"THE DEVELOPMENT OF A SOLID STATE WIND VELOCITY AND DIRECTION INDICATOR, SUITABLE FOR DATA LOGGING"

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DECLARATION

I declare that the contents of this thesis represents my own work and the opinions contained here are my own. It has not been submitted before for any examination at this or any other institute.

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SIGNATURE

NOVEMBER 1992

ABSTRACT

This thesis describes the development of a free standing, maintenance free anemometer which has no rotating parts. The principle of operation is based on the wind drag/force around a hollow P.V.C. pipe. The aim is to demonstrate how the strain occurring in the P.V.C. pipe, due to wind drag/force acting on it, can generate an electrical signal which can be mathematically manipulated to determine wind velocity and wind bearing.

OPSOMMING

Hierdie verhandeling beskryf die ontwikkeling van 'n vry staande, onderhoud vrye windmeter sonder enige roterende onderdele. Die wind se drukkrag veroorsaak 'n spanning in die P.V.C. pyp. Hierdie spanning word in 'n elektriese sein omgesit wat wiskundig gemanipuleer word om die wind spoed en wind rigting aan te dui.

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CHAPTER 1

INTRODUCTION

This thesis describes an investigation into the design and implementation of a reliable no rotating parts wind velocity and direction indicator.

The most common wind velocity and direction indicators are the conventional Cup Anemometer and hinged/pivoted Wind Vane. The most notable disadvantage of these meteorological instruments is that they contain rotating mechanical elements which require periodic lubrication and maintenance.

Mr. D.N. De Beer from The School of Electrical Engineering at the Cape Technikon commissioned *this project with the following major objectives :*

i) **To design a solid state Anemometer unit with no rotating parts.**

ii) **The unit should be maintenance free.**

iii) **The unit should be suitable for data logging interfacing.**

iv) **The unit should be designed to gather data on wind velocity and wind bearing for the display read-out.**

Most of the relevant information for the unit designed was obtained from technical literature, provided by various Technical Institutions as well as the Research and Development Centre, TELKOM, Cape Town.

Telephonic and written correspondence with various individuals involved with similar design projects as well as specialist Electronic Component Manufacturers, provided relevant data and application notes on related research projects. Furthermore various Marine Development Companies presented useful applied application documentation relevant to fulfilling the design criteria for the unit required.

The objectives of this thesis report are therefore : -

i) **To provide background information on the various Anemometer units that were investigated.**

ii) **To provide a detailed description and analysis of the proposed Anemometer unit.**

iii) **To provide field test results.**

iv) **To draw conclusions regarding the feasibility and practicality of the completed unit.**

The report commences with **Chapter 2** by providing background information on the various systems and transducers researched in the literature survey. This chapter also provides a basic schematic description of the actual proposed system.

Chapter 3 covers an investigation into the concepts involving wind and turbulent transfer and describes the method of manipulating the orthogonal wind vector components to translate wind pressure into wind velocity and wind bearing.

Chapter 4 provides a study into the fluid dynamics/mechanics and behaviour of the P.V.C. pipe anemometer unit when subjected to wind/air flow. The dimensional design parameters of the P.V.C. pipe anemometer unit are analysed and explained.

Chapter 5 describes the strain gauge transducers, strain gauge bridge configuration and orientation considered for the design in conjunction with the 'wind induced stress/strain sensing' P.V.C. pipe Anemometer unit.

Chapter 6 describes the analogue signal conditioning of the P.V.C. pipe mounted strain gauge bridges. This chapter also describes the analogue method of obtaining conditioned 'clean' analogue wind vector voltages for the digital conversion and microcontroller manipulation process.

Chapters 7 and 8 cover the hardware design, implementation of software digital interfacing, microcontroller and support circuitry, display read-out and 'data capture'.

Chapter 9 describes the power supply circuit designed for system power support.

Chapter 10 outlines the problems encountered during the implementation of the system and recommendations proposed for improvement of the design. This chapter continues to describe the environmental effects on the operation of the designed anemometer unit.

Chapter 11 provides information on the test procedures as well as the tabulated test results.

Chapter 12 covers the conclusions that were drawn and recommendations proposed for further application of the system.

CHAPTER 2

THE SYSTEMS/TRANSDUCERS INVESTIGATED

This chapter describes the basic arrangement of the proposed system. It is necessary to incorporate mechanical moving part anemometry in this survey since substantial information on geometric design parameters and on the measurement of wind velocity/bearing has been extracted for use in the design of solid state anemometry. Basic diagrams of the anemometers investigated are included in **APPENDIX A.**

The major types of anemometers may be classified as mechanical, thermo-electric, pressure and acoustical.

In order to meet the requirements the following anemometers were investigated. They are split into distinct categories : -

i)	**The Ventimeter**	**Mechanical**
ii)	**The Cup-Anemometer**	**Mechanical**
iii)	**The Hot-wire Anemometer**	**Thermo-electric**
iv)	**The Sonic Anemometer**	**Acoustical**
v)	**The Pressure-sphere Anemometer**	**Pressure**
vi)	**The Drag Anemometer**	**Force/Pressure**
vii)	**The Strain Gauge Anemometer**	**Force/Pressure**
viii)	**The Piezo-electric Anemometer**	**Acoustical/Pressure**

Furthermore, the following transducers were investigated : -

i) **Foil-strain gauges**

ii) **Semiconductor-strain gauges**

iii) **Piezo-electric transducers**

iv) **Pressure transducer integrated circuits**

Research also incorporated a study of stress/strain-sensitivity and elastic behaviour exhibited by metal-alloy and P.V.C. pipe members. A comprehensive investigation into the fluid dynamics/mechanics of structural pipe members related to air-flow was undertaken and is covered in detail in **Chapter 4**. The metal-alloy and P.V.C. pipe anemometer units constructed were : -

i)	**Stainless-steel Anemometer**	Prototype 1
ii)	**Aluminium-alloy Anemometer**	Prototype 2
iii)	**Aluminium-alloy Anemometer**	Prototype 3
iv)	**P.V.C. pipe Anemometer**	*Final design*

Based upon the above survey the unit was designed and constructed according to a strategy derived from the method employed by the **Drag Anemometer (vi)** and the **Strain Gauge Anemometer (vii).**

The fluid/dynamics/mechanics of these anemometers and the proposed anemometer unit are closely related. The method of employing strain gauge transducers for the translation of wind-induced stress/strain force into wind velocity and bearing is therefore used in the strain detection circuitry. The wind vector signals are conditioned and mathematically manipulated using appropriate C and Assembler language software programs for the data capture process and the display read-out.

2.1 Principle of operation, advantages and disadvantages of the Anemometers investigated

2.1.1 The Ventimeter [1]

This instrument is the simplest instrument for measuring wind velocity. The opening is directed into the wind. Wind force causes a disc to rise up the body of the instrument. The height to which it rises is proportional to wind velocity.

The exterior of the tube is graduated so that wind velocity can be read off directly. It is primarily a hand-held mechanical device.

Conflicting with thesis objective : -

i) The mechanical moving disc.

Advantages : -

i) Modular application.

ii) Robust construction.

iii) Portable unit.

iv) Easiest to use.

Disadvantages : -

i) Not accurate ; it can seldom be exposed to areas of clear wind and the readings obtained are not necessarily those of true wind velocity.

ii) It only measures wind velocity.

2.1.2 The Cup Anemometer [2 & 3]

This system employs the use of three revolving cups. The most common units employ the use of a reed switch to translate the rotation of the cups into a wind velocity.

The generator system is also fairly simple. The cup assembly drives a small dynamo and the magnitude of the voltage generated is directly proportional to the wind velocity.

More modern methods employ the use of a cup assembly rotating a toothed wheel which interrupts the light path between the light and photocell. These pulses are counted at fixed time intervals and are converted into wind velocity.

Conflicting with thesis objective : -

i) The mechanical rotating cup assembly.

Advantages : -

i) Modular application.

ii) Robust construction.

iii) Most reliable method of measuring wind speed.

Disadvantages : -

i) Intended for use in the horizontal position only.

ii) Tend to overspeed due to non-linear response to fluctuating winds.

iii) Has a rotating mechanical cup assembly which requires periodic lubrication and maintenance.

2.1.3 The Hot-wire Anemometer [4]

This is a solid state wind speed sensing system using a variation of the Kelvin Effect. An element is electrically heated to a temperature just above the ambient air temperature. The wind is then directed through holes in the transducer casing over the element causing it to be cooled and a compensation current is needed to bring the element back to its original temperature. The amount of current drawn is proportional to the wind speed blowing over the element.

Advantages : -

i) Solid state, no moving parts.

ii) Sets of Hot-wires can be oriented so as to measure the three directional components of wind movement.

iii) Maintenance free.

Disadvantages : -

i) Calibration is complicated. For accurate work a given Hot-wire probe must be calibrated in the fluid in which it is used.

ii) Temperature sensing is complicated.

2.1.4 The Sonic Anemometer [5]

This anemometer is among the newest developments in anemometry. Extensively used at Athletics Sports meetings for determination of wind assistance in track and field events. The principle of operation is based on the theory that sound travels faster from an emitter to a receiver in the direction of the wind and, conversely, travels more slowly against the wind.

The main components of the instrument are transmitters and receivers for the generated sound waves and circuitry for measuring phase shifts and for frequency adjustments. The speed of sound varies with factors such as air temperature, water vapour pressure and atmospheric pressure.

With three sets of emitters and receivers oriented in the x, y and z directions, it is possible to determine three orthogonal components of wind velocity simultaneously.

Advantages : -

i) No moving parts.

ii) Maintenance free.

iii) Robust construction.

iv) Relatively low power consumption.

v) Accurate.

Disadvantages : -

i) Requires accurate calibration for correct frequency response and for drift of anemometer output at zero wind velocity.

ii) Sensor configuration, circuitry and set up procedure is extremely critical for accurate correlation of wind velocity.

iii) Expensive ultrasonic transducers are required to eliminate zero reading variation with temperature.

2.1.5 The Pressure-sphere Anemometer [6]

This anemometer is also referred to as the anemoclinometer. It can be used to measure downwind, crosswind and the vertical components of wind velocity simultaneously.

It consists of a small metal sphere with electronic pressure sensors placed in holes facing directly into the wind and at 90° angles to the main axis. Pressure differences between the various sets of holes are used to calculate the three dimensional wind velocity vector components.

Advantages : -

i) No moving parts.

ii) Maintenance free.

iii) Accurate electrical outputs of the pressure transducers can be analysed to give orthogonal components of the wind vector.

Disadvantages : -

i) Expensive transducers are required.

ii) Complicated design of transducer assembly housing.

2.1.6 The Drag Anemometer [2]

Rapid fluctuations of wind speed in three dimensions can also be measured with the Drag Anemometer. The drag force of the wind on an aerodynamic shape is proportional to the square of the wind velocity.

This force can be measured by the deflection of a strain gauge attached to an object held perpendicularly to the wind. Since the wind is not constant in direction, three mutually perpendicular wind sensing elements with strain gauges attached can be used to resolve the instantaneous wind velocity and direction.

Advantages : -

i) No rotating parts.

ii) Maintenance free.

iii) Accurate.

iv) Measures wind velocity and direction.

Disadvantages : -

i) Critical signal conditioning is required to convert small signal variation into wind velocity.

ii) Requires adequate temperature compensation and remote sensing of the anemometer output at zero wind velocity.

iii) Cumbersome transducer assembly housing.

iv) Not easily transportable as the frame mounting and wind sensing elements make this an extremely bulky anemometer.

2.1.7 The Strain Gauge Anemometer [7]

A feasible and inexpensive strain gauge anemometer was researched by the Georgia Institute of Technology. This anemometer, however, was never developed. This is a highly specialised design and involves a system where wind vector components are manipulated to determine wind speed.

The unit consists of a vertical steel rod, one end of which is connected to the intersection of two horizontal paper-thin steel beams and the other end has a sphere attached.

The force of the wind generates a drag on the sphere which is resolved into North-minus-South and East-minus-West displacements of the thin steel beams. These displacements are sensed by strain gauges and vector voltages Vn-s and Ve-w are produced, which are proportional to the drag on the sphere. Since the drag on the sphere varies with the square of the wind velocity, Vn-s and Ve-w are proportional to the square of wind velocity. This squared relationship assumes a constant Drag Co-efficient on the sphere.

Analogue multiplier integrated circuits, summing and logarithmic amplifiers then condition and manipulate the wind vector voltages to determine true wind velocity for the analogue display meter.

Advantages : -

i) Solid state.

ii) No rotating parts.

iii) Maintenance free.

iv) Accurate.

Disadvantages : -

i) Measures wind velocity only.

ii) Analogue electronics used demands/requires extensive calibration techniques for signal conditioning and manipulation.

iii) Mechanical design of the anemometer unit is delicate.

2.1.8 The Piezo-Electric Anemometer [8]

This anemometer was researched but according to Syrinx Innovations Ltd. of Edinburgh, Scotland, was not feasible for development.

The device consists of a solid wind deflector cylinder which has four smaller identical hollow tubes equispaced about the wind deflector column. Each tube is open at the top but closed at the bottom by a film of polymeric piezo-electric material.

Wind blowing across the open end induces Helmholz resonance of the air column within the tube and hence movement of the film at the bottom. The average output of the four films is a function of wind speed, and the relationship of the output amplitudes from the several films indicates wind direction.

Advantages : -

i) No moving parts.

ii) Maintenance free.

iii) Solid construction of hardware unit.

iv) Good design.

Disadvantages : -

i) Requires accurate a.c. signal conditioning.

ii) System needs crucial protection from environmental elements such as rain and snow, to prevent tubes from filling with water.

Other wind indicators researched were the conventional pivoted wind-vane for measuring wind direction as well as a variety of propeller anemometers. Although these systems have rotating parts, the research material provided valuable insight into the orthogonal and geometric properties of wind-flow and the measurement thereof.

The second part of the initial research covers the important aspect in converting mechanical displacement of the wind detection unit into electrical signals as a function of the wind vector components imposed on the hardware unit. A literature survey, substantiated by experiments with various transducers used in air-flow measurement was conducted.

2.2 Principle of operation, advantages and disadvantages of the transducers investigated

2.2.1 Foil Strain Gauges [1]

A resistance strain gauge is a device which experiences a change of electric resistance when it is strained. It is almost always connected in a bridge configuration.

The strain gauge measures force indirectly. The resistance strain gauge is a resistive element which changes in length, hence resistance, as a force applied to the base on which it is mounted causes stretching or compression. It is perhaps the most well known transducer for converting force into an electrical variable. The foil strain gauge consists of a thin wire of conducting film arranged in a coplanar pattern. **(Refer to Chapter 5 : Figure 5.2)**

The gauge is cemented to a base or carrier and is mounted so that as much as possible of the length of the conductor is aligned in the direction of the stress that is being measured. Foil type gauges are produced by photo-etching techniques.

The resistance change with strain of a single strain gauge is small compared to the initial impedance value of the strain gauge. Strain gauges are therefore connected in a Wheatstone bridge configuration.**(Refer to Chapter 5 : Section 5.3 : Strain Gauge Bridge Configurations)**

Strain gauges are low-impedance devices. They require significant excitation power to achieve reasonable output voltage levels. A typical strain gauge bridge will have a 350 Ω impedance and is specified as having a sensitivity in terms of millivolts per volt of excitation at full scale.

The maximum excitation potential, as well as the recommended potential, will be specified. For a 10 Volt device with a rating of 3 millivolt per volt (3mV/V), 30 millivolts of signal will be available at full-scale loading. The output can be increased by increasing the drive to the bridge, but self-heating effects are a significant limitation to this approach. They can cause erroneous readings or even device destruction if prolonged.**(Refer to Chapter 6 : Section 6.2.5 : Bridge Excitation Programming of the 1B32 AN)**

Advantages : -

i) Inexpensive.

ii) Extensive range available.

iii) Linear response to measured strain.

iv) Accuracy.

v) Durability, uniform quality, large current capacity.

vi) Self-temperature compensated.

Disadvantages : -

i) Small differences in the temperature co-efficients of the bridge elements are responsible for temperature sensitivity thereby limiting the performance of the strain gauge. This necessitates the control of the excitation current to prevent thermal drift.

ii) Requires high quality, low level signal conditioning.

2.2.2 Semiconductor-Strain Gauges [1]

These devices have been derived from foil-strain gauges. Bridge types are pre-assembled from individual gauges and output a voltage. They have outputs that are ten times higher than those of the foil variety and impedances in the order of Kilo-ohms. It is often necessary to use a current source for excitation so as to minimise temperature induced effects.

Advantages : -

i) Sensitivity is far greater than that of foil-strain gauges.

Disadvantages : -

i) Expensive.

ii) Fragile.

iii) Lack of ductility.

iv) Increased non-linearity and sensitivity to temperature.

2.2.3 Piezo-electric transducers [1]

Piezo-electric force transducers are employed where the forces to be measured are dynamic (continually changing over short period - usually of the order of milliseconds). These devices utilise the effect that changes in charge are produced in certain materials when they are subjected to physical stress.

Piezo-electric devices produce substantial output voltage in instruments such as accelerometers for vibration studies. Output impedance is high. Thus charge amplifier configurations with low input capacitance are required for signal conditioning.

The output of a piezo-electric transducer may be modelled as a voltage source in series with a small capacitor. Step inputs of physical force result in an effective capacitance change.

Advantages : -

i) Inexpensive.

ii) Suitable transducer for vibration studies.

Disadvantages : -

i) Requires low bias-current charge amplifier configurations for signal conditioning.

ii) Responds to a.c. signals only.

2.2.4 Pressure transducer integrated circuits [2 & 3]

Pressure transducer types measure flow by monitoring the change in pressure between a static reference pressure and a flow induced pressure, or pressure drop across a constriction.

There are three general categories of pressure measurement : - absolute, gauge and differential.

Absolute pressure devices measure pressure with reference to zero pressure, (vacuum). Gauge pressure is measured in relation to ambient (sea-level atmospheric pressure, or an arbitrary level). Differential pressure transducers measure the difference between two pressures and, of the three types, were most suitable for use as a sensor for wind measurement.

Advantages : -

i) Accurate.

ii) Robust.

iii) Temperature compensated.

iv) Low power requirement.

Disadvantages : -

i) Very expensive.

ii) Response is non-linear.

2.3 <u>The Structural Pipe Members investigated</u>

Three prototype anemometer units were constructed and tested before the final P.V.C. pipe anemometer unit was designed. A brief description of the design of prototypes 1, 2 and 3 and their limitations is provided in the following paragraphs.

The fluid mechanics/dynamics of the P.V.C. pipe member chosen for the final design is not discussed here but is covered in **Chapter 4**. Furthermore the properties of the materials used are provided in **Appendix B.**

2.3.1 The Stainless-steel Anemometer unit

A prototype stainless-steel hardware anemometer unit was constructed by bonding eight active strain gauge transducers to the circumference of a stainless-steel pipe (height = 1 metre ; diameter = 25 mm).

Manual stress/strain experiments were conducted on the pipe. The stainless-steel anemometer unit was subjected to considerable tensile/compressive stresses. The stainless-steel pipe member was subjected to a considerable amount of "finger tip" induced force/pressure (which is far in excess of hurricane wind pressure), before a bridge output swing of 1 mV p-p was achieved.

Considerable strain gauge bridge output signal amplification was necessary (gain in excess of 5000). This caused amplification of small signal offset and inaccuracy at smaller strains (or generally, at lower wind velocities).

Advantages : -

i) Resistant to corrosion.

ii) Robust, high tensile strength and elastic limit.

- Stainless-steel has a tensile strength of 1295 MN/m^2.

  (Refer to APPENDIX B : Properties of materials)

- Mean wind pressure at hurricane wind velocity is 1.388 KN/m^2.

  (Refer to Chapter 3 : Figure 3.1)

- Hence, the elastic limit of the Stainless-steel pipe was never in danger of being exceeded.

  (Refer to Chapter 5 : 5.1.4 : Elastic Limit)

iii) Natural heatsink for transducers. Has a high thermal conductivity property.

(Refer to Chapter 10 : 10.6 : Thermal dissipation of the strain gauges)

iv) Change in length of the pipe in the environmental temperature range (0°C to 40°C) for this design is negligible : -

(Refer to Chapter 10 : 10.7.2 : Effect of temperature on the stainless-steel anemometer unit)

Disadvantages : -

i) Too rigid, not elastic enough for translation of strain-related wind pressure : -

(Refer to APPENDIX B : Properties of materials : Young's Modulus)

ii) Metal structure, good conductor of electricity. Has a low resistivity property. Susceptible to lightning strikes.

(Refer to Chapter 10 : 10.7.5 : Susceptibility of the pipe members to lightning strikes)

2.3.2 The Aluminium-alloy Anemometer units

Prototype anemometer units number 2 and 3 were constructed from aluminium-alloy. Physical dimensions of prototype 2 were identical to the prototype 1 stainless-steel unit and comparative tests were conducted.

Prototype 2 employed an alternative strain gauge configuration using four active strain gauge elements and four temperature compensating dummy gauges for the bridge completion circuitry. The dummy gauges were bonded to the aluminium pipe to control temperature induced strain. Stress / strain experiments yielded an improvement in strain-sensitivity but signal amplification required a gain of 5000 which distorted small signal offsets.

A prototype 3 Aluminium anemometer unit was constructed, with physical dimensions (h = 1.8m d = 25mm), with eight fully-active strain gauge transducers bonded to the circumference of the pipe. A slight improvement in strain-sensitivity was realised but limitations in the elastic nature of aluminium proved that considerable signal amplification was necessary for successful translation of strain related wind pressure from the aluminium pipe.

Advantages : -

i) Resistant to corrosion.

ii) Robust, high tensile strength and elastic limit.

- Aluminium-alloy has a tensile strength in the range 320 - 550 MN/m^2.

  (Refer to APPENDIX B : Properties of materials : Tensile Strength)

- Mean wind pressure at hurricane wind velocity is 1.388 KN/m^2.

  (Refer to Chapter 3 : Figure 3.1)

- Hence, the elastic limit of the Aluminium-alloy pipe was never in danger of being exceeded.

  (Refer to Chapter 5 : 5.1.4 : Elastic Limit)

iii) Natural heatsink for transducers. Has a high thermal conductivity property.

(Refer to Chapter 10 : 10.6 : Thermal dissipation of the strain gauges)

iv) Change in length of the pipe in the design temperature range (0°C to 40°C) for this design is negligible : -

(Refer to Chapter 10 : 10.7.3 : Effect of temperature on the aluminium anemometer unit)

Disadvantages : -

i) Too rigid, not elastic enough for this application : -

(Refer to APPENDIX B : Properties of materials : Young's Modulus)

ii) Metal structure, good conductor of electricity. Has a low resistivity property. Susceptible to lightning strikes.

(Refer to Chapter 10 : 10.7.5 : Susceptibility of the pipe members to lightning strikes)

2.3.3 The P.V.C. Pipe Anemometer unit

A final P.V.C. pipe anemometer unit was constructed. Eight fully-active strain gauge transducers were bonded to the circumference, near the base of a P.V.C pipe (height 1 metre ; diameter 40 mm).

The design was supported by moderate strain gauge bridge signal amplification (333.3) and required a bridge excitation of 4 Volts. The P.V.C. pipe was subjected to a constant air-flow ranging from 0 m/s to 40 m/s, in the experimental wind tunnel at Stellenbosch University.

Recorded results proved that the unit operated with efficient linearity throughout the tested wind velocity range. **(Refer to Chapter 11 : TEST RESULTS)**

Advantages : -

i) P.V.C. is resistant to corrosion.

ii) Robust, high tensile strength.

- P.V.C. has a tensile strength in the range 30 - 70 MN/m^2.

  (Refer to APPENDIX B : Properties of materials).

- Mean wind pressure at hurricane wind velocity is 1.388 KN/m^2.

  (Refer to Chapter 3 : Figure 3.1)

- Hence, the elastic limit of the P.V.C. pipe was never in danger of being exceeded.

  (Refer to Chapter 5 : 5.1.4 : Elastic Limit)

iii) Improvement in elasticity over Aluminium and Stainless-steel units previously tested. (i.e. improvement in linear tensile or compressive stress for P.V.C.)

(Refer to APPENDIX B : Properties of materials : Young's Modulus)

iv) P.V.C. is a good insulator. The resistivity of P.V.C. exceeds those of metals by a factor of 10^{22}. Therefore it is not as susceptible to lightning strikes as aluminium or stainless steel.

(Refer to Chapter 10 : 10.7.5 : Susceptibility of the pipe members to lightning strikes)

v) The change in length of the pipe in the design temperature range (0°C to 40°C) is negligible. P.V.C. has a lower Co-efficient of thermal expansion than Stainless-steel and Aluminium-alloy.

(Refer to APPENDIX B : Properties of materials : Co-efficient of thermal expansion)

Therefore, the change in length of the P.V.C. pipe with temperature changes is smaller for P.V.C. than for the Stainless-steel and Aluminium-alloy pipe members.

(Refer to Chapter 10 : 10.7.1 : Effect of temperature on the P.V.C. pipe anemometer unit)

Disadvantages : -

i) Aluminium and stainless-steel have higher thermal conductivity factors than P.V.C. This characteristic allows them to operate as a natural heatsink for resistance strain gauge transducers bonded to them.

(Refer to Chapter 10 : *10.6 : Thermal dissipation of the strain gauges*)

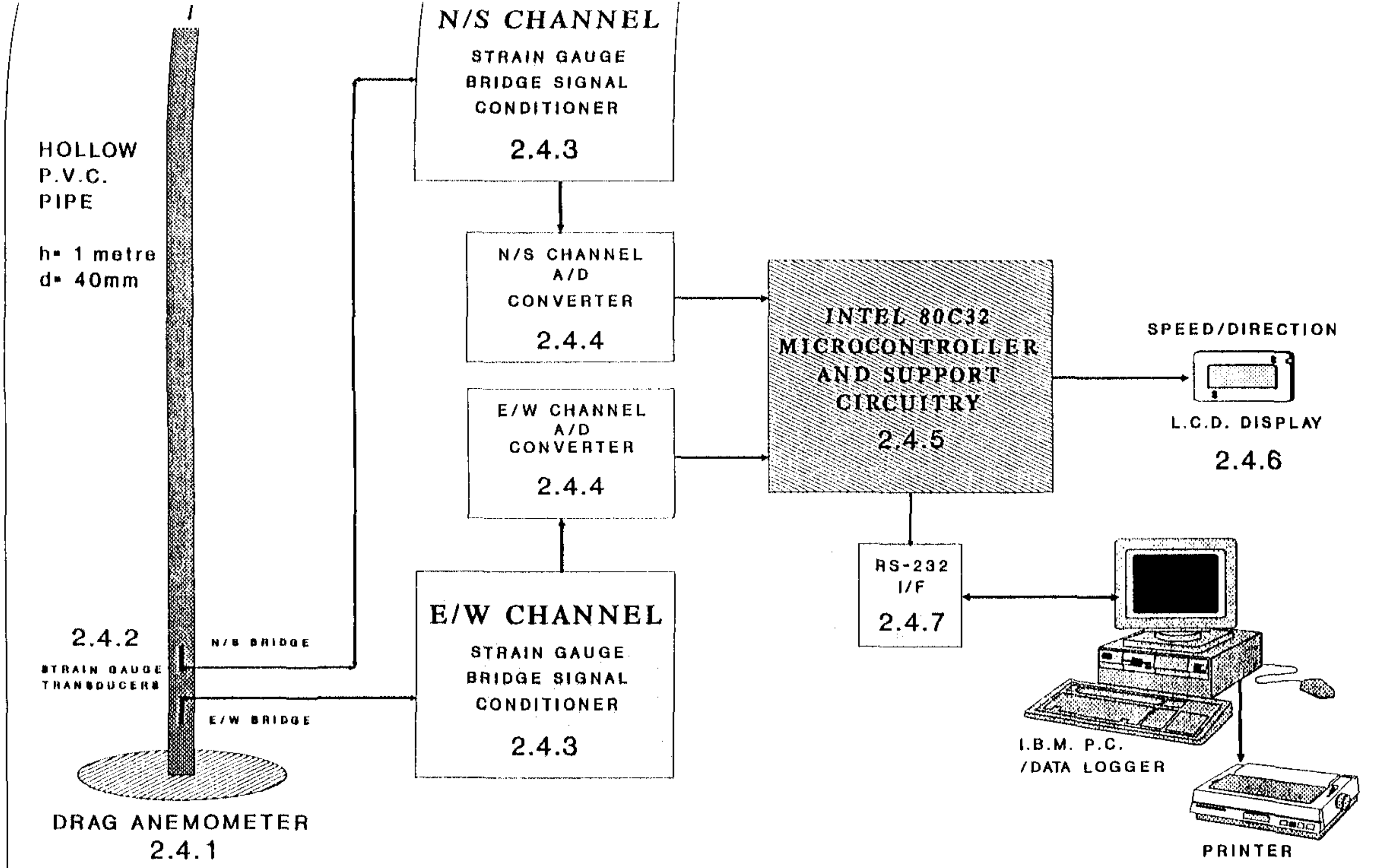


Figure 2.1 : DRAG ANEMOMETER SCHEMATIC

ii) Bridge excitation supply voltage in excess of 5 Volts can be applied to the strain gauge transducers without effecting the performance of the transducers. The same does not apply for the P.V.C. pipe.

(Refer to APPENDIX B : Properties of materials : Thermal conductivity)

Bridge excitation in excess of 5 Volts will cause temperature-induced apparent strain as a result of unstable transducer performance due to temperature rise in the gauges (I^2R loss). This is a potential source of error but can be controlled by reducing bridge excitation supply voltage to 4 Volts or less, and by correct selection of strain gauge transducers and transducer bridge configuration, which is discussed in greater detail in **Chapter 5**.

2.4 Proposed Design System

This section covers a basic description of the proposed design system. **Figure 2.1** is a schematic representation of the designed anemometer unit and support devices.

2.4.1 The Anemometer

A hollow P.V.C. pipe, with **height = 1 m; diameter = 40 mm** mounted vertically and solidly fixed at the bottom end.

2.4.2 The Transducers

Strain gauge transducers mounted equidistantly at North, South, East and West points on the pole circumference monitor changes in stress at precise sections on the pole circumference.

The gauges are self-temperature compensated and specifically dedicated for the type of material that they are attached to. The gauges are effectively 120 Ohm precision resistors. The gauges, when attached to a specimen will exhibit a change in resistance when the specimen is strained.

Resistance change with strain is small when compared to the initial value of the strain gauge resistance, thus strain gauges are connected in a bridge configuration.

Two strain gauge bridges are provided on the P.V.C. pipe, a North/South Channel bridge and an East/West Channel bridge. Two separate excitation voltages are applied to each of these channels and each channel is monitored separately.

2.4.3 Signal Conditioning

Two high quality low-level analogue signal conditioning channels are required to provide excitation over long leads to the remote pole mounted N/S and E/W channel bridge configured strain gauges.

The signal conditioning allows remote sensing over these long leads for fixed excitation. The N/S and E/W channel bridge outputs are then amplified, chopped and filtered before the clean signal is applied to two separate A/D converter channels **(2.4.4)**, one for the N/S channel and one for the E/W channel.

2.4.4 Analogue-to-Digital Converters

The clean signal is applied to two separate A/D converter channels, one for the N/S channel and one for the E/W channel, and a digital voltage output is derived.

It is essential to note that an analogue offset voltage of 19.53 mV represents 1 least significant bit for the ADC stage as frequent reference to this design criterion is mentioned in proceeding chapters.

2.4.5 Manipulation of conditioned signals

The conditioned digital ADC wind vector signals are then applied to an INTEL 80C32 Microcontroller and support circuitry for mathematical manipulation to determine wind velocity in the range 0 m/s to 35 m/s and wind direction for the display **(2.4.6)**.

2.4.6 The LCD Display

The display provides a read-out of bridge offset adjustment, wind velocity in m/s, wind direction (8 compass positions) and wind angle/bearing in degrees.

2.4.7 RS-232 Serial Port

An RS-232 Serial Port is also provided for data logging of the wind velocity information to an IBM P.C. for recording purposes.

2.5 References

Anemometry

1. Dick, N.C. 1974 "Yacht Sailing Instrumentation" pp 35 - pp 36

2. Pick, W.H. 1938 "A short course in Elementary Meteorology" pp 156 - pp 157

3. Pollock, N. 1981 "Wind speed and direction meter" Wireless World, February 1981

4. Bergen, J.D. 1971 "An inexpensive Heated Thermistor Anemometer" Agr. Meteor., 8 : pp 395 - pp 405

5. Campbell, G.S. Unsworth, M.H. 1979 "Sonic Anemometer for Eddy Correlation" Journal of Appl. Meteorol., 18 : pp 1072 - pp 1077

6. Thurtell, G.W. 1970 "Three Dimensional Pressure-sphere Anemometer System" Journal of Appl. Meteorol., 9 : pp 379 - pp 385

7. Connelly, J.A. 1974 "Analog Multipliers determine true
Lundberg, M.B. wind speed"
E.D.N., April 20, 1974
pp 69 - pp 72

8. U.K. PATENT 1988 GB 2 203 246 A
"Polymeric Piezo-electric wind speed/
direction indicator"

Transducers

1. Sheingold, D.H. 1980 "Transducer Interfacing Handbook"
pp 28 - pp 30

2. National Semiconductor 1987 "The Pressure Transducer Handbook"

3. Sensym Inc. 1988 "I.C. Pressure Transducer Short-form Catalogue"

CHAPTER 3

WIND TURBULENCE AND TRANSFER

This chapter describes an investigation into the concepts involving wind and turbulent transfer. It is beyond the scope of this work to discuss the many large scale and local seasonal patterns of winds that prevail in different climatic regions of the world.

A brief outline of the orthogonal components of wind pressure transfer is provided and related to the proposed design.

3.1 The Beaufort Scale [1]

Of the many scales used to express wind strength, that devised by Admiral Sir Francis Beaufort in 1805 and now known as the "Beaufort Scale" has been most widely adopted internationally. This scale, which divides wind velocities into 17 strengths, is given in **Figure 3.1 (overleaf).**

As for the wind direction, this is usually expressed in terms of points of the compass, but is often convenient to express it as a bearing in degrees (0^o to 360^o) reckoning north as zero and measuring the angle in a clockwise direction.

The P.V.C. pipe Anemometer unit was designed to record wind velocities in the range 0.9 m/s (Light air, Beaufort number = 1) to 39.2 m/s (Hurricane wind speed, Beaufort number = 13). **Refer to Figure 3.1 : THE BEAUFORT SCALE OF WIND FORCES.**

Furthermore, the unit was designed to record 8 wind compass bearing positions. They are : - North, South, East, West, North-East, South-West, North-West and South-East.

BEAU-FORT NO.	DESCRIPTION OF WIND	LIMITS OF MEAN WIND SPEED AT 10 metres above flat ground in an open situation				MEAN WIND FORCE	AVER WIND VEL.
B	WIND CONDITION	Knots	M.P.H.	Km/h	m/s	N/m^2	m/s
0	CALM	< 1	< 1	< 1	< 0.3	****	0
1	LIGHT AIR	1 to 3	1 to 3	1.6 to 4.8	0.3 to 1.5	0.48	0.9
2	LIGHT BREEZE	4 to 6	4 to 7	6.4 to 11.2	1.6 to 3.3	3.83	2.5
3	GENTLE BREEZE	7 to 10	8 to 12	12.8 to 19.2	3.4 to 5.4	13.41	4.4
4	MODERATE BREEZE	11 to 16	13 to 18	20.8 to 28.8	5.5 to 7.9	32.10	6.7
5	FRESH BREEZE	17 to 21	19 to 24	30.4 to 38.4	8.0 to 10.7	62.72	9.4
6	STRONG BREEZE	22 to 27	25 to 31	40.0 to 49.6	10.8 to 13.8	110.12	12.3
7	MODERATE GALE	28 to 33	32 to 38	51.2 to 60.8	13.9 to 17.1	172.37	15.5
8	FRESH GALE	34 to 40	39 to 46	62.4 to 73.6	17.2 to 20.7	258.55	19.0
9	STRONG GALE	41 to 47	47 to 54	75.2 to 86.4	20.8 to 24.4	368.68	22.6
10	WHOLE GALE	48 to 55	55 to 63	88.0 to 100.8	24.5 to 28.4	502.74	26.5
11	STORM	56 to 63	64 to 72	102.4 to 115.2	28.5 to 32.6	670.32	30.6
12	HURRICANE	64 to 71	73 to 82	116.8 to 131.2	32.7 to 36.9	861.84	34.8
13	*****************	72 to 80	83 to 92	132.8 to 147.2	37.0 to 41.4	1101.24	39.2
14	*****************	81 to 89	93 to 103	148.8 to 164.8	41.5 to 46.1	1388.52	43.8
15	*****************	90 to 99	104 to114	166.4 to 182.4	46.2 to 50.9	1675.80	48.6
16	*****************	100 to 108	115 to125	184.0 to 200.0	51.0 to 56.0	2058.84	53.5
17	*****************	109 to 118	126 to136	201.6 to 217.6	56.1 to 61.2	2489.76	58.7

Figure 3.1 : THE BEAUFORT SCALE OF WIND FORCES

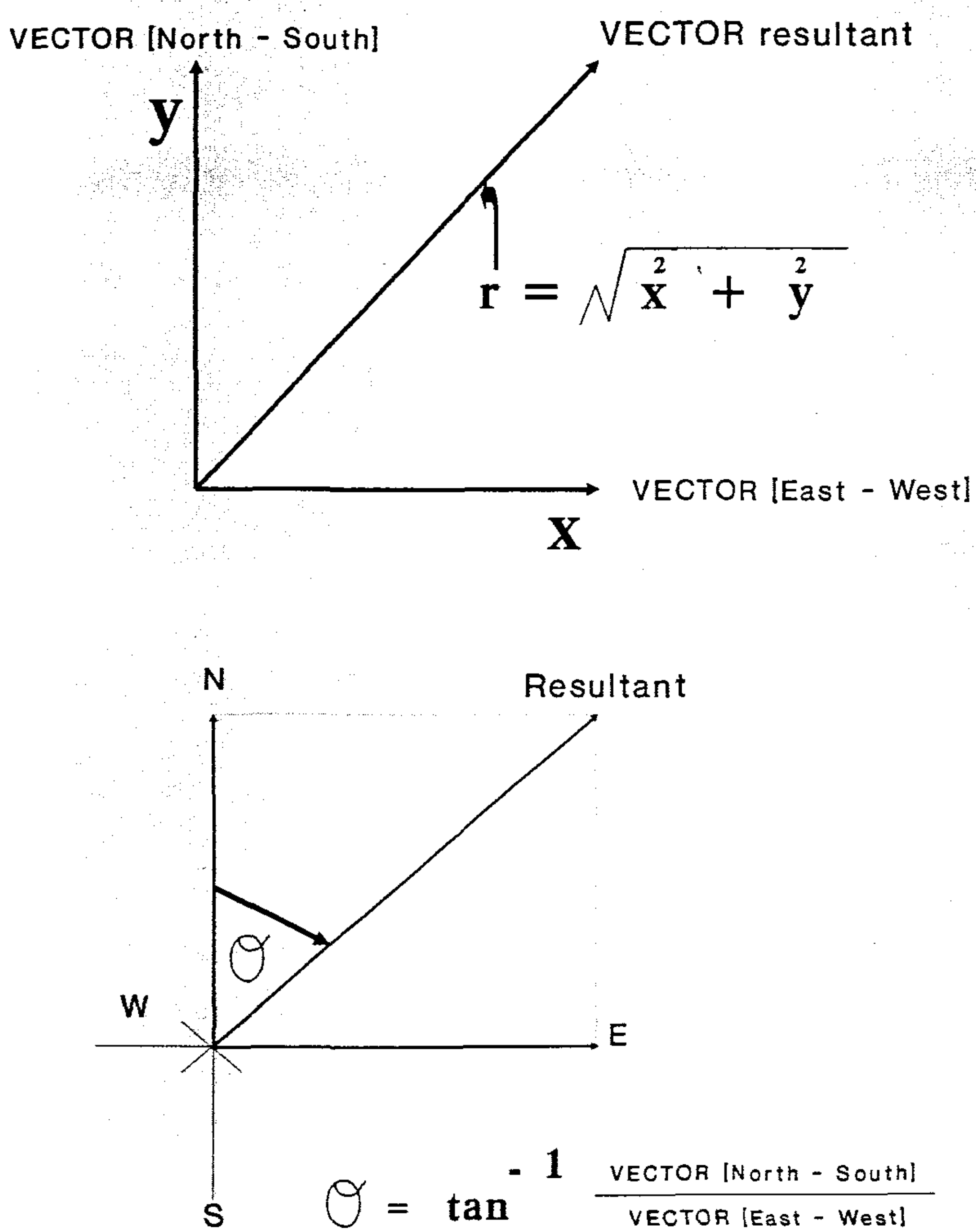


FIG. 3.2 : WIND VECTOR COMPONENTS

3.2 Design parameters : Necessary points to note

The proposed wind measuring instrument will translate the wind-induced drag/force subjected to a hollow P.V.C. pipe into wind velocity and bearing. Although the proposed system will be capable of accurate operation over a wide temperature range, conservative temperature range limits between **0°C** and **40°C** were chosen for the design. Hence, the proposed system must be able to operate as efficiently for example at the North Pole as it should at the Equator.

3.3 Wind Vector Analysis : Wind Velocity [2]

This is best explained by the fact that wind behaviour can be seen as a current of air which produces an augmentation of pressure on portions of fixed or constrained bodies, in this application, a hollow P.V.C. pipe. This wind force can be divided into North-minus-South (N-S) and East-minus-West (E-W) wind vector components.

Figure 3.2 is a graphical representation of these wind vector components.

For the design, wind velocity readout will be 0 m/s when both these vectors are zero. As soon as the wind measuring instrument detects wind pressure and translates either a N-S or E-W digital voltage offset for the analogue to digital converter stage of one least significant bit a resultant wind velocity and wind bearing is registered.

The resolution for the analogue to digital conversion stage is 19.53 mV. The ADC0820 is an 8-bit analogue to digital converter integrated circuit **(Refer to Chapter 7 : 7.2.1).**

The resolution for the ADC0820 is calculated as follows : -

ADC0820 Resolution = 8 bits $\Leftrightarrow$ 2^8 = 256 discrete digital voltage levels

ADC0820 analogue input voltage range (selected) = + 0 Volts to + 5 Volts

Therefore : -

$5 \div 256 = 19.53$ mV = one least significant bit for the ADC0820

Wind pressure is proportional to the **square** of wind velocity. In this design, a resultant wind vector (wind pressure) can be derived from the N-S and E-W vectors. The relationship for this would be : -

Resultant Wind Vector = $[\,(\text{Wind Vector N-S})^2 + (\text{Wind Vector E-W})^2\,]^{1/2}$

The Wind Velocity relationship is : -

Wind Velocity = $[\,(\text{Wind Vector N-S})^2 + (\text{Wind Vector E-W})^2\,]^{1/4}$

And the True Wind Velocity is : -

True Wind Velocity =$[\,(\text{Wind Vector N-S})^2 + (\text{Wind Vector E-W})^2\,]^{1/4} \times C$.

The **Calibration Factor (C.)** is a constant and is a combination of the following physical properties incorporated in the designed system : -

Gauge Factor	**: property of Strain Gauge Transducers**
Strain-Sensitivity	**: property of P.V.C. pipe material**
Resistivity	**: property of P.V.C. pipe material**
Young's Modulus	**: property of P.V.C. pipe material**
Thermal Expansion Co-eff.	**: property of P.V.C. pipe material**
Reynolds Number	**: primarily dependant upon dimensions of P.V.C. pipe**

The **Calibration factor** is primarily influenced by the physical properties of the pipe material used as well as by its physical dimensions. Initially, a **Calibration factor** value of 10.0 was chosen for the design.

Wind tunnel tests upon a hollow P.V.C. pipe with a cross-sectional area of $0{,}04m^2$, proved that the wind velocity results were linear and in accordance with theoretical computations and formulations. The **Calibration factor** value was reduced from 10.0 to 4.0 for calibrated wind velocity display read-out.

3.4 Wind Vector Analysis : Wind Bearing [3]

The North-minus-South and East-minus-West wind vector components are mathematically manipulated using appropriate software to provide a wind bearing display read-out. The mathematical representation of this is : -

$$\tan\theta = \frac{y}{x} = \frac{\text{Wind Vector (N-S)}}{\text{Wind Vector (E-W)}}$$

$$\theta = \tan^{-1}\frac{y}{x} = \frac{\textbf{Wind Vector (N-S)}}{\textbf{Wind Vector (E-W)}}$$

where θ is a bearing between **0°** and **360°**, on the circumference of the P.V.C. pipe. **(Figure 3.2 refers)**

3.5 References

1. Golding, E.W. 1977 "The Generation of Electricity by Wind Power" Chapter 8 : p100 - p103

2. Connelly, J.A. Lundberg, M.B. 1974 "Analog Multipliers determine true wind speed" E.D.N., April 20, 1974

CHAPTER 4

FLUID DYNAMICS/MECHANICS

Fluid dynamics/mechanics is the science that deals with the action of forces on fluids. Aerodynamics is a particular category of fluid dynamics/mechanics that deals with the flow of air past or around solid objects.

This chapter describes the fluid dynamics/mechanics and behaviour of the P.V.C. pipe Anemometer unit when subjected to wind-flow. The geometric and dimensional parameters of the P.V.C. pipe Anemometer unit are analysed. This chapter also describes the terms : Drag, Reynolds number, Co-efficient of drag, Vortex shedding and Strouhal number related to air-flow around a two-dimensional cylinder.

4.1 Drag

A body subjected to a flowing fluid such as wind/air is acted on by pressure and viscous forces from the flow. The sum of the forces (pressure, viscous, or both) that acts parallel to the free stream direction is called the drag.**[1]** The P.V.C. pipe Anemometer unit designed, when exposed to wind-flow in the velocity range of 0 m/s to 40 m/s, is subjected to drag.

The unit designed had the following dimensions : -

Height	**(h) = 1 metre**
Diameter	**(d) = 40 mm**

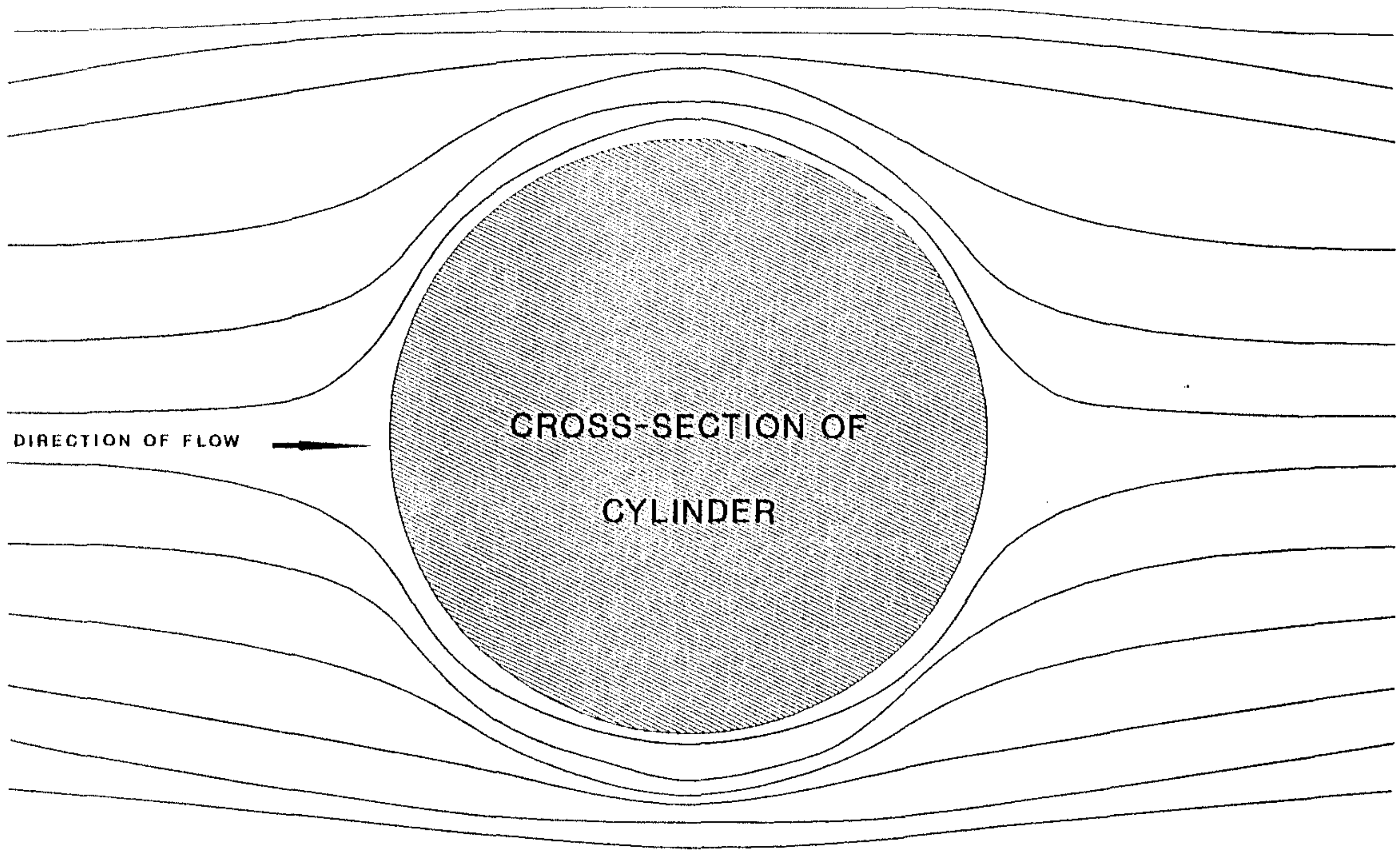


Figure 4.1 : **Laminar air-flow around a circular cylinder.**

4.2 Laminar and Turbulent air-flow

The layer of air near the surface of the P.V.C. pipe that undergoes a change in velocity because of wind-induced shear stress at the surface is called the boundary layer. The fluid particles directly adjacent to the surface circumference of the pipe have zero velocity. The tendency is for the layer of reduced velocity to grow in thickness in the direction of the air/wind-flow. However, because the main stream of air outside the boundary layer is accelerating in the same direction, the boundary layer remains quite thin up to the mid-section of the P.V.C. pipe **[2]**.

The patterns of **Figure 4.1** are typical of streamline or laminar air-flow around a circular cylinder in which adjacent layers of fluid (air) slide smoothly past each other. At higher air flow velocities the boundary layer causes abrupt changes in velocity and the air-flow becomes irregular.

This is called turbulent air-flow **[3]**. The nature of the wind-flow (0 m/s to 40 m/s) around the P.V.C. pipe is important for the determination of linear operation of the wind sensing unit.

4.3 Reynolds number

The P.V.C. pipe anemometer unit can be regarded as a circular hollow cylinder. When the velocity of a fluid (such as air) flowing around a two dimensional cylinder exceeds a certain critical value (dependant on the properties of air and the diameter of the cylinder), the nature of the flow is either laminar or turbulent.

Experiments show that a combination of four factors determine whether flow of a fluid (such as air) around a two dimensional circular cylinder (P.V.C. pipe) is laminar or turbulent. This combination is known as the Reynolds number, **Re**, and is defined as : -

$$\boxed{\mathbf{Re} = \frac{\mathbf{V} \times \mathbf{d} \times \rho}{\eta}} \qquad [4]$$

where ρ is the density of the fluid (Kg/m^3), **V** the average forward velocity (m/s), η the viscosity of the fluid ($N.s/m^2$), and **d** the diameter of the pipe (m). An important point to note is that the Reynolds number is not dependant on the height of the pipe but on its diameter.

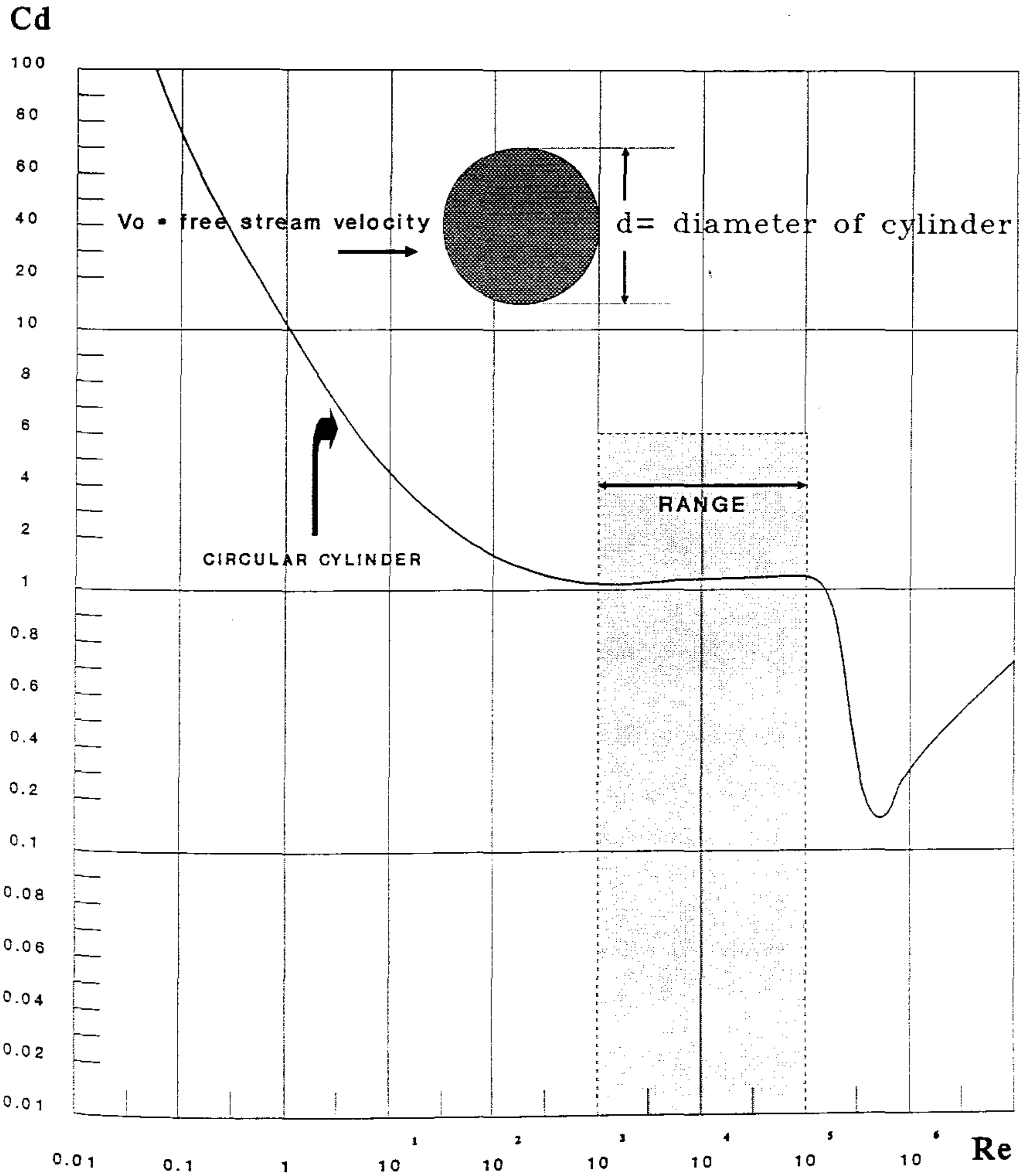
The Reynolds number of a system forms the basis for the study of the behaviour of real systems through the use of small scale models. A common example is the wind tunnel in which the aerodynamic forces on a scale model of an aircraft wing are measured. The forces on a full size wing are then deduced from these measurements. [5]

If the Reynolds number is large **(Re > 2000)**, *then the flow will be turbulent* and if the Reynolds number is smaller **(Re < 2000)** the flow will be laminar. *There are many* reasons for flow classifications as certain types of problems (e.g. : steady flow problems and unsteady flow problems) require different methods of solution. [6]

4.4 Co-efficient of Drag for cylindrical two dimensional bodies *

*** Roberson and Crowe - "Engineering Fluid Mechanics : - 4TH EDITION"**

"Determination of the drag around three dimensional bodies which have angular form (e.g. a cylinder) is calculated from a two dimensional projection. Thus Roberson and Crowe refer to a cylinder as a cylindrical two dimensional body".



$$Re = \frac{Vo \times d \times p}{u}$$

Figure 4.2 : **Co-efficient of drag vs. Reynolds number for a two-dimensional circular cylinder.**

The Co-efficient of drag on the P.V.C. pipe can be calculated if the total drag on the pipe is measured by means of a force dynamometer in a wind tunnel.**[1]**

If the pressure and the shear stress distribution around the P.V.C. pipe are known, the Co-efficient of drag, **Cd** on the pipe can be calculated using the following equation : -

$$Cd = \frac{Fd}{A_p \times \rho \times \frac{V^2}{2}} \qquad [1]$$

Where Cd = Co-efficient of drag

Fd = the total drag force acting on the P.V.C. pipe (N)

Ap = the projected area of the P.V.C. pipe (m^2)

ρ = the fluid density of air (Kg / m^2)

V = the free-stream velocity (wind velocity in m/s)

The projected area **Ap** is the silhouetted area that would be seen by a person looking at the P.V.C. pipe from the direction of flow. The projected area of the P.V.C. pipe with its axis normal to the flow is **d x h. Cd** is a function of Reynolds number, **Re.[1]**

The Co-efficient of drag versus Reynolds number for a two dimensional cylinder is illustrated in **Figure 4.2. [1]**

The P.V.C. pipe Anemometer unit has the following dimensions **(Refer to paragraph 4.1 : Drag) : -**

Height (h) = 1000 mm

Diameter (d) = 40 mm

The properties of air at normal atmospheric pressure and room temperature of 20°C are :-

Viscosity of air (η) = 1.81 x 10^{-5} N.s/m²

Density of air (ρ) = 1.2 kg/m3 [1]

The maximum and minimum wind velocities chosen for the calculation of Reynolds number are :-

V_{min} = 0.9 m/s (light air-flow)

V_{max} = 39.2 m/s (strong hurricane wind)

Reynolds number is calculated as follows : -

$$\boxed{Re = \frac{V \times d \times \rho}{\eta}} \quad [4]$$

hence : Re = 2.39 x 10^3 at V_{min} = 0.9 m/s

and : Re = 1.04 x 10^5 at V_{max} = 39.2 m/s

The Co-efficient of drag is calculated as follows : -

$$\boxed{Cd = \frac{Fd}{Ap \times \rho \times \frac{V^2}{2}}} \quad [1]$$

Cd = 0.99 at V $_{min}$ = 0.9m/s and wind force $_{(min)}$ = 0.48 N/m^2

Cd = 1.19 at V $_{max}$ = 39.2m/s and wind force $_{(max)}$ = 1101.24 N/m^2

The Reynolds number is in the range **10^3** to **10^5. Figure 4.2** illustrates the relationship between Reynolds number and Drag Co-efficient.

The Co-efficient of drag, **(Cd)** is reasonably constant between Reynolds numbers of **10^3** and **10^5.**

The Reynolds number at these wind velocities is greater than **2000** for the designed P.V.C. pipe Anemometer unit and the wind-flow is therefore turbulent. In this design the Reynolds number range is only dependant on the diameter of the P.V.C. pipe Anemometer. The Density and Viscosity of air at Normal Atmospheric Pressure and Room Temperature are constants and the wind velocity range was chosen. The effect of increasing or decreasing the diameter of the pipe is explained later in this chapter.

Then, from **Figure 4.2.**, showing the Co-efficient of drag vs. Reynolds number for two dimensional bodies, it can be seen that **Cd** lies in the range **1.0** to **1.2** for this design.

The total drag force acting on the P.V.C. pipe anemometer unit was calculated as follows : -

$$\boxed{Fd = \frac{Cd \times A_p \times \rho \times V}{2}} \qquad [1]$$

$\boxed{A_p = h \times d}$ *** projected area of the P.V.C. pipe**

Where **Fd** is the total drag force **(N)**, **Cd** is the Co-efficient of drag and **Ap** (m^2) is the projected area of the P.V.C. pipe. The density of air is ρ **(Kg/m³)** and **V (m/s)** represents the wind velocity. Thus total drag force acting on the P.V.C. pipe at minimum and maximum wind velocities were computed as follows : -

$Fd_{(min)}$ = 0.019 N : at V_{min} = 0.9 m/s

$Fd_{(max)}$ = 44.05 N : at V_{max} = 39.2 m/s

4.5 The relationship between Wind force and the Beaufort Scale

Table 4.1 has been extracted from the Beaufort Scale of Wind Forces, courtesy of the Air Ministry Meteorological Office.[7]

Type of wind	Average wind velocity	Average wind pressure
	m/s	(N/m^2)
Light air	0.9	0.48
Light breeze	2.5	3.83
Gentle breeze	4.4	13.41
Moderate breeze	6.7	32.10
Fresh breeze	9.4	62.72
Strong breeze	12.3	110.12
Moderate gale	15.5	172.37
Fresh gale	19.0	258.55
Strong gale	22.6	368.68
Whole gale	26.5	502.74
Storm	30.6	670.32
Hurricane	34.8	861.84
*************	39.2	1101.24

Table 4.1 : The Beaufort Scale of Wind Forces (extract)

The Projected Area **(Ap)** of the P.V.C. pipe is **0.04 m²**.

The wind force acting on the projected area of the pipe was calculated as follows : -

Fd = P x Ap   where   P = Average Wind Pressure

$Fd_{(min)}$ = 0.48 x 0.04 = 0.019 N : at Minimum Wind Velocity 0.9 m/s

Fd(max) = 1101.24 x 0.04 = 44.05 N : at Maximum Wind Velocity 39.2 m/s

Table 4.2 is a comparison of Wind Drag/Force calculations. The left hand column of the table represents drag/force calculated from the Reynolds number and Co-efficients of drag and the right hand column represents the drag/force calculated from the wind pressure values extracted from the Beaufort Scale of Wind Forces.

Average Wind Velocity	REYNOLDS NUMBER	Co-efficient of drag	Wind Force calculated from REYNOLDS NO.		Wind Force calculated from the Beaufort Scale
m/s	Re	Cd	NEWTONS (N)		NEWTONS (N)
0.9	**2.4**	**1.00**	**0.019**	Lower limit	**0.019**
2.45	6.5	1.10	0.15		0.15
4.4	11.7	1.15	0.54		0.54
6.7	17.8	1.16	1.28		1.28
9.4	25.0	1.18	2.51		2.51
12.3	32.6	1.20	4.41		4.41
15.5	41.1	1.20	6.89		6.89
19.0	50.4	1.20	10.34		10.34
22.6	59.9	1.19	14.75		14.75
26.5	70.3	1.19	20.11		20.11
30.6	81.2	1.19	26.81		26.81
34.8	92.3	1.19	34.47		34.47
39.2	**104.0**	**1.19**	**44.05**	Upper limit	**44.05**

Figure 4.2 : Wind drag/force acting on the P.V.C. pipe (diameter = 40 mm)

Hence, the diameter (40mm) of the P.V.C. Anemometer unit chosen in this design is suitable for accurate and linear translation of wind pressure into wind velocity.

4.6 The wind pattern behaviour around the P.V.C. pipe

The P.V.C. pipe Anemometer unit can be represented by a cylindrical two-dimensional body. This sub-section covers the relationship between Reynolds number and Co-efficient of drag and explains how this affects cylindrical bodies.

4.6.1 Discussion of Cd for two-dimensional bodies

Refer to Figure 4.2 :- Reynolds no. vs Co-efficient of drag.

At lower Reynolds numbers, Co-efficient of drag **(Cd)** changes with the Reynolds number, **(Re)**. The change is due to the relative change in viscous resistance. Above **Re** = $\mathbf{10^4}$, the flow pattern remains virtually unchanged, thereby producing constant values of Pressure Co-efficient (Cp) over the body. Constancy of Cp at high Reynolds numbers is reflected in constancy of Cd. This characteristic, the constancy of Cd at high values of Re, is representative of most bodies that have angular form.**[1]**

However, certain bodies of rounded form, such as circular cylinders (the P.V.C. pipe Anemometer), show a remarkable decrease in Cd with an increase in Re from about $\mathbf{10^5}$ **to** $\mathbf{5 \times 10^5}$.**[1]**

The P.V.C. pipe Anemometer unit of diameter **40 mm**, when exposed to wind velocity **(0 to 40 m/s)**, exhibits a constancy of Cd of approximately **1.0** since the calculated Reynolds no. range is between $\mathbf{10^3}$ and $\mathbf{10^5}$. However, practical wind tunnel tests on the P.V.C.

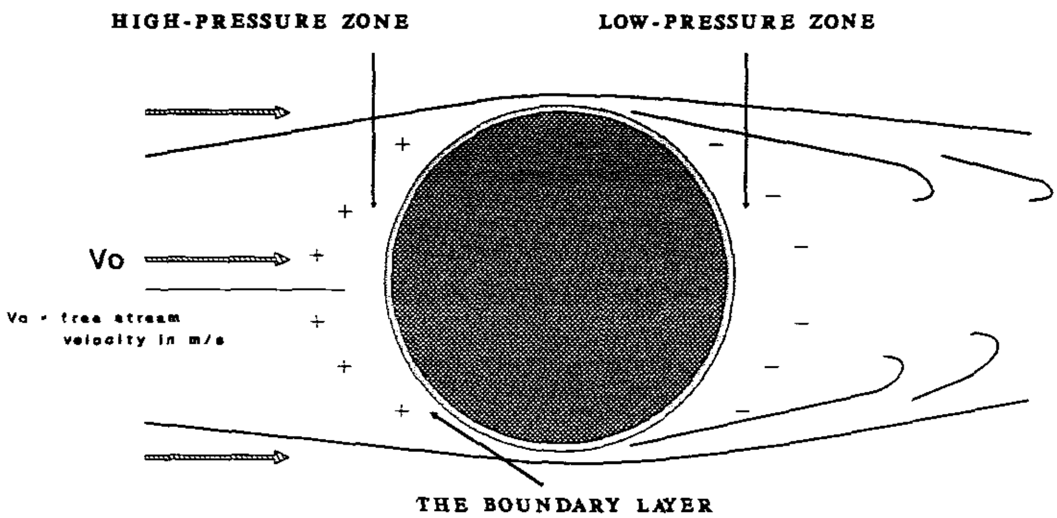


Figure 4.3 : Flow pattern around a cylinder for :

$10^{3} < Re < 10^{5}$

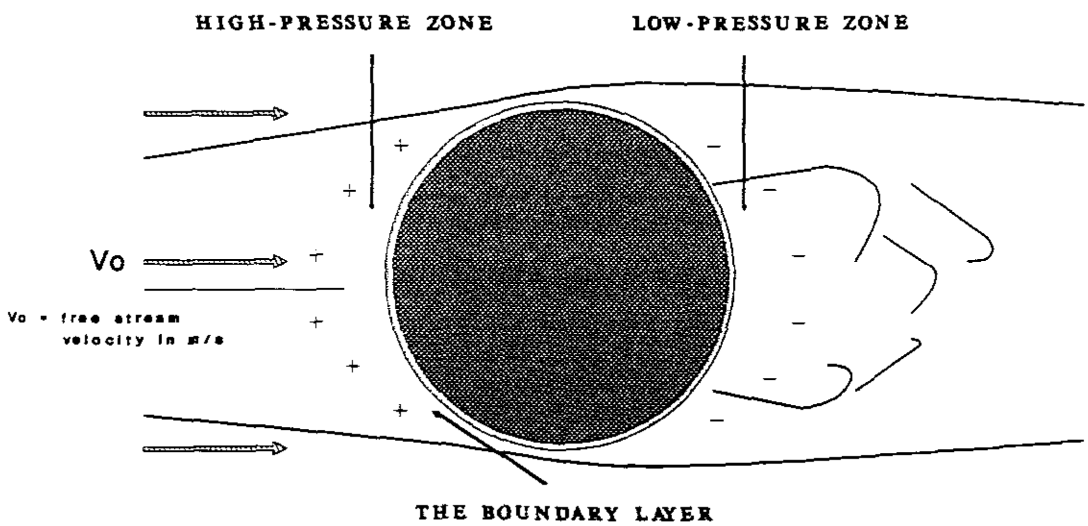


Figure 4.4 : Flow pattern around a cylinder for :

$Re > 10^{5}$

REFERENCE : -

ROBERSON, J.A. 1990 "Engineering Fluid Mechanics : - 4TH EDITION"
CROWE, T.C. pp 469 - pp 485

pipe **(d = 40mm)** proved that results were linear up to **45 m/s**, far in excess of Hurricane wind velocity.

The reduction in Cd at Reynolds numbers of approximately $\mathbf{10^5}$ is due to a change in flow pattern triggered by a change in the character of the boundary layer around the cylinder.**[1]**

For Reynolds numbers less than $\mathbf{10^5}$, the boundary layer around the circumference of the pipe is laminar, and separation occurs about midway between the front and rear of the cylinder/pipe. **(Refer to Figure 4.3)**

Hence the entire rear half of the P.V.C. pipe/cylinder is exposed to a relatively low pressure, which in turn produces a relatively high value for Cd.

When the Reynolds number is increased to approximately $\mathbf{10^5}$, i.e. in this design, if the P.V.C. pipe diameter is increased other parameters were selected (Wind Velocity range, Viscosity of Air, and Density of Air at room temperature are constants), the boundary layer on the surface of the cylinder becomes turbulent which causes higher velocity fluid to be mixed into the region close to the wall of the cylinder.**[1]**

As a consequence of the presence of this high velocity, high-momentum fluid in the boundary layer, the flow proceeds further downstream along the surface of the cylinder against the adverse pressure before separation occurs as represented in **Figure 4.4.**

Hence, the flow pattern causes Cd to be reduced for the following reason : with the turbulent boundary layer, the streamlines downstream of the cylinder mid-section diverge somewhat before separation. Thus the pressure of the point of separation and also in the

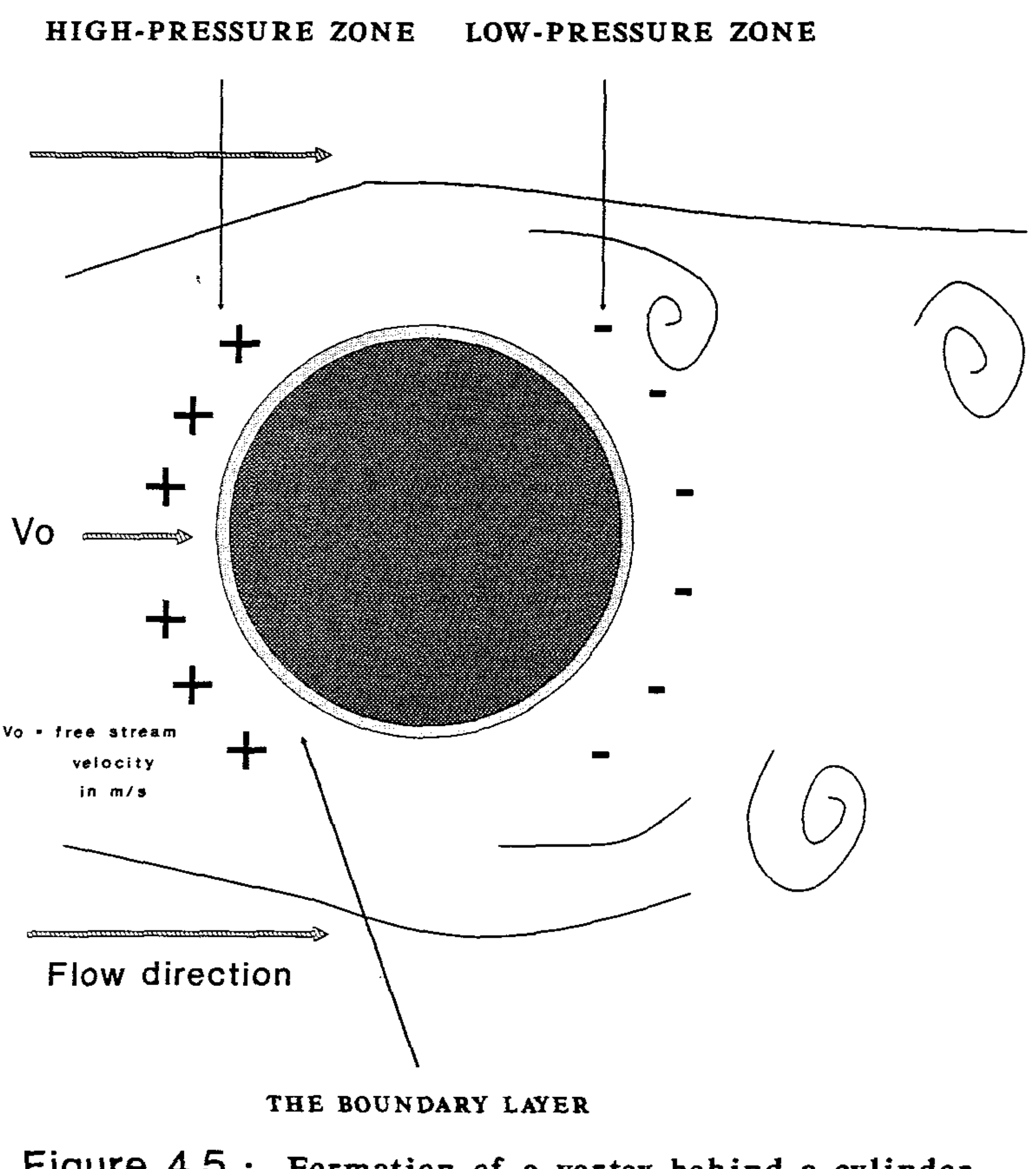


Figure 4.5 : Formation of a vortex behind a cylinder.

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ROWE, T.C. ꞏ pp 469 - pp 485

zone of separation occurs further upstream. Therefore the pressure at the point of separation and also in the zone of separation is significantly greater under these conditions than when separation occurs further upstream.[1]

The pressure difference between the front and rear surfaces of the cylinder is thus less at high values of Re, yielding a lower drag and a lower Cd.

4.7 Vortex shedding from cylindrical bodies

In this design it was necessary to investigate the vibration effects of the P.V.C. pipe anemometer unit when exposed to wind-flow.

Figures 4.3 and 4.4 show the average (temporal mean) flow pattern around a cylinder. A further phenomenon of air-flow around a cylinder is the formation of vortices at Reynolds numbers above **Re = 50.** These vortices are shed periodically downstream at the P.V.C. pipe. Hence, the detailed flow pattern might appear as in **Figure 4.5.**

In this figure a vortex is in the process of formation near the top of the cylinder. Below and to the right of the first vortex are two other vortices, which were formed and shed a short time before. Thus the flow process in the wake of a cylinder involves the formation and shedding of vortices alternately from one side and then the other.

This phenomenon is of major importance in Engineering design and is of particular importance in the design of the P.V.C. pipe Anemometer unit. The alternative formation and shedding of vortices creates a regular change in pressure with consequent periodicity in side thrust on the P.V.C. pipe.[1]

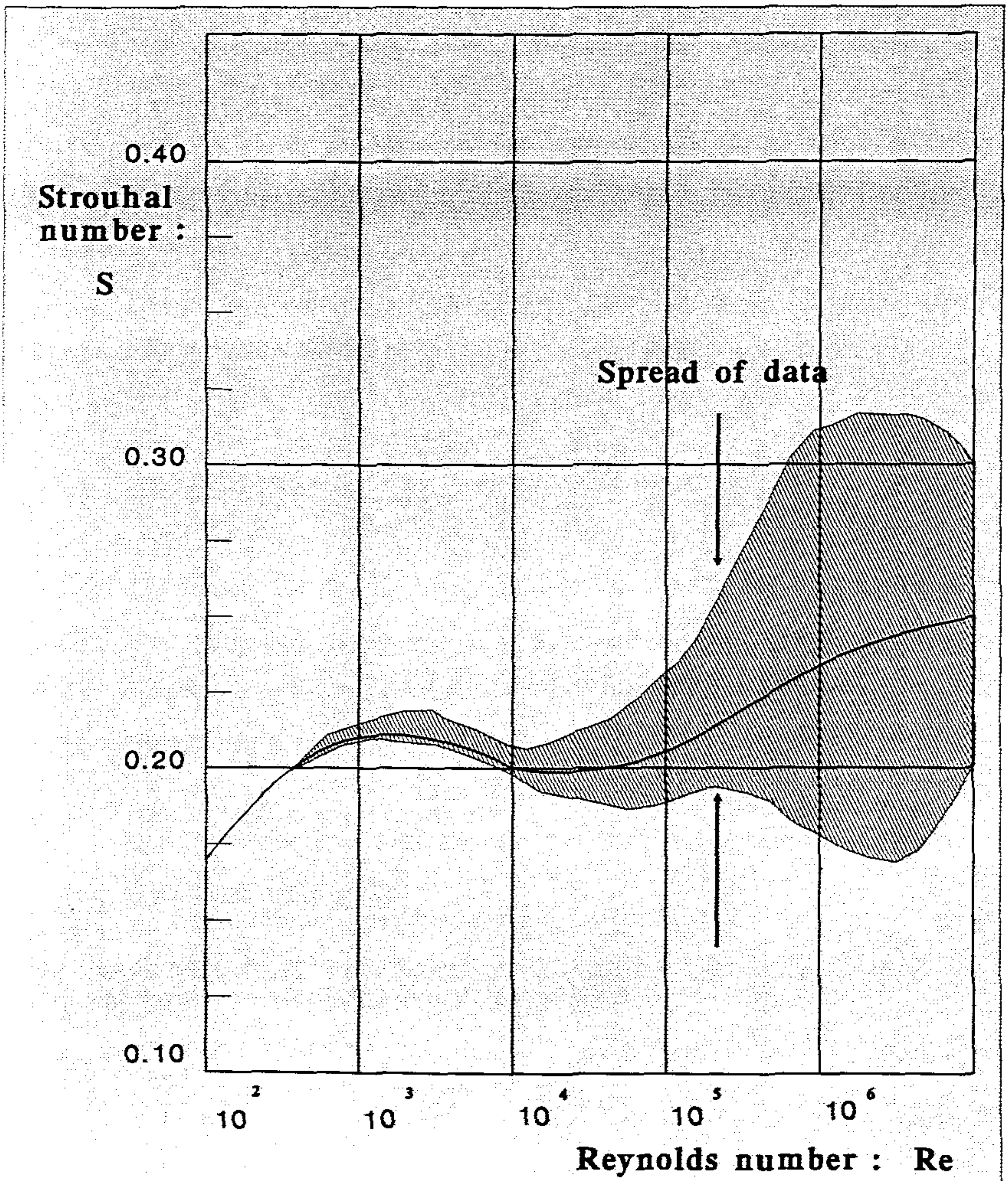


Figure 4.6 : **Strouhal number vs. Reynolds number for flow past a circular cylinder.**

If the frequency of the vortex shedding is in resonance with the natural frequency of the P.V.C. pipe that produces it, large amplitudes of vibration with resulting large stresses can develop. The operational frequency range as a function of the Reynolds number range of the designed P.V.C. pipe Anemometer had to be determined. Experiments prove that the frequency of shedding is given in terms of the **Strouhal number, (S),** and this in turn is a function of the Reynolds number.

The Strouhal number is defined as : -

$$\boxed{s = \frac{n \times d}{Vo}} \qquad [1]$$

where **n** is the frequency of shedding of vortices from one side of the P.V.C. pipe, in Hz, **d** is the diameter of the pipe (40 mm) and **Vo** is the free-stream velocity (m/s). The free-stream wind velocity range for this calculation was chosen as **0.5 m/s** (minimum) to **40 m/s** (maximum).

The relationship between the Strouhal number and the Reynolds number for Vortex shedding is illustrated in **Figure 4.6**.

Reynolds number at 0.5 m/s and 40 m/s are respectively :-

$$Re_{(min)} = 1.33 \times 10^3$$

$$Re_{(max)} = 1.06 \times 10^5$$

Therefore Strouhal number from Figure 4.6 is :-

$$S_{(min)} = 0.222$$

$$S_{(max)} = 0.222$$

Therefore at wind velocity 0.5 m/s (min) n is :-

$$n = 5.55 \text{ Hz}$$

and at wind velocity 40 m/s (max) n is :-

$$n = 222 \text{ Hz}$$

Thus the frequency range of vortex shedding for the design is between 5.55 Hz and 222 Hz for the chosen wind velocity range 0.5 m/s to 40 m/s.

The frequency range of vortex shedding of the P.V.C. pipe calculated for these wind velocities could be translated to measure wind velocity. However, although this method was considered, the wind pressure-to-wind velocity translation relationship was preferred.

The **ANALOG DEVICES 1B32 AN Signal Conditioner,** discussed later in **Chapter 6,** incorporates an integral three-pole low-pass filter (fc = 4 Hz). The vortex shedding frequencies above 4 Hz are filtered by this I.C. package.

4.8 References

1. Roberson, J.A. Crowe, T.C.	1990	"Engineering Fluid Mechanics : - 4TH EDITION" pp 469 - pp 485
2. Sears, F.W. Zemansky, M.W. Young, H.D.	1982	"University Physics : - 6TH EDITION" pp 265 - pp 266
3. Roberson, J.A. Crowe, T.C.	1990	"Engineering Fluid Mechanics : - 4TH EDITION" pp 178 - pp 180
4. Holman, J.P.	1971	"Experimental Methods for Engineers" pp 197 - pp 198
5. Sears, F.W. Zemansky, M.W. Young, H.D.	1982	"University Physics : - 6TH EDITION" pp 275 - pp 279
6. Roberson, J.A. Crowe, T.C.	1990	"Engineering Fluid Mechanics : - 4TH EDITION" pp 102 - pp 104
7. Golding, E.W.	1977	"The Generation of Electricity by Wind Power" pp 103

CHAPTER 5

THE STRAIN GAUGE TRANSDUCERS

In this chapter an investigation into resistance strain gauge transducers related to the fluid dynamics/mechanics in tandem with the behaviour of the hardware P.V.C. pipe anemometer unit is conducted.

No solid object is perfectly rigid and when forces are applied to any object, changes in dimension occur. These changes of dimension are sometimes imperceptible to the human eye and occur in things that appear as rigid structures.

The changes in value of the dimensions of a P.V.C. pipe, divided by the original value of the dimension is a ratio called the **strain** and is what shall be measured. The strain occurring in a hollow P.V.C. pipe, with base rigidly mounted, and erected perpendicular to the approach flow of the wind, can provide an electrical signal which is a measure of the strain in the pipe.[1]

5.1 Explanation of some basic Strain Measurement terms

5.1.1 Stress

When forces act on a body, reactive forces are induced within the body. These reactive forces are distributed throughout the body, and the density of these forces that is, the force per unit area, is called the **stress**.

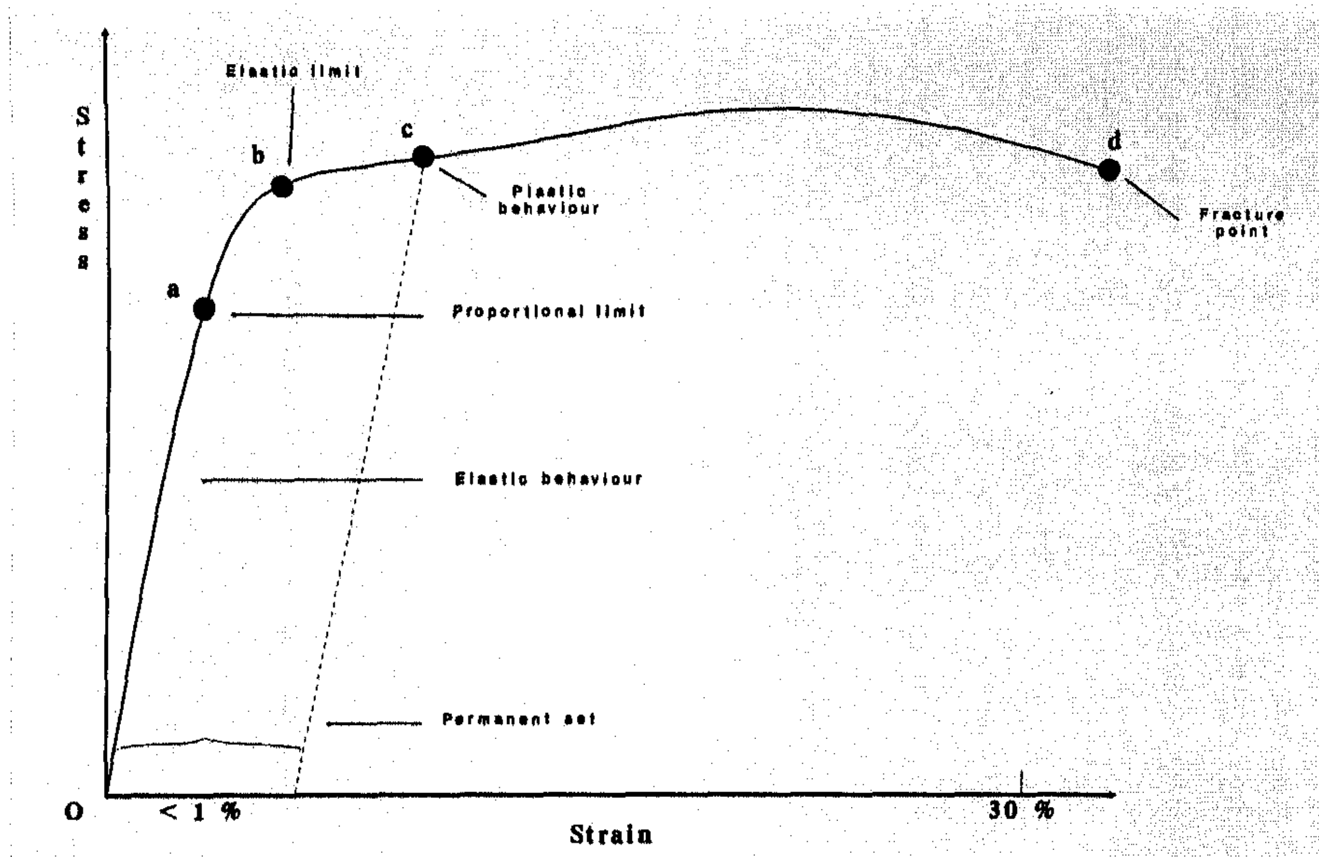


Figure 5.1 : **Stress-strain plot for a 'ductile' material under tension**

REFERENCE : -

SEARS, F.W. *1982* *"UNIVERSITY PHYSICS : - 6TH EDITION"*
ZEMANSKY, M.W. *pp 215*
YOUNG, H.D.

$$\boxed{\text{Stress}(\sigma) = \frac{F}{A}}$$ [1] **where F is the Force in Newtons (N)**

and A is the Area (m^2) over which the Force is applied.

5.1.2 Strain

Any relative change in dimension of a body under stress is called strain. The nature of the strain occurring will obviously depend on the nature of the applied stress, but the strain is measured as a ratio.

The strain occurring in a body experiencing tensile or compressive stress will be the ratio of the change in length to the unstressed length of the body : -

$$\boxed{\text{Strain}(\varepsilon) = \Delta L / L}$$ [1]

For tensile stress the change in length, (ΔL) will be an increase, and (L) is regarded as positive, so the strain will be positive. For compressive stress, the change in length will be a decrease, and the strain will be a negative quantity.

5.1.3 Elastic Moduli

If a solid body is subjected to a gradually increasing stress, and if both the stress and resulting strain are measured a plot of stress against strain can be graphically represented as shown in **Figure 5.1**.

Over a certain range of values of induced stress, the plot is essentially a straight line, and the slope of that line is called the **Elastic Modulus (E). [1]**

$$\text{Elastic Modulus (E)} = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\varepsilon} \qquad [\,1\,]$$

: where the Force per unit area (F / A) in N/m^2

When the stress is linear tensile or compressive stress, the Elastic Modulus is called **Young's Modulus (Y).**[1]

MATERIAL	YOUNG'S MODULUS
Steel	196
Aluminium-alloy	70-72
P.V.C	1.0-3.5

Table 5.1 (above) : Young's Moduli of some common materials. (extracted from APPENDIX A)

5.1.4 Elastic Limit [1&2]

When external forces producing stress and strain are applied to an elastic body and then removed, the body will return to its original unstressed dimensions. Most materials are elastic in this sense for small strains, but there is a limit to the amount of strain from which a material can recover. This limit is called the elastic limit of the material.**[1]**

The relationship between stress and its corresponding strain plays an important role in the branch of physics called the theory of elasticity, or its engineering counterpart, strength of materials. A typical stress-strain diagram for a ductile material is shown in **Figure 5.1.**

The stress is simple tensile stress and the strain is the percentage elongation. During the first portion of the curve (up to strain of less than 1%), the stress and strain are proportional until the point **a**, the proportional limit is reached. **[2]**

From **a** to **b**, the stress and strain are not proportional, but nevertheless, if the load is removed at any point between **O** and **b**, the curve will be retraced and the material will return to its original length. In the region **Ob**, the material exhibits elastic behaviour and the point b is called the elastic limit. Up to this point, the forces exerted by the material are conservative; when the material returns to its original shape, work done is recovered. The deformation is said to be reversible. **[2]**

If the material is loaded further, the strain increases rapidly, but when the load is removed at some point beyond **b**, say **c**, the material will not return to its original length but traverses the thin dotted line in **Figure 5.1**. The length at zero stress is now greater than the original length, and the material is said to have a permanent set. Further increase of load beyond **c** produces a large increase in strain until a point **d** is reached at which fracture takes place. **[2]**

From **b** to **d**, the material is said to undergo plastic deformation. A plastic deformation is irreversible. If large plastic deformation takes place between the elastic limit and the fracture point, the material is said to be ductile. If, however, fracture occurs soon after the elastic limit is exceeded, the material is said to be brittle. **[2]**

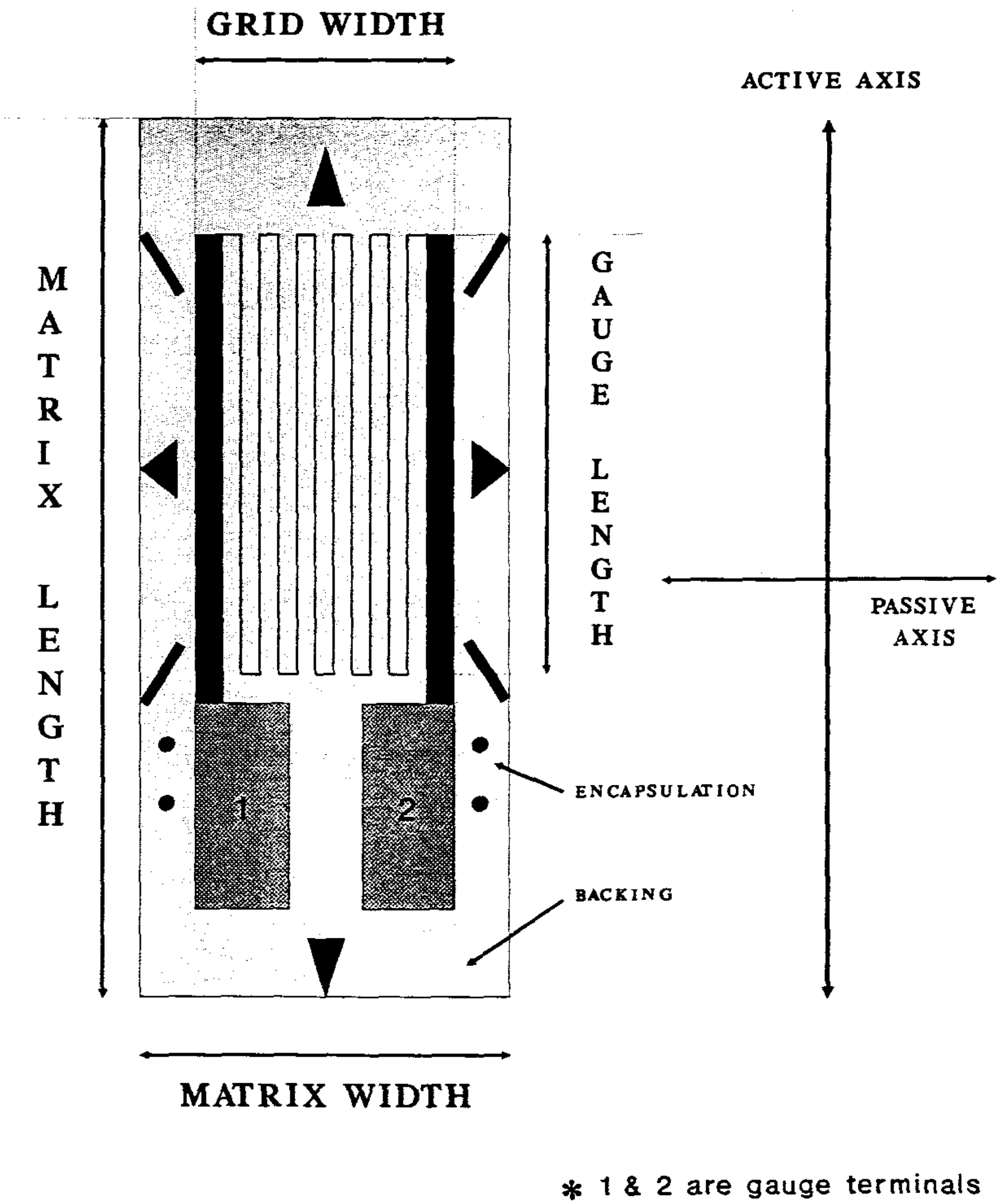


Figure 5.2 : Single-active-axis strain gauge

P.V.C. has a **Tensile Strength** in the range **30 to 70 MN/m^2.**

(Refer to APPENDIX B : iii)

Mean wind pressure at hurricane wind velocity is **1.388 KN/m^2.**

(Refer to Chapter 3 : Figure 3.1).

Hence, the elastic limit of the P.V.C. pipe was never in danger of being exceeded.

5.2 Resistance Strain Gauges

Strain gauges are deformation sensitive; that is, they are able to sense and respond to a deformation in the form of a change in finite length. The most common electrical resistance strain gauges used universally are bonded gauges. That is, the gauge is ultimately bonded to the surface on which the strain is desired, and is therefore deformed along with the surface.

A foil gauge is made by etching a pattern on a very thin metal foil as in **Figure 5.2.** The foil is bonded to a thin base of plastic. When in use, the bonded gauge is cemented firmly to the member under investigation, with the foil side out. An electrical current is passed through the foil. The resistance of the element (foil) changes as the surface under it (and therefore the gauge) is strained. The basic principle involved is Lord Kelvin's discovery that a wire changes its electrical resistance when deformed.

Since the foil is bonded throughout its length, the gauge is able to sense a compressive strain as well as a tensile strain. The resistance change, which is accurately proportional to the strain, can be measured by appropriate instruments.

A resistance strain gauge can be used on the surface of almost any solid engineering material, such as metal, plastic, concrete, wood, glass and paper.**[3]**

Kyowa Electronic Instruments of Tokyo, Japan provide a complete line of high performance foil-strain gauges, their application is almost unlimited and they are usable with most types of materials of all configurations and structures.
(Refer to APPENDIX C for the Kyowa Catalogue of Strain Gauge listings)

The gauges used during the experimental stage on the Aluminium and Stainless Steel structures and finally the P.V.C. pipe are of the SELCOM TYPE (Self-Temperature-Compensating Strain Gauges). These are gauges in which the Thermal Expansion Co-efficient of the foil is controlled.

These gauges are constructed from material which has been subjected to particular metallurgical processes and which produce very small thermal output over a specified range of temperature when bonded onto the material for which the gauge has been specifically designed.

SELCOM gauges can be supplied in six types depending on the application. **Kyowa** manufacture strain gauges for application to Stainless-steel, Aluminium-alloy, plastics, wood , ordinary Steel and Magnesium-alloy.**[4]**
(Refer to Appendix C : Kyowa Strain Gauge listings page 1 and 2 : Thermal Expansion co-efficients; Kinds and Characteristics)

Kyowa Strain Gauges used on the Anemometer pipe members were :

Stainless Steel	**KFG-2N-120-C1-16 L 1M 2R**
Aluminium	**KFC-2-C1-23**
Plastics	**KFP-2-C1-65**

The Strain Gauge listings explain the strain gauge coding system.
(Refer to APPENDIX C)

5.2.1 Properties of Resistance Strain Gauges

Consider a conductor of uniform cross-sectional area, **A (m^2)** and length, **L (m)**, made of a material with resistivity, P (Ωm). The resistance **R** (Ω) of such a conductor is given by : -

$$\boxed{R = \frac{\rho \times L}{A}} \qquad [5]$$

If this conductor is now subjected to linear tensile or compressive stress, for example due to a certain wind drag-pressure/force acting on it, its resistance will change because of dimensional changes, and because of a property of materials called piezo-resistance which indicates a dependence of resistivity **(P)** on the mechanical strain.**[5]**

If a foil-strain gauge, specifically selected for the type of material under test is firmly applied to the surface of the material, any changes in dimensions of the material will cause an identical fractional change of the dimensions of the foil-strain gauge.

5.2.2 The Single-Active Axis Foil-Strain Gauge

The simplest strain gauge, designed to measure linear tensile or compressive strain, takes the basic form as shown in **Figure 5.2**.

A change of dimension in the direction labelled the active-axis will cause a change in resistance of the major portion of the gauge, whereas a change in dimension in the direction labelled the passive-axis will change the resistance of only a small portion of the total length of the gauge. Thus, the change in resistance, divided by the total resistance of the gauge, will be much greater for strain occurring along the active-axis than for the same strain occurring along the passive-axis.

The ratio of the resistance change which occurs for a given strain along the passive-axis to the resistance change which occurs when the same strain occurs along the active-axis is termed the cross-sensitivity of the gauge.**[1]**

The cross-sensitivity of the gauge in **Figure 5.2** is approximately 0.1, because the length of wire along the active-axis is about ten times the length of wire along the passive-axis.

5.2.3 Gauge Factor [6]

The Gauge Factor of such a strain gauge is defined as the fractional change in the resistance of the gauge, divided by the fractional change in the length of the gauge along the active-axis : -

$$\boxed{\textbf{Gauge Factor}(K) = \frac{\Delta R / R}{\Delta L / L}} \qquad [6]$$

$$\boxed{\textbf{Strain}(\varepsilon) = \Delta L / L} \qquad [6]$$

$$\boxed{\Delta R / R = \varepsilon \times K} \qquad [6]$$

Thus, the fractional change in resistance of the gauge is equal to the applied strain along the active-axis multiplied by the Gauge Factor.

Most gauges have a Gauge Factor in the range **1.8 to 2.2**, the variations being mainly due to slight differences in the gauge material and corresponding differences in the magnitude of the piezo-resistive effect. [1]

5.3 Strain Gauge Bridge Configurations

Resistance change with applied strain is extremely small compared to initial value of strain gauge resistance. Strain gauges are therefore used in a bridge configuration. [7]

First consider the resistance change of a single gauge attached to the circumference, near the base of a P.V.C. pipe.

* AT BALANCE, $E_o = 0$ if $\frac{R1}{R4} = \frac{R2}{R3}$

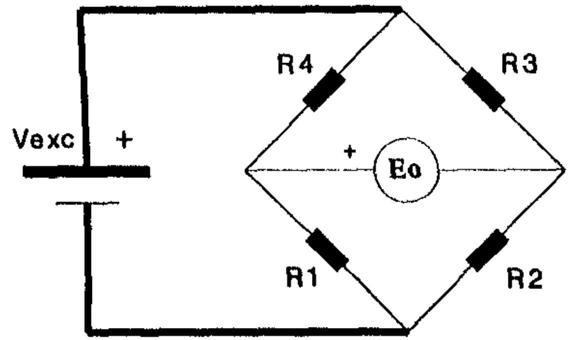


Figure 5.3 : Basic bridge circuit- voltage excitation and voltage readout

* $E_o = x.\frac{Vexc}{4}$ for $x \gg 1$

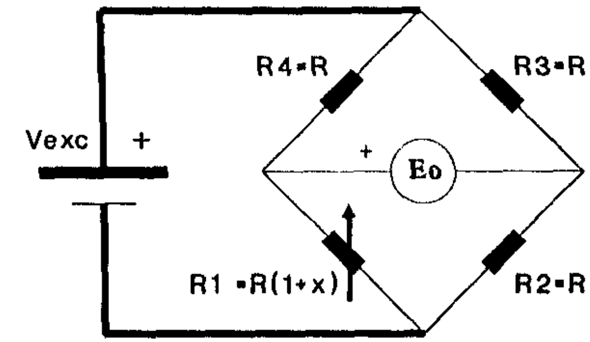


Figure 5.4 : Bridge used to read deviation of a single variable element

* $E_o = x.\frac{Vexc}{2}$ for $x \gg 1$

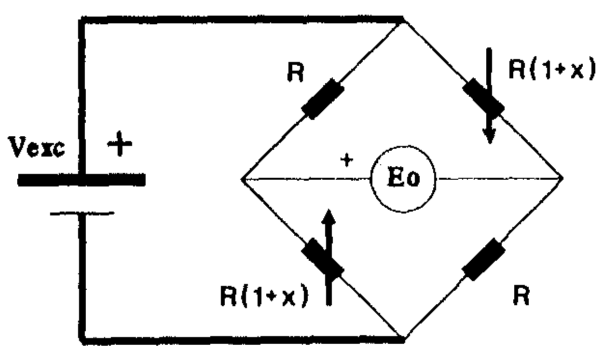


Figure 5.5 : Bridge with two variable elements

* $E_o = x.Vexc$

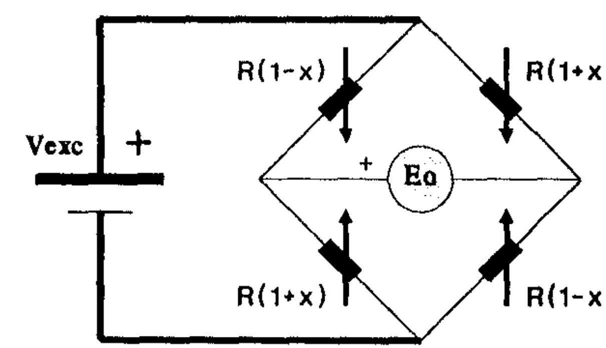


Figure 5.6 : All elements variable.

Kyowa Strain Gauges, fixed to the P.V.C. pipe have a Gauge Factor, **(K)** = **2.15** and a resistance, **(R)** = **120 Ω** . P.V.C. has a Young's Modulus, **(Y)** = **2.3 GPa**. Assuming a constant Wind Stress/Pressure, **(σ)** = **1388.52 Pa**, (85 Knot wind, upper Hurricane limit for this design), subjecting tensile stress on the P.V.C. pipe, the change in resistance of a single strain gauge can be calculated : -

The following are the known parameters : -

K = 2.15	**: Gauge Factor**
R = 120 Ω	**: Strain Gauge resistance**
Y = 2.3 GPa	**: Young's Modulus : - P.V.C.**
σ = 1388.52 Pa	**: Wind Stress/Pressure : - upper limit**

Strain (ε) = $\sigma/Y = 0.6037\ \mu\varepsilon$ microstrain

$$\Delta R = K \cdot \varepsilon \cdot R = 1.5575 \times 10^{-4}\ \Omega$$

Hence, resistance change of a single strain gauge with applied strain is small, even when the P.V.C. pipe is subjected to hurricane wind pressure.

5.3.1 The Wheatstone Bridge [7]

Figure 5.3 shows the common Wheatstone bridge. A bridge consists of four two-terminal elements connected to form a quadrilateral, a source of excitation (voltage in this application), connected along one of the diagonals, and a detector of voltage comprising the other diagonal. The detector measures the difference between the outputs of two potentiometric dividers connected across the excitation supply.

A bridge measures an electrical property of a circuit element indirectly , by comparison against a certain similar element. In this application the bridge configuration provides a differential voltage.

When **R1/R4 = R2/R3** , the resistance Wheatstone bridge shown in **Figure 5.3** is at null, irrespective of the magnitude of voltage excitation, voltage readout or the impedance of the detector. Therefore, if the ratio **R2/R3** is fixed as **K**, a null is achieved when **R1 = KR4.**

5.3.2 The Single-Element Strain Gauge Bridge [7]

For the majority of strain gauge bridge applications, the deviation of one or more resistors in a bridge from an initial value must be measured as an indication of the magnitude (or a change) of the measurand.

Figure 5.4 shows a bridge with all strain gauge resistances nominally equal. **R2, R3** and **R4** are dummy gauges i.e. they are not measuring strain but form part of the bridge completion circuitry. **R1** is variable by a factor, **(1+x)**, where **x** is a fractional deviation around zero, as a function of measured strain.

The relationship between the bridge output and **x** is not linear, but for small ranges of **x** it is sufficiently linear for many applications. For example, if **Vexc = 10 V** and the maximum value of **x is ± 0.002**, the output of the bridge will be linear to within **0,1 %** for a range of outputs from **0 to ± 5mV**, and to **1 %** for a range **0 to ± 50 mV (± 0.02 range for x).**

The sensitivity of a bridge is the ratio-to-the-excitation-voltage of the maximum expected change in the value of the output, in the examples given in the last paragraph, the sensitivities are ± **0.5 mV/V** and ± **5 mV/V**.[6]

5.3.3 The Two-Element Strain Gauge Bridge [7]

The bridge sensitivity can be doubled if two identical variable strain gauge elements are used e.g. at positions **R3** and **R1**, as shown in **Figure 5.5.** **R2** and **R4** are **dummy** strain gauges not subjected to strain and form part of the bridge completion circuitry.

If **R3** and **R1** are aligned and bonded to opposite faces of the P.V.C. pipe, the bridge output will be doubled, but the same degree of non-linearity exists. Experiments with Stainless-steel and Aluminium tubing (height = 1m ; diameter = 25 mm) as Anemometer hardware units, using the two-element strain gauge bridge, were conducted.

Due to the nature of Stainless-steel and Aluminium (both materials are comparatively rigid as opposed to P.V.C., which has a much lower Young's Modulus of Elasticity, resistive swings in the attached strain gauges are small, making it less sensitive. Signal conditioning and amplification techniques can compensate for this but the trade-off of sensitivity against linearity, as well as bridge offset drift due to the higher bridge excitation voltage required makes this an unattractive solution.[7]

5.3.4 The Full-Element Strain Gauge Bridge [7]

The Full-element strain gauge bridge was chosen for this design. **Figure 5.6** shows a bridge consisting of four resistors, two of which increase and two of which decrease in the same ratio.

Two identical two-element strain gauges , attached to opposite faces of a thin carrier to measure its bending , could be electrically configured in this way. The output of such a bridge would be four times the output for a single-element bridge , furthermore , the complimentary nature of the resistance changes would result in a linear output. This arrangement was best suited for the design.[7]

Wind vector resultant is determined from a North-South wind vector and an East-West wind vector in this design, and seen as two separate wind vector channels. To illustrate how the Full-element strain gauge bridge is employed, consider one channel initially, the North-South channel.

A full-element (all element variable) strain gauge bridge is bonded to the P.V.C. pipe. Two identical strain gauges are attached to the North face and another two to the South face on the circumference of the P.V.C. pipe. Stress in the pipe may be tensile or compressive but the complimentary nature of the resistance changes results in a linear output.

The East-West channel would have an identical configuration. Hence, there are eight strain gauges bonded to the P.V.C. pipe, two on the North face, two on the South face, two on the East face and two on the West face of the pipe circumference.

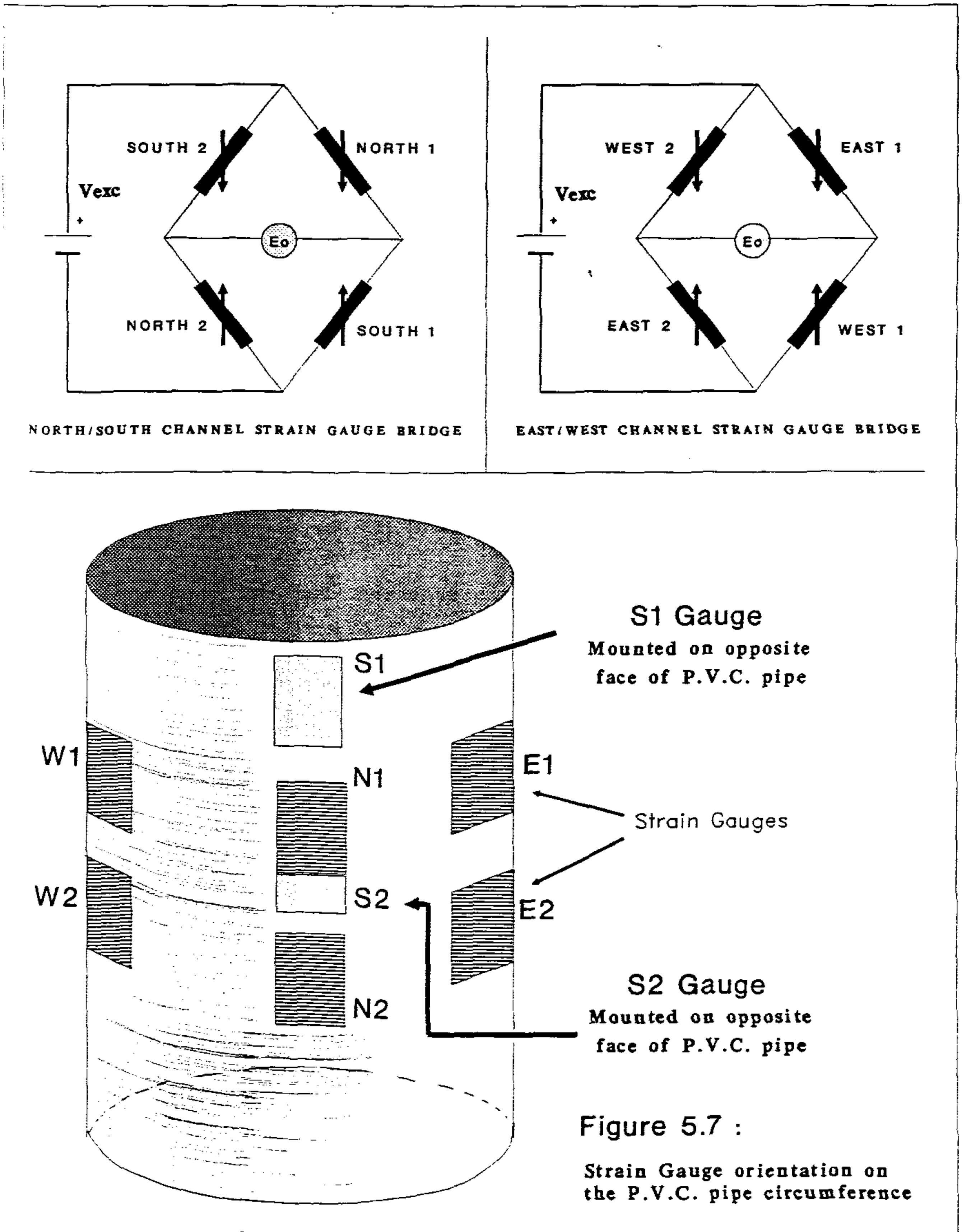


Figure 5.7 :

Strain Gauge orientation on the P.V.C. pipe circumference

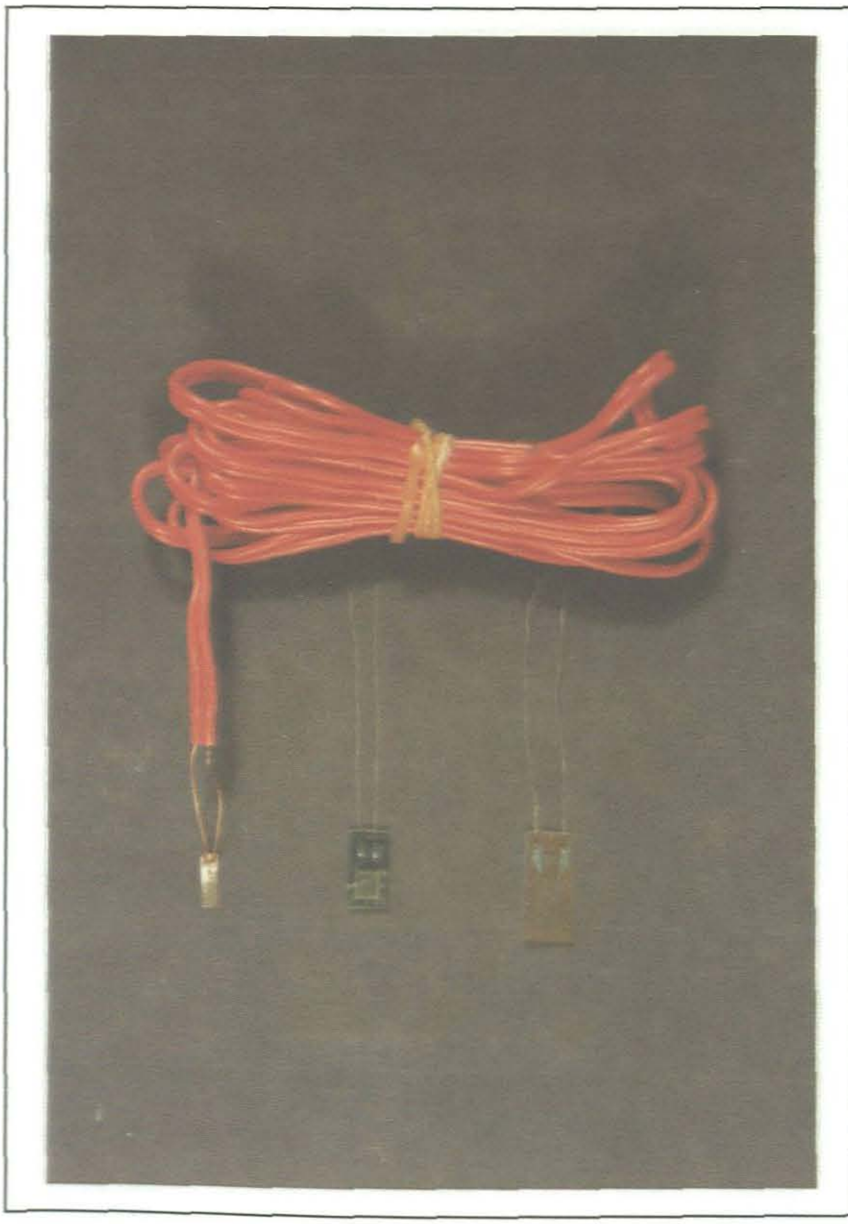


Figure 5.8 : **Types of strain gauges used (Photograph 1) : -**

- **Stainless-steel (left)** : **KFG-2N-120-C1-16 L 1M 2R**
- **Aluminium (centre)** : **KFC-2-C1-23**
- **P.V.C. (right)** : **KFP-2-C1-65**

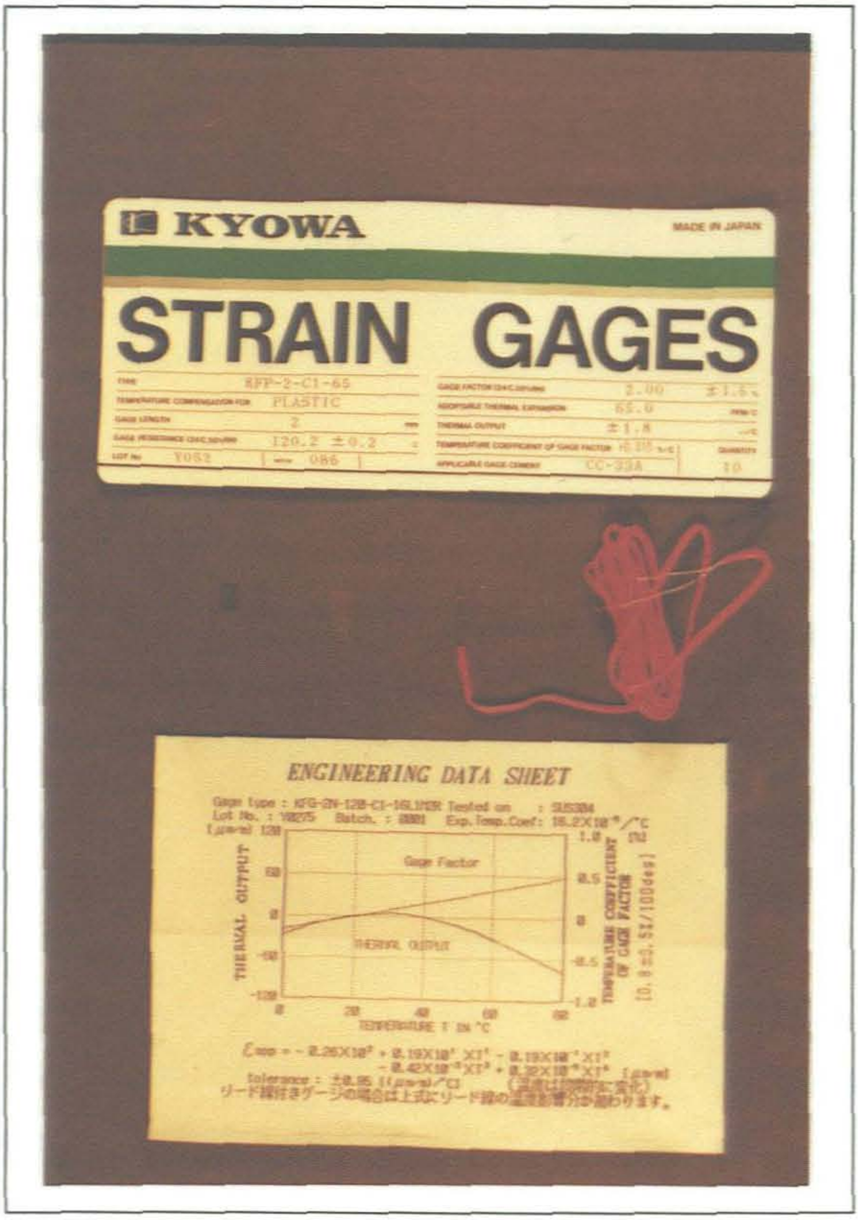


Figure 5.9 : **Engineering Data Sheet : KFP-2-C1-65 : - Strain gauges for plastics used on the P.V.C. pipe anemometer unit (Photograph 2)**

Figure 5.7 shows the all elements variable strain gauge bridge configuration as well as their orientation on the P.V.C. pipe circumference, to measure bending strain in the member.

5.4 Strain Gauge Selection

The initial step in preparing for any strain gauge installation is the selection of the appropriate gauge for the task. Careful, rational selection of gauge characteristics and parameters can be very important in : - optimising the gauge performance for specified environmental and operating conditions, obtaining accurate and reliable strain measurements, contributing to the ease of installation, and minimising the total cost of the gauge installation.

So vast is the available range that it is difficult to foresee any situation for which there is no gauge suitable. Most manufacturer's catalogues give full information on gauge selection **(Refer to APPENDIX C).** Any detailed treatments would be out of context in this thesis. Essentially, the choice of a suitable gauge incorporates consideration of physical size and form, resistance and sensitivity, operating temperature, temperature compensation and strain limits.

Figure 5.8 shows the three types of strain gauges that were used on Stainless-steel and Aluminium prototype Anemometers and finally on the P.V.C. pipe Anemometer unit.**(Photograph 1)**

Figure 5.9 illustrates the Engineering data sheets provided with **KFP-2-C1-65** Strain Gauges for plastics used on the P.V.C. pipe Anemometer unit.**(Photograph 2)**

TABLE 5.2 CHARACTERISTICS OF THE STRAIN GAUGES INVESTIGATED

KIND	OPERATING TEMPERATURE RANGE Degrees C	COMPENSATED TEMPERATURE RANGE Degrees C	STRAIN LIMIT AT ROOM TEMP.(%)	TYPE USED	TEMP. COMP. FOR	GAUGE LENGTH mm	GRID WIDTH mm	GAUGE FACTOR	GAUGE RESISTANCE Ohms
1 FOIL PHESTER GAUGE KFC series	-196 TO +150	+10 TO +100	2.8%	KFC-2-C1-23	Aluminium alloy	2	2.3	2.14 +/- 1%	119.8 +/- 0.2R
2 FOIL GAUGE FOR PLASTICS KFP series	-20 TO +80	+10 TO +60	3%	KFP-2-C1-65	Plastic	2	2	2.0 +/- 1.5%	120.2 +/- 0.2R
3 FOIL ALLOY GAUGE KFG series	-20 TO 100	+10 TO +80	5%	KFG-2N-120-C1-16L1M2R	Stainless steel	2	0.84	2.15 +/- 1%	120.4 +/- 0.4R

Figure 5.10 : **Strain gauge orientation on the circumference of the strain gauge/P.V.C. pipe combination (Photograph 3)**

Table 5.2 lists the characteristics of the Strain Gauges investigated.

5.4.1 Fixing the gauge to the P.V.C. pipe member

In fixing gauges to a body the prime aim is to ensure that strains in the body are transmitted accurately to the gauge. The operation is quite straight-forward but requires care and patience if the gauge is to give reliable results. The most important feature is to ensure that the gauge is bonded evenly and securely on to the P.V.C. pipe surface. It is essential that the latter should be clean of scale and grease but left slightly roughened to secure curing of the cyanoacrylate adhesive.

After lightly cleaning the back of the gauge, and applying a thin coating of **Kyowa CC 33 A Cyanoacrylate adhesive (see Appendix C : Kyowa Cat. No. 3002A)** to the P.V.C. surface, the gauge is placed in position and pressed evenly and firmly to remove excess cement and air bubbles. The adhesive transforms to a solid within a minute after being pressed into a thin film between the gauge and the P.V.C. surface.

The adhesive layer must be thin, continuous, and not subject to creep when subjected to stress. Creep occurs if the adhesive layer remains fluid, so that the gauge can move relative to the body surface to which it has been bonded. Final drying under radiant heat is advisable, followed by an insulation resistance test of each gauge. The gauges are moisture proofed with a marine standard silicone sealant.

Figure 5.10 illustrates the arrangement of the eight gauges on the P.V.C. pipe circumference.**(Photograph 3)**

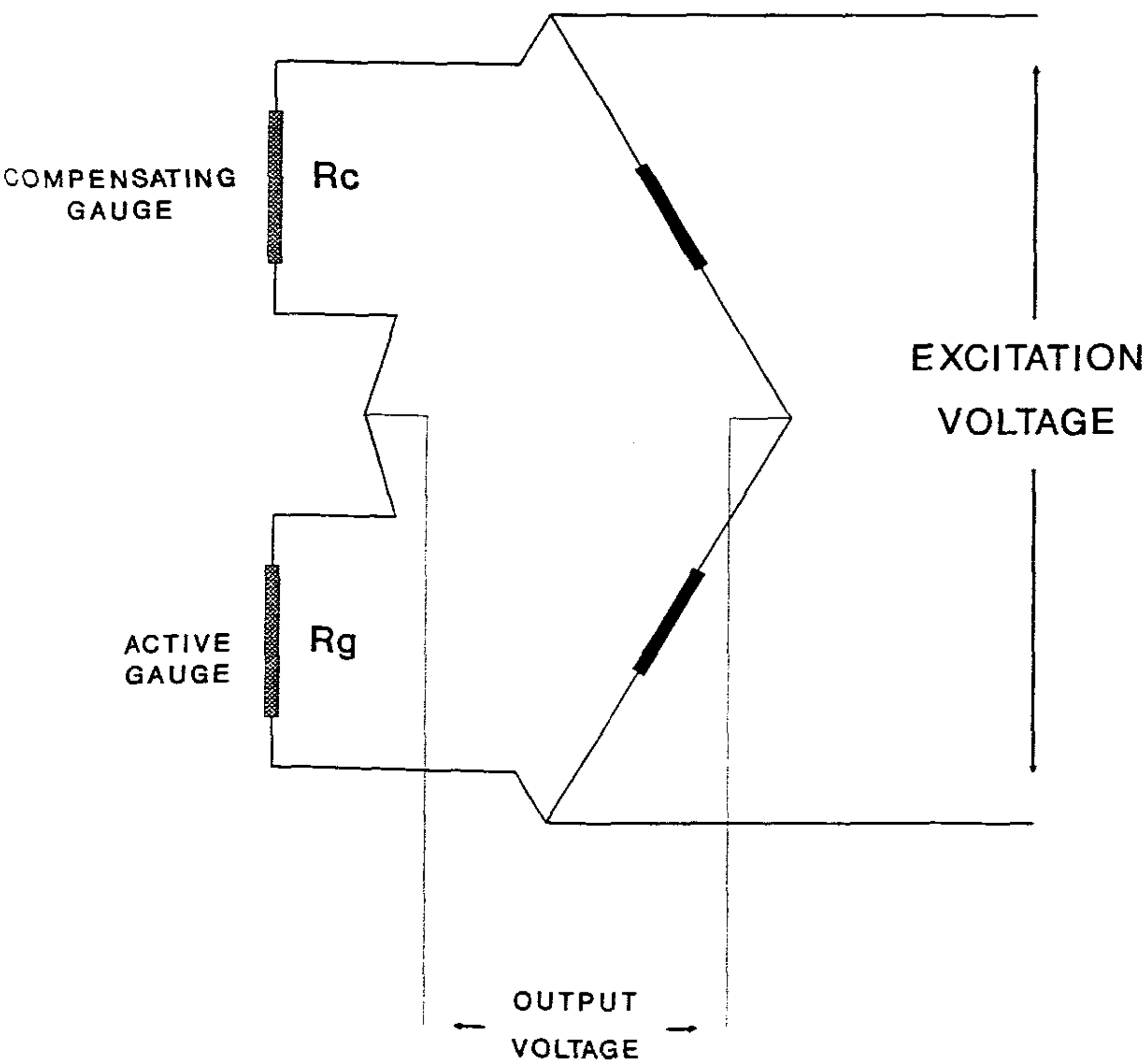


Figure 5.11 : **Bridge circuit for use with compensating gauge**

5.4.2 Strain Gauge Temperature Compensation [8]

The errors in strain measurement due to temperature variations can be significantly reduced by using a second gauge to compensate for them. The earliest form of compensation made use of the strain gauge bridge circuit to provide automatic correction for thermal output.

The basic schematic is shown in **Figure 5.11** where the active strain gauge is **Rg** and the compensating gauge (or compensating dummy) is **Rc**. It is a characteristic of such bridge circuits to remain balanced if equal resistance changes occur in two adjacent bridge arms.

If **Rc** is therefore mounted on a small, unstrained block of the same material as the specimen and placed close enough to the active gauge location so that they both experience the same temperature changes, resistance changes in both arms due to thermal output will be equal, and will be cancelled in the bridge circuit. Any resistance change in **Rg** due to mechanical strain will unbalance the bridge and result in an output signal. This is potentially a very powerful form of temperature compensation and is most practical in situations where very slow temperature changes occur. **[8]**

5.4.3 Temperature Compensation for the design

A special case of this compensation method is available when strain is to be measured in a bending beam or pipe. Two identical strain gauges can then be mounted on the North face and two on the South face of a P.V.C. pipe, (constituting a N/S channel) as in **Figure 5.7 and 5.10**. Gauges will also be bonded in close thermal proximity of each other.

Bending will cause resistance changes that are equal in magnitude but opposite in sign to occur in **G1** and **G2** and in **G3** and **G4**, which will quadruple bridge output. Resistance change due to thermal output will be equal in magnitude and of the same sign and will thus cancel. This is referred to as a 'fully-active full bridge' and is identical to the Full-element strain gauge bridge previously discussed.

Hence, this type of gauge configuration is suitable for linear strain gauge bridge output and temperature compensation for the design. Furthermore maximum strain gauge bridge output is maintained as each strain gauge is measuring wind-induced strain.

5.4.4 SELCOM TYPE Strain Gauges [4]

Improvement in temperature compensation is achieved by the use of Self-Temperature-Compensated gauges. These are gauges constructed from material which has been subjected to particular metallurgical processes **(see Appendix C)** and which produce very small (and calibrated) thermal output over a specified range of temperature when bonded onto the material for which the gauges has been specifically designed. Gauges chosen in this design for the P.V.C. pipe were Self-Temperature-Compensated for plastics.**[4]**

5.5 Strain Gauge Bridge Balancing

Thus far the **self-temperature-compensated gauges** for plastics have been selected. Two gauges bonded on the **North face** and two bonded to the **South face** of a P.V.C. pipe connected in a full-bridge configuration, represent a North-South channel strain gauge bridge. A further four strain gauges are bonded in the same way to the **East and West faces** of the P.V.C. pipe forming an identical but separate East-West channel strain gauge bridge.

* *AT BALANCE, Eo = 0 if* $\frac{R1}{R4} = \frac{R2}{R3}$

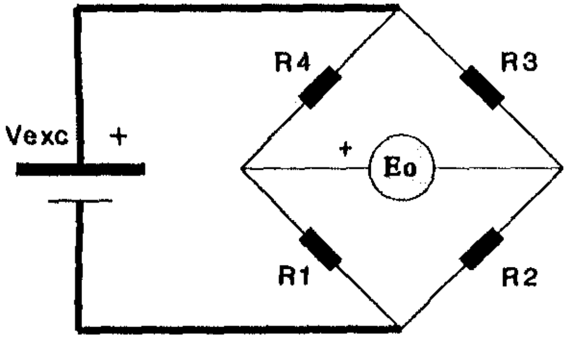


Figure 5.12 : **Basic Wheatstone bridge**

Rg1 & Rg2 are 120R Strain Gauges
R2 is a 120R Precision resistor

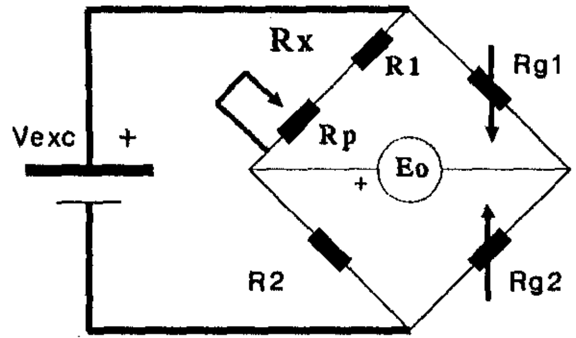


Figure 5.13 : **Single arm bridge balancing**

Rg1,Rg2,Rg3,Rg4 are 120R Strain Gauges

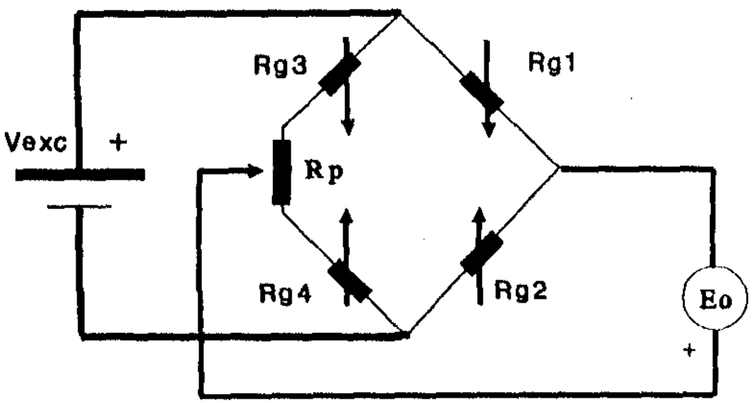


Figure 5.14 : **Apex bridge balancing**

Rg1,Rg2,Rg3,Rg4 are 120R Strain Gauges

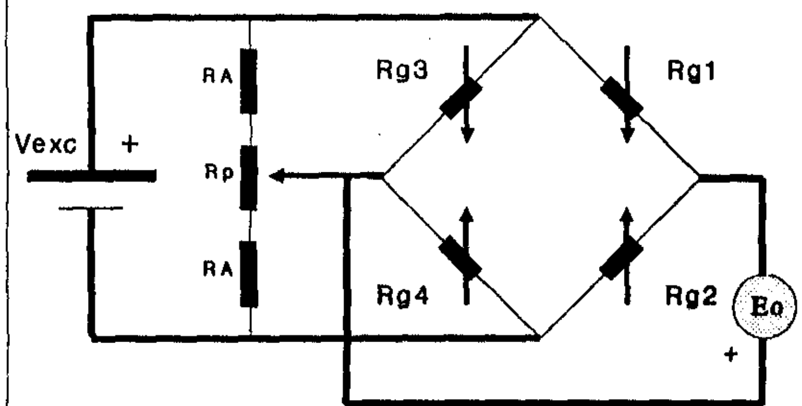


Figure 5.15 : **Parrallel bridge balancing**

In the discussions of the various bridge configurations, it was assumed that all arms of the bridge have equal resistance, so that the bridge output is zero. However, in practice resistances differ slightly in value because of manufacturing tolerances on the gauges. Strain introduced into the gauges during fixing or static strain in the P.V.C. pipe member must be ignored in the measurement of strain changes.

In spite of these differences, the required bridge output voltage must be zero before application of stress to the P.V.C. pipe. The adjustment of the output voltage to zero is termed bridge balancing. In the design, bridge offset voltage required at static stress conditions had to be less than 19.53 mV (1 L.S.B. for the analogue- to-digital conversion discussed later in **Chapter** 7).

Consider the bridge circuit of **Figure 5.12**.

For the open circuit output voltage to be zero, the voltage drop across **R2** must be equal the voltage drop across **R1**, that is, the ratio's **R2 /(R3+R2)** and **R1 /(R4+R1)** must be equal.

Under these conditions the reciprocals of these ratios are also equal : -

R3/R2 = R4/R1

For the bridge to be balanced, the ratio of values of the upper and lower resistors in each side of the bridge must be equal.

5.5.1 Single Arm Bridge Balancing [1]

A possible method of balancing the bridge is shown in **Figure 5.13.**

The resistance of one arm of the bridge, in this case **R1**, is chosen to be somewhat less than the resistance in each of the other arms, **(about 10%)**. A potentiometer, **Rp**, having an overall resistance about **20%** of that in other arms is connected in series with **R1**. The total resistance **Rx** of that arm of the bridge can be varied by ± **10%** about the nominal value of the other arms and can be set such that : -

$$Rx/R2 = Rg1/Rg2$$

The bridge output voltage will then be zero. This method is used in many strain gauge measurement applications but is not suitable for this design. Four strain gauges are used as arms of the bridge in this design and it is not convenient to choose one gauge with a lower resistance than the others.

5.5.2 Apex Bridge Balancing [1]

An alternative method of balancing the strain gauge bridge is shown in **Figure 5.14.**

In this case, the potentiometer **Rp** can be connected so that movement of the wiper increases the resistance of one arm of the bridge and simultaneously decreases the other to achieve the required balance condition.

5.5.3 Parallel Balancing [1]

This method of strain gauge bridge balancing was chosen for the proposed design. A **10KΩ**; ten turn wire wound potentiometer, **Rp**, with resistance tolerance ± **5%** was placed in parallel with two arms of the bridge to cause simultaneous increase in the resistance of one arm and decrease in the resistance of the other as in **Figure 5.15.**

The **10KΩ** precision metal film resistors **(RA)** in series with the ends of the pot restrict the total variation in the ratio of the two arms to the range required to ensure bridge balance. The percentage variation in the ratio is calculated as follows : - refer to **Figure 5.15.**

When the pot wiper is at the centre, each of the left-hand arms of the bridge is made up of the gauge resistance in parallel with **RA + ½ Rp : -**

Effective resistance = (RA + 0.5 Rp) // Rg3

= 119.05 Ω

Ratio of the two arms = 1 : 1

When the wiper is at the top of the pot : -

Upper-arm resistance = 118.58 Ω

Lower-arm resistance = 119.28 Ω

Ratio of upper-arm to lower-arm resistance = 0.994 : 1

Percentage variation in the ratio is **0.6 %**. Bridge excitation voltage was set at **4 Volts**. Therefore adjustable offset voltage across Rp is limited to **24 mA.**

The strain gauge bridge output voltage offset is applied directly to the input of the **1B32 AN Signal Conditioner(discussed in Chapter 6).**

Under 'no wind conditions' the input offset voltage required at the 1B32 AN Signal Conditioner input must be less than **60 μA.**

5.6 References

1. The Open University	1975	"Introduction to Instrumentation : - The Measurement of Strain" pp 5 - pp 34
2. Sears, F.W. Zemansky, M.W. Young, H.D.	1982	"University Physics : - 6TH EDITION" pp 215
3. Byars/Snyder/Plants	1983	"Engineering Mechanics of deformable bodies : - 4TH EDITION" pp 473 - pp 474
4. Kyowa Electronic Instruments Ltd.	1990	"Strain Gages : - Catalog no. 3001B"

5. Doebelin, E.O.	1982	"Measurement Systems : - Application and Design" pp 224 - pp 225
6. Hearn, E.J.	1985	"Mechanics of Materials : - 2ND EDITION" pp 602
7. Sheingold, D.H.	1980	"Transducer Interfacing Handbook" pp 29 - pp 33
8. Micro-Measurements	1991	"Catalog 500 : - PART B Strain Gage Technical Data"

CHAPTER 6

BRIDGE TRANSDUCER SIGNAL CONDITIONING

The purpose of any instrumentation system concerned with bending strains in pipe members is to enable these strains to be indicated visually to an observer or to be recorded for future analysis.

Chapter 5 showed how a voltage representing strain in the P.V.C. pipe anemometer unit is obtained. Techniques for converting this voltage into a wind vector voltage must be considered.

This chapter covers the strain gauge bridge signal conditioning and begins with a brief outline of the analogue assemblage of components initially used for wind vector signal conditioning and the translation of wind vector voltages for the determination of true wind velocity.

The chapter explains why this analogue method of absolute signal conditioning (from wind vector to display) was aborted in favour of a precision dedicated single integrated circuit package signal conditioner.

The operation and function of the **ANALOG DEVICES 1B32 AN** Bridge Transducer Signal Conditioner I.C. used in the final design is described in detail.

6.1 The initial Analogue Wind Velocity circuit

A highly specialised design, using analogue integrated circuitry for wind vector signal conditioning and analogue manipulation of the conditioned signals for the determination of true wind velocity was investigated and designed.

This method had been researched by the Georgia Institute of Technology in 1974. However, at that time, limited dedicated signal conditioning and microcontroller component integrated circuits were available to the designer.

Initially, during the earlier stages of the development of this project, it was decided that a similar analogue design approach could be applied to the aluminium pipe anemometer unit for the determination of true wind velocity. Although this method was attempted, it stressed the importance of the requirement for a precision bridge transducer signal conditioner for the conditioning of the strain gauge bridge circuits and proved beyond all doubt that further manipulation of the conditioned signals could be achieved by using a microcontroller I.C., memory support and appropriate software packages.

6.1.1 Operation of the Analogue Wind Velocity circuit

When the magnitude of a vector quantity such as wind velocity must be measured, special analogue techniques must be employed to resolve North-minus-South (N-S) and East-minus-West (E-W) vectors into resultant magnitude.

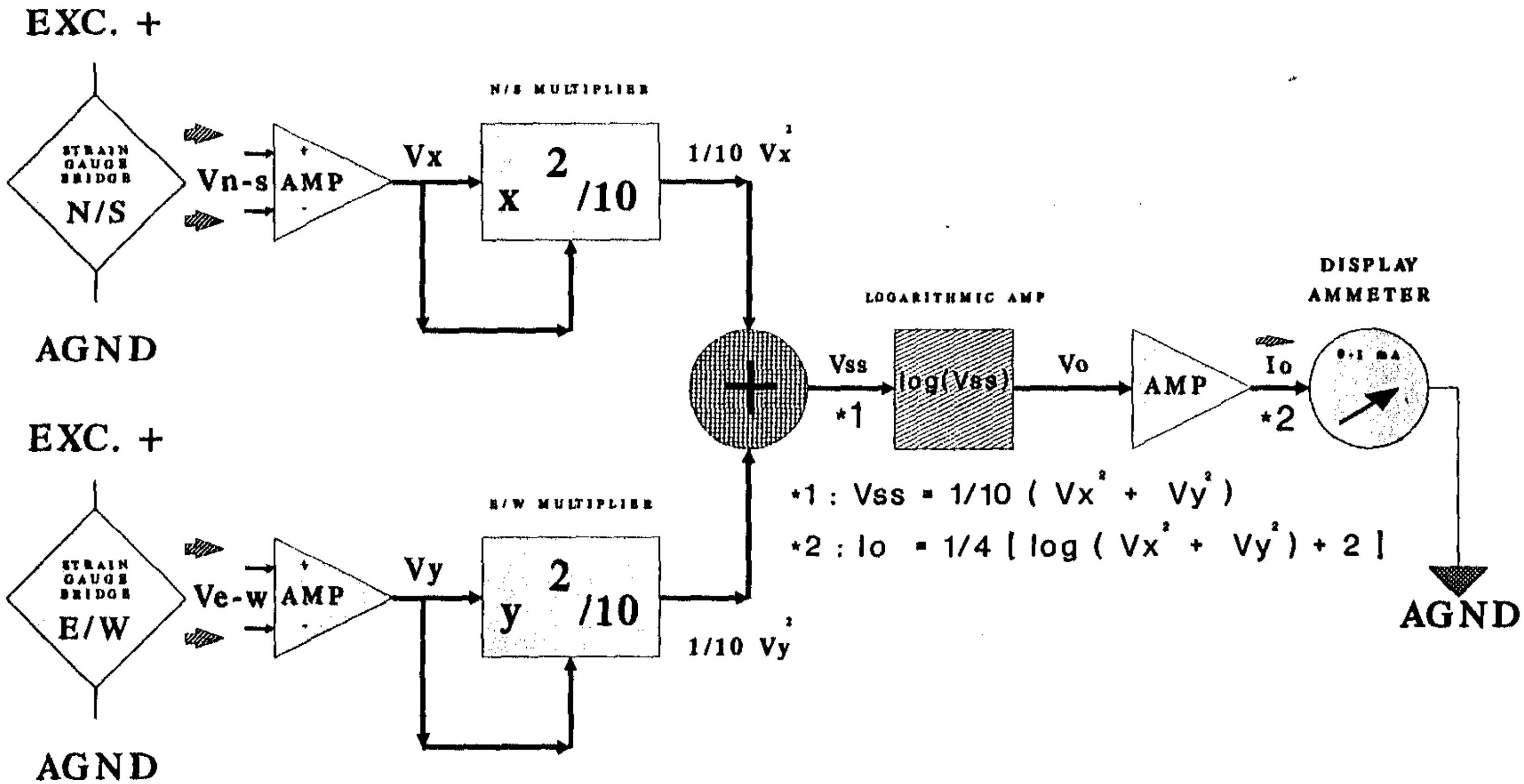


Figure 6.1 : ANALOGUE SYSTEM BLOCK DIAGRAM

Details use of analogue multipliers,summing and logarithmic amplifiers in a wind-speed indicator

With a pair of I.C. analogue multipliers, Motorola MC1495L [1] and several I.C. operational amplifiers, Harris HA2705 [2], an inexpensive Strain Gauge Drag Anemometer system was assembled.**(Refer to Figure 6.1)**

The prototype 1 aluminium pipe anemometer was interfaced to this circuit. The wind induced stress force generated a drag on the anemometer which is resolved into N-S and E-W displacements of the strain gauges bonded to the aluminium pipe.

These displacements produce two separate vector voltages **Vn-s** and **Ve-w** (outputs from two separate strain gauge bridges). These voltages are proportional to the wind induced stress force in the pipe, caused by the wind drag/force on the pipe. The drag on the pipe varies with the **square** of wind velocity, therefore Vn-s and Ve-w are proportional to the **square** of wind velocity.

Figure 6.1 is a block schematic diagram of the initial analogue circuit designed.

Strain gauge bridge Excitation voltage is provided from the circuit supply rails and was fixed between + 5 Volts and analogue-ground. All inputs were low-pass filtered (10 Hz to 20 Hz) to eliminate noise and to integrate the strain gauge outputs.

The aluminium pipe/strain gauge anemometer combination proposed that a wind velocity of approximately 2 m/s would produce a signal voltage in the micro-volt range while a velocity of 40 m/s would generate a signal in the milli-volt range (the actual velocity/voltage output relationship was not measured as this design was shelved before progression to the test/experimental stage was reached).

High impedance input amplifiers (**1 : HA2705**) normalise the strain gauge voltages such that a +/- 0.1 Volt to +/- 10.0 Volt range on one strain gauge input with the other input grounded results in a 0 mA to 1 mA range for the analogue display meter.

Amplifier signals are then **squared (2 : MC1495L Analogue Multipliers**), and **summed (3 : HA2705 used as a summing amplifier**), before they are applied to the logarithmic amplifier (**4 : HA2705 used as a logarithmic amplifier**), as the **Vss** signal.

Taking the **square root** of **Vss** would yield, **Vresultant**, the magnitude of the **Vn-s** and **Ve-w** wind vector voltages. Since these individual voltages are proportional to the **square** of wind velocity, **Vw**, the **Vss** voltage is a function of the **fourth power** of Vw. Therefore, in order to obtain true wind velocity, **Vw**, the **fourth root** of **Vss** must be extracted.[3]

Hence the following relationships are realised : -

i) **Vector Voltage N/S = Vn-s**

ii) **Vector Voltage E/W = Ve-w**

iii) **$Vss = (Vn\text{-}s)^2 + (Ve\text{-}w)^2$**

iv) **$Vresultant = (Vss)^{1/2} = [\,(Vn\text{-}s)^2 + (Ve\text{-}w)^2\,]^{1/2}$**

v) **Wind Velocity = $Vw = (Vresultant)^{1/2} = (Vss)^{1/4} = [(Vn\text{-}s)^2 + (Ve\text{-}w)^2]^{1/4}$**

To avoid practical difficulties encountered by extraction of the **fourth root** of Vss, a logarithmic stage is used. "This stage takes the natural logarithm of Vss. The output of this stage, Vo, is logarithmic and the effect of Vw being squared doubles the output voltage, **(Vo = 2 ln Vw)**. Note that for any desired quantity, q, related to an input signal Vin as **Vin = f(q^{2p})** ,the output of a logarithmic amplifier with this input is **Vout = 2p ln f(q).**" [3]

6.1.2 Problems encountered

Several problems were encountered during the implementation of the circuit, the more notable being offset and gain adjustments of the multipliers, random noise at low signal levels and temperature sensitivity. The offsets of the multipliers could not be adjusted so that squared outputs were balanced with respect to positive and negative inputs. Furthermore, the multiplier gains could not be balanced with respect to one another.

The complicated behaviour of analogue signal conditioning, particularly attempts at obtaining squared voltage outputs from analogue multipliers made this method extremely limited in its practical application of vector component manipulation. The design was aborted and it was decided that signal conditioning of the Strain Gauge bridge vector voltages would be separately controlled by a dedicated precision analogue signal conditioning integrated circuit. The digital signal manipulation of the conditioned analogue vector voltages is covered in **Chapter** 7.

6.2 Bridge Excitation Voltage and Signal Conditioning

The separate N/S channel and E/W channel strain gauge bridge circuits used in the design were discussed in **Chapter 5**. The choice of circuitry to produce the excitation voltage will depend on the degree of precision and special requirements for the system. A stable bridge driving potential and bridge signal conditioning may be obtained through the use of a complete signal conditioning package. For minimum component count and at a realistic cost, complete signal conditioners provide programmable transducer bridge excitation voltage in addition to amplification and filtering.

6.2.1 The Strain Gauge Bridge Signal Conditioner

The ANALOG DEVICES 1B32 AN Bridge Transducer Signal Conditioner [4] is a precision, chopper based, signal conditioning component ideally suited for high accuracy applications of load cells and bridge transducers. This device was most suitable for strain gauge bridge signal conditioning in this design. **(Refer to APPENDIX D : iii : 1B32 AN SPECIFICATIONS)**

Two 1B32 AN signal conditioners were used in the design, one for the N/S channel bridge and one for the E/W channel bridge.

The 1B32 AN has the following features : -

i) **Reasonable cost**
ii) **Complete signal conditioning solution**
iii) **Small package 28-Pin Double DIP**
iv) **Internal Thin-Film Gain Network**
v) **High Accuracy**
vi) **Low Input Offset Tempco : $\pm$ 0.07 $\mu V/^oC$**
vii) **Low Gain Tempco : $\pm$ 2ppm/^oC**
viii) **Low Non-linearity : 0.005% max**

ix) **High CMR : 140db min (60Hz, G = 1000 V/V)**

x) **Programmable Bridge Excitation: +4 V to +15 V**

xi) **Remote Sensing**

xii) **Low-Pass Filter (fc=4Hz)**

6.2.2 General description of the 1B32 AN

The 1B32 AN takes advantages of hybrid technology for high reliability as well as higher density. Functionally, the signal conditioner consists of three basic parts : a high performance chopper-based amplifier, a low-pass filter and an adjustable transducer excitation source.

The chopper-based amplifier features an extremely low input offset temperature co-efficient of ± **0.07 μV/oC** and excellent non-linearity of **0.005%** maximum over its full gain range of **100 to 5000 V/V**. The 1B32 AN has a thin-film resistor network for pin strapping the gain to **500 V/V or 333.3V/V**. The gain temperature co-efficient for these fixed gains is a highly stable ± **2ppm/oC**. Additionally, the gain can be set to any value in the gain range with two external resistors. The bandwidth of the chopper is **4 Hz at G = 100 V/V. (Refer to APPENDIX D : iii : 1B32 AN SPECIFICATIONS page 2 : DYNAMIC RESPONSE)**

The integral three-pole, low-pass filter offers a 60db/decade roll-off from 4 Hz to reduce common-mode noise and improve system signal-to-noise ratio.

The 1B32 AN regulated transducer excitation stage features low output drift (± **40 ppm/oC)** and can drive 120 Ω or higher resistance strain gauge bridge circuits. The excitation is preset at +10 Volts with other voltages between + 4 Volts and + 15 Volts

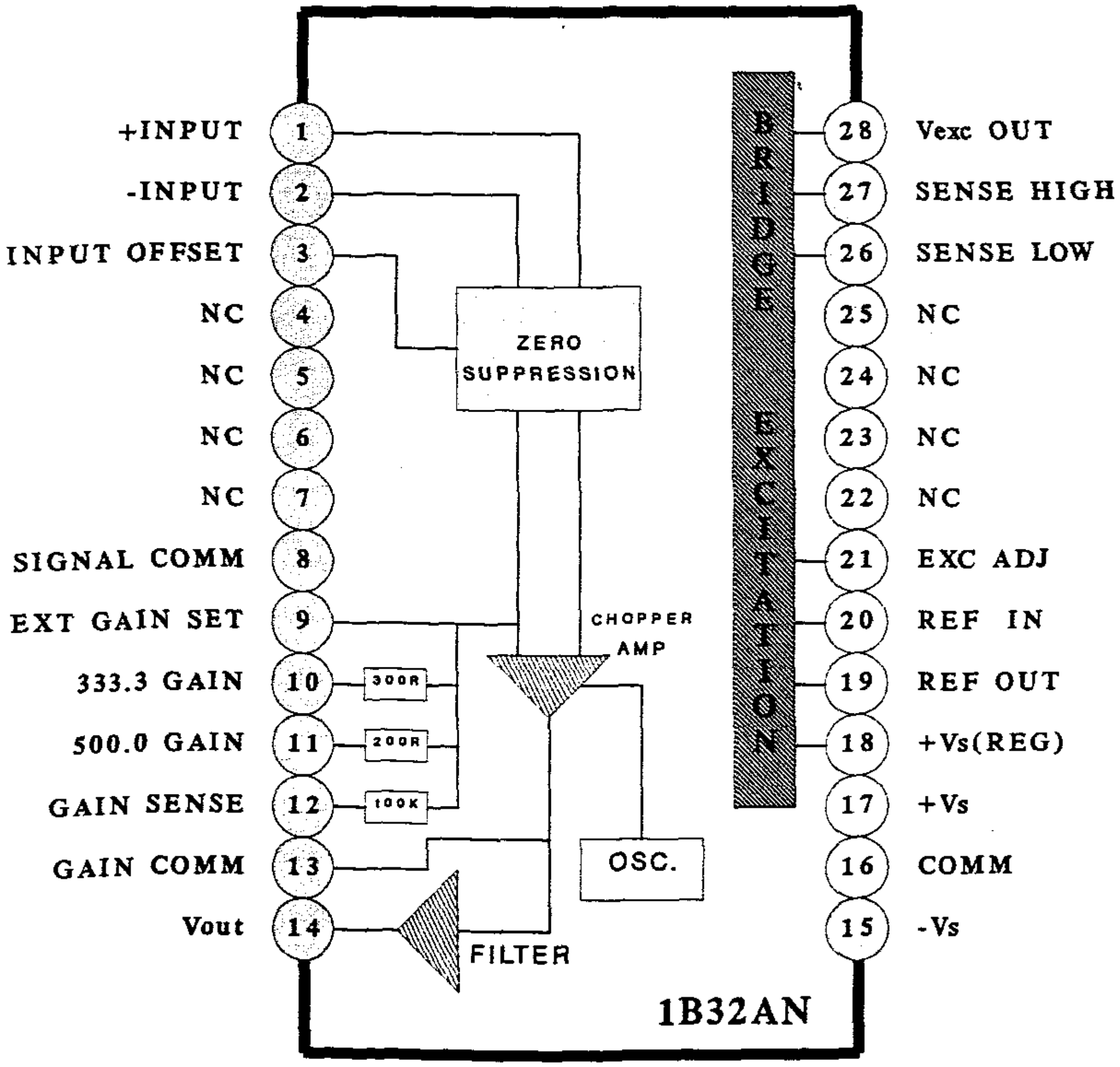


Figure 6.2 : 1B32 Block Diagram and Pinout

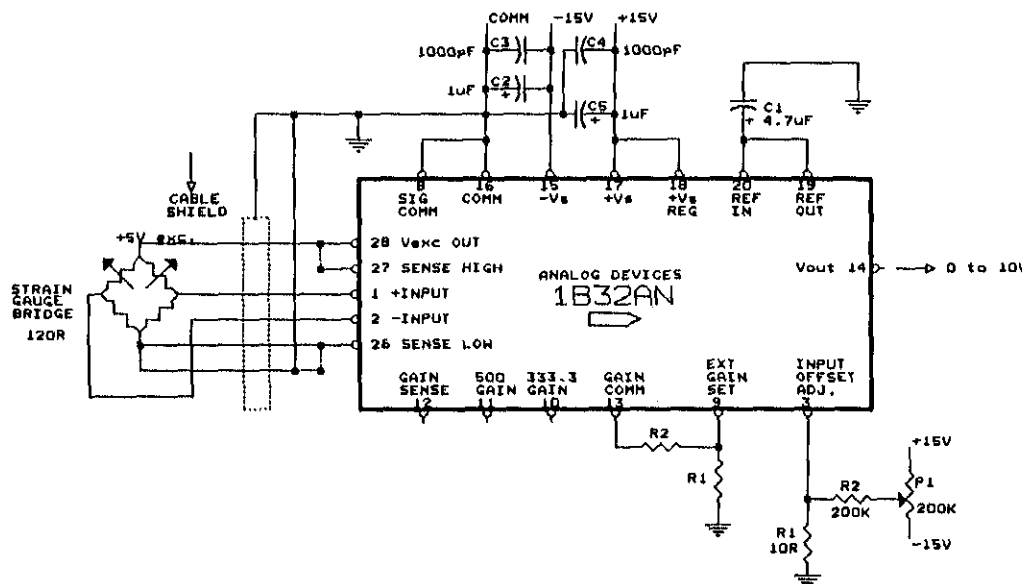


Figure 6.3 :External Gain Setting

ANALOG DEVICES 1B32AN	
Size B	Document Number BRIDGE TRANSDUCER SIGNAL CONDITIONER
REV	

programmable with external resistors. This section also has a remote sensing capability to allow for lead-wire compensation in strain gauge bridge circuits.

The 1B32 AN is fully specified over the industrial temperature range (- 25°C to + 85°C).

6.2.3 Gain setting of the 1B32 AN

The differential gain of the 1B32 AN can be either pin strapped or programmed externally with two resistors. The internal thin-film gain network **(Figure 6.2)** provides gains of 500 and 333.3 for standard strain gauge bridge sensitivities of 2mV/V and 3mV/V.

This is achieved by connecting GAIN SENSE (Pin 12) to GAIN COMMON (Pin 13) and grounding Pin 10 or Pin 11. The strain gauge P.V.C pipe combination had a sensitivity in the millivolt per volt range. The gain temperature co-efficient using the internal network is ± **2ppm/°C.**

Additionally, the gain can be set to any value in the gain range (up to 5000 V/V) with two external resistors connected to Pins 9 and 13, with Pins 11 and 12 unconnected, effectively floating the internal gain network of the 1B32 AN.

To program the gain externally, two resistors are connected as shown in **Figure 6.3** The gain equation is : -

$$G = 1 + R2/R1$$

Experiments with various gains were conducted before it was concluded that a gain, **G = 333.3** was most suitable for the design. This reduced external component count and

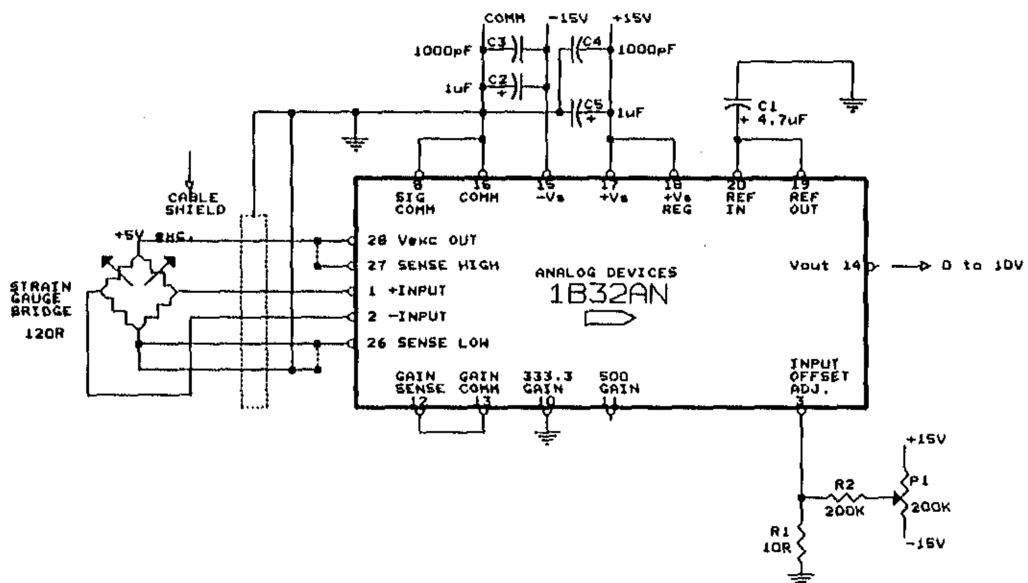


Figure 6.4 :Internal Gain Strapping

ANALOG DEVICES 1B32AN		
Size B	Document Number BRIDGE TRANSDUCER SIGNAL CONDITIONER	REV

eliminated the possibility of increased amplifier gain drift due to further resistance tolerance and temperature co-efficient factors being introduced by the external resistor gain network.

6.2.4 Offset adjustment of the 1B32 AN

The input referred offset adjust has the same sensitivity as the inputs of the 1B32 AN. The voltage level at INPUT OFFSET ADJUST, (Pin 3) is gained by the same factor as the input signal to provide a ± 10 Volt output adjustment.

Figure 6.4 shows an external network and potentiometer set up for a ± 7.5 mV span at the input, which gives a ± 2.5 Volt (7.5 mV x 333.3) output adjust capability. Wider ranges can be chosen with appropriate resistor and potentiometer values.

However, although experiments using external resistors for offset adjustment were conducted, it was decided that the elimination of external components would reduce the cost, component count and inaccuracies introduced by increased resistance tolerance and temperature co-efficient factors. It must be added that in a specialist design using a 1B32 AN which has precision temperature co-efficient specifications, any external resistive component used to support the design would preferably need to have a temperature co-efficient of ± 50ppm/°C.**(Refer to APPENDIX D : iii : 1B32 AN SPECIFICATIONS page 3 : NOTES)**

Offset adjustment of the 1B32 AN was not required and pin 3 was connected to the analogue-ground line. The parallel strain gauge bridge balancing method discussed in **Chapter 5** ensured bridge balance and input offset at the 1B32 AN inputs at less than **60 μV.**

After signal conditioning and amplification by **333.3**, the 1B32 clean analogue output at zero wind velocity was less than **19.53 mV**. This was suitable as a signal (after amplification) of **19.53 mV** represents one least significant bit for the **ADC0820 analogue-to-digital converter integrated circuit** discussed in **Chapter** 7.

6.2.5 Bridge Excitation Voltage Programming

The bridge excitation section is an adjustable regulated supply with an internally provided reference voltage at + 6.8 Volts. It is configured as a gain stage with the output preset at +10 Volts. For a desired excitation voltage range, the trimpot value **Rt** and resistor value **Rext** is determined by the following equations : -

$$\mathbf{Rt} = \frac{\mathbf{10\ K\Omega \times Vref\ out}}{\mathbf{Vexc - Vref\ out}} \qquad \textbf{where Vref out = 6.8 Volts}$$

$$\mathbf{Rext} = \frac{\mathbf{20\ K\Omega \times Rt}}{\mathbf{20\ K\Omega - Rt}}$$

At Vexc = 4 Volts : -

$Rt = 2.43 \times 10^4\ \Omega$

Rext = 113.33 KΩ

At Vexc = 10 Volts : -

Rt = 21.25 KΩ

Rext = 340 KΩ

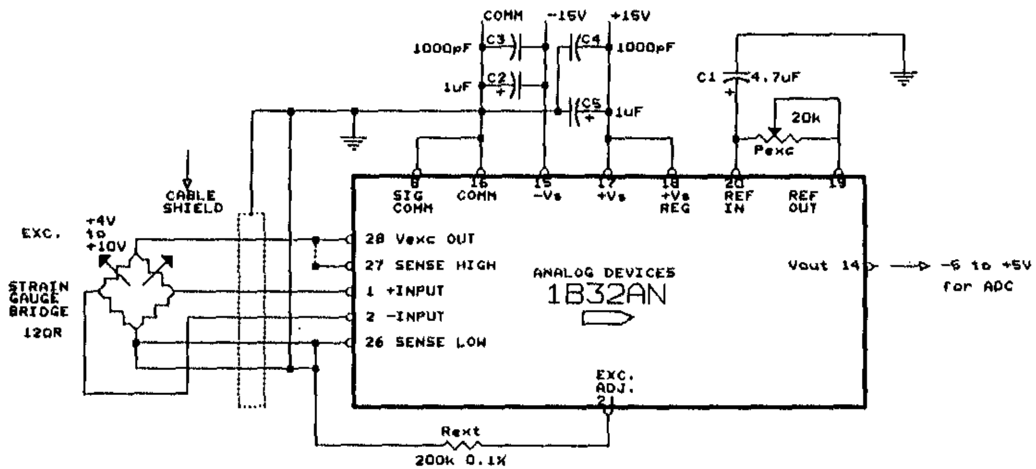


Figure 6.5 :Constant Voltage Excitation ; +4V to +10V Range

ANALOG DEVICES 1B32 AN		
Size B	Document Number BRIDGE TRANSDUCER SIGNAL CONDITIONER	REV
Date: January 1, 1980 Sheet		

The value of **Rt** was chosen as **20 KΩ** and **Rext** was chosen as **200 KΩ** for the design.

The excitation voltage of the 1B32 AN is preset at 10 V. To decrease Vexc down to an adjustable voltage excitation range between +4 V and +10 V a **200 KΩ** precision metal-film resistor must be connected between EXC.ADJ. and SENSE LOW (Pins 21 and 26). The adjustment range is then controlled by connecting a **20 KΩ** precision trimmer potentiometer between pins 19 and 20. A 4.7 μF tantalum capacitor from REF IN (Pin 20) to common (Pin16) is connected to lower the voltage noise at the reference input. These connections are shown in **Figure 6.5.**

An excitation voltage of 4 Volts proved most suitable for the strain gauge bridge circuit as this eliminated thermal output from the gauges and minimised power consumption of the 1B32 AN. Experiments proved that when the excitation voltage was adjusted beyond 5 Volts, the strain gauges produced a small thermal output due to the power dissipated across the strain gauge bridge.

Table 6.1 shows the power dissipated in the strain gauge bridge circuit at various excitation voltage settings.

Excitation Voltage	Bridge Impedance	Power Dissipation
Volts (V)	Ohms (Ω)	Power (mW)
+10	120	883.3
+8	120	533.3
+7	120	408.3
+6	120	300.0
+5	120	208.3
+4	120	133.3

Table 6.1 : I^2R loss in strain gauges at various Excitation Voltages

6.3 Applying the 1B32 AN Signal Conditioner

The 1B32'S regulated transducer excitation stage also has a remote sensing capability to allow for lead-wire compensation in 6-wire load cells and other transducer bridge configurations.

6.3.1 Strain Gauge to 1B32 AN lead-wire arrangement

Each of the strain gauge transducers described in Chapter 5 have one four meter long screened pair lead-wire connection. The full-strain gauge bridge circuit in Chapter 5 is configured from these lead-wire pairs on the P.C.B. in close proximity to the 1B32 AN Signal Conditioner.

As previously described, there are two strain gauge bridge circuits, one being a North/South channel bridge (4 strain gauges) and the other an East/West channel bridge circuit (4 strain gauges). Hence, one bridge is configured with its bridge balancing potentiometer in close proximity to a N/S channel 1B32 AN Signal Conditioner and the other is configured in an identical way to a separate E/W channel 1B32 AN.

It is more practical to explain the excitation and remote sensing capabilities of the 1B32 AN, related to one channel only, as both channels are identical.

6.3.2 Remote sensing of lead-wire

An excitation voltage of 4 Volts is applied to the P.C.B. configured strain gauge bridge lead-wires. The remote sensing inputs of the 1B32 AN may be P.C.B. connected as shown in **Figure 6.4**. The resistance at the excitation and sense lines should not exceed 10 Ω.

6.3.3 Strain Gauge output signal interfacing

The strain gauge bridge output is connected via the P.C.B. configured screened lead-wires directly to the positive input (pin 1) and negative input (pin 2) of the 1B32 AN. The chopper-amplifier gain of 333.3 provides an amplifier output voltage range (chosen for the design) between +5 Volts and -5 Volts. This voltage range is level shifted by two **10 KΩ** precision metal-film resistors to produce a 0 Volt to 5 Volt range for the **ADC0820** (Analogue-to-Digital Converter I.C.) discussed later in **Chapter** 7.

6.3.4 The Power Supply tracks

The 1B32 AN requires a dual power supply rail and has a rated operating voltage potential between +/- 12 Volts to +/- 18 Volts d.c. Conservatively, a +/- **12 Volt** supply was chosen for the design to minimise power consumption of the 1B32 AN.

The Vs REG INPUT (pin 18) must be connected to +Vs (pin 17) and power supplies are decoupled with 1 μF tantalum and 100 pF ceramic capacitors as close to the 1B32 AN as possible. **(see Figure 6.4)**

6.4 References

1. Motorola Semiconductor Products Inc.	1990	"Analysis and basic operation of the MC1595 Analogue Multiplier" AN-489 : - Ed Renschler
2. Harris Semiconductor Products Division	1991	"HA2700/2704/2705 : - Low Power, High Performance Operational Amplifiers"
3. Connelly, J.A. Lundberg, M.B.	1974	"Analog Multipliers determine true wind speed" E.D.N., April 20, 1974
4. Analog Devices Inc.	1990	"Data Acquisition Components and Subsystems : - Transducers, Conditioners and Instruments"

CHAPTER 7

HARDWARE : THE SIGNAL/PROCESSOR CIRCUIT

7.1 Introduction

This chapter describes the **INTEL 80C32** Microcontroller and its supporting circuitry. The separate N/S and E/W channel conditioned analogue output voltage signals from the 1B32 AN Signal Conditioners are converted to two separate N/S and E/W channel digital output voltages by the **ADC 0820**, analogue-to-digital converters. The N/S and E/W channel digital voltage outputs are then connected to the memory mapped 8-bit Address/Data bus. The Microcontroller and its supporting circuitry are responsible for translation of these voltages into wind velocity and direction read-out for the display, as well as for data capture to an I.B.M. P.C.

Refer to **Figure 7.1** for the Signal Conditioner/Microcontroller block schematic diagram. The schematic diagram of the Signal Conditioner/Microcontroller circuit is provided in **APPENDIX D.**

7.2 Hardware Design

7.2.1 The Analogue-to-Digital Converter [1]

The ADC0820 is a CMOS 8-bit high speed microprocessor compatible A/D converter. The analogue output voltages from the E/W and N/S channel 1B32 AN Signal Conditioners are level shifted to allow the two separate A/D converters (one N/S channel and one E/W channel) to accept ± 5 V analogue inputs.

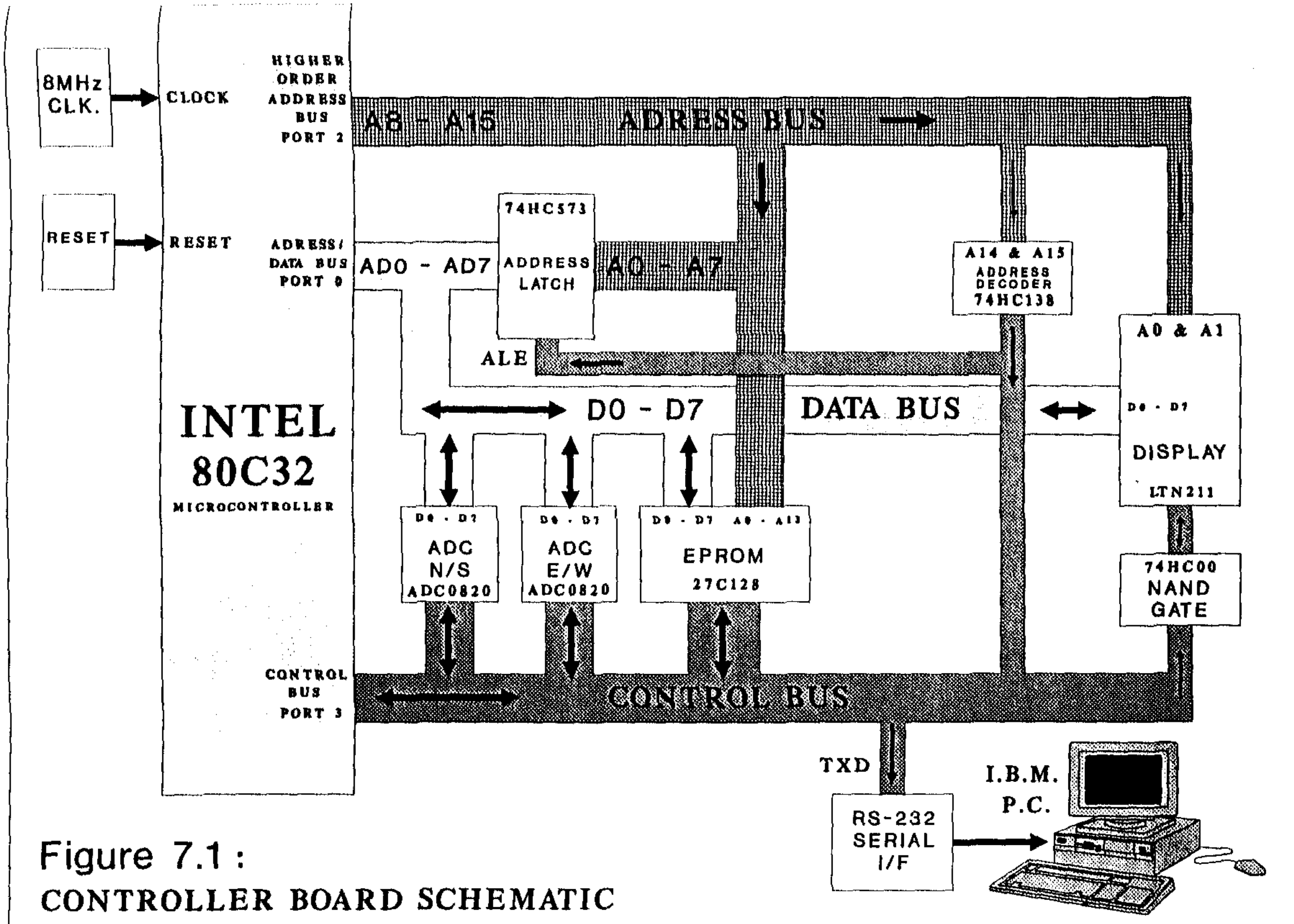


Figure 7.1 :
CONTROLLER BOARD SCHEMATIC

Latched TRI-STATE outputs drive the Data bus directly as an output port without the need for external interfacing logic. The ADC 0820 offers a 1.5 μs (micro-second) conversion time and converts the 0 V to 5 V analogue input voltage range to a digital value varying between 0 and 255, where 0 = 0 V (analogue) and 255 = 5 V (analogue).

The supply voltage and reference voltage of the ADC0820 are set at + 5 V d.c. The ADC0820 has a built in track and hold function and does not require external clocking. The ADC0820 was used in the WR-RD MODE (pin 7 strapped high). This reduced conversion time down to 1.5 μs (micro-seconds).

The ADC0820 was chosen for the design because of its 1.5 μs (micro-seconds) high speed conversion time. However, the ADC0804, 8 bit A/D converter (100 μs conversion time) could have been used as it was later realised that the high speed conversion of the analogue-voltages was not necessary.

The 1B32 AN Signal Conditioner package discussed in **Chapter 6** has a three-pole active filter, (fc = 4 Hz) at its conditioned voltage output. The analogue-to-digital converter would only have to sample these voltages at about 4 Hz. Thus the actual analogue-to-digital conversion time required would only be about 250 ms (milli-seconds).

The key specifications and features of the ADC0820 are :

Resolution	**: 8 bits**
Conversion time	**: 2.5μS MAX (RD mode)**
Conversion time	**: 1.5 μS MAX (WR-RD Mode) selected**
Total Unadjusted Error	**: ±½ LSB and ± 1 LSB**
Single supply	**: 5V**
Ratiometric or Absolute	**: Absolute Reference Vref. = 5 V was reference operation selected**

7.2.2 The Processor and Latch [2 & 3]

An INTEL 80C32 8-bit Control-Processor was used in this design. This CMOS device features low current consumption.**[2]**

The Address/Data (AD0 to AD7) bus is shared on Port 0 and the lower address byte is latched by the 74HC573.**[3]**

The 80C32 has four 8-bit Ports which are used as follows :

i) **Port 0 :**

Is an 8-bit bi-directional I/O port. It is the multiplexed lower-order address and data bus during access to the 1B32 AN Signal Conditioners, 27128 EPROM and LTN 211 display.

ii) **Port 1 : not used**

iii) Port 2 :

Is an 8-bit bi-directional I/O port. This port emits the higher-order address byte during access to the EPROM (A8 to A13). A14 and A15 are used as inputs by the 74HC138 to select either the 27128 EPROM, 1B32 AN Signal Conditioners or the LTN211 display.

iv) Port 3 : is used as follows : -

P3.2	**INT 0**	**: external interrupt 0**
P3.3	**INT 1**	**: external interrupt 1**
P3.6	**WR**	**: external data memory write strobe**
P3.7	**RD**	**: external data memory read strobe**

The Address Latch Enable (ALE) output of the 80C32 is connected to the **'c' input** of the 74HC573 Latch. The pulse from the ALE output latches the lower byte of the address during access to the EPROM.

The reset input (RESET), will reset the 80C32 if the RESET pin is kept high for two machine cycles while the oscillator is running. The RESET pin is connected to Vcc via a 10µF tantalum capacitor and to digital ground (DGND) via a resistor to reset the 80C32 automatically on power up.

Furthermore the EA/Vp pin is strapped to DGND for external (EPROM) program execution. The 80C32 uses the on-chip oscillator in conjunction with an 8 MHz crystal. The crystal is connected between X1 , and X2 pins.

The 80C32 Microcontroller has the following specifications :

256 Bytes Internal Data Memory

32 I/O lines (four 8-bit Ports , providing 5 Interrupts)

2x 16-bit Timers / Event Counters

64K Program Memory (16K : 27128 EPROM used)

5V Operating Voltage

3.5 to 12.0 MHz Oscillator Frequency (8 MHz used)

7.2.3 The EPROM 27128 [4]

The INTEL 27128 is a 5V only, 131.072-bit ultraviolet erasable and electrically programmable read-only memory (EPROM). The 27128 is compatible with the 12 MHz 8051 family. The standard 27128 access time is 250 nS which is compatible with the 80C32 microcontroller working at 8 MHz, chosen for this design. The 128 k (16k x 8 bit) EPROM has 14 address lines for access of the program code.

7.2.4 The 3-to-8 Line Decoder [5]

The Signal Conditioner/Microcontroller board is memory mapped and selection of the two separate N/S and E/W channel ADC0820 analogue-to-digital converters, 27C128 EPROM and LTN 211 display is done by the 74HC138 Decoder under 80C32 Microcontroller control. Three inputs (A , B and C) provide a selection of eight outputs. The C input is held low (DGND) since only the A and B inputs are required to decode the 4 outputs required in this application.

Decoding is as follows :

SELECT			OUTPUTS
A	B	C	
0	0	0	EPROM (27128)
0	1	0	N/S Channel A.D.C.
1	0	0	E/W Channel A.D.C.
1	1	0	L.C.D. Display

The CMOS 74HC138 features high noise immunity and low power consumption and all inputs are protected from damage due to static discharge by diodes to Vcc and ground.

The specifications of the 74HC138 are :

Typical propagation delay : 20 μs

Wide power supply range : 2V - 6V (5V used)

Low quiescent current : 80 μA max

Low input current : 1 μA max

Fan-out of 10 LS - TTL loads.

7.2.5 Quad 2-Input NAND Gate [6]

The MM74HC00 is a CMOS I.C. which has 4 NAND gates. Each gate has a buffered output. All devices have a high noise immunity and the ability to drive 10 LS - TTL loads. All inputs are protected from damage due to static discharge by internal diode clamps to

Vcc and ground. The I.C. uses the RD, WR and CS3 lines to generate an ENDISP enable signal for the LTN 211 display.

The logic equation implemented by the MM74HC00 for the enabling of the display is as follows : -

$$\mathbf{ENDISP = CS\,3\ .\ (RD + WR)}$$

The features of the MM74HC00 are :

Typical propagation delay	**: 8 ns**
Wide power supply range	**: 2 - 6V (5V used)**
Low quiescent current	**: 20 μA max**
Low input current	**: 1 μA max**
Fan-out of 10 LS - TTL loads.	

7.2.6 The L.C.D. Display [7]

The LTN211 is a 5 x 7 dot, 16-character, 2 line dot matrix module L.C.D. display with driver and controller LSI integrated circuit mounted on a single printed circuit board. The LSI controller incorporates a built-in ROM-based character generator with 160 characters and RAM display data with 8 characters. The module is capable of generating 160 fixed and 8 write program characters.

The LTN 211 operates from an extensive instruction set : display clear, cursor home, display on/off, cursor on/off, character blink, cursor shift and display shift. Contrast is adjusted (R6) by varying the contrast voltage between 0V and 5V. The display is enabled via the MM74HC00 Quad 2-input NAND gate.

Key specifications and features of the LTN 211 are :

Character size	**: 2.96 x 5.56 mm**
Supply voltage	**: + 5V**
Power consumption	**: 7.5 mW**
Illumination mode	**: reflective/transflective**
Data interface	**: parallel 4 or 8 bits**

7.2.7 The RS-232 Port Facility [8]

The MAXIM RS-232 Driver/Receiver provides the required levels for RS-232 Serial communication between the Signal Conditioner/Microcontroller board and the P.C. The 232 has three sections : a dual transmitter, a dual receiver and a +5V to approximately +10V dual charge pump voltage converter. In this application only the transmitter was required for data capture of wind velocity readings to an I.B.M. P.C. The voltage converter is used to obtain the correct level on the Serial Port during the transmission of the data to the I.B.M. P.C.

The RS-232 Serial Port is full duplex, meaning it can transmit and receive simultaneously. The Serial Port can operate in 4 modes. For this application the port operates in Mode 1 where 10 bits are transmitted or received : a start bit, 8 data bits and a stop bit.

Timer 1 is used to generate a baud rate of 9600. The Serial Port transmits the bits through a Serial Buffer, (SBUF). The initialisation of the Serial Port and the transmission of wind velocity data can be seen from routines in the program listings in the **Appendix E.**

7.3 References

1. National Semiconductor 1988 "LINEAR DATABOOK 2"
pp 3 : 91

2. Intel Corporation 1988 "8-BIT EMBEDDED
CONTROLLER HANDBOOK"

3. National Semiconductor 1988 "CMOS LOGIC DATABOOK"
pp 3 : 320

4. Intel Corporation 1988 "MEMORY COMPONENTS
HANDBOOK"
pp 4 : 54

5. National Semiconductor 1988 "CMOS LOGIC DATABOOK"
pp 3 : 108

6. National Semiconductor 1988 "CMOS LOGIC DATABOOK"
pp 3 : 3

7. Philips Components 1989 "PRODUCT SPEC. : -
LTN211 L.C.D. Display"

8. Maxim Integrated Products 1989 "PRODUCT SPEC. : -
RS-232 Line Drivers/Receivers"

CHAPTER 8

SOFTWARE

This chapter describes the implementation and function of the software used to determine wind velocity and direction for the display readout and data capture to an I.B.M P.C.

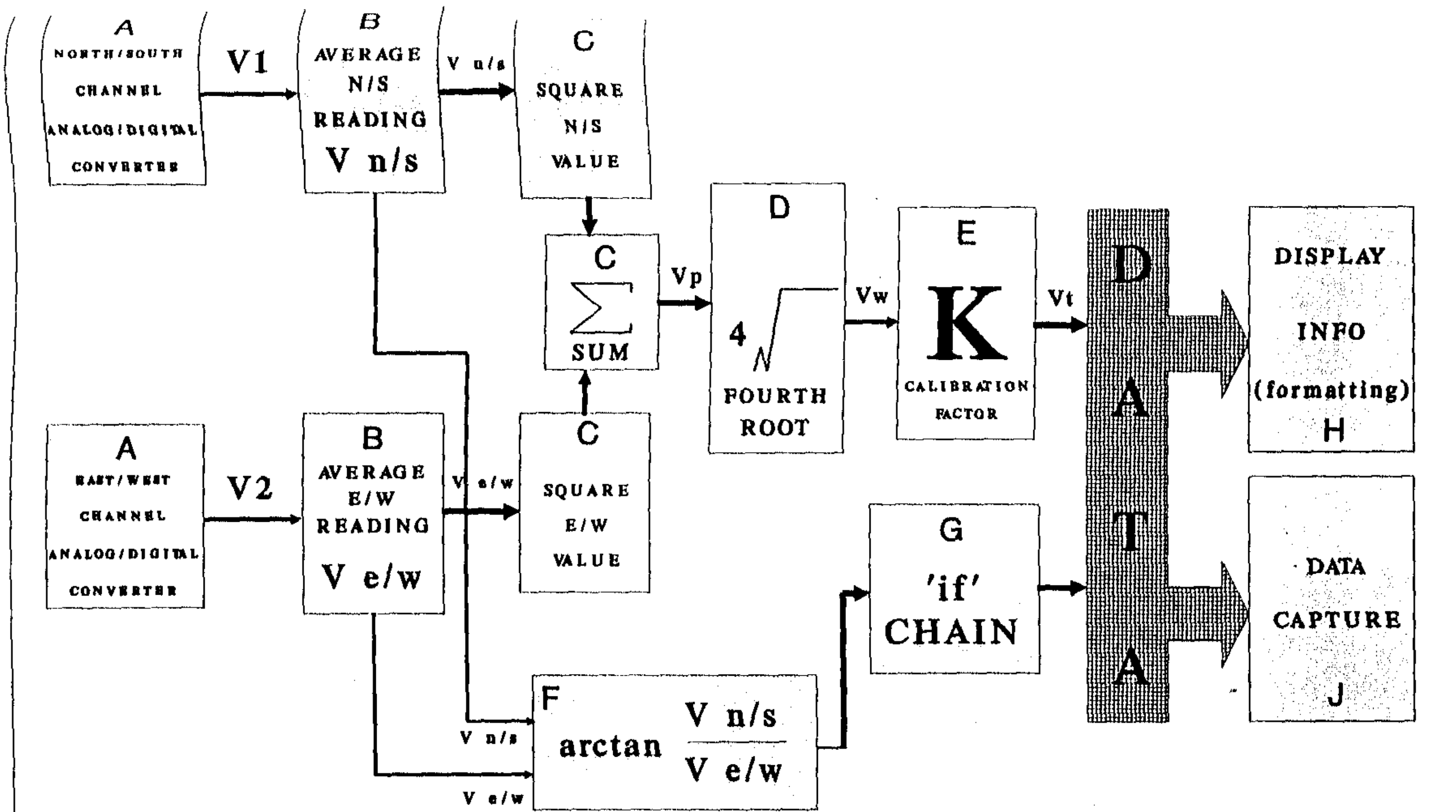
The C Programming Language is a general-purpose programming language which features economy of expression and a powerful set of mathematical software functions. C provided the necessary mathematical functions for the manipulation of the wind vector voltages for the determination of wind velocity and bearing. The display routine ' Putchar ' is an Assembler Language routine which was incorporated in the C run-time library enabling the return of ASCII characters to the L.C.D. display.

8.1 Wind Data Software Process

The block diagram, **Figure 8.1** shows the basic structure of the manipulation of wind vector voltages for the determination of wind data.

A.

N/S and E/W channel vector voltages V1 and V2 are digital voltage outputs from each of the respective separate channel analogue-to-digital converters. These wind vector voltages represent the amplified, filtered vector voltages produced by wind induced strain acting on the P.V.C. pipe Anemometer unit.



WIND VELOCITY $$Vt = \sqrt[4]{(V\ n/s)^2 + (V\ e/w)^2} * K$$

WIND BEARING $$Wb = \arctan \frac{V\ n/s}{V\ e/w}$$

Figure 8.1 : **Wind Data Software Process**

B.

The instantaneous V1 and V2 vector voltages are then averaged over 250 readings in a software loop producing two separate voltages, Vn/s and Ve/w. This prevents spurious display read-out.

Wind Velocity Software Process

C.

The wind force generates a drag on the P.V.C. pipe anemometer unit which is resolved into N-S (North-minus-South) and E-W (East-minus-West) displacements of the strain gauges. These displacements produce vector voltages, Vn/s and Ve/w which are proportional to the drag on the P.V.C. pipe anemometer. Since the drag on the P.V.C. pipe varies with the square of wind speed, Vn/s and Ve/w are proportional to the square of wind velocity, Vw. [1]

The wind velocity display information is derived from the Vn/s and Ve/w vector voltages. The Vn/s and Ve/w vector voltages are squared and summed and a resultant Vp is produced.

D.

Taking the square root of Vp would yield the magnitude of the N/S and E/W vector voltages, Vp. However, since these individual voltages are proportional to the square of wind velocity Vw, Vp is a function of the fourth root of Vw. In order to obtain true wind velocity the fourth root of Vw is extracted.

E.

A multiplication calibration factor is incorporated in the software. This is a function of the amalgamated physical constants introduced by the nature, dimensions and physical properties of the P.V.C. pipe member. The resultant true wind velocity, Vt appears on the L.C.D. display readout **(H)** and is also captured to an I.B.M. P.C. **(J).**

Wind Direction Software Process

F.

The separate vector voltages Vn/s and Ve/w are software manipulated using the arctan function. This function divides the Vn/s by Ve/w and returns a bearing to the display **(H)** between 180° and -180°.**[2]**

G.

This resultant bearing is simultaneously filtered through a software **' if ' chain,** which returns a dedicated compass direction readout for the L.C.D. display **(H)**.**[2]**

8.2 The MIKE1.C : Anemometer Test program-code

The Assembler-Program-code, **PUTCHAR.S03** and the C-Program-code, **MIKE1.C : Anemometer Test** are listed in **APPENDIX E** . A detailed explanation of the **MIKE1.C** C-program code and flowcharts are also provided in **APPENDIX E**.

CHAPTER 9

THE POWER SUPPLY

This chapter provides a brief description of the designed power supply. The supply provides power to the two 1B32 AN signal conditioners and support circuitry.

9.1 The Power Supplv Circuit

The power supply circuit is designed to supply each of the two 1B32 AN signal conditioner packages with + 12 V and - 12 V d.c. In addition to this, it provides the INTEL 80C32 Microcontroller, 74HC573 Latch, 74HC138 Address Decoder, 27128 EPROM, LTN211 Display and MAXIM RS-232 Interface with + 5 V d.c.

An analogue ground line is connected to the 1B32 AN analogue signal conditioners whereas the microcontoller and support are provided with a digital ground line. The separate ground line arrangement isolates the analogue section of the circuit from digital noise.

9.1.1 Operation of the Power Supply

Refer to **Appendix D : ii** for the schematic circuit diagram and voltage regulator data sheets. The power supply works of a 220V a.c. mains supply. A 20 V-0-20 V dual rail supply is produced from the secondary of T1 and is full-wave rectified via U1. 25 Volt dual polarity voltages are than smoothed by C1 and C2.

The positive 28V supply voltage is provided at the VI input of the **LM7805, 5 Volt voltage regulator integrated circuit.[1]** The 7805 is mounted on an adequate heatsink. The 5 Volt and ground rails (digital ground) are provided to the microcontroller and support section circuitry. Current consumption of this section of the circuitry was measured as 35 mA. Reasonably conservative power consumption of this section of the circuit was obtained due to the use of components employing CMOS technology.

In addition to this, the dual polarity 28 V rails are extended to the **LM 326 dual polarity 12V tracking regulator integrated circuit.[2]** Tight regulation, transient protection and thermal shutdown are characteristics of this 14 pin dual-in-line package.

The 12 V voltages along with the analogue ground rail (Pin 11) are connected to the 1B32 AN signal conditioner. The minimum rated operating voltage for the signal conditioners is + 12 V and - 12 V. The current consumption of the 1B32 AN signal conditioners is greatly influenced by the length of lead wire from the conditioner to the transducer, and by the impedance of the Strain gauge bridge circuit. Bridge excitation voltage was reduced to the rated minimum of 4 Volts. The combined current consumption of the two signal conditioners was then measured as 73 mA.

9.2 References

1.National Semiconductor 1988 "LINEAR DATABOOK 1"
California, U.S.A. pp 1 : 251

2.National Semiconductor 1988 "LINEAR DATABOOK"
California, U.S.A. pp 1 : 85

CHAPTER 10

PROBLEMS ENCOUNTERED

This chapter describes the problems encountered during the design of the anemometer unit.

10.1 Elasticity of pipe members

Chapter 2 refers to the three prototype anemometer units constructed and tested before the final P.V.C. pipe anemometer unit was designed. The three prototype units were too rigid and had to be subjected to considerable tensile/compressive stress before a suitable output signal was obtained.

10.2 Strain Gauge selection

The full-element strain gauge bridge chosen for this design is discussed in **Chapter 5; (Refer to 5.3.4).**

120Ω Strain gauges were selected for the bridge. Excluding the value of the bridge balancing potentiometer, the bridge impedance is 120Ω. Excitation voltage was set to 4 volts, the rated minimum supplied by the 1B32 AN signal conditioner. Power dissipated across the strain gauge bridge is therefore limited to 133.3 mW, limiting the resistance change in the bridge caused by thermal drift in the gauges.

An improvement in eliminating thermal drift and resistance changes in the bridge can be achieved by using 350Ω strain gauges. Bridge impedance would then be 350Ω and with

4V excitation voltage, resulting power dissipation in the strain gauge bridge would be 46mW. Thus, thermal drift in the gauges would be negligible.

10.3 Cable interference

Initially considerable input offset drift to the 1B32 AN Signal Conditioner input caused inaccuracy at the amplifier output. This was due to the type of cable used in connection between the strain gauges and the P.C. board. To eliminate noise in the form of interfering signals, 50 Hz mains pickup and signal coupling via power supplies and ground paths, screened cable pairs were used to connect strain gauges to the P.C. board.

Bridge completion is achieved on the P.C. board in close proximity to the 1B32 AN signal conditioners. Tracks connect the bridge output directly to the 1B32 AN (pins 1 and 2) on the P.C. board. The screened leadwires were originally connected to a 'screw type' in line connector on the P.C. board.

Dry joint connections caused interfering signals which produced inaccuracies at the 1B32 AN amplifier output. The strain gauge leadwires and shield/screen were then soldered directly on to the P.C. board. These interfering signals were thus reduced to an insignificant level due to improvement in the layout and construction of the leadwires on the P.C. board.

10.4 Bridge balancing potentiometer

The parallel strain gauge bridge balancing circuit discussed in **Chapter 5 : 5.5.3** was selected for the design.

4V excitation voltage, resulting power dissipation in the strain gauge bridge would be 46mW. Thus, thermal drift in the gauges would be negligible.

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10.4 Bridge balancing potentiometer

The parallel strain gauge bridge balancing circuit discussed in **Chapter 5 : 5.5.3** was selected for the design.

Initially, P.C.B. mount, 13 turn linear track, miniature trimming potentiometers were used for the design. Numerous experiments were conducted using different potentiometer and resistance values for strain gauge bridge balancing.

Finally an off board mounted 10KΩ, ten turn, wirewound potentiometer (tolerance 5%, Temperature co-efficient 80 ppm/°C) was placed in parallel with two arms of the strain gauge bridge. This potentiometer and bridge balancing method was preferred over the P.C. board mounted miniature trimmers as this eliminated bridge offset drift to an acceptable range for the 1B32 AN signal conditioner amplifier input. MIL-specification potentiometers would be the most suitable choice for the bridge balance circuit, but are not readily available in the R.S.A.

10.5 Component selection and P.C.B. design

The initial prototype circuit design consisted of two single signal conditioner printed circuit boards (p.c.b.). The two signal conditioner boards were connected to a separate microcontroller and support integrated circuit p.c.b.

Considerable amplifier offset drift problems were experienced due to cable ground loops and additional tolerances introduced by external resistor and potentiometer components supporting the 1B32 AN signal conditioner.

The problems were eliminated by the design of a single signal conditioner/microcontroller printed circuit board. Cable connections between the analogue and digital circuitry were thus eliminated and two separate ground tracks, an analogue ground track and a digital ground track were provided on the printed circuit board. This isolated digital noise which had previously affected the performance of the signal conditioners and analogue-to-digital converter integrated circuits.

A further improvement was realised by careful and symmetrical routing of the ground tracks between the printed circuit board mounted components.

Resistor and potentiometer components supporting the 1B32 AN amplifier gain and input offset were eliminated. Additional tolerances introduced by these components were thus reduced. The internal resistor network within the 1B32 AN was pin strapped for a gain of 333.3. The gain temperature co-efficient for this fixed gain is ± **2 ppm/°C**. Input offset adjustment for the 1B32 AN was controlled by the bridge balancing potentiometer. Precision resistor and trimpot components were used for excitation voltage control. These components exhibit a temperature co-efficient of ± **50 ppm/°C maximum** and have resistance tolerances of **0.1%** and **5%** respectively.

The Vcc and DGND pins of the Microcontroller and support integrated circuits were decoupled using 1nF tantalum capacitors. The + 12V and - 12V power rails to the 1B32 AN were decoupled with 1uF tantalum and 1000pF ceramic capacitors.

A further improvement in noise isolation was realised after power rail decoupling of the 74HCT138 decoder integrated circuit. This eliminated drift of the E/W channel ADC output due to noise on the ADC chip select input.

An improvement in the design would be to replace the two ADC0820 integrated circuits and the **INTEL 80C32 Microcontroller** with the **PHILIPS 80C552 Microcontroller**. The 80C552 has eight built in analogue-to-digital converters. The additional address and control lines between the ADC0820 and 80C32 Microcontroller would then be eliminated. Furthermore, the possibility of ground loop voltage problems between the analogue-to digital converter integrated circuits and microcontroller would be eliminated.

10.6 Thermal dissipation of the strain gauges

Since the foil resistance strain gauge is a passive rather than active (self-generating) sensor, an excitation current must flow through the gauge in order to develop an output signal. For a fixed strain level and given gauge characteristics, the output is directly proportional to gauge excitation. Read-out instrument considerations make it desirable to apply as much excitation as the gauge in use can tolerate without degradation in performance. Such degradation occurs when self-heating of the grid causes an excessive rise in either the grid-plane temperature or the local specimen temperature. [1]

Under normal conditions, essentially all of the heat developed in the gauge must flow through the backing and adhesive layer into the specimen. Metallic specimens are fair to excellent heatsinks, depending on their size, shape and thermal conductivity. An aluminium-alloy specimen is superior to to a stainless-steel specimen in this respect as it has a larger thermal conductivity property. [1]

(Refer to APPENDIX B : Properties of materials : Thermal Conductivity)

Unfilled polyvinyl-chloride (P.V.C.) is a thermal insulator rather than a heatsink, and an appreciable amount of gauge heat must be transferred by convection when specimens of this type are involved. [1]

(Refer to APPENDIX B : Properties of materials : Thermal Conductivity)

Errors due to gauge self-heating effects show up in several ways, principally as instability of gauge readings (temperature induced apparent strain), even at zero load, strain gauge creep occurring at only moderately increased ambient temperatures (creep occurs when the adhesive layer becomes fluid), and a substantial reduction in the maximum practical temperature for accurate strain measurements (reduction in specified operating temperature range of the strain gauge).[1]

Voids in the adhesive glueline or imperfections in the grid will result in hot spots that degrade the strain gauge performance radically. Changes in the thermal output curve occur due to both grid-plane temperature rise and local specimen heating.[1]

Various experiments were conducted by changing the excitation voltage to the strain gauge bridge. **Chapter 6 : 6.2.5** refers to excitation voltage programming of the 1B32 AN. **Table 6.1** shows the power dissipated in the strain gauge bridge at various excitation voltage settings. **Chapter 2 : 2.3.3** substantiates the reason for limiting excitation voltage to 4 Volts.

10.7 Influence of environmental elements

The P.V.C. anemometer unit was designed to operate efficiently in the environmental temperature range **0^oC to 40^oC.** The strain gauge/P.V.C. pipe combination had to be protected from the environmental elements. The pipe mounted strain gauges were silicone moisture proofed with a marine sealant manufactured by Dow Corning.

The P.V.C. pipe anemometer unit designed had the following physical properties **(Extracted from APPENDIX B : Co-efficient of thermal expansion) :**

Thermal Expansion Co-efficient : $\alpha = 1.0 \times 10^{-6}\ /^oC$

Length of P.V.C. pipe : L = 1 metre

The chosen temperature range for efficient operation is between **0oC** and **40oC.** The device was calibrated at **20oC** (room temperature). The change in design range temperature and room/calibration temperature is therefore :

$$\Delta T = 20^{o}C$$

10.7.1 Effect of temperature on the P.V.C. pipe

Most solid materials expand when heated and contract when cooled. The P.V.C. pipe has length **L** at initial temperature (room/calibration temperature) and when the temperature increases/decreases by an amount ΔT, the length of the P.V.C. pipe increases/decreases by **ΔL.** In the designed unit **ΔL** is proportional to **L** as they represent the same material and are subjected to the same temperature variation . Introducing a proportionality constant **α,** (Thermal Expansion co-efficient), this relationship is :

$$\boxed{\Delta L = \alpha \times L \times \Delta \times T} \qquad [2]$$

Taking room/calibration temperature as **20oC** and operational environmental design temperature range between **0oC** and **40oC,** calculated change in length of the P.V.C. pipe anemometer unit is :

$$\Delta L = 2 \times 10^{-5} \text{ metres}$$

Therefore :

At 0oC Length of P.V.C. pipe = 0.99998 metres

At 40oC Length of P.V.C. pipe = 1.00002 metres

Since the length **(L)**, of the P.V.C. pipe at room/calibration temperature is **1 metre** and the change in length of the pipe **(ΔL)**, at change in temperature **(ΔT)**, of **20°C** is **2 x 10^{-5} metres,** the percentage change in length **(L)**, of the pipe is :

% Variation from original length = 0.002 %

The change in pipe length due to temperature changes is negligible. Furthermore, the Self-temperature-compensating strain gauge transducers in conjunction with the full strain gauge bridge configuration selected for this design, bonded to the P.V.C. pipe, compensate for this calculated change in length of the pipe. **Chapter 5** covers the strain gauge selection and bridge configuration design in detail.

10.7.2 Effect of temperature on the Stainless-steel pipe

A prototype 1 Stainless-steel pipe anemometer unit was constructed (height = 1 metre ; diameter = 25 mm).

Stainless-steel has a Thermal Expansion Co-efficient, $\alpha = 17.3 \times 10^{-6}$ / °C.**(Refer to APPENDIX B : Properties of materials)**

$$\boxed{\Delta L = \alpha \times L \times \Delta \times T} \quad [2]$$

Taking room/calibration temperature as **20°C** and operational environmental design temperature range between **0°C** and **40°C,** calculated change in length of the Stainless-steel pipe anemometer unit is :

$$\Delta L = 3.5 \times 10^{-4} \text{ Metres}$$

Therefore :

At 0^oC Length of P.V.C. pipe = 0.99965 metres

At 40^oC Length of P.V.C. pipe = 1.00035 metres

Since the length **(L)**, of the Stainless-steel pipe at room/calibration temperature is **1 metre** and the change in length of the pipe **(ΔL)**, at change in temperature **(ΔT)**, of **20^oC** is **3.5×10^{-4} metres,** the percentage change in length **(L)**, of the pipe is :

% Variation from original length = 0.035 %

The change in pipe length due to temperature changes is negligible. Furthermore, the Self-temperature-compensating strain gauge transducers in conjunction with the full strain gauge bridge configuration selected for this design, bonded to the Stainless-steel pipe, compensate for this calculated change in length of the pipe. **Chapter 5** covers the strain gauge selection and bridge configuration design in detail.

10.7.3 Effect of temperature on the Aluminium pipe

A prototype 2 Aluminium-alloy pipe anemometer unit was constructed (height = 1 metre ; diameter = 25 mm).

Aluminium has a Thermal Expansion Co-efficient, $\alpha = 23 \times 10^{-6}$ / ^oC.**(Refer to APPENDIX B : Properties of materials)**

$$\boxed{\Delta L = \alpha \times L \times \Delta \times T} \quad [2]$$

Taking room/calibration temperature as **20°C** and operational environmental design temperature range between **0°C** and **40°C**, calculated change in length of the Aluminium. pipe anemometer unit is :

$$\Delta L = 4.6 \times 10^{-4} \text{ Metres}$$

Therefore :

At 0°C Length of P.V.C. pipe = 0.99954 metres

At 40°C Length of P.V.C. pipe = 1.00046 metres

Since the length **(L)**, of the Aluminium-alloy pipe at room/calibration temperature is **1 metre** and the change in length of the pipe **(ΔL)**, at change in temperature **(ΔT)**, of **20°C** is **4.6 x 10^{-4} metres**, the percentage change in length **(L)**, of the pipe is :

% Variation from original length = 0.046 %

The change in pipe length due to temperature changes is negligible. Furthermore, the Self-temperature-compensating strain gauge transducers in conjunction with the full strain gauge bridge configuration selected for this design, bonded to the Aluminium-alloy pipe, compensate for this calculated change in length of the pipe. **Chapter 5** covers the strain gauge selection and bridge configuration design in detail.

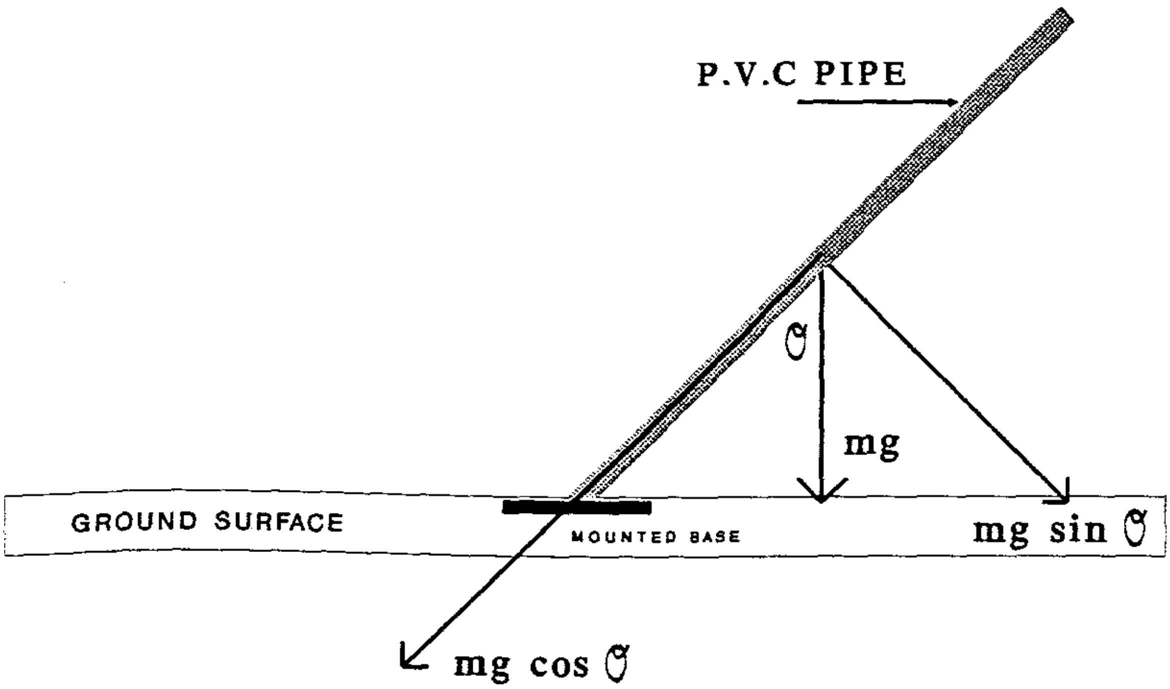


Figure 10.1 : Effect of Gravitational Force on P.V.C pipe.

10.7.4 Effect of Gravitational Force on the P.V.C. pipe

Figure 10.1 represents an example of the exaggerated effect of gravitational force on the P.V.C. pipe. The smallest wind force increment acting on the P.V.C. pipe anemometer occurs between wind velocities of **0.3 m/s (light air)** and **1.6 m/s (light breeze).** This wind force increment is **3.35 N/m^2.** This information is extracted from **Chapter 3 : Figure 3.1 : The Beaufort Scale of Wind Forces**

If we assume the P.V.C. pipe mass **(m),** to be **350 grams** with the pipe fixed such that its length is almost parallel to the earth's surface, the maximum allowable tilt angle (before the smallest wind force increment is affected), of the P.V.C. pipe relative to the earth's surface is calculated as follows :

$$F_{down} = mg \sin \theta \qquad \text{where } g = 9.8\ m/s^2 \qquad [2]$$

$$\text{Therefore } \theta = 77.6^o$$

This is an exaggerated representation of the gravitational force acting on the P.V.C. pipe and calculation shows that the smallest wind force increment is only affected by gravitational force when the pipe is at an angle of 77.6^o relative to the earth's surface. Hence, we can assume that the operation of the P.V.C. pipe Anemometer unit is not affected by gravitational forces acting on it.

10.7.5 Susceptibility of the pipe members to lightning strikes

The Aluminium-alloy, Stainless-steel and P.V.C. pipe members have the following **Resistivity (ρ)** properties.

(Extracted from APPENDIX B : Properties of materials : Resistivity) : -

Aluminium-alloy	:	$\rho = 2.86 \times 10^{-8}\ \Omega.m$
Stainless-steel	:	$\rho = 71.4 \times 10^{-8}\ \Omega.m$
P.V.C.	:	$\rho = > 10^{13}\ \Omega.m$

The Resistivity, (ρ) of a conductor is described as follows : -

The current density **(J)** in a conductor depends on the electric field **(E)**, and on the nature of the conductor. The Resistivity (ρ) of a particular material is the ratio of electric field to current density : -

$$\boxed{\rho = \frac{E}{J}} \qquad [3]$$

The resistivity is the electric field per unit current density. The greater the resistivity, the greater the the field needed to establish a given current density. A perfect conductor would have zero resistivity and a perfect insulator an infinite resistivity. Metals and alloys have the lowest resistivities and are the best conductors. The resistivities of insulators exceed those of metals by a factor of the order 10^{22}.

Consider a conductor of uniform cross-sectional area, **A (m^2)** and length, **L (m)**, made of a material with resistivity, **P (Ωm)**. The resistance **R (Ω)** of such a conductor is given by : -

$$\boxed{R = \frac{\rho \times L}{A}} \qquad [4]$$

The anemometer pipe members had the following physical dimensions : -

Material	Length (L)	Diameter (D)	Cross-sectional area (A)
Stainless-steel (prototype 1)	**1 m**	**25 mm**	**0.025 m^2**
Aluminium-alloy (prototype 2)	**1 m**	**25 mm**	**0.025 m^2**
Aluminium-alloy (prototype 3)	**1.8 m**	**25 mm**	**0.045 m^2**
P.V.C. (final design)	**1 m**	**40 mm**	**0.04 m^2**

The calculated resistance (Ω) of the various anemometer pipe units are as follows : -

Stainless-steel	**(prototype 1)**	**:**	**$R = 2.9 \times 10^{-6}\ \Omega.m$**
Aluminium-alloy	**(prototype 2)**	**:**	**$R = 1.1 \times 10^{-6}\ \Omega.m$**
Aluminium-alloy	**(prototype 3)**	**:**	**$R = 2.1 \times 10^{-6}\ \Omega.m$**
P.V.C.	**(final design)**	**:**	**$R = 2.5 \times 10^{14}\ \Omega.m$**

Hence, of the anemometer pipe members constructed, the Stainless-steel anemometer (prototype 1) has the lowest resistance and is therefore the most susceptible to lightning strikes. The Aluminium-alloy anemometer pipe members (prototype 2 and 3) also have a low resistance and are susceptible to lightning strikes.

The P.V.C. pipe anemometer has a high resistance (characteristic of an insulator) and is therefore not as susceptible to lightning strikes as the Stainless-steel and Aluminium-alloy anemometer pipe members.

10.8 References

1. Micro-Measurements Division, North Carolina, U.S.A. — "CATALOG 500 : Part B : - Strain Gage Technical Data"

2. Sears, F.W., Zemansky, M.W., Young, H.D. — 1982 — "University Physics - 6TH EDITION" pp 69 - pp 70, pp 289 - pp 290

3. Doebelin, E.O. — 1982 — "Measurement Systems : - Application and Design" pp 224 - pp 225

4. Sears, F.W., Zemansky, M.W., Young, H.D. — 1982 — "University Physics - 6TH EDITION" pp 537 - pp 539

CHAPTER 11

TEST RESULTS

The objective of this thesis and dissertation was to design and develop an anemometer with no rotating parts suitable for data logging interfacing.

11.1 Results

The important characteristics of the designed anemometer are resolution, sensitivity and drift of anemometer output at zero wind velocity. Wind velocity levels indicated a maximum wind velocity resolution of better than 2 m/s. Experiments and calibration were conducted in the wind tunnel at Stellenbosch University.

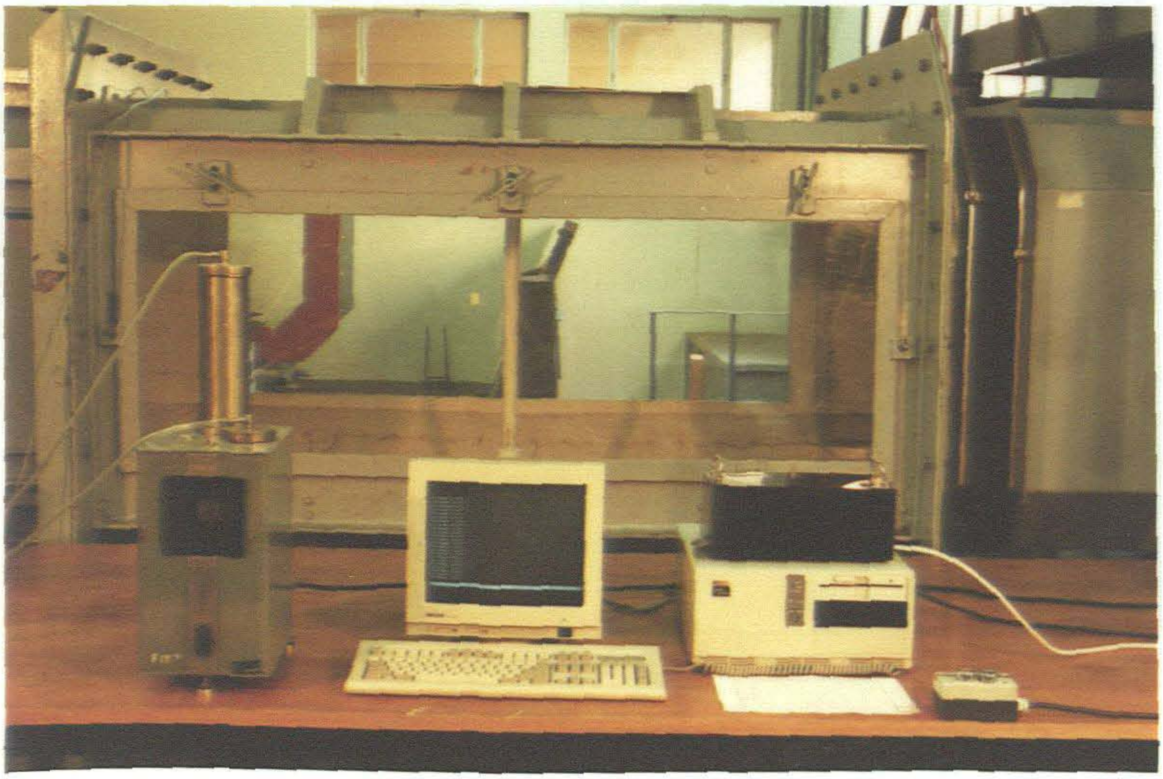
The response is linear. The scatter results from uncertainties in both the PVC pipe Anemometer readings and the reading of the calibration manometer for wind velocity since fluctuations in both were averaged by eye. Furthermore, when completely shut the hydraulically operated doors in the wind tunnel exhibited a gap of 3 cm, which represented a further uncertainty. The Anemometer was calibrated for zero wind velocity with the doors in this condition. It is certain that a small amount of air was dragged through the tunnel because of the gap in the doors. The Anemometer and calibration manometer were therefore adjusted for null wind velocity under this condition.

Theoretical and experimental results are in good general agreement. Observed wind tunnel velocity agreed well with analytical prediction, particularly after software calibration.

Initially wind velocity overspeeding was experienced. The software calibration factor was reduced from an amplification factor of 10.0 to 4.0 for corrected wind velocity display read-out. Wind velocity in the range 2 m/s to 35 m/s was then recorded.

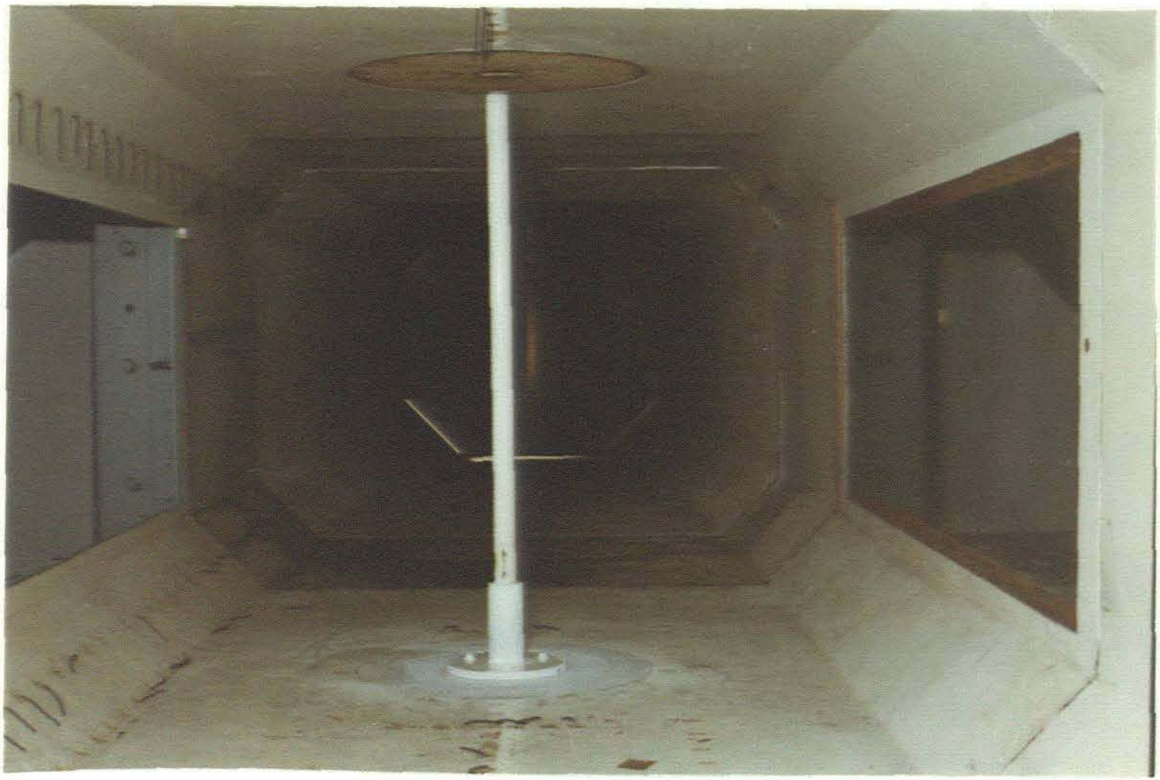
BEAU-FORT NO.	DESCRIPTION OF WIND	ACTUAL MANO-METER HEIGHT (AIR PRESSURE)	WATER MANO-METER ΔP	MEAN WIND VEL. RANGE	MEAN WIND FORCE	AVER WIND VEL.	LTN211 DISPLAY READ-OUT
B	WIND CONDITION	mm	mm_{water}	m/s	N/m²	m/s	m/s
0	CALM	****	****	< 0.3	****	0	****
1	LIGHT AIR	0.05	2.45	0.3 to 1.5	0.48	0.9	1
2	LIGHT BREEZE	0.39	2.73	1.6 to 3.3	3.83	2.5	2
3	GENTLE BREEZE	1.37	3.52	3.4 to 5.4	13.41	4.4	4
4	MODERATE BREEZE	3.27	5.06	5.5 to 7.9	32.10	6.7	6
5	FRESH BREEZE	6.41	7.61	8.0 to 10.7	62.72	9.4	9
6	STRONG BREEZE	11.26	11.54	10.8 to 13.8	110.12	12.3	11
7	MODERATE GALE	17.63	16.70	13.9 to 17.1	172.37	15.5	16
8	FRESH GALE	26.44	23.83	17.2 to 20.7	258.55	19.0	19
9	STRONG GALE	37.70	32.96	20.8 to 24.4	368.68	22.6	23
10	WHOLE GALE	51.40	44.06	24.5 to 28.4	502.74	26.5	27
11	STORM	68.54	57.94	28.5 to 32.6	670.32	30.6	32
12	HURRICANE	88.12	73.81	32.7 to 36.9	861.84	34.8	36
13	***********	112.60	93.64	37.0 to 41.4	1101.24	39.2	40

Figure 11.1 : Wind tunnel test results



The wind tunnel at the Univ. of Stellenbosch showing the following (from left to right) : -

- Water Manometer : test apparatus for the measurement of wind pressure in the tunnel
- I.B.M. compatible personal computer : logged data displayed on the P.C. screen
- Signal conditioner, Microcontroller and L.C.D. display housing (above P.C.)
- Hydraulic door controller
- The P.V.C. pipe anemometer mounted in the wind tunnel (background)



Wind tunnel with hydraulic doors shut (gap between the doors is clearly visible)

Wind tunnel with hydraulic doors open (fan is visible)

Figure 11.1 is a representation of the **BEAUFORT SCALE OF WIND FORCES** and the incorporated wind tunnel test results.

The last column includes the recorded display output in m/s, although in later experiments wind velocities in excess of 41 m/s were recorded. The third and fourth columns represent conversion tables for the water manometer calibration device. Water manometer level height is calculated as follows : -

Density of water : (ρ_{water}) = **1000 Kg/m^3** **[1]**

Gravitational acceleration : (G) = **9.8 m/s^2**

$$H_{water} = \frac{\text{mean wind force}}{\rho_{water} \times G} \quad *$$

* Courtesy of Stellenbosch University Dept. of Mechanical Engineering

The water level manometer height is a calculated value. In order to obtain manometer readings of actual air pressure in the wind tunnel a conversion table is provided at the tunnel. This is provided for the calculation of the change in manometer water level height as a function of air pressure in the tunnel. This level **(ΔP_{water})** is the actual visual calibration level setting on the manometer in mm (water). This is calculated as follows : -

Density of air : (ρ_{air}) = 1.2 Kg/m^3 [2]

$$\Delta P_{water} = \frac{H_{water} \times 2.98}{\rho_{water}} \quad *$$

* Courtesy of Stellenbosch University Dept. of Mechanical Engineering

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

This circuit concept and realisation has wide ranging applications in the sensor market, not only as a wind velocity and direction indicator, but as a general air-flow measurement device.

The device itself could be used as a calibration instrument in wind tunnel experiments. Many possible applications exist. In fulfilling the imposed design criteria there are a number of applications which can benefit from the system. This design used a strain Gauge/P.V.C. pipe combination as a wind detector, however, other sensor devices can be interfaced to the designed dual channel Strain Gauge Signal Conditioner/Microcontroller circuit module and with appropriate software changes various options are available. Typical applications include barometry, air and fluid flow measurement and motion sensing.

Furthermore the versatility of strain gauge and strain gauge derived transducer products for use in Electronic, Mechanical, Civil and Architectural fields from strain sensing to data capture is vast. The Strain Gauge Signal Conditioning and Microcontroller circuit designed is suitable for the following types of strain derived measurement : -

(i) **Torque measurement**

(ii) **Displacement measurement**

(iii) **Acceleration measurement**

(iv) **Pressure measurement**

The designed anemometer unit is simple, robust and has reasonably low power consumption. Although the unit has not been tested in the field, a serial port has been provided for recording purposes. The biggest advantage of the designed unit is the design simplicity of the P.V.C. anemometer unit and the versatility of the signal conditioner/microcontoller circuit as a **'stress/strain detector, signal conditioner, analyser and recorder module'.** The unit is also reasonably inexpensive and cost compares favourably with conventional cup-anemometers available on the market.

❖❖❖❖❖❖❖❖❖❖❖❖❖

BIBLIOGRAPHY

TRANSDUCERS :

SHEINGOLD, D.H.	1980	"Transducer Interfacing Handbook"
NATIONAL SEMICONDUCTOR COMPANY	1988	"The Pressure Transducer Handbook"
KYOWA ELECTRONIC INSTRUMENTS	1990	Strain Gages : - CATALOG NO 3001B CATALOG NO 3002A
MICRO-MEASUREMENTS DIVISION	1990	CATALOG 500 : - Part A : Strain Gage Listings Part B : Strain Gage Technical
SENSYM INCORPORATED	1991	Short-form CATALOG : - I.C. Pressure Transducer
THE OPEN UNIVERSITY	1975	"Instrumentation : - Unit 1: Introduction to Instrumentation Unit 2: The Measurement of Strain

ANEMOMETRY :

GOLDING, E.W.	1977	"The Generation of Electricity by Wind Power"
BERGEN, J.D.	1971	"Agric. Meteorol. 8 : p395-p405"
CAMPBELL, G.S. UNSWORTH, M.H.	1979	"Journal of Appl. Meteorol. 18 : p1072-p1077"

DICK, N.C.	1974	"Yacht Sailing Instrumentation"
THURTELL, G.W.	1970	"Journal of Appl. Meteorol. 9 : p379-p385"
CONNELLY, J.A. LUNDBERG, M.B.	1974	"E.D.N., April 1974"
POLLOCK, N.	1981	"Wireless World, February 1981"
U.K. PATENT APPLICAT.	1988	"GB 2 203 246 A"

PHYSICS,MECHANICS AND INSTRUMENTATION :

CROWE, J.A. ROBERSON, C.T.	1990	"Engineering Fluid Mechanics : - 4TH EDITION"
HOLMAN, J.P.	1971	"Experimental Methods for Engineers"
DOEBELIN, E.O.	1982	"Measurement Systems : - Application and Design"
HEARN, E.J.	1985	"Mechanics of Materials : - 2ND EDITION"
SEARS, F.W. ZEMANSKY, M.W. YOUNG, H.D.	1982	"University Physics : - 6TH EDITION"

HARDWARE :

HOROWITZ, P. HILL, W.	1987	"The Art of Electronics"
INTEL CORPORATION	1988	"8-Bit Embedded Controller Handbook"

INTEL CORPORATION 1988 "Memory Components Handbook"

NATIONAL SEMICONDUCTOR COMPANY 1988 "Linear Databook 1"

NATIONAL SEMICONDUCTOR COMPANY 1988 "Linear Databook 2"

NATIONAL SEMICONDUCTOR COMPANY 1988 "CMOS Logic Databook"

PHILIPS COMPONENTS 1989 "Product Specification : - LTN211 Liquid Crystal Display"

MAXIM INTEGRATED PRODUCTS 1989 "Product Specification : - RS-232 Line Drivers/Receivers"

BOURNS(Trimpot) LTD. 1985 "CATALOGUE : - Resistive and Inductive Components"

BECKMAN INDUSTRIAL 1992 "H. Kopp Group - CATALOGUE : - Trimmers/Potentiometers"

HARRIS SEMICONDUCTOR PRODUCT DIVISION 1992 "Short-form Guide : - HA2705 Operational Amplifier"

MOTOROLA SEMICONDUCTOR PRODUCTS INC. 1992 "Analysis and basic operation of the MC1495L Analogue Multiplier I.C."

ANALOG DEVICES INCORPORATED 1991 "Data Acquisition Components and Subsystems Databook : - Transducers and Conditioners"

SOFTWARE :

DE BEER, D.N.	1990	"Micro-Processor Systems : - MIC550"
ABEL, P.	1987	"I.B.M. P.C. Assembler Language and Programming"
KERNIGHAN, B.W. RITCHIE, D.M.	1988	"The C Programming Language : - 2ND EDITION"

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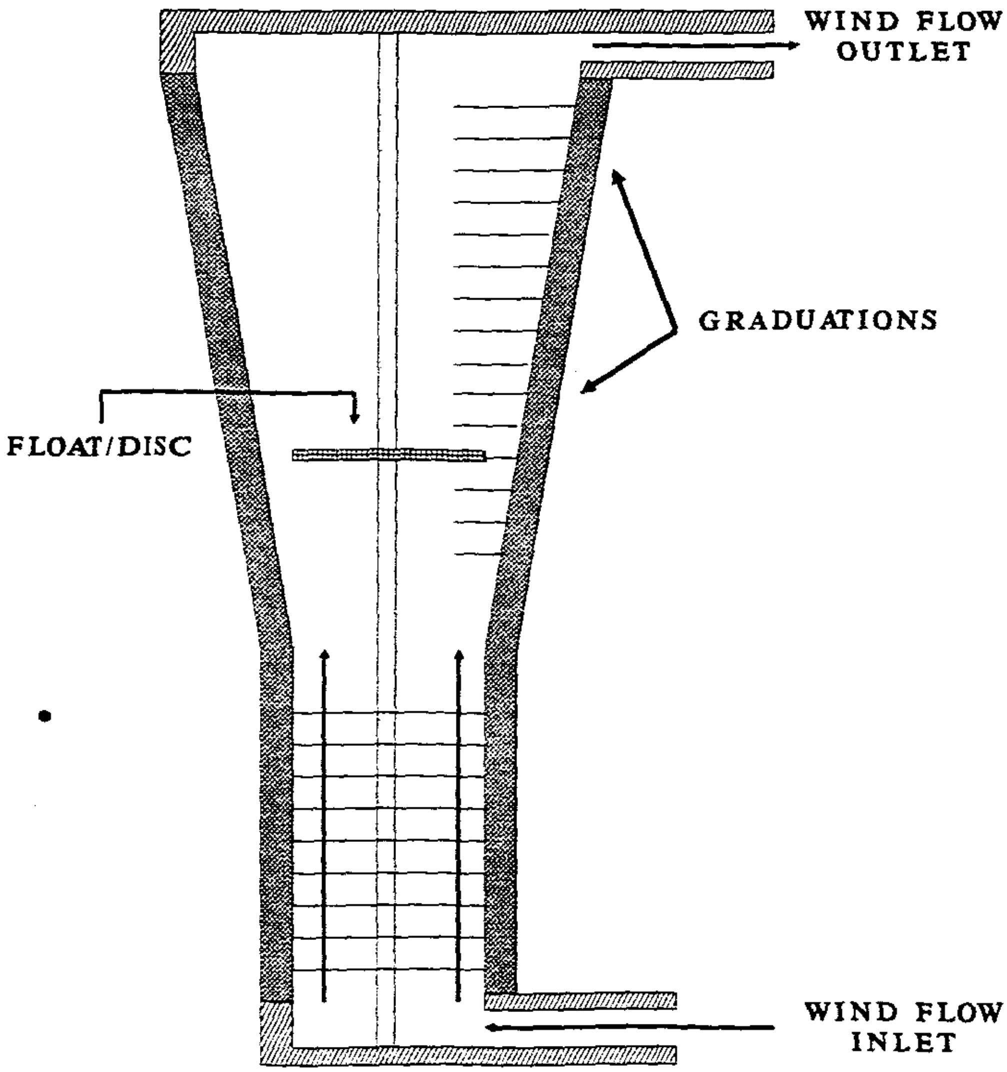
MR. C. EDGE
LAMBDA ELECTRONICS
Cape Town
R.S.A.

APPENDIX A

ANEMOMETER BLOCK DIAGRAMS

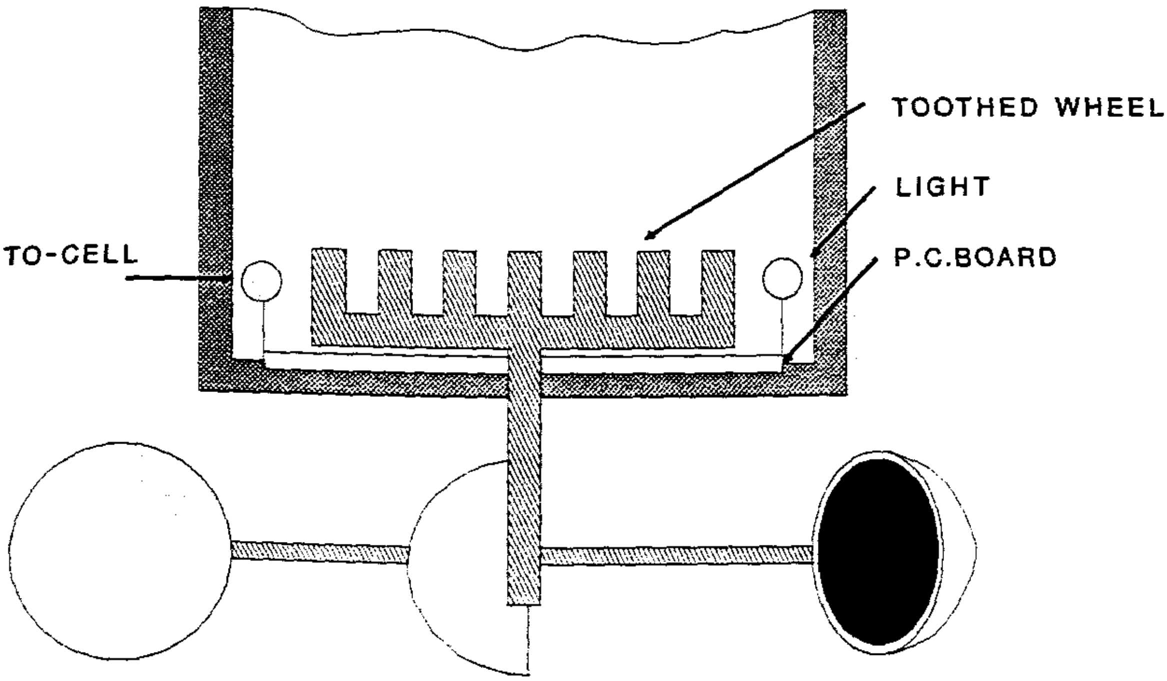
CONTENTS :

APPENDIX A : i



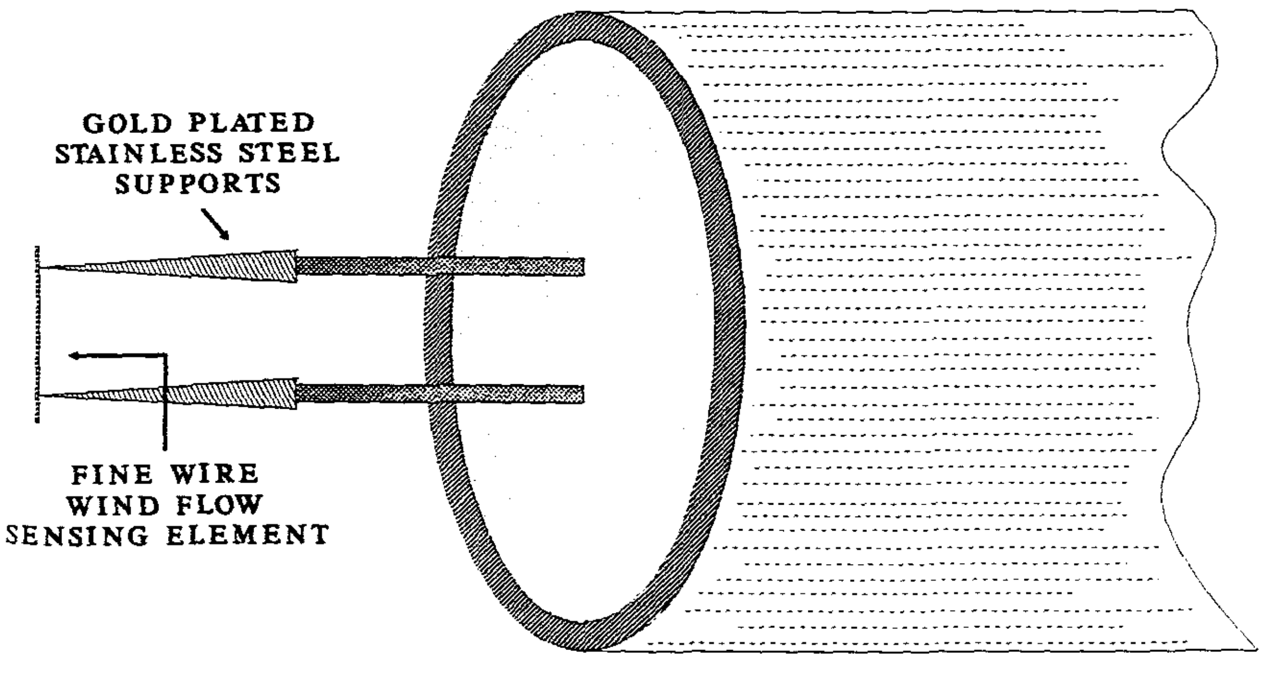
THE VENTIMETER

APPENDIX A : ii



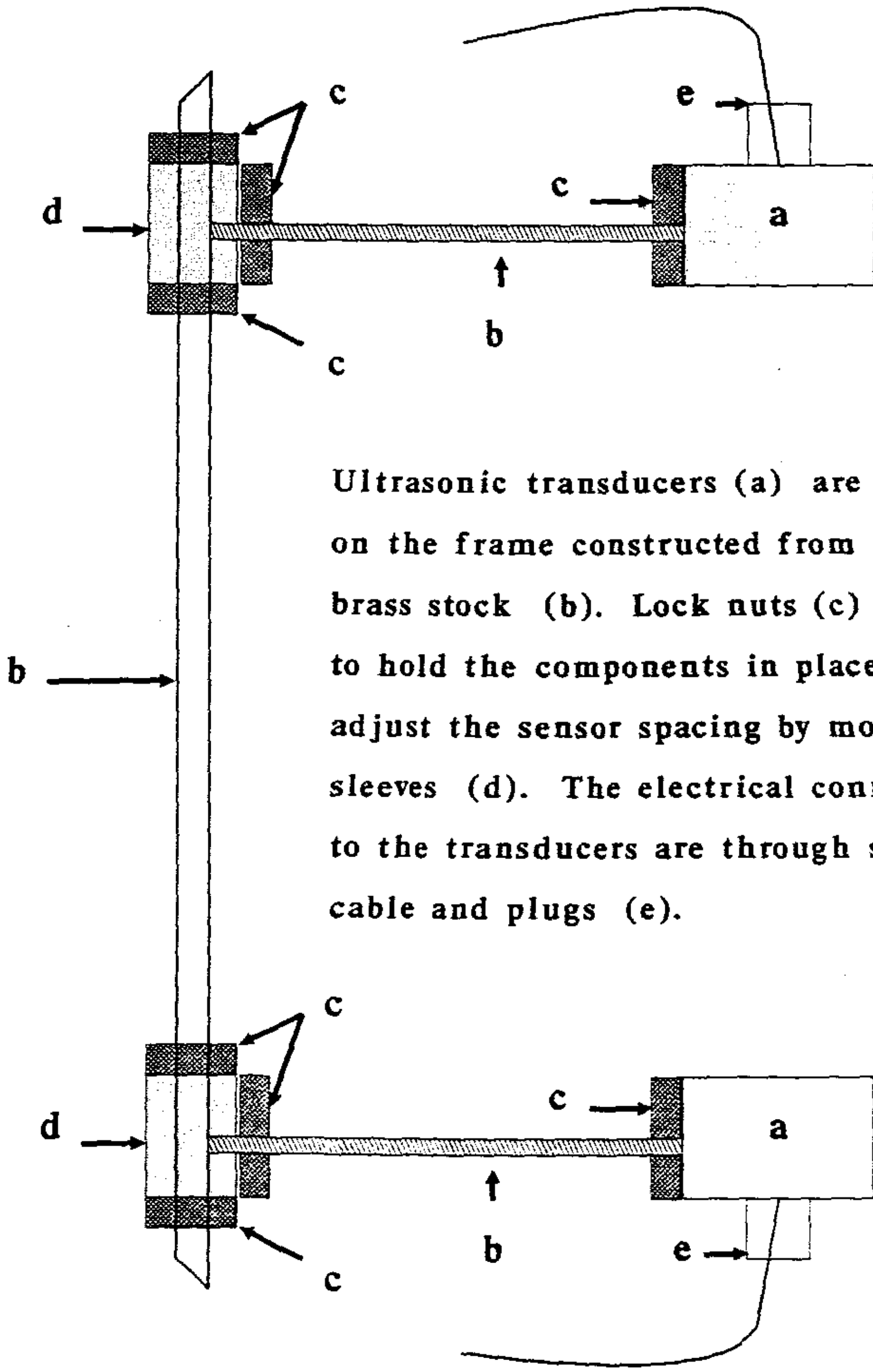
THE CUP ANEMOMETER

APPENDIX A : iii



THE HOT-WIRE ANEMOMETER

APPENDIX A : iv

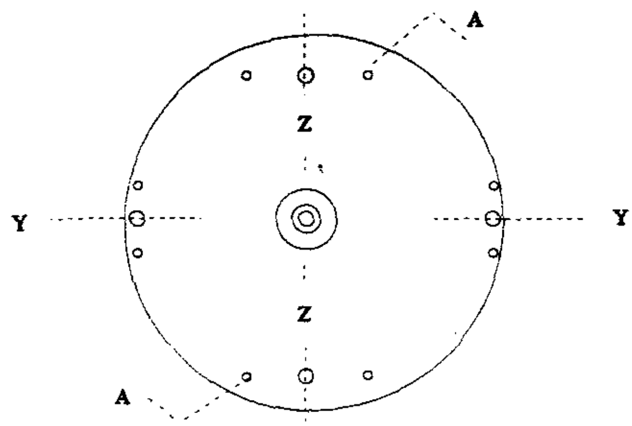


Ultrasonic transducers (a) are mounted on the frame constructed from threaded brass stock (b). Lock nuts (c) are used to hold the components in place and to adjust the sensor spacing by moving the sleeves (d). The electrical connections to the transducers are through shielded cable and plugs (e).

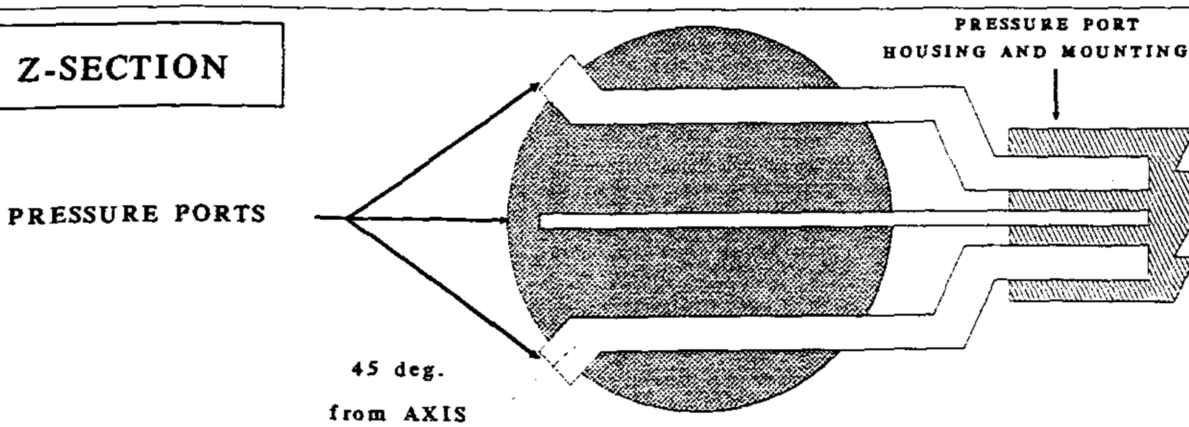
THE SONIC ANEMOMETER SENSING HEAD

APPENDIX A : V

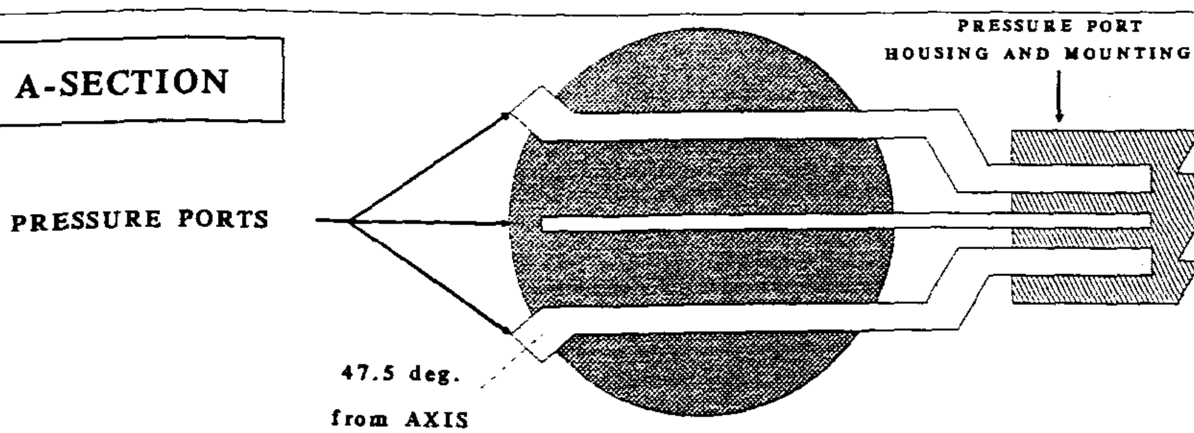
FRONT ELEVATION



Z-SECTION



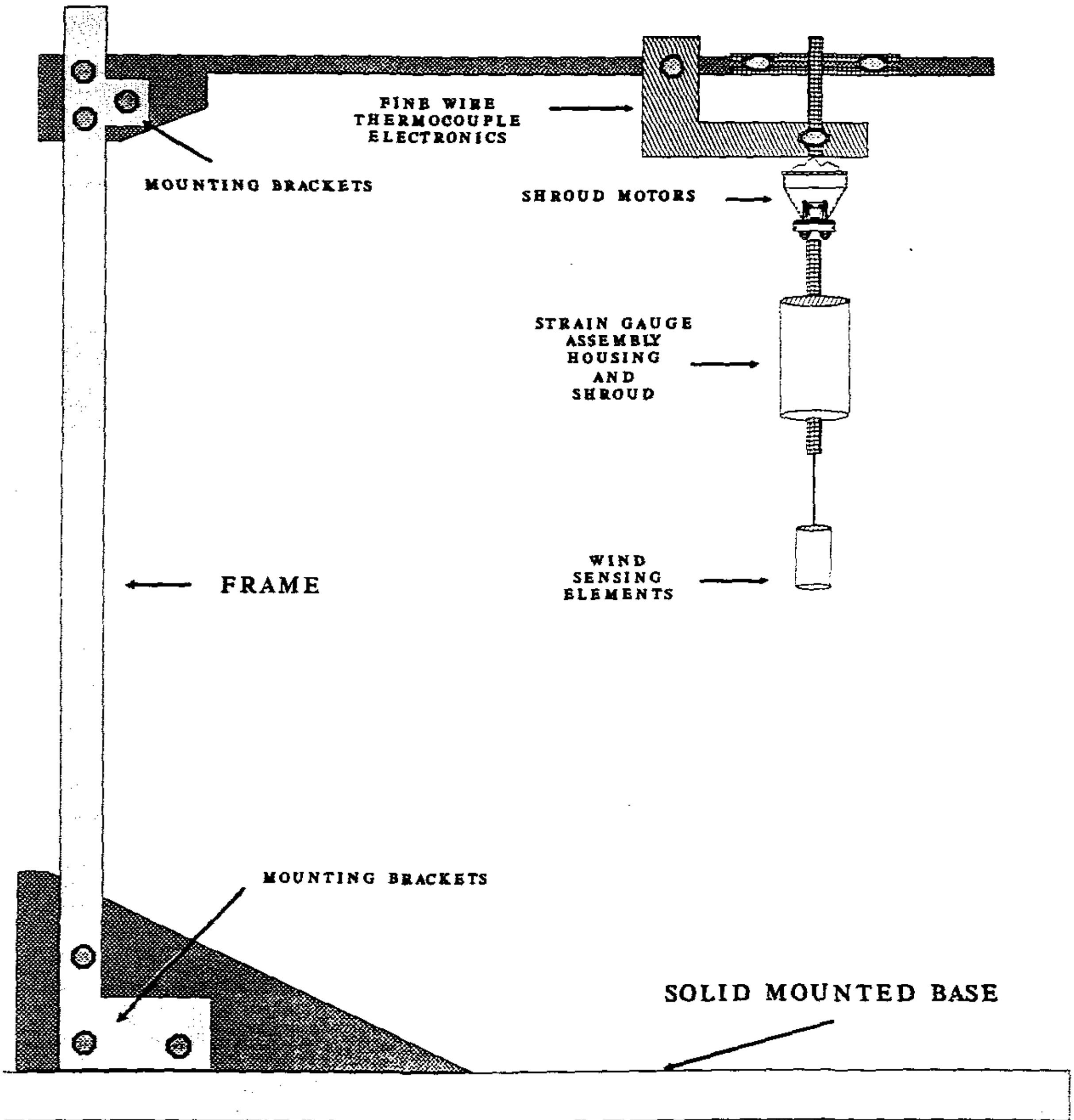
A-SECTION



Front and cross-section views of the Anemometer head, with Y and Z coordinates shown in front view.

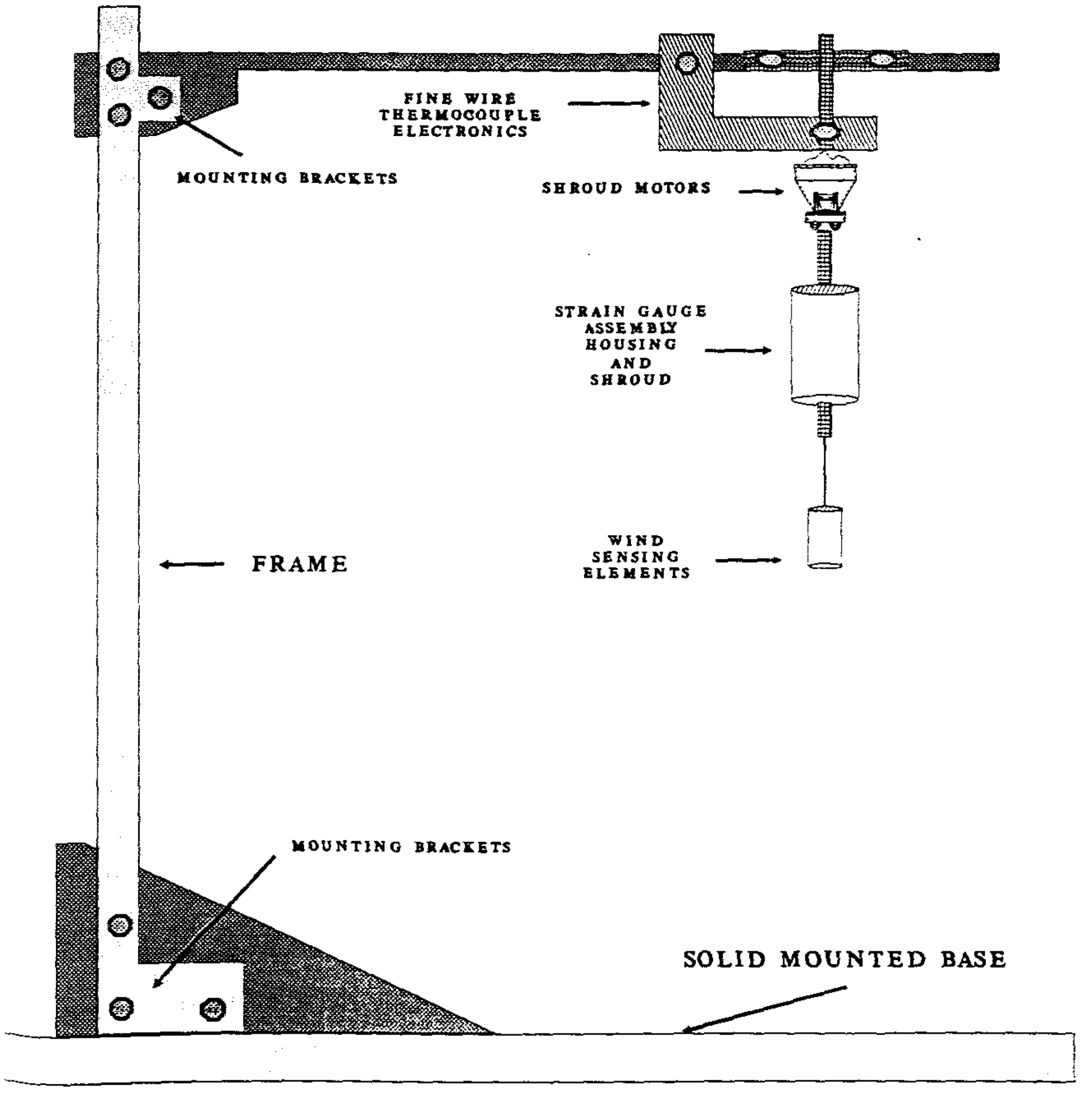
THE PRESSURE-SPHERE ANEMOMETER

APPENDIX A : vi



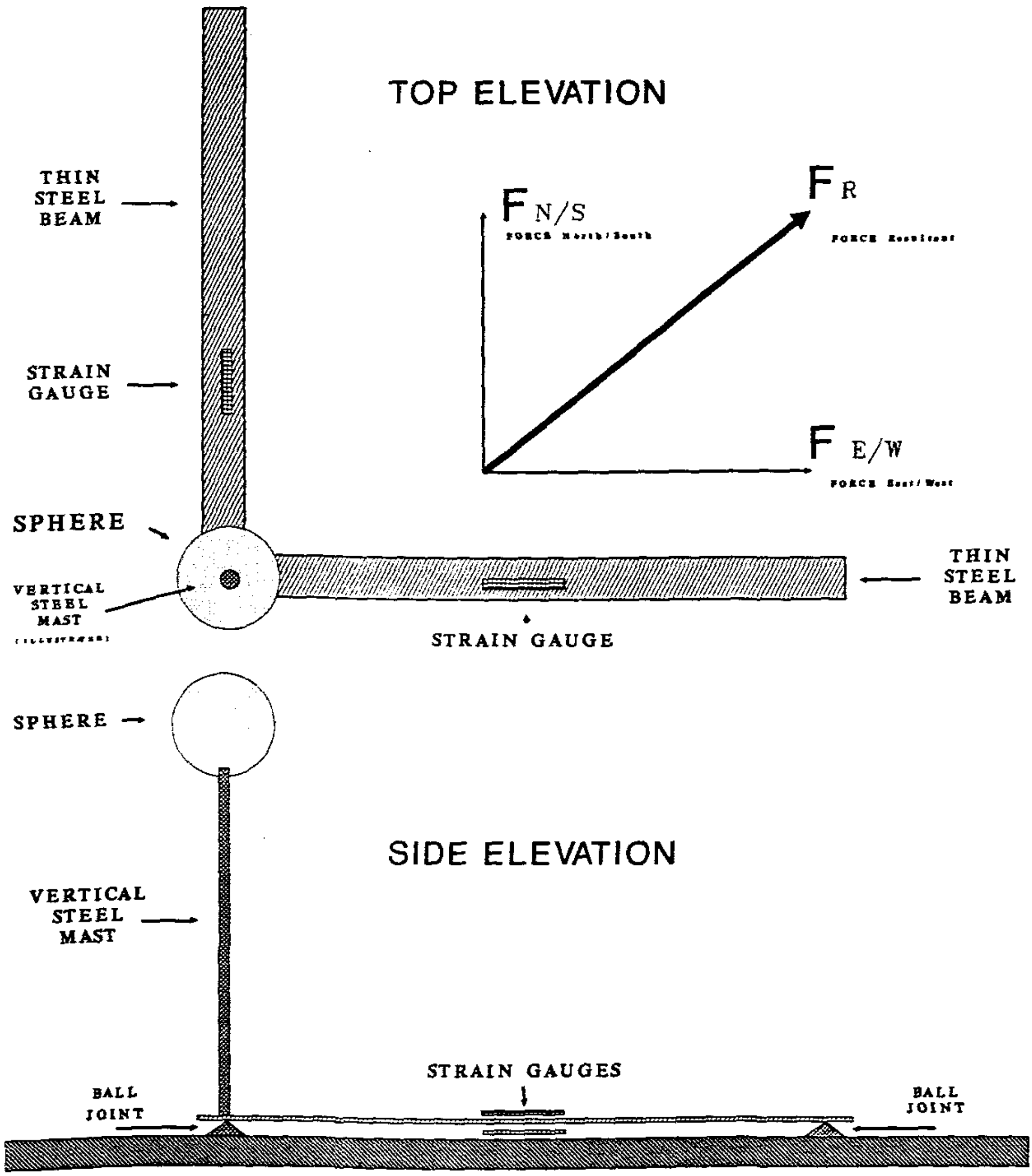
THE DRAG ANEMOMETER

APPENDIX A : vi



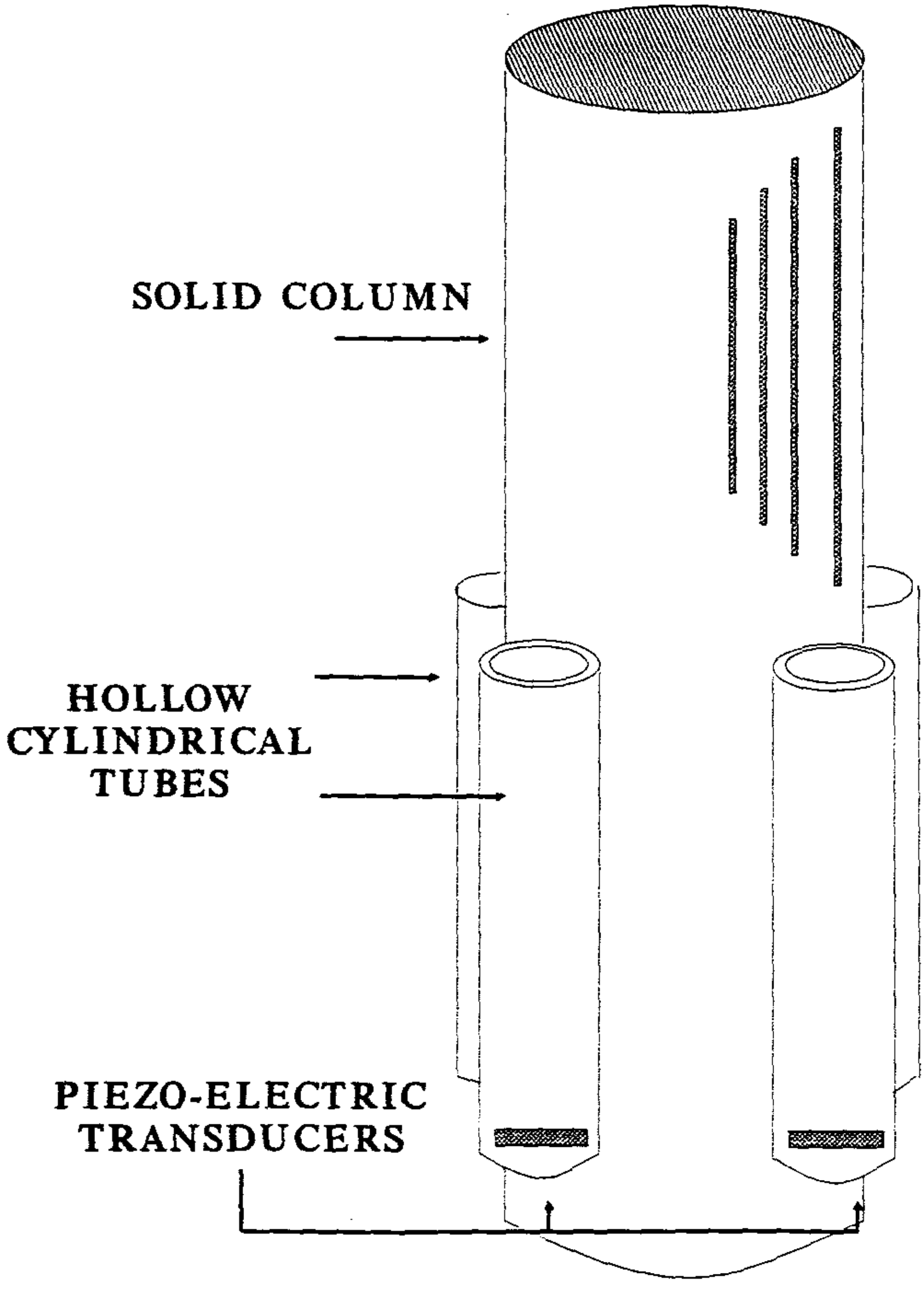
THE DRAG ANEMOMETER

APPENDIX A : vii



THE STRAIN GAUGE ANEMOMETER

APPENDIX A : viii



THE PIEZO-ELECTRIC ANEMOMETER

APPENDIX B

PROPERTIES OF MATERIALS

CONTENTS:

i) Aluminium-alloy

ii) Stainless-steel

iii) P.V.C.

* Table of mechanical properties of engineering materials			
Material	Tensile strength	Young's modulus	Co-eff. of thermal expansion
	MN/m^2	GN/m^2	$x\ 10^{-6}/^oC$
i) Aluminium-alloy	320-550	70-72	23
ii) Stainless-steel	295	196	17.3
iii) P.V.C.	30-70	1.0-3.5	0.5-1.0

*Extracted from : -

BENHAM, P.P. "Mechanics of engineering materials"
CRAWFORD, R.J. - Appendix C : pp610-pp611

* Heat transfer and resistance properties of engineering materials		
Material	**Resisitivity** ρ	**Thermal Conductivity** **k**
	$\Omega.m$	$J.s^{-1}.m^{-1}.(C^{o})^{-1}$
i) Aluminium-alloy	2.63×10^{-8}	210
ii) Stainless-steel	7.2×10^{-8}	16.2
iii) P.V.C.	$> 10^{13}$	0.14

*Courtesy of the CSIR

APPENDIX C

STRAIN GAUGE LISTINGS

CONTENTS:

APPENDIX C : i

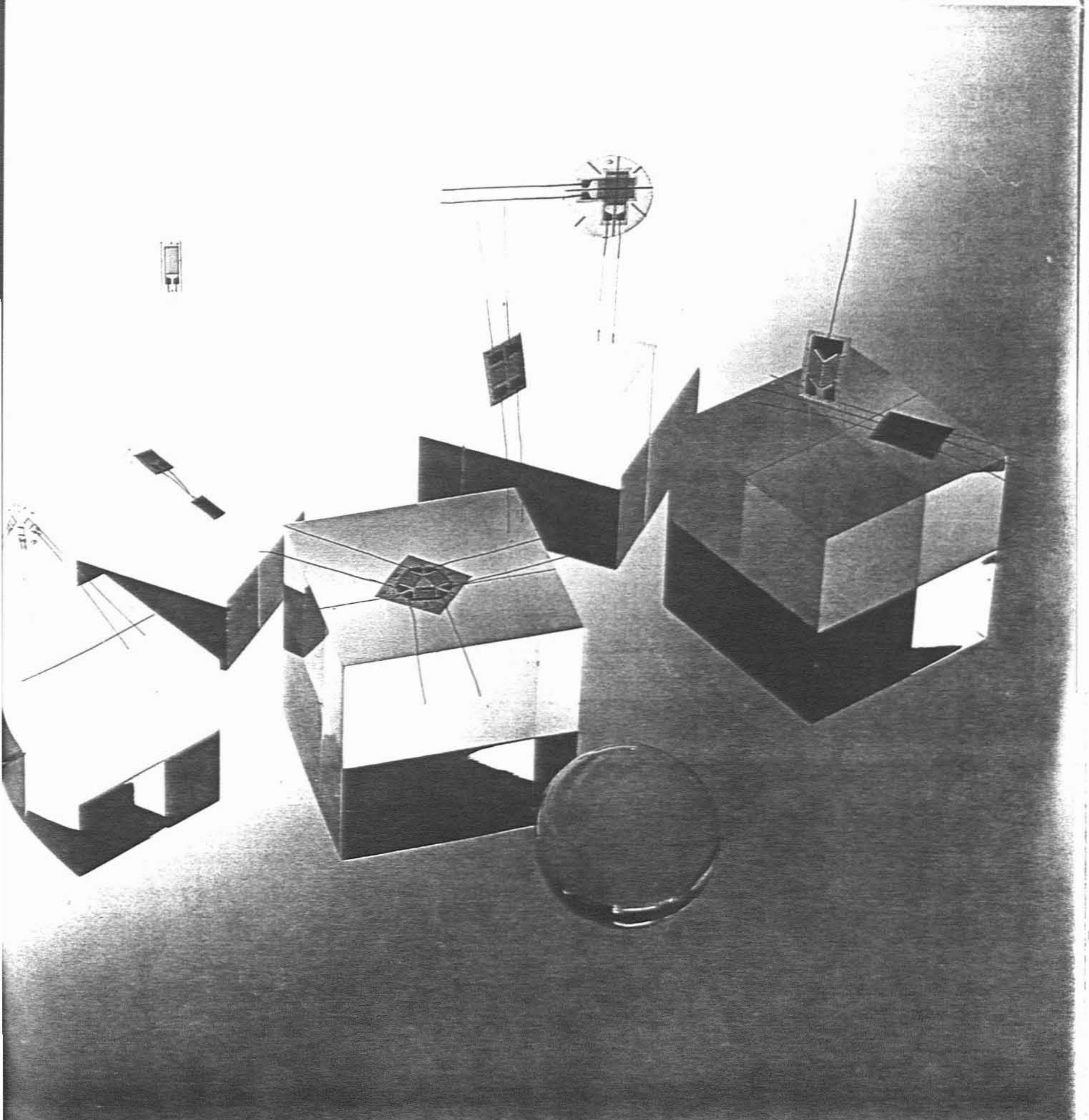
i) Kyowa Electronic Instruments : CAT. NO. 3001B

KYOWA
KYOWA ELECTRONIC INSTRUMENTS CO., LTD.

STRAIN GAGES

A complete line of
high performance strain gages
and accessories

CAT. NO. 3001B



ɔroduced Japan's first strain gages about 35 years ago. ɛn, Kyowa has continued manufacturing and develop- ɪr and newer gages so much so that today high per- ɜ Kyowa gages are actively serving in all the industrial

ɜges are capable of measuring all kinds of strain, rang- static strains to dynamic strains of some thousands well as impact strains. Their application is almost un- nd they are usable with all kinds of materials of all tions and structures, without handling problems. ɹipped with testing equipment in conformity with ɜtes National Aeronautical Standards (NAS 942) and man Standards (VDI/VDE 2635), Kyowa is always satisfy the most demanding customer's requirements.

■ Kyowa Strain Gage Coding System

KFR-5-350-C1-11 L30-3

- KFR: Resistive Material & Base Material Classification
- 5: Gage Length in millimeters
- 350: Gage Resistance in Ω (No indication for 120Ω)
- C1: Gage Pattern
- 11: Thermal Expansion Coefficient of SELCOM gage compatible material.
- L30: Lead Wire Provision. Figures indicate lead wire length in cm. No indication for gage lead (25mm) only.
- 3: With 3-lead-wire. No indication for gages with 2-lead-wire.

Purpose Gages

ɲly for strain measuring of metals at ɜmperatures and classified into two foil gages and wire gages. Foil gages are ɲ resistant foil (mainly copper-nickel everal microns in thickness bonded on esin film and etched in desired patterns gage configurations. They feature uni- ity, durability, large current capacity characteristics over long periods.

gages with lead wires are attracting ntion as they eliminate the need for ng. Kyowa's range of gages with lead tensive and here too Kyowa can more the fast increasing customer demand. which were popular in earlier stages ɪry of strain gages, are today used for ɔoses only.

ɹrpose Gages

ɲ to general-purpose gages, Kyowa ɲe following special-purpose gages to ssible applications.

elongation gages/high temperature gages/ resistive gages/low temperature gages/ gages/embeddment gages/bending gages/ tics

uctor Strain Gages

ɪy a semiconductor resistive element, far greater sensitivity than foil or They can also be connected directly pes for measurement.

ɪge package bears the gage's specifica- the case of the SELCOM gages, suit- ing materials for immediate identifi- roper application.

SELCOM Gage®

Most of Kyowa gages are of the SELCOM (Self-Temperature-Compensating) type, which is free from the effect of temperature variations. It is a gage in which the thermal expansion coefficient of the foil or wire is controlled. If the right type of gage is used for the right material, zero shift should be within $\pm 1.8 \times 10^{-6}/^{\circ}C$, which means that high accuracy measurement is assured. SELCOM gages can be supplied in six types depending on the application – wood, construction steel, stainless steel, aluminum alloy, and magnesium alloy.

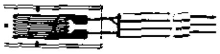
Compatible measuring object	Thermal expansion coefficient	Last figure/s in coding	Base color
Wood	$5.0 \times 10^{-6}/^{\circ}C$	5	–
Ordinary steel, concrete	$10.8 \times 10^{-6}/^{\circ}C$	11	Red
Stainless steel	$16.2 \times 10^{-6}/^{\circ}C$	16	Orange
Aluminum alloy	$23.4 \times 10^{-6}/^{\circ}C$	23	Green
Magnesium alloy	$27.0 \times 10^{-6}/^{\circ}C$	27	Yellow
Plastics	$65.0 \times 10^{-6}/^{\circ}C$	65	–

inds and Important Characteristics of Kyowa Strain Gages

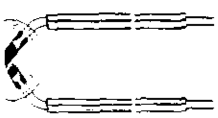
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
General-Purpose	Foil Phester Gage KFC	Cu-Ni Foil	Phester	−196~+150	+10~+100	2.8%	4.5 x 10⁶	PC-6, CC-33A, PC-12,	General/residual stress, transducer
	Foil Strain Gage KFR	Special Alloy Foil	Polyimide	−196~+180	0~+150	2.2%	1.0 x 10⁶	PC-6, CC-33A, PC-12, EP-18	General stress, transducer
	Foil Polyimide Gage KFD	Cu-Ni Foil	Polyimide	−196~+200	+10~+100	2.8%	4.0 x 10⁶	PC-6, CC-33A, PC-12, EP-18	General/residual stress, transducer
	Paper Gage K	Cu-Ni Wire	Paper	−100~+80	+10~+80	1.5%	1.6 x 10⁵	CC-33A, BC-11	General stress, plaster model test
High Temperature	Foil Strain Gage KFH	Special Alloy Foil	Polyimide	−196~+250	+10~+250	2.1%	2.0 x 10⁵	PC-6, PC-12	General stress under high temp.
	High Temp. Foil Gage KFA	Special Alloy Foil	Asbestos	−50~+350	+10~+300	1.0%	2.0 x 10⁵	PI-32	General stress under high temp.
	High Temp. Gage KH-G3	Ni-Cr Wire	Ni-Cr	−50~+500	0~+500	0.3%	*1 1 x 10⁴	Spot Welding HC-25A	General stress under high temp.
	High Temp. Gage KH-G4	Special Alloy Foil	Stainless steel	−50~+350	+10~+300	0.5%	*2 1 x 10⁷	Spot welding	General stress under high temp.
Low temp.	Foil Strain Gage KFL	Special Alloy Foil	Polyimide	−269~+180	−200~+50	2.2%	1.0 x 10⁶	PC-6, CC-33A, UC-26	General stress under low temp.
High Elongation	High Elong-Foil Gage KFE	Cu-Ni Foil	Polyimide	−10~+80	*	10%	1.0 x 10⁶	EP-18	High elongation mainly in metals
	Ultra High Elong. Foil Gage KLM	Cu-Ni Wire	Special Plastics	−10~+80	*	20%	1 x 10⁴	EC-30, CC-33A	High elongation mainly in plastics
	High Elong. Gage KL	Cu-Ni Wire	Paper	−10~+60	*	6%	1.6 x 10⁵	EC-10	High elongation mainly in wood
For plastics	Foil Gage for Plastics KFP	Cu-Ni Foil	Phester	−20~+80	+10~+60	3%	1 x 10⁶	CC-33A	General stress in plastics or alike
Water proofed	Water-proofed Gage KFW	Cu-Ni Foil	Phester	−10~+90	+10~+90	2.6%	3 x 10⁴	CC-33A, PC-12, EP-18	Outdoor, underwater
For Concrete	Foil Phester Gage KFC	Cu-Ni Foil	Phester	−196~+150	+10~+100	2.8%	4.5 x 10⁶	PC-6, CC-33A PC-12, EP-18	General stress
	Phester Gage KC	Cu-Ni Wire	Phester	−196~+150	+10~+80	1.8%	1.5 x 10⁵	PC-6, CC-33A PC-12, EP-18	General stress
	Embeddment Gage KM	Cu-Ni Wire	Acryl	−10~+70	0~+50	0.3%	—	Embeddment	Internal stress in mortar or alike
Non-magneto-resistive	Non-inductive Gage KFN	Special Alloy Foil	Polyimide	−196~+180	0~+150	1%	1 x 10⁴	PC-6, CC-33A	In AC magnetic field
	Non-magneto-resistive Gage KBN	Special Alloy Wire	Phenol	−196~+180	*	2%	1.5 x 10⁵	PC-6, CC-33A, PC-12, EP-18, PC-13	In DC magnetic field
	Shielded Gage KFS	Cu-Ni Foil	Phenol	−196~+150	+10~+100	0.5%	1 x 10⁴	PC-6, PC-12 CC-33A	Under high potential
[illegible]	Bending Strain Gage KFF	Cu-Ni Foil	Plastics	−50~+80	+20~+60	0.2%	*2 4 x 10⁶	CC-33A, PC-12, EP-18	Bending stress in high pressure vessels
Semiconductor Gages	General Purpose Gage KSP	P-type Si	Phenol	−50~+170	*	0.3%	*3 2 x 10⁶	PC-12, CC-33A	General stress, transducer
	Dual-element self-temp. compensating KSP-F2	P-type N-type Si	Phenol	−50~+170	+20~+70	0.3%	*3 2 x 10⁶	PC-12, CC-33A	Zero-drift temperature compensated/ general strain
	Self-temperature comp. KSN	N-type Si	Phenol	−50~+170	+20~+70	0.3%	*3 2 x 10⁶	PC-12, EP-17 (E5 only), CC-33A	Zero-drift temperature compensated/transducer
	High Output KSPH	P-type Si	Phenol	−50~+170	*	0.3%	*3 2 x 10⁶	PC-12, CC-33A	High output transducer
	Ultra High Linearity KSPL	P-type Si	Phenol	−50~+170	*	0.3%	*3 2 x 10⁶	PC-12, CC-33A	Transducer with fine output linearity
	Remarks				*Self-temperature compensating type (SELCOM GAGE) not available.	In accordance with NAS	Strain level in accordance with NAS: ±1500x10⁻⁶ *1 half amplitude 500x10⁻⁶ *2 alternating ±500x10⁻⁶ *3 alternating ±1000x10⁻⁶	Colored letters and figures indicate adhesives used for characteristics testing.	

Specifications are subject to change without notice for improvement.

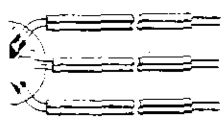
l-Purpose Gage



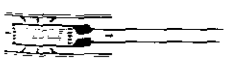
C1 (with 3 lead wires)



16 (with 2 lead wires)



17 (with 2 lead wires)



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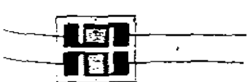
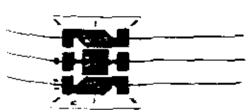
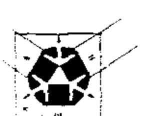


D1

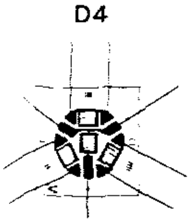
D2



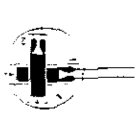
D3



D4



D6



D16

KFC Phester Foil Strain Gage

This gage has a metal foil sensitive element backed by phester, phenol resin degenerated with epoxy, and is compatible with most adhesives of the thermo-curing and room-temperature-curing types, and features ease of bonding, superior creep characteristics, and is versatile in applications.

(with 2 lead wires)

Type	Resistance value (Ω)	Gage factor (App.)	Dimensions (mm) Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFC-5-C1-11 L30 KFC-5-C1-11 L100 KFC-5-C1-11 L300 KFC-5-C1-11 L500	120	2.1	5	2	10x3.4	10	The last figure/s in a gage designation indicates the length (in cm) of 2-conductor parallel vinyl clad copper leads with the exception that gages of which gage length is less than 1mm are with polyester clad copper leads. Also available upon request are: Gages with 16 in the end of its designation (for stainless steel); 23 (for aluminum alloy); and 27 (for magnesium alloy). PC-6 −196 ~ +150°C PC-12 −10 ~ +80°C CC-33A −10 ~ +80°C EP-18 −10 ~ +80°C
KFC-2-C1-11 L30 KFC-2-C1-11 L100 KFC-2-C1-11 L300 KFC-2-C1-11 L500		2.1	2	2.3	7.2x3.7		
KFC-1-C1-11 L15 KFC-1-C1-11 L30		2.1	1	1.4	4.2x2.8		
KFC-03-C1-11 L15 KFC-03-C1-11 L30		2.1	0.3	1.4	3.5x2.7		
KFC-5-D16-11 L30 KFC-5-D16-11 L100 KFC-5-D16-11 L300 KFC-5-D16-11 L500		2.1	5	1.9	ϕ11	5	
KFC-2-D16-11 L30 KFC-2-D16-11 L100 KFC-2-D16-11 L300 KFC-2-D16-11 L500		2.1	2	1.4	ϕ8		
KFC-1-D16-11 L15 KFC-1-D16-11 L30		2.1	1	1.4	ϕ4		
KFC-5-D17-11 L30 KFC-5-D17-11 L100 KFC-5-D17-11 L300 KFC-5-D17-11 L500		2.1	5	1.9	ϕ11		
KFC-2-D17-11 L30 KFC-2-D17-11 L100 KFC-2-D17-11 L300 KFC-2-D17-11 L500		2.1	2	1.4	ϕ8		
KFC-1-D17-11 L15 KFC-1-D17-11 L30		2.1	1	1.4	ϕ5		

(with 3 lead wires)

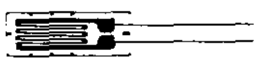
Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFC-5-C1-11 L500-3	120	2.1	5	2.0	10x3.4	10	With 5m 3-lead-wire
KFC-2-C1-11 L500-3		2.1	2	2.3	7.2×3.7		

Gages for use with stainless steel (16 in the designation end), and aluminum alloy (23) and magnesium alloy (27) are available upon request.

(Standard type)

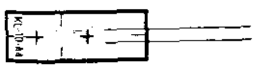
Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFC-30-C1-(11, 16, 23, 27)	120	2.1	30	3.3	37x5.2	10	PC-6 −196 ~ +150°C PC-12 −196 ~ +150°C CC-33A −196 ~ +120°C EP-18 −50 ~ +100°C Gage pattern D9 and D19 gages are with 100mm long polyester clad copper leads. Other gages are with 25mm long silver clad copper leads.
KFC-20-C1-(11, 16, 23, 27)		2.1	20	5	28x8		
KFC-10-C1-(11, 16, 23, 27)		2.1	10	3	16x5.2		
KFC-6-C1-(11, 16, 23, 27)		2.1	6	1.7	10x3.4		
KFC-5-C1-(11, 16, 23, 27)		2.1	5	2.2	10x3.4		
KFC-3-C1-(11, 16, 23, 27)		2.1	3	2.2	8x4.2		
KFC-2-C1-(11, 16, 23, 27)		2.1	2	2.3	7.2x3.7		
KFC-1-C1-(11, 16, 23, 27)		2.1	1	1.4	4.8×2.4		
KFC-03-C1-(11, 16, 23, 27)		2.1	0.3	1.4	3.5x2.4		
KFC-2-D1-(11, 16, 23, 27)		2.1	2	3.2	10x8.5	5	
KFC-2-D2-(11, 16, 23, 27)		2.1	2	3.4	12x7		
KFC-2-D3-(11, 16, 23, 27)		2.1	2	3.6	11x11		
KFC-2-D4-(11, 16, 23, 27)		2.1	2	3.4	12x12		
KFC-1-D4-(11, 16, 23, 27)		2.1	1	1.7	7x7		
KFC-2-D6-(11, 16, 23, 27)		2.1	2	3.4	17x17		

igh Elongation Strain Gage



C1

A9



A4

KFE High Elongation Foil Strain Gage

When used with CC-15A adhesive, this gage exhibits epoch-making foil gage performance in that it measures high elongation strains as great as 8 to 10%. Superior in creep characteristics and gage factor uniformity to conventional high-elonga tion gages. Can be used in the elastic region in th same manner as general-purpose gages.

Type	Resistance value (Ω)	Gage factor (App.)	Dimensions (mm) Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFE-5-C1	120	2.1	5	2.0	11x3.4	10	EP-18 up to app. 10% strain
KFE-2-C1		2.1	2	2.2	8x4.2		EP-18 up to app. 8% strain

KLM Ultra High Elongation Strain Gage

With a special plastic film as its base, this gage is so constructed as to prevent stress concentration from occurring at the juncture of the resistive element and gage lead. It can be used on a smalle range of elastic material such as hard rubber o plastics.

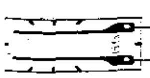
Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KLM-6-A9	120	1.9	6.5	3.8	17.5x7.5	10	EC-30 up to app. 20% strain

KL High Elongation Strain Gage

With carefully selected Japanese paper as its base, this gage permits ease of bonding to wood and other porous materials.

Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KL-10-A4	120	1.8	10	2.8	28x10	10	EC-10 up to app. 6% strain
KL-6-A4		1.8	6	4.8	20x10		EC-10 up to app. 6% strain

ain Gage for Plastics



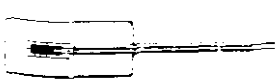
C1

KFP Foil Strain Gage for Plastics

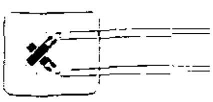
This SELCOM gage is suitable for comparatively high elongation strains in plastics and other materials. Ease of bonding and superior temperature characteristics permit highly stable and accurate measurement.

Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFP-2-C1-65	120	2.1	2	2	10x4.7	10	CC-33A −20~+80°C Use surface treating agent, S-8 together for cementing Teflon, polyethylene, etc.
KFP-5-C1-65		2.1	5	2.5	13x5.2		
KFP-2-350-C1-65	350	2.1	2	2.4	10x5.2		
KFP-5-350-C1-65		2.1	5	2.6	13x5.2		

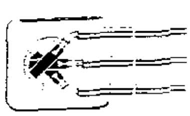
aterproofed Strain Gage



C1



D16



D17

KFW Waterproofed Strain Gage

Waterproof construction with a coating of special resin on this KFC-type gage permits outdoor and even underwater application. Due to the high flexibility of the resin used, ease of bonding even to curved surfaces is insured.

(with 2 lead wires)

Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFW-5-C1-(11,16,23)L100 KFW-5-C1-(11,16,23)L500	120	2.1	5	2	30x12	10	CC-33A −10~+90°C PC-12 −10~+90°C EP-18 −10~+90°C The last figure in a type designation indicates the length (cm) of 2 parallel vinyl lead wires. No insulation resistance decrease with over 100 hours' water submersion (100 kg/cm²).
KFW-2-C1-(11,16,23)L100 KFW-2-C1-(11,16,23)L500		2.1	2	2.3	30x12		
KFW-5-D16-(11,16,23)L100 KFW-5-D16-(11,16,23)L500		2.1	5	1.9	21x18	5	
KFW-2-D16-(11,16,23)L100 KFW-2-D16-(11,16,23)L500		2.1	2	1.4	21x18		
KFW-5-D17-(11,16,23)L100 KFW-5-D17-(11,16,23)L500		2.1	5	1.9	21x18		
KFW-2-D17-(11,16,23)L100 KFW-2-D17-(11,16,23)L500		2.1	2	1.4	21x18		

(with 3 lead wires)

Type	Resistance value (Ω)	Gage factor (App.)	Gage length	Grid width	Base LxW	Gages per pack	Applicable adhesive Remarks
KFW-5-C1-(11,16,23)L500-3	120	2.1	5	2	30x12	10	with 3 parallel vinyl lead wires, 5m long
KFW-2-C1-(11,16,23)L500-3		2.1	2	2.3	30x12		

APPENDIX C : ii

ii) Kyowa Electronic Instruments : CAT. NO. 3002A

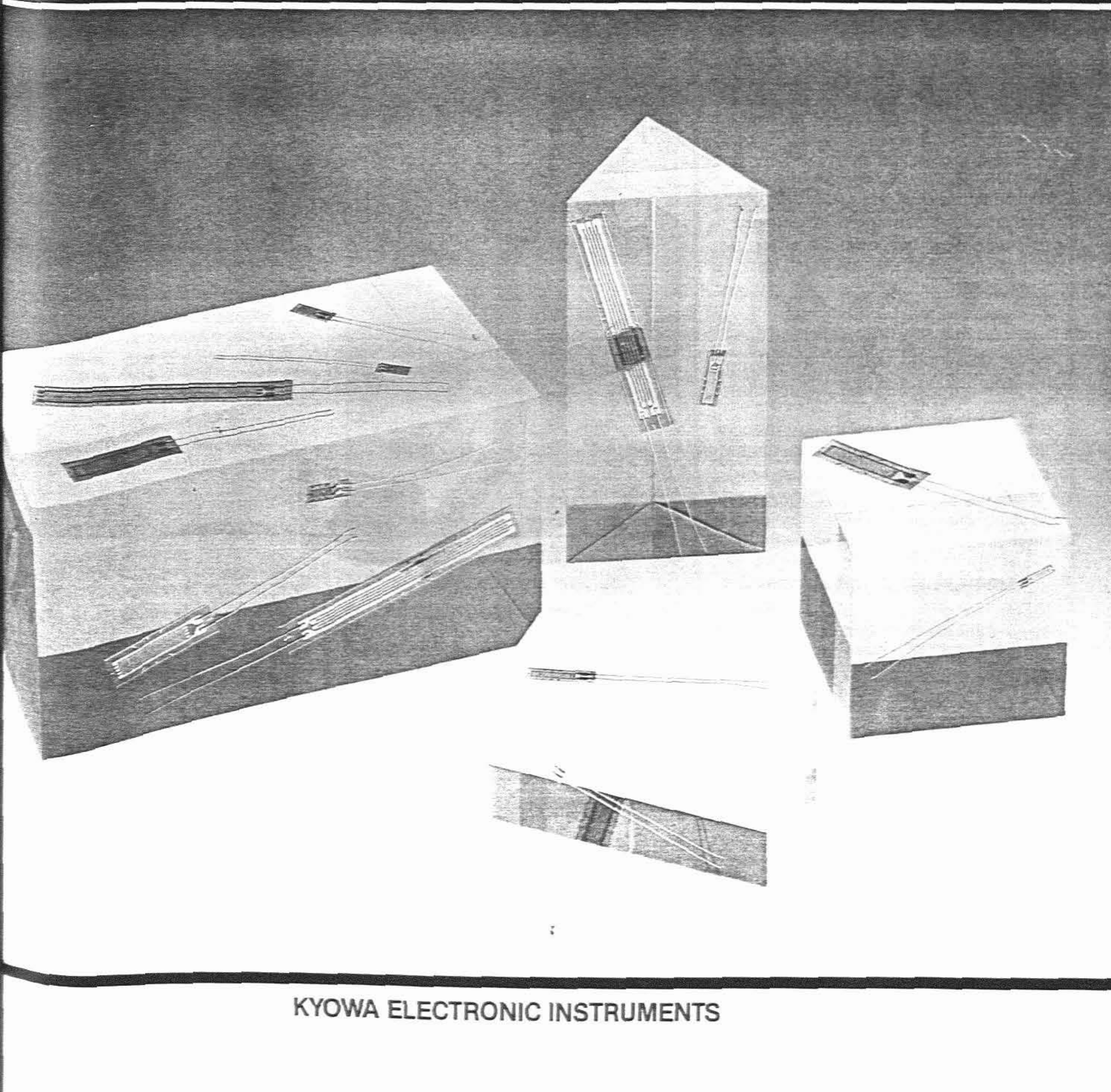
KYOWA

CAT. NO. 3002A

KFG SERIES

COMPLETE LINE OF NEW FOIL STRAIN GAGES

nabling easier, more accurate strain sensing and analysis

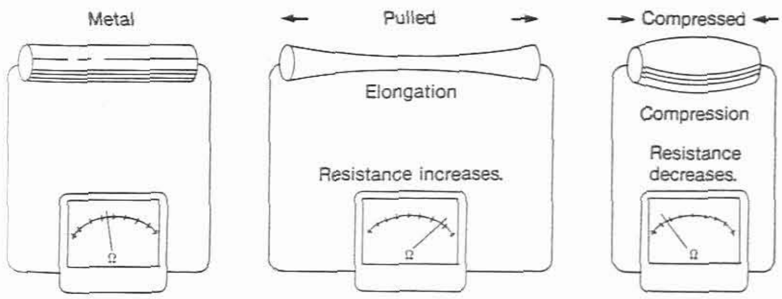


KYOWA ELECTRONIC INSTRUMENTS

Principle of strain gages

When pulled or compressed, a metal changes its electrical resistance.

When pulled, a metal's electrical resistance increases and when compressed, it decreases.

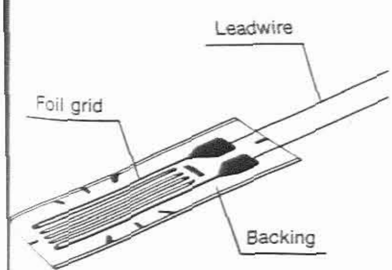


This change is proportionate to the magnitude of occurring elongation or compression.

hat is, a strain, tensile or com- essive, of a metal can be detected measurement of a change of elec- cal resistance. This is the principle a strain gage.

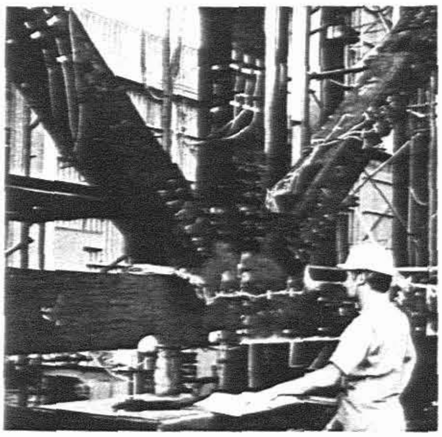
The structure of a strain gage

strain gage is so constructed that a etal resistor element, i.e. a metal foil id, is formed on a carrier matrix acking) made of an insulation aterial such as plasctis. This metal sistor element changes its electrical sistance in proportion to the agnitude of an external load applied.



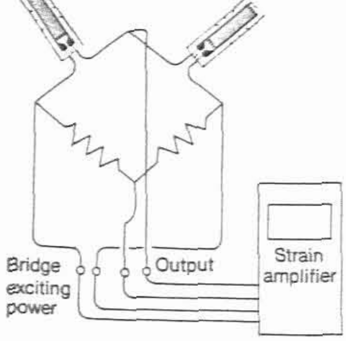
A strain gage is bonded to the surface of a measruing objective.

strain gage is bonded to the surface a measuring objective using an ex- usive adhesive. A strain gage is then ongated or compressed in one body th a measuring objective.



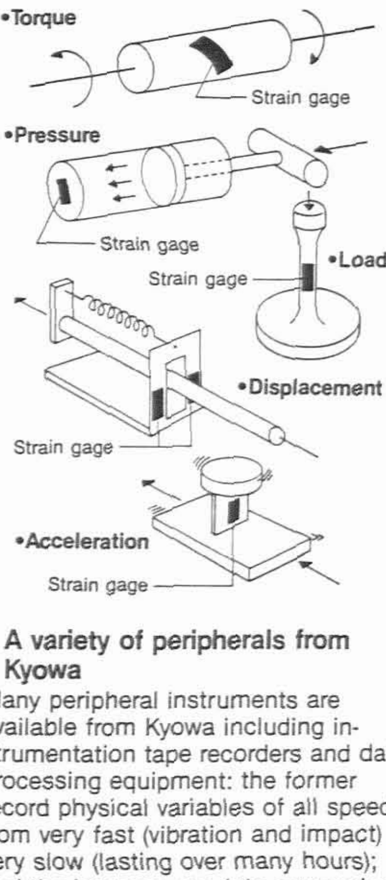
■ Strain amplifier is a "must".

A change of electrical resistance thus detected is very small. Generally, this detection is made in the form of a voltage signal from a strain-gage bridge circuit. Hence, there is the need for a strain amplifier which excites a bridge circuit and sufficiently amplifes a generated voltage signal.



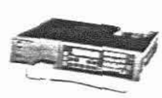
■ A strain gage also serves as a sensor device.

Strain gages are actively serving in all industrial and research fields as not only efficient measures of stress measurement but also sensor devices with which all physical variables are converted into electric signals.

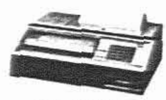


■ A variety of peripherals from Kyowa

Many peripheral instruments are available from Kyowa including instrumentation tape recorders and data processing equipment: the former record physical variables of all speeds from very fast (vibration and impact) to very slow (lasting over many hours); and the latter serves data processing and analysis on measuring sites.



Data Logger (UCAM-10A)



Data Analyzer (DAA-100A)

Multiconditioner Cluster System (MCC Series)

Instrumentation Tape Recorder (RTP-670A)

Strain gage coding system

AGE PATTERN
ESISTANCE IN OHMS
CTIVE GAGE LENGTH
ERIES DESIGNATION

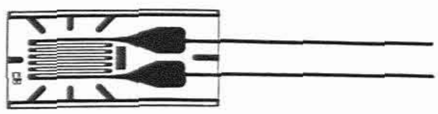
SELF-TEMPERATURE-COMPENSATION (S-T-C)
EXTENSION LEADWIRE
LEADWIRE LENGTH
NUMBER OF LEADWIRE CONDUCTORS
COLOR OF LEADWIRE

KFG-10-120-C1-11 L 1M 2 R

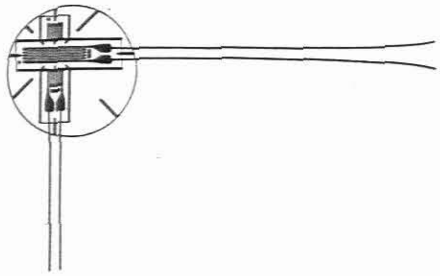
30: 30 mm	2N: 2 mm (*)
10: 10 mm	1 : 1 mm
5: 5 mm	1N: 1 mm (*)
3: 3 mm	02 : 0.2 mm
2: 2 mm	

): Small matrix model

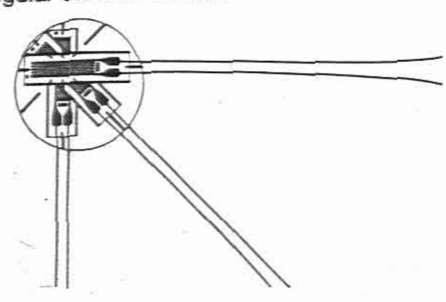
C1 : Uniaxial



D16: Biaxial, 2-element
90° stacked rosette



D17: Triaxial, 3-element 45°
rectangular stacked rosette



★C1 pattern with 2-wire flat cable
R: Red (standard)
White(W), green(G), yellow(Y) and black(B) are available upon request.
★C1 pattern with 3-wire cable
R: Red stripes (standard)
Blue(L) and yellow(Y) are available upon request.
★D16 pattern with 2-wire cable
S: Red (0°) and white (90°)
★D16 pattern with 3-wire cable
S: Red stripes (0°) and yellow stripes (90°)
★D17 pattern with 2-wire cable
S: Red (0°), green (45°) and white (90°)
★D17 pattern with 3-wire cable
S: Red stripes (0°), blue stripes (45°) and yellow stripes (90°)

15C: 15 cm	1M: 1 m
30C: 30 cm	3M: 3 m
	5M: 5 m

L: Stranded copper wire, flat cable, vinyl insulation
N: Solid copper wire, polyester insulation

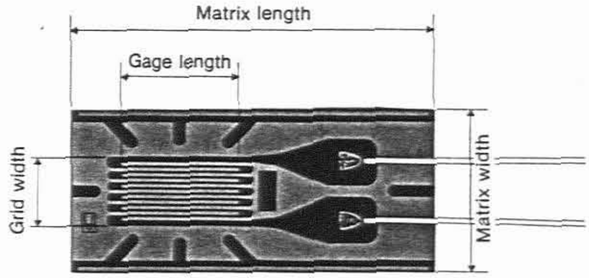
S-T-C Code	Thermal expansion coefficient (PPM/°C)	Matrix color	Applicable material
11	10.8	Red	Iron, Concrete
16	16.2	Orange	Stainless steel, Copper
23	23.4	Green	Auminum, Tin
27	27.0	Yellow	Magnesium

FG gage listings

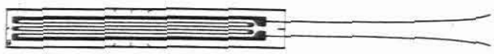
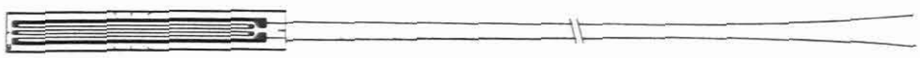
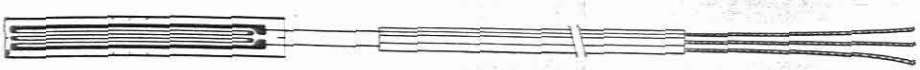
ieral performance

resistance: 120Ω±0.4Ω or 120Ω±0.8Ω
factor: 2.10±10%
e life: 1×10[7] cycles (strain level: ±1500 micro-strain)
limit: 5% (at room temperature)
ge resistance: 100MΩ
ensated temperature range: +10 to +80°C
ting temperature range: −20 to +100°C

• Gage dimensions



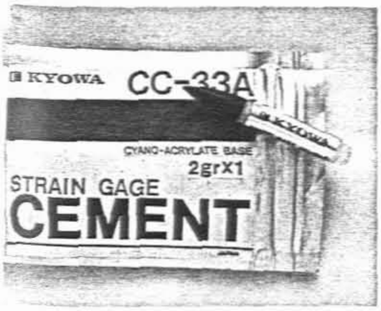
iaxial gages

Gage pattern	Type (•)	Resistance (Ω)	Gage factor	Dimensions (mm) Gage length	Grid width	Matrix length	Matrix width	Gages per pack	Extension leadwire length	Remark
 ×1	KFG-30-120-C1-XX	120±0.4	2.1	30	3.3	37	5.2	10		
	KFG-30-120-C1-XX N15C 2	120±0.8	2.1	30	3.3	37	5.2	10	15 cm	
	KFG-30-120-C1-XX N30C 2	120±0.8	2.1	30	3.3	37	5.2	10	30 cm	
	KFG-30-120-C1-XX L1M 2 R	120±0.8	2.1	30	3.3	37	5.2	10	1 m	
	KFG-30-120-C1-XX L3M 2 R	120±0.8	2.1	30	3.3	37	5.2	10	3 m	
	KFG-30-120-C1-XX L5M 2 R	120±0.8	2.1	30	3.3	37	5.2	10	5 m	
	KFG-30-120-C1-XX L3M 3 R	120±0.8	2.1	30	3.3	37	5.2	10	3 m	3-wire system
	KFG-30-120-C1-XX L5M 3 R	120±0.8	2.1	30	3.3	37	5.2	10	5 m	

tions are subject to change without notice for improvement.

(•): Insert desired S-T-C code in spaces marked XX.

C-33A adhesive



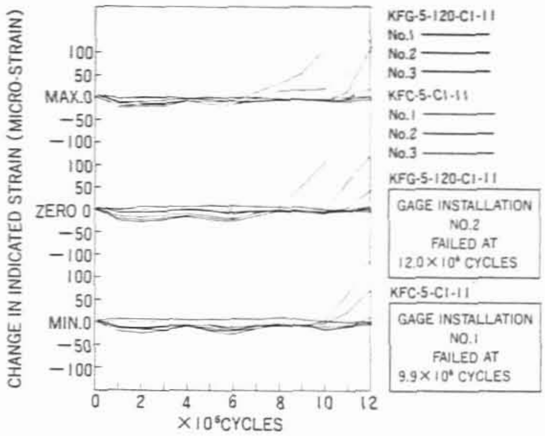
instant adhesive is exclusively
gned for use with KFG gages and
ides superior workability. Used
KFG gages, the adhesive fully ex-
s its high performance.

e	CC-33A
	2gr×1 2gr×5
n component	Ethyl-α-cyanoacrylate
rating erature range	−196 to +120°C
e rements	One-minute thumb pressure, 0.5 to 1kgf/cm²
life	4 months at +10°C
gation ability	5% at +25°C
icable gages	KFG, KFC, etc.

■ Gage characteristic data

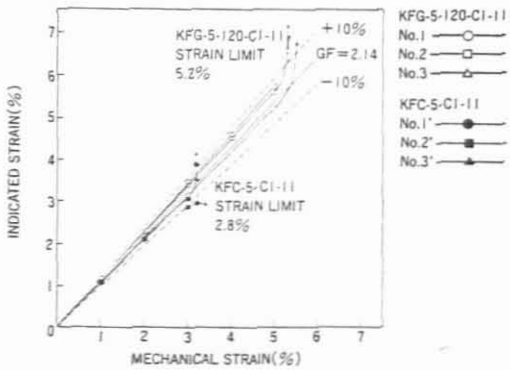
● Fatigue life

The result of a test conducted in conformity with NAS 942 Std., shown at right, has proven a fatigue life of 12x10^6 cycles, far superior to conventional gages.



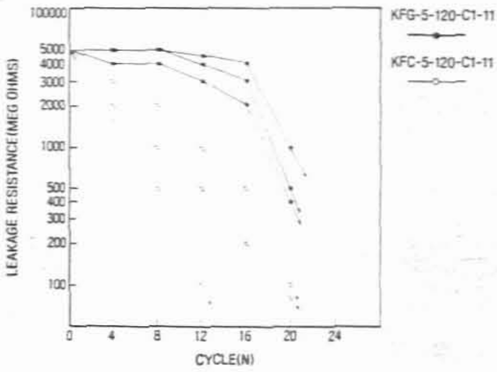
● Strain limit

KFG gages has proven a strain limit of 5% or higher, which doubles the strain limit of conventional gages.



● Leakage resistance

KFG gages deliver leakage resistance far superior to conventional gages thanks to the newly developed backing.



APPENDIX D

CIRCUIT DIAGRAMS

CONTENTS:

i) SIGPROC.SCH

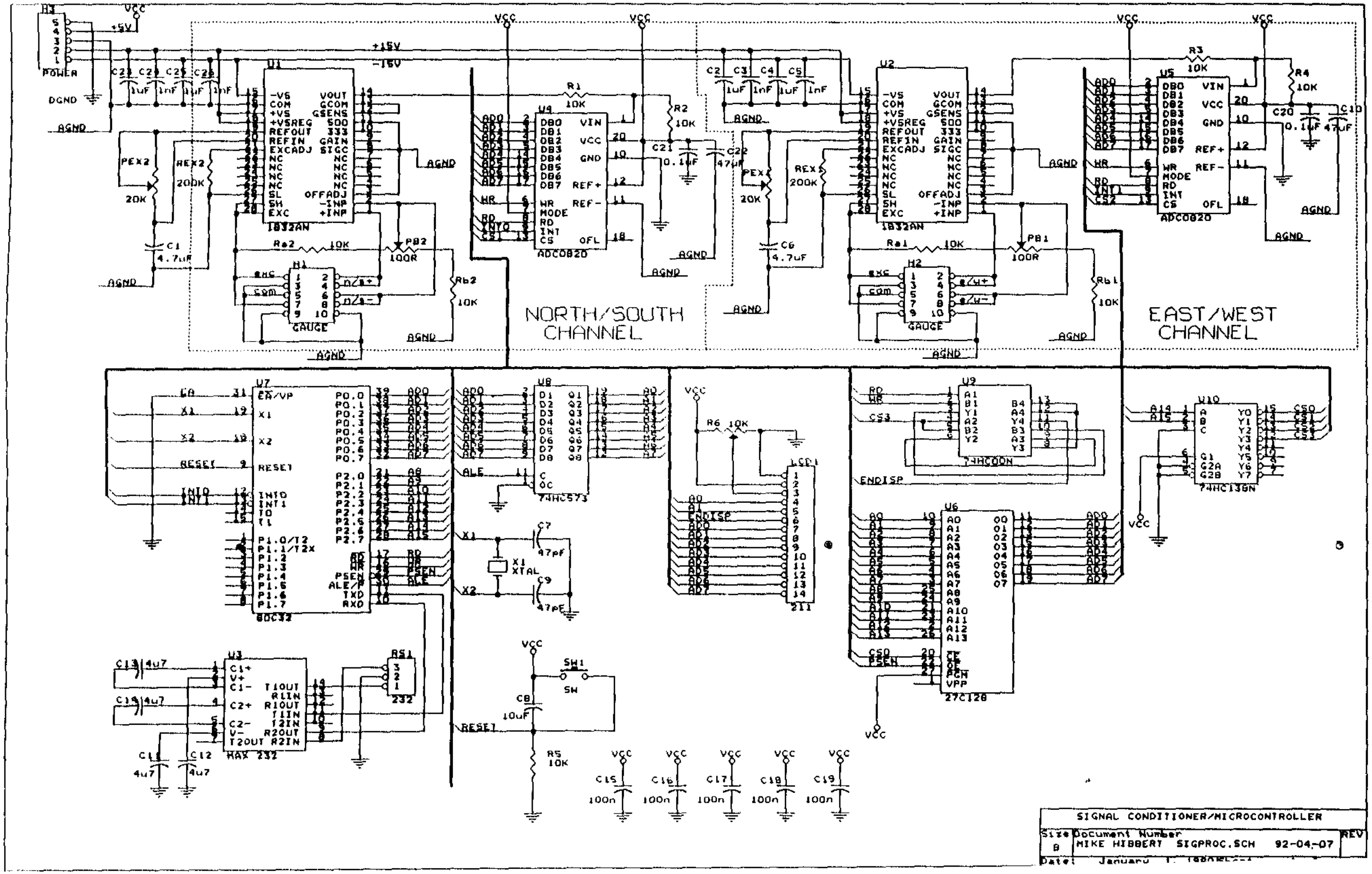
ii) POWER SUPPLY CIRCUIT

iii) DATA SHEET : 1B32 AN Signal Conditioner

iv) DATA SHEET : LM 326 Voltage Regulator

APPENDIX D : i

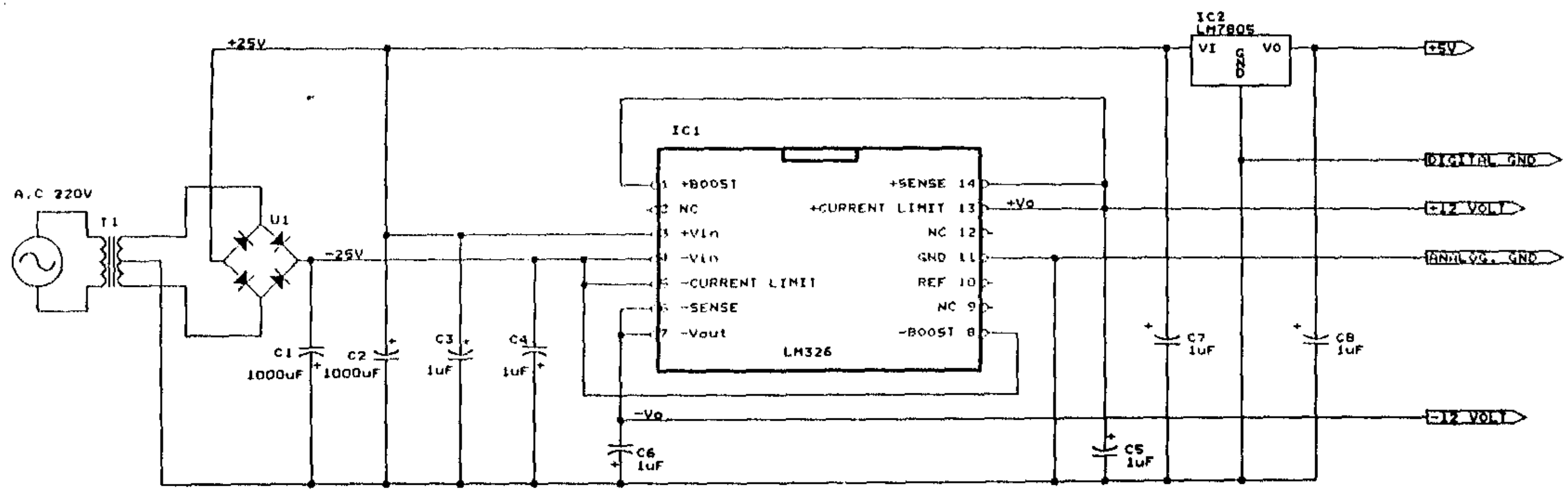
i) SIGPROC.SCH



NORTH/SOUTH CHANNEL
EAST/WEST CHANNEL
POWER
1B32AN
ADC0820
GAUGE
80C32
74HC573
74HC00N
74HC138N
27C128
MAX 232
SIGNAL CONDITIONER/MICROCONTROLLER
Size B
Document Number
MIKE HIBBERT SIGPROC.SCH 92-04-07
REV

APPENDIX D : ii

ii) POWER SUPPLY CIRCUIT



APPENDIX D :Figure 9.1		
Size B	Document Number POWER SUPPLY CIRCUIT	REV
Date: January 1, 1980	Sheet of	

APPENDIX D : iii

iii) DATA SHEET : 1B32 AN Signal Conditioner

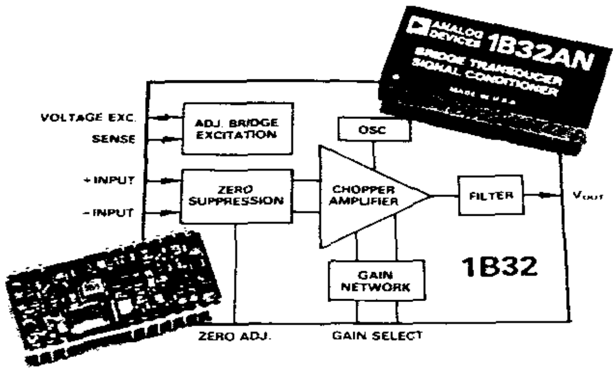
ANALOG DEVICES

Bridge Transducer Signal Conditioner

FEATURES
Low Cost
Complete Signal-Conditioning Solution
Small Package: 28-Pin Double DIP
Internal Thin-Film Gain Network
High Accuracy
- Low Input Offset Tempco: ±0.07μV/°C
- Low Gain Tempco: ±2ppm/°C
- Low Nonlinearity: ±0.005% max
- High CMR: 140dB min (60Hz, G = 1000V/V)

Programmable Bridge Excitation: +4V to +15V
Remote Sensing
Low Pass Filter (f_C = 4Hz)

APPLICATIONS
Weigh Scales
Instrumentation: Indicators, Recorders, Controllers
Data Acquisition Systems
Microcomputer Analog I/O



;ENERAL DESCRIPTION
lodel 1B32 is a precision, chopper-based, signal-conditioning omponent ideally suited for high-accuracy applications of load ells and bridge transducers. Packaged in a compact 28-pin lastic double DIP, the 1B32 takes advantage of hybrid technology r high reliability as well as higher channel density. Functionally, e signal conditioner consists of three basic parts: a high perrmance chopper-based amplifier, a low-pass filter and an adistable transducer excitation source.

he chopper-based amplifier features extremely low input offset mpco of ±0.07μV/°C (RTI, G = 500V/V) and excellent nonearity of ±0.005% max over its full gain range of 100 to 00V/V. The 1B32 has a thin-film resistor network for pinrapping the gain to 500V/V or 333.3V/V (for 2mV/V and nV/V load cells). The gain tempco for these fixed gains is a ghly stable ±2ppm/°C. Additionally, the gain can be set to y value in the gain range with two external resistors. The nplifier also has a wide-range input referred zero suppression pability (±10V), which can easily be interfaced to a D/A nverter. The bandwidth of the chopper is 4Hz at G = 100V/V.

e integral three-pole, low-pass filter offers a 60dB/decade roll- f from 4Hz to reduce common-mode noise and improve system nal-to-noise ratio.

e 1B32's regulated transducer excitation stage features low put drift (±40ppm/°C typ) and can drive 120Ω or higher istance load cells. The excitation is preset at +10V with er voltages between +4V and +15V programmable with ernal resistors. This section also has remote sensing capability allow for lead-wire compensation in 6-wire load cells and er bridge configurations.

The 1B32 is fully specified over the industrial (−25°C to +85°C) temperature range.

DESIGN FEATURES AND USER BENEFITS
Pin-Strappable Gain: The internal resistor network can be pin-strapped for gains of 500V/V and 333.3V/V for 2mV/V and 3mV/V load cells. The tracking network guarantees a gain tempco of ±6ppm/°C max.

Custom Trimmable Network: For volume applications, the 1B32 can be supplied with a custom laser trimmed gain network. Contact factory for further information.

Wide Range Zero Suppression: The output can be offset by ±10V for nulling out a dead load or to do a tare adjustment.

Remote Sensing: Voltage drops across the excitation lead-wires are compensated by the regulated supply, making 6-wire load-cell interfacing straightforward.

Programmable Transducer Excitation: The excitation source is preset for +10V dc operation without external components. It is user-programmable for a +4V to +15V dc range (@ 100mA) to optimize transducer performance.

Low-Pass Filter: The three-pole active filter (f_C = 4Hz) reduces 60Hz line noise and improves system signal-to-noise ratio.

One Technology Way; P. O. Box 9106; Norwood, MA 02062-9106 U.S.A.
Tel: 617/329-4700 Twx: 710/394-6577
Telex: 174059 Cables: ANALOG NORWOODMASS

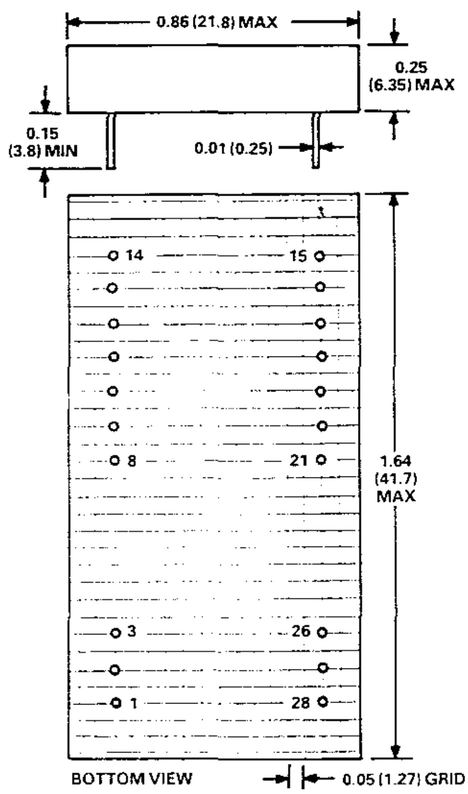
:IFICATIONS (typical @ +25°C and V_S = ±15V unless otherwise noted)

	1B32AN
:ange	100V/V to 5000V/V
al Gain Setting	333.3V/V and 500V/V
:quation	$1 + \frac{R_F}{R_I}$
:quation Accuracy[1]	±0.1%
'emperature Coefficient[2]	±2ppm/°C (±6ppm/°C max)
:onlinearity	±0.005% max
[VOLTAGES	
)ffset Voltage, RTI	
ial, @ +25°C, G = 1000V/V	±40μV
m-Up Drift, G = 1000V/V, 10 min	Within ±1μV
[emperature (−25°C to +85°C)	
= 1000V/V	±0.07μV/°C (±0.2μV/°C max)
: Other Gains	$\pm\left(0.06 + \frac{15}{G}\right)\mu V/°C$
: Offset Adjust Range	±10V
3IAS CURRENT	
@ 25°C	±3nA
:emperature (−25°C to +85°C)	±50pA/°C
)IFFERENCE CURRENT	
@ +25°C	±3nA
:emperature (−25°C to +85°C)	±10pA/°C
RESISTANCE	
:ntial	100MΩ
on Mode	100MΩ
'OLTAGE RANGE	
Differential Input	±0.1V
:um Differential Input	+5V
nput Range	0 to +7.5V
1kΩ Source Imbalance[3]	
100V/V to 5000V/V @ dc	86dB
00V/V, @ 60Hz	120dB
000V/V, @ 60Hz	140dB min
NOISE	
e, G = 1000V/V	
Iz to 10Hz	1μV p-p
:, G = 1000V/V	
Iz to 10Hz	3pA p-p
OUTPUT	
e, 2kΩ Load, min	±10V
:	±5mA
ance, dc to 2Hz, G = 100V/V	0.6Ω
apacitance	500pF
: Short Circuit Duration (to Ground)	Indefinite
IC RESPONSE	
ignal Bandwidth	
B Gain Accuracy, G = 100V/V	4Hz
G = 1000V/V	3.5Hz
ate	20V/sec
wer	0.5Hz
: Time, G = 100V/V, ±10V Output	2sec
to ±0.1%	
SS FILTER	
er of Poles	3
Frequency (−3dB Point)	4Hz
:f	60dB/decade

(Continued on next page)

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



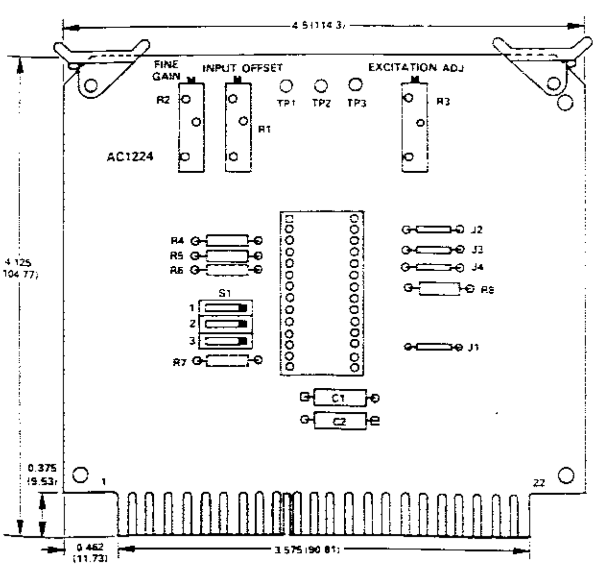
PIN DESIGNATIONS

PIN	FUNCTION	PIN	FUNCTION
1	+INPUT	15	$-V_S$
2	−INPUT	16	COMM
3	INPUT OFFSET ADJ	17	$+V_S$
4	NC	18	$+V_S$ REG
5	NC	19	REF OUT
6	NC	20	REF IN
7	NC	21	EXC ADJ
8	SIGNAL COMM	22	NC
9	EXT GAIN SET	23	NC
10	333.3 GAIN	24	NC
11	500 GAIN	25	NC
12	GAIN SENSE	26	SENSE LOW
13	GAIN COMM	27	SENSE HIGH
14	V_{OUT}	28	V_{EXC} OUT

Model	1B32AN
BRIDGE EXCITATION	
Regulator Input Voltage Range	+9.5V to +28V
Output Voltage Range	+4V to +15V
Regulator Input/Output Voltage Differential	+3V to +24V
Output Current[4]	100mA max
Regulation, Output Voltage vs. Supply	±0.05%/V
Load Regulation, I_L = 1mA to 50mA	±0.1%
Output Voltage vs. Temperature (−25°C to +85°C)	±40ppm/°C
Output Noise, 0.1Hz to 10Hz[5]	300μV p-p
Reference Voltage (Internal)	+6.8V ±5%
Sense & Excitation Lead Resistance	10Ω max
POWER SUPPLY	
Voltage, Rated Performance	±15V dc
Voltage, Operating	±12V to ±18V dc
Current, Quiescent[6]	+4mA, −1mA
ENVIRONMENTAL	
Temperature Range	
Rated Performance	−25°C to +85°C
Operating	−40°C to +85°C
Storage	−40°C to +100°C
Relative Humidity	0 to 95%, Noncondensing, @ +60°C
CASE SIZE	0.83" × 1.64" × 0.25" (21.1 × 41.7 × 6.35mm) max

NOTES
Using internal network for gain.
For pin-strapped gain. The tempco of the individual thin-film resistors is ± 50ppm/°C max.
V p-p 60Hz common-mode signal used in test setup.
Derate 2mA/°C from +50°C.
.7μF capacitor from REF IN (Pin 20) to COMM.
Excluding bridge excitation current and with no loading on the output.
Specifications subject to change without notice.

AC1224 Mounting Card



AC1224 Connector Designation

PIN	FUNCTION	PIN	FUNCTION
T	V_{EXC} OUT	1	+INPUT
U	SENSE HIGH	2	−INPUT
V	SENSE LOW	12	V_{OUT}
X	REF OUT	19	$-V_S$
Y	REF IN	20	COMM
Z	EXC ADJ	21	$+V_S$
		22	$+V_S$ REG

The AC1224 mounting card is available for the 1B32. The AC1224 is an edge connector card with a socket for plugging in the 1B32. In addition it has provisions for switch selecting internal gains as well as installing gain resistors. Adjustment pots for offset, fine gain and excitation are also provided. The AC1224 comes with a Cinch 251-22-30-160 (or equivalent) edge connector.

APPENDIX D : iv

iv) DATA SHEET : LM 326 Voltage Regulator

National Semiconductor

Voltage Regulators

LM125/LM225/LM325/LM325A, LM126/LM326 Voltage Regulators

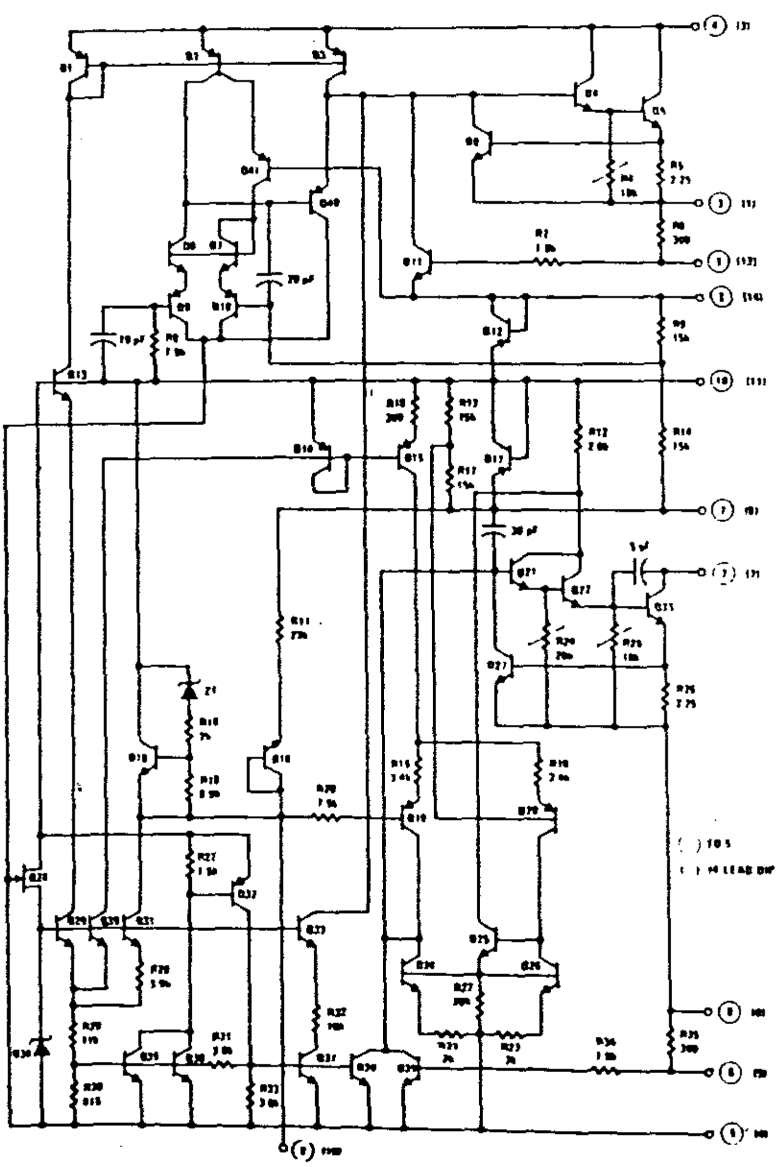
General Description

These are dual polarity tracking regulators designed to provide balanced positive and negative output voltages at current up to 100 mA, the devices are set for ±15 V and ±12 V outputs respectively. Input voltages up to ±30 V can be used and there is provision for adjustable current limiting. These devices are available in three package types to accomodate various power requirements and temperature ranges.

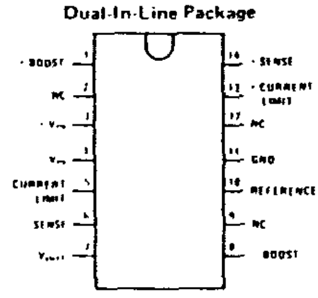
Features

- ±15V and ±12V tracking outputs
- Output current to 100 mA
- Output voltages balanced to within 1% (LM125, LM126, LM325A)
- Line and load regulation of 0.06%
- Internal thermal overload protection
- Standby current drain of 3 mA
- Externally adjustable current limit
- Internal current limit

Schematic and Connection Diagrams

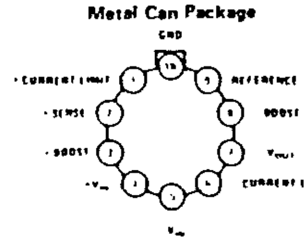


Dual-In-Line Package



Order Number LM325AN, LM325N, or LM326N
See Package N14A

Metal Can Package



Order Number LM125H, LM325H, LM126H, or LM326H
See Package H10C

Absolute Maximum Ratings

Input Voltage	±30V
Forced V_O^+ (Min) (Note 1)	−0.5V
Forced V_O^- (Max) (Note 1)	+0.5V
Power Dissipation (Note 2)	Internally Limited
Output Short-Circuit Duration (Note 3)	Indefinite
Operating Temperature Range	
LM126	−55°C to +125°C
LM326	0°C to +70°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Electrical Characteristics LM126/LM226/LM326 (Note 2)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Output Voltage	T_j = 25°C				
LM126, LM326		11.8	12	12.2	V
		11.5		12.5	V
Input-Output Differential		2.0			V
Line Regulation	V_{IN} = 15V to 30V I_L = 20 mA, T_j = 25°C		2.0	10	mV
Line Regulation Over Temperature Range	V_{IN} = 15V to 30V, I_L = 20 mA		2.0	20	mV
Load Regulation	I_L = 0 to 50 mA, V_{IN} = ±30V,				
V_O^+	T_j = 25°C		3.0	10	mV
V_O^-			5.0	10	mV
Load Regulation Over Temperature Range	I_L = 0 to 50 mA, V_{IN} = ±30V				
V_O^+			4.0	20	mV
V_O^-			7.0	20	mV
Output Voltage Balance	T_j = 25°C				
LM126, LM326				±125	mV
				±250	mV
Output Voltage Over Temperature Range	$P \leq P_{MAX}$, $0 \leq I_O \leq 50$ mA				
LM126	$15V \leq \lvert V_{IN} \rvert \leq 30V$	11.68		12.32	V
LM326		11.32		12.68	V
Temperature Stability of V_O			±0.3		%
Short Circuit Current Limit	T_j = 25°C		260		mA
Output Noise Voltage	T_j = 25°C, BW = 100 – 10 kHz		100		μVrms
Positive Standby Current	T_j = 25°C, I_L = 0		1.75	3.0	mA
Negative Standby Current	T_j = 25°C, I_L = 0		3.1	5.0	mA
Long Term Stability			0.2		%/kHr
Thermal Resistance Junction to Case (Note 4)					
LM126/LM326H			45		°C/W
Junction to Ambient LM326N			150		°C/W

Note 1: That voltage to which the output may be forced without damage to the device.

Note 2: Unless otherwise specified, these specifications apply for T_j=−55°C to +150°C on LM126, T_j=0°C to +125°C on LM326, V_{IN}=±20V, I_L=0 mA, I_{MAX}=100 mA, P_{MAX}=2.0W for the TO-5 H Package I_{MAX}=100 mA. I_{MAX}=100 mA, P_{MAX}=1.0W for the DIP N Package.

Note 3: If the junction temperature exceeds 150°C the output short circuit duration is 60 seconds.

Note 4: Without a heat sink, the thermal resistance junction to ambient of the TO-5 Package is about 150° C/W. With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending on the efficiency of the sink.

APPENDIX E

PROGRAM LISTING AND FLOWCHART

CONTENTS:

APPENDIX E : i

i) PUTCHAR.S03 : Assembler Language Program

```
-------------------------------------------------------;
               PUTCHAR.S03                             ;
                                                       ;
          int putchar (int val);                       ;
                                                       ;
80C552.  Prints on serial port 0.                      ;
 for text output.  Can be modified for other           ;
ware configurations.                                   ;
-------------------------------------------------------;
  MODULE   putchar
  EXTERN   _R                       ; SELECTED REG BANK
  EXTERN   io_stream
  PUBLIC   putchar
  RSEG     CODE
r:
  CJNE     R3,#0AH,PLAIN            ; LF (\n)?
  MOV      A,#0DH                   ; Yes, first CR
  MOV      R3,A
  LCALL    SEND_IT
  SJMP     P_OUT
  LCALL    SEND_IT
  RET

:
  PUSH     _R+0
  PUSH     _R+1
  PUSH     DPL
  PUSH     DPH
  MOV      R1,#io_stream
  MOV      A,@R1
  CJNE     A,#02H,lcd
  MOV      A,R3
  MOV      153,A                    ; Address of SBUF
  JNB      TI,$                     ; Wait for transmission
  CLR      TI
  SJMP     s_out                    ; Jump out
  MOV      DPH,#80H                 ; Address H of LCD display
  MOV      DPL,#02H                 ; Address L of status register
  MOVX     A,@DPTR                  ; Read status
  ANL      A,#80H                   ; Bitmask 'busy' bit
  JNZ      wait                     ; Repeat if busy
  MOV      A,@R1                    ; Test io_stream
  JNZ      command
  MOV      DPL,#01H                 ; io_stream= LCD_DATA
  MOV      A,R3
  MOVX     @DPTR,A                  ; Send byte
  SJMP     s_out                    ; Jump out
 :MOV      DPL,#00H                 ; io_stream= LCD_COMMAND
  MOV      A,R3
  MOVX     @DPTR,A                  ; Send byte
  POP      DPH                      ; Clean up
  POP      DPL
  POP      _R+1
  POP      _R+0
  RET
  END
```

APPENDIX E : ii

ii) MIKE1.C : Anemometer Test; C-program code

```
*****************************************************************************/
         MIKE1.C : Anemometer Test                                        */
         MIKE '92                                                         */
*****************************************************************************/

ude      <stdarg.h>
ude      <stdio.h>
ude      <io51.h>
ude      <math.h>

ne       DATA             0x00             /* Stream for output    */
ne       COMMAND          0x01
ne       RS232            0x02

ne       LINE_1           0x80             /* LCD Commands         */
ne       LINE_2           0xC0
ne       CLEAR            0x01

ne    Q0                  22.5             /* Dividing Angles      */
ne    Q1                  67.5
ne    Q2                  112.5
ne    Q3                  157.5

ne       ADC0_wr          0x2000           /* Hardware Addresses   */
ne       ADC1_wr          0x4000

         W[6]= "W     ";                   /* Text Strings         */
         SW[]= "SW    ";
         S[6]= "S     ";
         SE[]= "SE    ";
         E[6]= "E     ";
         NE[]= "NE    ";
         N[6]= "N     ";
         NW[]= "NW    ";
         NU[]= "NULL  ";

         io_stream = DATA;                 /* Global Variables     */
         x, y;
         offx= 128, offy= 128;
         angle;
         speed;
         calfactor= 4;

         init_display    ( void )

  io_stream= COMMAND;
  putchar ( 0x38 );                /* Function Set         */
  putchar ( 0X0C );                /* Display Set          */
  putchar ( 0x06 );                /* Entry Mode           */
  putchar ( CLEAR );               /* Clear display        */
  io_stream= DATA;


         init_rs232              ( void )

  output  ( TMOD, 0x21 );                  /* Set Timer 1 Mode     */
  output  ( TH1,  0xFD );                  /* Set Timer 1 Reload   */
  set_bit ( TR1_bit );                     /* Start Timer 1        */
  output  ( SCON, 0x70 );                  /* Set Serial Port Mode */
  output  ( PCON, 0x00 );                  /* Reset SMOD           */


         capture_data    ( )               /* Get average ADC read */
```

```
ıed char    i= 0;
  for       ( i= 0; i< 250 ; i++ )
  {
            write_XDATA ( ADC0_wr,00 );      /* Start A/D conversion */
            write_XDATA ( ADC1_wr,00 );
            while ( read_bit(INT0_bit) );    /* Wait for ADC          */
            while ( read_bit(INT1_bit) );
            x+= (float)( offx- read_XDATA( ADC1_wr ));      /* Read */
            y+= (float)( offy- read_XDATA( ADC0_wr ));
  }
  x/= 250.0;                                 /* Average              */
  y/= 250.0;


            process_data    ( )

  angle=          get_angle        ( x, y );
  speed=(int)     get_speed        ( x, y );
  direction=      get_direction    ( );


            set_disp        ( char function )

  io_stream= COMMAND;
  putchar ( function );
  io_stream= DATA;


            get_speed       ( double in1, double in2 )

  return    ( pow( (in1*in1+ in2*in2), 0.25 )* calfactor );


            get_angle ( double in1, double in2 )

  return    ( atan2( in2, in1 )* 180/3.141593 );


            *get_direction ( )

  if        ( !x && !y )    return   ( NU );
  if        ((  Q3<= angle )||  ( angle< -Q3 ))      return    ( W  );
  if        (( -Q3<= angle )&&  ( angle< -Q2 ))      return    ( SW );
  if        (( -Q2<= angle )&&  ( angle< -Q1 ))      return    ( S  );
  if        (( -Q1<= angle )&&  ( angle< -Q0 ))      return    ( SE );
  if        (( -Q0<= angle )&&  ( angle< Q0  ))      return    ( E  );
  if        ((  Q0<= angle )&&  ( angle< Q1  ))      return    ( NE );
  if        ((  Q1<= angle )&&  ( angle< Q2  ))      return    ( N  );
  if        ((  Q2<= angle )&&  ( angle< Q3  ))      return    ( NW );


            display_data    ( void )

  set_disp( LINE_1 );      printf   ( "%+3.0f  %+3.0f ", x, y );
  set_disp( LINE_1+11);    printf   ( "%+3.0f ", angle );
  set_disp( LINE_2 );      printf   ( "S= %2.0u m/s D= " ,speed);
  set_disp( LINE_2+12);    printf   ( "%s", *direction );
  io_stream= RS232;
  printf  ( "Wind Speed: %2.0u m/s \n", speed );
  io_stream= DATA;


            main            ( void )
```

```
 t_display      ( );
.t_rs232        ( );
ile ( 1 )

      capture_data     ( );
      process_data     ( );
      display_data     ( );
```

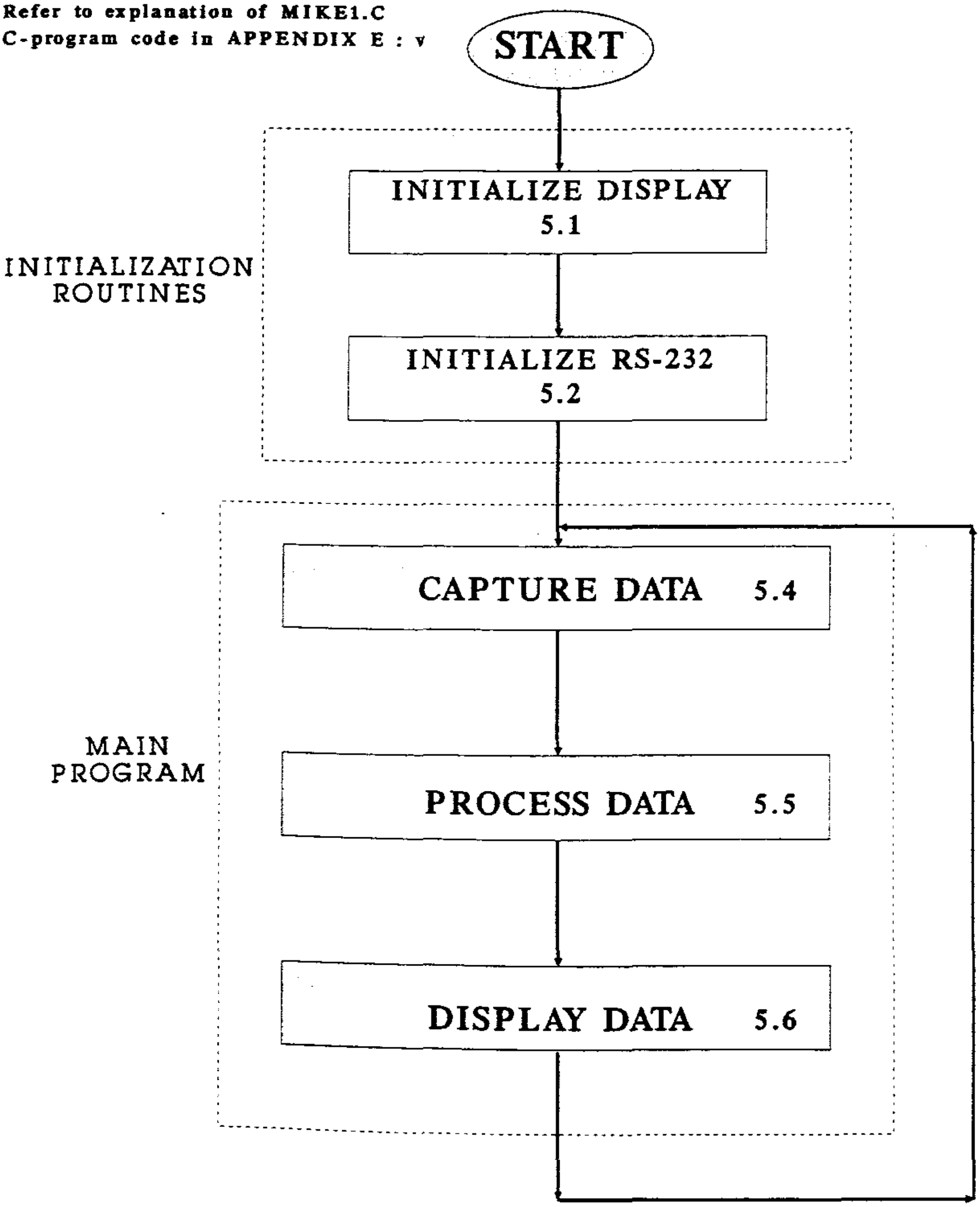
APPENDIX E : iii

iii) Flowchart : MIKE1.C/PUTCHAR.S03

MIKE1.C : ANEMOMETER TEST

FLOWCHART

Refer to explanation of MIKE1.C C-program code in APPENDIX E : v



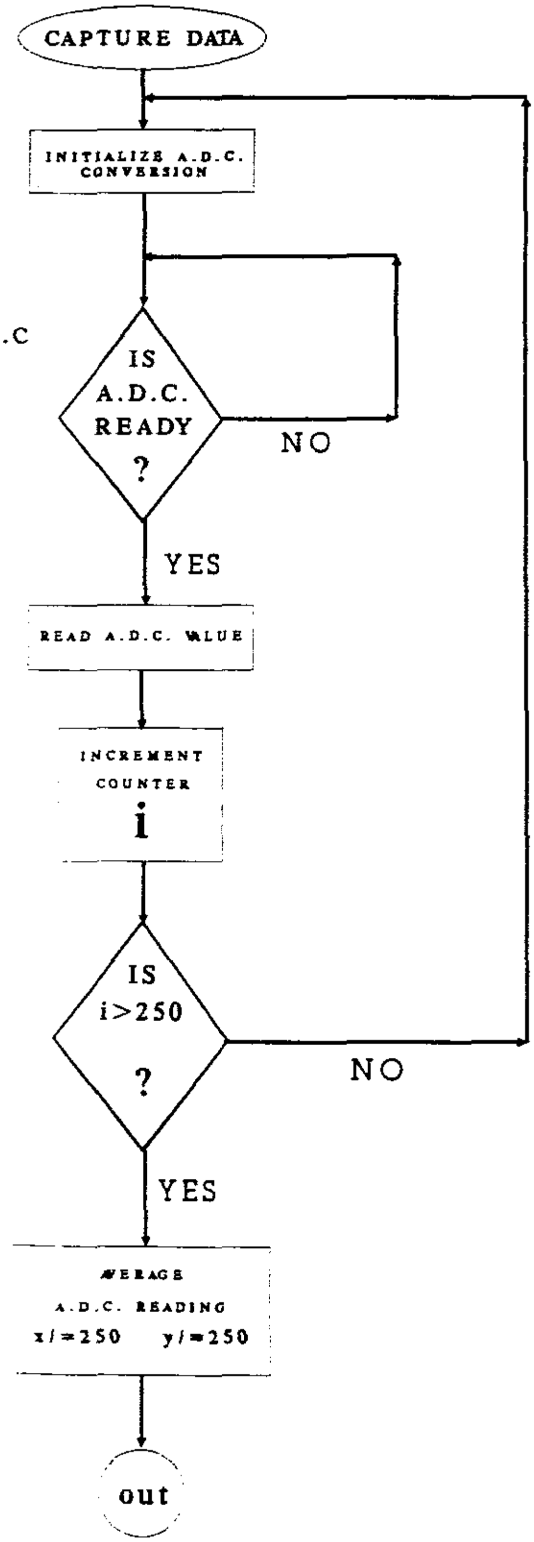
APPENDIX E : iv

iv) Flowchart : capture-data routine

The capture_data routine (5.4)

FLOWCHART

Refer to section 5.4 of the MIKE1.C C-program code : capture_data.



APPENDIX E : v

v) Detailed explanation of MIKE1.C C-program code

APPENDIX E : v

Explanation of the MIKE1.C C-program code

1. Header Files

The first lines of the program-code consists of the following directives :-

#include <starg.h>
#include <stdio.h>
#include <io51.h>
#include <math.h>

The **#include** directives at the beginning of the source file access the function prototype declarations for library functions from headers. The details of how headers are accessed are implementation dependent. **#include** is a way of combining declarations together for a large program.

#include directives guarantee that all the source files will be supplied with the same definitions and variable declarations. The properties of library functions are specified in more than a dozen Header Files.

When the name of a library is bracketed by < and > a search is made for the Header File in a standard set of places, for example, on UNIX Systems, typically in the directory /USR/INCLUDE.

1.1 The Standard Header <starg.h>

The standard header **<starg.h>** contains a set of macro definitions that provide facilities for stepping through a list of function arguments of unknown number and type.

1.2 The Standard Header <stdio.h>

The Standard Input/Output Header File **<stdio.h>** includes input and output functions, types and macro's defined in **<stdio.h>**.

<stdio.h> tells the compiler to include information about the standard input/output library. This library implements a simple model of text input and output. A text stream consists of a sequence of lines, each line ending with a newline character. The library maintains input/output control during system operation by ensuring that input/output functions are implemented correctly.

1.3 The Header <io51.h>

This library contains information supporting operation of the 8051 family of Microcontrollers.

The header file **<io51.h>** declares library register functions, type and macro's for the 8051 family of Microcontrollers for use by the compiler.

1.4 The Header <math.h>

The header **<math.h>** declares mathematical functions and macro's. This library uses double precision floating point numbers. The powerful set of mathematical functions provided by this library, particularly the trigonometric and power series functions were most suitable for the software calculation of wind velocity and direction from the information provided by the N/S and E/W channel analogue-to-digital converters.

For example in the **get_angle** routine for the software calculation of wind bearing/angle in the C program-code the arctan mathematical function is implemented as follows : -

C-code :

```
( atan2 ( in2, in1 ) * 180/3.141593 )
```

Trigonometric operation returned :

$$\tan^{-1}(in2/in1) \text{ in the range } [-\pi, \pi]$$

Angles for trigonometric functions are expressed in radians. Conversion to degrees is implemented by multiplying by 180^o and dividing by 3.141593 (π).

In the **get_speed** routine for the software calculation of wind velocity the following mathematical function calculates the 'square' of the N/S channel, the 'square' of the E/W channel, sums them, then calculates the 'fourth root' of the result and finally multiplies this value by a calibration factor. The procedure is as follows : -

C-code :

```
( pow ( ( in1*in1 + in2*in2 ), 0.25 ) * calfactor )
```

Mathematical function :

$$(in1^2 + in2^2)^{1/4} \times calfactor$$

2. The #define lines

The **#define** lines define the symbolic names and symbolic constants. **#define** takes the following format : -

#define	**name**	**replacement text**

The **#define** lines define a symbolic constant to be a particular string of characters. Any re-occurrence of **name** will be replaced by the corresponding replacement text. The symbolic constants are written in uppercase letters.

2.1 The DATA, COMMAND and RS232 #define lines

#define	name	replacement text
#define	**DATA**	**0x00**
#define	**COMMAND**	**0x01**
#define	**RS232**	**0x02**

The **#define DATA, COMMAND** and **RS232** symbolic constants make program-code easier to read and debug. It is easier to recognise and understand text in the program-code than to debug program-code where hex-addresses appear frequently. These **#define** lines represent the software stream for output to the LTN211 display and the RS-232 Serial port.

2.2 The LINE_1, LINE_2 and CLEAR #define lines

#define	name	replacement text
#define	**LINE_1**	**0x80**
#define	**LINE_2**	**0xC0**
#define	**CLEAR**	**0x01**

The **#define** lines **LINE_1, LINE_2** and **CLEAR** are the symbolic constants for the L.C.D. commands for the transmission of ASCII characters to the LTN211 display module. The starting address for line 1 of the display is 0x80. 0xC0 defines the address for line 2 of the display and 0x01 defines the clear display command.

2.3 The ADC_0 and ADC_1 #define lines

#define	name	replacement text
#define	**ADC0_wr**	**0x2000**
#define	**ADC1_wr**	**0x4000**

These **#define** lines define the hardware addresses of the North/South channel A.D.C. (0x2000) and the East/West channel A.D.C. (0x4000).

2.4 The Q0, Q1, Q2 and Q3 #define lines

#define	name	replacement text
#define	**Q0**	**22.5**
#define	**Q1**	**67.5**
#define	**Q2**	**112.5**
#define	**Q3**	**157.5**

The **#define** lines **Q0, Q1, Q2** and **Q3** represent the dividing angles for the software calculation of wind compass direction and character string generation (e.g. "NW" text string) from the wind bearing/angle (e.g. 120°) value returned after the **get_angle** routine.

Figure A is a geometric representation of the wind direction compass positions and the wind bearing/angle relative to the wind dividing angles.

3. The "char" type name specifiers : Wind Direction Text Strings

```
char          W   [ ] = "W      " ;
char          SW  [ ] = "SW     " ;
char          S   [ ] = "S      " ;
char          SE  [ ] = "SE     " ;
char          E   [ ] = "E      " ;
char          NE  [ ] = "NE     " ;
char          N   [ ] = "N      " ;
char          NW  [ ] = "NW     " ;
char          NU  [ ] = "NULL   " ;
```

The **char** type name specifiers are character declarations for the wind compass direction text strings used in the program for transmission of wind direction text information to the display. These declarations announce the properties of the variables. Here, the 8 wind direction compass positions and the 'NULL' zero wind vector string are declared as characters.

The **char** declaration declares a list of variables, "W   " to "NULL   " , six characters wide. The **char** declaration is a single byte variable capable of holding one character in the local character set. These direction text strings are preceded by pointer variables used by the program-code to return to the direction text strings.

4. The Global Variables

The C-programming language has the facility for declaring global variables. Globals are declared outside of all program routines/blocks and classes. This facility allows the declared variables to retain their values throughout the program.

4.1 char io_stream = DATA ;

The **char** declaration declares the properties of io_stream as a variable pointer for the transmission of DATA output to the display.

4.2 float x, y ;

The **x** and **y** variables are declared as single precision floating point numbers. They are normally used when variables are to be in conjunction with mathematical software functions. The values returned to **x** and **y** represent the A.D.C. digital offset voltages and are represented as a single byte having any value between 0 and 255. A float is a 32-bit quantity with at least six significant digits and may have a fractional part.

These variables can have A.D.C. offset values between 0 and 255 (128 when zero wind vector is translated during 'no wind conditions'), where 0 represents an A.D.C. analogue input voltage of 0V, 255 represents an input voltage of +5 V and 128 represents an analogue input voltage of 2.5 V.

The x and y variables are the actual values at the outputs of the N/S and E/W channel A.D.C's. These are global variables used in the **get_angle, get_speed** and **get_direction** subroutines for the **process_data** routine and **printf** statements. These routines use the x and y global variables for the determination of wind bearing/angle, wind velocity and wind compass direction. The results are used to display this data on the L.C.D display.

4.3 float offx = 128 , offy = 128

The x and y variables are also displayed as a measure of wind vector offset values from the N/S and E/W channel offset values. A float is a 32-bit quantity. The program statement which reads as follows is a representation of this : -

float offx = 128 , offy = 128

These declared float variables are used for the calculation of the A.D.C. offset voltages in the program routine **capture_data.**

4.4 double angle ;

Here angle is declared as a double precision floating point number since the **get_angle** routine uses the **atan2** y/x mathematical C-function and the value returned to **angle** will have a fractional part.

4.5 int speed ;

The variable **speed** is declared as an **integer**. Integer variables have no fractional part. Wind velocity readout will be a positive integer value 2-digits wide and with no decimal places. Declaring speed as an integer is part of a "rounding off" process for displaying a wind velocity range from 0 m/s to 99 m/s.

4.6 float calfactor ;

The calibration factor, **calfactor** is declared as a single precision floating point number. The calfactor value is used in the **get_speed** subroutine which uses the 'square, sum and fourth route' C-mathematical function discussed in **1.4**.

5. The "main" function : The start of program execution

return type	function name	argument/parameter
void	**main**	**(void)**

The return type of **main** is **void**, which states explicitly that no value is returned. The **void** return type specifies an empty set of values. It is used as the type returned by the **main** function which generates no value. The program begins executing at the beginning of **main** (the function name). Every C-program structure must have a **main** function.

main calls other functions to perform routines and libraries included in the source file. The libraries included in the source file are listed at the beginning of **APPENDIX E : (Refer to Section 1 : Header files).**

The **main** function also receives **void** as an argument/parameter value. The term argument/parameter is used for an expression passed by a function call such as main. **main** is defined to be a function with the **void** argument which indicates that there are no arguments for **main**.

The program is divided into 5 functions called from main :

```
void        main        (void)
{
      init_display      ( ) ;
      init_rs232        ( ) ;
      while (1)
      {
            capture_data      ( ) ;
            process_data      ( ) ;
            display_data      ( ) ;
```

```
        }
}--
```

The function called **init_display**, initializes the LTN211 L.C.D. display module. **init_rs232** initializes the serial port for transmission of data to an I.B.M. P.C.

while (1) is used as a "loop forever" instruction. This is followed by the routine **capture_data** which reads in the A.D.C. N/S and E/W channel x and y variable values **(Refer to Section 4 : Global Variables)** and averages each x and y variable over 250 readings.

The **process_data** routine uses these averages x and y float variables to process the data and return angle as a double precision floating point number **(Refer to Section 4 : Global Variables).**

The **display_data** routine uses the **printf** statement to display the following processed data as an LTN211 L.C.D. display read-out : -

Wind Vector Channel N/S Offset (as a value between -128 and +127)
Wind Vector Channel E/W Offset (as a value between -128 and +128)
Wind Angle/Bearing as a value from +180° to -180°
Wind Velocity as a value between 0 m/s and 99 m/s
Wind Direction as a character string of 8 direction compass positions

APPENDIX E : V

INSTRUCTION \ ADDRESSES	RS	R/W	D7	D6	D5	D4	D3	D2	D1	D0
Display clear	0	0	0	0	0	0	0	0	0	1
Cursor home	0	0	0	0	0	0	0	0	1	*
Entry mode set	0	0	0	0	0	0	0	1	I/D	S
Display on/off control	0	0	0	0	0	0	1	D	C	B
Cursor display shift	0	0	0	0	0	1	S/C	R/L	*	*
Function set	0	0	0	0	1	DL	1	0	*	*
CG RAM address set	0	0	0	1	ACG					
DD RAM address set	0	0	1	ADD						
Busy flag/address read	0	1	BF	AC						
CG RAM/DD RAM data write	1	0	write data							
CG RAM/DD RAM data read	1	1	read data							
Liquid Crystal Display								LTN211		

NOTES :

I/D	•1:increment	I/D	•0:decrement
S	•1:display shift	S	•0:display freeze
D	•1:display on	D	•0:display off
C	•1:cursor on	C	•0:cursor off
B	•1: character at cursor position blinks	B	•0: character at cursor position does not blink
S/C	•1:display shift	S/C	•0:cursor move
R/L	•1:right shift	R/L	•0:left shift
DL	•1:8 bits	DL	•0:4 bits
BF	•1:during internal operation	BF	•0:end of internal operation

Figure B : LTN211 Instruction Set

5.1 The init_display routine

return type	function call	argument/parameter
void	**init_display**	**(void)**

```
{
      io_stream= COMMAND ;
      putchar     ( 0X38 ) ;
      putchar     ( 0x0C ) ;
      putchar     ( 0x06 ) ;
      putchar     ( CLEAR ) ;
      io_stream= DATA
}
```

The **init_display** routine is the first function called from main. The void argument indicates that no arguments are declared for **init_display**.

The LTN211 L.C.D. display module initialization procedure is as follows : -

Refer to **Figure B**, the instruction set for the LTN211 display module.

The Assembler language routine "**PUTCHAR.S03**" is used for cursor control and text output to the LTN211 and to the IBM P.C. screen. The 'putchar' function is incorporated in the C-runtime library enabling the return of ASCII characters to the display and P.C. 'putchar' will print a character each time it is called, for example : -

putchar (c)

prints the contents of the integer variable 'c' as a character.

The **io_stream= COMMAND** line sets the LTN211 display for the acceptance of commands. The command address is **hex 01**, the replacement text defined in the # define lines of the C-program code. The Assembler language program, "PUTCHAR.S03" sets up the command address of the LTN211.

putchar (0x38) returns a value hex 38 as "Function set" command to the LTN211. DL = 1 sets the display to accept 8 bit inputs.

putchar (0x0C) returns hex 0C as a command to the display. The least significant bit D0 is set low to disable blinking of the character at the cursor
position (B=0). D1 is set low, and the cursor is switched off (C=0). D2 is set high, setting the display on (D=1).

putchar (0x06) returns hex 06 as an "Entry mode" command to the display. Display freeze is enabled by setting D0 low (S=0). D1 is set high to increment the cursor position each time a text character is sent to the display (I/D=1).

putchar (CLEAR) uses the defined replacement text 0x01 defined in the program code. The LTN211 is cleared after the command set-up initialization and is ready to accept DATA.

The **io_stream= DATA** sets up the address for data to be sent to the LTN211. (For wind data information as a display read-out).

5.2 The init_rs232 routine

Documentation on the software serial interfacing, the Serial Port Control Register and Timer and Serial Port modes is in **APPENDIX E : vi**

output (TMOD, 0x21) ;

The first line of the routine sets up the Timer/Counter Mode Control Register (TMOD) to operate in timer mode (c/T=0). Timer 1 is set to operating mode 2 as an 8-bit auto reload timer. **(Refer to APPENDIX E, Figure 6 : TMOD)**

output (**TH1, 0xFD**) ;

This sets Timer 1 to a reload value of hex FD. Timer 1 is used to generate a baud rate of 9.6 K at the oscillator frequency, fosc of 11.059 MHz. **(Refer to APPENDIX E, Figure 15 : Timer 1 Baud Rates)**

set_bit (**TR1_bit**) ;

This line starts Timer 1. TR1 is the Timer 1 run control bit in the Timer/Counter Control Register. The counted input hex FD is enabled to Timer 1 when TR1 = 1 and GATE = 0. **(Refer to APPENDIX E, Figure 6 :TMOD and Figure 8 : TCON).**

output (SCON, 0x70) ;

This line sets the Serial Port Mode. It specifies the Serial Port Control Register (SCON) for operation as an 8-bit UART with a variable baud rate. (SM 0 = 0; and SM 1=1 for mode 1 operation). SM 2 = 1 is set to allow multi-processor communication between the 80C32 Serial Port (RXD and TXD) and the I.B.M. P.C. REN = 1 is set to enable serial reception **(Refer to APPENDIX E, Figure 14 : SCON)**.

output (**PCON, 0x00**) ;

This line resets the Serial Port Mode Control Register, (SMOD). The Power Control Register (PCON) is cleared, clearing the most significant bit which clears SMOD **(Refer to APPENDIX E, Figure 28 : PCON)**.

5.3 while (1)

The C-code, **while (1)** is not proceeded by the semi-colon ' ;' which indicates that this individual statement is terminated here.

while (1) is a continuous loop, ("loop forever") and continues to read in information from the A.D.C. channels (**capture_data**); calculate wind velocity and direction from this information (**process_data**) and display this data on the L.C.D. display and to the I.B.M. P.C. screen (**display_data**).

5.4 The capture_data routine

```
void                capture_data  ( )

{

unsigned char      i= 0 ;
              for  ( i= 0;  i< 250;  i++ )
              {
               write_XDATA ( ADC0_wr,00 ) ;
               write_XDATA ( ADC1_wr,00 ) ;
               while ( read_bit (INT0_bit) ) ;
               while ( read_bit (INT1_bit) ) ;
               x+= (float) ( offx- read_XDATA ( ADC1_wr ) ) ;
               y+= (float) ( offy- read_XDATA ( ADC0_wr ) ) ;

              }
               x/= 250.0 ;
               y/= 250.0 ;
```

The **capture_data** routine reads in the A.D.C. N/S and E/W channel 8-bit values (from 0 to 255 depending on wind vector force) and averages these over 250 readings before returning float variables to x and y. The averaging of the A.D.C. channels prevents spurious readings for the eventual display read-out.

return type	function name	argument/parameter
void	**capture_data**	**( )**

The first line declares the function name as **capture_data**. The return type of **capture_data** is **void** which states that no value is returned. The method of communicating data between functions is for the calling function to provide a list of values called arguments, to the function it calls. The parenthesis proceeding the function name surrounds the argument list. In this code, **capture_data** is defined as a function that expects no arguments which is indicated by an open/empty list inside the parenthesis.

```
unsigned char    i= 0 ;
      for    ( i= 0;  i< 250;  i++ )
```

The type qualifier **unsigned char** is always positive or zero and obeys the laws of arithmetic modulo 2^n where n = number of bits in the type. Here there are 8 bits. Unsigned char variables can have values between 0 and 255. (The A.D.C channels were averaged over 250 readings).

The **for** statement is a loop. Within the parenthesis are the parts of the loop. The three parts are separated by semicolons.

The first part of the loop is the initialization : -

```
i= 0 ;
```

This is done once before the loop proper is entered.

The second part is the test controlling the loop : -

i< 250 ;

This condition is evaluated and if true, the body of the loop is executed. The body of the loop lies between the parenthesis expressions { and }. The body of the loop commences at { and ends at }.

This loop will read in 250 N/S channel A.D.C. values and 250 E/W channel A.D.C. readings. These readings will be added and each result is then returned to x and y respectively. These readings must then be divided by 250 for calculation of an average reading. The condition is, "is i less than 250." The less than sign, < is the relational operator.

The body of the loop is described as follows. Input and output use the **read** and **write** system calls which are accessed from the programs through two function calls named **write_XDATA** and **read_XDATA**.

```
write_XDATA  ( ADC0_wr,00 ) ;
write_XDATA  ( ADC1_wr,00 ) ;
```

These statements initialize ADC0 and ADC1 channels and start the analogue-to-digital conversion. ADC0 and ADC1 represent the N/S and E/W ADC channels respectively. The first argument is the address where data is to go to, (hex 2000 for ADC0 and hex 4000 for ADC1). The 2nd argument is the number of bits to be transferred. The value 00 represents a single byte which is transferred.

```
while  ( read_bit (INT0_bit) ) ;
while  ( read_bit (INT1_bit) ) ;
```

These **while** *statements wait for each ADC conversion by reading the interrupt bits of* each ADC. Once a full 8-bit conversion is completed, the interrupt bit is set in the ADC.

```
x += (float) ( offx- read_XDATA (ADC1_wr) ) ;
y += (float) ( offy- read_XDATA (ADC0_wr) ) ;
```

The **x** and **y** global variables were declared as float in the program code. **offx= 128** and **offy= 128** global variables were also declared as floats.

The 8-bit values read in from the ADC channels (values between 0 and 255 depending on the wind vector force) are subtracted from the respective **offx** and **offy** values (128). Thus at zero wind vector force (128) the float variable returned to x will be zero. The + = mathematical operator indicates that values are read in and added to **x** and **y** until 250 readings are read in. Once 250 readings are read in, the loop condition is completed and the program exits from the body of the loop.

```
x/ = 250.0
y/ = 250.0
```

The resultant values in x and y are divided by 250 and the average values are then returned to x and y as global float variables.

5.5 The process_data routine

The **process_data** routine consists of 3 parts : -

angle = get_angle (x, y) ;

: - which will calculate the wind bearing/angle in degrees from the assigned x and y global float variables and return an assigned double precision floating point number to angle.

speed = (int) get_speed (x, y) ;

: - which will calculate the wind velocity from the assigned x and y float variables which are type cast as integers and return an assigned integer result to speed.

direction = get_direction ( ) ;

: - which will assign a pointer to direction for the text strings : "W","SW","S","SE","E","NE","N","NW" and "NULL" declared as **'char'** (character strings) in the program code **(Refer to Section 3)**.

angle = get_angle (x,y) ;

After the **capture_data** routine, the returned global float variables **x** and **y** are the averaged N/S and E/W A.D.C. channel values.

From these **x** and **y** global variables an angle in degrees is returned to **angle** as a double precision floating point number : -

double angle ;

This value is calculated from the called function named **get_angle** : -

```
return type        function name        arguments/parameters
double             get_angle     ( double in 1,  double in 2 )
{
      return       ( a tan 2 ( in 2,  in 1 ) *  180/3.141593 ) ;
}
```

This function uses the assigned x and y float variables to determine wind bearing/angle as follows : -

The resultant return type is cast as a double precision floating point number (**double**). The arguments/parameters type cast the x and y global float variables as double precision floating points, (**double in 1, double in 2**).

return (a tan 2 (in 2, in 1) * 180/3.141593)

calculates a value in degrees and returns this value to angle as a double precision floating point number as follows : -

a tan 2 (in 2, in 1) calculates a value in radians as $\tan^{-1}$ in2/in1 in the range [-II,+II].

* is the multiplication operator. The value in radians multiplied by 180/3.141593 or 180/II will result in a wind bearing/angle in degrees. This double precision floating point number is returned to **'angle' (see section 4 : global variables).**

The routine **get_speed** returns an integer to speed which is the value for wind velocity.

speed = (int)   get_speed   (x, y) ;

The assigned global float variables **x** and **y** are type cast as integers and a resultant integer will be returned to **speed. (Refer to Section 4 : Global Variables).**

The wind velocity value is calculated from the **x** and **y** float variables which are type ca as double precision floating point numbers in the **get_speed** function. A double precisi floating point result is returned from **get_speed**. This resultant double precision floati point number is then type cast/ assigned as an integer in the **speed = (int)** statement.

The resultant integer is the value for calculated wind velocity. This value is calculat from the called function named **get_speed** : -

```
return type         function name        arguments/ parameters
double              get_speed     (double in 1, double in 2)
{
        return      ( pow ( (in 1 * in 1 +  in 2 * in 2),  0.25 ) *  calfactor )
}
```

The type casting procedure of the resultant return type and of the global float variables and y as double precision floating point numbers is identical to the method described in t **get_angle** routine.

return (pow ((in 1 * in 1 + in 2 * in 2), 0.25) * calfactor) ;

calculates a value in m/s and returns this value to **speed** as a double precision floati point number. **speed (int)**, type casts this number as an integer.

The mathematical representation of this calculation is as follows : -

$$(in1^2 + in2^2)^{1/4} \times 4$$

calfactor was declared as a float and is equal to 4. The multiplication operator is t symbol *.

The **get_direction** routine returns a pointer to direction in the statement : -

direction = get_direction ( ) ;

This is a pointer to the declared text strings : -

"W","SW","S","SE","E","NE","N","NW" and "NULL" which are declared as characters. **(Refer to section 3)**

return type	pointer/ function name	argument
char	*** get_direction**	**( )**

The variable return type is specified as a character, **char**. The * de-referencing operator when applied to a pointer accesses the object the pointer points to. **get_direction** has no arguments.

The first line at the **if** chain checks the **x** and **y** global variables and if they are both zero, a pointer value, (NU) is returned to direction. The **!** symbol is the logical 'not equal to' operator in the C-programming language.

The statement is explained as follows : -

if not x & not y
: return pointer NU to 'direction'

If x = zero and y = zero then !x = 1 and !y = 1. Therefore !x && !y = 1 and return a pointer NU to **'direction'.**

This condition/result will only occur when the N/S and E/W channel analogue input offset voltages are both less than + or - 19.53 mV(1 least significant bit for the A.D.C. conversion stage is equal to an analogue voltage of 19.53 mV).

Figure B is a representation of the wind direction dividing angles for the determination of actual wind compass direction. The proceeding **if** chain from line 2 to line 9 to compare the value in degrees in **angle** to determine the pointer position for the eventual display of character strings discussed in **Section 3**. The || is the logical **'or'** operator and **&&** is the logical **'and'** operator. This is explained as follows **(Refer to Figure B)** : -

if +157.5° <= 'angle' || 'angle' < -157.5°
: return pointer W to 'direction'.

if -157.5° <= 'angle' && 'angle' < -112.5°
: return pointer SW to'direction'.

if -112.5° <= 'angle' && 'angle' < -67.5°
: return pointer S to 'direction'.

if -67.5° <= 'angle' && 'angle' < -22.5°
: return pointer SE to 'direction'.

if -22.5° <= 'angle' && 'angle' < +22.5°
: return pointer E to 'direction'.

if +22.5° <= 'angle' && 'angle' < +67.5°
: return pointer NE to 'direction'.

if +67.5° <= 'angle' && 'angle' < +112.5°
: return pointer N to 'direction'.

if +112.5° <= 'angle' && 'angle' < +157.5°
: return pointer NW to 'direction'.

5.6 The display_data routine

The **display_data** routine is a routine that is used to display N/S and E/W A.D.C. channel offset, wind bearing in degrees, wind velocity in m/s and wind direction as a compass direction character string.

This appears as an LTN211 liquid crystal display read-out.

The **display_data** routine also displays wind velocity data to the screen of an I.B.M. P.C. via the RS232 Serial Port.

Within the **display_data** program routine is the set_disp function which sets the LTN211 cursor and line positions for display of wind information. The LTN211 is a 16 character, 2 line L.C.D. display module.

In **init_display**, **io_stream** address was set to **DATA** after initialization of the display. The display is ready to accept data. The cursor is set to the beginning of the first line of the L.C.D. display.

print f ( )

printf writes formatted data to standard output. Returns the number of characters transmitted or a negative value if an error was encountered. Output is performed through library function **putchar** which is adapted in the Assembler language program **"PUTCHAR.S03"** for the targeted LTN211display and IBM P.C. screen display.

A summary of the **printf** conversion specifiers are shown below. Each conversion specification is introduced by the **%** modulus operator. Conversion specifications are within the brackets.

% {flags} {field width} {.precision} {char}

flags : -
+ signed values will always begin with plus or minus sign.
space values will always begin with minus or space

field width : -
Number of characters printed.

.precision : -
Number of digits for floating point value conversion.

char : -
f : floating point constant
u : unsigned decimal value
s : string constant

The function **printf,** prints a character to the display.

function name	("argument 1", argument 2, argument 3) ;
print f	**(" %+3.0f %+3.0f ", x, y) ;**

This statement prints the global float variables **x** and **y** (ADC0 and ADC1 offset) to the display.

printf is a library function in **<stdio.h>** that prints output , the string of characters between the quotes. The format for printing the parenthesised list of arguments is as follows : -

The first, **% + 3.0f** indicates that argument 2, the global float, **x**, must be printed as a floating point number (denoted by **f**), three digits wide (denoted by **3**) with no decimal places after the decimal point (denoted by **.0**).

The flag + indicates that this is a signed value and will always begin with + or - sign. Argument 3 is formatted in the same way. The formatted argument variables x and y have values from + 128 to -127 and are the ADC N/S and E/W channel offset values.

function name	("argument 1", argument 2) ;
print f	**("%3.0f ", angle) ;**

This statement prints the wind bearing/angle to the LCD display. The display cursor is moved to **LINE1 + 11** on the display.

angle is printed as a value between -180 and +180.

set_disp (LINE_2) ;

The display cursor is advanced to the beginning of line 2 of the LTN211 display.

function name	("argument 1", argument 2);
printf	**("S= %2.0u m/s D= " , speed) ;**

The characters **S =**, proceeded by the argument 2 (the value for wind velocity, an integer variable), proceeded by a space and then by the characters **m/s** is printed on line 2. The actual value printed between = and m/s is an unsigned decimal number, 2 digits wide with no decimal places.

This is the wind velocity display read-out and can only be a positive number from 0 to 99. (The hardware anemometer unit was designed to measure wind velocity in the range 0 m/s to 45 m/s.)

A space, then the characters **D** = , proceeded by a space are also printed on line 2 of the display after the string, S= ** **m/s**.

The display cursor position is advanced to line 2 + 12.

set_disp (LINE_2 + 12) ;

function name ("argument 1", argument 2) ;
print f ("%s", * direction) ;

The character strings, **"W"**, **"SW"**, **"S"**, **"SE"**, **"E"**, **"NE"**, **"N"**, **"NW"** and **"NULL"** are printed to the display immediately proceeding the **D** = and **space** characters of the **printf** statement discussed in the previous paragraph.

The * **direction**, argument 2 is a pointer to direction which in turn holds a pointer to these character strings.

The 8 compass direction positions are thus displayed for example as : -

D = NE

or as : -

D = NULL
(under 'no wind' conditions)

The **io_stream** address is then set to the RS232 Serial Port address for printing of wind velocity information to the I.B.M. P.C. screen : -

function name	("argument 1", argument 2)
print f	**("Wind Speed: %2.0u m/s \n", speed) ;**

This prints the text,' **Wind Speed : 40 m/s** '(example for wind velocity value = 40) on the I.B.M. P.C. screen.

The format is the same as for the previous **printf** statements. **\n**, is the new line character, which when printed advances the output to the left margin on the next line for reception of the next wind velocity reading.

Wind velocity readings are instantaneously displayed and updated on the screen.

io_stream = DATA

The **io_stream** = **DATA** statement then sets the **io_stream** address for the acceptance of the next data.

APPENDIX E : VI

vi) INTEL 80C32 Port structures and initialization

intel.

8051, 8052 AND 80C51 HARDWARE DESCRIPTION

INTRODUCTION

This chapter presents a comprehensive description of the on-chip hardware features of the MCS®-51 micro-controllers. Included in this description are

- The port drivers and how they function both as ports and, for Ports 0 and 2, in bus operations
- The Timer/Counters
- The Serial Interface
- The Interrupt System
- Reset
- The Reduced Power Modes in the CHMOS devices
- The EPROM versions of the 8051AH, 8052AH and 80C51BH

The devices under consideration are listed in Table 1. As it becomes unwieldy to be constantly referring to each of these devices by their individual names, we will adopt a convention of referring to them generically as 8051s and 8052s, unless a specific member of the group is being referred to, in which case it will be specifically named. The "8051s" include the 8051AH, 80C51BH, and their ROMless and EPROM versions. The "8052s" are the 8052AH, 8032AH and 8752BH.

Figure 1 shows a functional block diagram of the 8051s and 8052s.

Table 1. The MCS-51 Family of Microcontrollers

Device Name	ROMless Version	EPROM Version	ROM Bytes	RAM Bytes	16-bit Timers	Ckt Type
8051AH	8031AH	8751H, 8751BH	4K	128	2	HMOS
8052AH	8032AH	8752BH	8K	256	3	HMOS
80C51BH	80C31BH	87C51	4K	128	2	CHMOS

Special Function Registers

A map of the on-chip memory area called SFR (Special Function Register) space is shown in Figure 2. SFRs marked by parentheses are resident in the 8052s but not in the 8051s.

8051, 8052 and 80C51 Hardware Description

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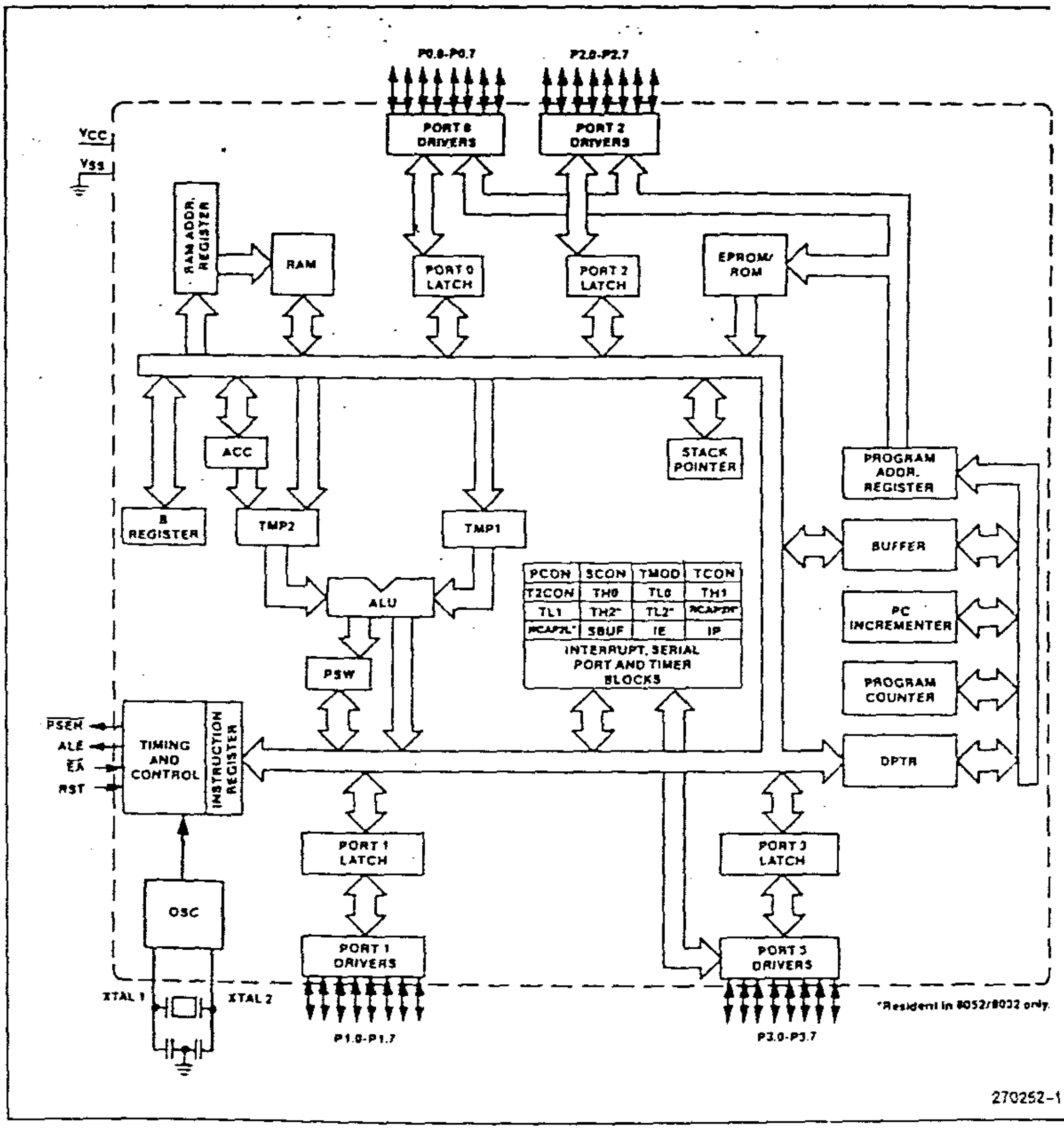


Figure 1. MCS-51 Architectural Block Diagram

8 Bytes

F8									FF
F0	B								F7
E8									EF
E0	ACC								E7
D8									DF
D0	PSW								D7
C8	(T2CON)		(RCAP2L)	(RCAP2H)	(TL2)	(TH2)			CF
C0									C7
B8	IP								BF
B0	P3								B7
A8	IE								AF
A0	P2								A7
98	SCON	SBUF							9F
90	P1								97
88	TCON	TMOD	TL0	TL1	TH0	TH1			8F
80	P0	SP	DPL	DPH				PCON	87

Figure 2. SFR Map. (. . .) Indicates Resident In 8052s, not In 8051s

Note that not all of the addresses are occupied. Unoccupied addresses are not implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have no effect.

User software should not write 1s to these unimplemented locations, since they may be used in future MCS-51 products to invoke new features. In that case the reset or inactive values of the new bits will always be 0, and their active values will be 1.

The functions of the SFRs are outlined below.

ACCUMULATOR

ACC is the Accumulator register. The mnemonics for Accumulator-Specific instructions, however, refer to the Accumulator simply as A.

B REGISTER

The B register is used during multiply and divide operations. For other instructions it can be treated as another scratch pad register.

PROGRAM STATUS WORD

The PSW register contains program status information as detailed in Figure 3.

STACK POINTER

The Stack Pointer Register is 8 bits wide. It is incremented before data is stored during PUSH and CALL executions. While the stack may reside anywhere in on-chip RAM, the Stack Pointer is initialized to 07H after a reset. This causes the stack to begin at location 08H.

DATA POINTER

The Data Pointer (DPTR) consists of a high byte (DPH) and a low byte (DPL). Its intended function is to hold a 16-bit address. It may be manipulated as a 16-bit register or as two independent 8-bit registers.

PORTS 0 TO 3

P0, P1, P2 and P3 are the SFR latches of Ports 0, 1, 2 and 3, respectively.

SERIAL DATA BUFFER

The Serial Data Buffer is actually two separate registers, a transmit buffer and a receive buffer register. When data is moved to SBUF, it goes to the transmit buffer where it is held for serial transmission. (Moving a byte to SBUF is what initiates the transmission.) When data is moved from SBUF, it comes from the receive buffer.

TIMER REGISTERS

Register pairs (TH0, TL0), (TH1, TL1), and (TH2, TL2) are the 16-bit Counting registers for Timer/Counters 0, 1, and 2, respectively.

CAPTURE REGISTERS

The register pair (RCAP2H, RCAP2L) are the Capture registers for the Timer 2 "Capture Mode." In this mode, in response to a transition at the 8052's T2EX pin, TH2 and TL2 are copied into RCAP2H and RCAP2L. Timer 2 also has a 16-bit auto-reload mode and RCAP2H and RCAP2L hold the reload value for this mode. More about Timer 2's features in a later section.

CONTROL REGISTERS

Special Function Registers IP, IE, TMOD, TCON, T2CON, SCON, and PCON contain control and status bits for the interrupt system, the Timer/Counters, and the serial port. They are described in later sections.

(MSB) (LSB)

CY	AC	F0	RS1	RS0	OV	—	P

Symbol	Position	Name and Significance
CY	PSW.7	Carry flag.
AC	PSW.6	Auxiliary Carry flag. (For BCD operations.)
F0	PSW.5	Flag 0 (Available to the user for general purposes.)
RS1	PSW.4	Register bank select control bits 1 &
RS0	PSW.3	0. Set/cleared by software to determine working register bank (see Note).
OV	PSW.2	Overflow flag.
—	PSW.1	User definable flag.
P	PSW.0	Parity flag. Set/cleared by hardware each instruction cycle to indicate an odd/even number of "one" bits in the Accumulator, i.e., even parity.

NOTE:
The contents of (RS1, RS0) enable the working register banks as follows:

(0.0)—Bank 0 (00H–07H)
(0.1)—Bank 1 (08H–0FH)
(1.0)—Bank 2 (10H–17H)
(1.1)—Bank 3 (18H–1FH)

Figure 3. PSW: Program Status Word Register

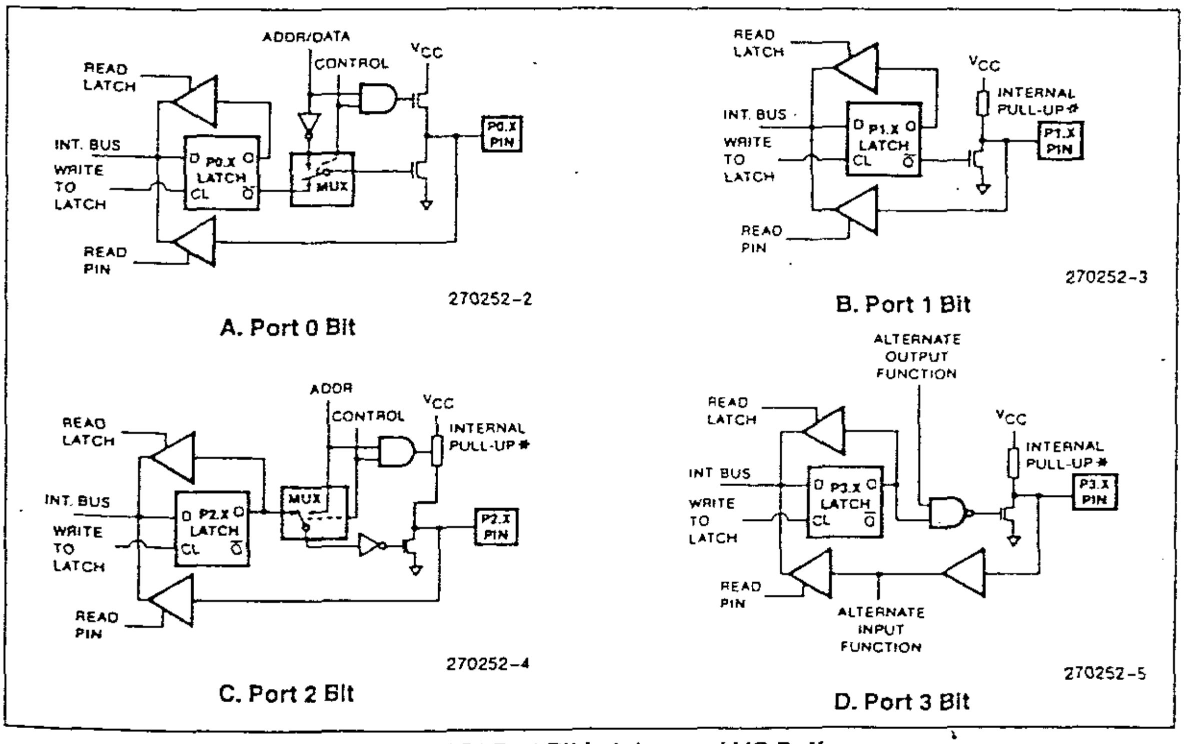


Figure 4. 8051 Port Bit Latches and I/O Buffers
*See Figure 5 for details of the internal pullup.

PORT STRUCTURES AND OPERATION

All four ports in the 8051 are bidirectional. Each consists of a latch (Special Function Registers P0 through P3), an output driver, and an input buffer.

The output drivers of Ports 0 and 2, and the input buffers of Port 0, are used in accesses to external memory. In this application, Port 0 outputs the low byte of the external memory address, time-multiplexed with the byte being written or read. Port 2 outputs the high byte of the external memory address when the address is 16 bits wide. Otherwise the Port 2 pins continue to emit the P2 SFR content.

All the Port 3 pins, and (in the 8052) two Port 1 pins are multifunctional. They are not only port pins, but also serve the functions of various special features as listed on the following page.

Port Pin	Alternate Function
*P1.0	T2 (Timer/Counter 2 external input)
*P1.1	T2EX (Timer/Counter 2 Capture/Reload trigger)
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt)
P3.3	$\overline{\text{INT1}}$ (external interrupt)
P3.4	T0 (Timer/Counter 0 external input)
P3.5	T1 (Timer/Counter 1 external input)
P3.6	$\overline{\text{WR}}$ (external Data Memory write strobe)
P3.7	$\overline{\text{RD}}$ (external Data Memory read strobe)

*P1.0 and P1.1 serve these alternate functions only on the 8052.

The alternate functions can only be activated if the corresponding bit latch in the port SFR contains a 1. Otherwise the port pin is stuck at 0.

I/O Configurations

Figure 4 shows a functional diagram of a typical bit latch and I/O buffer in each of the four ports. The bit latch (one bit in the port's SFR) is represented as a Type D flip-flop, which will clock in a value from the internal bus in response to a "write to latch" signal from the CPU. The Q output of the flip-flop is placed on the internal bus in response to a "read latch" signal from the CPU. The level of the port pin itself is placed on the internal bus in response to a "read pin" signal from the CPU. Some instructions that read a port activate the "read latch" signal, and others activate the "read pin" signal. More about that later.

As shown in Figure 4, the output drivers of Ports 0 and 2 are switchable to an internal ADDR and ADDR/DATA bus by an internal CONTROL signal for use in external memory accesses. During external memory accesses, the P2 SFR remains unchanged, but the P0 SFR gets 1s written to it.

Also shown in Figure 4, is that if a P3 bit latch contains a 1, then the output level is controlled by the signal labeled "alternate output function." The actual P3.X pin level is always available to the pin's alternate input function, if any.

Ports 1, 2, and 3 have internal pullups. Port 0 has open drain outputs. Each I/O line can be independently used as an input or an output. (Ports 0 and 2 may not be used as general purpose I/O when being used as the ADDR/DATA BUS). To be used as an input, the port bit latch must contain a 1, which turns off the output driver FET. Then, for Ports 1, 2, and 3, the pin is pulled high by the internal pullup, but can be pulled low by an external source.

Port 0 differs in not having internal pullups. The pullup FET in the P0 output driver (see Figure 4) is used only when the Port is emitting 1s during external memory accesses. Otherwise the pullup FET is off. Consequently P0 lines that are being used as output port lines are open drain. Writing a 1 to the bit latch leaves both output FETs off, so the pin floats. In that condition it can be used a high-impedance input.

Because Ports 1, 2, and 3 have fixed internal pullups they are sometimes called "quasi-bidirectional" ports. When configured as inputs they pull high and will source current (IIL, in the data sheets) when externally pulled low. Port 0, on the other hand, is considered "true" bidirectional, because when configured as an input it floats.

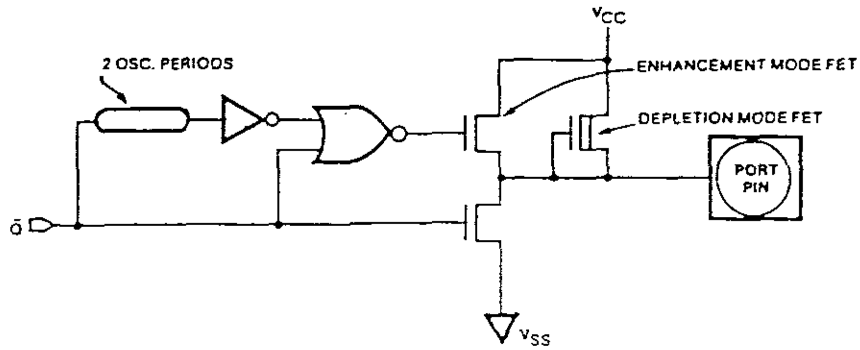
All the port latches in the 8051 have 1s written to them by the reset function. If a 0 is subsequently written to a port latch, it can be reconfigured as an input by writing a 1 to it.

Writing to a Port

In the execution of an instruction that changes the value in a port latch, the new value arrives at the latch during S6P2 of the final cycle of the instruction. However, port latches are in fact sampled by their output buffers only during Phase 1 of any clock period. (During Phase 2 the output buffer holds the value it saw during the previous Phase 1). Consequently, the new value in the port latch won't actually appear at the output pin until the next Phase 1, which will be at S1P1 of the next machine cycle. See Figure 39 in the Internal Timing section.

If the change requires a 0-to-1 transition in Port 1, 2, or 3, an additional pullup is turned on during S1P1 and S1P2 of the cycle in which the transition occurs. This is done to increase the transition speed. The extra pullup can source about 100 times the current that the normal pullup can. It should be noted that the internal pullups are field-effect transistors, not linear resistors. The pullup arrangements are shown in Figure 5.

In HMOS versions of the 8051, the fixed part of the pullup is a depletion-mode transistor with the gate wired to the source. This transistor will allow the pin to source about 0.25 mA when shorted to ground. In parallel with the fixed pullup is an enhancement-mode transistor, which is activated during S1 whenever the port bit does a 0-to-1 transition. During this interval, if the port pin is shorted to ground, this extra transistor will allow the pin to source an additional 30 mA.



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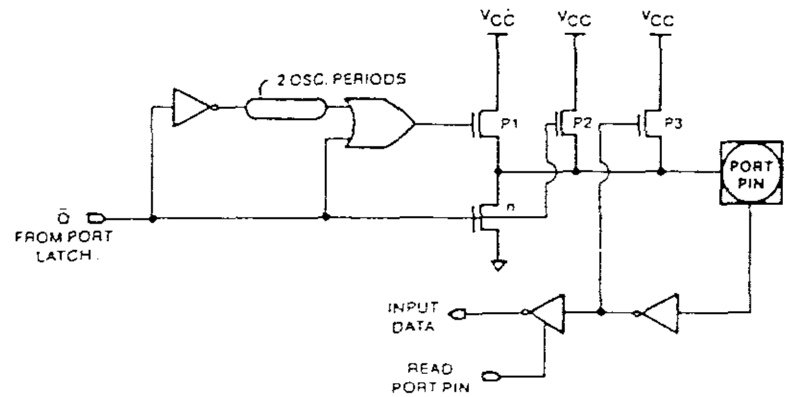
A. HMOS Configuration. The enhancement mode transistor is turned on for 2 osc. periods after Q̄ makes a 0-to-1 transition.



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B. CHMOS Configuration. pFET 1 is turned on for 2 osc. periods after Q̄ makes a 0-to-1 transition. During this time, pFET 1 also turns on pFET 3 through the inverter to form a latch which holds the 1. pFET 2 is also on.

Figure 5. Ports 1 And 3 HMOS And CHMOS Internal Pullup Configurations. Port 2 is Similar Except That It Holds The Strong Pullup On While Emitting 1s That Are Address Bits. (See Text, "Accessing External Memory".)

In the CHMOS versions, the pullup consists of three pFETs. It should be noted that an n-channel FET (nFET) is turned on when a logical 1 is applied to its gate, and is turned off when a logical 0 is applied to its gate. A p-channel FET (pFET) is the opposite: it is on when its gate sees a 0, and off when its gate sees a 1.

pFET1 in Figure 5 is the transistor that is turned on for 2 oscillator periods after a 0-to-1 transition in the port latch. While it's on, it turns on pFET3 (a weak pull-up), through the inverter. This inverter and pFET form a latch which hold the 1.

Note that if the pin is emitting a 1, a negative glitch on the pin from some external source can turn off pFET3, causing the pin to go into a float state. pFET2 is a very weak pullup which is on whenever the nFET is off, in traditional CMOS style. It's only about $1/_{10}$ the strength of pFET3. Its function is to restore a 1 to the pin in the event the pin *had* a 1 and lost it to a glitch.

Port Loading and Interfacing

The output buffers of Ports 1, 2, and 3 can each driv LS TTL inputs. These ports on HMOS versions can driven in a normal manner by any TTL or NMOS cuit. Both HMOS and CHMOS pins can be driven open-collector and open-drain outputs, but note that to-1 transitions will not be fast. In the HMOS device the pin is driven by an open-collector output, a 0-t transition will have to be driven by the relatively we depletion mode FET in Figure 5(A). In the CHM device, an input 0 turns off pullup pFET3, leaving o the very weak pullup pFET2 to drive the transition.

In external bus mode, Port 0 output buffers can ea drive 8 LS TTL inputs. As port pins, they require ext nal pullups to drive any inputs.

Read-Modify-Write Feature

Some instructions that read a port read the latch and others read the pin. Which ones do which? The instructions that read the latch rather than the pin are the ones that read a value, possibly change it, and then rewrite it to the latch. These are called "read-modify-write" instructions. The instructions listed below are read-modify-write instructions. When the destination operand is a port, or a port bit, these instructions read the latch rather than the pin:

ANL	(logical AND, e.g., ANL P1, A)
ORL	(logical OR, e.g., ORL P2, A)
XRL	(logical EX-OR, e.g., XRL P3, A)
JBC	(jump if bit = 1 and clear bit, e.g., JBC P1.1, LABEL)
CPL	(complement bit, e.g., CPL P3.0)
INC	(increment, e.g., INC P2)
DEC	(decrement, e.g., DEC P2)
DJNZ	(decrement and jump if not zero, e.g., DJNZ P3, LABEL)
MOV, PX.Y, C	(move carry bit to bit Y of Port X)
CLR PX.Y	(clear bit Y of Port X)
SETB PX.Y	(set bit Y of Port X)

It is not obvious that the last three instructions in this list are read-modify-write instructions, but they are. They read the port byte, all 8 bits, modify the addressed bit, then write the new byte back to the latch.

The reason that read-modify-write instructions are directed to the latch rather than the pin is to avoid a possible misinterpretation of the voltage level at the pin. For example, a port bit might be used to drive the base of a transistor. When a 1 is written to the bit, the transistor is turned on. If the CPU then reads the same port bit at the pin rather than the latch, it will read the base voltage of the transistor and interpret it as a 0. Reading the latch rather than the pin will return the correct value of 1.

ACCESSING EXTERNAL MEMORY

Accesses to external memory are of two types: accesses to external Program Memory and accesses to external Data Memory. Accesses to external Program Memory use signal $\overline{PSEN}$ (program store enable) as the read strobe. Accesses to external Data Memory use $\overline{RD}$ or $\overline{WR}$ (alternate functions of P3.7 and P3.6) to strobe the memory. Refer to Figures 36 through 38 in the Internal Timing section.

Fetches from external Program Memory always use a 16-bit address. Accesses to external Data Memory can use either a 16-bit address (MOVX @DPTR) or an 8-bit address (MOVX @Ri).

Whenever a 16-bit address is used, the high byte of the address comes out on Port 2, where it is held for the duration of the read or write cycle. Note that the Port 2 drivers use the strong pullups during the entire time that they are emitting address bits that are 1s. This is during the execution of a MOVX @DPTR instruction. During this time the Port 2 latch (the Special Function Register) does not have to contain 1s, and the contents of the Port 2 SFR are not modified. If the external memory cycle is not immediately followed by another external memory cycle, the undisturbed contents of the Port 2 SFR will reappear in the next cycle.

If an 8-bit address is being used (MOVX @Ri), the contents of the Port 2 SFR remain at the Port 2 pins throughout the external memory cycle. This will facilitate paging.

In any case, the low byte of the address is time-multiplexed with the data byte on Port 0. The ADDR/DATA signal drives both FETs in the Port 0 output buffers. Thus, in this application the Port 0 pins are not open-drain outputs, and do not require external pullups. Signal ALE (Address Latch Enable) should be used to capture the address byte into an external latch. The address byte is valid at the negative transition of ALE. Then, in a write cycle, the data byte to be written appears on Port 0 just before $\overline{WR}$ is activated, and remains there until after $\overline{WR}$ is deactivated. In a read cycle, the incoming byte is accepted at Port 0 just before the read strobe is deactivated.

During any access to external memory, the CPU writes 0FFH to the Port 0 latch (the Special Function Register), thus obliterating whatever information the Port 0 SFR may have been holding. If the user writes to Port 0 during an external memory fetch, the incoming code byte is corrupted. Therefore, do not write to Port 0 if external program memory is used.

External Program Memory is accessed under two conditions:

1) Whenever signal $\overline{EA}$ is active; or
2) Whenever the program counter (PC) contains a number that is larger than 0FFFH (1FFFH for the 8052).

This requires that the ROMless versions have $\overline{EA}$ wired low to enable the lower 4K (8K for the 8032) program bytes to be fetched from external memory.

When the CPU is executing out of external Program Memory, all 8 bits of Port 2 are dedicated to an output function and may not be used for general purpose I/O. During external program fetches they output the high byte of the PC. During this time the Port 2 drivers use the strong pullups to emit PC bits that are 1s.

TIMER/COUNTERS

The 8051 has two 16-bit Timer/Counter registers: Timer 0 and Timer 1. The 8052 has these two plus one more: Timer 2. All three can be configured to operate either as timers or event counters.

In the "Timer" function, the register is incremented every machine cycle. Thus, one can think of it as counting machine cycles. Since a machine cycle consists of 12 oscillator periods, the count rate is 1/12 of the oscillator frequency.

In the "Counter" function, the register is incremented in response to a 1-to-0 transition at its corresponding external input pin, T0, T1 or (in the 8052) T2. In this function, the external input is sampled during S5P2 of every machine cycle. When the samples show a high in one cycle and a low in the next cycle, the count is incremented. The new count value appears in the register during S3P1 of the cycle following the one in which the transition was detected. Since it takes 2 machine cycles (24 oscillator periods) to recognize a 1-to-0 transition, the maximum count rate is 1/24 of the oscillator frequency. There are no restrictions on the duty cycle of the external input signal, but to ensure that a given level is sampled at least once before it changes, it should be held for at least one full machine cycle.

In addition to the "Timer" or "Counter" selection, Timer 0 and Timer 1 have four operating modes from which to select. Timer 2, in the 8052, has three modes of operation: "Capture," "Auto-Reload" and "baud rate generator."

Timer 0 and Timer 1

These Timer/Counters are present in both the 8051 and the 8052. The "Timer" or "Counter" function is selected by control bits C/$\overline{T}$ in the Special Function Register TMOD (Figure 6). These two Timer/Counters have four operating modes, which are selected by bit-p (M1, M0) in TMOD. Modes 0, 1, and 2 are the s for both Timer/Counters. Mode 3 is different. The operating modes are described in the following tex

MODE 0

Either Timer in Mode 0 is an 8-bit Counter wit divide-by-32 prescaler. This 13-bit timer is MCS compatible. Figure 7 shows the Mode 0 operation a applies to Timer 1.

In this mode, the Timer register is configured a 13-Bit register. As the count rolls over from all 1s to 0s, it sets the Timer interrupt flag TF1. The coun input is enabled to the Timer when TR1 = 1 and eit GATE = 0 or $\overline{INT1}$ = 1. (Setting GATE = 1 allc the Timer to be controlled by external input $\overline{INT1}$, facilitate pulse width measurements.) TR1 is a cont bit in the Special Function Register TCON (Figure GATE is in TMOD.

The 13-Bit register consists of all 8 bits of TH1 and t lower 5 bits of TL1. The upper 3 bits of TL1 are inc terminate and should be ignored. Setting the run fl (TR1) does not clear the registers.

Mode 0 operation is the same for Timer 0 as for Tim 1. Substitute TR0, TF0 and $\overline{INT0}$ for the correspon ing Timer 1 signals in Figure 7. There are two differe GATE bits, one for Timer 1 (TMOD.7) and one f Timer 0 (TMOD.3).

MODE 1

Mode 1 is the same as Mode 0, except that the Tim register is being run with all 16 bits.

(MSB)							(LSB)
GATE	C/$\overline{T}$	M1	M0	GATE	C/$\overline{T}$	M1	M0
Timer 1				Timer 0			

GATE	Gating control when set. Timer/Counter "x" is enabled only while "$\overline{INTx}$" pin is high and "TRx" control pin is set. When cleared Timer "x" is enabled whenever "TRx" control bit is set.
C/$\overline{T}$	Timer or Counter Selector cleared for Timer operation (input from internal system clock). Set for Counter operation (input from "Tx" input pin).

M1	M0	Operating Mode
0	0	8-bit Timer/Counter "THx" with "TLx" as 5-bit prescaler.
0	1	16-bit Timer/Counter "THx" and "TLx" are cascaded; there is no prescaler.
1	0	8-bit auto-reload Timer/Counter "THx" holds a value which is to be reloaded into "TLx" each time it overflows.
1	1	(Timer 0) TL0 is an 8-bit Timer/Counter controlled by the standard Timer 0 control bits. TH0 is an 8-bit timer only controlled by Timer 1 control bits.
1	1	(Timer 1) Timer/Counter 1 stopped.

Figure 6. TMOD: Timer/Counter Mode Control Register

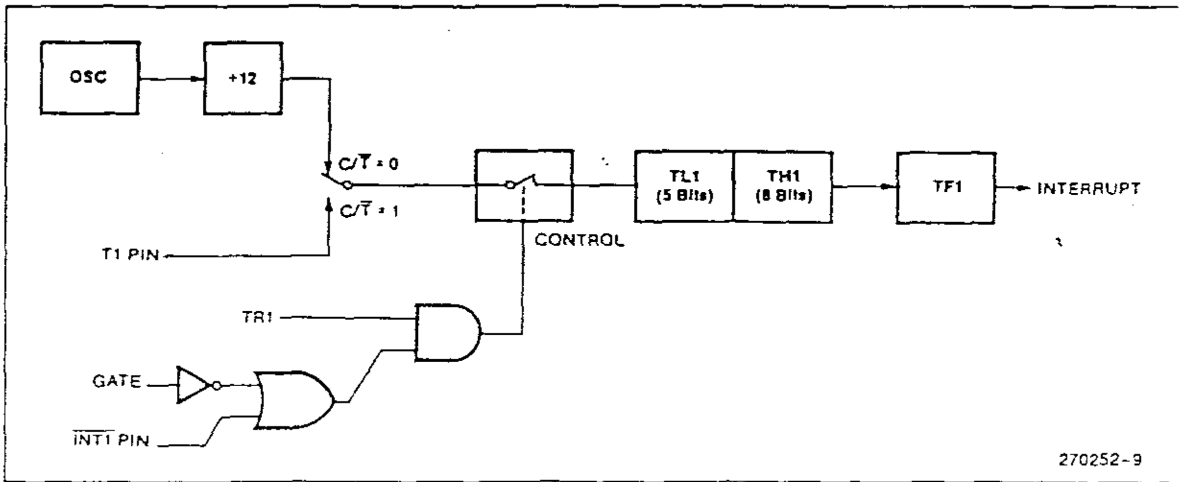

Figure 7. Timer/Counter 1 Mode 0: 13-Bit Counter

(MSB)							(LSB)
TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0

Symbol	Position	Name and Significance
TF1	TCON.7	Timer 1 overflow Flag. Set by hardware on Timer/Counter overflow. Cleared by hardware when processor vectors to interrupt routine.
TR1	TCON.6	Timer 1 Run control bit. Set/cleared by software to turn Timer/Counter on/off.
TF0	TCON.5	Timer 0 overflow Flag. Set by hardware on Timer/Counter overflow. Cleared by hardware when processor vectors to interrupt routine.
TR0	TCON.4	Timer 0 Run control bit. Set/cleared by software to turn Timer/Counter on/off.
IE1	TCON.3	Interrupt 1 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT1	TCON.2	Interrupt 1 Type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.
IE0	TCON.1	Interrupt 0 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
IT0	TCON.0	Interrupt 0 Type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.

Figure 8.TCON: Timer/Counter Control Register

MODE 2

Mode 2 configures the Timer register as an 8-bit Counter (TL1) with automatic reload, as shown in Figure 9. Overflow from TL1 not only sets TF1, but also reloads TL1 with the contents of TH1, which is preset by software. The reload leaves TH1 unchanged.

Mode 2 operation is the same for Timer/Counter 0.

MODE 3

Timer 1 in Mode 3 simply holds its count. The effect is the same as setting TR1 = 0.

Timer 0 in Mode 3 establishes TL0 and TH0 as tw separate counters. The logic for Mode 3 on Timer 0 i shown in Figure 10. TL0 uses the Timer 0 control bits C/$\overline{T}$, GATE, TR0, $\overline{INT0}$, and TF0. TH0 is locked int a timer function (counting machine cycles) and take over the use of TR1 and TF1 from Timer 1. Thus, TH now controls the "Timer 1" interrupt.

Mode 3 is provided for applications requiring an extr 8-bit timer or counter. With Timer 0 in Mode 3, a 8051 can look like it has three Timer/Counters, and a 8052, like it has four. When Timer 0 is in Mode 3 Timer 1 can be turned on and off by switching it out o and into its own Mode 3, or can still be used by th serial port as a baud rate generator, or in fact, in an application not requiring an interrupt.

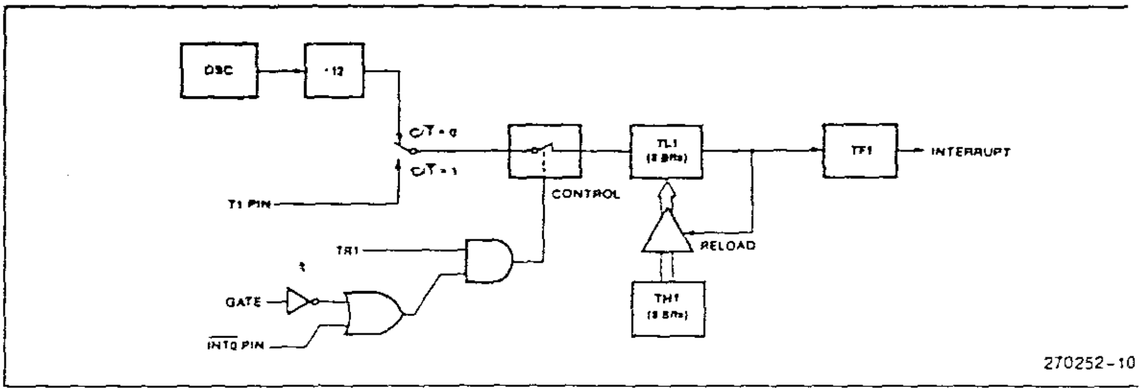

Figure 9. Timer/Counter 1 Mode 2: 8-Bit Auto-Reload

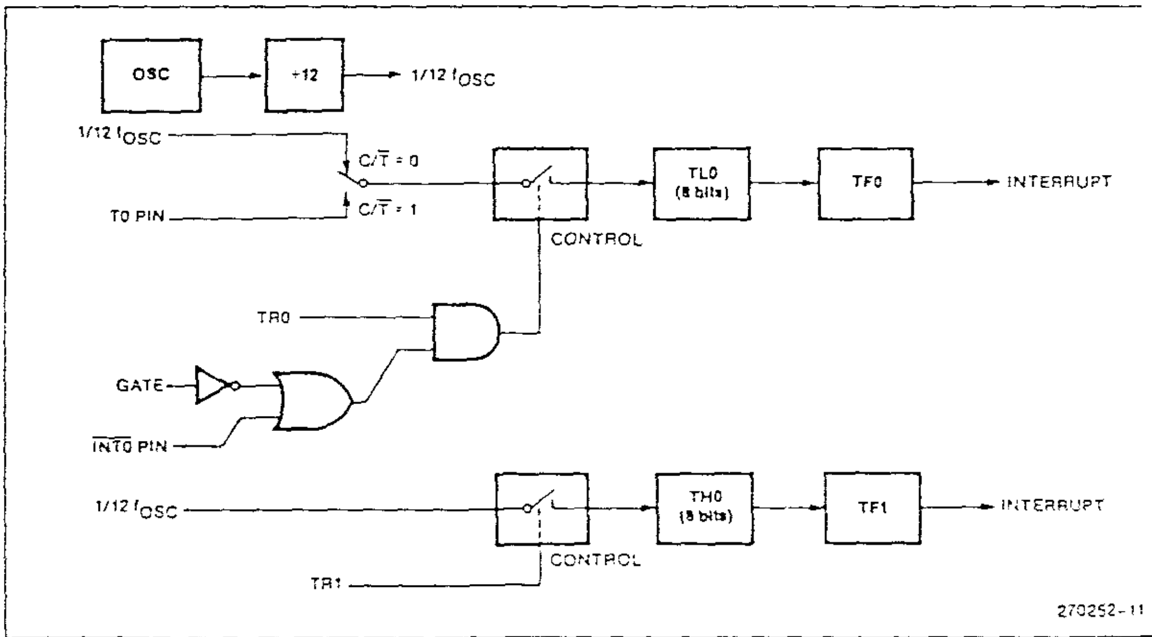

Figure 10. Timer/Counter 0 Mode 3: Two 8-Bit Counters

Timer 2

Timer 2 is a 16-bit Timer/Counter which is present only in the 8052. Like Timers 0 and 1, it can operate either as a timer or as an event counter. This is selected by bit C/$\overline{T2}$ in the Special Function Register T2CON (Figure 11). It has three operating modes: "capture," "auto-load" and "baud rate generator," which are selected by bits in T2CON as shown in Table 2.

Table 2. Timer 2 Operating Modes

RCLK + TCLK	CP/$\overline{RL2}$	TR2	Mode
0	0	1	16-bit Auto-Reload
0	1	1	16-bit Capture
1	X	1	Baud Rate Generator
X	X	0	(off)

(MSB) (LSB)

TF2	EXF2	RCLK	TCLK	EXEN2	TR2	C/$\overline{T2}$	CP/$\overline{RL2}$

Symbol	Position	Name and Significance
TF2	T2CON.7	Timer 2 overflow flag set by a Timer 2 overflow and must be cleared by software. TF2 will not be set when either RCLK = 1 or TCLK = 1.
EXF2	T2CON.6	Timer 2 external flag set when either a capture or reload is caused by a negative transition on T2EX and EXEN2 = 1. When Timer 2 interrupt is enabled, EXF2 = 1 will cause the CPU to vector to the Timer 2 interrupt routine. EXF2 must be cleared by software.
RCLK	T2CON.5	Receive clock flag. When set, causes the serial port to use Timer 2 overflow pulses for its receive clock in Modes 1 and 3. RCLK = 0 causes Timer 1 overflow to be used for the receive clock.
TCLK	T2CON.4	Transmit clock flag. When set, causes the serial port to use Timer 2 overflow pulses for its transmit clock in modes 1 and 3. TCLK = 0 causes Timer 1 overflows to be used for the transmit clock.
EXEN2	T2CON.3	Timer 2 external enable flag. When set, allows a capture or reload to occur as a result of a negative transition on T2EX if Timer 2 is not being used to clock the serial port. EXEN2 = 0 causes Timer 2 to ignore events at T2EX.
TR2	T2CON.2	Start/stop control for Timer 2. A logic 1 starts the timer.
C/$\overline{T2}$	T2CON.1	Timer or counter select. (Timer 2) 0 = Internal timer (OSC/12) 1 = External event counter (falling edge triggered).
CP/$\overline{RL2}$	T2CON.0	Capture/Reload flag. When set, captures will occur on negative transitions at T2EX if EXEN2 = 1. When cleared, auto-reloads will occur either with Timer 2 overflows or negative transitions at T2EX when EXEN2 = 1. When either RCLK = 1 or TCLK = 1, this bit is ignored and the timer is forced to auto-reload on Timer 2 overflow.

Figure 11. T2CON: Timer/Counter 2 Control Register

In the Capture Mode there are two options which are selected by bit EXEN2 in T2CON. If EXEN2 = 0, then Timer 2 is a 16-bit timer or counter which upon overflowing sets bit TF2, the Timer 2 overflow bit, which can be used to generate an interrupt. If EXEN2 = 1, then Timer 2 still does the above, but with the added feature that a 1-to-0 transition at external input T2EX causes the current value in the Timer 2 registers, TL2 and TH2, to be captured into registers RCAP2L and RCAP2H, respectively. (RCAP2L and RCAP2H are new Special Function Registers in the 8052.) In addition, the transition at T2EX causes bit EXF2 in T2CON to be set, and EXF2, like TF2, can generate an interrupt.

The Capture Mode is illustrated in Figure 12.

In the auto-reload mode there are again two options, which are selected by bit EXEN2 in T2CON. If EXEN2 = 0, then when Timer 2 rolls over it not only sets TF2 but also causes the Timer 2 registers to be reloaded with the 16-bit value in registers RCAP2L and RCAP2H, which are preset by software. If EXEN2 = 1, then Timer 2 still does the above, but with the added feature that a 1-to-0 transition at external input T2EX will also trigger the 16-bit reload and set EXF2.

The auto-reload mode is illustrated in Figure 13.

The baud rate generator mode is selected by RCLK = 1 and/or TCLK = 1. It will be described in conjunction with the serial port.

SERIAL INTERFACE

The serial port is full duplex, meaning it can transmit and receive simultaneously. It is also receive-buffered, meaning it can commence reception of a second byte before a previously received byte has been read from the receive register. (However, if the first byte still hasn't been read by the time reception of the second byte is complete, one of the bytes will be lost). The serial port receive and transmit registers are both accessed at Special Function Register SBUF. Writing to SBUF loads the transmit register, and reading SBUF accesses a physically separate receive register.

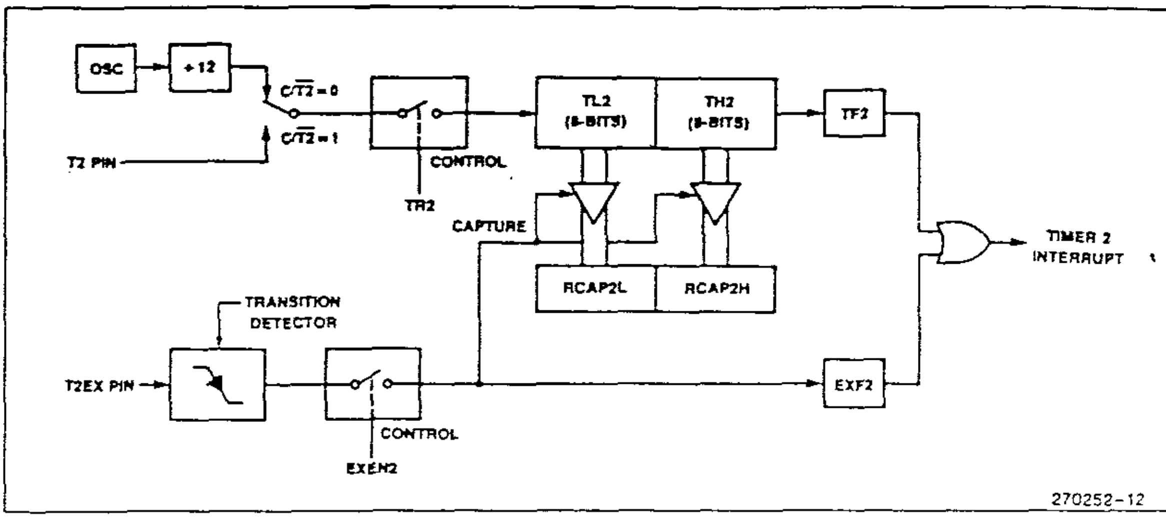

Figure 12. Timer 2 In Capture Mode

The serial port can operate in 4 modes:

Mode 0: Serial data enters and exits through RXD. TXD outputs the shift clock. 8 bits are transmitted/received: 8 data bits (LSB first). The baud rate is fixed at 1/12 the oscillator frequency.

Mode 1: 10 bits are transmitted (through TXD) or received (through RXD): a start bit (0), 8 data bits (LSB first), and a stop bit (1). On receive, the stop bit goes into RB8 in Special Function Register SCON. The baud rate is variable.

Mode 2: 11 bits are transmitted (through TXD) or received (through RXD): a start bit (0), 8 data bits (LSB first), a programmable 9th data bit, and a stop bit (1). On Transmit, the 9th data bit (TB8 in SCON) can be assigned the value of 0 or 1. Or, for example, the parity bit (P, in the PSW) could be moved into TB8. On receive, the 9th data bit goes into RB8 in Special Functon Register SCON, while the stop bit is ignored. The baud rate is programmable to either $1/32$ or $1/64$ the oscillator frequency.

Mode 3: 11 bits are transmitted (through TXD) or received (through RXD): a start bit (0), 8 data bits (LSB first), a programmable 9th data bit and a stop bit (1). In fact, Mode 3 is the same as Mode 2 in all respects except the baud rate. The baud rate in Mode 3 is variable.

In all four modes, transmission is initiated by any instruction that uses SBUF as a destination register. Reception is initiated in Mode 0 by the condition RI = 0 and REN = 1. Reception is initiated in the other modes by the incoming start bit if REN = 1.

Multiprocessor Communications

Modes 2 and 3 have a special provision for multiprocessor communications. In these modes, 9 data bits are received. The 9th one goes into RB8. Then comes a stop bit. The port can be programmed such that when the stop bit is received, the serial port interrupt will be activated only if RB8 = 1. This feature is enabled by setting bit SM2 in SCON. A way to use this feature in multiprocessor systems is as follows.

When the master processor wants to transmit a block of data to one of several slaves, it first sends out an address byte which identifies the target slave. An address byte differs from a data byte in that the 9th bit is 1 in an address byte and 0 in a data byte. With SM2 = 1, no slave will be interrupted by a data byte. An address byte, however, will interrupt all slaves, so that each slave can examine the received byte and see if it is being addressed. The addressed slave will clear its SM2 bit and prepare to receive the data bytes that will be coming. The slaves that weren't being addressed leave their SM2s set and go on about their business, ignoring the coming data bytes.

SM2 has no effect in Mode 0, and in Mode 1 can be used to check the validity of the stop bit. In a Mode 1 reception, if SM2 = 1, the receive interrupt will not be activated unless a valid stop bit is received.

Serial Port Control Register

The serial port control and status register is the Special Function Register SCON, shown in Figure 14. This register contains not only the mode selection bits, but also the 9th data bit for transmit and receive (TB8 and RB8), and the serial port interrupt bits (TI and RI).

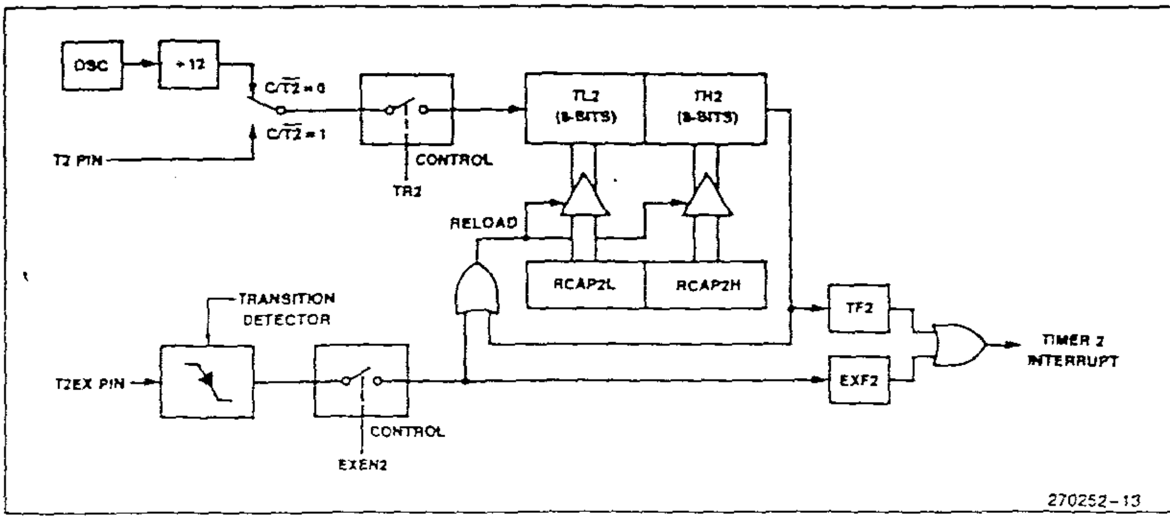

Figure 13. Timer 2 in Auto-Reload Mode

(MSB) (LSB)

SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Where SM0, SM1 specify the serial port mode, as follows:

SM0	SM1	Mode	Description	Baud Rate
0	0	0	shift register	$f_{osc.}/12$
0	1	1	8-bit UART	variable
1	0	2	9-bit UART	$f_{osc.}/64$ or $f_{osc.}/32$
1	1	3	9-bit UART	variable

- SM2 enables the multiprocessor communication feature in Modes 2 and 3. In Mode 2 or 3, if SM2 is set to 1 then RI will not be activated if the received 9th data bit (RB8) is 0. In Mode 1, if SM2 = 1 then RI will not be activated if a valid stop bit was not received. In Mode 0, SM2 should be 0.
- REN enables serial reception. Set by software to enable reception. Clear by software to disable reception.
- TB8 is the 9th data bit that will be transmitted in Modes 2 and 3. Set or clear by software as desired.
- RB8 in Modes 2 and 3, is the 9th data bit that was received. In Mode 1, if SM2 = 0, RB8 is the stop bit that was received. In Mode 0, RB8 is not used.
- TI is transmit interrupt flag. Set by hardware at the end of the 8th bit time in Mode 0, or at the beginning of the stop bit in the other modes, in any serial transmission. Must be cleared by software.
- RI is receive interrupt flag. Set by hardware at the end of the 8th bit time in Mode 0, or halfway through the stop bit time in the other modes, in any serial reception (except see SM2). Must be cleared by software.

Figure 14. SCON: Serial Port Control Register

Baud Rates

The baud rate in Mode 0 is fixed:

$$\text{Mode 0 Baud Rate} = \frac{\text{Oscillator Frequency}}{12}$$

The baud rate in Mode 2 depends on the value of bit SMOD in Special Function Register PCON. If SMOD = 0 (which is the value on reset), the baud rate $^1/_{64}$ the oscillator frequency. If SMOD = 1, the baud rate is $^1/_{32}$ the oscillator frequency.

$$\text{Mode 2 Baud Rate} = \frac{2^{SMOD}}{64} \times (\text{Oscillator Frequency})$$

In the 8051, the baud rates in Modes 1 and 3 are determined by the Timer 1 overflow rate. In the 8052, these baud rates can be determined by Timer 1, or by Timer 2, or by both (one for transmit and the other for receive).

Using Timer 1 to Generate Baud Rates

When Timer 1 is used as the baud rate generator, the baud rates in Modes 1 and 3 are determined by the Timer 1 overflow rate and the value of SMOD as follows:

$$\text{Modes 1, 3 Baud Rate} = \frac{2^{SMOD}}{32} \times (\text{Timer 1 Overflow Rate})$$

The Timer 1 interrupt should be disabled in this application. The Timer itself can be configured for either "timer" or "counter" operation, and in any of its 3 running modes. In the most typical applications, it is configured for "timer" operation, in the auto-reload mode (high nibble of TMOD = 0010B). In that ca the baud rate is given by the formula

$$\text{Modes 1, 3 Baud Rate} = \frac{2^{SMOD}}{32} \times \frac{\text{Oscillator Frequency}}{12x\,[256 - (TH1)]}$$

One can achieve very low baud rates with Timer 1 b leaving the Timer 1 interrupt enabled, and configurin the Timer to run as a 16-bit timer (high nibble c TMOD = 0001B), and using the Timer 1 interrupt t do a 16-bit software reload.

Figure 15 lists various commonly used baud rates anc how they can be obtained from Timer 1.

Baud Rate	f_{OSC}	SMOD	Timer 1 C/$\overline{T}$	Timer 1 Mode	Timer 1 Reload Value
Mode 0 Max: 1 MHZ	12 MHZ	X	X	X	X
Mode 2 Max: 375K	12 MHZ	1	X	X	X
Modes 1, 3: 62.5K	12 MHZ	1	0	2	FFH
19.2K	11.059 MHZ	1	0	2	FDH
9.6K	11.059 MHZ	0	0	2	FDH
4.8K	11.059 MHZ	0	0	2	FAH
2.4K	11.059 MHZ	0	0	2	F4H
1.2K	11.059 MHZ	0	0	2	E8H
137.5	11.986 MHZ	0	0	2	1DH
110	6 MHZ	0	0	2	72H
110	12 MHZ	0	0	1	FEEBH

Figure 15. Timer 1 Generated Commonly Used Baud Rates

Using Timer 2 to Generate Baud Rates

In the 8052, Timer 2 is selected as the baud rate generator by setting TCLK and/or RCLK in T2CON (Figure 11). Note then the baud rates for transmit and receive can be simultaneously different. Setting RCLK and/or TCLK puts Timer 2 into its baud rate generator mode, as shown in Figure 16.

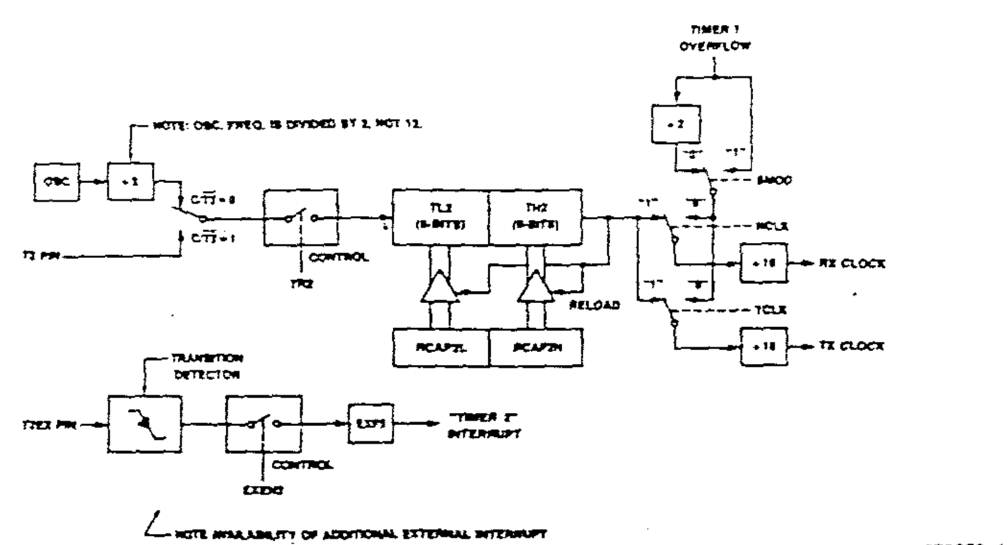

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Figure 16. Timer 2 in Baud Rate Generator Mode

The baud rate generator mode is similar to the auto-reload mode, in that a rollover in TH2 causes the Timer 2 registers to be reloaded with the 16-bit value in registers RCAP2H and RCAP2L, which are preset by software.

Now, the baud rates in Modes 1 and 3 are determined by Timer 2's overflow rate as follows:

$$\text{Modes 1, 3 Baud Rate} = \frac{\text{Timer 2 Overflow Rate}}{16}$$

The Timer can be configured for either "timer" or "counter" operation. In the most typical applications, it is configured for "timer" operation (C/$\overline{T2}$ = 0). "Timer" operation is a little different for Timer 2 when it's being used as a baud rate generator. Normally, as a timer it would increment every machine cycle (thus at $1/12$ the oscillator frequency). As a baud rate generator, however, it increments every state time (thus at $1/2$ the oscillator frequency). In that case the baud rate is given by the formula

$$\text{Modes 1, 3 Baud Rate} = \frac{\text{Oscillator Frequency}}{32x\,[65536 - (\text{RCAP2H, RCAP2L})]}$$

where (RCAP2H, RCAP2L) is the content of RCAP2H and RCAP2L taken as a 16-bit unsigned integer.

Timer 2 as a baud rate generator is shown in Figure 16. This Figure is valid only if RCLK + TCLK = 1 in T2CON. Note that a rollover in TH2 does not set TF2, and will not generate an interrupt. Therefore, the Timer 2 interrupt does not have to be disabled when Timer 2 is in the baud rate generator mode. Note too, that if EXEN2 is set, a 1-to-0 transition in T2EX will set EXF2 but will not cause a reload from (RCAP2H, RCAP2L) to (TH2, TL2). Thus when Timer 2 is in use as a baud rate generator, T2EX can be used as an extra external interrupt, if desired.

It should be noted that when Timer 2 is running (TR2 = 1) in "timer" function in the baud rate generator mode, one should not try to read or write TH2 or TL2. Under these conditions the Timer is being incremented every state time, and the results of a read or write may not be accurate. The RCAP registers may be read, but shouldn't be written to, because a write might overlap a reload and cause write and/or reload errors. Turn the Timer off (clear TR2) before accessing the Timer 2 or RCAP registers, in this case.

More About Mode 0

Serial data enters and exits through RXD. TXD outputs the shift clock. 8 bits are transmitted/received: 8 data bits (LSB first). The baud rate is fixed at $1/12$ the oscillator frequency.

Figure 17 shows a simplified functional diagram of the serial port in Mode 0, and associated timing.

Transmission is initiated by any instruction that uses SBUF as a destination register. The "write to SBUF" signal at S6P2 also loads a 1 into the 9th position of the transmit shift register and tells the TX Control block to commence a transmission. The internal timing is such that one full machine cycle will elapse between "write to SBUF," and activation of SEND.

SEND enables the output of the shift register to the alternate output function line of P3.0, and also enables SHIFT CLOCK to the alternate output function line of P3.1. SHIFT CLOCK is low during S3, S4, and S5 of every machine cycle, and high during S6, S1 and S2. At S6P2 of every machine cycle in which SEND is active, the contents of the transmit shift register are shifted to the right one position.

As data bits shift out to the right, zeroes come in from the left. When the MSB of the data byte is at the output position of the shift register, then the 1 that was initially loaded into the 9th position, is just to the left of the MSB, and all positions to the left of that contain zeroes. This condition flags the TX Control block to do one last shift and then deactivate SEND and set TI. Both of these actions occur at S1P1 of the 10th machine cycle after "write to SBUF."

Reception is initiated by the condition REN = 1 and RI = 0. At S6P2 of the next machine cycle, the RX Control unit writes the bits 11111110 to the receive shift register, and in the next clock phase activates RECEIVE.

RECEIVE enables SHIFT CLOCK to the alternate output function line of P3.1. SHIFT CLOCK makes transitions at S3P1 and S6P1 of every machine cycle. At S6P2 of every machine cycle in which RECEIVE is active, the contents of the receive shift register are shifted to the left one position. The value that comes in from the right is the value that was sampled at the P3.0 pin at S5P2 of the same machine cycle.

As data bits come in from the right, 1s shift out to the left. When the 0 that was initially loaded into the rightmost position arrives at the leftmost position in the shift register, it flags the RX Control block to do one last shift and load SBUF. At S1P1 of the 10th machine cycle after the write to SCON that cleared RI, RECEIVE is cleared and RI is set.

More About Mode 1

Ten bits are transmitted (through TXD), or received (through RXD): a start bit (0), 8 data bits (LSB first) and a stop bit (1). On receive, the stop bit goes into RB8 in SCON. In the 8051 the baud rate is determined by the Timer 1 overflow rate. In the 8052 it is determined either by the Timer 1 overflow rate, or the Timer 2 overflow rate, or both (one for transmit and the other for receive).

Figure 18 shows a simplified functional diagram of the serial port in Mode 1, and associated timings for transmit receive.

clock signal is gated off to the CPU. In Power Down (PD = 1), the oscillator is frozen. The Idle and Power Down modes are activated by setting bits in Special Function Register PCON. The address of this register is 87H. Figure 26 details its contents.

In the HMOS devices the PCON register only contains SMOD. The other four bits are implemented only in the CHMOS devices. User software should never write 1s to unimplemented bits, since they may be used in future MCS-51 products.

IDLE MODE

An instruction that sets PCON.0 causes that to be the last instruction executed before going into the Idle mode. In the Idle mode, the internal clock signal is gated off to the CPU, but not to the Interrupt, Timer, and Serial Port functions. The CPU status is preserved in its entirety: the Stack Pointer, Program Counter, Program Status Word, Accumulator, and all other registers maintain their data during Idle. The port pins hold the logical states they had at the time Idle was activated. ALE and $\overline{PSEN}$ hold at logic high levels.

There are two ways to terminate the Idle. Activation of any enabled interrupt will cause PCON.0 to be cleared by hardware, terminating the Idle mode. The interrupt will be serviced, and following RETI the next instruction to be executed will be the one following the instruction that put the device into Idle.

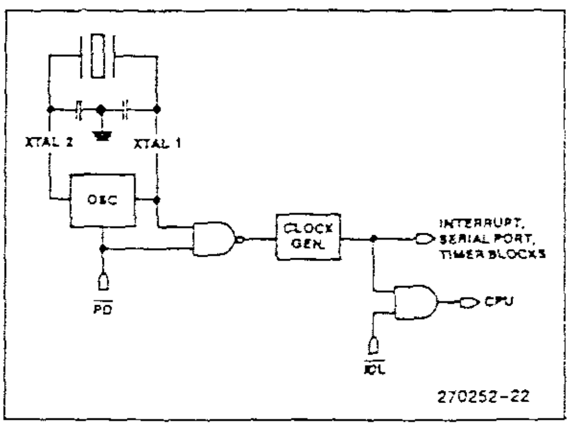

Figure 27. Idle and Power Down Hardware

(MSB) (LSB)

SMOD	-	-	-	GF1	GF0	PD	IDL

Symbol	Position	Name and Function
SMOD	PCON.7	Double Baud rate bit. When set to a 1 and Timer 1 is used to generate baud rate, and the Serial Port is used in modes 1, 2, or 3.
—	PCON.6	(Reserved)
—	PCON.5	(Reserved)
—	PCON.4	(Reserved)
GF1	PCON.3	General-purpose flag bit.
GF0	PCON.2	General-purpose flag bit.
PD	PCON.1	Power Down bit. Setting this bit activates power down operation.
IDL	PCON.0	Idle mode bit. Setting this bit activates idle mode operation.

If 1s are written to PD and IDL at the same time, PD takes precedence. The reset value of PCON is (0XXX0000).

In the HMOS devices the PCON register only contains SMOD. The other four bits are implemented only in the CHMOS devices. User software should never write 1s to unimplemented bits, since they may be used in future MCS-51 products.

Figure 28. PCON: Power Control Register

The flag bits GF0 and GF1 can be used to give an indication if an interrupt occurred during normal operation or during an Idle. For example, an instruction that activates Idle can also set one or both flag bits. When Idle is terminated by an interrupt, the interrupt service routine can examine the flag bits.

The other way of terminating the Idle mode is with a hardware reset. Since the clock oscillator is still running, the hardware reset needs to be held active for only two machine cycles (24 oscillator periods) to complete the reset.

The signal at the RST pin clears the IDL bit directly and asynchronously. At this time the CPU resumes program execution from where it left off; that is, at the instruction following the one that invoked the Idle Mode. As shown in Figure 25, two or three machine cycles of program execution may take place before the internal reset algorithm takes control. On-chip hardware inhibits access to the internal RAM during this time, but access to the port pins is not inhibited. To eliminate the possibility of unexpected outputs at the port pins, the instruction following the one that invokes Idle should not be one that writes to a port pin or to external Data RAM.

POWER DOWN MODE

An instruction that sets PCON.1 causes that to be the last instruction executed before going into the Power Down mode. In the Power Down mode, the on-chip oscillator is stopped. With the clock frozen, all func-