Ultrasonic Anemometer

Seminar Presentation

Group 10

Nicolas Castellanos
Anthony Chalmers
Marshall van den Hoogen

Visimetrics Inc. | DALHOUSIE UNIVERSITY

1. Project Overview & Specifications

Project Overview

Project Background

- used to measure wind direction and speed using ultrasonic sound waves
- lack of moving parts makes them appropriate for long-term use in harsh marine environments

Problem Statement

The Ultrasonic Anemometer team has been tasked with the design and testing of an ultrasonic anemometer for Dr. Peter Gregson of Visimetrics Inc. that will significantly decrease the cost for personal use.

Project Requirements & Specifications

Design Criteria

- **Wind Speed:** 0 to 30 m/s with an accuracy & precision of ±5%
- **Wind Direction:** Accuracy of ±3° over designed operating range
- **Output Rate:** 2 Hz.

Design Constraints

- **Serial Communication:** The device must interface using common marine protocols, including NMEA0183.
- **Device Cost:** The material cost of the device must be below $100 per single unit.

Performance Goals

- **Ingress Protection Rating:** IP67
- **Built in diagnostics**

2. Project Objectives & Deliverables

Short Term Project Goals & Deliverables

1. **Acceptance Test Plan**
   - Test Plan to ensure the proof-of-concept meets design requirements
   - Documentation of the testing procedure, equipment, and results

2. **Theory of Operation**
   - Short description of the theory behind the design decisions of the prototype

3. **Data Processing Algorithm**
   - Development of a DSP algorithm for the required calculations and generation of system outputs

4. **System Hardware Architecture**
   - Description of the hardware components required to perform analog amplification, filtering, and processing

Long Term Project Goals & Deliverables

1. Proof-of-Concept Implementation

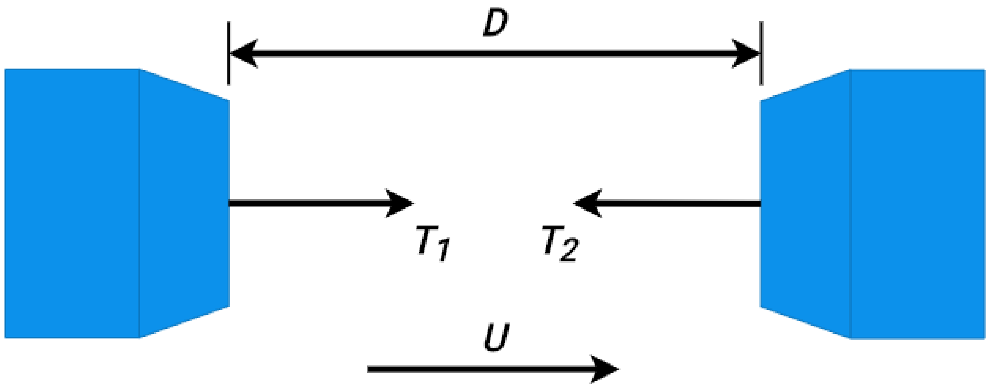
- A prototype that will measure wind speed along a single axis
- encompass a combination of concepts used to achieve the required functionality

2. Project Report

- an outline of the theory of operation
- a description of the data processing algorithm and system hardware architecture
- summary of the proof-of-concept implementation and acceptance test plan
- provide an analysis of the performance of the device

3. System Design & Verification

Theory of Operation



$$T_1 = \frac{D}{(v + U)} \qquad T_2 = \frac{D}{(v - U)}$$

$$U = \frac{D}{2}(\frac{1}{T_1} - \frac{1}{T_2})$$

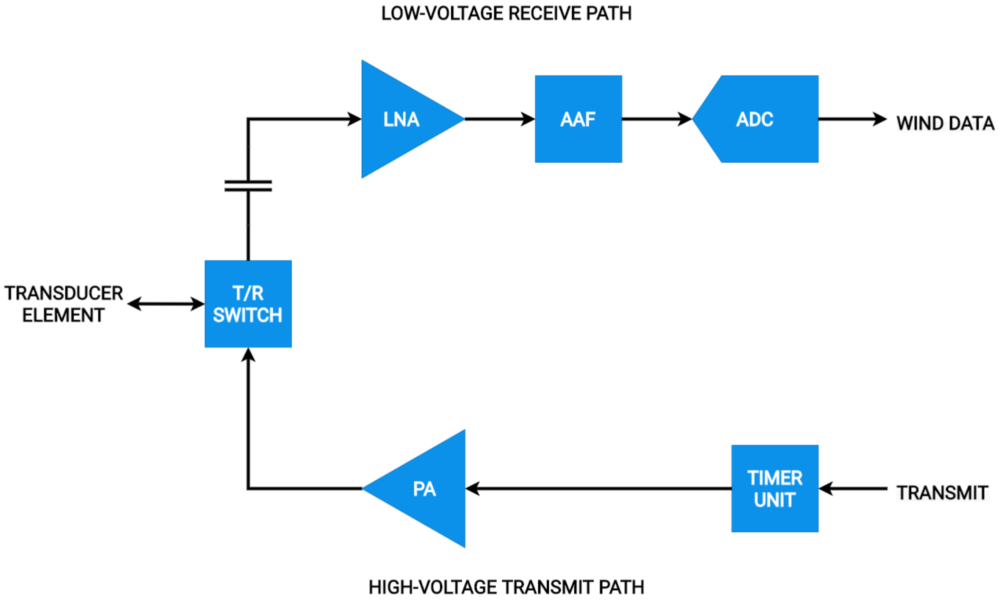
Hardware Block Diagram

High-Voltage Transmit Path

- Timer Unit on MCU generates low-voltage pulses
- High-voltage Power Amplifier (PA) excites the transducer element

Low Voltage Receive Path

- Transmit Receive (T/R) Switch protects LNA input from high-voltage transmit signal
- Low-Noise Amplifier (LNA) provides fixed gain without significantly degrading SNR
- Anti-Aliasing Filter (AAF) restricts the bandwidth of the received signal to prevent aliasing
- Analog to Digital Converter (ADC) samples received signal



High-Voltage Transmit Path Design

Design Requirements

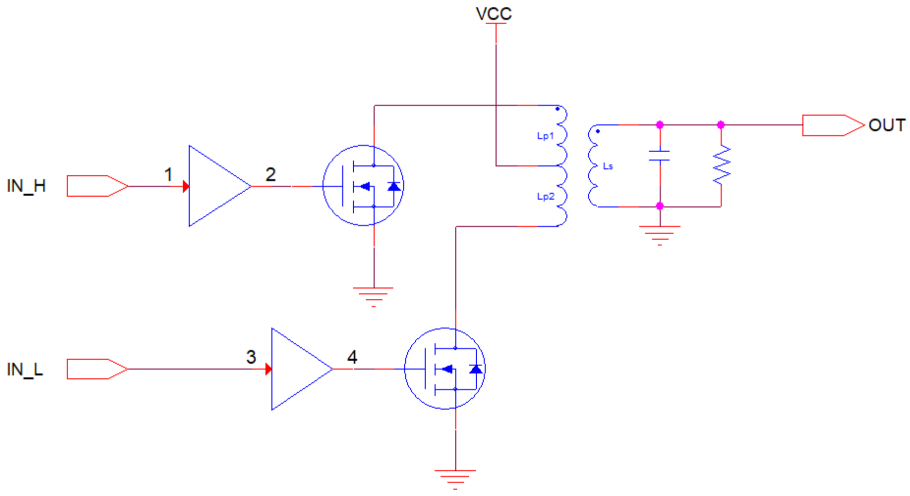
- Increase the voltage and power of the 40 kHz square wave driving signal generated by the microcontroller
- Obtain a sufficient SNR across the channel
- Minimize power dissipation

Design Decisions

- **Topology:** Center-Tap Transformer driven in push-pull configuration using two complementary low-side power MOSFETS
- **Driving Voltage:** 100 Vpp, resulting in a received voltage level of 30 mVpp

Design Verification

- Apply two 3.3 V square waves to input of power amplifier and probe output using oscilloscope

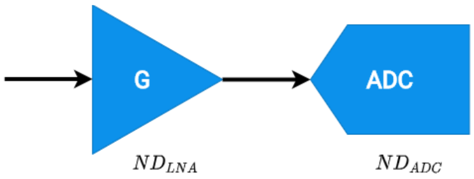


Low-Voltage Receive Path Design

Design Requirements

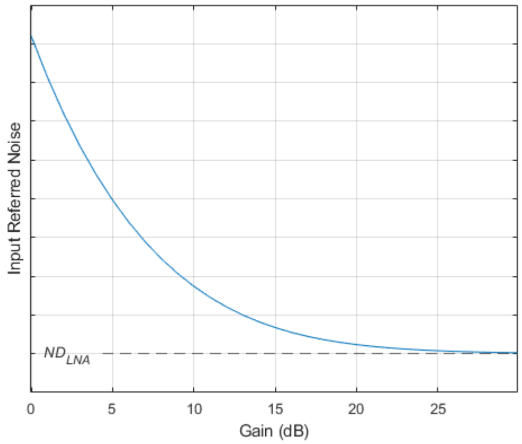
- Amplify the received signal without significantly degrading its SNR
- Reduce effect of quantization noise from ADC
- Restrict bandwidth of received signal to prevent aliasing within the band of interest

$$IRN = \sqrt{ND_{LNA}^2 + (ND_{ADC}/G)^2}$$



Design Decisions

- **Topology:** Monolithic LNA based on LMP7731 low-noise operational amplifier with active low-pass anti-aliasing filter
- **Passband Gain:** Select such that input referred noise is dominated by noise density of LNA



Design Verification

- Use oscilloscope or spectrum analyzer to measure frequency response and noise density

Software Block Diagram

Control Layer

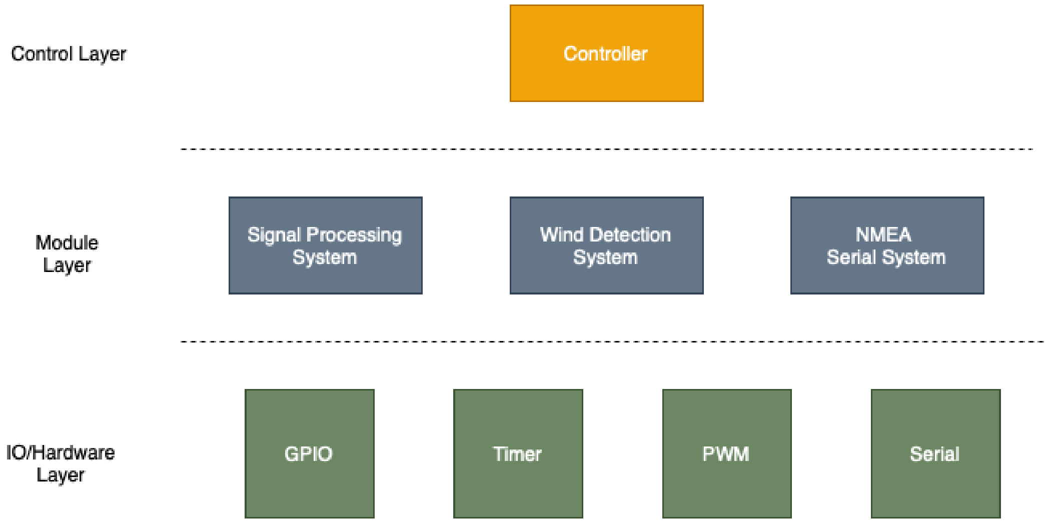
- Manages the state of the device and the tasks that are being performed

Module Layer

- Contains modules that will control the ultrasonic transducers for the device

IO/Hardware layer

- Low-level drivers that manage the hardware for the various sensors and amplifiers in use



Digital Signal Processing Design

Design Requirements

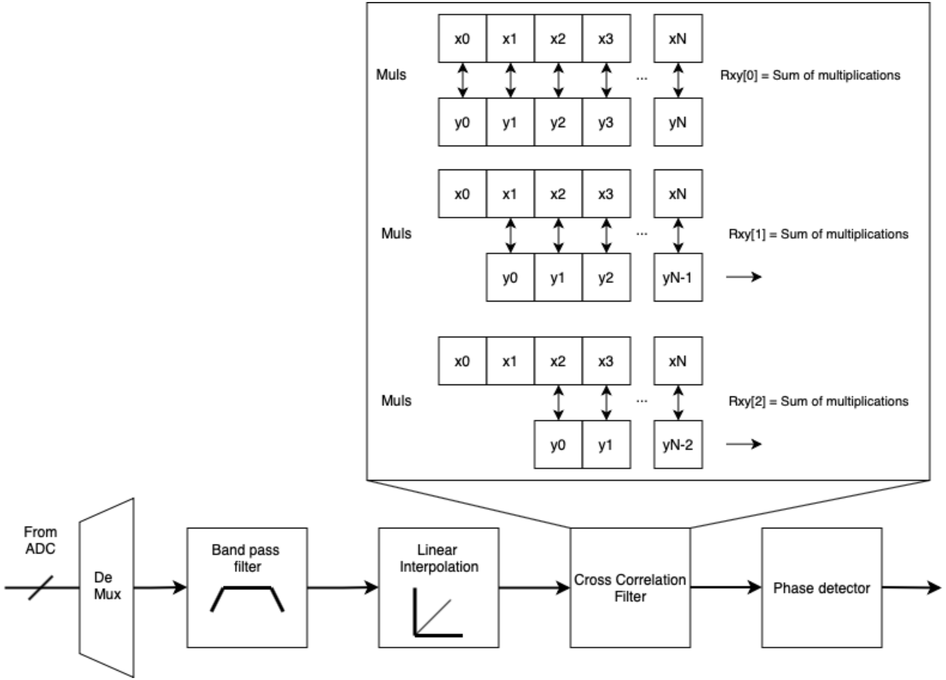
- Achieve a 2 Hz output rate
- Wind direction accuracy of ±3°in various wind condition
- Margin of ±5% of apparent wind speed

Design Decisions

- **Wind Measurement Algorithm:** Cross correlation provides superior accuracy to ToF for measurement of time shifts.
- Signal must be sampled at high speed

Design Verification

- Two 40 KHz 1 Vpp sinusoidal signals with different phases will be generated and will be input to the signal processing system.
- The output signal from the signal processing system will be compared to an oscilloscope.



4. Preliminary Results

Power Amplifier

Verification Criteria

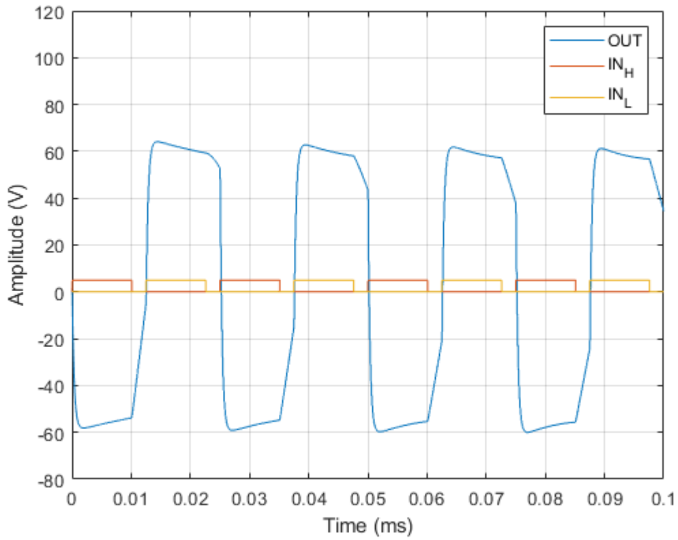
- Amplify two 3.3 Vpp 40.2 kHz square wave signals to achieve approximately 100 Vpp across transducer

Verification Method

- Perform a transient analysis in PSpice using the simulation schematic of the power amplifier
- Connect the output of the power amplifier to the lumped element model of the ultrasonic transducer element

Results

- The output signal from the power amplifier satisfies the design requirements



Digital Signal Processing

Verification Criteria

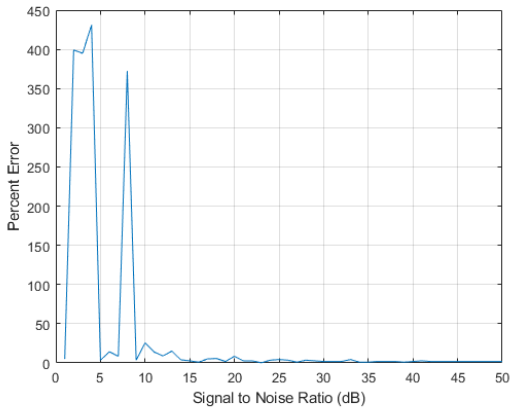
- Correctly recreated signal from simulated sampling and resampling of two signals at a specific SNR

Verification Method

- Determine % error of calculated vs actual time shifts at various SNR values

Results

- SNR value > 15 will provide us the necessary resolution to accurately compute the shift in signals within the margin of error



5. Design Integration Testing

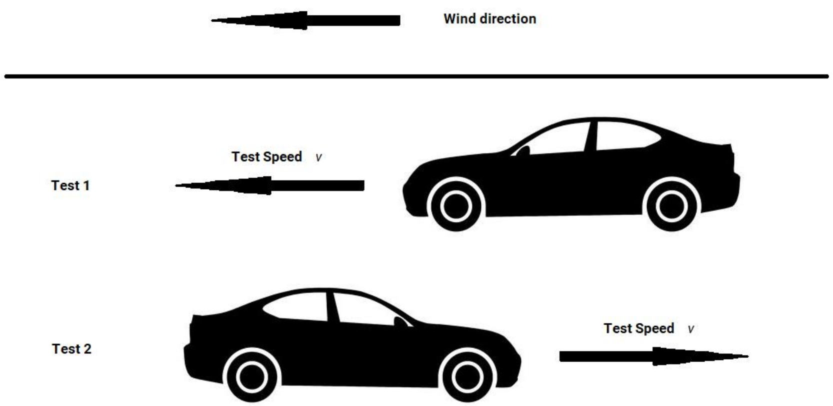
Prototype Testing Plan

High Speed Wind Test

- tested in a controlled environment while being exposed to a single axis of wind
- average of each trial of two tests will allow for the calibration of the signal response relative to actual wind speed
- wind angle can also be controlled

Low Speed Wind Tunnel Test

- controlled low speed test to verify accuracy and repeatability of results



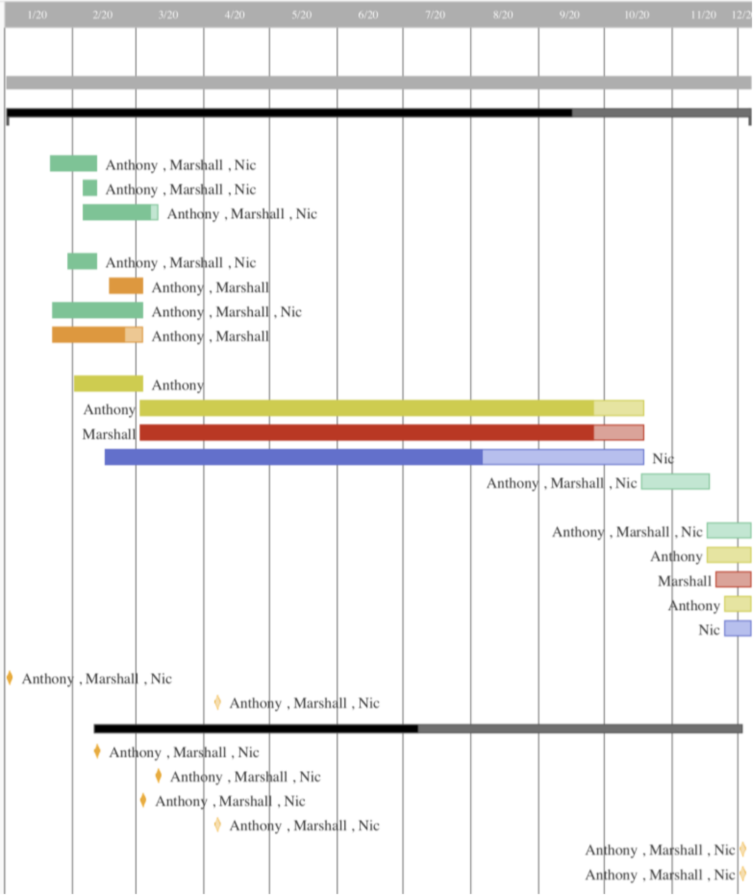
6. Project Management

Budget

Expense	Cost
Ultrasonic Transducers	$25
Low-Noise Amplifier & Anti-Aliasing Filter	$50
Power Amplifier	$100
Microcontroller	$40
Test Fixtures & Enclosures	$100
Total Cost	$315
Initial Budget	$500
Expected Remaining Budget	**$185**

Project Scheduling

Group 10 Ultrasonic Anemometer	start	end	76%
Ultrasonic Anemometer	**01/02/20**	**12/06/20**	**76%**
Specifications	-	-	**0%**
Define Problem and Project Deliverables	01/22	02/11	100%
Determine Functions and Attributes of Project	02/06	02/11	100%
Develop Acceptance Test Plan	02/06	03/10	90%
Exploratory	-	-	**0%**
Perform Exploratory Analysis	01/30	02/11	100%
Select & Characterize Ultrasonic Transducers	02/18	03/03	100%
Explore Theory of Operation	01/23	03/03	100%
Explore Algorithms and Hardware Architectures	01/23	03/03	80%
Development	-	-	**0%**
Develop System Hardware Block Diagram	02/02	03/03	100%
Design System Hardware	03/03	10/18	90%
Design System Software	03/03	10/18	90%
Develop Test Hardware and Fixtures	02/16	10/18	70%
Implement POC Prototype	10/18	11/17	0%
Evaluation	-	-	**0%**
Software, Hardware, Test Enclosure Integration	11/17	12/06	0%
Ultrasonic Driver Acceptance Testing	11/17	12/06	0%
Software System Acceptance Testing	11/21	12/06	0%
DSP System Acceptance Testing	11/25	12/06	0%
Direction and Velocity System Acceptance Testi...	11/25	12/06	0%
Milestones	-	-	**0%**
Kickoff Meeting	01/02	01/02	100%
Capstone Conference	04/06	04/06	0%
Deliverables	**02/11/20**	**12/02/20**	**50%**
Assignment 1	02/11	02/11	100%
Assignment 2	03/10	03/10	100%
Presentations	03/03	03/03	100%
Midterm Progress Report	04/06	04/06	0%
Final Presentation	12/02	12/02	0%
Final Report	12/02	12/02	0%



Questions?