Sensor Technology Limited

SENSOR

An Ultrasonic Anemometer

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SERVICE PAPER
ULTRASONIC ANEMOMETER

BACKGROUND.

1.   On the 12 of June 1992, a service paper entitled "Ultrasonic Anemometer" was presented. In this service paper the theory of operation as well as the functional design of the ultrasonic anemometer were described. This anemometer which is to be used in recreational sailing was then built following the original specifications with a few modifications. Upon evaluation, the anemometer was found to perform very well.

AIM.

2.   The aim of this paper is to provide a statement of the design modifications and performance analysis of the hand held ultrasonic anemometer.

DISCUSSION.

a. General system description.

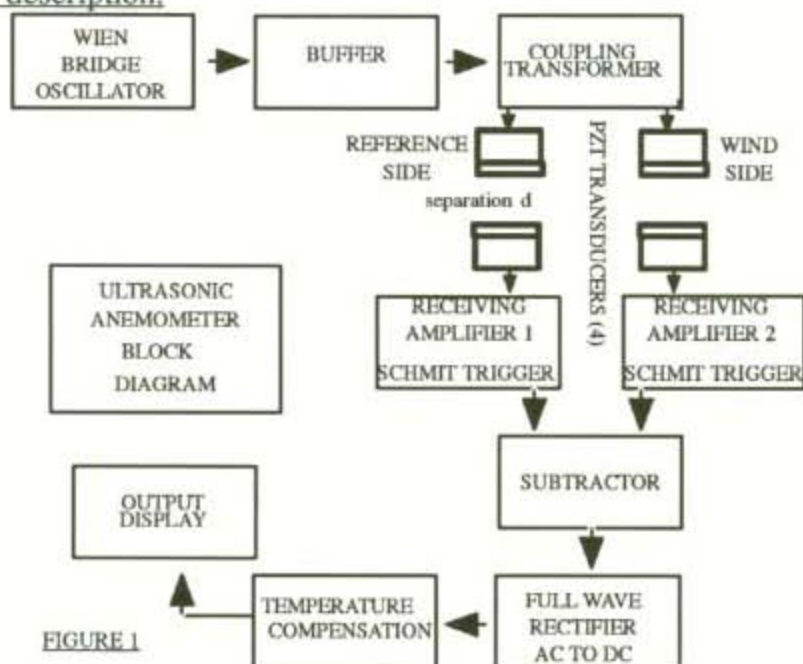FIGURE 1

b. System description including the new components.

3.   As shown in figure 1, we start by producing a signal with a Wien bridge oscillator. The gain of the oscillator is set to avoid clipping of the output sine wave. This signal of frequency f_0 goes through a unity gain buffer and then through a 1 to 1 ratio coupling transformer. The signal is then branched off to the two parallel transducers. We can now broadcast this signal into the air. One side is sheltered from the wind, the other is not. On reception, the two piezoelectric receiving transducers pick up their respective sound wave and generate the reception signals. These two signals are processed separately. Each received signal goes through an amplifier which amplifies the signal up to an acceptable state slightly lower than their saturation level. A set of Schmit triggers are added to act as auto gain controllers. The signals at this point are in a square wave shape. They have equal amplitudes but the phase difference in between them depends on the wind speed. The two signals are then sent to the subtracter which acts as a phase comparator. We convert a phase shift into a voltage signal. Thus the signal coming out of the subtracter has a wind speed dependent amplitude. We must send this signal to a rectifier prior to taking its dc voltage value. The rectifier converts the ac signal into a fairly flat dc level. This dc level is put through a temperature compensation block which consists of a temperature dependant gain amplifier. The final output is obtained by simply putting this adjusted dc level through an indicator. Circuit diagrams of the different components are illustrated and described in the chapters to come. Also, the overall design specifications of the anemometer are compared to its true specifications in Annex A. Many of the circuits used in this design project are based on existing circuits discussed in the references listed in Annex B. A full illustration of the systems signal flow is displayed in Annex C.

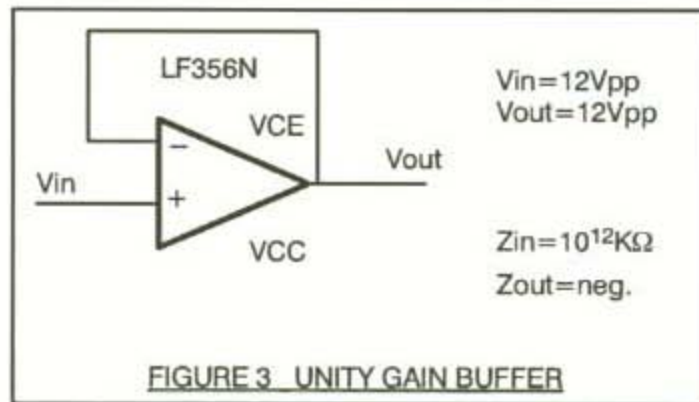c. The variable gain Wien bridge oscillator.

4.   The Wien bridge oscillator used in the previous report was inadequate. It saturated easily, had an unstable gain and created a lot of noise on the ground. A new Wien bridge oscillator with adjustable and stable gain was then chosen. A detailed circuit diagram of the oscillator is illustrated in figure 2. Equation 1 gives us the frequency of oscillation f_0 given R and C. R and C were chosen based on the components available in the laboratory as well as actual testing. For sufficient oscillation gain we manually adjust the 100K pot. Here we obtain an oscillation frequency of approximately 40KHz (40.96KHz experimentally) with R=5.1kΩ and C=800pf. The two diodes allow

for a stabilized gain. This oscillator saturates at around 15 volts peak to peak. We set the gain such that Vout=12Vpp. This sinusoidal output is then sent to the buffer. The output impedance of this stage is approximately 600 Ohms. This new design no longer requires the use of a low pass filter to smooth out the output sine wave.

R=5.1KΩ
R1=12KΩ
C=800PF

$Z_o \approx 600\Omega$
$F_o = 40.96$KHz
Vout=12Vpp

FIGURE 2 WIEN BRIDGE OSCILLATOR
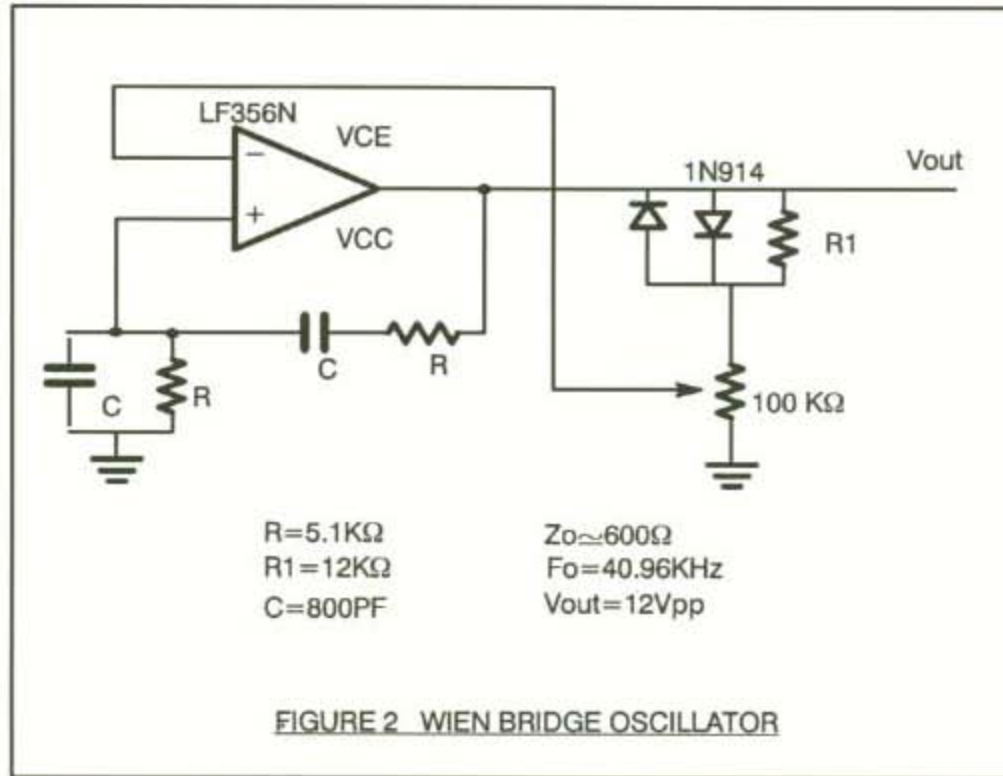
$$f_o = \frac{1}{2\pi RC}$$ *Equation 1*

d. The unity gain buffer.

Vin=12Vpp
Vout=12Vpp

$Z_{in} = 10^{12}$KΩ
Zout=neg.

FIGURE 3   UNITY GAIN BUFFER

5.   To avoid overdrawing from the oscillator a buffer is added. It's sole purpose is to

provide higher current output capability. The sine wave conserves its voltage amplitude. The output impedance of this stage is lowered allowing easier matching with the transformer of the next stage.

e. The electrical to sound and sound to electrical stage.
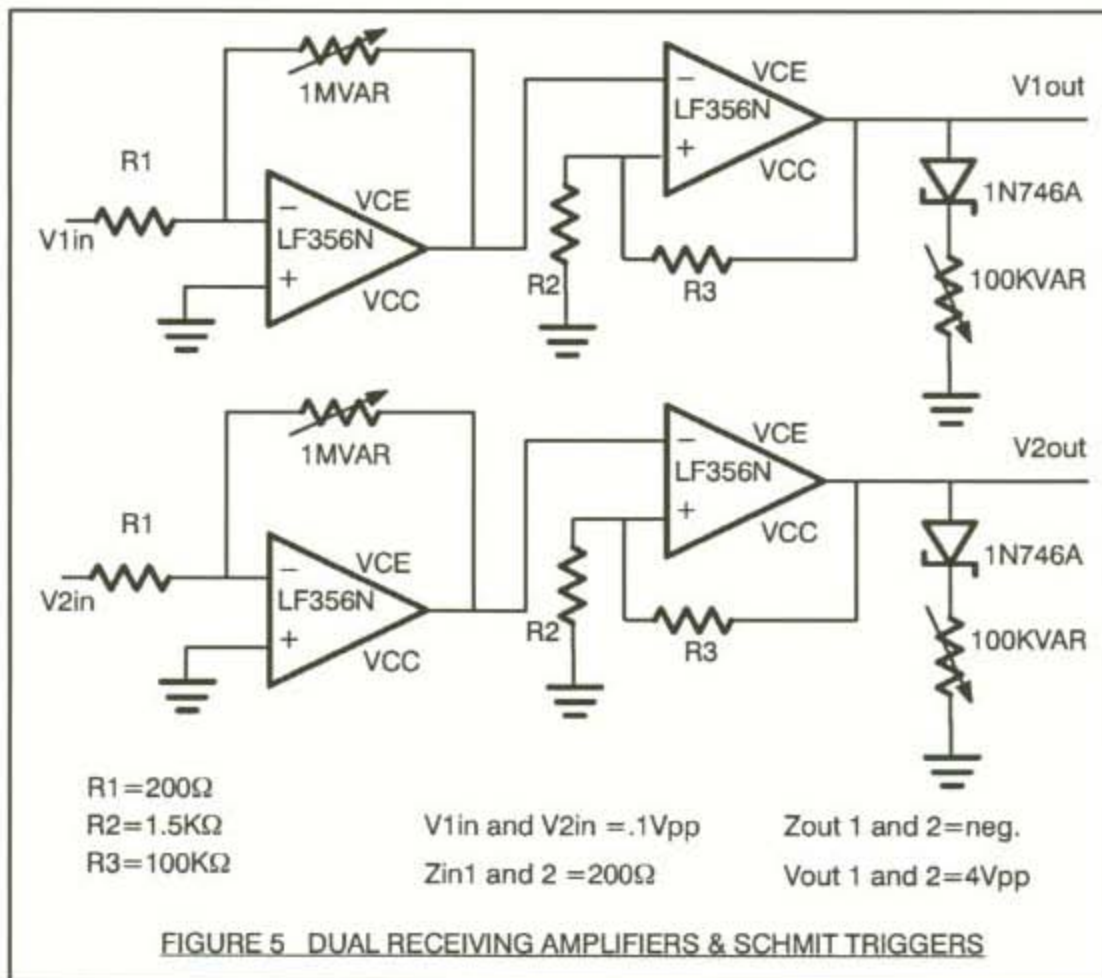
6.   Figure 4 illustrates the set-up of the piezoelectric transducers. Note that a coupling transformer (approximately 1:1) is added to help reduce ground noise and signal deformation. This transformer is only used on the output side and replaces the old set-up where a resistor was hooked up between the transducers and ground. This practice proved to be unacceptable as we were causing strong ground noise. If we broadcast a signal through the transducers, we will be able to pick up roughly 1/100th of the output amplitude. This sensitivity was determined experimentally. Now we have two separate received signals of .1 volts peak to peak. Note that the amplitude of the received sound waves will change with different atmospheric conditions. This is not however a major concern since in the next stage, the Schmit triggers section will act as an auto gain controller to counter this effect.

FIGURE 4   AIR TRANSMISSION STAGE
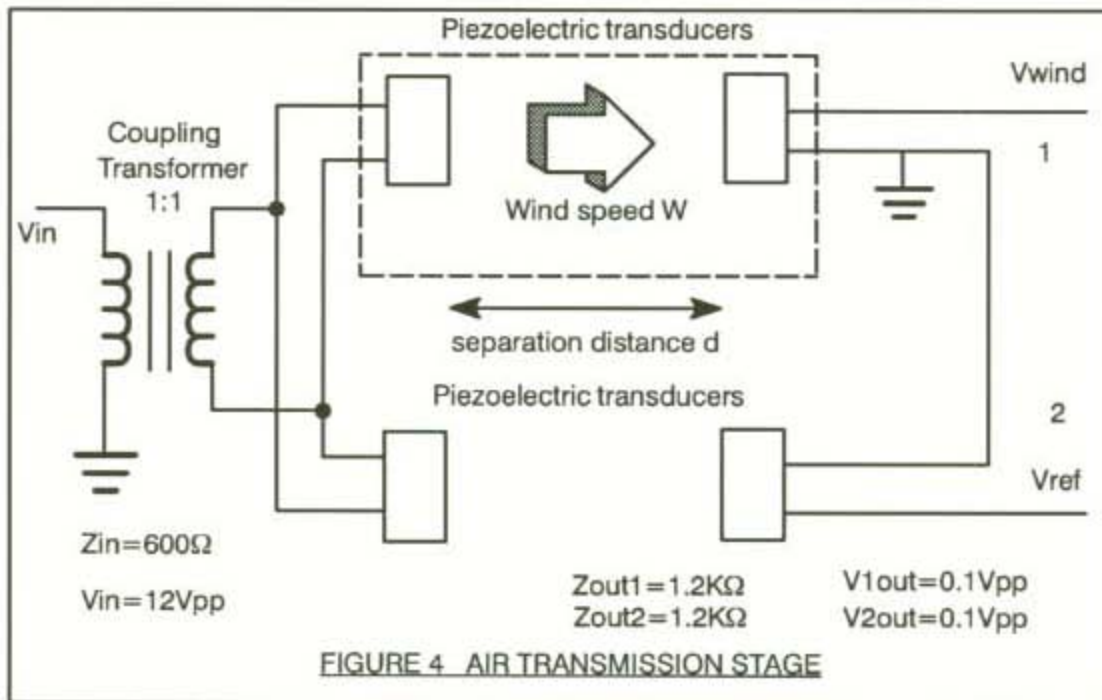
f. The dual receiving amplifier and Schmit trigger sets

7.   These amplifiers are simple op. amp. inverting amplifiers amplifying the input signals .1Vpp to signals of approximately 10Vpp. The signal amplitudes are not very important be-

cause the desired information is only in the phase shift between the two signals. Once the signals are amplified to an acceptable level (i.e. detectable by Schmit triggers) they are put through their respective Schmit trigger. This Schmit trigger act as an auto gain controller and converts the two signals to square waves of equal shape and of 4Vpp. These newly converted waves will retain their shape regardless of the fluctuations of the transmitted wave as long as those fluctuations stay within 40% of the original signal. The detailed circuit of these receiving amplifiers is shown in figure 5.

| R1=200Ω		
R2=1.5KΩ	V1in and V2in =.1Vpp	Zout 1 and 2=neg.
R3=100KΩ	Zin1 and 2 =200Ω	Vout 1 and 2=4Vpp

FIGURE 5 DUAL RECEIVING AMPLIFIERS & SCHMIT TRIGGERS

Note that after the Schmit trigger a diode and resistor were added to limit the amplitude of the output signal. The original design did not make use of the two Schmit triggers. Instead we amplified the received signals to the saturation level of the op. amps. giving us poor square waves. This method was dropped when large differences in the shape of the two waves were noticed.

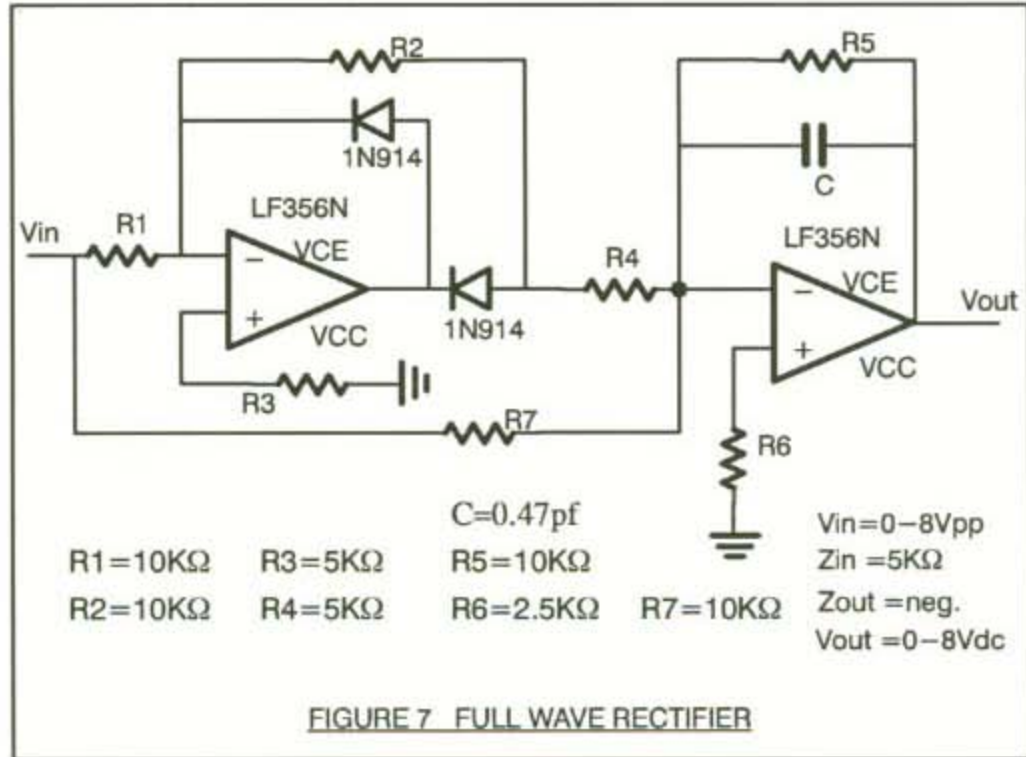g. The phase comparator or subtracter.

8.   The two input signals have the same amplitude and square shape. A simple way to

compare their phase shift is to use an op. amp. subtracter. In this case we set all resistors to a single a value R=1.2kΩ. The value of R could take several other values but we must insure that it always remains greater than the output impedance of the previous stage. The output signal is equal to the difference of the input signals at any given moment in time ($V = V_{wind} - V_{ref}$). The shape of the output will vary as a function of the phase shift between the two input signals. We will have a flat 0 volt level when the phase shift=0 and a full square wave of 8 volts peak to peak at a phase shift of 180 degrees. The detailed circuit of the phase shift comparator is illustrated in figure 6. This bloc performs according to original design specifications.
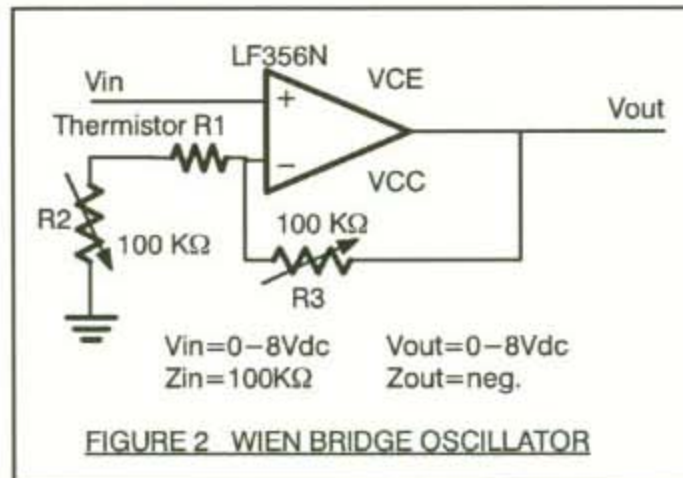

R1=R2=R3=R4=1.2KΩ
V1in and V2in =4Vpp
Zin1 and 2 =1.2KΩ

Zout =neg.
Vout =0 to 8Vpp

FIGURE 6   PHASE SHIFT COMPARATOR
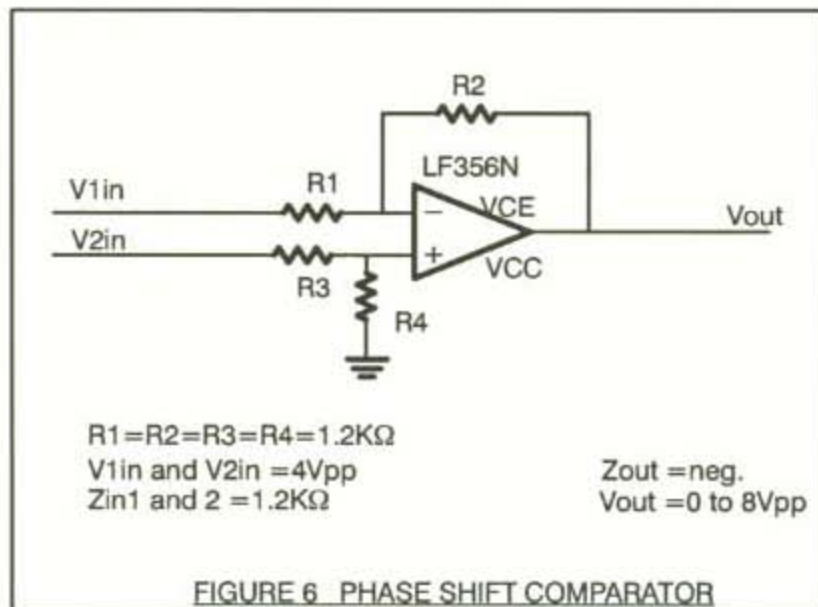
h. The full wave rectifier for AC to DC conversion.

9.   In this stage we are concerned with the conversion of an ac signal to a dc level. The circuit used is illustrated in figure 7. We have a square input signal of 8 volts peak to peak max and have a 0 to 8Vdc level out. . The value of the anti–ripple capacitor C was determined experimentally to be 0.47pf. The original design called for different values of resistors. Experimentally these resistor values did not work. New values were taken from Lt(N) Wigle who was using the same type of full wave rectifier. These new values when tested worked very well. Theoretically the old values should have worked. When tested on a computer simulator they also worked. It is not clear as to why experimentally they failed to perform as predicted. It was also found unnecessary to add a dc shift because at 0Vpp in, we did get 0Vdc out thus not requiring a dc level shift to get the desired 0Vdc output.

C=0.47pf

| R1=10KΩ | R3=5KΩ | R5=10KΩ | | Vin=0-8Vpp |
| R2=10KΩ | R4=5KΩ | R6=2.5KΩ | R7=10KΩ | Zin =5KΩ |

Zout =neg.

Vout =0-8Vdc

FIGURE 7   FULL WAVE RECTIFIER

i. Temperature compensation.

Vin=0-8Vdc   Vout=0-8Vdc
Zin=100KΩ   Zout=neg.

FIGURE 2   WIEN BRIDGE OSCILLATOR

10.   In order to compensate for the effect of temperature an extra block was added. This bloc consists of a temperature dependant gain non-inverting amplifier as shown in figure 8. The gain of the amplifier is defined in equation 2. It was determined theoretically that the wind speed indication increased in a quasi-linear fashion with temperature. Varying the gain of the amplifier as a function of temperature is a good way to compensate for this effect. As the temperature rises

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the thermistors impedance decreases allowing the overall gain to rise. It was impossible to calibrate this bloc due to the restricted meteorological conditions. To calibrate this bloc we would require to bypass the block and set the resistor value of the next stage such that the indicator is at its maximum for a wind of 60 km/h at 0°c. Then at 30°c we look at the drop in indicator value and thus calculate the gain needed to obtain a full reading again. Knowing the impedance values of the thermistor from 0 to 30°c (choosing a thermistor with a linear variation as a function of temperature) and using equation 2 we then set the two variable resistors to the desired values in order to obtain this desired gain factor.

$$Gain = \frac{(R1 + R2 + R3)}{(R1 + R2)}$$ *Equation 2*

j. Anemometer output and display.

11.   The last stage of the anemometer is simply composed of an indicator in series with a large variable resistor connected to ground as illustrated in figure 9. By adjusting the resistor during calibration we made sure to employ the dials full measurement range. Graph 1 represents the dial indication vs wind speed in km/h. To obtain a reading on the anemometer display we first adjust the internal separation distance d (reference side) physically such that the indicator reads as close to zero as possible with no wind (i.e. insure the two signals are in phase). Then by placing the wind side transducers into the wind, the value of the indicator is read and referenced on the graph to find the corresponding wind speed. An indication of 10 per example is equivalent to 60 km/h.

FIGURE 9 ANEMOMETER DISPLAY AND OUTPUT

dial

GRAPH 1 DIAL VS WIND VELOCITY.
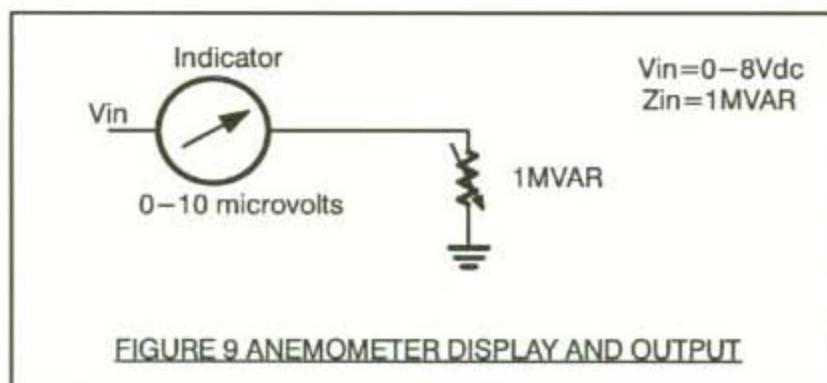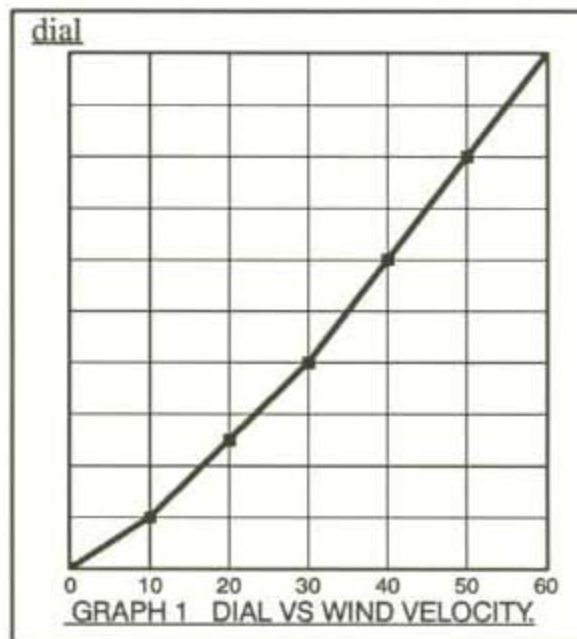
k. Other considerations.

12.   Most of the operational amplifiers were dc biased to ensure that no other dc signals other than the ones of interest could be used. This was a critical factor with all the dc blocks (rectifier, temperature compensation and display.) which helped eliminate erroneous results. We also connected the ground to the actual casing of the anemometer to increase the ground plane and therefore reduce ground noise.

CONCLUSION.

13.   In this paper, we have reviewed the design modifications and the performance of the ultrasonic anemometer. We now know that the design proved to be feasible as our results were satisfactory. All stages of the design had clear signals in and out. Very little noise was noticeable on the ground which lead to precise results. The only weakness of the system is the measurement of low velocity winds (< 20km/h). It is believed that this could have been caused by the large size of the transducers in comparison to the separation distance d. This physical constraint causes turbulence and a reduction of the effective separation distance. This reduced separation distance also made it possible to measure winds of up to 80 km/h (i.e. 80 km/h represents an 180° phase shift in-

ULTRASONIC ANEMOMETER DESIGN SPECIFICATIONS.

1.	Power supply:	2	9V batteries
2.	Operating frequency:	39.16kHz	
3.	Wind range measurement:	0 to 60 km/h +/– 5	
4.	Separation between transducers:	d=8.8cm	
5.	Operating temperatures:	0 to 30˚c	
6.	Manual Adjustments:	gain, dc offset, zero.	
7.	Dimensions:	Must be portable.	

ULTRASONIC ANEMOMETER TRUE SPECIFICATIONS.

1.   Power supply: 2   9V batteries

2.   Operating frequency: 40.96kHz (New oscillator)

3.   Wind range measurement: 0 to 80 km/h +/– 5 (Actual d smaller due to turbulence from transducer)

4.   Separation between transducers: d=8.8cm

5.   Operating temperatures: 0 to 30˚c

6.   Manual Adjustments: gain, zero. (Dc offset not required)

7.   Dimensions: 5"x4"x10" (i.e. portable)

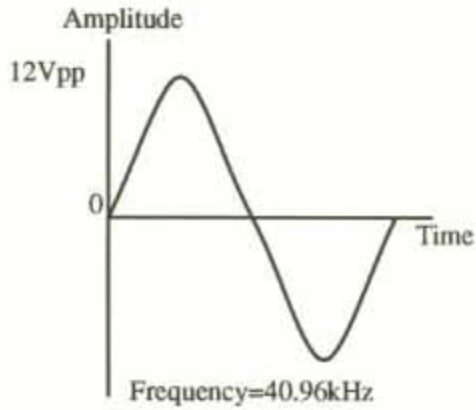## REFERENCES AND ACKNOWLEDGEMENTS.

References.

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2.   Physics for Technical Education. Ewen & Heaton. First Edition, Prentice Hall, New Jersey, 1981.

3.   Encyclopedia of Pysical Science and Technology. Volume 1. Section: Acoustic Wave Devices. E.K. Sittig. Robert A. Meyers, Editor, Academic Press Inc., Orlando Florida, 1987.

4.   Electronic Principles. A.P. Malvino. Third edition, McGraw–Hill Book Company, New York, 1984.

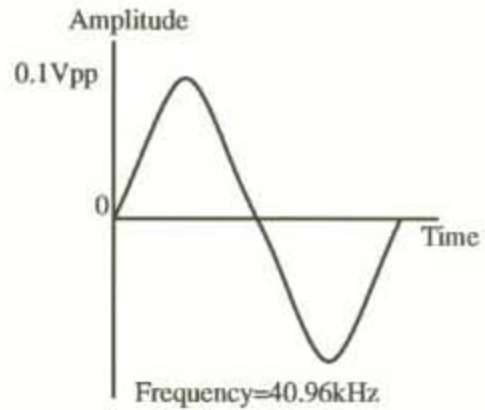Acknowledgments.

1.   Ultrasonic anemometer idea suggested by Dr. P. Rochon; Royal Military College, Kingston, Ontario.

2.   Four piezoelectric air operation transducers courtesy of Dr. S. E. Prasad; B.M. Hightech Inc., Collingwood, Ontario.
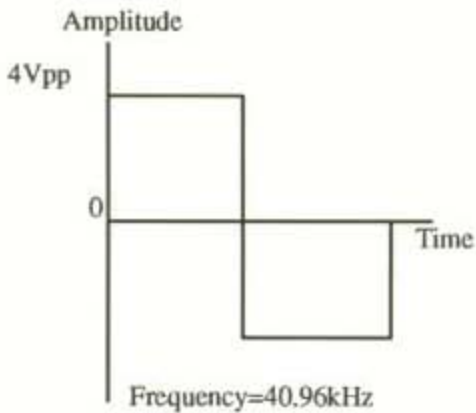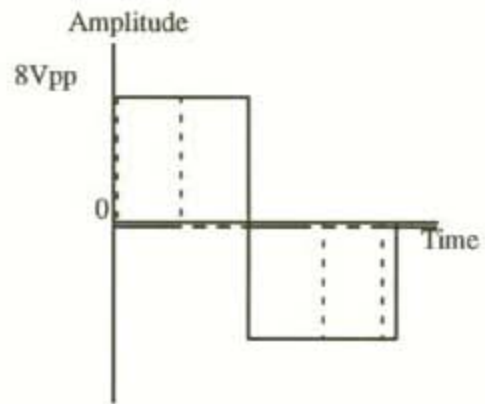
System signal flow.

Amplitude

12Vpp

0

Time

Frequency=40.96kHz

Output from oscillator and buffer

Amplitude

0.1Vpp

0

Time

Frequency=40.96kHz

Input to receivers

Amplitude

4Vpp

0

Time

Frequency=40.96kHz

Output from Schmit triggers

Amplitude

8Vpp

0

Time

Max output from subtracter ——
(180° phase shift)

Other outputs from subtracter
(90° phase shift) - - - -

(0° phase shift) —— - -

Outputs from full wave rectifier and temperature compensation both 0–8Vdc levels