DALHOUSIE UNIVERSITY

Visimetrics Inc.

DESIGN OF AN ULTRASONIC ANEMOMETER

FINAL PRESENTATION

Anthony Chalmers
Nicolas Castellanos
Marshall van den Hoogen
ECED4901 Senior Year Project II

1 PROJECT OVERVIEW

OVERVIEW: PROJECT INTRODUCTION

WHAT IS AN ANEMOMETER?

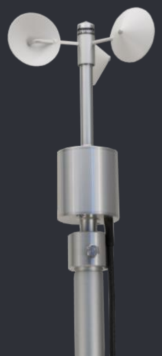
Electrical or mechanical device used for measuring wind speed and direction

USE CASES

- Environmental monitoring
- Wind power monitoring
- Weather observation (e.g., forecasting and marine)

TYPICAL STYLES

- Cup anemometer (left)
- Vane anemometer (right)
- Ultrasonic anemometer



Images from:

https://www.campbellsci.com/a100lk

https://www.ahlborn.com/en_UK/products/digital-vane-anemometer-for-air

OVERVIEW: BACKGROUND & SIGNIFICANCE

WHY AN ULTRASONIC ANEMOMETER?

- Eliminate moving parts
- Potential for robust designs
- Ability of high accuracy and precision measurements

PURPOSE OF PROJECT

- Develop operating theory
- Design a robust low-cost prototype
- Suitable for smaller marine vessels

Image from:

http://www.rushsc.ie/minigalnano/?dir=Laser%20Nationals%20Aug%202017/RACE%202

OVERVIEW: PROJECT REQUIREMENTS & CONSTRAINTS

REQUIREMENT	DESCRIPTION
Wind Speed Measurement	Capture the wind speed with 5% of accuracy from 1–30 m/s
Wind Direction Measurement	Capture the wind direction within 3° of accuracy from 1–30 m/s
Measurement Output	Display measured data to the user at a minimum rate of 2 Hz

CONSTRAINT	DESCRIPTION
Serial Communication	The device must interface over common marine data buses, including NMEA0183
Device Cost	The material cost of the device must be below $100 per single unit

OVERVIEW: PROJECT OBJECTIVES & DELIVERABLES

#	DELIVERABLE	DESCRIPTION
D1	Acceptance Test Plan	Used to ensure design meets defined requirements
D2	Theory of Operation	Theory use for obtaining measurements
D3	Data Processing Algorithm	Software architecture for managing sub-systems, signal processing and measurement calculations
D4	System Hardware Architecture	Hardware architecture for analog signal processing
D5	POC Implementation	Feasible prototype able to take measurements on a single axis
D6	Project Report	Detailed summary of the project design process

2 SYSTEM DESIGN & VERIFICATION

DESIGN: THEORY OF OPERATION

MEASURING WIND SPEED AND DIRECTION

- The speed and direction of the wind is measured using the Time of Flight (TOF) of ultrasonic signals

MEASUREMENT MODEL

- The TOF from the transmitter to the receivers is given by the following equations:

$$t_{R1} = \frac{L}{v - u \cdot cos(\theta)}$$

$$t_{R2} = \frac{L}{v + u \cdot cos(\theta)}$$

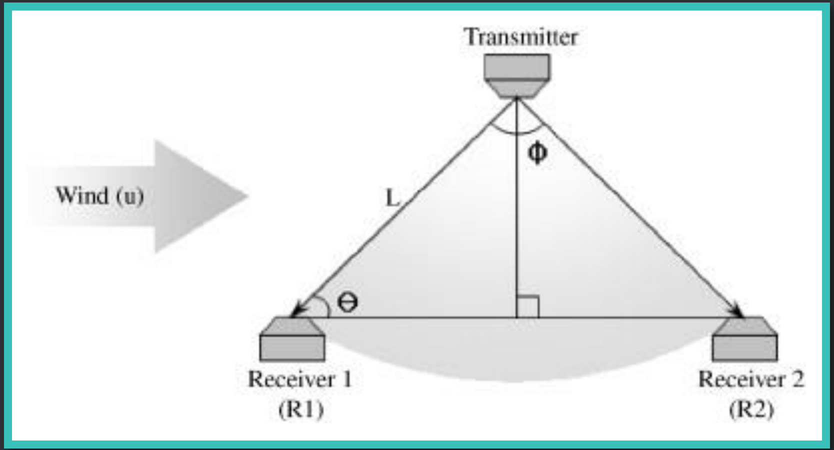
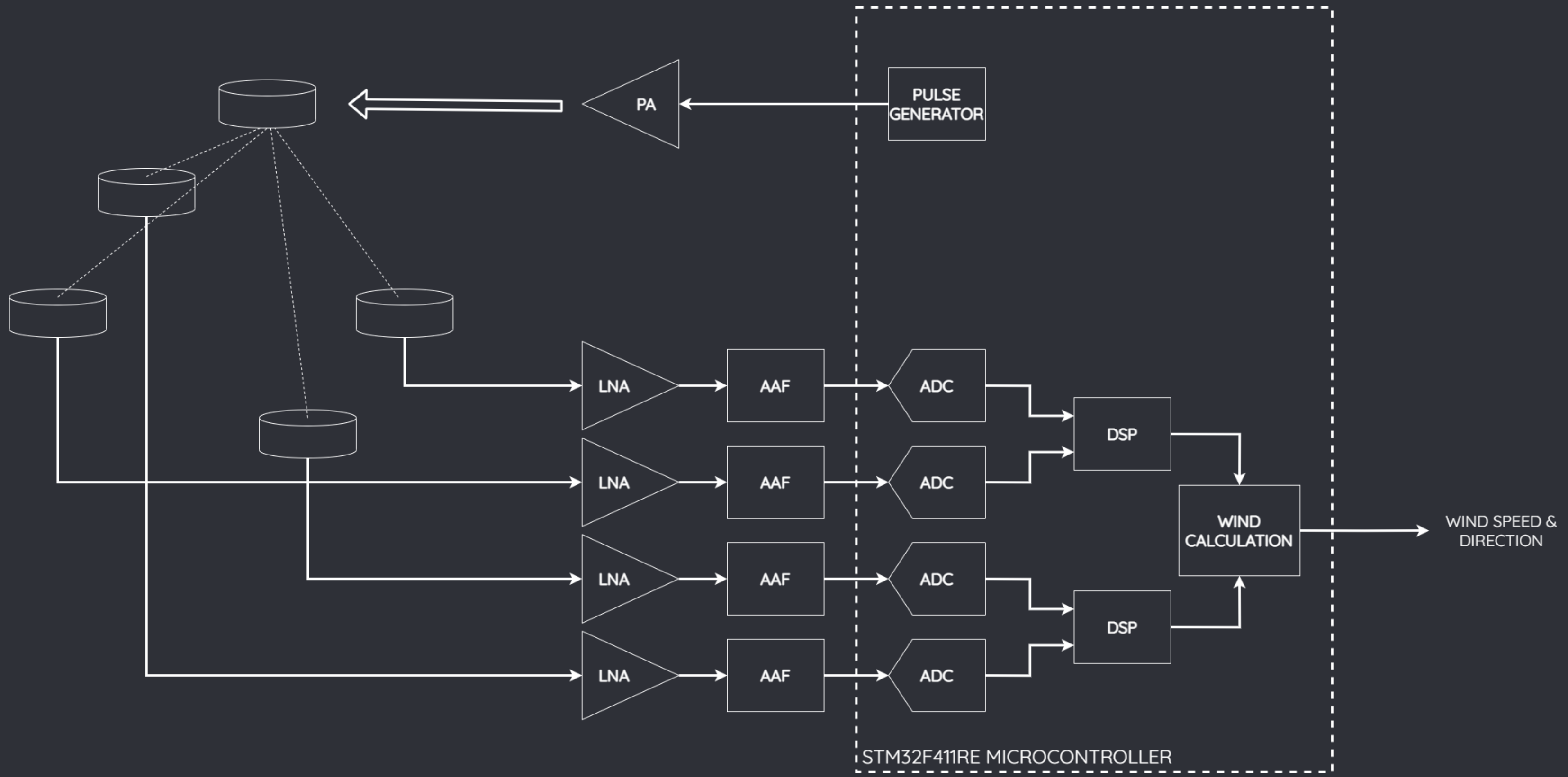


Figure from:
D. Han, S. Kim and S. Park, "Two-dimensional ultrasonic anemometer using the directivity angle of an ultrasonic sensor," Microelectronics Journal, vol. 39, no. 10, pp. 1195-1199, 2008

DESIGN: SYSTEM BLOCK DIAGRAM



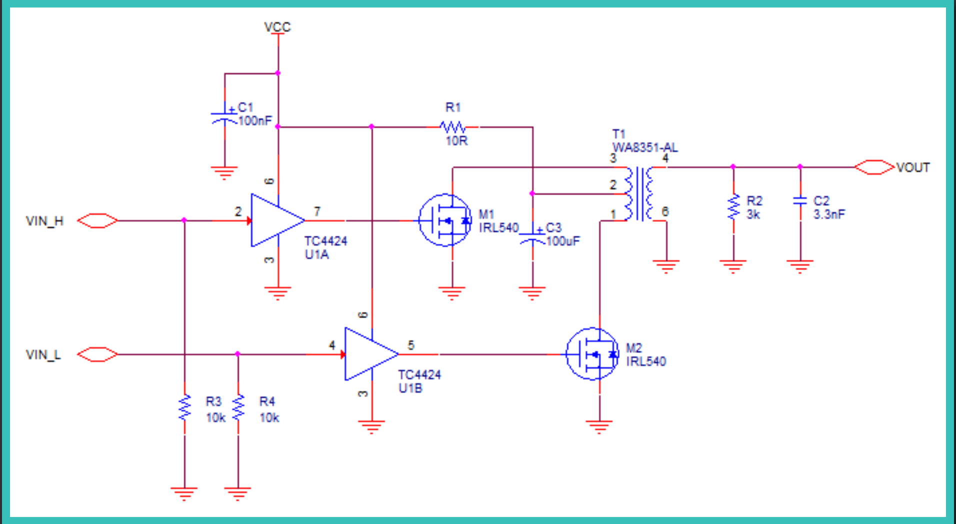
DESIGN: TRANSMITTER

DESIGN REQUIREMENTS

- Increase the voltage and power of the 40 kHz square wave driving signal
- Obtain a sufficient SNR across the channel
- Minimize power dissipation

DESIGN DECISIONS

- Topology: Center-Tap transformer driven in push-pull configuration using two complementary low-side power MOSFETS
- Driving Voltage: 100 Vpp



DESIGN: TRANSMITTER VERIFICATION

OBJECTIVE

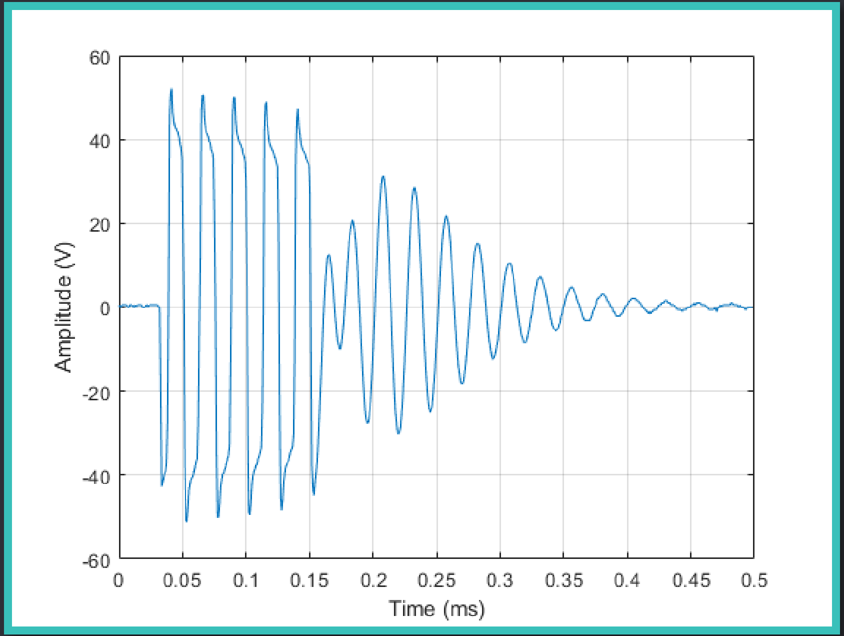
- Verify that the transmitter produces that expected driving voltage

PROCEDURE

- Apply two 40 kHz square wave signals to input of power amplifier and probe output using oscilloscope

RESULTS

- There is some ringing after the signal has been transmitted, which occurs at around 0.17ms in the oscilloscope capture
- The total time to transmit a 125µs signal is approximately 400µs



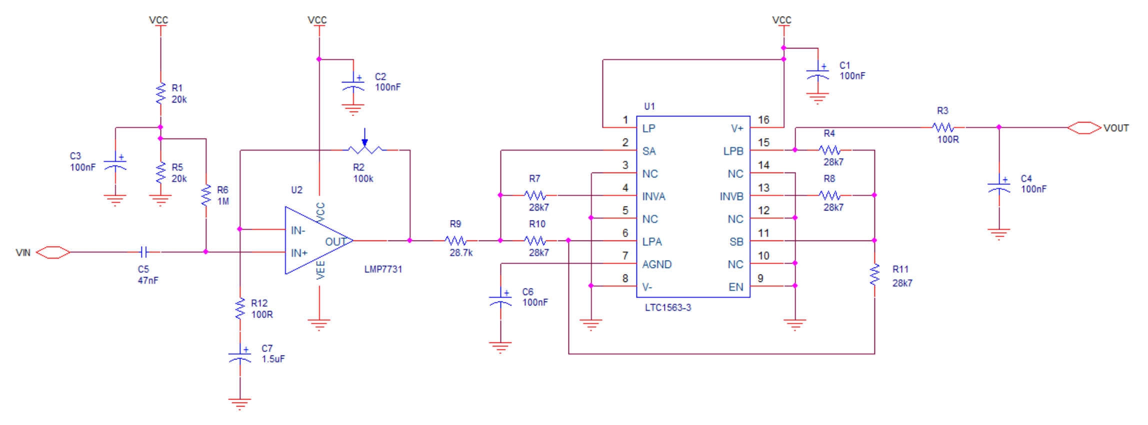
DESIGN: RECEIVER

DESIGN REQUIREMENTS

- Amplify the receiver signal without significantly degrading its SNR
- Reduce the effective quantization noise from the ADC
- Restrict the bandwidth of the received signal

DESIGN DECISIONS

- Topology: Monolithic LNA based on LMP7731 low-noise operational amplifier with 4th order active Bessel low-pass filter



DESIGN: RECEIVER VERIFICATION

OBJECTIVE

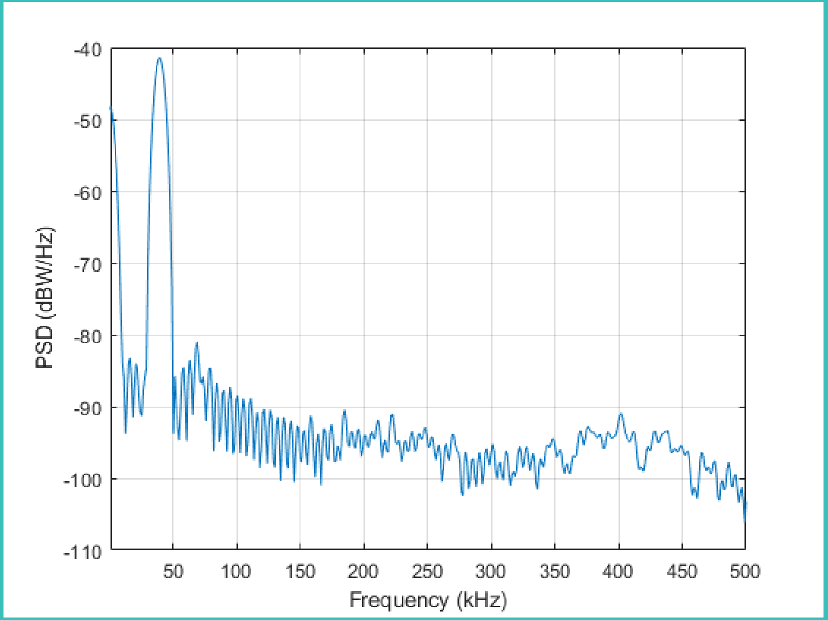
- Measure the noise performance of the receiver

PROCEDURE

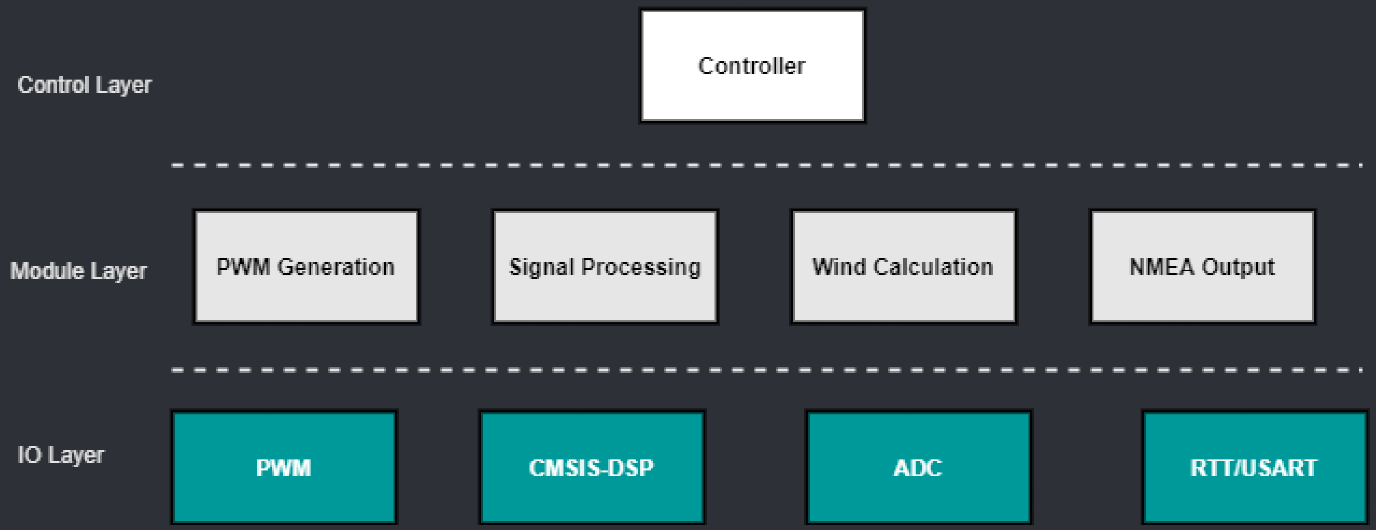
- Generate a 40 kHz sine wave using a signal generator
- Input the sine wave to receiver and adjust the gain of the preamplifier
- Sample the signal and plot the PSD of the signal in MATLAB

RESULTS

- The Signal to Noise and Distortion Ratio (SINAD) is approximately 50 dBc



DESIGN: SOFTWARE ARCHITECTURE



DESIGN: PWM GENERATION

REQUIREMENTS

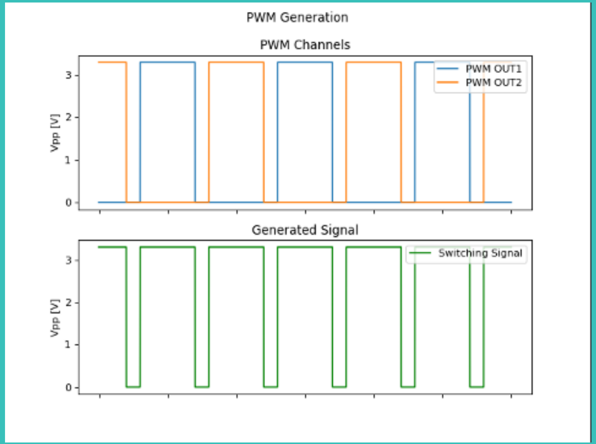
- Two 40 kHz 3.3 Vpp Signals
- N-pulse waveform generation
- Symmetric PWM
- Signals must be 180° out of phase

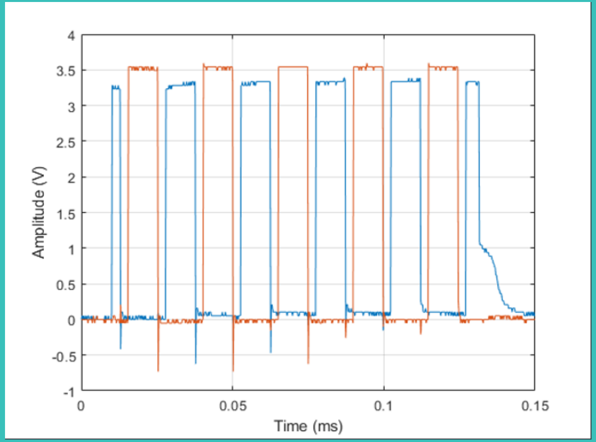
DESIGN DECISIONS

- Configure 40 kHz clock for TIM2 timer
- Apply center-aligned PWM mode
- Count n-cycles for necessary waveform

VERIFICATION

- 10 pulse wave form at a configurable frequency was generated
- Wave pulses cut out at both ends of the waveform





DESIGN: DIGITAL SIGNAL PROCESSING

REQUIREMENTS

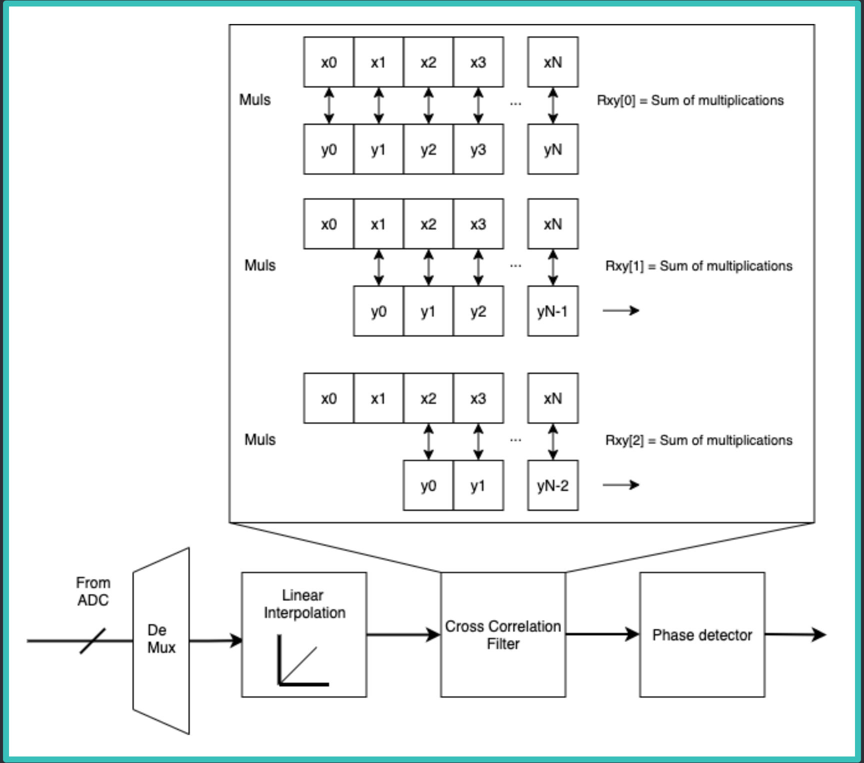
- Accurate measurement of time shift between signals
- High speed sampling over 14MSPS to achieve performance standards based on specifications of prototype

DESIGN DECISIONS

- Transmit and sample received signal
- Interpolate received signal to achieve sampling rate needed
- Apply cross correlation filter to measure difference between received signals

VERIFICATION

- Using JTAG link, received signals from oscilloscope were programmed in memory and cross correlation output was extracted and plotted in MATLAB



DESIGN: WIND CALCULATION

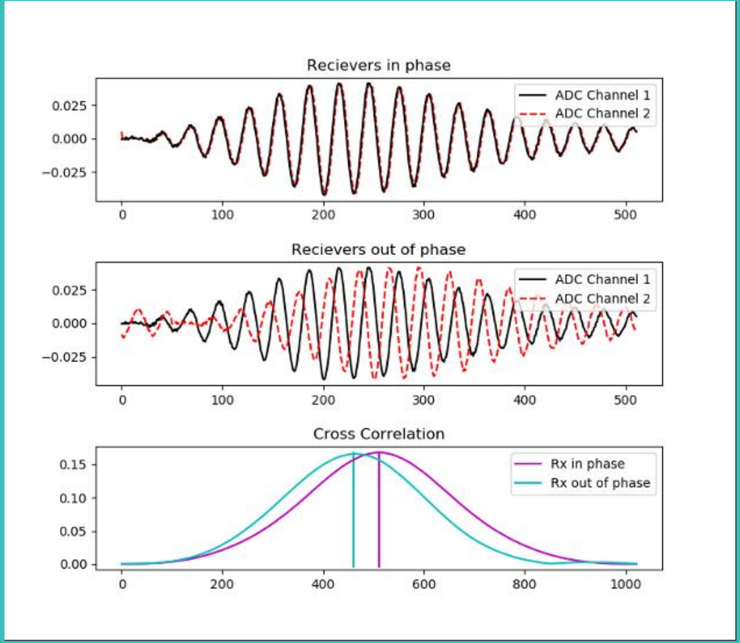
REQUIREMENTS

- Accurately measure the 1-D magnitude of wind velocity across the anemometer's measurement chamber
- Accurately measure the angle of directivity of wind in 1-D

DESIGN DECISIONS

- Measure difference between in-phase and out-of-phase correlation peaks
- Compute wind speed through time shift of correlation differences

$$u = -\frac{L-\sqrt{t^2v^2-L^2}}{t\cos\theta}$$



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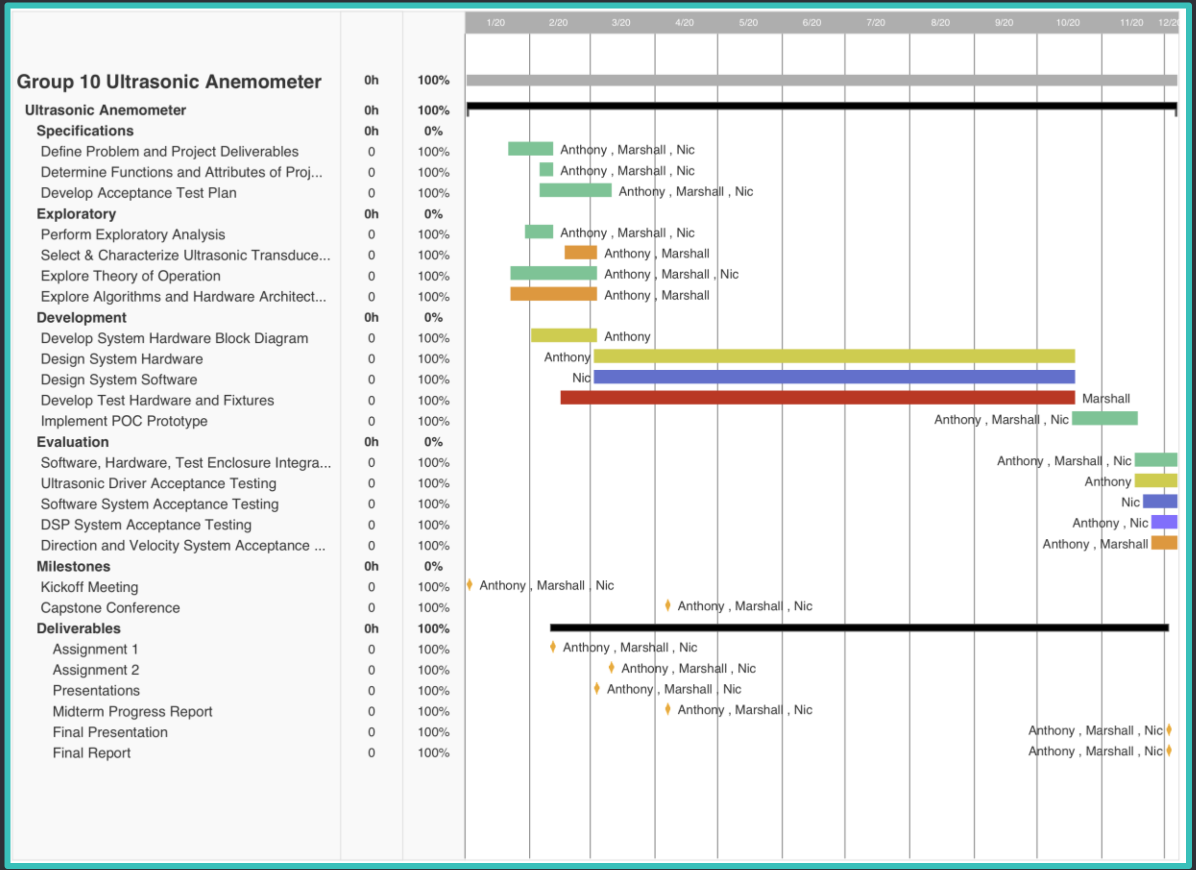
PROJECT PLANNING

PLANNING: PROJECT SCHEDULING

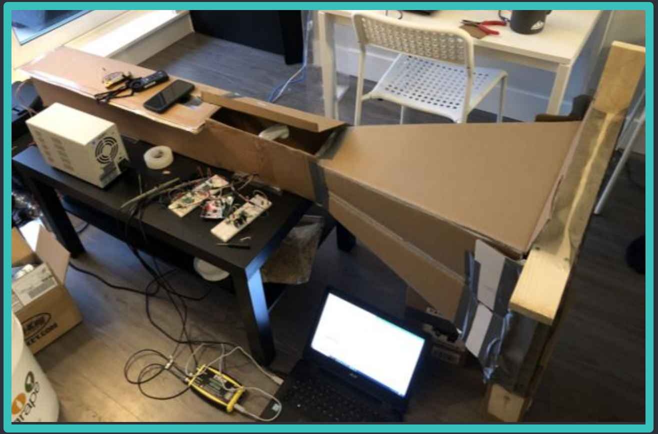


PLANNING: PROJECT BUDGET

	Qty	Description	Vendor	Vendor No.	Unit Price	Extended Price (CAD$)
	4	IC OPAMP GP 1 CIRCUIT SOT23-5	Digi-Key	LMP7731MF/NOPBCT-ND	2.46	9.84
	2	IC FILTER 256KHZ LOWPASS 16SSOP	Digi-Key	LTC1563-3CGN#PBF	7.31	14.62
	25	RES 28.7K OHM 1/4W 1% AXIAL	Digi-Key	28.7KXBK-ND	0.0788	1.97
	5	RES 1M OHM 1/4W 5% AXIAL	Digi-Key	1.0MQBK-ND	0.15	0.75
	10	RES 100 OHM 1/4W 0.1% AXIAL	Digi-Key	100ADCT-ND	0.706	7.06
	5	CAP TANT 1.5UF 10% 35V RADIAL	Digi-Key	478-11088-ND	0.95	4.75
	2	TRIMMER 100KOHM 0.25W PC PIN TOP	Digi-Key	3266W-104LF-ND	6.27	12.54
	5	RES 3K OHM 1W 5% AXIAL	Digi-Key	3.0KW-1-ND	0.44	2.2
	10	RES 20K OHM 1/4W 0.1% AXIAL	Digi-Key	20KADCT-ND	0.706	7.06
	15	CAP ALUM 0.1UF 20% 50V RADIAL	Digi-Key	732-8847-1-ND	0.14	2.1
	5	CAP CER 0.047UF 250V X7R RADIAL	Digi-Key	445-180691-1-ND	0.68	3.4
	5	CAP FILM 1000PF 5% 100VDC RADIAL	Digi-Key	495-2473-1-ND	0.45	2.25
	4	SOT23-5/SC59-5/SC-74A TO DIP-6	Digi-Key	PA0086-ND	3.81	15.24
	2	SSOP-16 TO DIP-16 SMT ADAPTER	Digi-Key	PA0182-ND	5.22	10.44
	1	FAN 150X50MM 12VDC VANE TACH	Digi-Key	1688-1693-ND	53.54	53.54
	5	RES 10 OHM 3W 5% AXIAL	Digi-Key	YAG1228CT-ND	0.72	3.6
	10	MOSFET N-CH 100V 28A TO-220AB	Digi-Key	IRL540PBF-ND	2.396	23.96
	5	CAP 100 UF 20% 25 V	Digi-Key	732-9511-1-ND	0.34	1.7
	5	CAP CER 3300PF 250V C0G RADIAL	Digi-Key	445-173338-1-ND	0.58	2.9
	5	IC GATE DRVR LOW-SIDE 8DIP	Digi-Key	TC4424CPA-ND	3.65	18.25
	5	RES 15K OHM 1W 5% AXIAL	Digi-Key	15KW-1-ND	0.44	2.2
	5	CONN IC DIP SOCKET 8POS TIN	Digi-Key	A120347-ND	0.25	1.25
	5	RES 10K OHM 1/4W 5% AXIAL	Digi-Key	10KQBK-ND	0.15	0.75
	5	CAP ALUM 1UF 20% 50V RADIAL	Digi-Key	732-8851-1-ND	0.14	0.7
	4	HEAT SINK TO-220 .500" COMPACT	Digi-Key	HS107-ND	0.54	2.16
	4	MOUNTING KIT TO-220	Digi-Key	HS417-ND	3.65	14.6
	2	TSSOP-20 TO DIP-20 SMT ADAPTER	Digi-Key	PA0035-ND	6.78	13.56
	1	HEATSHRINK 1/16" X 4' BLACK	Digi-Key	Q2F3X116B-ND	0.6	0.6
	2	NUCLEO F411RE	Digi-Key	497-14711-ND	19.57	39.14
	8	Ultrasonic Sensing Transformer	Coil Craft	WA8351-AL	2.29	18.32
Total Cost						**$291.45**
Remaining Budget						**$208.55**

4 SYSTEM TESTING & RESULTS

TESTING: WIND TUNNEL DESIGN & IMPLEMENTATION

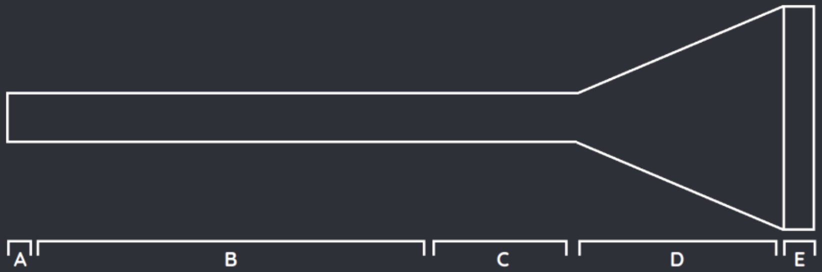


REQUIREMENTS & CONSTRAINTS

- Variable speed (0–8 m/s)
- Consistent flow
- Low-cost due to budget
- Large enough to house the designed prototype

DESIGN DECISIONS

- A. 150mm x 150mm 12V DC PWM controlled fan
- B. 1.7m diffuser tunnel
- C. 30cm Test chamber
- D. 75cm condenser
- E. Alignment filter



RESULTS

- Verified speed of 0–5.4 m/s
- Extremely consistent

TESTING: PROTOTYPE DESIGN & IMPLEMENTATION

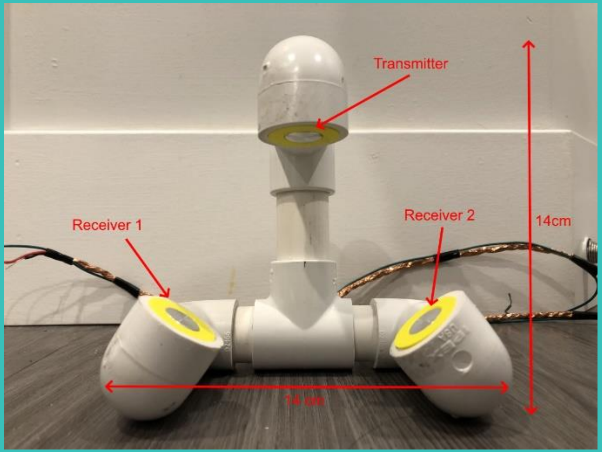
REQUIREMENTS & CONSTRAINTS

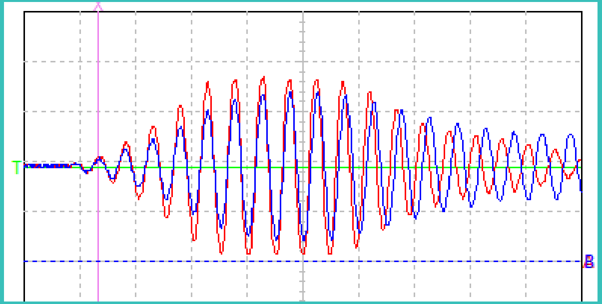
- Measure wind speed along a single axis with an accuracy of 10% from 1–30 m/s
- Prototype must fit inside 15 cm x 15 cm wind tunnel

DESIGN DECISIONS

- Dimensions: 14 cm x 14 cm
- Build prototype using plumbing fixtures
- Effective sampling rate given by:

$$F_s = \frac{v^2 - u_{res}^2 \cos^2(\theta)}{2Lu_{res}\cos(\theta)} \approx 14\ MSPS$$





TESTING: WIND SPEED

PROCEDURE

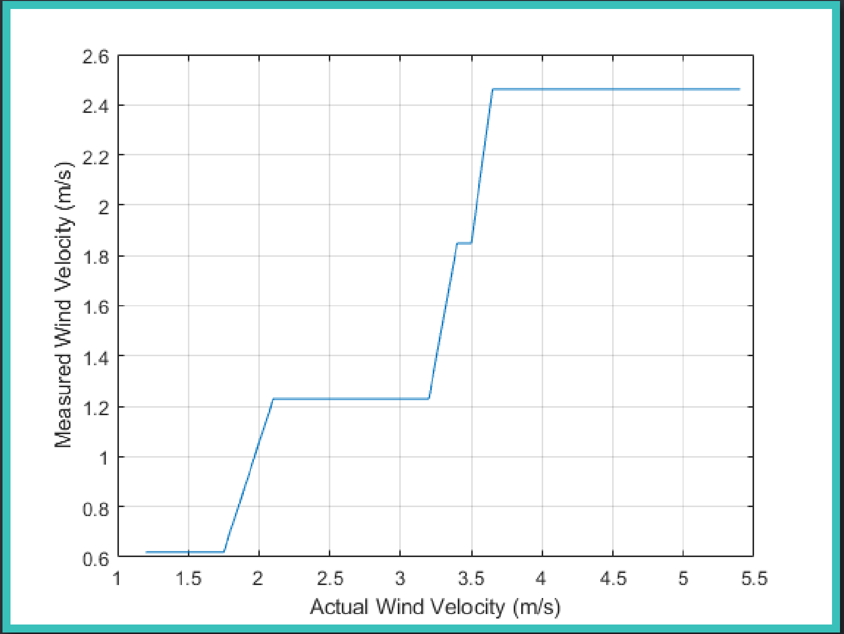
- Prototype was placed in the wind tunnel
- The fan speed was incremented slowly
- The wind speed was measured using a BTMETER BT-816B

RESULTS

- The wind speed measured by the prototype does not match the wind speed measured by the handheld anemometer
- The resolution is approximately 0.6 m/s

DISCUSSION

- Wind speed increases linearly, despite poor resolution
- Poor accuracy and resolution most likely due to sampling issues



TESTING: WIND DIRECTION

PROCEDURE

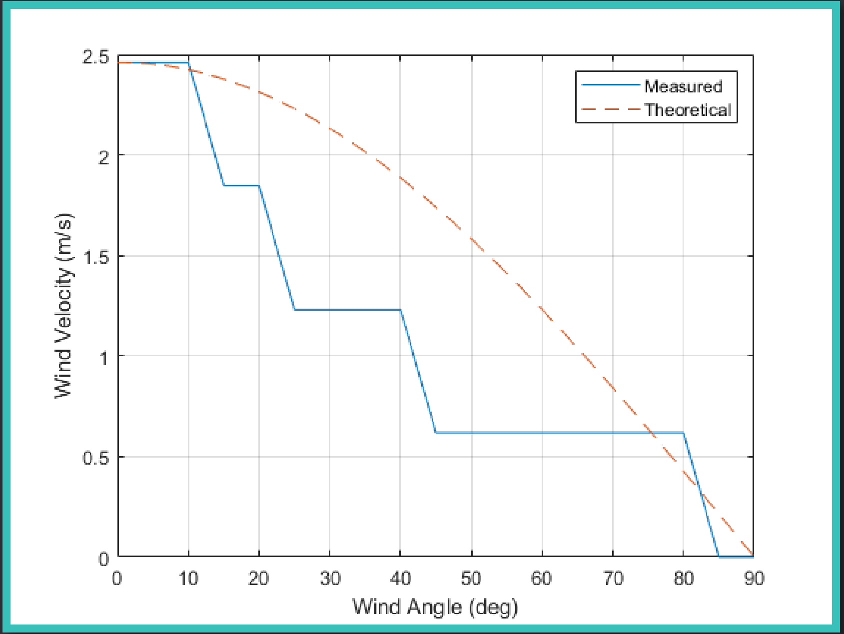
- Prototype was placed in wind tunnel
- Fan speed was set to max
- Prototype was turned in increments of 5° up to 90°

RESULTS

- Wind speed measured by prototype does not exactly follow theoretical wind speed curve

DISCUSSION

- Error most likely due to sampling issues and environmental influences



5 FUTURE WORK & CONCLUSION

FUTURE WORK

HARDWARE

- Acceptance testing needs to be performed to determine exact driving requirements
- Preamplifier may need to be redesigned to increase gain
- Anti-aliasing filter may exceed requirements, and may need to be redesigned to reduce cost

SOFTWARE

- PWM Generation should be configured to prevent cut off first and last pulse
- ADC should be set up in Continuous Conversion mode to achieve 2.4 MSPS
- Explore q15 math operations as they can be significantly optimized for speed
- Further calculations are necessary for 2-D wind speed measurement

VALIDATION TESTING

- Prototype must be retested after bugs are fixed
- High speed testing must be carried out

CONCLUSION

- Having achieved an initial stage of testing we are happy to conclude our project with promising results

- The research and design that was performed during this project proved that low-cost ultrasonic anemometers for marine applications are viable and are promising when it comes to measuring the speed of the wind using ultrasonic sound waves

- We are confident that further modifications and improvement to the system would produce performance that would be competitive with current devices on the market at a much lower price

Thank you!

ANY QUESTIONS?