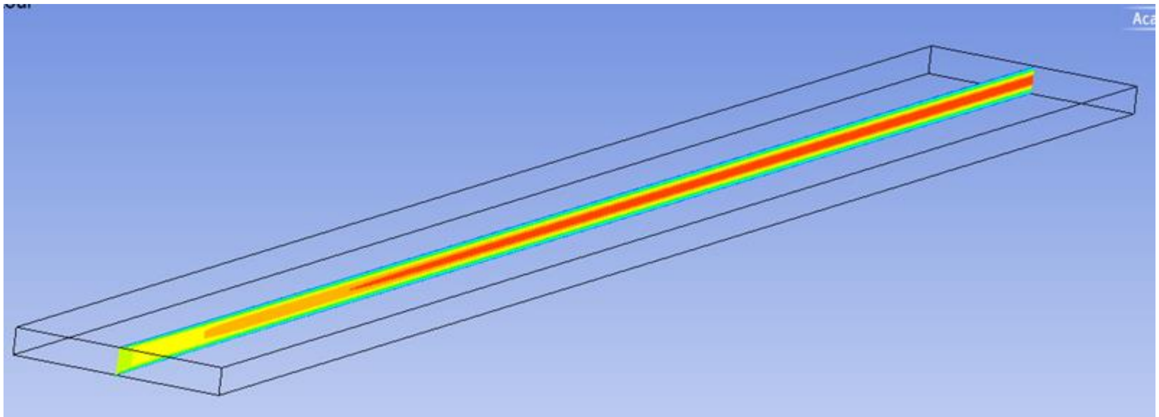


Figure 3-60 Centerline velocity at reynolds number of 100

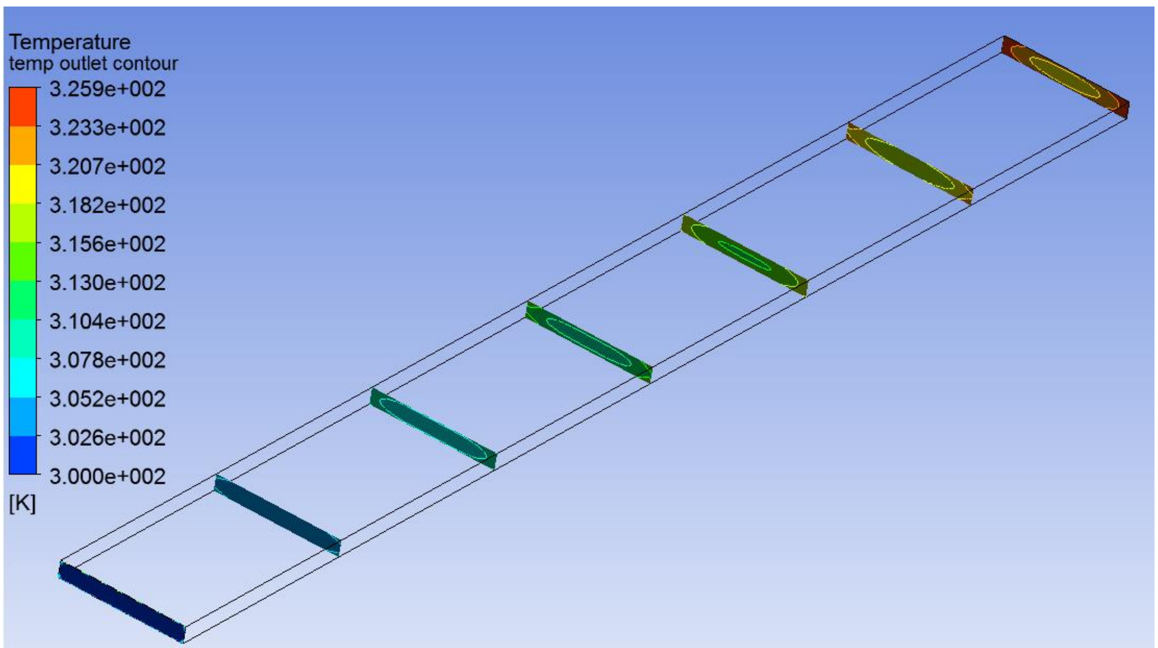


Figure 3-61 Temperature across duct at reynolds number of 100

4.0 Related Standards

4.1 Standards

Standard are something that most of us accept as part of our life. A standard is “a set of characteristic or qualities that describes the features of a product, process, or service.” The Institute of Electrical and Electronics Engineers Standard Association(IEEE) is an organization that produce a broad range of standards in different fields.In this project, all the electronic equipments that we are using should meet the requi rement of IEEE standandard, which is able to reduce the safety, environment, complixity issues.

4.1.1 Power Supply Standards

4.1.1.1 295-1969 - IEEE Standard for Electronics Power Transformers

- Work for signal and power Applications
- Frequencies should larger than 1 Hz
- Working Voltage should less than 2 kV
- Power rating should less than 10 kvA

4.1.1.2 10 CFR Part 430 - DoE Efficiency Standards for PSU

- when output power is less than 1W, the minimum average efficiency have to greater than 0.497*Power output +0.067
- when output power is between 1W to 49 W, the minimum average efficiency have to greater than 0.075*ln(output power)+0.567
- when output is greater than 49W, the minimum average efficiency have to greater than 0.86
- Under no load condition, the maximum power must not exceed the 0.3 W

The figure above showed the power efficiency for different applied output power:

Output Power	Minimum Average Efficiency	Maximum Power Under No Load
$P_{out} < 1$ W	$> 0.497 \times P_{out} + 0.067$	< 0.300
1 W $< P_{out} <$ 49 W	$> 0.075 \times \ln(P_{out}) + 0.561$	< 0.300
$P_{out} > 49$ W	> 0.860	< 0.300

Table 4-1 Multiple voltage power supply efficiency requirements

This is important to know the efficiency under different cases, so the user is able to expect the slowest performance of the products that they are purchase.

4.1.2 Heater Standards

Heater standards will all generally be focused in one main direction, safety. Heaters are relatively simple but also can be fairly dangerous, especially when dealing with the high heat density units we are using. These heaters can very easily burn a user or start a fire and proper precautions must be taken in order to prevent these types of accidents from happening. Thankfully standards can help us with that, as you will see below.

4.1.2.1 OSHA Safety Standards

The OSHA standard 1926.154(a)(1) states that fresh air shall be supplied in sufficient quantities to maintain the health and safety of workmen. Where natural means of fresh air supply is inadequate, mechanical ventilation shall be provided. OSHA standard 1926.154(b)(1) states that temporary heating devices shall be installed to provide clearance to combustible material not less than the amount shown in the table below.

Heating Appliance	Minimum Clearance (inches)		
	Sides	Rear	Chimney Collector
Heater, circulating type	12	12	18
Heater, radiant type	36	36	18

Table 4-2 OSHA heater safety distances

4.1.3 Fan Standards

Standards for fans are going to mainly come down to one major talking point, safety. With our high-power models spinning upwards of 11,000 RPM user safety becomes a legitimate concern. Thankfully there are standards set in place to protect users in cases such as ours, which we will go into below.

4.1.3.1 OSHA Saftey Standards

The OSHA standard 29 CFR 1910.212(a)(5) outlines the specific requirements of exposed fan blades. It states that employees must be protected from exposed fan blades by providing a guard over the fan if the fan is under 7 feet off of the floor. This standard further specifies that the guard opening shall be no larger than one half inch and that there is no exemption from this requirement. OSHA standard 1910.95(a) outlines noise level requirements for a workplace. These requirements are laid out such that a person may work a given amount of time at a certain noise level and as the level increases the amount of time allowed decreases. Because the threshold starts at 90 dB and only goes up from there our fan will have absolutely no issues staying below that level and this standard will not cause an issue for us.

4.1.4 USB Standards

Standards for USB allows for a known variable in not only our data rate which is incredibly important in our application due to the fast response time of all of the sensors and massive amounts of data that will be flowing, but also for a reliable power source. Our power supply will supply power to most of the devices but our FPGA will be run off of USB power. Due to the standards set in place we know for a fact that the power delivery and transfer rates will be exactly as we expect them to be.

4.1.4.1 Universal Serial Bus Specification

The USB is specified to be an external device, which is the extension to the PC architecture that introduced by the industry standard with a focus in PC peripherals that enable consumer's application.The following criteria are the standard of the USB:

- ease of use for the extension of computer architecture
- low cost solution that supports transfer rates up to 480Mb/s
- full support for real time datas of many application
- Protocol flexibility for mixed-mode isochronous data transfers and asynchronous messaging
- Integration in commodity device technology
- Comprehension of various PC configurations and form factors
- Provision of a standard interface capable of quick diffusion into product
- Enabling new classes of devices that augment the PC's capability

In this design, The USB. 3 is required due to the super speed data transfer rate, it can be up to 625 Mbytes per second, which is about 10 times faster than the previous one. The specification provide 5 V voltage supply to power USB connected devices, the voltage can be no higher than 5.25 V and less than 4.45 V between the positive and negative power bus line.

4.2 Impact of standards

Standards, though they may seem tedious and impractical, are actually incredibly important to not only obvious cases such as work safety but also efficiency within the project. Although we are always striving to make products faster, cheaper, and easier, these benefits cannot come at the cost of worker health and safety, and this is what standards help to avoid. Standards also allow for a streamlined protocol that will incorporate the steps of the project in a fashion that produces maximum output with less effort.

4.2.1 Power Supply

Power supply design, placement, and integration has a huge impact from standards. Everything from safety for the user, protection of the parts, reducing noise levels, and helping eliminate power waste using a more efficient design are all affected greatly and improved by standards.

4.2.1.1 Safety

Power supply safety is an absolutely critical point that we must be extremely careful about, especially considering we are building our own unit. We must ensure that users will be protected from electric shock first and foremost. When dealing with high voltage systems such as a power supply the potential for shock is very high. We must take every precaution possible to ensure that all circuits are properly grounded and that there are no exposed wires that a user or other component could possibly touch. This risk is compounded even further when one considers the high power capacitors inside of a power supply. We must ensure that the unit itself cannot be opened or otherwise tampered with, on purpose or accidentally, as doing so could cause serious bodily harm to the user. Another important safety precaution we must take into account is fire hazards. With high voltage electricity the risk for a spark is high and something slightly flammable nearby could ignite. We must take into consideration surroundings not only on the power supply and test rig itself, but also the test environment that it will ultimately be used in. We must make sure that in the off chance all of our precautions to prevent electric shock and spark fail and a spark jumps that there is nothing nearby that could catch. The unit itself and its immediate surroundings on the test rig will be made with only non-flammable materials.

When working with high power electronics things can get very hot. This poses a safety risk if a hot surface is exposed as a user could accidently touch it and receive burns. Heat must be properly dissipated over a large area to bring the temperature down to a reasonable level. This will be conducted using large heatsinks as well as heat shields should the temperature still be too high. Furthermore, if a part is known to be very hot it will be labeled as such using OSHA standard symbols so that users will know to avoid contact with that area. Lastly, cuts and abrasions are a definite possibility, especially when dealing with a hand-made unit such as ours. Exposed metal edges, points, etc can very easily scratch or cut a user should they not notice the hazard. In order to prevent this from happening we will be sure to file down any rough edges or points or otherwise cover them up.

4.2.1.2 Noise

Noise levels are an important consideration when designing the system as we must remember that this rig will be set up in a lab environment with other workers present and having a system that is incredibly loud could be an issue, With power supplies this will fall into two categories, fan noise and coil whine. Fan noise is an obvious one as the fan is running all the time and in a unit as small as ours will be a very small fan will be used. Small fans that spin at a high rate are known to produce a quite annoying high-pitched shriek in many cases. We will have to choose a fan that reduces or eliminates that noise so as to help keep down the noise levels of the entire system. Coil whine is a problem that in this case will be specific to the power supply. When current passes through the coils we will use to smooth out the power delivery tiny amounts of vibration can occur which in the right situation can produce a very audible squeal or whine. We will have to design our power supply with this in mind and perform testing to ensure that this will not happen in our unit.

4.2.1.3 Power Consumption

Power consumption, though not a specific requirement set in place by Harris, is something we are aiming to reduce in our test rig. Being electrical and computer engineers we always want to attempt to reduce the amount of wasted electricity and make all of our systems as efficient as possible. By utilizing high-quality components and the proper designs in our power supply, we can mitigate a significant portion of our overall power consumption and help to increase the efficiency of the entire rig.

4.2.2 Heaters

Standards play a significant role in heater design and implementation as well. One must not only think about the obvious safety side of things (burns, short circuits, fires, etc) but also the overall power consumption of the units. All of these things are greatly affected by standards.

4.2.2.1 Safety

Heater safety is a very important consideration when operate the system. Because it used for heating up the test rig for our experiment, the output power can be reach as high as 200 W. it can be potential for people to burn, harm themselves or may start a fire.In order to avoid the sparks, we have to make sure not to short the power and cause the electric shock to the user.We have to ensure that not to using the heater manufacuted before 90's, some of them may still on stock. the older heater with relay switches can spontaneous heat in the dial off position.we have ensure that there is insulator to protect the area that is not going to heat for this experiment.We have to ensure that the test environment is not extremely cold or hot, so heater can be work as it normally work.We have to ensure that the user must not able to touch the heater by accidently, so the heater have to be inside of the test rig, and no parts can expose to the users.

4.2.2.2 Power Consumption

Power consumption is not a requirement set in place by Harris, but being electrical and computer engineers we wanted to attempt to make our system as efficient as possible. All the heater that we are choosing is high efficiency, the electronic component doesn't have much loss for the heater that we are choosing.

4.2.3 Fan

Fans are typically not thought of as a major part of many systems and standards for them are therefore many times not thought about. However, standards are just as important for our fan design and implementation as they are for our power supply and heaters. We must consider the obvious safety hazards as well as noise issues and power consumption. Standards can help to improve all of these aspects.

4.2.3.1 Safety

Fan safety is a very important consideration we must make for several reasons. Because we are using a server fan that spins up to 11,000 RPM in our system, there are legitimate concerns about fairly significant bodily harm that could result from sticking a finger in to the blades as these types of fans have been known to completely sever appendages. To combat this hazard we will be placing a metal guard over the fan such that a finger would not be able to slip through. Depending on how dangerous we deem the system after that we may even go as far as attaching a small tube extension after the fan with a guard over it as well so as to completely reduce the possibility of any accidents happening.

4.2.3.2 Noise

Because this is a test rig in a lab environment noise will not a major problem. Having said that though, excessive unnecessary noise should be avoided for the convenience of the engineers who will be using the rig. Although size, airflow, and cost were the major deciding factors when selecting a fan, if we found one that was noticeably quieter than the competition with comparable performance we went with it. Regardless of these considerations, the inherent nature of a small fan spinning at an extremely high RPM is going to result in a fairly noisy final product.

4.2.3.3 Power Consumption

Power consumption is not a requirement set in place by Harris, but being electrical and computer engineers we wanted to attempt to make our system as efficient as possible. Our fan choices all give great performance for the amount of amperage they draw. Compared to some of the other subsystems the fans will be a drop in the bucket as far as power consumption is concerned.

4.2.4 USB

USB is as important as other design , and is a major part for the interface issue as other system. understand the safety standard and power consumption standard is as important as other part of system, so it able to decrease the misunderstanding of two electronic equipment.we must consider the dangerous effect can caused by misusing the USB and may potentially lost the test data.

4.2.4.1 Safety

USB drive are reuseable memory storage devices that known as external data storage of PC computer, and it commonly refer to memory stick or the flash drive. Since it gotten s cheap and can store a lot of datas, up to 20 Gbytes, they commonly use everywhere. And the safety issue take place for this point. Since the USB device is so popular, cyber criminals are starting viruses and worms that specifically target them. That’s dangerous, This design requires the microcontroller read the data from the USB drive, so if someone as user plugs the infected USB stick to the microcontroller, it may receive the bug and potentially cripple the whole testing system, and it cost time and money to fix it, and may result the physical threat to user's body.Since the device is portable and easy to lose,we have to ensured that all the software and datas have to duplicated in other drive.

4.2.4.2 Power Consumption

In this design project, the power consumption for USB is not essential to discuss. But as the electrical engineer, it is require us to know the power efficiency for all the electronic devices. According to the USB spec, the Vbus stay between 4.4 V to 5.25 V, and always test the worst case in order to resolve the problem.As the result of the USB specfication, and consider the time condition, it may consume up to 500 mA, so it is about few watts power consumption distributed in USB itself only.

5.0 Design Constraints

As with all designs there are certain constraints defined that dictate the development of the project. These constraints vary in levels of impact on design decisions and can affect the outcome of the project in very major ways. These constraints are detailed either by our senior design coordinator Dr. Samuel Richie in class and in the syllabus, or by our customer Harris in our project description and specification documents. The cold plate test rig provided **shall** meet the characteristics of this item description, conform to the UCF engineering design teams' own drawings and meet all listed specifications and standards. Harris Corporation and its' representatives reserve the right to require proof of conformance prior to delivery.

5.1 Economy

This project was commissioned by the Harris Corporation and is more than sufficiently funded at the level of $5000 provided. The funding is meant for completion of a single test apparatus rig. There is no indication of further production or marketability of the device as it is strictly a test apparatus used for research. The senior design coordinators will act as advisors to ensure that we don't overspend our budget and allot the funds properly.

5.2 Time

The amount of time available for the development of this project is fixed. Because this is a senior design project, we the students will be able or available to work during the two semester periods allocated for the course. Although not all of the work is required to be done during that period, the given time is expected to be sufficient for completion of the assignment. As long as the project is shown to be functioning by the time we hit the deadline, the project is considered acceptable. Although this is the case, we do not think this will apply to us as we are almost certain about meeting all of the requirements laid out by the customer by the end of the second period.

Our group is scheduled to start work on the project in the Spring semester of 2015 and finish the project at the end of the Fall semester of 2015. The project group members are all students and some may be employed elsewhere and therefore not all of the time available to us will be dedicated to the progress of the project. This is why we set out a planned timeline with deliverables at the end of each period. Said timeline is detailed in Table 9-1 of this report. All of the members from both groups will be taking the Summer semester off. Most of the members will be working on internships, full time jobs, or taking the opportunity to travel or vacation. This means most of the members may be too busy to work on the project. Although this may be the case for most of the members, that doesn't mean the project will go without consideration or development during the Summer period. In fact the break would provide a great opportunity to review design decisions and re-develop accordingly.

Tasks accomplished in the Spring semester:

- Requirement definition
- Detailed block diagram
- Trade studies
- In depth research
- Part selection
- System design
- Preliminary review
- Documentation

Tasks to be accomplished in the Fall semester

- Design review
- Prototyping
- Assembly
- Testing
- Verification
- Experimentation
- Documentation

5.3 Environment

The cold plate test rig shall be capable of operating without physical or electrical damage under any combination of the environmental conditions listed below.

- The test rig shall be capable of operating under external temperature conditions between 5°C to 40°C.
- The test rig internal operating temperature shall not exceed 100°C when measured as the air temperature in any section of the test rig.
- The test rig shall be capable of operating at altitudes from TBD feet below sea level to TBD feet above sea level.
- The test rig shall be resistant to cases of minor to moderate shock and vibration.
- The test rig and its sensors shall be resistant to effects of dust and humidity, especially in pressure measurement.

5.4 Geometry

Harris Test Apparatus

- All engineering drawings shall be dimensioned in US customary units.
- Total assembled test rig length shall not exceed 8 feet.
- Total assembled test rig width shall not exceed 4 feet.
- All components of disassembled test rig shall be capable of beings stored in a storage are not exceeding 16 square feet.

Electronic Components

- Shall be housed in protective casing on top of the top outside wall.
- Width - TBD at PCB assembly
- Length - TBD at PCB assembly

5.5 Reliability

This device should be able to produce consistent and accurate results. If not, then it is useless. It needs to do so because the entire purpose of the device is to test cold plates under different conditions and measure minute phenomena. Measurement consistency is a key requirement of the system.

5.6 Safety

Power dissipation performance must be well understood prior to integrating devices on a printed-circuit board (PCB) to ensure that any given device is operated within its defined temperature limits. When a device is running, it consumes electrical energy that is transformed into heat. So it required know how much heat does each electrical components is able to handle,when Start to design the control system for our project, we have make sure each op amp, transistor, resistor, capacitor can handle the heat under our test.

Electrical Safety

- Electronics shall be properly grounded.
- Electronics that produce heat shall be properly insulated from flammable materials.
- All wires shall be properly insulated to prevent shorts.
- No wires shall be exposed to the user during operation, modification, or installation.
- Electronics shall have proper surge protection.
- All solder used in heated areas shall not melt within operating temperatures.
- All electronics shall be able to withstand operating temperatures.

Operational Safety

- There shall be a finger guard attached to the air output side of the fan during operation.
- All external or exposed edges and corners of the test rig shall have a radius in a manner which minimizes the possibility of laceration or puncture.

5.7 Maintenance

The device should be able to be serviced easily. This mean that users of the device should be able to open it up to access the inside of the duct. Because air will constantly be moving through the duct it will accumulate dust over time. The dust would interfere with the functionality of the device by increasing friction in the duct as well as possibly changing the conductivity properties of the plate by adding insulation. The first is unacceptable because the device is designed to measure friction factors and so improper maintenance would result in data with errors. Dust could also be a problem because it could be ignited by the heaters. Easy maintenance means that opening the device should only require one person and very few tools. If screws are removed they should be made as to not fall out of their sockets and get lost. Wires should be routed as to not interfere with the opening and closing of device. If they have to go in an area that requires that they be removed for cleaning then they should have connectors that allow for easy connecting and disconnecting.

5.8 Ease of Use

The goal of this project is to have a testing rig that can be used by a researcher to determine the reynolds number and friction coefficients of a duct with a specific cold plate. The researcher should not have to know the inner workers of the device. The user should be able to input their test conditions into the computer and dial the heat output on the variac and then just run the test and collect data. This straightforward procedure is essential to the project because the tests must be able to be carried out in sequence with ease and repeatability. We are assuming that the user has a certain amount of technical knowledge though. This is a cold plate testing rig that outputs data on the fluid mechanics of the duct and so we assume that the end user has knowledge of the scientific concepts behind the data they are collecting. If they didn't then the device would be useless to them by definition. For this reason it is unnecessary for us to walk the end user through what a reynolds number or friction factor is, we simply just output the data for them to view. One of the reasons we chose LabVIEW as our software for data processing is because the end user is assumed to have access and knowledge of it. By using a program they are already familiar with we reduce that chances that they will be confused and decrease the learning curve for the device. Also because the data processing system we build in LabVIEW is easily editable a more advanced end user can easily tweak our system if he or she feels the need to change how the data is collected.

5.9 Portability

Weight

- The weight of any individual sub-assembly shall not exceed 44 pounds so as to allow for one-person lifting (MIL-STD-1472G).

Portability is important in this project because the device will not be designed at the location it will be used or reviewed. The device also need to be capable of being installed and stored in an office building. This means that it has to be able to be broken down into sections that can fit through a doorway and be carried by one person. This means that where the device separates it needs to have interfaces that allow it to connect and disconnect easily. Whenever you create a junction you create an area of reduced structural integrity. So we need to make sure that the connectors that hold the junction together are strong enough to hold the device together under strain and not be damaged. To further complicate things because the duct is under pressure the junction can cause a leak. This means that we need to make sure that the junction is properly sealed by using a gasket or some similar technology. Portability also extends to the software we create because the device needs to be easily interfaceable at different locations. We are already at an advantage here because we are using LabVIEW. Harris has LabVIEW and so they will be able to connect our device to any computer with LabVIEW. All we need to do is provide a file with our system data for LabVIEW to open.

5.9 Manufacturability

This product does not need to be mass manufactured and so any process that need to be done to complete it only needs to be done once. This allows us some room for inefficient processes. While the term inefficient process seems like a bad think it is important to note that for a product that will only be created once, it may be more practical to focus on other constraints then time or part ingredient efficiency. An important constraint is the availability of tools. Because this project is being created by a group of students our access to tools is less extensive than for a large company. Because of this the style of how we design things is slightly different. For example when creating the chassis we elected to use panels that could be screwed together by hand. While this is more practical for a small group of students it may not be as fast or cost effective as say rivets or a weld. In manufacturing this product it is also important to note that the device is a prototype. Because of this it is important that the device be able to be taken apart and changed easily. To achieve that we need to use screws that can be unscrewed instead of more permanent means of sticking things together such as glue, nails, rivets or welds. To some degree we can get things machined and we will have to. The cold plate must be cut to dimension and holes must be drilled in its surface to allow the attachment of thermocouples. The chassis itself will need to have holes drilled in it to accommodate screws and the insulating plates must have holes in them to accommodate the thermocouple wires passing through them.

6.0 Design

6.1 Hardware

Most of the design process focused on the hardware because this device is mostly implemented in hardware. In in following section we will cover the design aspects of the following devices.

- DC power supply
- AC power supply
- Thermocouples
- Pressure Transducers
- Heaters
- Orifice plates
- Fans
- Feedback Control Systems
- Data Acquisition Devices

6.1.1 AC/DC Power Supply

Because we must power both the electronics as well as the heaters we are forced to use two power supplies, one DC for the DAQ, fan, sensors, etc and one AC for the heaters. The requirements and therefore the design of each is radically different and so we have separated them.

6.1.1.1 DC Power Supply Requirments

The DC power supply must be able to output:

- +12V @ 4A
- -12V @ 0.5A
- +5V @ 0.5A

The DC power supply must be able to input

- 120V AC @ 60Hz

The DC power supply is responsible for providing powering the feedback controller, fan, thermocouple amplifiers and digital logic such as the FPGA if we elect for that route. As such it is one of the most important components of the project, not because it is the central element of the project but because so much relies on it. We we requested by DR. Richie to design and build our own DC power supply and so we have elected to put most of the power load on the AC power supply and thus simplify our DC power supply. If we are unable to create a power supply that can met our requirements within a reasonable amount of time we will elect to buy a premade power supply.

6.1.1.2 DC Power Supply Design

The design of the DC power supply is fairly simple in theory but relatively complicated in practice. Our different components require different voltages in order to run and each voltage that we add on creates another rail on the power supply. Below we see a figure detailing the voltage requirements for each subsystem.

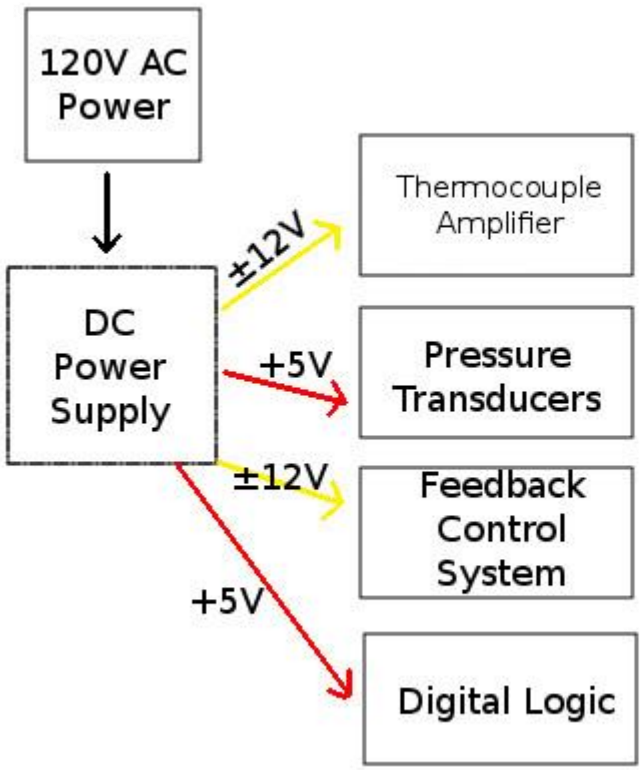


Figure 6-1 DC power supply rail requirements

Creation of these rails is complex and requires a multitude of parts attached to a PCB. Utilizing the Texas Instruments Webench platform we can easily create the design we are looking for by simply inputting our input voltage, output voltages, and output amperages. It will then take those numbers and design a unit for us to create. Using the WebBench we found that our input power of 120V AC would need to be converted to DC and stepped down to a 24V and a 10V DC output using two rails. From there the 24V rail will be stepped down to a positive 12V rail and a negative 12V rail. The 10V output would be stepped down to a positive 5V rail. Creating this design would require creating a total of five separate rails in order to achieve our desired three outputs. Our efficiency would be fairly respectable at about 80% which, while lower than most off-the-shelf models, is still within the range we were hoping to achieve.

Externally the power supply will be fairly unassuming. We will place the PCBs in a box, possibly clear acrylic or simply sheet steel, in order to protect the fragile internals as well as protect the user from the high voltage components. The box will have a female standard 120V plug on the input side and wires exiting the other side for each of the components we must power. The wire exit hole will be grommeted to prevent the wires from being cut on the housing and a stress reliever will be installed to prevent the wires from being pulled out of the unit.

6.1.1.3 AC Power Supply Requirements

The AC power supply must be able to output:
- 5 - 120 V AC @ 60 Hz
- 0 - 200 Watts

The AC power supply must be able to input
- 120V AC @ 60 Hz

The AC power supply is responsible for powering the heaters. We chose to use an AC power supply because it greatly lightens the load on our DC power supply. And because we have to design our own power supply it made sense to us to reduce the load on it. Our AC power supply will take the form of a variac. The variac will allow us to adjust the voltage on the heaters by simply turning a dial. Depending of the voltage required and the capabilities of the variac we may end up cascading it with a fixed transformer. We would do this to better center the range of the variac on the range of the heater output we would like to see. We will print a custom label for the variac so that the end user can dial the desired power output of the heaters instead of the output voltage of the variac.

6.1.1.4 AC Power Supply Design

The design of the AC power supply is a cascade of a variac and transformer. Because the power is AC transforming it from one voltage to another is very straightforward and only required two components.

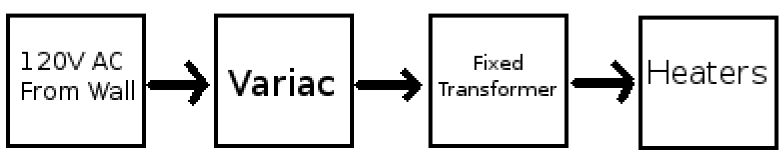


Figure 6-2 AC power supply block diagram

Because the Variac will be adjustable by the user we will do calculations to determine the heater output wattage at each dial setting using the known heater resistance and the known output voltage. This will allow for the user to simply choose the setting on the dial that corresponds with the heat level they wish to test at.

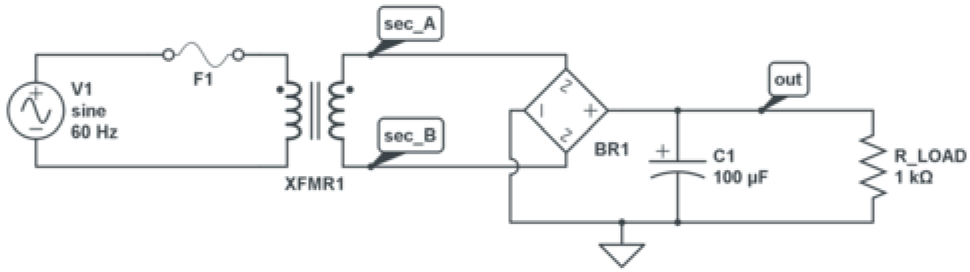


Figure 6-3: AC power supply schematic

The figure above show the circuit of the AC power supply.An AC power supply, which included transformer and bridege rectifier can drop the wall AC 120V power to a useful low output voltage to power up the heater.

6.1.2 Heaters

The heaters are essential to this project. Without then we could not test for the thermally developing condition. The project required a maximum heat output of 200 watts over two plates of area 288in^2 . This gave a watt density of 0.34 watts per in^2 which can be achieved by most heaters. So selection came down to cost and ease of installation. We elected for flexible matt heaters because they could be easily sandwiched between the cold plate and the insulation plate. They are thin matts and their wires come out of their side which allows us to route the wires more easily. The other determining factor was cost as the flexible matt heaters are a lot cheaper than ceramic heaters.

The heater is sandwiched between the insulating plate and the cold plate. This way the heat from the heater is forced to flow to the cold plate and the electronics behind the insulating plate are safe. The heater is powered by our AC power supply. By adjusting the voltage of the AC power supply we can adjust the power output of the heaters. This is because the heater is just a resistor and the power dissipated in a resistor is the voltage across it multiplied by the current running through it. The current running through it is a function of the voltage across it and so effectively the power dissipated by the heater is just a function of the voltage applied across it. There is one catch however. The function relating the resistance of the nichrome wire inside the heater is not a necessary linear and so we must get the resistance vs temperature curve from the datasheet of the heater we buy. We can use this curve to map the input voltage to the heater to the heat output in watts of the heater at steady state conditions. Of course the insulating plate and cold plate will both affect the steady state temperature of the heater and so actual testing will need to be done on the system as a whole to determine the steady state temperature of different heater output wattages. Below is shown a graph relating the resistance of nichrome wire to its temperature.

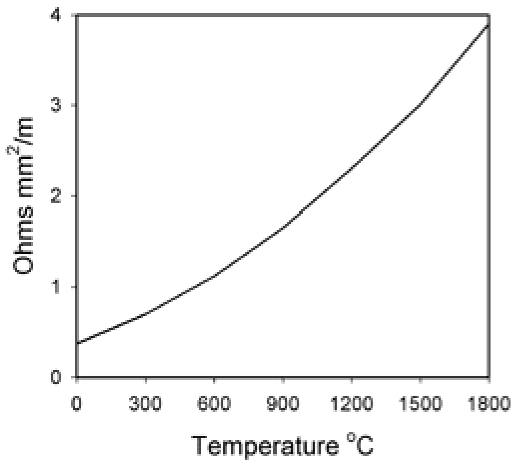


Figure 6-4 Resistance vs temperature for nichrome

6.1.3 Sensors

6.1.3.1 Temperature Sensors

We elect the Thermocouple for the Harris project. It has a main advantage over the other two sensors, the fast response time, which is the most important consideration for this Harrs' project, even though sacrifice the accuracy and linearity of the sensor. But there is another way to improve the accuracy.we can using calibrated accurate sensor place side by side of the Thermocouple sensor, then read the exact temperature value, and calculate the difference when write the software to read the feedback. There is few important reasons that we have to using the temperature sensor for our project. The first is that the temperature measurement is most important objective of this project, and it need the temperature datas before they can analyze anything else.The DAQ require to read the data, and control the pulsation and speed of the fan to adjust the inside temperature to any temperature that we desired. Secondly,the main objective is using the design test rig to test various cold plate articles for heat transfer coefficient, so it need temperature data to calculate the heat transfer coefficient. since the temperature may varies in different location, it require large amount of the temperature sensor to complete the task, the figure shown below is the relative location of each temperature sensor located.

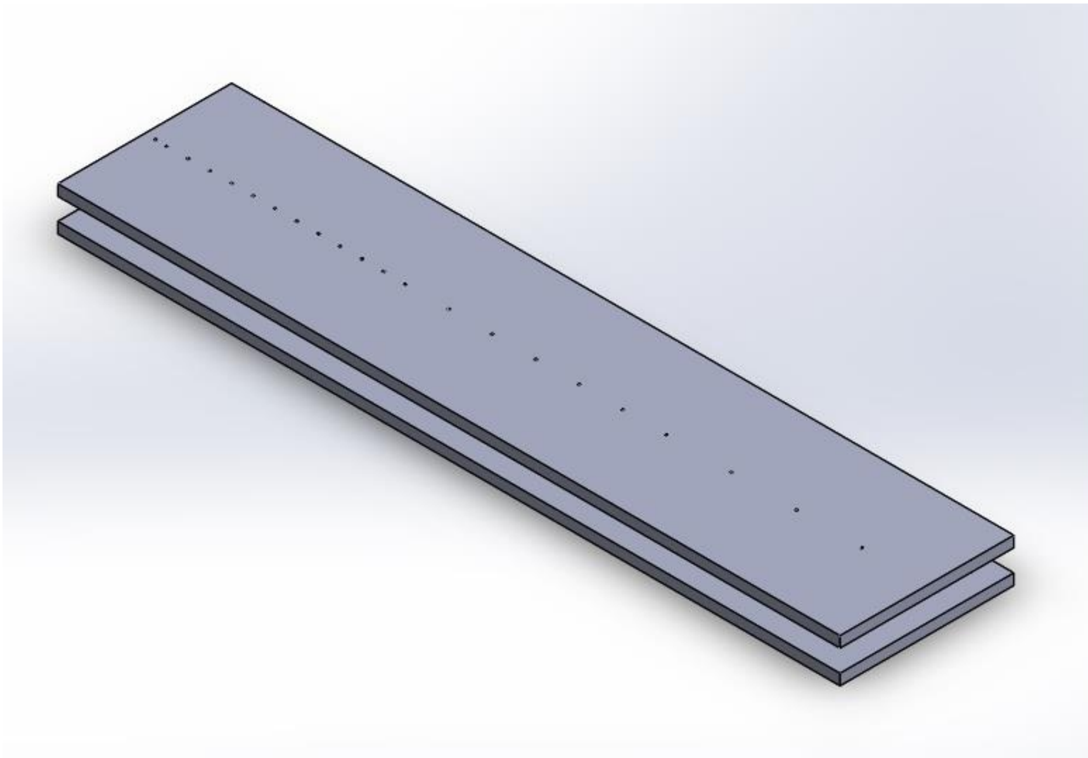


Figure 6-5: Temperature sensor locations on endplates

It need 24 temperature sensors to measure the surface of each end plate, and 2 for air temperature in inlet and outlet.Since each temperature sensor is closed to each other, so they have to be shiled to avoid the thermal effect to others. The thermocouple we chose is J type, it give us wider temperature range and higher time constant, so that it can result better performance for the entire system.The thinner of the wire produce the better performance of the time response, but in the other hand, the wire is easier to broke compare to wider wires. So the optimization test is required for this part, the test would show the result that the point has highest time constant and hard to break.

6.1.3.2 Mass Flow Sensors

We elected to use an orifice plate as our mass flow sensor. It had a couple advantages over the other sensors as outlined in the sensor selection section of this document. These include its quick response time of 10ms and its more reasonable cost of $600. This sensor was particularly important to the success of the project for two reasons. The first is that the mass flow of the air through the box is necessary for the calculation of the Reynolds number as well as the friction factors and both of these calculations are part of the main objective of the project. Secondly the mass flow sensor is critical to creating the air velocity pulsation condition. The orifice plate must talk to the feedback controller so that the controller can drive the fan to create pulsations. Because of the pulsation condition it was important that the mass flow sensor be able to respond fast enough to resolve a 10Hz pulsation.

The choice of the orifice plate does add some complications to the project. The duct must be regular, circircular and uninterrupted three duct diameters upstream and downstream of the plate. The flow moving through the plate must also be laminar meaning that it is developed and that there is no turbulence. Because the testing rig is mean to observe the flow in the duct as it develops it became impractical to put the orifice plate at the inlet of the duct. Secondly because the duct has to be circular upstream and downstream of the orifice plate and the duct of the test rig itself is rectangular we had to add a section of circular pipe to the outlet end of the duct between the heaters and fan. This section of duct had to be long enough to allow the air inside the duct to become developed again after transitioning from a rectangular duct to a circular one.

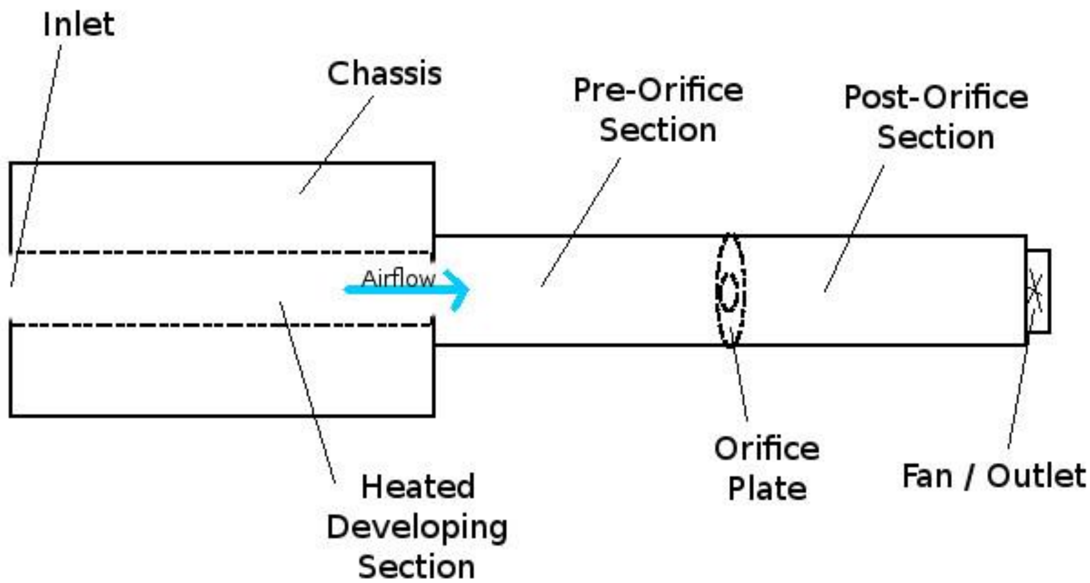


Figure 6-6 Airflow diagram

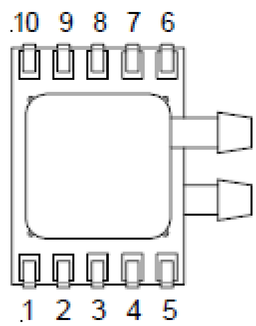
The orifice plate will be milled by a company to the specification we provide. We decide what pressure drop we would like to see at a specific velocity and the company will mill it. We will choose our plate so that the max air velocity our duct will experience (0.67 m/s) will create a pressure near the top end of the range of our pressure transducer and so the minimum air velocity (0.034 m/s) will be near the bottom of the range of our pressure transducer. We do this because the transducer is most accurate near the center of it range and because if we stretch the range of pressure to fit as big as possible within the range of the sensor then we will have maximised the resolution of our data. The taps for measuring the pressure across the orifice plate can be placed immediately on either side of the plate for maximum effect or one pipe diameter upstream and downstream of the plate for a satisfactory effect. The pressure transducer will then convert the pressure differential to a voltage that will be read by the feedback controller and the data acquisition device.

6.1.3.3 Pressure Sensors

Our choice for pressure the pressure sensors was the Sensortechnics LBA low differential pressure sensor. This sensor has a range of 0-25 Pa, a linear amplified output of 0.5 to 4.5 V, an output current of 1mA, an accuracy rating of 2.25% FSS, a high flow impedance, and it complies with various quality standards such as RoHS, REACH, ISO 13485:2003, and ISO 9001:2008. It is also calibrated and temperature compensated. It has an operating temperature range of -20 to +80 °C. It is resistant to up to a level of 20g of vibration and 500g of mechanical shock. All of these factors must be taken into consideration during utilization of or storage/transportation of the device and therefore must be treated with care so as to keep it functioning properly.

Figure 6-7 LBA pressure sensor image

The LBA differential pressure sensor is shown above. For its dimensions it has a length of 17.70 mm, a width of 18.03 mm, and a height of either 8.18 mm or 16.05mm. The internal electronics are housed within the casing on both the top and bottom sections of the sensor. The sensor is a PC mounted sensor. It comes with either SMD or DIP mounting pins. The protruding ports are where the connections to the tubes are made. The top port is the high pressure port and this is important since the part we are ordering is unidirectional.



Pin	Connection
1	GND
2	$+V_S$
3	GND (Main)
4	V_{out} (bidirectional devices)
5	V_{out} (unidirectional devices)
6, 7, 8, 9, 10	GND

Figure 6-8 LBA pin configuration

Above is the top-down diagram view of the sensor showing the pin layout. Pins 1, 3, 6, 7, 8, 9, and 10 all have to be connected to the same GND and no voltage should ever be applied to any of them. Pin to is the power source pin and should be connected to a supply voltage source Vs = 5 ± 0.25 V_{DC} whenever intended to be running. Since this is a unidirectional device, pin 5 will act as the output V_{out} and will be fed into an ADC in the DAQ section.

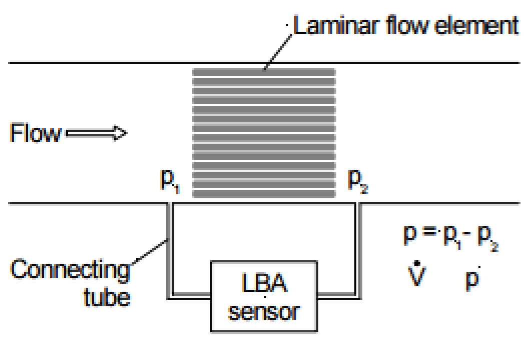


Figure 6-9 LBA application diagram

The purpose of the two LBA differential pressure sensors are to measure the total pressure drop across the test section of the main duct and the drop across the orifice plate. The sensors are board mounted and therefore are not in direct contact with the walls of the element under test needing measurement. The sensor needs to be able to access the air within the test system environment in order to measure the pressure accurately. Figure 6-6 above is an diagram for the exact same application we are trying to test. The sensor is mounted on the board and extended connecting tubes are mounted on both ports of the sensor and mounted on the other end to the wall. The tubes should be flush with the level of the wall and not protruding so as to not disturb the system. The high pressure port should be connected to point 1 of the diagram which is closest to the flow source and before the laminar flow element. the low pressure port should be connected can be connected anywhere along the system, but should be connected at the point 2 which is the end of the laminar flow element and before any other elements that may affect the pressure. This configuration will allow for accurate measurement of the system's total pressure differential which will be measured by subtracting the pressure of point 2 from point 1.

6.1.4 DAQ

6.1.4.1 Pre-Made DAQ

The pre-made DAQ greatly simplifies the design of the of the data acquisition system. We simply just attach the analog output wires of our sensors to the analog input ports of the DAQ and the digital outputs of the DAQ to the digital inputs of the digital potentiometers. We then just plug the DAQ into the USB port of the computer and we are good to go.

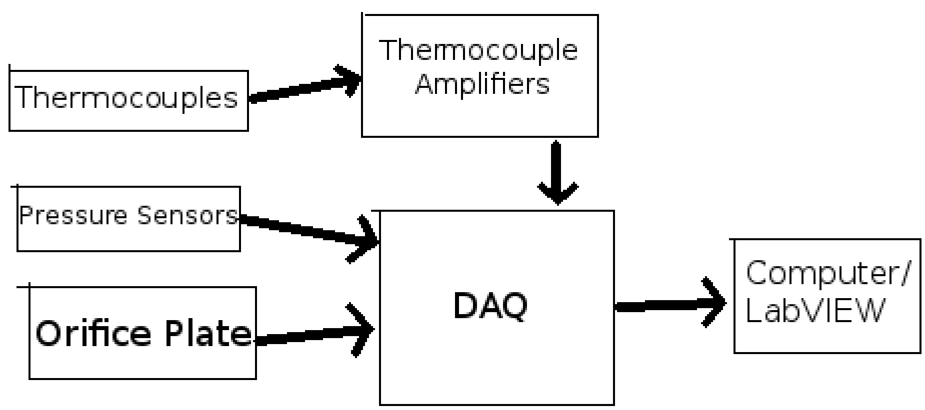


Figure 6-10 DAQ interface block diagram

6.1.4.2 FPGA DAQ

The design of the custom data acquisition system is fairly complex. We need to connect all of the components together in a way that is efficient and isn't susceptible to error.

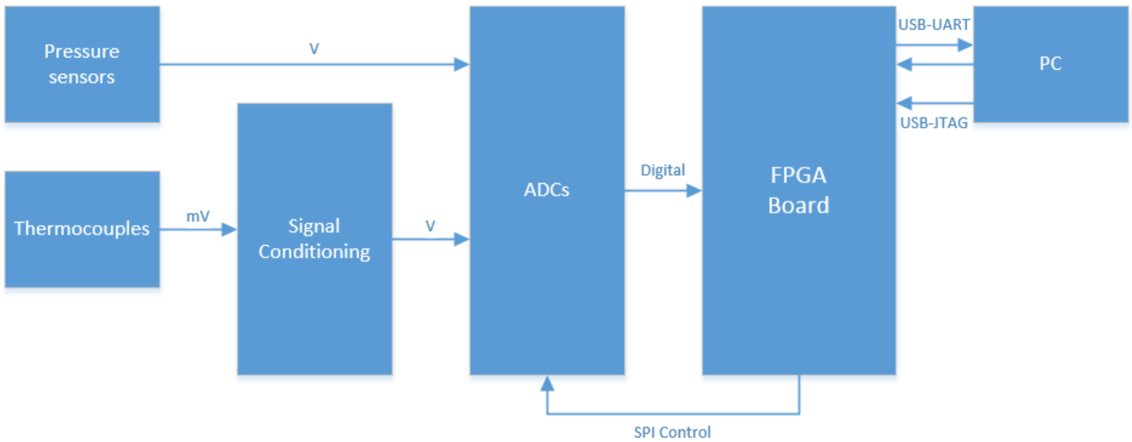


Figure 6-11 Hardware flow block diagram

The above figure shows the flow of data across the data acquisition system. The data acquisition portion of the PCB will house the pressure sensors, thermocouple connections, signal conditioning circuitry, and analog to digital converters. The ADCs will then be connected to the FPGA through its PMOD external pin connections using the SPI interface protocol to communicate. The FPGA will then communicate to the PC using a USB-UART communication channel. The FPGA will also be interfaced by a USB-JTAG connection. This is the expected representation for the flow of data in the custom DAQ system. As long as all of the connections are made properly, the device should function properly.

The pressure sensors will be mounted directly on the board using pin connections detailed in the sensor documentation which is also described in section 6.1.1.3. The output to the sensors is already amplified, linearized, and mostly noise resistant and therefore does not require any signal conditioning. The reference voltage for the ADC will have to be the same as the max value of the output range for the sensors which is 4.5 V_{DC}. The sensors will require a voltage source at the magnitude of 5 V. The output to the sensors will be connected directly to one of the SE inputs of the ADC. The thermocouples will need to be connected by external wiring. Therefore the PCB will require female wire headers to mount the thermocouple wires to. The output of the thermocouple sensors is in mV and therefore needs to go through the signal conditioning circuit to at least be amplified to a level that is compatible with the ADCs. This will most likely be the same as the max pressure sensor output of 4.5 V. Additional buffering or filtering may be needed to reduce noise.

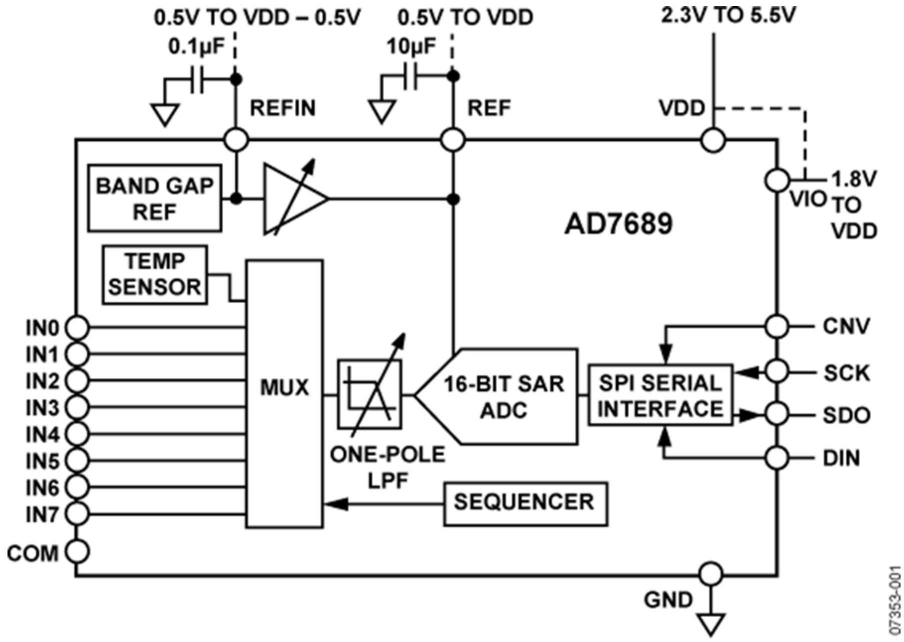


Figure 6-12 ADC internal schematic diagram

The ADC that was chosen was the AD7689. It has 8 input channels and has a 16-bit SAR architecture. The 8 inputs are multiplexed into a single ADC using a sequencer to select the channel. The device is controlled by the SPI serial interface. The control signals come from the SPI master module in the FPGA. The supply input voltage V_{DD} needs to be in the nominal range of 2.3 to 5.5 V. The reference voltage can be anywhere from 0.5V to the level of the supply voltage. Therefore we can give feed a 4.5 V signal to match the output coming from the pressure sensors and amplified thermocouples.

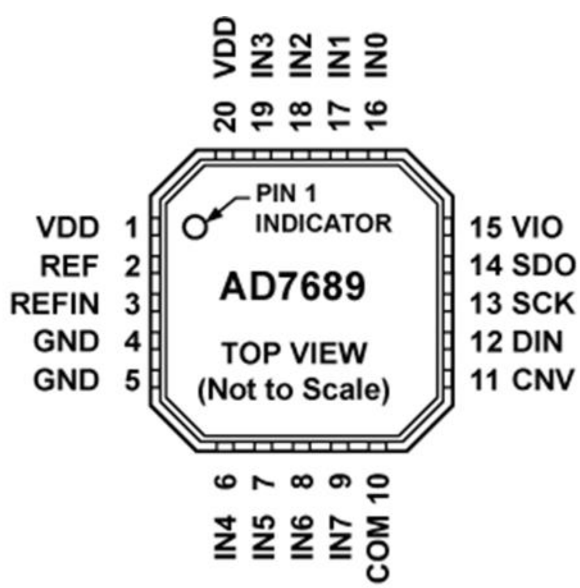


Figure 6-13 Pin configuration for ADC

The above figure shows the shape and pin configuration for the AD7689 ADC. The values determined previously need to be fed into the correct pins according to this layout.

The ADCs will be mounted directly on the PCB board. This is done by soldering the joints onto the system ground plane as recommended by the documentation for the product.

The FPGA is obviously the most complex part of the design and therefore a development board is used instead of attempting to integrate it into the design for the PCB. The board will be connected to the the PCB through external pins located on PMOD connectors at the sides of the board.

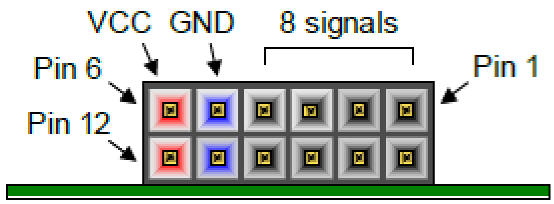


Figure 6-14 PMOD connector front view

The figure above shows the pin configuration of the connectors. The ADC outputs, SPI controls, and fan controls will go through this connector. Although the connectors have 12 pins, only 8 of them are used for passing signals externally. The Vcc signals both supply 3.3 V.

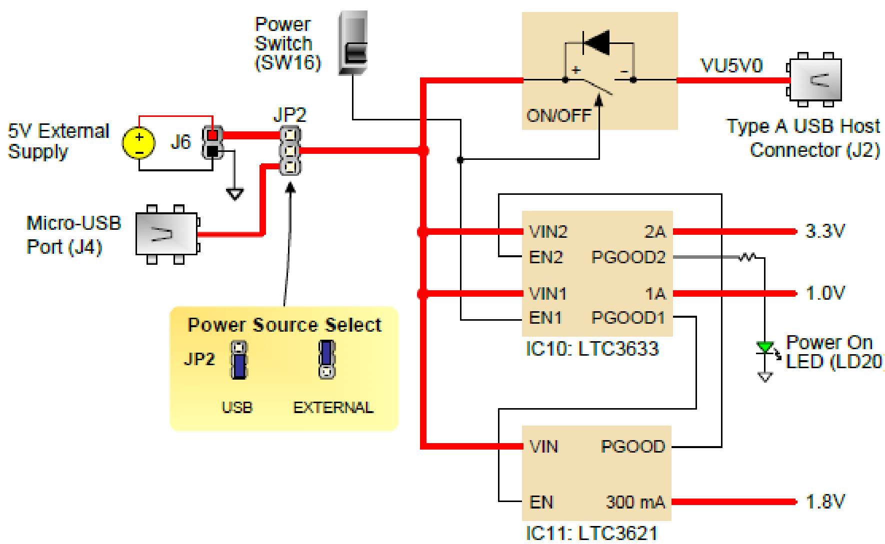


Figure 6-15 Basys3 power circuitry

The board is fully powered by either an external supply or a USB connection. The board can be turned on and off using a switch. The power circuitry diagram is shown above. The board regulates and uses various voltage values that correspond to different modules.

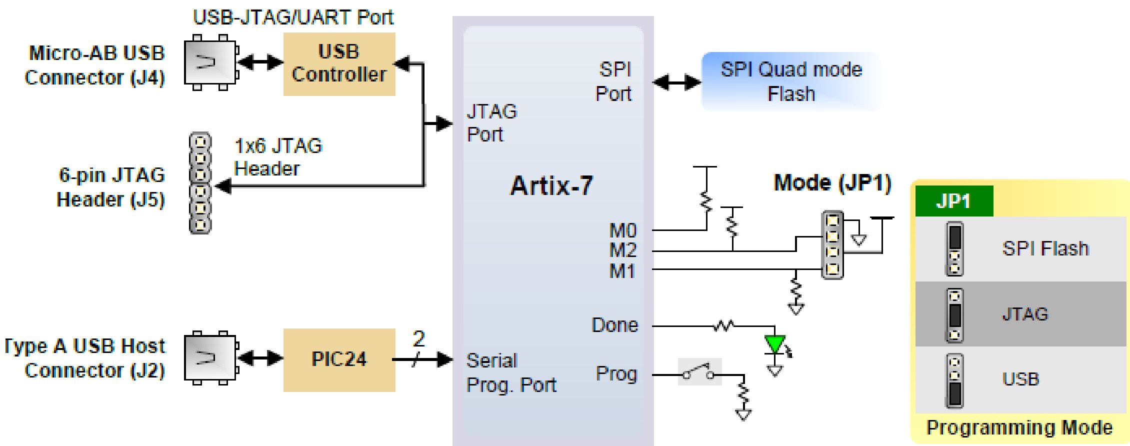


Figure 6-16 Basys3 configuration

The Basys3 board has multiple options for configuring the Atrix-7 FPGA. The first and more rudimentarily obvious way is through the JTAG connections. A special cable is need for this kind of connection to be made. The more useful and viable way of programming the device is through the USB connection which goes through a USB controller to use JTAG programming or through a PIC24 for serial programming. The third mode is by SPI flash which uses an internal SPI connection with the program preloaded onto the flash module. The device is programmed using a set of software that can create .bit programming files from HDL code or schematic sources. This bit file also contains the pin configurations associated with the design.

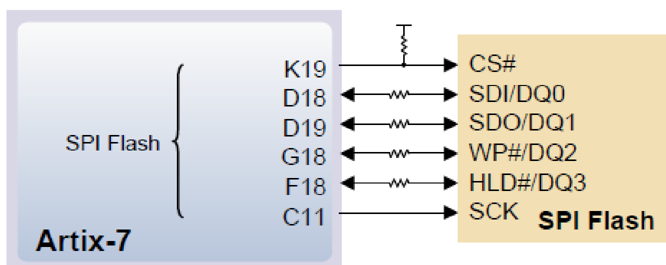


Figure 6-17 External memory

The board, in addition to the internal memory in the Atrix-7, sports a 32Mbit external Flash module with an SPI interface. This is useful for non-volatile storage of any kind of data. In this case, data acquisition control and data variables will be stored in the flash for quick, easy, and safe access.

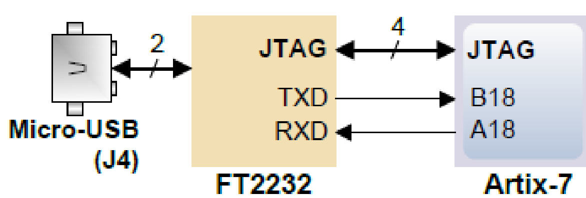


Figure 6-18 USB-UART module

Data logging for the DAQ will be done through a USB-UART connection with the PC. Data will be handled by embedded software to be sent and received through the A18 and B18 pins. The USB-UART connection will then be handled by the USB micrcontroller.

6.1.6 Fans

The fan subsystem design will be centralized around a few key topics including fan size, adapting the fan to the exhaust tube, and wiring up the fan. In order to attempt to speed up the cycling rate we have purchased the physically smallest fan that would meet our airflow requirements. We believe that a smaller fan will result in less weight leading to less inertia which will help the fan spin up and slow down quicker. To add to this, a smaller fan has smaller blades which should have less drag in the air and therefore get up to speed faster. Exactly how much of an impact these changes will make will be determined in our testing. Because there are so many variables involved with this system things could cause us to see less airflow from our fan than the spec sheet says it should put out. Because of this we also purchased two other fans of slightly larger sizes with proportionally larger airflow potential that we will also test. The fan that produces the best results will be chosen for the final design. Adapting the fan to the exhaust tube is also a critical design point we must consider. Because we are looking at a very small 40mm fan which is square and the exhaust tube is 4-5 inches and round, we must have a way to attach the two very securely and without any air leaks. To facilitate this we will create an adapter that is 40mm on one side and tapers up to the size of the exhaust tube on the other side. The fan side will have holes drilled in it for fan screws to thread in to and a gasket will be placed between the fan and adapter to prevent any air from leaking past. On the exhaust tube side there will be a lip that extends out with an inside diameter the same as the exhaust tube outside diameter which will allow for a tight press fit. Sealant will be spread around the joint to prevent air leakage.

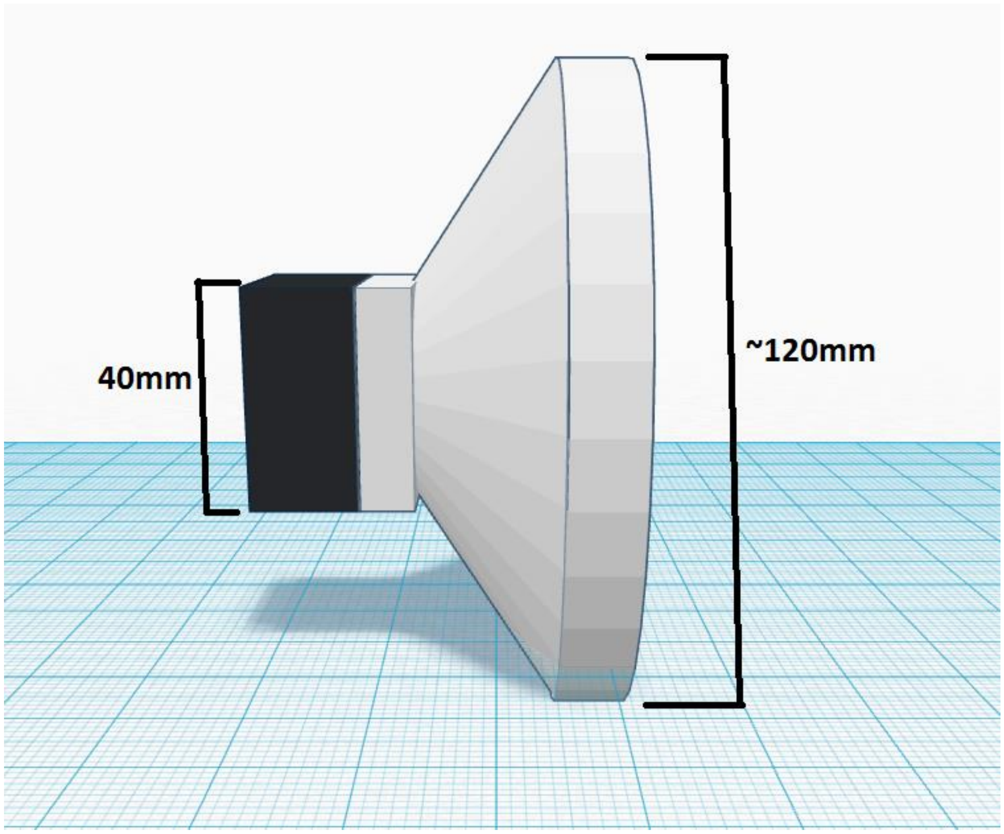


Figure 6-19 Exhaust tube to fan adapter

Wiring the fan will be a fairly simple task, Because we decided to go with a standard fan rather than a PWM one, we only have to worry about two wires, a power and ground. The ground will be hooked up to the black ground wire on our power supply and the power will be hooked up to our linear control system which will deliver power to the fan based on how much flow we need and how fast we are trying to cycle the fan. More about the fan control subsystem can be read in section 6.2.1.4.

6.1.7 Wiring

Like all electronics project wiring is essential to this one. Wires connect all of our different components and sloppy wiring can cause many issues in a project. To keep our wires organized and protected be elected to create a wire duct above and below the insulating plate to hold our wires. This duct is protected from the heaters because of the insulating plate and helps to protect the wires further by removing them from the area where cold plates will be interchanged. And of course we could not run the wires through the heated channel because they would cause disturbances in the flow of air.

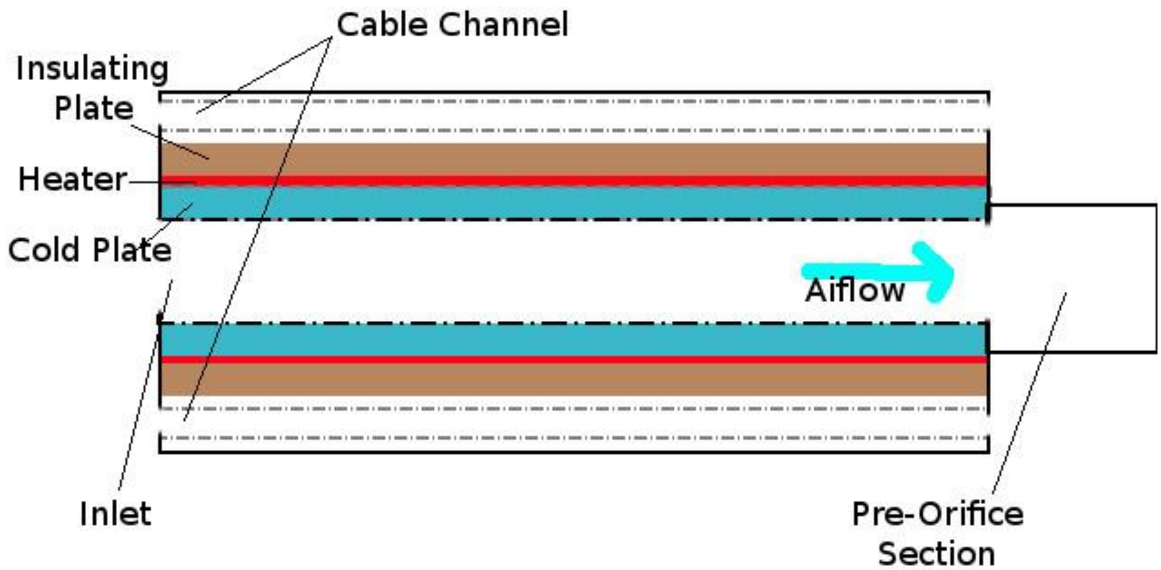


Figure 6-20 Chassis diagram

The next consideration in wiring is signal noise. Because the wires will all be in a duct together running in parallel signals in one wire will induce signals in another. This cross talk is undesirable because it add error to our measurement. Because of this we must shield the sensor wires from each other. This can be accomplished by using shielded wires. It is also important that we use shielded wires for the heaters. In fact it is more important that we shield the heater wires then the sensor wires. This is because the heaters are driven by an AC signal and the power moving through them is a lot greater than the power of the signals in the sensor wires. Because of this the heater wires will generate more interference than the sensor wires. There are many types of shielded wire available for purchase and they operate on a few different principles. Some shielded wires accomplish their shielding passively by wrapping the wire in a metal sheath. Others will connect the outer sheath to the same wires return journey. This makes it so the inside wire and outside sheath always have opposite currents and thus cancel each other's magnetic fields out.

Another important consideration is the current capacity of the selected wires. While this consideration is less important for the sensor wires it is very important for the heater wires. If the current in a wire is too much the wire will heat up. When the wire heats up a little it can cause long term durability issues in the project. If the wire heats up a lot it could melt its sheath off and short on another wire or even light on fire. Both of these scenarios are bad for the project and can be potentially dangerous. For this reason we will carefully select wires that can handle the current we are sending through them. Wires with thicker diameters are more capable of handling current. It is also important that we use properly ground our electronics and chassis so that if any shorts occur they do so safely. Are wires will also be properly covered so that there are not accidental shorts or electrocutions when people are working with the device.

6.2 Software

6.2.1 DAQ

6.2.1.1 Interfaceing the pre-built DAQ

Interfacing with the pre-built DAQ is simple. We will be using LabVIEW to collect and process our data and the pre-built DAQ we chose is LabVIEW compatible. To Interface with the DAQ we simply plug the DAQ into the USB port of the computer and drag a DAQ block into the block diagram of our system in LabVIEW. We then set this block to connect to the USB port containing our DAQ and LabVIEW handles the rest. Because of the plug and play nature of LabVIEW it becomes easy to switch out one DAQ for another if we need to do so.

6.2.1.2 Interfacing the FPGA DAQ

The FPGA based DAQ will connect to LabVIEW in a very similar way to the prebuilt DAQ. The Main difference is that because the FPGA DAQ is custom built we will have to create drivers for it to interface with the software system. These drivers will most likely be developed in C as it is a low level language with a lot of support for embedded application support and we are all comfortable programing in it. We will also have to create a module to interface it with LabVIEW. Once all this is done the FPGA DAQ will interface in the same way. We drop a DAQ block into the block diagram and attach it to the USB port our DAQ is connected to.

6.2.1.3 Sensor Data

There are three types of sensor data we will be collecting. The first is temperature data from the thermocouples, the second is pressure sensor data for the manometer and the third is also pressure sensor data from a manometer but is representative of the velocity of the air in the duct because it is measuring the pressure drop on the orifice plate. The thermocouples output a small voltage and so will be amplified by an op-amp circuit close to the sensor itself. The op-amp circuit will output a voltage between -10 and 10 volts that represents the temperature of the thermocouple. The manometers output a voltage between 0.5 and 4.5 volts representing the pressure drop across them. We have 46 thermocouple sensors and two differential manometers. This brings us to a total of 48 analog inputs. The thermocouple amplifiers will require a DC power supply with a +12 and -12 rail. The thermocouple amplifier will also include a low pass filter to remove an high frequency noise in the output.

6.2.1.4 Fan Control

We will use a linear control system (feedback controller) to control our fan. This will allow our fan to compensate for disturbances and system characteristics on-the-fly. While the exact type of controller is yet to be determined the general design of the system is the same. The velocity of the air in the duct needs to follow the function Vel = A(1 +

B*cos(2*pi*f*t) with A between 0.034 and 0.67 meters per second, B between 0.3 and 0.7, and f between 0.1 and 10 Hz. This function describes a sinusoidal change in velocity on top of a DC value. So the air will always be flowing in the positive direction but its speed will increase and decrease sinusoidally in time. The controller must must also be able to meet the case where B is 0. This case, the steady state case, is also required.

In order to implement a controller to create this velocity profile in our cold plate testing rig we needed to first design an analog circuit that outputs the desired function. We decided that an analog circuit was preferable as opposed to driving a digital to analog converter with software. This is because software is prone to delays and the exact time it takes to execute a loop might not be constant. This leads to issues with timing that can be compensated for but add an unnecessary amount of work to our project. We elected to use an op-amp based circuit consisting of an oscillator, a DC value generator, and a summing amplifier. The oscillator is a wein bridge oscillator and requires three digital potentiometers to control from software. The first two (R1 and R9) take the same value and control the frequency of oscillation. The third (R2) controls the amplitude of oscillation. The DC value generator is simply a non-inverting amplifier with one digital potentiometer (R5). This potentiometer controls the value of the DC value generator. The summing amplifier then sums the sine wave with the DC value and gives us the function we are looking for.

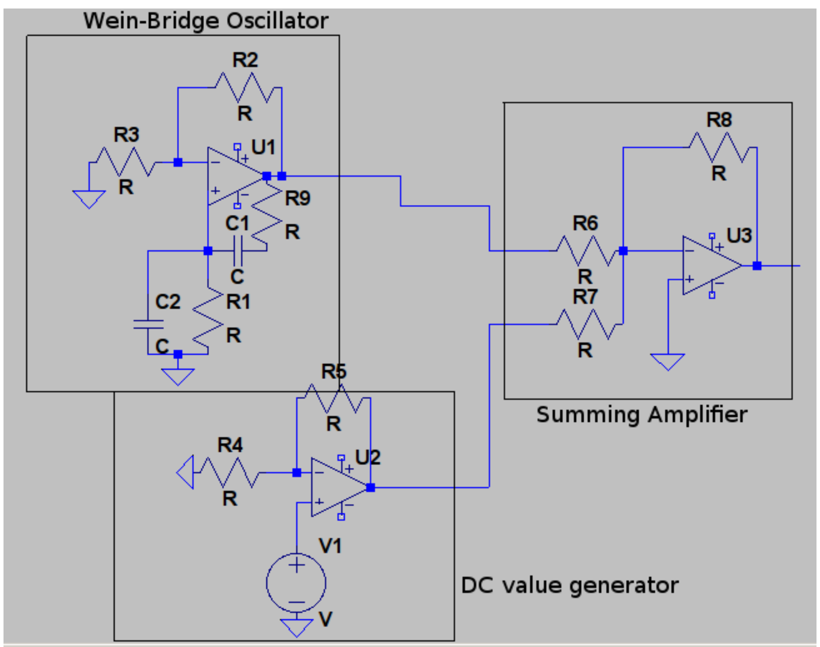


Figure 6-21 Function generator circuit

Once we have obtained the function we are looking for this function must be fed into the feedback control system as a reference. The feedback control system will then try to follow the reference input. The feedback controller compares the measured velocity to the reference velocity and then tries to minimise the difference. The velocity of the air in the system is measured by the orifice plate. the orifice plate measures the velocity of the air by measuring the pressure drop across the plate. The manometer that measures this pressure drop outputs the data as an analog voltage between 0.5 and 4.5 volts. We have a linearized function that converts pressure drop to air velocity. An analog circuit will process the pressure drop data and output a voltage representing the velocity data. This is the voltage that will be compared to the reference. Based on the value of the difference of the reference and the measured velocities and how fast the difference is changing the controller will increase or decrease the voltage on the fan.

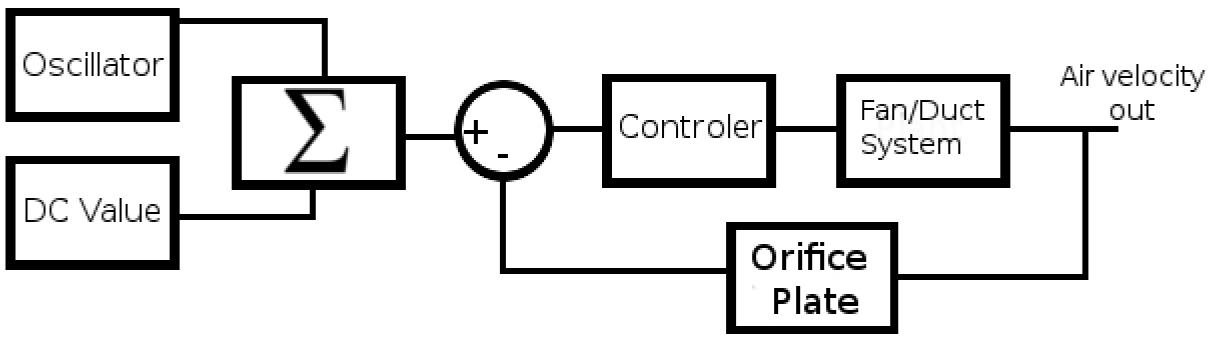


Figure 6-22 The generalized feedback controller

The exact type of controller has yet to be determined. We will design our controller by first obtaining a model of the fan-duct system. To do this be will choose a generalized transfer function of the order we think the plant (fan-duct system) is. We do not know the order of the plant and so we will need to start with a first order model and test its validity. If the first order model is insufficient then we will have to model the system as a second order system. The advantage of modeling the plant as a generalized transfer function is that we can easily test for the coefficients of the systems and just plug them in. For example is the system is first order we can use the transfer function T(S) = K/(Tou*S + 1) to represent the system. By applying a unit step function to the input we can determine K and Tou from the resulting output assuming the data is sufficiently accurate. Once we have a model of our plant we can use it and the requirements to decide on a type of controller. We will first attempt to use a simple controller such as a proportional, integral, derivative, lead or lag controller and the root locus approach. If that proves insufficient then we will goto the more complicated observer based controller.

To build an observer based controller we will have to start the same way as for a simpler controller. We will have to test the fan-duct system and create a mathematical model. Like with the simpler controllers the model can be first order, second order or in some cases a cascade of second order functions. Once we have obtained the transfer function by one of the means discussed previously in this document we have to transform the transfer function from an algebraic function of s to a differential equation. Alternatively if that method does not produce a sufficient model of the system then we can try for a numerical solution. When doing a numerical solution be find the mathematical equations for all of the dynamic forces involved in our system. So for example in our system we have a fan and a duct. The fan is a motor and a blade. We can get the equation for the torque produced by the motor as it is related to the voltage applied to the motor. and we can find the force the blade produces on the air as a function of torque, air resistance and air velocity. For the duct we can find the equations relating the flow of air through the duct to the resistance and momentum of the flow. We then plug one equation into the next to solve for an equation that directly related applied voltage to the fan motor to the change in the velocity of the air in the duct. This is going to be a differential equation and may not be linear. If the equation is not linear then it must be linearized. When linearizing an equation you are sacrificing the overall validity of an equation for an equation that is valid within a certain range. The range is relative to the order of the approximation you create. A higher order approximation will have a wider range of validity but will be more complex and thus take more effort to compute. It is also important to center the equation around the operating point. This allows you to get away with a smaller range and thus save on complexity. Once you have obtained a linear differential equation representing the relation between the system input and output you have to assign states to the orders of the transfer function. It is usually advantageous to make each state a function of the previous state but it is possible to just create a matrix with an arbitrary selection of stated and then use a transform to convert the matrix to one of the known standards. Once you have the equation in one of the standard forms it it easy to apply analytical methods to design controllers. Most of these methods involve deciding on the desired location of the system transfer function poles and the algorithmically solving for the controller gains that will move the poles there. One method called the Q-R method allows the designer to simply adjust values in a matrix of weights and have them automatically correspond to aspects of the system such as overshoot and settling time. This way the designer can sit at a computer with a simulation and tweak the values until the response is satisfactory. One disadvantage of a full-state controller is that it requires access to all the states of a system. In practical application this isnt going to happen. The cost of the extra sensors alone makes it impractical and not all states can be measured at all. In this case it is required to create an observer. The observer is a system that works with the controller to estimate the values of states that cannot be measured. The observer is basically a real time analog simulation created from the model we obtained when finding the transfer function of the fan-duct system. The observer is itself controlled by a feedback loop that constantly corrects the observer so that its outputs match the outputs of the real system. This has to be done because it is impossible to create a perfect model of any system and so if the observer was left to its own devices it would slowly drift. As the output of the observer is driven to be the same as the actual system its internal states are driven to represent the internal states of the fan-duct system. It is usually advantageous to have the observer update at least two to five times faster then the controller because the control relies on the observer and so it is important that the observer data be accurate for the controller. The full state observer can then use these states to control the system. While the full state controller is more effective at placing the system poles and thus controlling the system it is also considerably more complex and has more room for error. Below is an example of an observer system.

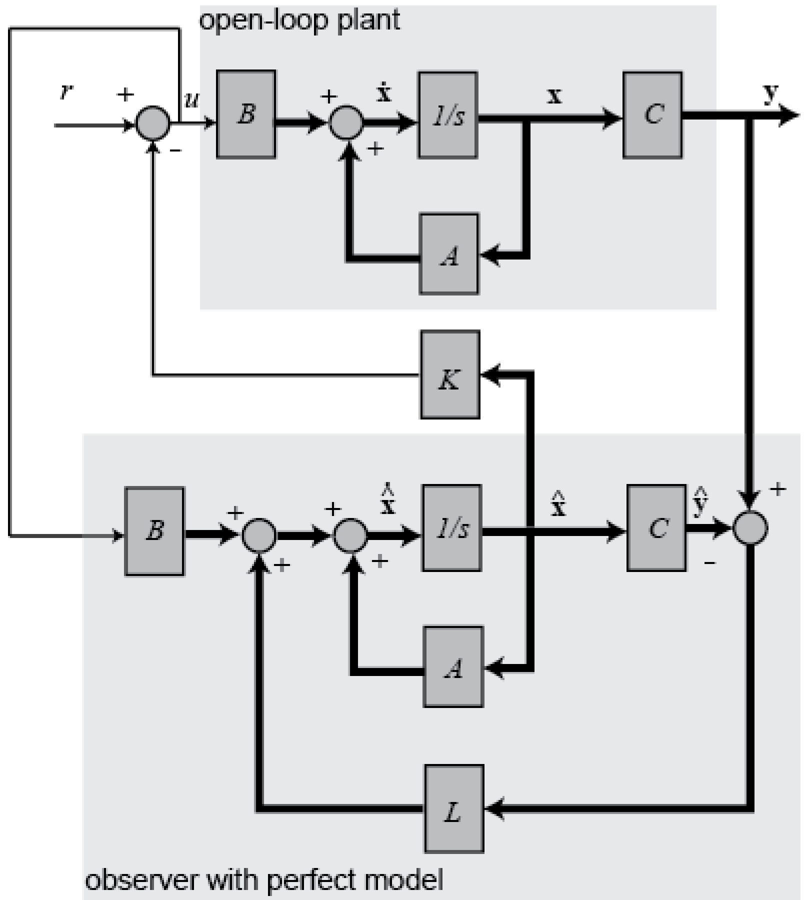


Figure 6-23 Generalized Observer controller block diagram

6.2.2 Desktop Application

The data we obtain from our sensors needs to be processed and recorded. At first we thought of creating our own desktop application to to this. But it quickly became apparent that this would be a lot of unnecessary work that may introduce new sources of error in our project. Because this project is designed for Harris and Harris uses LabVIEW it made sense to use LabVIEW to collect and process our data. LabVIEW is compatible with many data acquisition devices and it makes it easy to add new modules to it. When it comes to the actual processing of data LabVIEW makes it simple. In LabVIEW you can create virtual systems by creating a block diagram from parts in the LabVIEW library. The data acquisition devices can be dragged and dropped onto the page and their data can be piped to other blocks that can perform functions on that data. Other blocks can input the data and log it to a file for future reference. Still other blocks can display data on a front panel. This allows us to do all the processing behind the scenes and then display the end result on this front panel. Because the system is virtual and can be edited from the block diagram prototyping become easier as we can just type in a new value or drag and drop a new block to change our system. And because Harris is familiar with LabVIEW any changes they want to make to our data processing system become trivial for them to implement. Our system can be saved to a file and then opened on any computer with LabVIEW and be ready to interface with our device.

7.0 Prototype Construction

In order to ensure that performance requirements are met and that each subsystem functions as it should, each member will be responsible for testing their respective components. A logical approach for testing will be established and a set of criteria will be created and met for each part. Because it would not be feasible for such a complex system, a full-blown prototype will not be made, however smaller "mini-prototypes" consisting of perhaps a few subsystems combined will be created in order to ensure that critical subsystems work together as intended. Once all of individual subsystems are verified they will all be merged together and the final product will begin testing.

7.1 Parts Acquisition and BOM

The parts required for the test rig will be acquired over summer 2015 so that we can start work immediately when the fall semester comes around, and hopefully take care of any issues that may arise before they cut in to our timeline. Every part we are looking at currently is available for immediate shipment and in many cases there are multiple vendors to fulfill the order should our primary vendor fall through. Although we don't want to be wasteful with our budget, because Harris was gracious enough to allocate a very large amount to us we are focussing less on finding the absolute best deal and more on ensuring each component is exactly what we want and that the distributor can get it to us quickly so that we may begin testing as soon as possible. The table below shows each individual part we will use in our test rig and the supplier for each.

Component	Model	Supplier	Cost / Amount
FPGA Board	Basys3 Atrix-7 Development Board	Digilent Inc.	$79.00 / 1
ADC	AD7689	Analog Devices	$5.99 / 6
DAQ - Pre Built Option*	DT9813-10V	Omega	$445 / 3
AC Power Supply	SC-5M	PHC Enterprise	$100 / 1
DC Power Supply	Hand-built	Texas Instruments	$50 / 1
Heaters	SRMU050408	Omega	$25
Temperature Sensor	BW series	Omega	$50 per 100ft
Mass Flow Sensor - Orifice Plate	Milled to spec by Meriam	Meriam	$600 / 1
Pressure Sensor	LBAS025UF6S	Sensortechnics	$138.85 (125.00 €) / 2
Plastic Tubing	59084 (2mm ID x 4mm OD x 1mm wall)	United States Plastic Corp.	$13.65
Fan	Delta 40mm	Newegg	$20 / 1
Wiring	18-12 gauge wire	eBay	~$0.25 per ft
PCB	TBD	TBD	~$50

Table 7-1 Parts acquisition table

The majority of parts will be purchased through online retailers, but some smaller items such as wires, nuts, bolts, etc will most likely be bought locally for convenience. PCB parts (resistors, capacitors, headers, etc) will be determined during the finalization of the PCB design.

7.2 Construction

A large part of the construction of the test rig will be done by the mechanical team, however most of the electronics will be handled by our team. All of the sensors and the fan have very specific pre-determined locations and we will therefore work very closely with the mechanical students on installing those parts so that the sensors get the exact readings we are looking for and the fan creates the airflow that we require. The software and interface between the test rig and an external computer will be handled completely by our team

7.2.1 Hardware Assembly

A good portion of the hardware assembly will be done by the mechanical students. They will handle assembling the outer shell, inner duct, heat exchangers, and the inlet and outlet. Our team will work closely with them to integrate the electronic portions in to what they created. Our assembly will consist of the following parts:

- Temperature Sensors
- Mass Flow Sensor
- Pressure Sensor
- Fan
- Heaters
- AC Power Supply
- DC Power Supply
- FPGA
- DAQ components

An overview of the external portions of the system can be seen in the figure below.

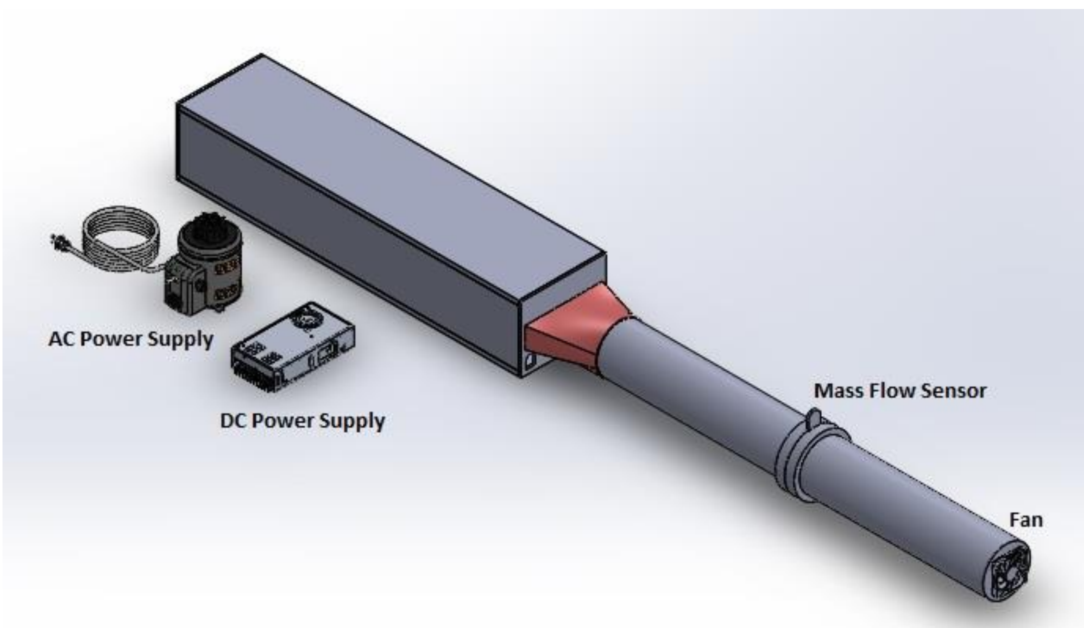


Figure 7-1 External system overview

Starting with the temperature sensors, the mechanical team has spent a lot of time calculating and running simulations to determine the absolute best positions for our temperature sensors. We came to the conclusion that we would require them in a high density toward the opening of the box as that is where we are expecting to see the temperature-based phenomenon we are looking for. Because our box is designed to be adjustable in not only air flow but also the separation distance of the heat exchangers, the range in which we are expecting to see the temperature fluctuation will change based on the current configuration. Because of this we are required to install the sensors at high density over a fairly large area. Within this high density area our temperature sensors will be only 0.5 inches apart from each other. As we move down the box we can reduce the density of the sensors until they are up to multiple inches apart toward the exhaust of the box. We are not expecting much variance toward the end so we will place much less sensors there. In total there will be 44 temperature probes attached to the top and bottom plates (22 probes on each plate).

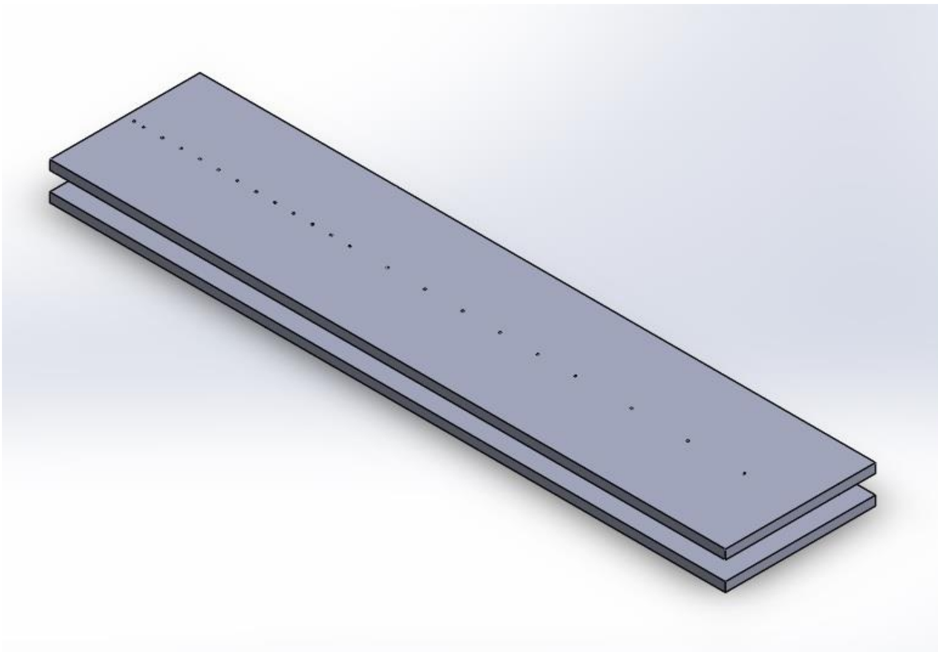


Figure 7-2 Temperature sensor location on heat exchanger

The physical mounting of the temperature sensors will be done in conjunction with the mechanical team. Because the sensors are so close to each other toward the intake side of the plate slots will be machined in the heat exchanger very close to the surface and each sensor will be very carefully affixed in place with thermally conductive adhesive. As the density decreases further down the plate individual holes will be drilled rather than slots and each sensor will be glued in to its individual slot.

The mass flow sensor we have chosen will be installed at the outlet of the box. Although we would have liked it mounted in the inlet, it requires multiple inches on either side of the sensor of completely unobstructed space which would mess up the specific airflow pattern the mechanical team is trying to achieve. Because all of the air must pass through this sensor it is installed in a sealed tube after the outlet of the box and before the fan, as seen in the figure at the beginning of this section. The pressure sensors are installed at the inlet and outlet of the box in order to give the pressure differential across the heat exchanger. Holes will be drilled in each location to allow the sensor to get a reading inside the box and the holes will be sealed in order to prevent air leaking around the sensor. The fan will be located at the very end of the system, after every sensor and heat exchanger. It will be attached the exhaust tube using a 3D printed adapter to allow the square fan to seal to the round tube. Sealant will be put around the joints in order to prevent air leakage.

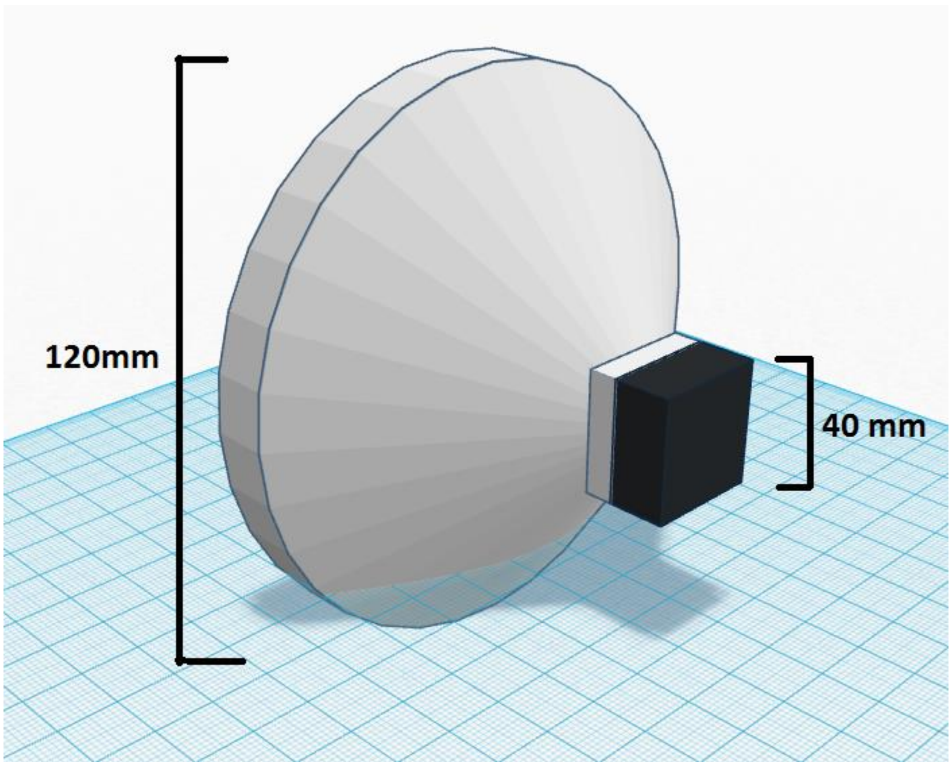


Figure 7-3 Exhaust tube to fan adapter

Heaters will be placed underneath each heat exchanger in order to simulate a real-world heat load. Each heater will be attached to an insulating plate and will press tightly up against the heat exchanger. We will be working very closely with the mechanical team for this portion as the heater will directly interface with their parts. They have designed a cam system whereby a knob is turned which is tightly press the insulating plate/heater combo in to the heat exchanger in order to ensure solid contact. The AC power supply used to drive the heaters will be placed on the top of the outer housing near the electronics box where the DC power supply and DAQ are. Because it requires physical contact from a user in order to turn the knob and adjust the power it must be easily accessible. It will be affixed using brackets and bolted directly to the box so that it does not move. The DC power supply and DAQ will be located inside of an electronics box which will be placed on top of the outer housing.

7.2.2 PCB Assembly

A major project requirement for senior design is the design and utilization of a printed circuit board (PCB). This is meant to give us embedded design experience and allows us to create a design from scratch without using any large-scale prebuilt part. For design of the PCB, a software called CadSoft EAGLE is used. EAGLE is used throughout the industry for PCB design and its final exported design files are accepted by most manufacturers. Since none of the members have any experience or tools for custom building PCBs, the need for an order to an manufacturer is apparent.

Possible PCB manufacturers recommended by our senior design coordinator include:

PCB-Pool: Good reviews, many helpful tools for visualizing the finished product, prices range from ~$40 to $100, fast delivery

OSH-Park: Community pool order, saves manufacturing and customer costs, long wait time, $5-$10 per sq. in.

Express PCB: flat $50 - $100, shipping $10, very fast delivery

4PCB: student discount, flat $33 - $66, free software

7.2.3 Software Creation

Because our test rig will interface with a computer in order to pass on data we must create software to perform the following tasks:

- Collect data from USB port as a host
- Arrange a display for the incoming data in a way that makes it easily readable
- Provide controls for the various components

The software is responsible for collecting the data from the DAQ and processing it. For the sake of simplicity and modularity we have elected to use LabVIEW to be our computer software. We will create a virtual system in LabVIEW that will input the data from the DAQ and display the requested data in the front panel. Creating a system in LabVIEW is simple. We just select blocks from the LabVIEW block library place them in the block diagram. We can implement just about any equation in these blocks. All we need to do is implement the equations that translate the data we collect to the data we want to display.

7.3 Integration in to the Mechanical Portion

Integration into the mechanical portion will be the biggest part of the assembly process during this project. The mechanical and electrical systems are very closely entwined and will therefore require close monitoring by both groups in all aspects to ensure that everything is assembled correctly and nothing interferes with other subsystems.

The integration will break down into the following categories:

- Temperature probes to heat exchanger
- Mass flow sensor to exhaust tube
- Fan to exhaust tube

- Pressure sensors to the inlet/outlet
- DC power supply to the housing
- AC power supply to the housing
- DAQ to the housing
- Wiring throughout the box

One of the most involved parts of this system will be the integration of the temperature probes and heat exchanger. Because the temperature probes must take readings of the heat exchanger at the surface rather than the back of the plate, slots and holes must be drilled in the exchanger for the probes to sit inside, placing them very close to the surface. As discussed in section 7.2.1, there will be a high density of temperature sensors at the inlet side of the plate and they will gradually reduce in density until the exhaust side. Because the density of sensors will be so high in the beginning, slots will be drilled rather than holes and the sensors will be affixed within these slots using a thermal adhesive (seen in the figure below). As the density decreases the slots will stop and individual holes will begin with a temperature sensor placed in each hole and held in place with adhesive.

Figure 7-4 Arctic Alumina thermal adhesive used to hold temp. sensors to the heat exchanger.

Next up is the mass flow sensor's integration with the exhaust tube. As seen in the figure below, the sensor will be sandwiched between two tubes to ease install and so that it can be easily broken down for transport purposes. The first portion of the tube will connect to the exhaust port of the box and run 6 inches unobstructed before reaching the sensor. The second tube will sandwich the sensor between it and the first tube using flanges with bolts through them and run another 6 inches unobstructed before reaching the fan.

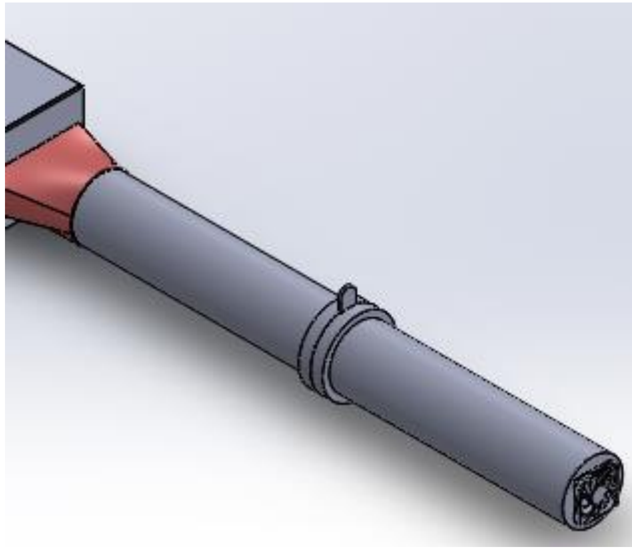


Figure 7-5 Mass flow sensor within the exhaust tube

The fan also must be integrated in to the exhaust tube which will be done with the help of a 3D printed adapter. Because the fan is much smaller than the exhaust tube (only 40mm across vs the tubes 4 inch diameter) and because the fan is square rather than round like the tube, an adapter will be created to join them together. This adapter will be drawn up in CAD and 3D printed in order to create it precisely and quickly. The adapter will be a simple cylinder that slips over the outside of the exhaust tube then tapers down in a conical shape until it reaches the size of the fan, at which point it will become square and holes will be drilled in to it to allow for screws to be driven through to hold the fan in place. Like the rest of the joints in the system, sealant will be spread over every joint to ensure there is no air loss that could throw off our results.

The pressure sensors must also be integrated in to the mechanical portion so that they are within the box and they can get their readings. The first sensor will be placed on the inlet side of the test rig. It will sit a few inches in to the intake so that it can get an accurate pressure reading as well as disturb the airflow as little as possible. A hole will be drilled in the duct for the sensor to stick through and it will be held in place with adhesive so that it doesn't move when breaking down the box for transport. The second sensor will sit at the exhaust side, just a few inches from the outlet. Again, a hole will be drilled for the sensor to poke in through and it will be sealed and held in place with adhesive. Having two sensors, one at the intake and the other at the exhaust gives us a pressure differential across the box which is a necessary requirement for Harris.

The DC power supply will be placed on the top of the outer housing out of the way of components but still relatively accessible. Because it will have a wall power cord plugged in to it, a power switch, and multiple cables running out of it, we want it to be somewhat easy to get to and work on. A small tray will be made (as seen in the figure below) exactly the size of the footprint of the power supply that will have low walls so that the power supply can sit inside of the tray snugly and not slide around. Elastic straps will be affixed to one side of the tray and will be stretched over the power supply and attached to the other side of the tray. This will ensure that the PSU is easy to remove and service if needed, but that it is also securely fastened so that it doesn't move around and potentially unplug something. This tray will be screwed down to the to housing.

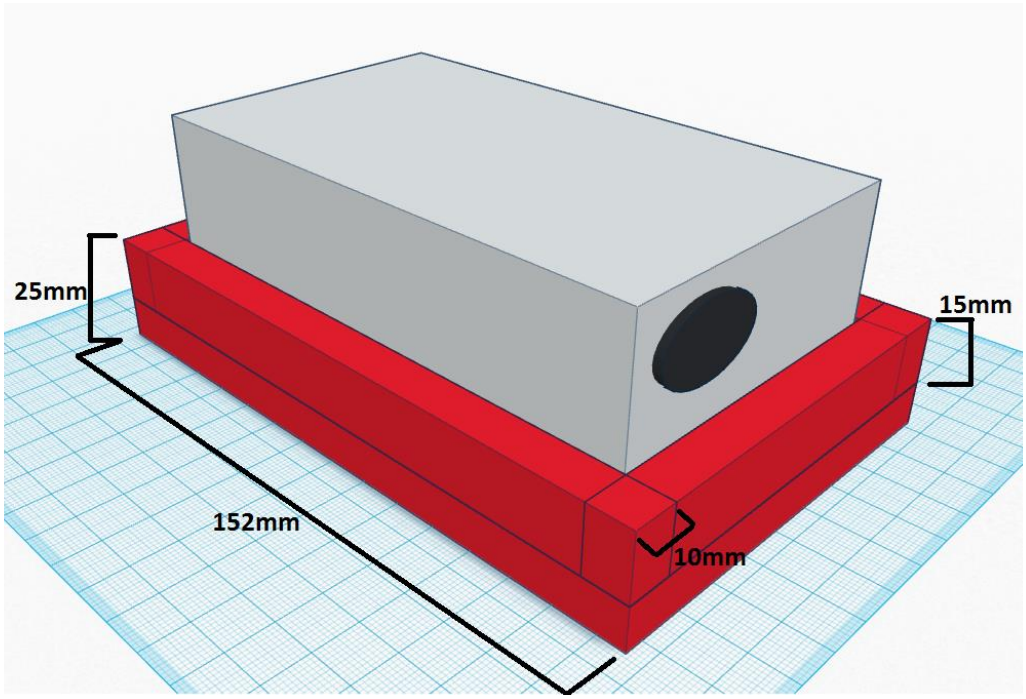


Figure 7-6 DC power supply tray

The AC power supply, which is just be a simple variac, will also be placed on the top of the box. Unlike the DC power supply, the AC one will require direct control from the user so that the wattage of the heaters can be adjusted. A knob on the the top of the unit will determine the power delivered and therefore this knob must be easily accessible and the entire unit must be held tightly so that it doesn’t move around from the user input. In order to do that it will be screwed down to the top of the box near the DC power supply. Most variacs, including the one we are looking at buying, have a plate affixed to the bottom of the unit with holes already drilled in it which will make this job very simple. The DAQ, like the AC power supply and DC power supply, will also be placed on the top of the box. Because it is a much more fragile component, we don’t want it completely exposed to the open environment as it could be easily damaged. To resolve this issue we will place the controller inside of a small box that can easily be opened up should the technician need to work on the controller and will have an opening on one side for cables to go through. This box can be seen in the figure below.

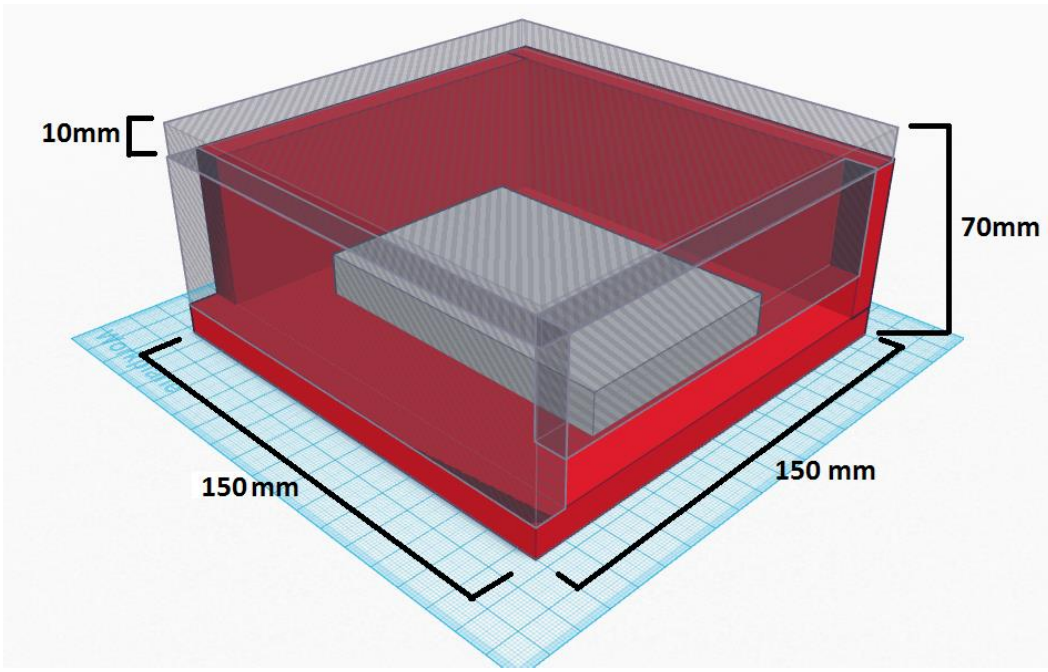


Figure 7-7 DAQ housing

With so many electrical components in our system, there are also a ton of wires. We will have a "cable channel" in the top and bottom of the box between the inner duct and the outer housing where all of the cables will run. One of the most important parts of this cable channel is that it must keep the power cables and sensor cables separate so that we can avoid noise on the sensor signals. To do this we will run power cables on one side of the box and signal cables as far away as possible on the other side of the box with an EMI shield placed in between. The cables themselves will of course also be shielded to prevent interference even further. An example of the cable channel can be seen in the system cut-away below.

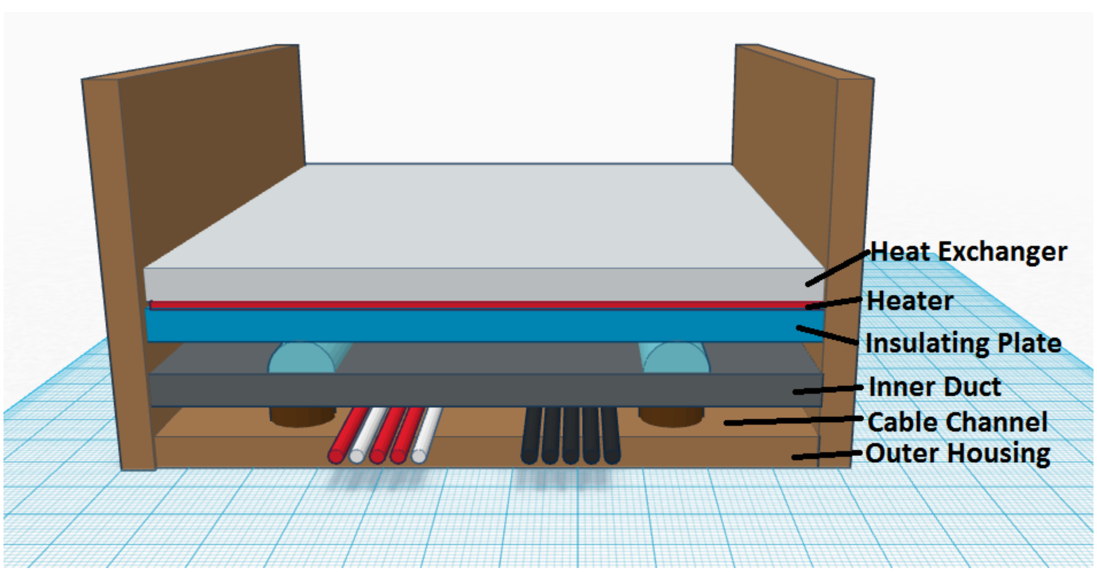


Figure 7-8 System cut-away (bottom half only)

8.0 Testing

The testing portion of our project will consist of two main sections, hardware testing and software testing. Each section will be broken down further into the different types of testing we will do and for each type we will go over each specific subsystem.

8.1 Hardware

The hardware testing section will be broken down into the following components:

- Fan
- Mass flow sensor
- Pressure sensor
- Temperature sensor
- Heaters
- DC power supply
- AC power supply
- DAQ

8.1.1 Preliminary Product Testing

Preliminary testing involves what we have done or will do in the very near future before going up to a full-scale test so that we will at least know that each component should do what we want. By performing these preliminary tests, we can reduce wasted time and money by buying and setting up a very small scale, rudimentary test rig to get a general idea of if each part will do what we expect it to.

Testing for the fan has already been completed. We built a very crude test rig consisting of a PVC pipe taped to a computer fan, as seen in the picture below. Holes were drilled in the pipe and pitot tubes were installed in order to obtain an air velocity reading. We applied 12V DC to the fan leads and watched the readout of the velocity on the computer screen. We timed it roughly going from zero to max velocity and recorded the time it took. The purpose of this test was to get a rough idea of the response time of a general purpose computer fan so that we could ensure we would be able to meet the cycling time requirement of at least 1 Hz. After testing two different sized fans, we found that even a low-end consumer-grade computer fan such as the ones we tested with were able to achieve a response time of 1-2 Hz which is within the range we need. We hope that smaller, more powerful fans will only increase this number.

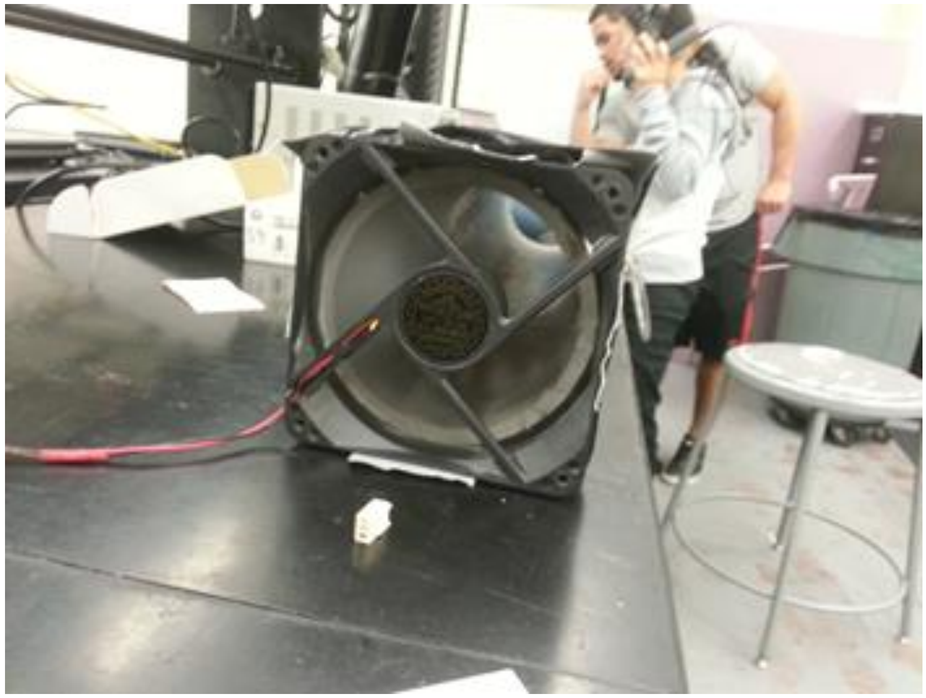


Figure 8-1 Initial fan testing

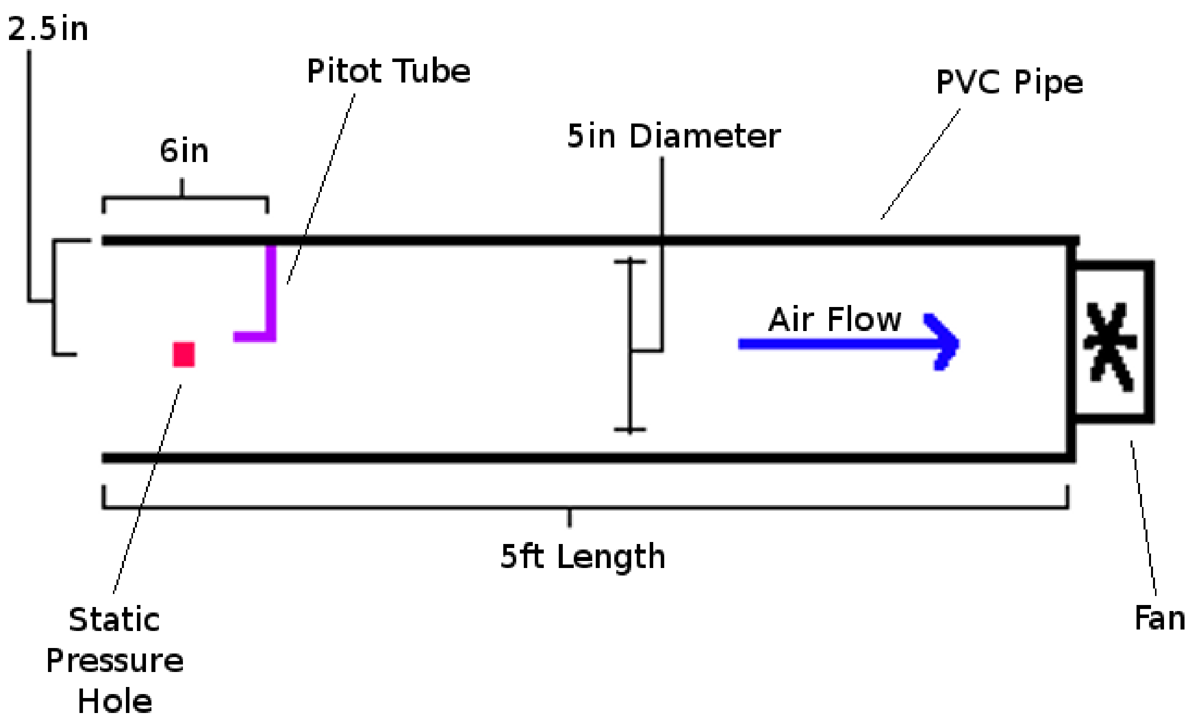


Figure 8-2 Fan testing rig diagram

Mass flow sensor testing will commence as soon as the sensor arrives. In our preliminary test we hope to find a few things including making sure the sensor works, how to calibrate it, and that it will give the readings we are looking for. Our test will be similar to the fan test above except that we will place the mass flow sensor at the end of the pipe and read the output from it on the computer. We will use the airspeed data we have already found, verify it against airspeed data we will collect with a different measuring device, and using simple formulas given the size of the pipe we can calculate the mass flow rate we should be seeing. If our sensor agrees with this data we can move on, otherwise we will try calibrating it and go again. The pressure sensor testing, much like the mass flow sensor testing, will be done in our makeshift duct. We can measure the inlet and outlet pressures and compare these results to what the mechanical students have calculated for a few specific flow rates. Differential pressure can be calculated by comparing the two measured pressures and taking the difference. This reading is critical to what the mechanical team is trying to accomplish so it is important that our readings here line up with where they should be. Response time will be testing by ramping up, ramping down, and abruptly stopping the airflow. We will observe how fast the reading increases or decreases and determine if it will suffice for our purposes. After verifying that the fans can meet the specified requirements we will use the testing rig we designed to find a general model for the transfer function of the fan duct system. We will do this by measuring the response of the system to a step input. With sufficiently clean data we can find the coefficients and determine the position of the fan-duct system's transfer function poles and this data will help us design our controller.

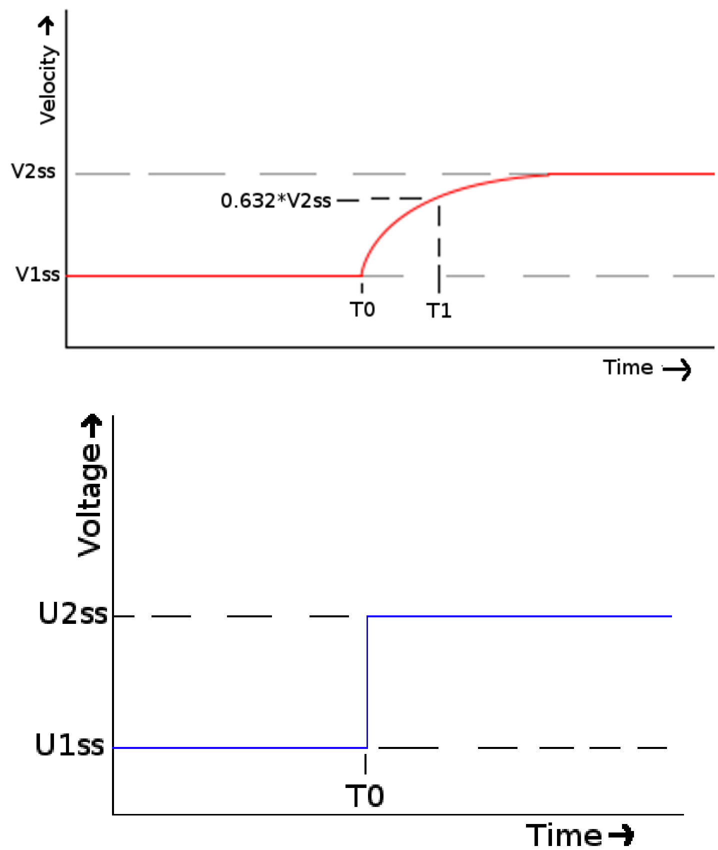


Figure 8-3 Theoretical response of fan-duct system

To determine the mathematical model of the fan-duct system from its unit step response we need to try a couple different generalized mathematical models. First we will assume that the fan-duct system can be sufficiently modeled by a first order system. This may not be true but we need to test if it is. A first order transfer function takes the form **T(s) = K/(Tou*s + 1)**. Where Tou is the time constant and K is the system gain. By inputting a step function into the system be can obtain these coefficients from the graph of the systems output. To find the coefficient K we use the equation **K = (V2ss-V1ss)/(U2ss-U1ss)**. This equation compares how the difference in the steady state values at the input effect the difference in the steady state outputs at the output thus finding the system gain. To find the coefficient Tou we need to calculate the time the output takes to go from its initial steady state value to 63.2% of its final steady state value. This is by definition the time constant of a system. Tou can be found with the equation **Tou = T1 -T0**. Depending of the values of the coefficients we find the pole of the fan-duct system transfer function. Depending on the location of this pole we may require a different controller. Possible types of controllers include proportional, differential, integral, lead, lag and observer based controllers. The fan-duct system may not be able to be represented by a first order system. If we are unable to represent it as a first order system we will have to model it as a second order system. We can obtain the data necessary to do this from the same test but by solving for different coefficients. A second order system is of the form **T(s) = K/(S^2 + zeta*w*S + w^2)** where zeta is the damping ratio and w is the undamped or natural frequency of the system.

The temperature sensors will be tested very simply using hot and cold water of known temps. We will have two cups of water, one containing cold water and the other containing hot water. A digital thermometer will be placed in to each cup and an exact temperature reading of the water will be noted. We will then place out temperature sensor into the water and ensure that its readings concur with those of the thermometer. This will tell us that the absolute readings of the sensors is correct, from there we will test the response time. Response time will be tested by quickly removing the sensors from the water and watching the readings to see how fast it falls or rises. Preliminary testing for the heaters will be pretty straight forward. We will plug them into a power source and make sure that they heat up as they should. Temperature will be measured with a IR thermometer to ensure that they are getting hot enough for our purposes. We will them unplug them and time to see roughly how long it takes to cool down, then plug them back and time the warm up time. While this isn't a critical design requirement, because Harris has requested that the heat source be adjustable, it would be helpful for the heaters and heat exchangers to heat up or cool down quickly to facilitate less downtime between tests at different heat loads.

The DC power supply will not require extensive testing as all it does is provide power. Before plugging it into our expensive electronics though we will at the very least do a quick voltage check to ensure that each rail is providing the voltage we are looking for. There will only be light loads on the power supply so we don't expect there to be any significant issues with ripple or amperage restrictions. Similar to the DC power supply, the AC power supply will not require much testing. We will plug it in and test the output of the variac at multiple different settings to ensure that the output is very close to what the dial says. The heaters will be plugged in to the power supply to ensure that it will be able to handle the load and that everything functions properly before we assemble it. Testing the DAQ will first involve plugging it in and ensuring that everything works as it should. We will plug in some of the sensors and watch the input on each pin to ensure that we are getting the signals we are expecting to see.

8.1.2 Hardware Test Environment

Our test environment will be variable depending on when and what we are testing. So far we have done some preliminary testing in the mechanical student's measurements lab. In this lab they have much of the air speed, temperature, and pressure sensors we need to test the different subsystems as well as verify our findings against to ensure that our sensor readings are correct. We have also done some testing in other areas such as the senior design lab. Although nothing in our rig is extremely fragile or overly heat-sensitive, the system is designed to be run in an air-conditioned indoor environment. The mechanical students have based all of their calculations and designs off of an ambient temperature range of what you would find inside so attempting to run the test rig outdoors could possibly cause many issues. We will be testing the majority of the sensors and other electronics either on campus in one of the many labs we have available or at one of the group members houses. Some considerations we have to take into account are the noise and heat levels. Our fan is a high-power server-grade unit that spins up to 11,000 RPM and therefore will make quite a bit of noise when run at full power. We must be mindful of others in the labs if we are doing testing involving fans, therefore some of that testing will most likely be done in a lab without noise restrictions. Our heater will also be getting very hot in order to sufficiently heat the heat exchangers and we must therefore be very careful in its handling and where we do our testing so as not to possibly damage equipment. The integration testing of our electronics with the mechanical students portions will be done most likely in the mechanical labs on campus as they provide the resources we need and are available often.

8.1.3 Durability Testing

Although we don't have the time or resources to do full-scale, long term durability testing, we will run tests on the following parts:

- Fans
- Temperature sensors
- Heaters

The fans are going to receive the most abuse in the entire system due the nature of how we are ramping them up and down. The constant and aggressive RPM changes will be hard on the motor and bearings as they were designed to run at a constant speed for extended periods of time, not be highly variable. The varying voltage and hard spikes will also be rough on the motor and electronics as most fans prefer a set voltage. By going with a high-quality server fan we are hoping that it will be built to a higher standard than a consumer-grade computer fan and will be able to withstand more abuse. These fans offer significantly longer MTBF due to their use in critical server applications which we believe should translate to longer life in our application as well, even with our unorthodox testing. To add to that, the fan we are using also supports PWM which means that the circuitry should be designed to handle voltage pulsing through the motor at high rates of speed, very much like what we are doing in our project. To test the durability of the fan itself we will leave it running at a set pulsation frequency for an extended period of time, most likely overnight and ensure that it was able to handle that. Because this test rig will be used by Harris engineers to find the issues they are having we are expecting long run-times and heavy use so we must ensure that the fan can handle it.

The temperature sensors will also be tested for durability as well. They will be subjected to long periods of high heat as well as fluctuating heat and we must therefore ensure that they can take it. We will do this testing by placing some of the sensors on or very near the heaters for extended periods of time while we are testing the heaters. As mentioned above, this test rig is expected to be used for hours on end so we must ensure that the temperature sensors are able to continue to function 100% after hours and hours spent under high heat load. The heaters will be durability tested at the same time as the temperature sensors. They will be plugged in to the power supply and the voltage will be run at multiple different settings for hours at a time. The hardest test will come when we run the heaters at full load for an extended period of time, most likely 3-4 hours. Adequate cooling will be supplied for the power supply as it will be getting stressed as well.

8.2 Software

The software we will be using for collection and processing of data will be LabVIEW. This makes the testing very easy. LabVIEW allows the creation of simulated systems to the collection and processing of data. Because of this the same system that we design to collect and process our data can be directly tested in LabVIEW. We just create a file of fake sensor data and feed it through the virtual system we created. The data will be processed as if it came from the actual sensors. Knowing what data we input into the system we can calculate by hand to find what data should be output by the system. If the data matches for each condition then the software is functioning properly.

9.0 Administrative Content

9.1 Team Management

In order to achieve efficient progress in a project, a team must have a good organizational structure. Our team’s structure was done in great detail in the early stages of planning. Taken into consideration during the definition of the team’s organization structure are methods by which inter/intra-team collaboration and communication efforts are done.

9.1.1 Collaboration

Because of the amount of work and range of expertise required by a project of this scale, a certain level of collaboration was needed. It was decided that an ECE team was to work together with a MAE team. The ECE team consists of two electrical engineering majors (Adam Blair and JinJin Lin) and two computer engineering majors (Patrick Armengol and Eric Guest) while the ME team consists of five mechanical engineers (Francisco Avila, Jason Carver, Beyonel Joseph, Jonathan Lopez and Daniel Zehl). Each senior design team was eager and committed to the project at assignment is able to provide the rest of the members with quality information based on expertise of each member's specialization. The two teams were first introduced during the first official meeting with Harris at UCF in which points of contact were determined and future meetings were scheduled.

One of the MAE team's roles in addition to their design of the test rig is to provide us (the ECE team) with vital information based on requirements given by Harris about the project. This information can range from details about the architectural aspects of the apparatus, which can help us visualize and make plans for the layout the components on the rig, to calculations of important heat/air transfer coefficients, which will determine qualities like expected measurement ranges and accuracy requirements so that we can be allowed to be selective with parts during the picking process. The separation of responsibilities is essential to the timely success of the project. This reduces the workload into manageable portions that can be completed in the allotted time by each member. This also allows for each member to be assigned something they are comfortable working on and may already have experience with. Therefore no time will need to be wastefully spent researching a subject that a member lacks expertise in. If any issues arise, the member assigned to the particular task can explain a certain aspect of the topic or decision in question.

This level of collusion is necessary not only between teams but a within each team. Each subsection of the design is written as a task and each member is assigned tasks. The members are required to cooperate at varying levels of the design process in order to develop a harmonious arrangement. For our part in the project, we needed to draft a system that dynamically controlled fans, heaters, and sensor data. Certain snippets of information pertaining to subsections were needed by each member. For example the member handling signal processing needed to know what the input voltages were for adc inputs and the member tasked with powering the system needed to know the power drop for each of the other components, on and off the board.

9.1.2 Communication

The facilitation of the exchange of information is imperative to progress. This need for a way to efficiently communicate is done through various mediums. The decision on how both our teams would communicate was done during the first meeting. During the initial meetings the exchange of contact information occurred. This information included names, phone numbers, and emails. Although this means of communication is a possible solution, it is much too inefficient and can only be used sparingly. Because of this we have created a mixed arrangement infrastructure for communication between and within groups. Future meeting times are done at the end of meetings and confirmed through email. Communication within our team is done through a social messaging platform that all of the members are likely to check frequently. Short, quick, or more important message can be done through sms text messaging. A point of contact is established for each team. This member is majorly responsible for communication between the groups and with the customer, Harris. The most comprehensive form of communication is meetings. There are meetings our own team members, meetings with the entire team, and meetings with the customer. Each of these types of meetings are done on weekly or biweekly basis. Towards the end of the semester they are held more frequently as there is a greater need for detailed planning and organization for final processes in the project's development.

9.2 Timeline & Deliverables

Project Main Steps	Estimated Time
Requirement Definition	1 week
Block Diagram	1 week
Trade Studies / Research	3 weeks
Part Selection	2 weeks
System Design	2 weeks
Design Review	1 week
Prototyping	2 weeks
Assembly	3 weeks
Testing and Verification	2 weeks
Experimentation	1 week
Documentation	1 week

Table 9-1 Project process time estimates

Table 9-1 above shows the estimated time required to finish each of the processes needed to complete the project design. The conclusion of each process is marked by a milestone deliverable which is presented amongst members or to the customer.

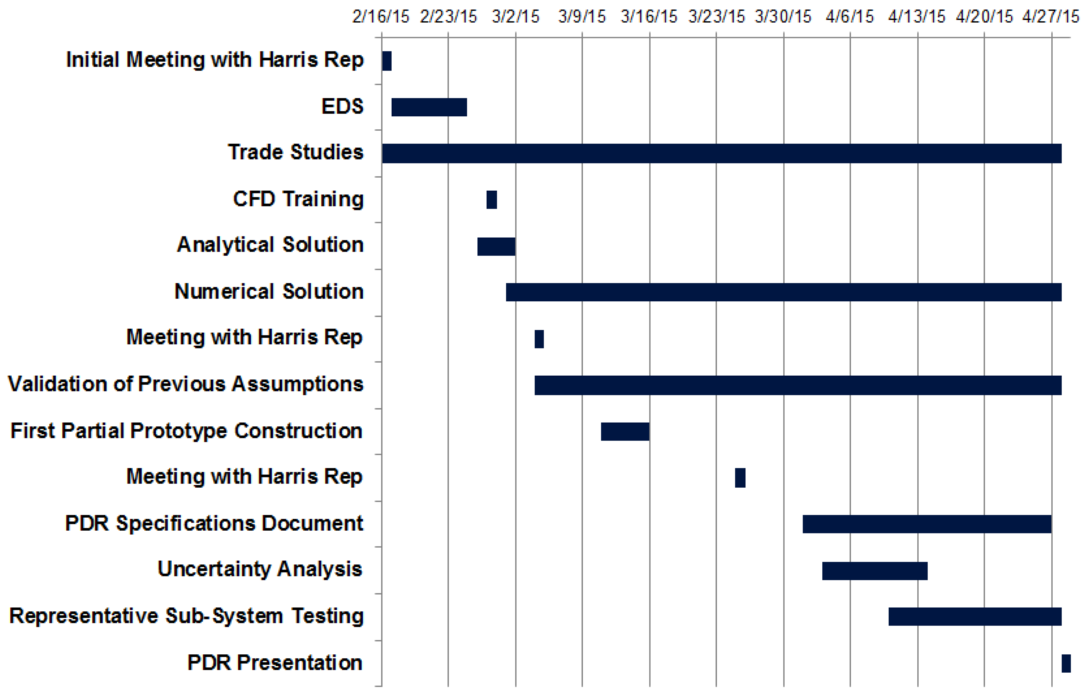


Figure 9-1 SD1 mechanical/ee timeline

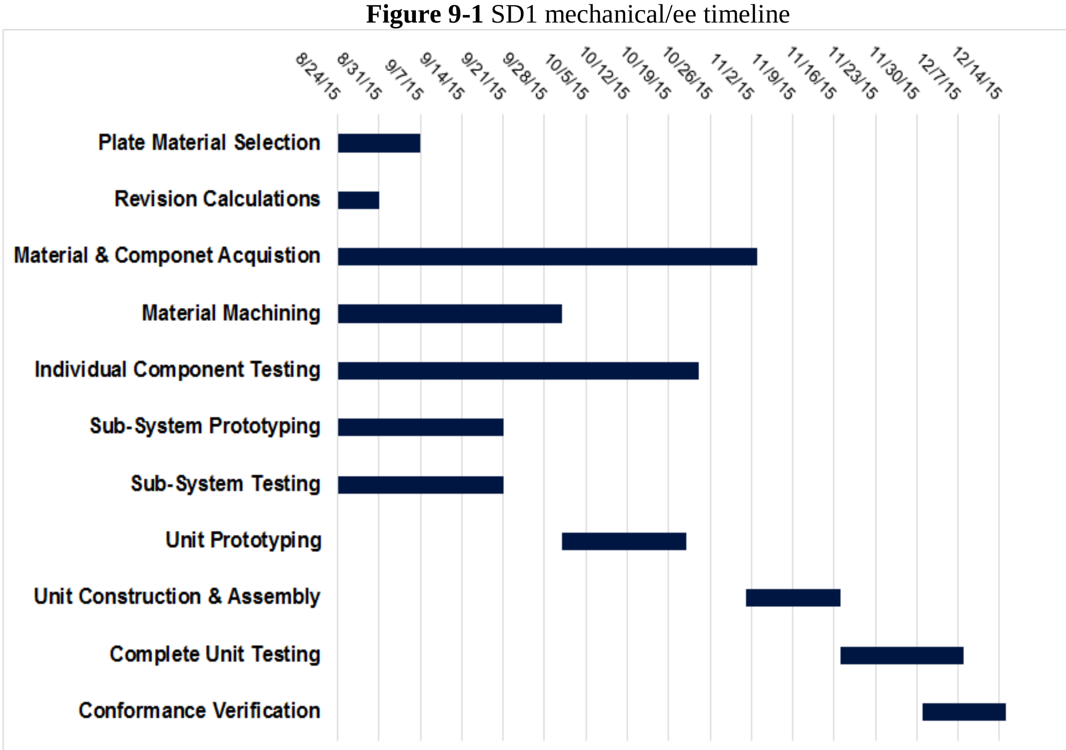


Figure 9-2: SD2 projected mechanical/ee timeline

Figure 9-1 and 9-2 above were given to us by the mechanical team as their past and projected timeline for the project. After discussion with the Harris representatives during our final presentation to them we concluded that this timeline would need to be expedited during our second semester simply due to how much of a workload we would be experiencing. To counter this we plan to take care of the more simple tasks of parts acquisition, limited initial testing, and machining over the summer.

9.3 Budget & Finances

As this project is commissioned by the customer Harris, the budget is decided by them. For this project the budget has already been predetermined. Harris have generously provided us with $5000 in order to be able to complete our design according to their specifications in a timely manner. It also allows us to prototype and experiment with different tools to assist with certain design steps like part selection.

The total amount of money used by us for the project, though yet to be determined, is expected to be much less than the given budget. This is mostly due to the fact that the bulk of the cost will be attributable to the ME side of the project. The construction of the test apparatus itself is costly. Our main costs on the ECE side are the (specialized) sensors and the PCB build/components.

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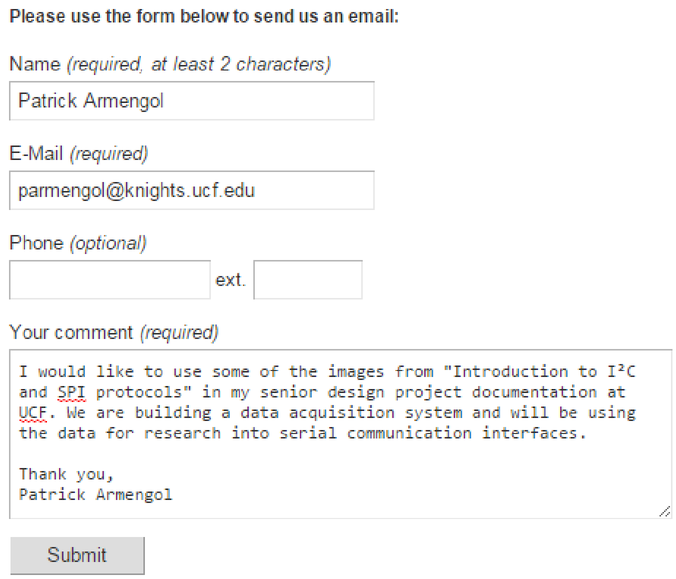
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Patrick Armengol

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Phone *(optional)*

ext.

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I would like to use some of the images from "Introduction to I²C and SPI protocols" in my senior design project documentation at UCF. We are building a data acquisition system and will be using the data for research into serial communication interfaces.

Thank you,
Patrick Armengol

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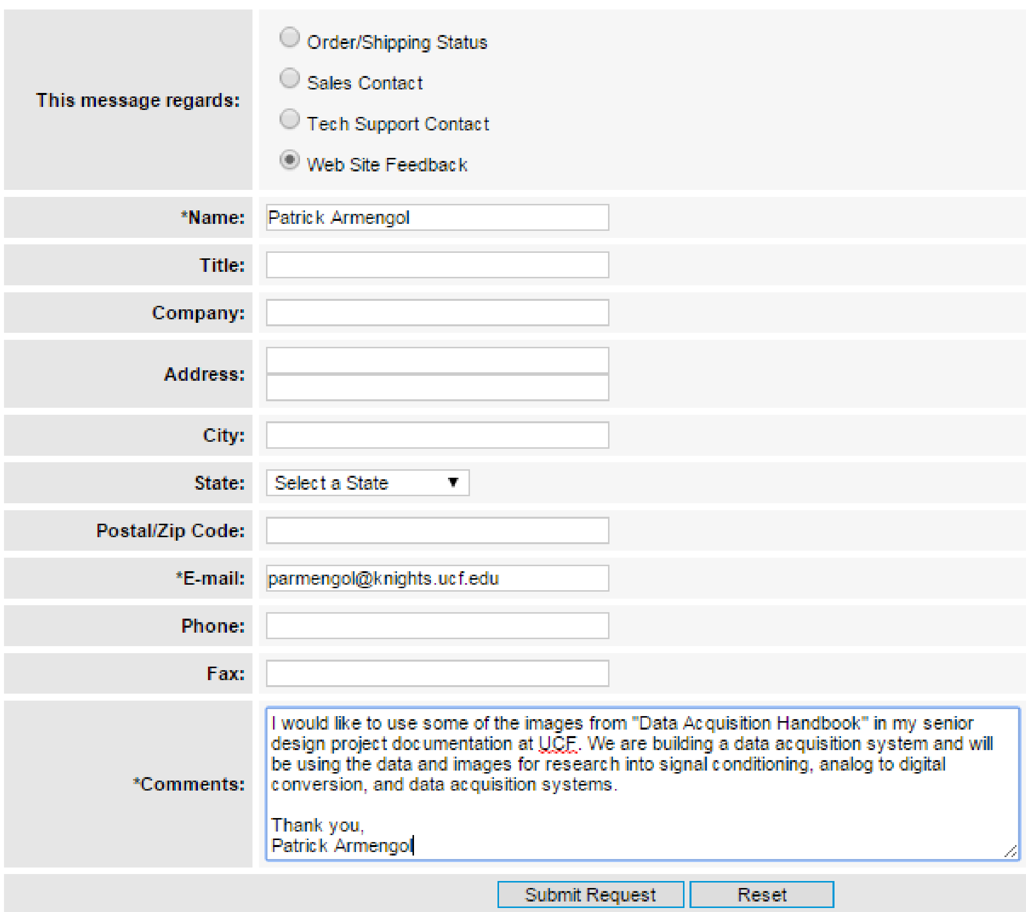
Byte Paradigm - Figures 3-37 through 3-40



This message regards:	Order/Shipping Status Sales Contact Tech Support Contact Web Site Feedback
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Address:	
City:	
State:	Select a State
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***E-mail:**	parmengol@knights.ucf.edu
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Measurement Computing - Figures 3-20 through 3-36

To: webmaster@digilentinc.com

Cc:

Subject:

Calibri 12

Hello,

I would like to use some of the images from the Basys3 board block diagrams and schematics in my UCF senior design project documentation. We are building a data acquisition system and will be using the board in our design.

Thank you,
Patrick Armengol

Digilent - Figures 6-14 through 6-18

product number / amount: LBAS025UF6S / 2

Comment: I would like to use some of the images from your resources on pressure sensors and the documentation of the LBA differential pressure sensor in my UCF senior design project documentation. We are building a data acquisition system and will be using the sensors in our design.

How did you learn about our website?:

Mandatory fields are marked with *

delete Send Email

Sensortechnics - Figures 3-4 through 3-9, 6-7 through 6-9

To: webmaster@omega.com

Cc:

Subject: Permission to Use Picture

To whom it may concern,

My name is Eric Guest and I am a senior computer engineering student at the University of Central Florida. I am emailing to request permission to use a picture pulled from your website for my senior design project. I appreciate your assistance and consideration in this matter.

Picture in question:

The dimensions diagram from the following spec sheet.
http://www.omega.com/pressure/pdf/PV100.pdf

To: toysareforboys@gmail.com

Cc:

Subject: Permission to Use Picture

Hello,

My name is Eric Guest and I am a senior computer engineering student at the University of Central Florida. I found your fan spec diagram on the bit-tech forums and I am emailing to request permission to use that picture for my senior design project. I appreciate your assistance and consideration in this matter.

Picture in question:

http://likestuff.globat.com/Gateway_i7/140mm%20case%20fan%20side%20panel%20cut%20out%20diagram%20dimensions%20cutout%20template.gif

To: infoas@arcticsilver.com

Cc:

Subject: Permission to Use Picture

To whom it may concern,

My name is Eric Guest and I am a senior computer engineering student at the University of Central Florida. I am emailing to request permission to use a picture of the Arctic Alumina Thermal Adhesive for my senior design project. I appreciate your assistance and consideration in this matter.

Picture in question:

http://www.arcticsilver.com/images_v2/aata/aata_addm1.jpg

Arctiv Silver - Figure

To: info@sagemetering.com

Cc:

Subject: Permission to use figure

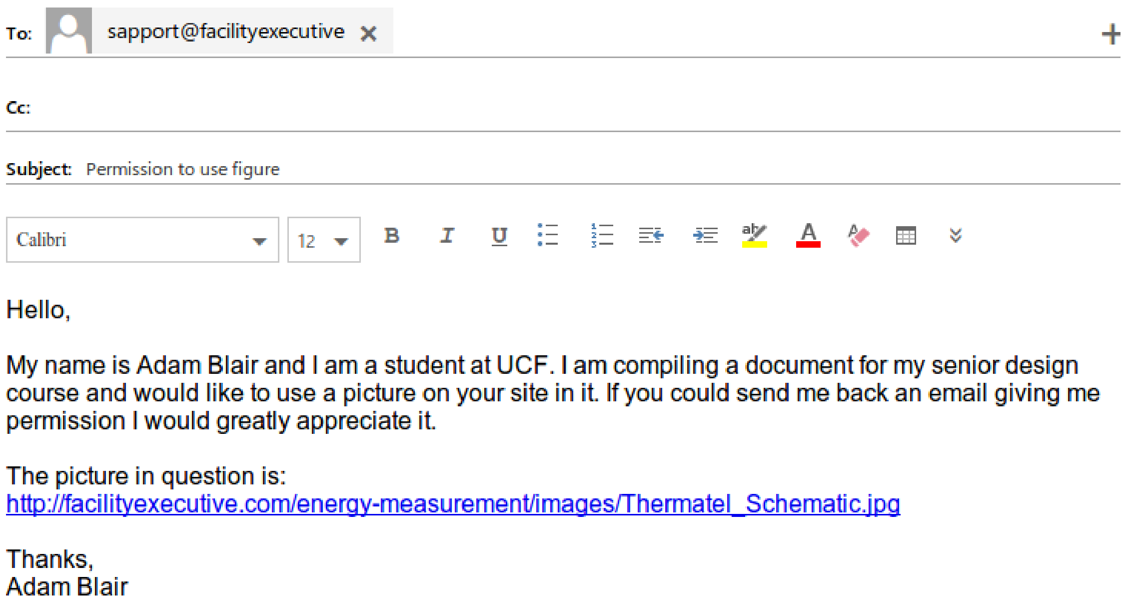
Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The picture in question is:
http://sagemetering.com/wp-content/uploads/2014/11/orifice-plate-300x251.png

Thanks,
Adam Blair

Sage Metering - Figure 3.13


To: sapport@facilityexecutive

Cc:

Subject: Permission to use figure

Calibri 12

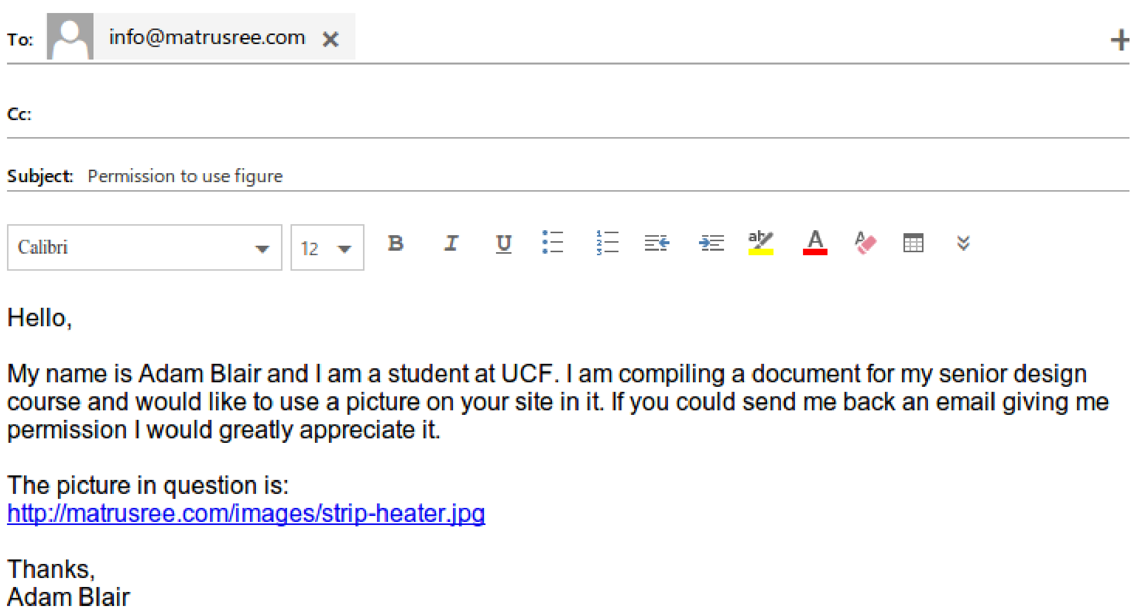
Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The picture in question is:
http://facilityexecutive.com/energy-measurement/images/Thermatel_Schematic.jpg

Thanks,
Adam Blair

Facility Executive - Figure 3.12


To: info@matrusree.com

Cc:

Subject: Permission to use figure

Calibri 12

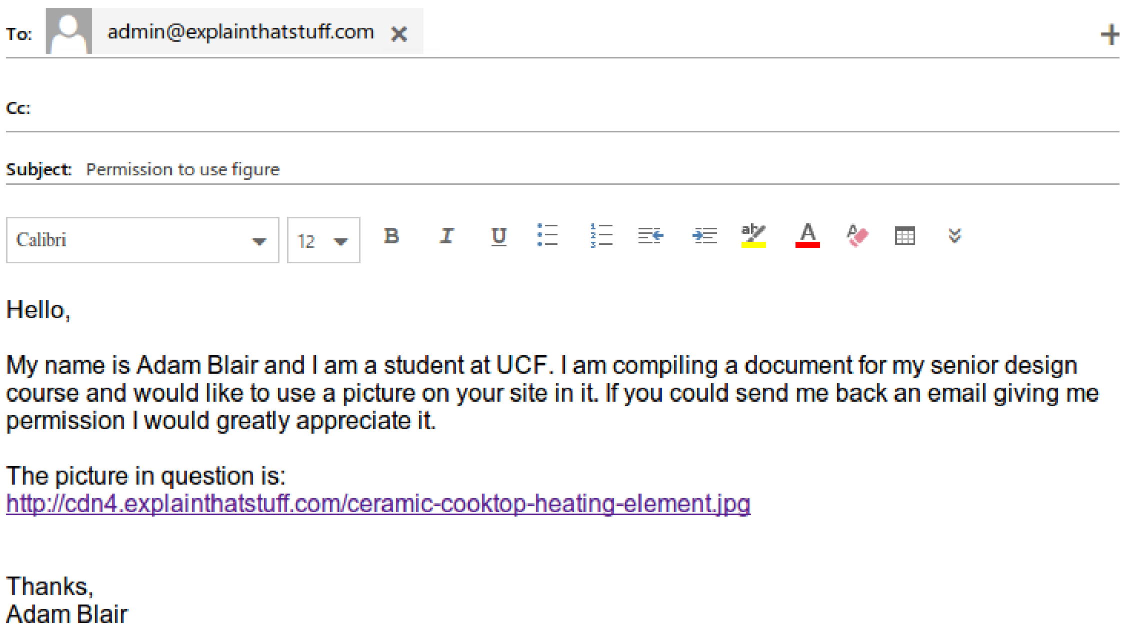
Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The picture in question is:
http://matrusree.com/images/strip-heater.jpg

Thanks,
Adam Blair

Matrusree Manufacturing - Figure 3.16



To: admin@explainthatstuff.com

Cc:

Subject: Permission to use figure

Calibri 12

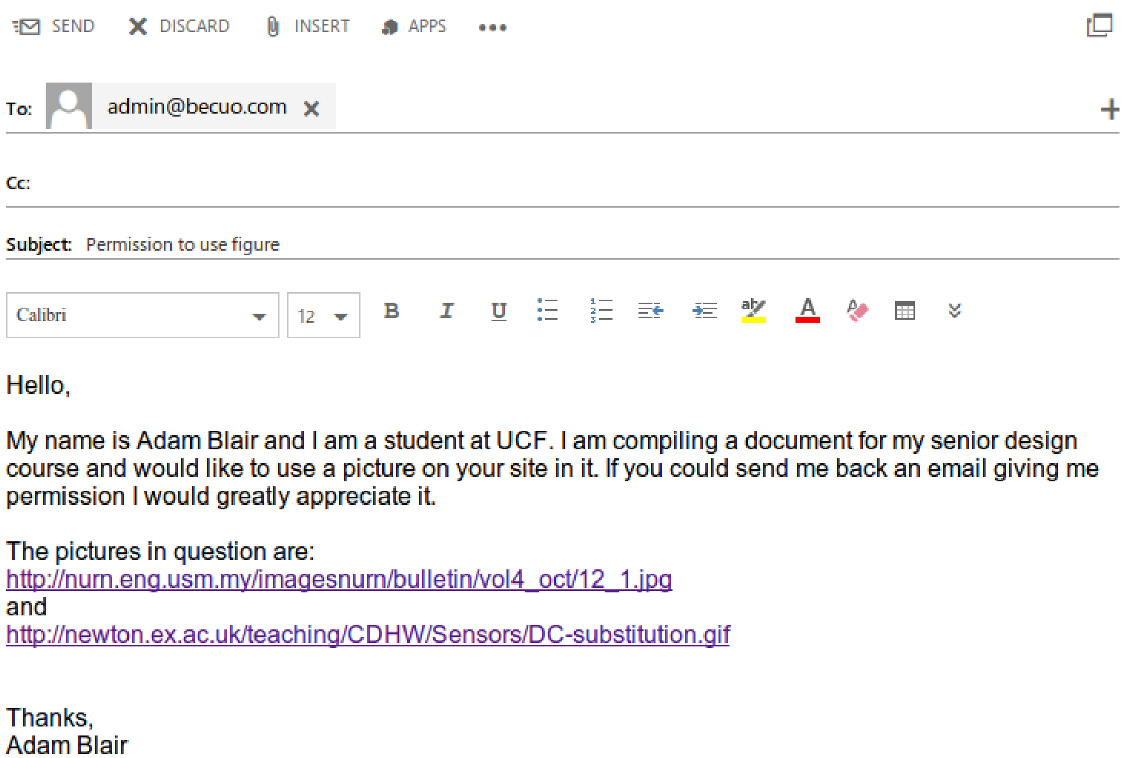
Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The picture in question is:
http://cdn4.explainthatstuff.com/ceramic-cooktop-heating-element.jpg

Thanks,
Adam Blair

Explain That Stuff - Figure 3.17



SEND DISCARD INSERT APPS

To: admin@becuo.com

Cc:

Subject: Permission to use figure

Calibri 12

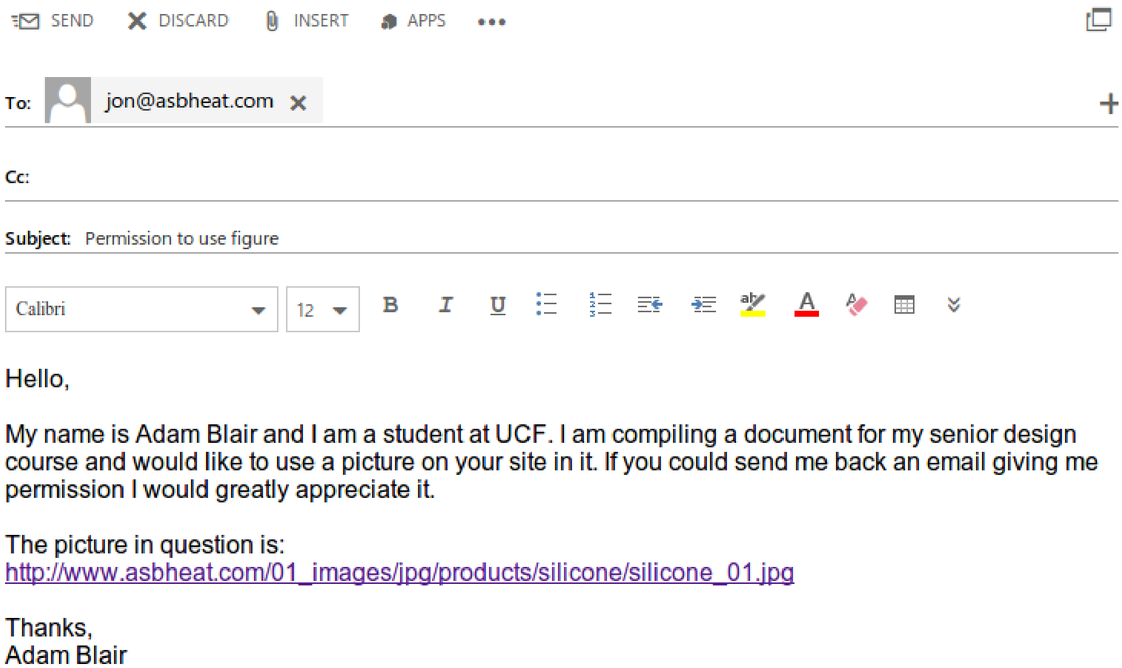
Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The pictures in question are:
http://nurn.eng.usm.my/imagesnurn/bulletin/vol4_oct/12_1.jpg
and
http://newton.ex.ac.uk/teaching/CDHW/Sensors/DC-substitution.gif

Thanks,
Adam Blair

Becuo - Figure 3.10, 3.11


SEND DISCARD INSERT APPS

To: jon@asbheat.com

Cc:

Subject: Permission to use figure

Calibri 12

Hello,

My name is Adam Blair and I am a student at UCF. I am compiling a document for my senior design course and would like to use a picture on your site in it. If you could send me back an email giving me permission I would greatly appreciate it.

The picture in question is:
http://www.asbheat.com/01_images/jpg/products/silicone/silicone_01.jpg

Thanks,
Adam Blair

ABS Heating Elements - Figure 3.18

Appendix B - References

Section 4.1.1.1
https://standards.ieee.org/findstds/standard/295-1969.html

Section 4.1.2.1
https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10675

Section 4.1.3.1
https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=20524