Concept Generation & Selection

EML 4551C – Senior Design – Fall 2011

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Google Mobile App for Compressor Performance (GE)

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Compressor Performance Application

Majority of technical issues for a compressor are on flow, not achieving.

Looking to design a simple flow measurement system that could be externally mounted on the inlet/outlet pipe to the compressor, the sensor(s) would transmit the information back to a Android phone where data could be stored/plotted.

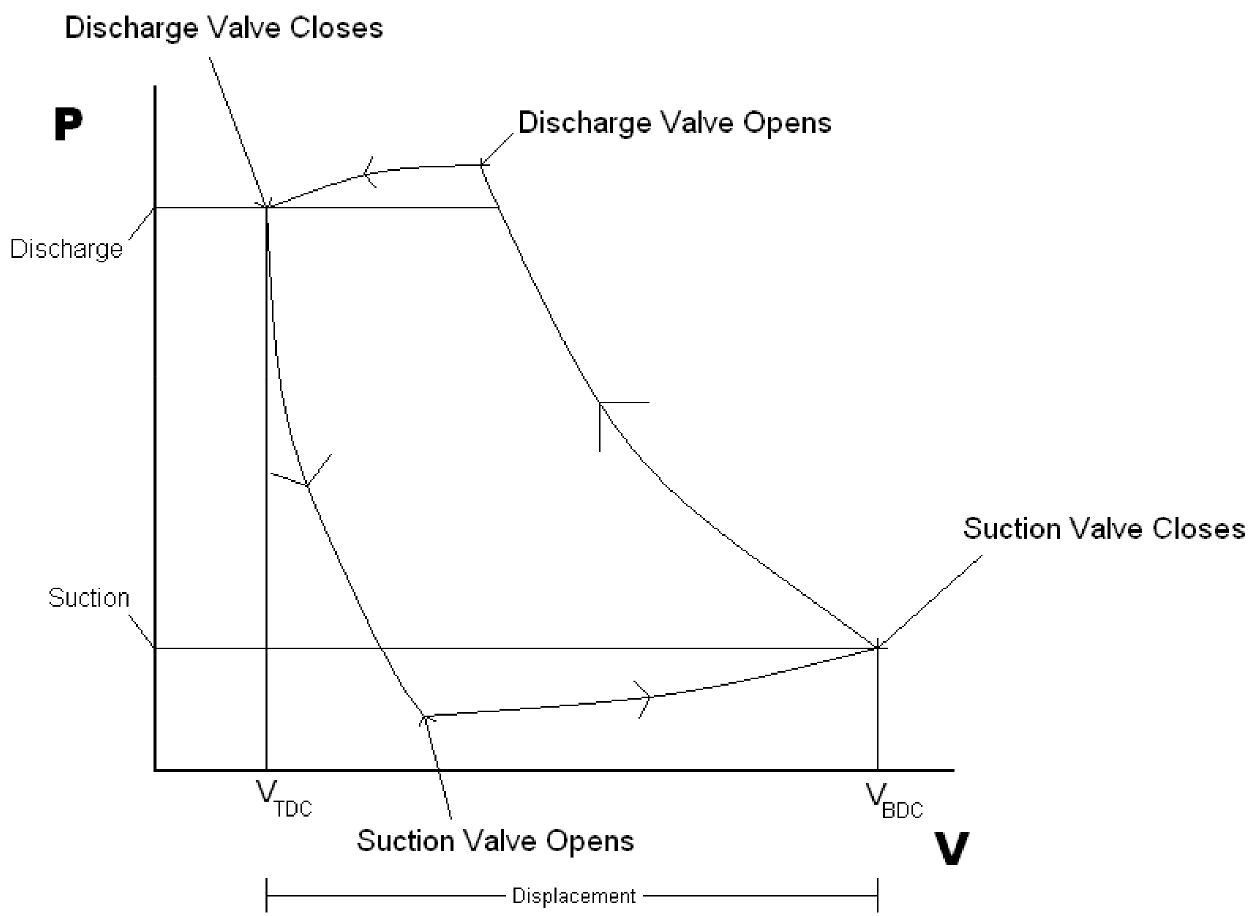
-As specified by Todd Hopwood (GE)

Design Product Specification

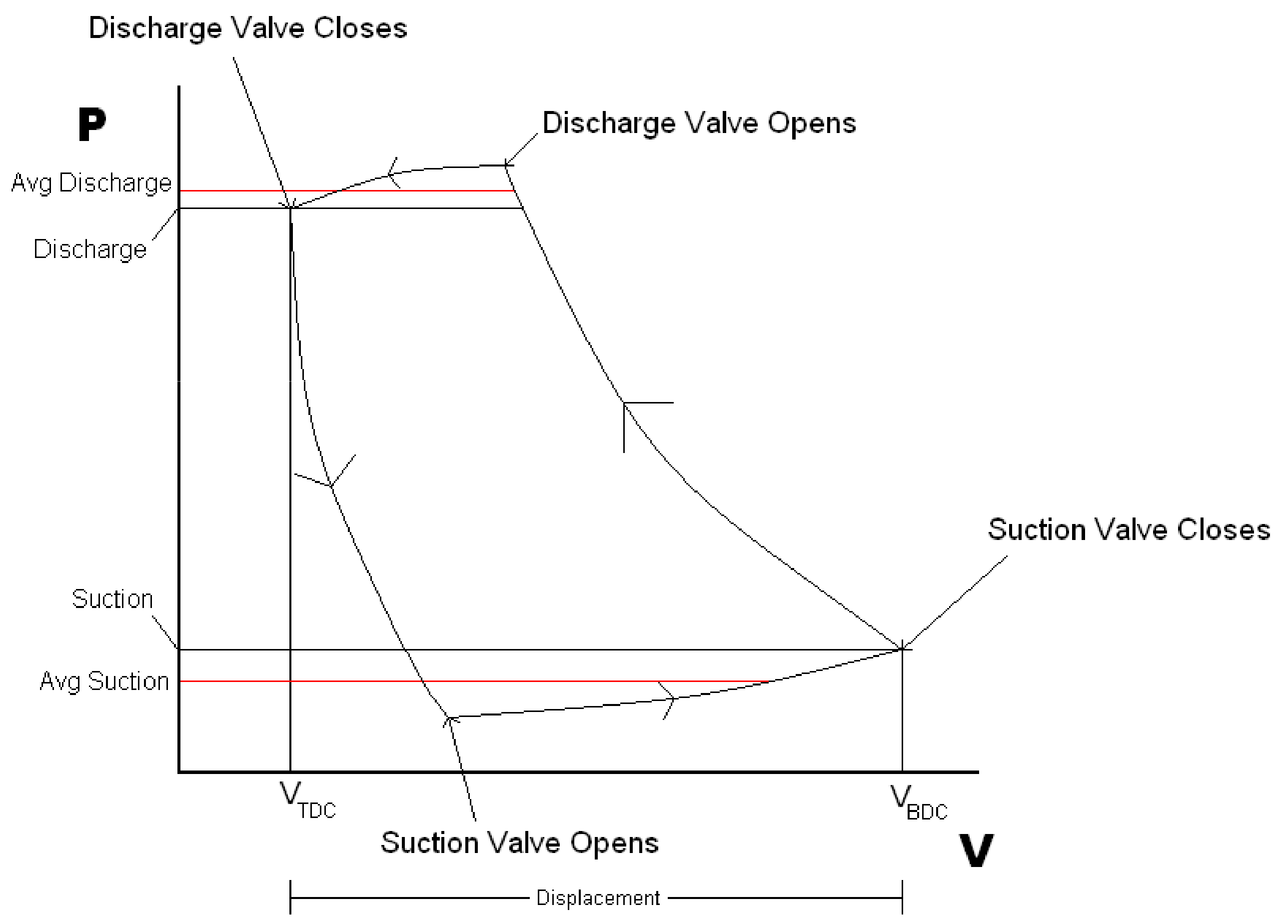
1. Data transferred through Wi-Fi or ? To an Android phone.
2. Setup time on the compressor less than 5 minutes, prefer 120 seconds or less.
3. No modifications allowed to the piping going to the package.
4. Software capturing data should be able to store the data and plot live.
5. Working Demo

As specified by Todd Hopwood (GE)

P-V Diagram


Discharge Valve Closes
P
Discharge Valve Opens
Discharge
Suction Valve Closes
Suction
V
TDC
V
BDC
Suction Valve Opens
V
Displacement

P-V Diagram



Discharge Valve Closes
P
Discharge Valve Opens
Avg Discharge
Discharge
Suction Valve Closes
Suction
Avg Suction
V
TDC
V
BDC
Suction Valve Opens
V
Displacement

P-V Diagram

pv_diagram_eng.exe

Calculating Pressure in Pipe

- Total pressure defined as:

$$P_{total} = P_{static} + P_{dynamic}$$

- Static pressure:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Calculating Static Pressure

- Discharge Pressure (ideal):

$$P_2 = P_1 \frac{V_1}{V_2}\frac{T_2}{T_1}$$

- Where:
  - V_1/V_2 = compression ratio
  - T_1 and T_2 are measured or assumed
  - P_1 is known

Static Pressure

- P_1 and P_2 are therefore the static pressures that will be used when modeling the P-V curve
- Assumptions
  - Known P_1
  - Ratio between P_{static} and $P_{dynamic}$ changes very little with a change in P_{total} in the range we are measuring

Dynamic Pressure Assumption

- So, any difference in our P-V curve from ideal case will be due solely to change in dynamic pressure:

$$P_{dynamic} = \frac{1}{2}\rho V^2$$

- Not a good assumption if very accurate measurement is needed, but likely good enough to detect a flow problem in a compressor

Pressure Drop in Pipe

- Pressure drop in pipe between valve and transducers:

$$\Delta p = f * \frac{L}{D} * \frac{1}{2} \rho V^2$$

- Where:

  f = Darcy friction factor

  L = distance between valve and middle of transducers

  D = inner diameter of pipe

  ρ = density of the fluid

  V = measured velocity of the fluid in the pipe

Pressure Drop in Pipe

- Since we assume Laminar flow:

$$f = \frac{64}{Re}$$

- Reynold's Number:

$$Re = \frac{\rho V D}{\mu}$$

- μ = Dynamic viscosity of the fluid
- So, pressure drop resolves to:

$$\Delta p = \frac{32 \mu L V}{D^2}$$

Calculating Cylinder Pressure

- Discharge:

$$P_{cyl} = P_2 + P_{measured} + \Delta p$$

$$P_{cyl} = P_2 + \frac{\rho V_{discharge}{}^2}{2} + \frac{32\mu L V_{discharge}}{D^2}$$

- Suction:

$$P_{cyl} = P_1 + P_{measured} - \Delta p$$

$$P_{cyl} = P_1 + \frac{\rho V_{suction}{}^2}{2} + \frac{32\mu L V_{suction}}{D^2}$$

Preliminary Pressure Calculator

- Demonstration of a pressure calculating algorithm

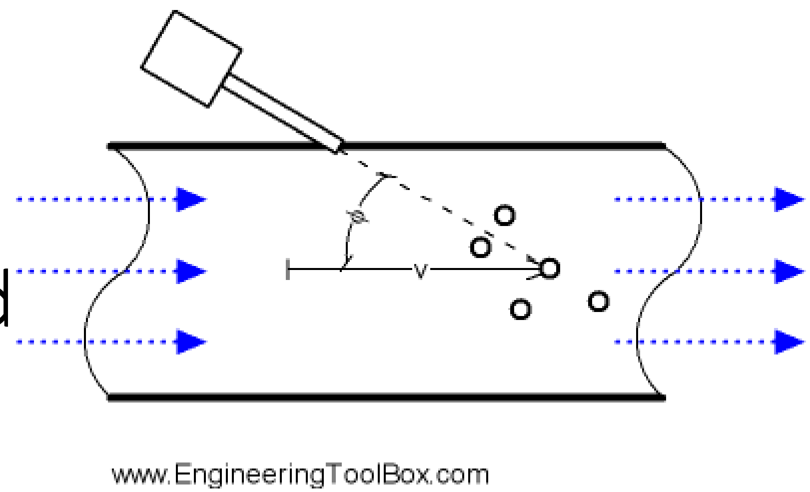
- For a single velocity value
  - Future iterations will send live output to our graphs

What Are Ultrasonic Transducers?

- Generate frequencies
  18 kHz and above by turning
  electrical signals into sound
- The rate these waves are slowed/reflected is dictated by the properties of the medium, including its motion
- This slowing can be calculated using several methods

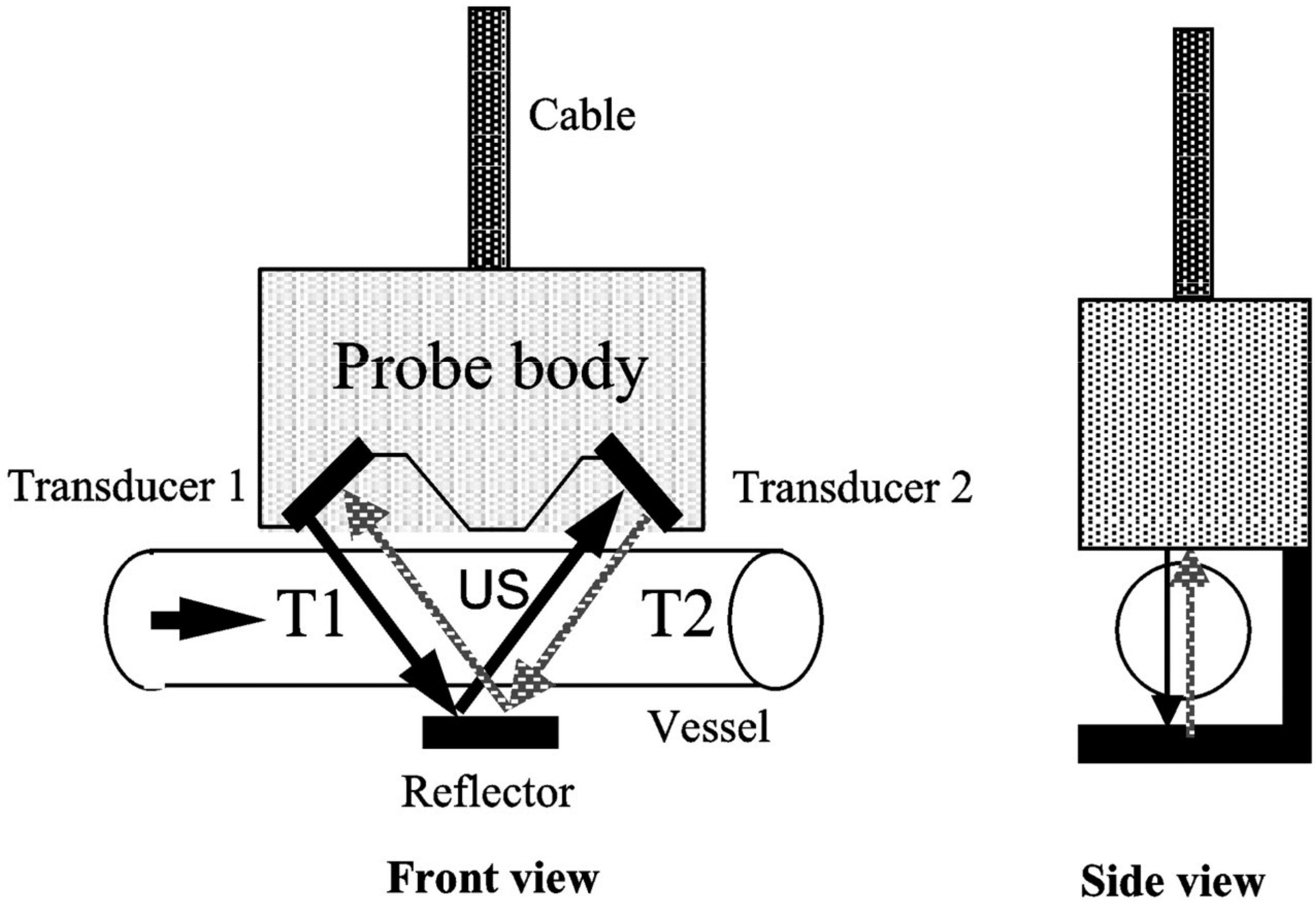
Doppler Effect

- Ultrasonic waves exit the emitter and enter the fluid and are reflected off particulate matter into the receiver.
- Measures the speed of the particles



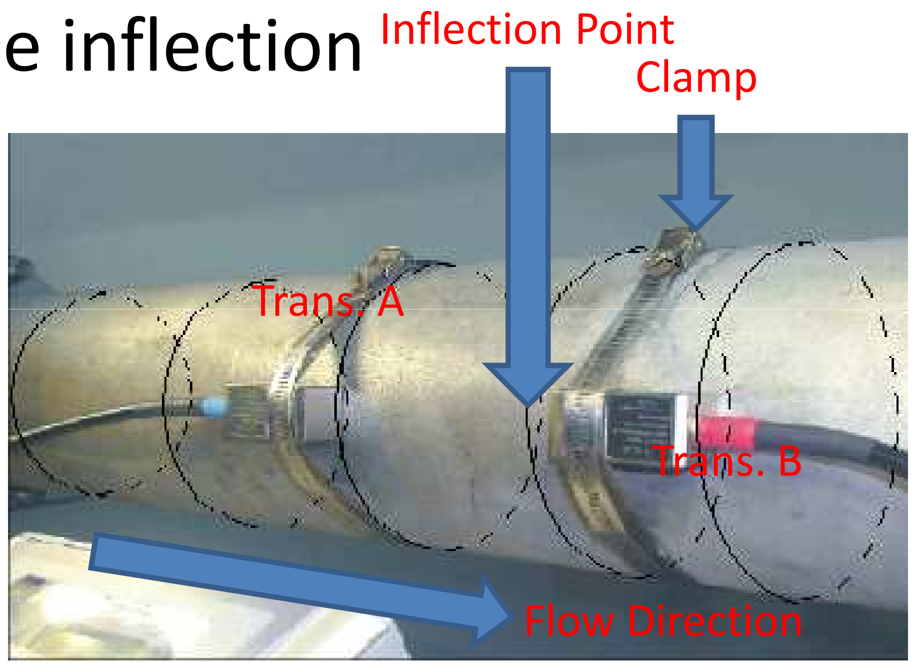
- Not applicable to fluids with very small or no particulate ("clean liquids" or gasses)

Transit-Time Flow Concept



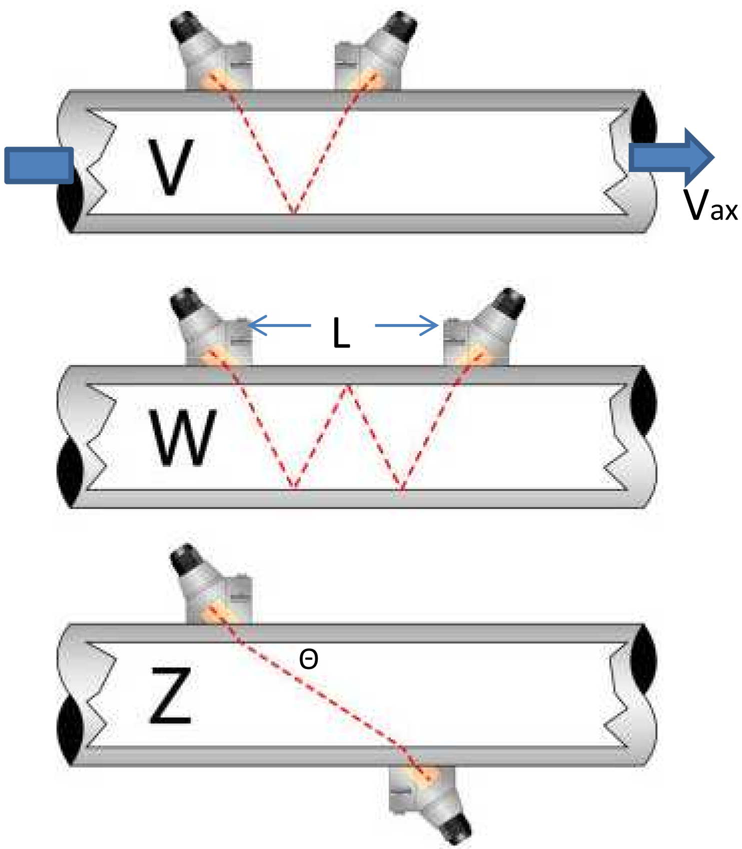
Transit-Time Flow Concept

- Ultrasonic waves exit the emitter of Trans. A and are reflected off the inflection pt. into detector B.



- Signal is slowed based on fluid properties and velocity of flow
- Fluid will flow faster in the direction of the flow

Transit-Time Flow Concept



(1) $$V_{ax} = \frac{L}{2\cos\Theta} \times \frac{\Delta t}{t_{up} \times t_{down}}$$

Where:

V_{ax} = the axial liquid velocity along the acoustic path

L = straight line distance between the centers of the faces of the upstream and downstream transducers

Θ = the path angle of transmission relative to the fluid at rest

t_{up} = the upstream transit-time

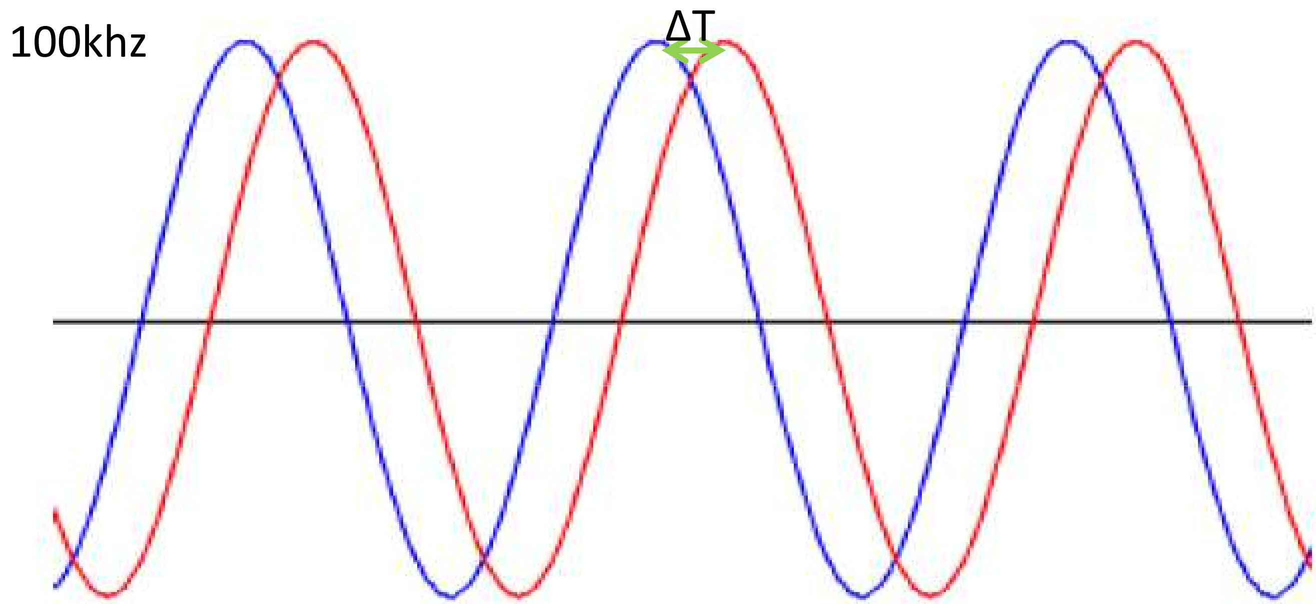
t_{down} = the downstream transit-time

$\Delta t = (t_{up} - t_{down})$ = the differential transit-time

Choice Methods of Deducing ΔT

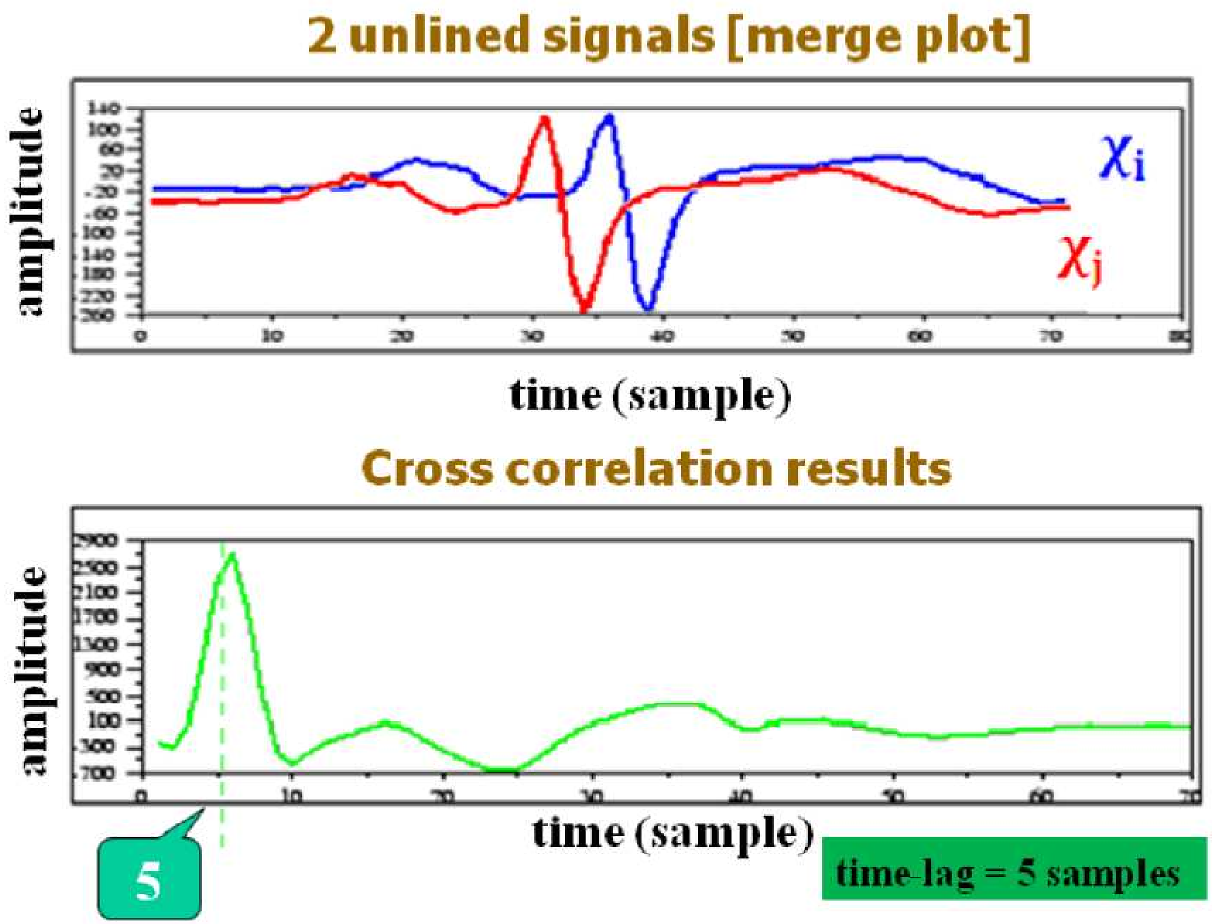
- Cross Correlation
  - Find phase shift between two sine waves using signal reconstruction for cross correlation
    - Only requires two samples per waveform
  - Information is in the signal
- Signal Burst
  - Send out bursts of ultrasonic signal and timestamp when it is received
  - Information is in the timing

Cross Correlation Method



- The transit time is calculated by finding the phase shift between the original sine wave sent out and the sine wave received.

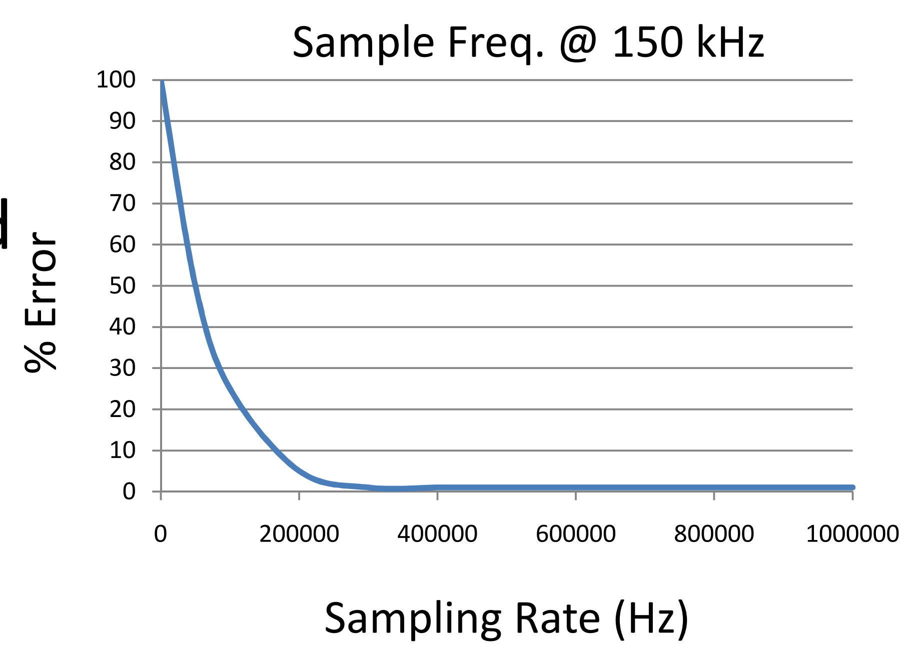
Cross Correlation Method



$$(f \star g)(t) \stackrel{\mathrm{def}}{=} \int_{-\infty}^{\infty} f^*(\tau)\ g(t+\tau)\,d\tau.$$

Cross Correlation Method

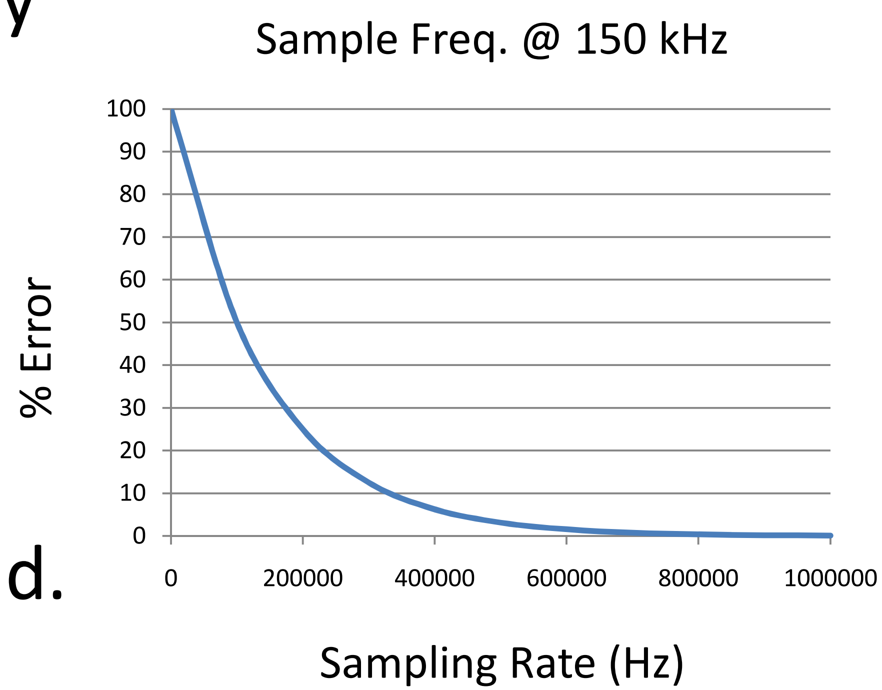
- Only need two samples per waveform to reconstruct signal
- Nyquist–Shannon sampling theorem
  - If a function contains frequencies of B hertz, it need only be sampled 1/2B times per second to perfectly reconstruct the signal



[Some Information]

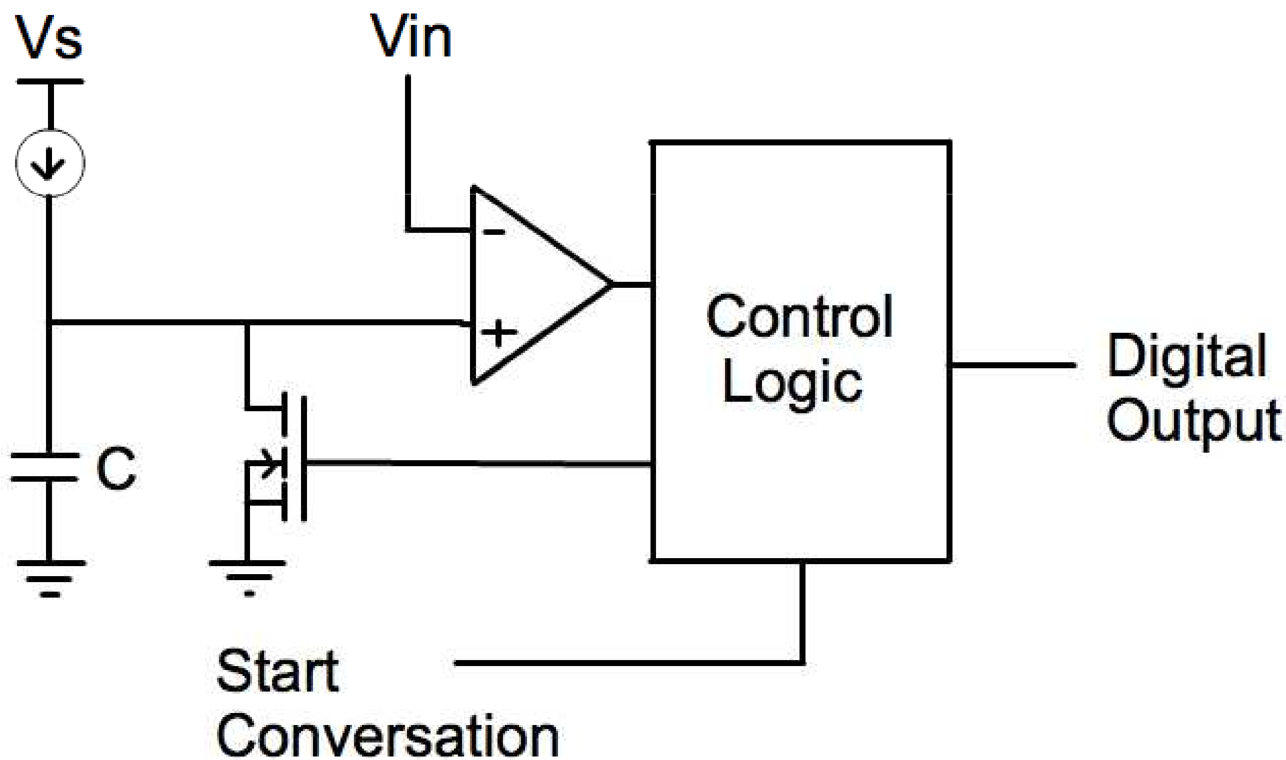
Signal Burst Method

- Bursts of signal can be sent through transducers with the microprocessor waiting for input
- The % Error is inversely proportional to the number of times the microprocessor checks for new information per second.



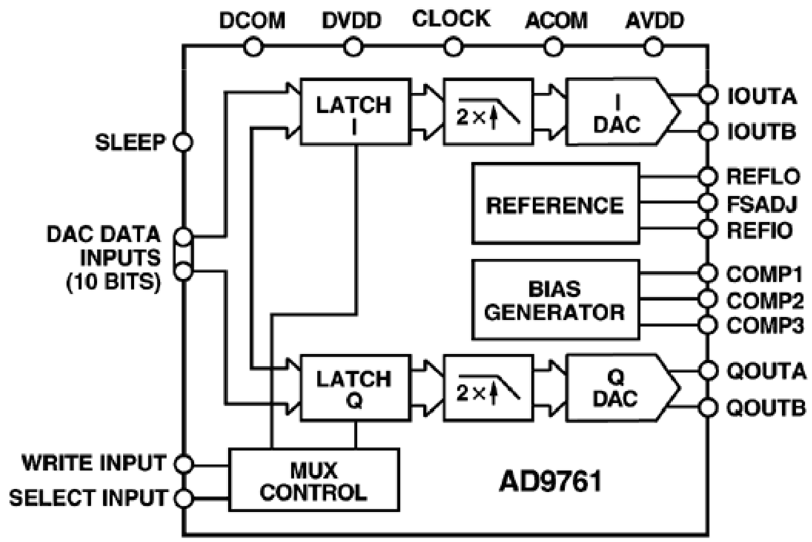
Signal Burst Method

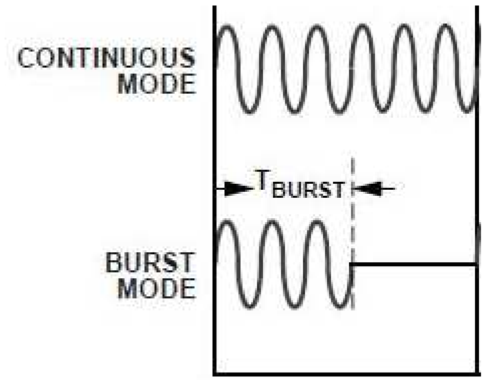
- Simple A/D converter



Signal Generation

- In order to generate a clean >100Khz signal, an external DAC may be needed
- Analog Devices Inc. carries a range of DAC's < $20 that are capable of doing this





AD9761 $10.16, Generates up to 30MHZ

Processing Using Cross Correlation

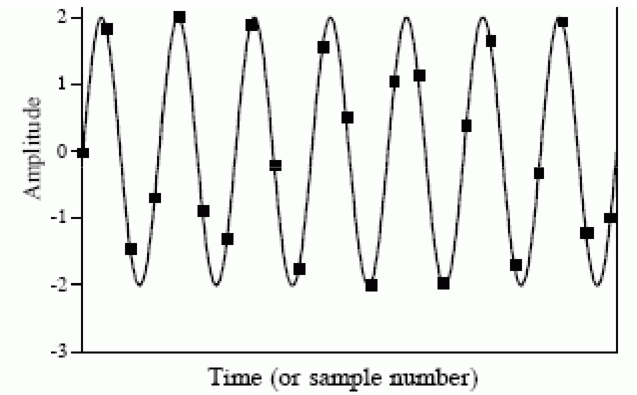
- 100Khz = Minimum frequency for an ultrasonic signal to properly penetrate a gas medium.
- The cross-correlation method requires us to reconstruct that >100Khz sine wave => our Analog to Digital converter must at least sample at 200Khz as per Nyquist Theorem.
- Floating point calculations required which a simple 8-bit microcontroller (i.e. Arduino), cannot do fast enough to have proper throughput.

TS-7800 SPC
500Mhz ARM9 CPU
Built-in 2khz ADC

TS-ADC24 Add-on
2Mhz ADC

Processing Using Cross Correlation

- Signals will need to be sampled and reconstructed before being cross correlated.



- Current meters using this method can get up to 256 samples/second.

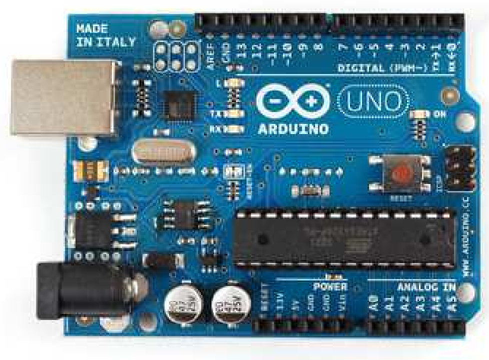
http://www.sierrainstruments.com/prnews/Sierra%20White%20Paper-%20Core%20Technology%20Ultrasonic.pdf

```
/* Calculate the mean of the two series x[], y[] */
 mx = 0;
 my = 0;
 for (i=0;i<n;i++) {
   mx += x[i];
   my += y[i];
 }
 mx /= n;
 my /= n;

 /* Calculate the denominator */
 sx = 0;
 sy = 0;
 for (i=0;i<n;i++) {
   sx += (x[i] - mx) * (x[i] - mx);
   sy += (y[i] - my) * (y[i] - my);
 }
 denom = sqrt(sx*sy);

 /* Calculate the correlation series */
 for (delay=-maxdelay;delay<maxdelay;delay++) {
   sxy = 0;
   for (i=0;i<n;i++) {
     j = i + delay;
     while (j < 0)
       j += n;
     j %= n;
     sxy += (x[i] - mx) * (y[j] - my);
   }
   r = sxy / denom;

   /* r is the correlation coefficient at "delay" */

 }
```

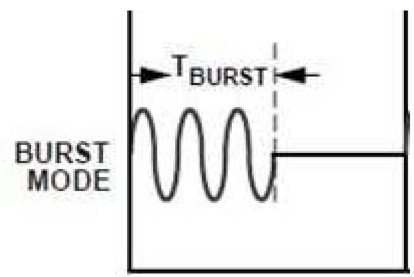
http://paulbourke.net/miscellaneous/correlate/

Processing Using Signal Burst

- Time stamps are used, calculate the time it takes for a single burst to reach the receiver.
- Requires a much lower sampling rate => cheaper hardware can be used.
- May still consider getting a single-board PC for this method to allow for further expansion down the road.



Ardunio Uno



Communication To Phone

- 802.11 Direct Wi-Fi
  - Proper Wi-Fi module would need to be purchased and implemented.
  - Can setup Ad Hoc network in order to make MCU/SPC an access point.
  - ~100m range if no obstructions present.
  - 11Mbps Bandwidth.
  - Secured by WPA2.
- BlueTooth
  - Proper BlueTooth module would need to be purchased and installed.
  - ~10m range.
  - 800-1000Kbps Bandwidth
  - May present some security issues.

- Androidplot is a third party library which adds plotting functionality to the development framework.
- It’s free and open source
- This is what will be graphing the data collected from the MCU/SPC

Androidplot

Compatibility

Android Version	Codename	API Level	Compatible
2.0.1	Donut	6	Yes
2.1	Eclair	7	Yes
2.2	Froyo	8	Yes
2.3.1	Gingerbread	9	Yes
2.3.3	Gingerbread	10	Yes
3.0	HoneyComb	11	Yes

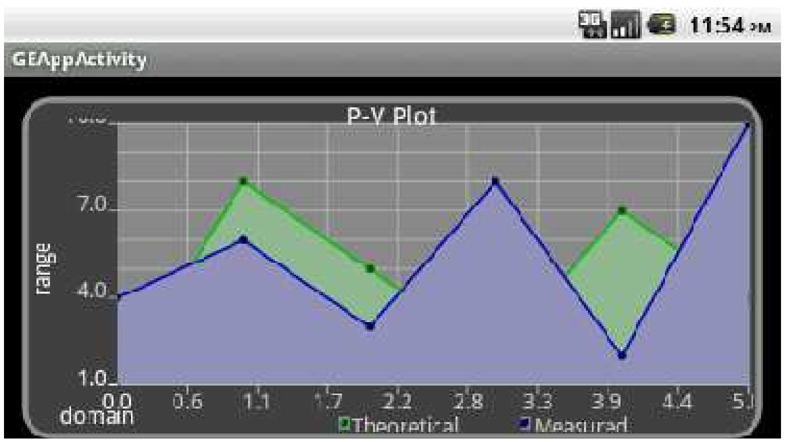
Database

- Storage Space limited by phone memory
- Solutions:
  - Delete old data
  - One element at a time or clear all

- Conserving memory:
  - Save snapshot of graph and delete raw data
  - Upload data/graphs to a server or email

Display

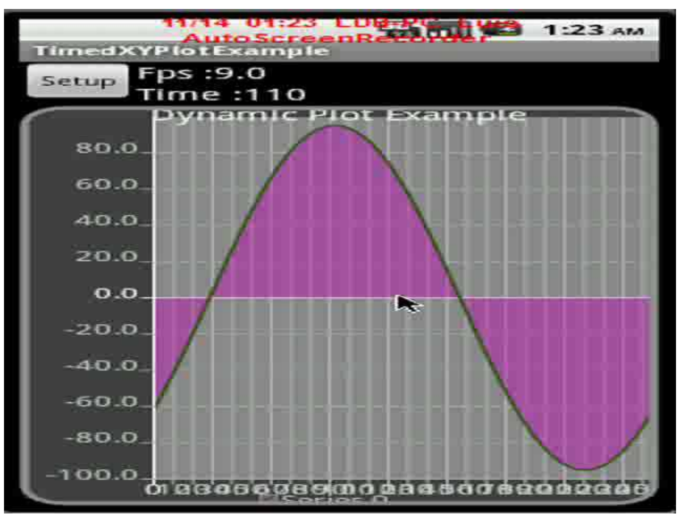
Goal is to use maximum screen space



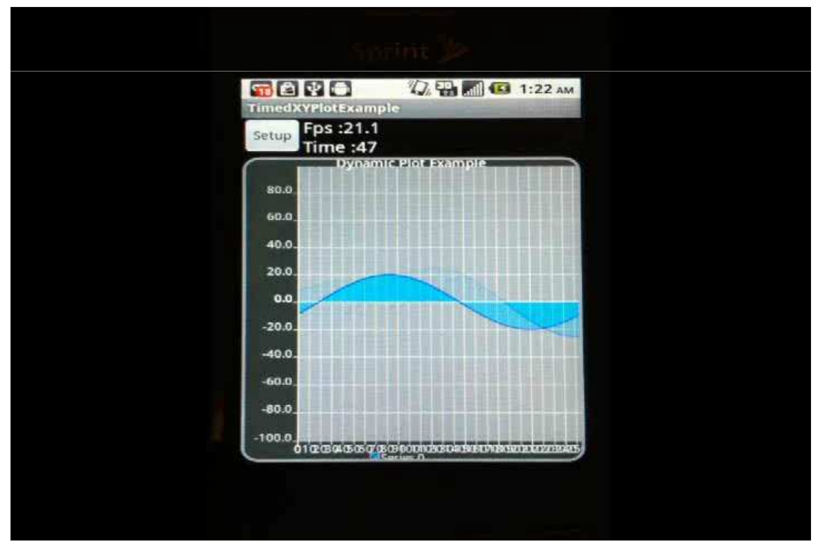
Plotting in Real Time

- Limited by how quickly data can be obtained and stored into database
  - Bluetooth 800-1000kbps of data transfer
  - Wi-Fi to Wi-Fi about 11Mbps of data transfer
- Limited by devices processing speed to update graph (fps)

Real Time Sine Wave on Emulator



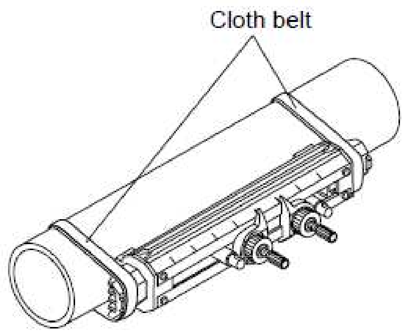
Real Time Sine Wave on LG Optimus S

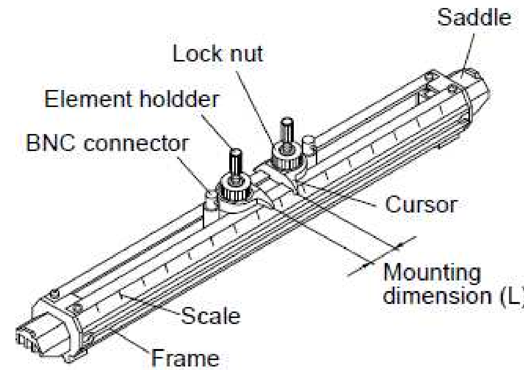


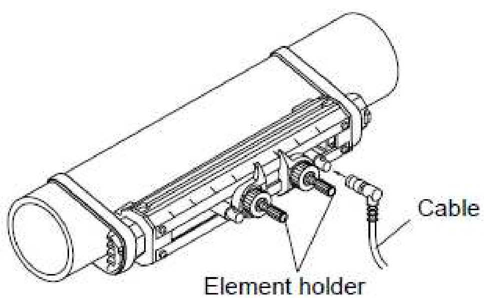
Mounting Systems

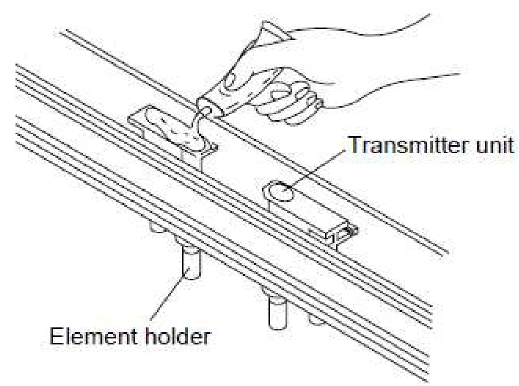
- Lubricating
- Attaching
- Locating

Setup Time Constraints









Pre-lubricated Sensors

Lubrication is used as an acoustic couplet

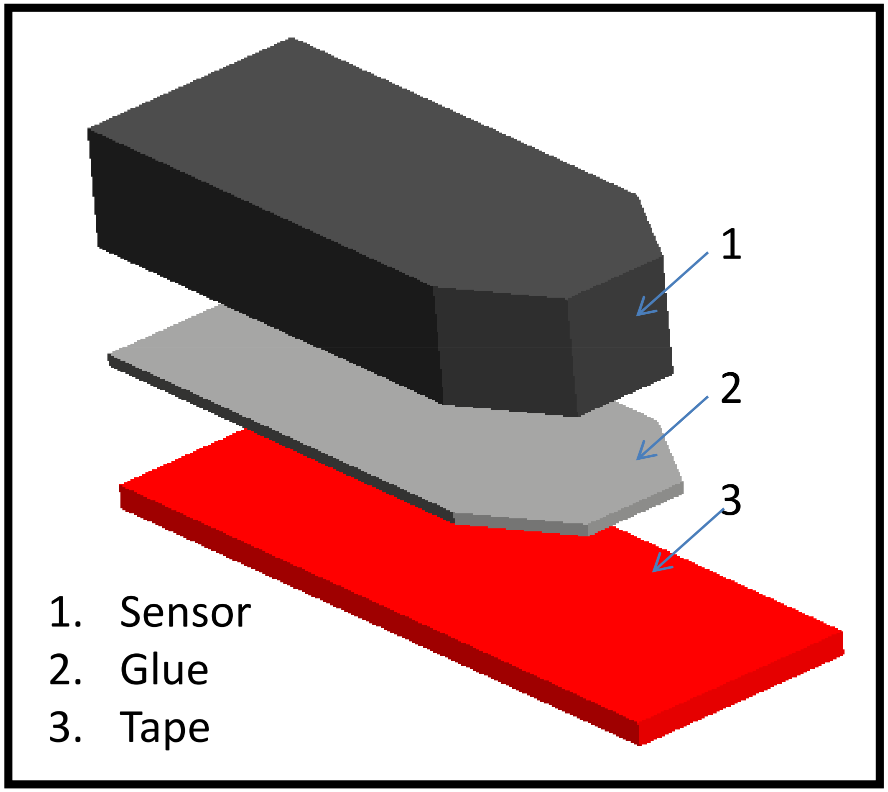


Figure 1: Exploded View

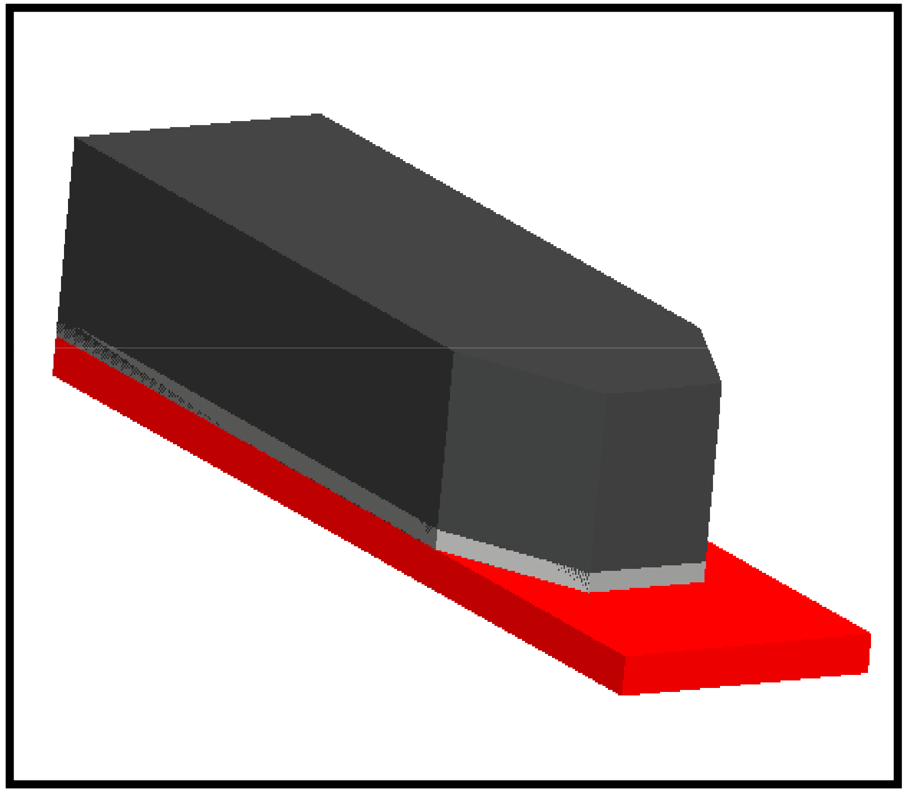


Figure 2: Assembled View

Velcro Bands

- Pros
  - Inexpensive
  - Readily available
  - Fits a wide range of pipes
- Cons
  - Temperature limits
  - Slippage
  - Not robust, for repeated usage

Figure 3: Velcro Belt

Quick Release Hose Clamps

Figure 4: Quick Release Hose Clamp

- Pros
  - Inexpensive
  - Readily available
  - Fits a wide range of pipes
  - Secure
- Cons
  - More Time Consuming

Interlocking Clamp

- Pros
  - Wont rust or Corrode
  - Fits a wide range of pipes
  - Secure
- Cons
  - Expensive (Custom Made)
  - More Time Consuming

Figure 5: Nylon Interlocking Clamp

Magnets

- Pros
  - Secure
  - Innovative
- Cons
  - Might effect sensor reading
  - Expensive
  - Not readily available

Figure 6: Round Magnet

Proper Placement

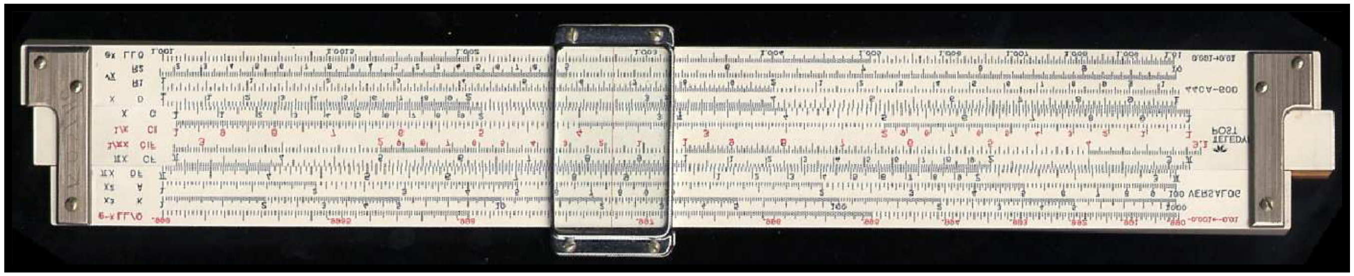


Figure 7: Slide Rule

- Sliding Measure
  - Similar to Slide Ruler
  - Ensures Proper location of the sensors
- Manual Measure with a Tape Measure

Cost Analysis

Sensors/DAC	Cost		
Ultrasonic Transducers	$1,000		
DAC	$20		
Single-Board PC		**Microcontroller**	
TS-7800	$229		
WiFi interface	$30	MCU	$25
Battery pack	$20	WiFi Shield	$90
TS-ADC24	$109	Battery pack	$20
Subtotal	**$388**	**Subtotal**	**$135**
	Low	**High**	
Total	**$1,155**	**$1408**	

Questions?