

Department of Mechanical Engineering

**Control aspects of a Diesel Generator used to power a  
SODAR device**

Author: Ollie Kelleher

Supervisor: Dr. Matthew Stickland

A thesis submitted in partial fulfilment for the requirement of degree in  
Master of Science in Renewable Energy Systems and the Environment

2010

## **Copyright Declaration**

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

The copyright of this thesis belongs to the author under the terms of the United Kingdom Copyright Acts as qualified by University of Strathclyde Regulation 3.50. Due acknowledgement must always be made of the use of any material contained in, or derived from, this thesis.

Signed: Ollie Kelleher

Date: 10/09/2010

## **Abstract**

The main aim of this project was to apply control and functional operation to a diesel generator that is used to charge batteries which in turn power a SODAR device. A detailed literature review was conducted of the wind industry and current and predicted wind measurement techniques used. The theoretical aspect of the SODAR device was analysed.

The generator used as part of this project was inspected and maintenance was conducted as necessary. The practical experimental aspect fell in line with the main aim of the project. Preliminary laboratory work consisted of a detailed study and understanding of a Campbell scientific data logger and then using it to perform basic experimental measurements. Further application of the data logger led to the acquisition of advanced software that was used to compile a program which monitored the battery charge and the fuel levels of the generator. Alarm signals were issued via a GSM modem in the event of certain conditions arising. The program was applied by uploading it to the data logger and wiring it up accordingly such that all input and output signals were detected as necessary.

## **Acknowledgements**

I would like to thank Dr. Matthew Stickland for all his help and guidance throughout this project. Special thanks must also go to Franco Casule of Campbell Scientific who was of great help in setting up the data logger used within this project. Also I would like to thank other members of faculty for the assistance and supplying necessary equipment throughout this project. They include Steven Black, John Redgate and Pat McGuinness. Finally I would like to thank my family for their support and assistance throughout this project and entire academic year.

## Table of Contents

<b>Copyright Declaration .....</b>	<b>i</b>
<b>Abstract.....</b>	<b>ii</b>
<b>Acknowledgements .....</b>	<b>iii</b>
<b>Table of Contents .....</b>	<b>iv</b>
<b>List of Figures.....</b>	<b>viii</b>
<b>List of Tables .....</b>	<b>x</b>
<b>Chapter 1: Introduction .....</b>	<b>1</b>
1.1 Objectives of Report .....	1
<b>Chapter 2: Background.....</b>	<b>2</b>
2.1 Environmental Concerns.....	2
2.2 Oil Costs.....	4
<b>Chapter 3: Wind Energy .....</b>	<b>5</b>
3.1 History of Wind Energy .....	5
3.1.1 Large-Scale Generation of Electricity .....	7
3.2 U.K. and Wind Energy.....	10
3.3 Problems associated with wind energy .....	12
3.4.1 Intermittency.....	12
3.4.2 Environmental Impacts.....	12
3.4 Wind Energy Resource .....	14
<b>Chapter 4: Measuring Wind .....</b>	<b>15</b>
4.1 Measuring Wind in remote Locations.....	15
4.2 LIDAR .....	17
4.3 Satellite .....	19
4.5 SODAR.....	22

4.5.1 Introduction to SODAR.....	22
4.5.2 History of SODAR .....	22
4.5.3 Theory of SODAR.....	24
4.5.4 SODAR Pulse Properties.....	27
4.5.5 Calculating Wind Component from SODAR.....	34
<b>Chapter 5: Mobile SODAR unit .....</b>	<b>36</b>
5.1 Introduction.....	36
5.2 SODAR device.....	36
5.3 SODAR Deployment Considerations .....	38
5.3.1 Power availability .....	39
5.3.2 Weather Conditions .....	39
5.3.3 Data Acquisition .....	40
5.3.4 Remote Communication .....	42
<b>Chapter 6: Using the Data Logger .....</b>	<b>43</b>
6.1 Introduction.....	43
6.2 Initial Retrieval .....	44
6.3 Powering the data logger .....	44
6.4 Establishing Communication .....	45
6.4.1 Setting up the apparatus.....	45
6.4.2 Connecting to the Data Logger.....	45
6.5 Preliminary Programming.....	46
6.5.1 Software description .....	46
6.5.2 Program Tests .....	47
6.5.3 Preliminary Programming Results.....	49
6.5.4 Discussion of Results.....	49

<b>Chapter 7: Applying the Data Logger .....</b>	<b>50</b>
7.1 Introduction.....	50
7.2 Engine Maintenance.....	50
7.2.1 Replacing the battery .....	50
7.2.2 Changing the Oil.....	51
7.2.3 Adjusting the throttle .....	51
7.3 Control and Operation Requirements .....	51
7.4 Programming Software .....	52
7.4.1 LoggerNet 4.0 .....	52
7.4.2 Edlog.....	53
7.5 Programming Description.....	53
7.5.1 Introduction .....	53
7.5.2 Digital I/O Ports.....	53
7.5.2 Flags.....	54
7.5.3 Run Generator.....	56
7.5.4 Output processing .....	56
7.5.5 Subroutines .....	57
7.6 Wiring the data logger .....	58
<b>Chapter 8: Results and Discussion .....</b>	<b>59</b>
8.1 Introduction.....	59
8.2 Laboratory experiments .....	59
8.3 Generator Repair .....	59
8.4 Data Logger Application.....	60
8.4.1 Achieved Goals.....	60
8.4.2 Identified issues .....	61

**Chapter 9: Conclusion and Recommendations.....62**

    9.1 Conclusions.....62

    9.2 Recommendations.....64

**References.....65**

**Appendix A: Prompt Sheet .....67**

**Appendix B: Program Code.....70**

**Appendix C: Wiring Diagram .....88**



## List of Figures

Figure 1: World Primary Energy percentage Consumption by Fuel Type 2006 .....	5
Figure 2: Early sail-wing horizontal-axis mill .....	6
Figure 3: First Large Windmill to generate electricity, Cleveland, U.S. ....	7
Figure 4: 200 kW Gedser Mill wind turbine, Denmark .....	8
Figure 5: Increase in size of Wind Turbine designs over last 30 years. ....	9
Figure 6: Submitted and Consented wind farm applications in recent years.....	11
Figure 7: Wind Energy Resource Map for the U.K. ....	14
Figure 8: SODAR and Anemometer measuring wind .....	15
Figure 9: Doppler Lidar Wind Measurement Concept .....	17
Figure 10: Inflow and wake wind LIDAR wind profile taken at the nacelle .....	18
Figure 11: Typical measurement taken from LIDAR device .....	19
Figure 12: SAR system viewing geometry .....	20
Figure 13: Map of Denmark showing SAR measured wind speed.....	21
Figure 14: Remtech arrayed SODAR .....	24
Figure 15: Graphic description of Mechanical and Thermal Turbulance.....	25
Figure 16: Principle of SODAR shown with phased array.....	26
Figure 17: Relationship between SODAR parameters .....	29
Figure 18: Hanning Shape pulse frequency spectra for different ramp times .....	32
Figure 19: Orientation of the SODAR beams.....	34
Figure 20: Internal view of SODAR device .....	37
Figure 21: Functioning Description of SODAR interface. ....	37
Figure 22: CR10X data logger and wiring panel .....	40
Figure 23: Processes, Instructions and storage areas .....	41
Figure 24: CR10X communication options .....	43

Figure 25: Data logger and supply voltage .....44

Figure 26: Screenshot of PC200W .....47

Figure 27: Preliminary data logger results .....49

Figure 28: Logger Net user interface .....52

## List of Tables

Table 1:Wind Energy Data .....	11
Table 2:SODAR internal components .....	37
Table 3:Preliminary measurements logged.....	49
Table 4: Ports used on data logger .....	54
Table 5:Flag description .....	55
Table 6:Final Storage data .....	56

## **Chapter 1: Introduction**

### **1.1 Objectives of Report**

The objectives of this report were as follows:

#### **Literature Review**

- Conduct an investigation into factors that motivate research in wind energy.
- Review the history of wind turbines and look at their evolution.
- Identify the U.K.'s position in relation to wind energy and the potential that lies in this field for development and for the economy.
- Develop an understanding of the funding that is available to subsidise capital costs involved in this area of renewable energy and the initiatives undertaken by the U.K. government to promote its development.
- Identify some of the problems that are associated with wind energy on and off shore.
- Look at existing methods of site surveying and measuring wind data for potential wind turbine installations.
- Look at the history of SODAR and its development to date.
- Explain the detailed theory behind SODAR and exactly how it works.
- Look at the mobile SODAR unit and identify some deployment considerations.

#### **Data Logger control and operation**

- Understand the data logger operation and conduct preliminary test programming.
- Explain control requirements of the mobile unit used to power SODAR.
- Identify issues with the generator and conduct maintenance as necessary.
- Describe the modifications, development and function of the program used to carry out the control and operation of the generator and other components.
- Highlight the outcome of the work conducted and recommend future work as appropriate.

## **Chapter 2: Background**

### **2.1 Environmental Concerns**

There has been a great increase in the demand for renewable energy over the last decade worldwide. World powers now acknowledge that fossil fuels are terminal and accept the need for pre-emptive action. Significant steps were approved in the Kyoto treaty. This agreement required participating countries to reduce greenhouse gas emissions to specified levels.

For the first five years of this century, 48% of total anthropogenic CO<sub>2</sub> emissions remained in the atmosphere. Effects include rising sea levels, glacier retreat, Arctic shrinkage, and altered patterns of agriculture. Predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact. The evidence behind the climate altering effects of greenhouse gas emissions is visible worldwide. Increased numbers of icebergs are breaking away each day. It is estimated that arctic sea ice is melting at a rate of 9% per decade. The International Panel on climate change predicts a mean global rise of 50cm in sea level over the next one hundred years. In order to achieve the long-term stabilisation of the atmospheric carbon dioxide concentration, the emissions will then have to be reduced by 56 percent by the year 2050 and approach zero towards the end of this century (*Daily, 2010*). There are a number of possible solutions proposed to confront this problem:

- Reduction of energy use (per person).
- Carbon capture and storage.
- Geo-engineering including carbon sequestration.
- Population control, to lessen demand for resources such as energy and land clearing.
- **Shifting from carbon-based fossil fuels to alternative energy sources.**

The latest report from the International Panel on Climate Change (IPCC) confirms that hundreds of technologies are now available, at low cost, to reduce climate damaging emissions, and that government policies need to remove the barriers to these technologies. It

is widely accepted that we cannot continue our current dependence on fossil fuels as a source of energy.

The European Union has taken a lead by proposing aggressive targets for emission cuts. A binding target to have 20% of the EU's overall energy consumption coming from renewables by the year 2020 has been set. In the U.K., The 2007 White Paper: "Meeting the Energy Challenge" sets out the Government's international and domestic energy strategy to address the long term energy challenges faced by the UK, and to deliver 4 key policy goals:

1. To put the UK on a path to cut carbon dioxide emissions by some 60% by about 2050, with real progress by 2020;
2. To maintain reliable energy supplies;
3. To promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve productivity;
4. To ensure that every home is adequately and affordably heated.

*(Government, 2007)*

Implementing these solutions will enable people to usher in a new era of energy, one that should bring economic growth, new jobs, technological innovation and, most importantly environmental protection.

## 2.2 Oil Costs

Another factor that has caused interest in renewable energy is the rising price in oil around the world. Oil accounts for 41% of the world's share of energy consumption. With oil recently costing as much as \$145 a barrel there is considerable demand for cheaper sources of energy. As this is only likely to increase in the coming years our attention will turn initially towards either nuclear or gas. These alternatives however, do not solve the long term problem due to the negative effects that they too can have on our environment.

Historically, surges in oil prices have generated sporadic interest in developing alternative energy sources including wind energy, which has proved to be the most commercially viable renewable resource in the short term.

All research indicates that the demand for energy will only increase and with limited supply of carbon based fossil fuels remaining it is essential that at least part of this demand is met through renewable sources. An increasing amount of money is being put into renewable energy research. The aim now is to develop reliable devices capable of providing a good alternative to conventional energy sources.

**Figure 1** displays the predicted energy consumption for each energy resource in quadrillion British Thermal Units (BTU), (1BTU= 1055 J). For the next 30-40 years carbon based liquids solids and gasses fossil fuels may continue to power the world, but the level of consumption and the cost will continue to rise until finally it has all run out. Unless new oilfields are discovered we will be left in a dark world.

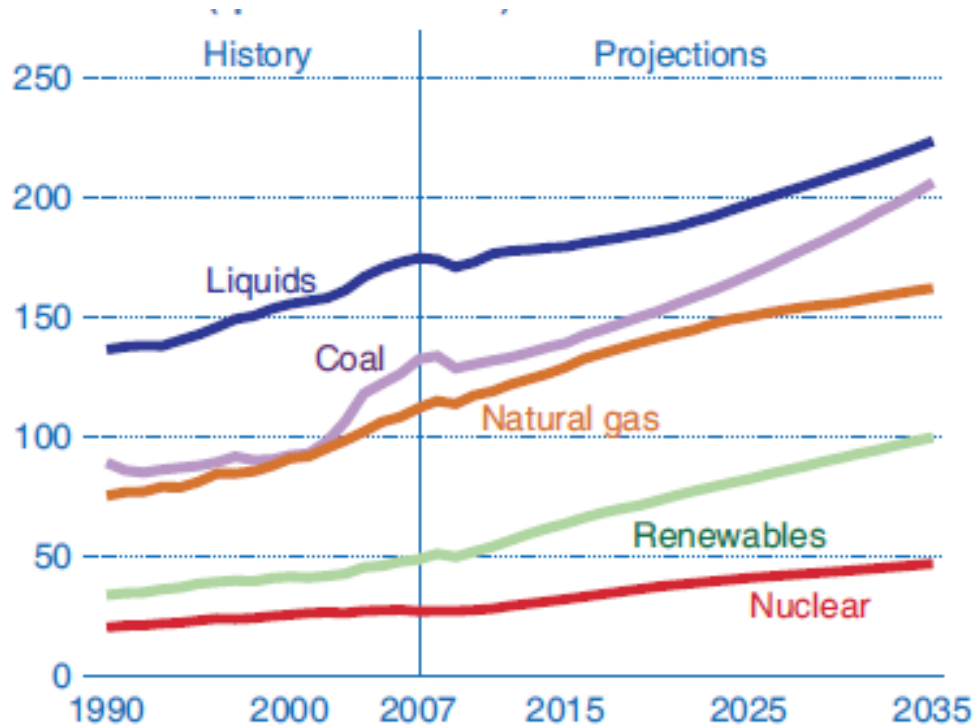


Figure 1: World Primary Energy percentage Consumption by Fuel Type 2006

(EAI, 2010)

## Chapter 3: Wind Energy

### 3.1 History of Wind Energy

Windmills were first developed for the use of grinding grain and pumping water. The earliest known design is the vertical axis system developed in Persia about 500-900 A.D. Vertical axis windmills were also used in China where they are thought to have originated. It is believed that the first windmill was invented in China over two thousand years ago however the earliest actual documentation of a Chinese windmill was in 1219 A.D.

The first windmills to appear in Western Europe were of a horizontal axis type. It is presumed that the switch from vertical axis Persian design was due to the fact that European water wheels had a horizontal configuration. They are also known to have had greater structural stability.



As early as 1390, the Dutch set out to refine the tower mill design, shown in **Figure 2**, which had appeared somewhat earlier along the Mediterranean Sea.



**Figure 2: Early sail-wing horizontal-axis mill**

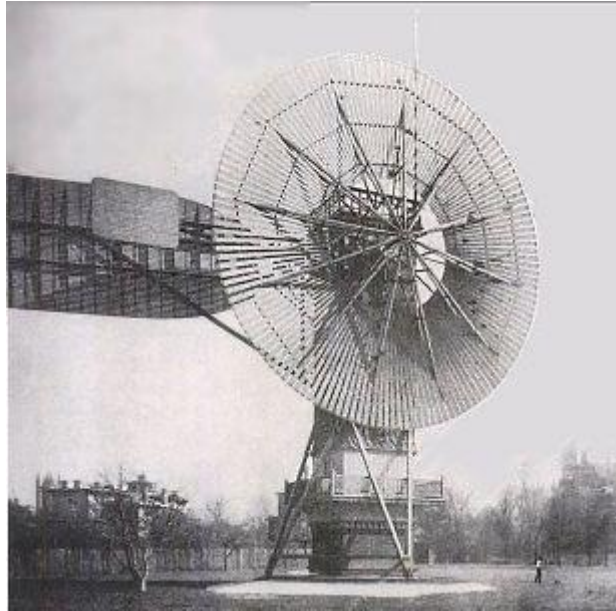
*(TelosNet, 2001)*

It took over five hundred years to gradually improve the efficiency of the windmill sail design as shown above. This process resulted in reaching a technological level which is now recognised by modern designers and considered crucial to the performance of modern wind turbine airfoil blades. Such advances include:

1. Camber along the leading edge,
2. Placement of the blade spar at the quarter chord position (25% of the way back from the leading edge toward the trailing edge),
3. Centre of gravity at the same 1/4 chord position,
4. Nonlinear twist of the blade from root to tip.

### 3.1.1 Large-Scale Generation of Electricity

The first use of a large windmill to generate electricity was a system built in Cleveland, Ohio, in 1888 by Charles F. Brush (**Figure 3**). The device was 17 meters in diameter.



**Figure 3: First Large Windmill to generate electricity, Cleveland, U.S.**

*(TelosNet, 2001)*

After World War I, the use of 25 kilowatt electrical output machines had spread throughout Denmark, but cheaper and larger fossil-fuel steam plants soon put the operators of these mills out of business.

Wind turbine development was enhanced by design improvements of aeroplane propellers and monoplane wings. Some of the first early small electrical-output wind turbines in the 1900's used modified propellers to drive direct current generators to produce electricity in remote locations.

The first bulk power systems were developed in Russia in 1921, where they designed a 100kW Balaclava wind generator. The machine ran successfully for two years generating 200,00kWh of electricity. Further experimental wind turbines were undertaken around Europe and the U.S after World War II as temporary shortages of fossil fuels drove research for alternative solutions. **Figure 4** shows the development towards a 3 blade structure that we are familiar with today. This period of high energy costs is reflective of circumstances we see

today, however, global warming and carbon reduction had yet to become a priority. Development continued worldwide until the 1960's when declining fossil-fuel prices once again made wind energy uncompetitive with steam-powered generating plants.

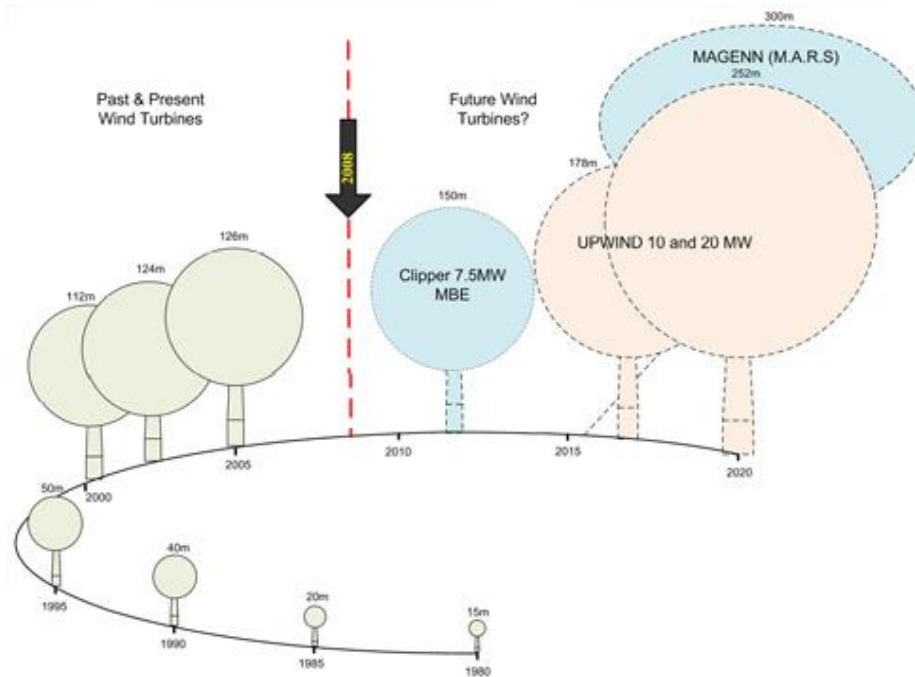


**Figure 4: 200 kW Gedser Mill wind turbine, Denmark**

*(TelosNet, 2001)*

The 1980's again saw a resurgence in wind power R&D, largely driven by increased fuel prices. Furthermore, in northern Europe countries such as Germany and Denmark were beginning to leverage excellent wind resources to create a small, but stable market for renewable energy organisations. Development was slow in the early 1990's as wind proved uncompetitive with the likes of nuclear and fossil fuel based power generation. Increased concern over global warming and government subsidisation increased interest, and with technological advancement in the mid 90's and today, we see off shore structures with a generation capacity in the region of 5MW. **Figure 5** shows the evolution in size of wind turbines over the past 30 years and the predicted generation capacity in the future with the

UPWIND project looking at development in the region of 10-20MW. In recent news from Clipper Wind power, a 7.5 MW prototype is expected to be ready for production by approximately 2012. This increase in size and capacity calls for accurate site surveying techniques up to heights at which the device will be operational. Methods will be discussed later in **Chapter 4** (EWEA, 2010).



**Figure 5: Increase in size of Wind Turbine designs over last 30 years.**

(EWEA, 2010)

### **3.2 U.K. and Wind Energy**

Renewable energy, and especially wind power, have had a significant impact on the British power generation market in recent years and are targeted to deliver 20% of total supply by 2020. With this target in mind, we can expect to see an increase in contribution from renewable resources in the near future. The UK has some of the richest renewable resources in Europe, notably wind and marine (wave and tidal stream) resources. If they can be harnessed effectively they can make a significant contribution to our long-term energy goals relating to climate change and security of supply.

Recognising the potential benefits of renewable energy to the UK's energy objectives, in 2002 the Government introduced the Renewable Obligation Electricity Generation (RO) to drive and support the growth of renewable energy generation. The Obligation allows generally higher cost renewable electricity generation to compete directly with conventional, fossil fuel based electricity generation. This obligation coupled with the proposed targets spurred a rapid development of wind farms both on and off shore in the last decade. The graph below (**Figure 6**) shows how the Renewable Obligation Certificates (ROC's) have encouraged development in the wind industry which has simultaneously increased demand in identifying potential sites and surveying and measuring data from them. Also shown in **Table 1** is the installed wind energy capacity on and off shore, the contributing TW hrs for a capacity factor of 29.4% onshore and 34.9% offshore, the number of homes that could be supplied assuming an average annual household consumption of 4700kWh, the amount of CO<sub>2</sub> savings that took place with the replacement of brown energy with green (CO<sub>2</sub> off set of 430 g/ kWh) and the estimated number of jobs created ( assuming 4 jobs are created in the UK for each MW installed onshore and 5.3 jobs for each MW installed off shore according to a report from Bain and Co) (*BWEA, 2009*).

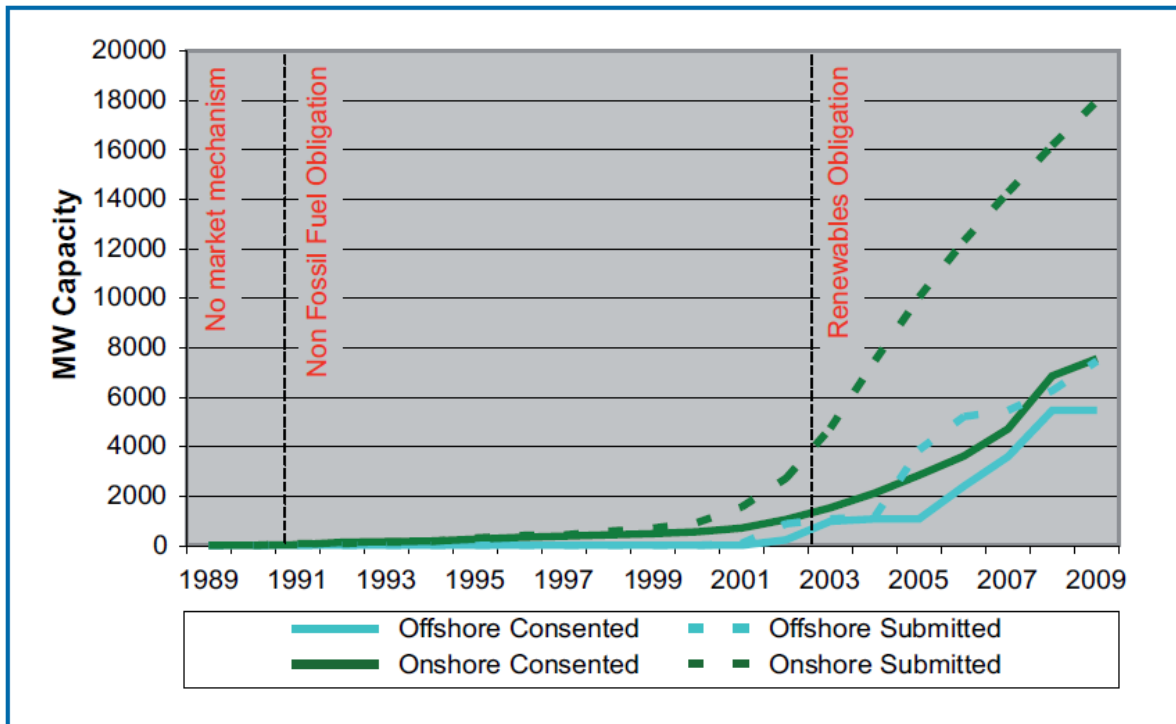


Figure 6: Submitted and Consented wind farm applications in recent years.

(BWEA, 2009)

	MW installed	TWhrs	Homes equivalent	CO <sub>2</sub> savings in tonnes	Jobs created
<b>Onshore</b>	3233	8.33	1771574	3,580,351	12932
<b>Off shore</b>	598	1.83	390100	788,391	3169
<b>Total</b>	3831	10.16	2161674	4,368,742	16101

Table 1: Wind Energy Data

(BWEA, 2009)

### **3.3 Problems associated with wind energy**

#### **3.4.1 Intermittency**

Wind energy production is intermittent and non-dispatchable. Effectively matching the supply to the demand is often a problem. As discussed most turbines have a capacity factor of around 30%. Most renewable energy sources are tied to strong grids where the base load power plants (generated by hydro-electric, coal or nuclear) minimise quality concerns and make it less important for wind generation to be matched to consumption. Also Intermittency can be balanced by using load management. This is when the load is adjusted or controlled rather than the power station output. An example of load management in the UK is the night storage heater, which is used to increase load overnight and therefore decrease the daytime load. Another is wind energy with hydropower to ensure a backup resource.

An example such as Pumped-storage hydroelectricity means that energy generated at peak output can be stored for times of high demand (*ECORATER, 2010*). There have also been significant developments in battery storage over the last number of years, although batteries are relatively expensive to use on a large scale.

#### **3.4.2 Environmental Impacts**

In Sweden, Denmark, the Netherlands and the UK a significant number of wind farms have been installed both on and offshore. Their impacts will not be fully understood until monitoring and research is conducted following their full installation. Placing wind farms offshore eliminates some of the obstacles encountered when sitting wind farms on shore, such as aesthetic impact on the landscape, annoyance to inhabitants from noise and flickering light, conflicts with other planning interests etc.

Further challenges remain. For example, the impact off shore wind turbines may have on: birdlife, marine life, hydrography and marine traffic. While there are now 20 years of experience in assessing and meeting environmental challenges associated with land based wind installations little is known of the effects of offshore wind installations.

Collection of information on existing sites, including the impacts on birds, flora and fauna, sub-sea noise, visual intrusion, and coastal impacts will prove vital in the future of offshore wind farm development and its environmental impacts (*Peinke, 2007*).

## **Birds**

The biggest environmental effect that wind farms have is on birds. Such effects include:

- A physical change of the habitat providing extra resting areas.
- A collision risk for flying birds/bats

During periods with low visibility (darkness, fog, and heavy rain) there is a high probability that flocks of birds could collide with a wind turbine if passing through a wind farm. The tailwind that is produced by wind turbines also elevates the flight altitude and the migration intensity of birds.

Suggestions have been made to use infrared cameras and microphones to study these effects on bird life however it is not sure how successful they will prove to be.

There are atlases available that show the migrating routes for birds. These should be consulted when considering the design and location of a wind farm. This will have an effect on the future potential locations.

Studies have shown that wind turbines off shore can kill up to 10 birds per year. Again if it is feared that some of those birds of migrating flocks are becoming endangered, planning permission may become restricted in the future in some areas (*MacKay, 2008*).

## **Below the sea surface**

Turbine foundations and the base supporting structure can have a serious impact on:

- Hydrodynamic system,
- Sediment characteristics,
- Benthos composition (increase of epibenthos),
- Fish fauna with possible implication to fisheries.

This can have a major impact on marine life in the surrounding waters and effect animals such as seals, dolphins, fish etc. if changes in the marine ecosystem result in a variability of the food chains.

There are other influencing factors such as:

- Risk of ship collisions,
- Sub-sea noise,

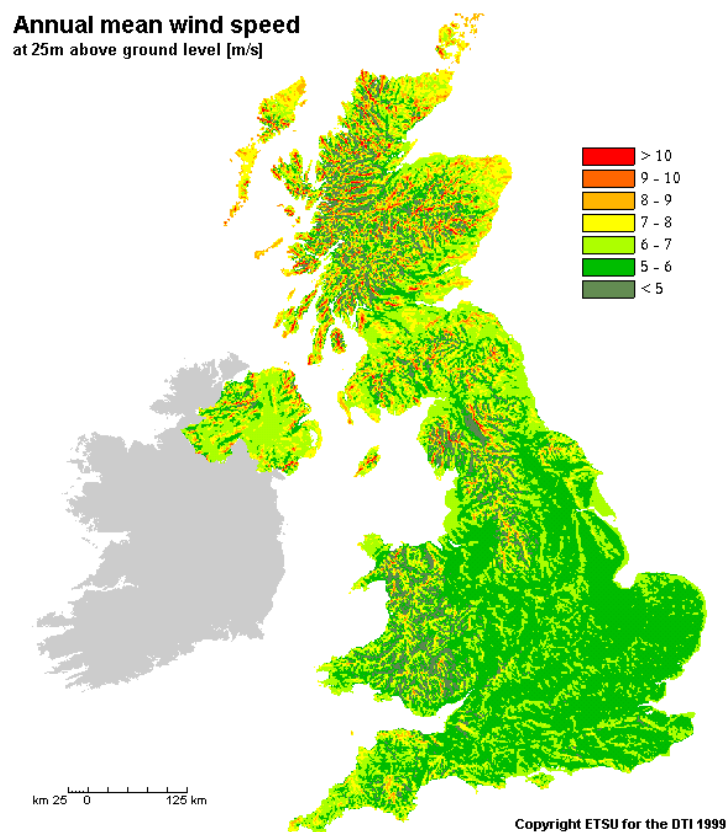


- Interaction with outdoor recreational life and activities (surfing, sailing, kayaking etc.)

However the overall predicted impact in these cases is suspected to be less significant (*Bruns, 2002*).

### **3.4 Wind Energy Resource**

The map in **Figure 7** shows the annual mean wind speed in the U.K. Clearly Scotland and Northern Ireland hold the best potential and therefore should exploit this resource as much as possible. It is critical that turbines are located in the most suitable location in order to harness maximum viability at the best cost. Such factors include the locality of transmission lines as well as resource availability and consistency along with the environmental impact and construction costs. Although off shore farms require higher initial capital investments to construct, in the longer-term they may prove more environmentally friendly and more economical due to their greater capacity.



**Figure 7: Wind Energy Resource Map for the U.K.**

(*ECORATER, 2010*)

## **Chapter 4: Measuring Wind**

### **4.1 Measuring Wind in remote Locations**

Wind power is moving towards the installation of wind farms in complex terrains, offshore, in forests, and at higher altitudes. As discussed, wind turbines are now of multi MW capacity and are ever growing. For this reason, there is increased demand for an improved understanding of winds at these identified new challenging environments. **Figure 8** shows the difference in altitude measurement capabilities of a SODAR relative to an anemometer mounted to a met mast.



**Figure 8: SODAR and Anemometer measuring wind**

*(Oldbaum, 2010)*

Traditionally, wind has been measured using cup anemometers mounted on metrological masts however, with the increased height (**Figure 8**) and remoteness of turbines there may not always be local masts for the site in question and the cost of erection and maintenance of them has become more expensive. Furthermore, using an anemometer limits measurements to one specific area of a turbine such as the centre of the rotor. There has been an increased need for determining the wind over the whole turbine rotor as discrepancies have been identified

between the measured wind at the rotor centre and the turbine performance (*InternationalEnergyAgency, 2007*).

In order to develop wind turbines on a potential site successfully, information should be gathered and collected for each specific site. Such methods include LIDAR, Satellite, and SODAR. By using remote sensing techniques wind profiles over the whole turbine can be measured. Each various technique is based around the same principle of the Doppler shift and they all hold particular advantages and limitations.

A recent development in the U.K. for remote sensing devices is the commissioning of the first LIDAR and SODAR test site in August 2010 by one of the leading energy consultancy companies; Natural Power. The site, located in Worcestershire has a 90m met mast which can enable correlation reports to be made against ground based devices to provide traceability back to anemometry. It is open to all developers, consultancies, research organisations and turbine manufacturers (*NaturalPower, 2010*).

As this project was based around the use of a SODAR device other methods will only be discussed briefly with more significant emphasis put on SODAR technology. Although most of the following theory was not applied in the experimental aspect of this report it was felt that it was of critical importance to comprehend it adequately due to the renewable nature of this course.

## 4.2 LIDAR

LIDAR (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to determine wind speed and direction at significant heights using the ground based device. It is similar to SODAR however it operates via the transmission and detection of light rather than sound. The range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. LIDAR is believed to be most suitable to replace the met mast based wind measurements used in power curve calculations for wind farms due to its level of accuracy in comparison to other methods.

LIDAR principle relies on measuring the Doppler shift of radiation scattered by natural aerosols carried by the wind. Typically, these are dust, water droplets, pollution, pollen or salt crystals. **Figure 9** shows the principal on which LIDAR technology is based.

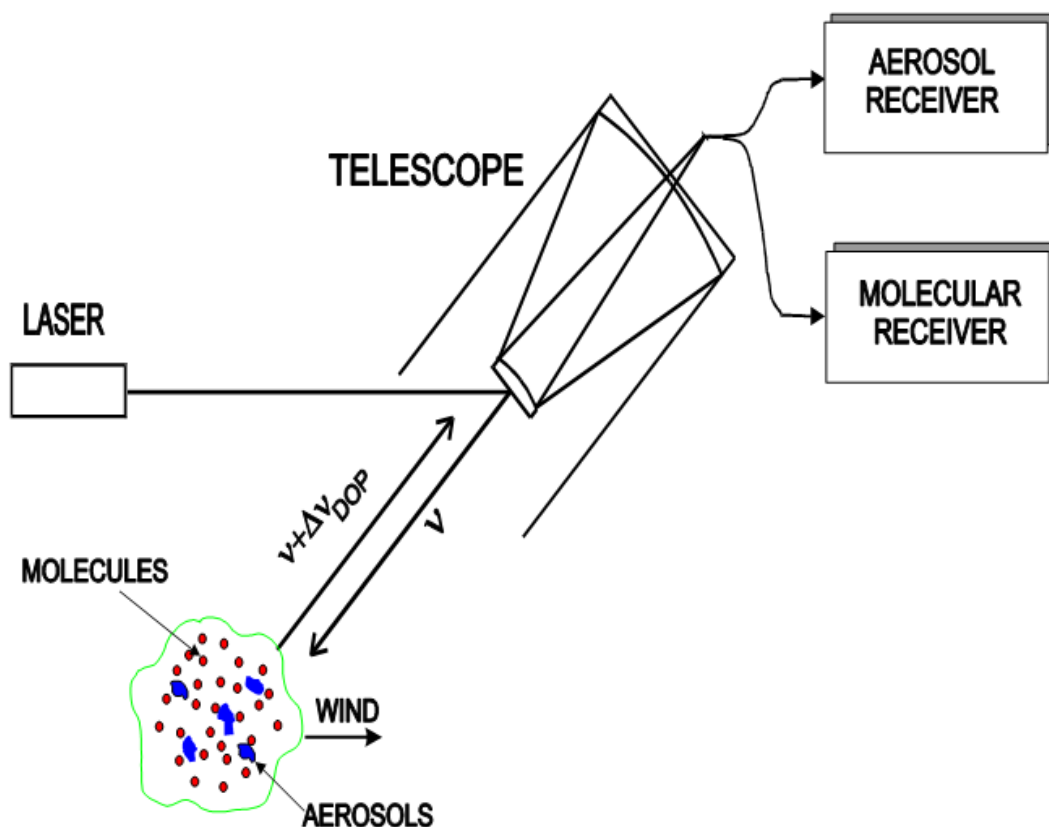


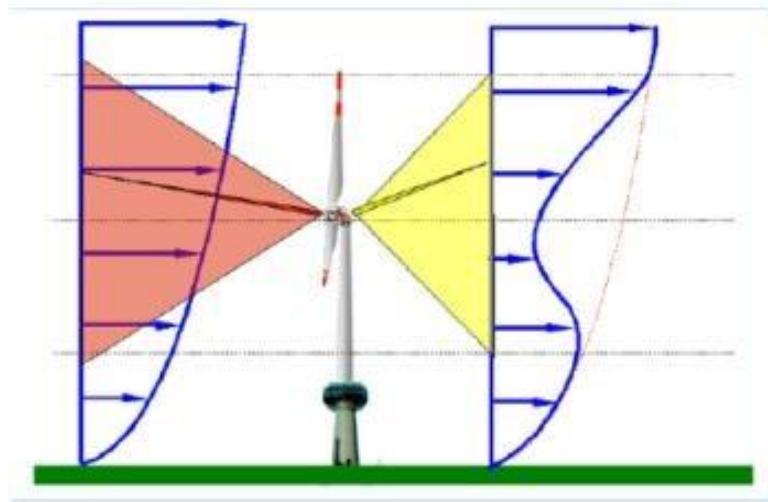
Figure 9: Doppler Lidar Wind Measurement Concept

(Gentry, 1999)

A new generation of fibre-based LIDARs has emerged over recent years that operates close to the theoretical limit of sensitivity and typically only needs to detect one photon for every

$10^{12}$  transmitted in order to measure wind speed. As the Doppler-shifted frequency is directly proportional to line-of-sight velocity, the wind speeds obtained by LIDAR instrument seem not to need calibration. This new technology which is available from companies such as LIDAR wind technologies (Windcube) and Natural Power (ZephIR) is extremely portable and can measure heights between 10m and 200m with acclaimed speed and direction accuracy errors of less than 0.5% and  $0.5^\circ$  respectively. Similar to SODAR, LIDAR is also a new instrument and its merits and limitations are not fully documented. In the case of the LIDAR, the measurement of the wind speed takes place on the surface of a cone where the depth changes as a function of the focus distance. It is believed that the LIDAR is the most accurate remote sensing device and is most likely to completely replace met masts in terms of absolute wind speed.

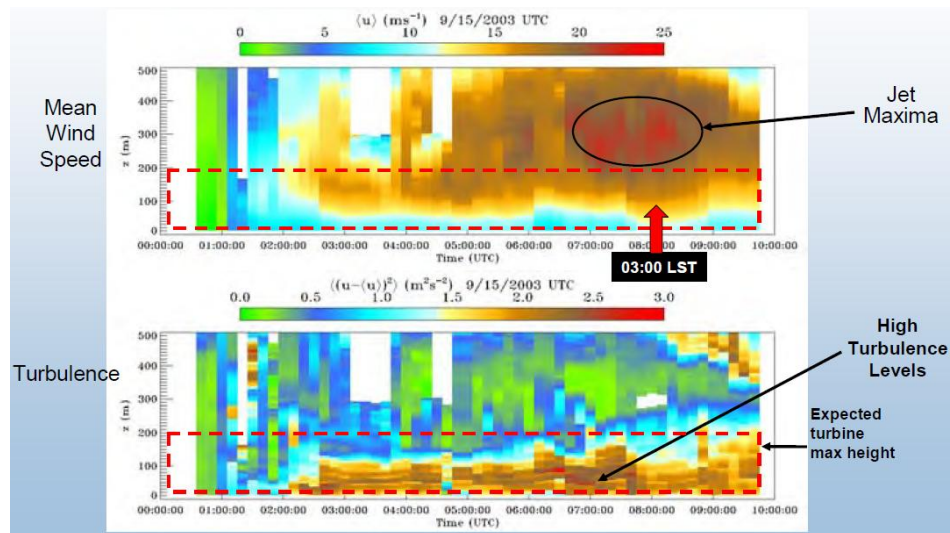
Research areas concerning LIDAR at the moment concentrates on two main topics, namely, power curve assessment and wind field measurement from the nacelle. The first deals with ground-based approaches to replace conventional anemometers mounted on a met mast. The second aims at the development and verification of new nacelle-based approaches to measure inflow and wake wind fields as shown below in **Figure 10**.



**Figure 10: Inflow and wake wind LIDAR wind profile taken at the nacelle**

*(RenewableEnergyWorld, 2008)*

**Figure 11** shows low level jet observation measurements taken from a LIDAR device where both wind speed and turbulence is recorded.



**Figure 11: Typical measurement taken from LIDAR device**

*(InternationalEnergyAgency, 2007)*

### **4.3 Satellite**

Satellite remote sensing methods are based on microwave scatterometry and (SAR) Synthetic Aperture Radar.

Satellite remote sensing provides wind maps 10m above sea level. The snap shot images are produced twice daily and the wind maps are produced at a resolution of around 25km therefore they are not immediately turbine site specific. Observations made by satellite remote sensing are restricted to off shore and are as close as 40km distance to the shoreline. Until recently satellites have not been used for offshore wind energy purposes even though over 5000 observations have been taken at almost every location worldwide since 1999 to date. The reason for this are:

- satellite wind mapping accuracy
- satellite wind mapping frequency
- low resolution satellite wind maps do not include the coastal zone
- technological methodologies to transfer satellite data to wind energy tools

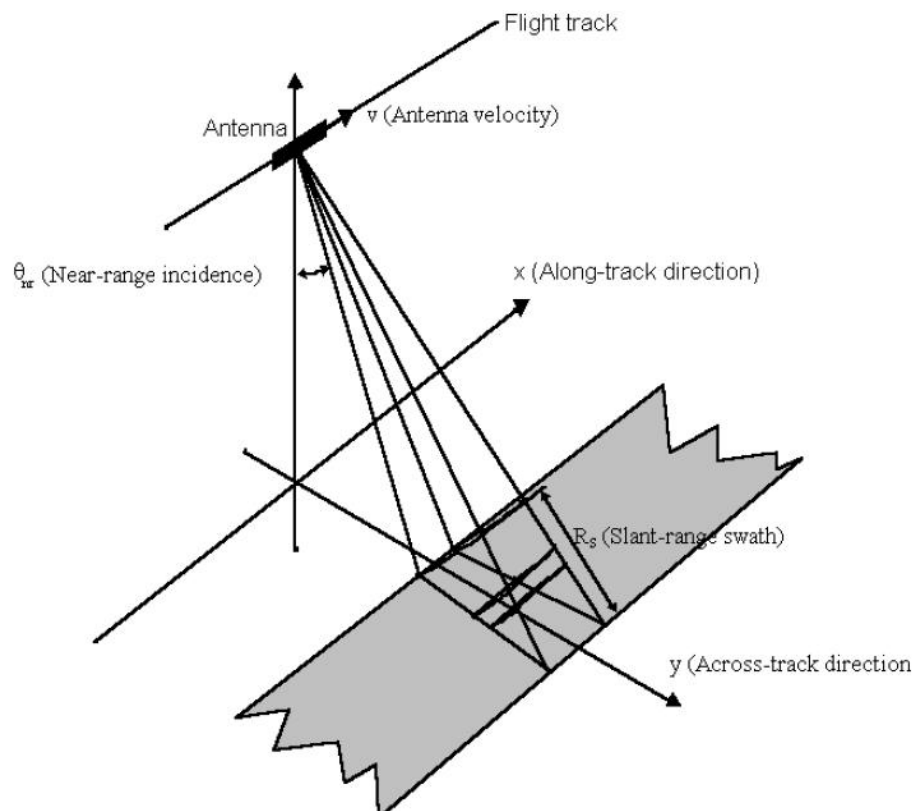
SAR however, produces wind maps near coastal areas in which most wind farms are located. The technology has been around since 1987 when the first Seasat carried the first SAR sensor on board a satellite platform.

SAR operates by looking sideways between the angles from near range to far range (see **Figure 12**). In this dimension, the slant range observations are made. The distance on the ground between near and far range is the swath width. The across track resolution is obtained through frequency modulation.

Azimuth range observations are made as the satellite travels along the flight track. The azimuth resolution is specified as one-half the antenna length. The synthetic aperture is obtained by tracking the individual phase and amplitude of individual return signals during a given integration time interval. Hence the distance is much longer than the physical length of the instrument antenna. It is the Doppler shift in each individual recorded signal in the backscatter signal that determines the position of the scatter in the azimuth position (C.B. Hasager, 2007).

The SAR illuminates a footprint and the signals returned from the footprint area are the backscattered values, the NRCS (Normalised Radar Cross Section).

It is again the relationship between NRCS and ocean wind speed, similar to the scatterometers, which is used to calculate the wind speed (C.B. Hasager, 2007).

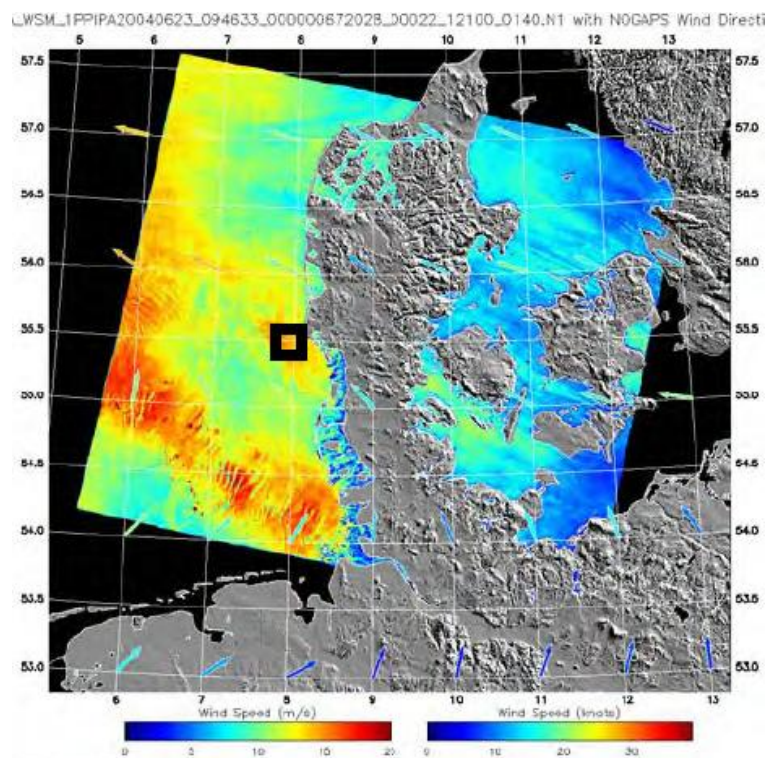


**Figure 12: SAR system viewing geometry**

(C.B. Hasager, 2007)

As a resource though, it is not as reliable, as there are much fewer wind maps available (less than 1000). By implementing statistical methods of few samples it is possible to obtain rough estimates of the wind resource.

There is a known accuracy of around 1.1 m/s standard error on a series of wind maps in comparison to offshore mast observations. This fact is particularly useful in determining and identifying potential locations to install offshore masts (or LIDAR/SODAR devices). On top of this if high quality met observations are available within a mapped area, the relative differences in winds between different locations can be estimated with higher accuracy, possibly around 0.6 m/s. **Figure 13** below shows wind maps calculated from SAR.



**Figure 13: Map of Denmark showing SAR measured wind speed**

*(InternationalEnergyAgency, 2007)*

One limitation with satellite and SAR data is the fact that it is based on the wind stress at the surface. For this reason there is a need to develop models to transfer this information to hub height for a potential turbine site. This may not always be worthwhile and accurate enough.



## **4.5 SODAR**

### **4.5.1 Introduction to SODAR**

SODAR (Sonic Detection and Ranging) devices are used to remotely measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere. This technology has been widely used for meteorology applications however its usage in wind energy, such as for measuring the wind field or the energy potential at a site, is relatively new. SODAR systems are similar to radar except that it uses sound waves rather than radio waves in the detection process. It is also similar to SONAR (Sound Navigation Ranging). The main difference in this instance is the medium in which sound travels through. SONAR systems detect the presence of objects underwater, while SODAR operates on the principal of reflection due to scattering of sound by atmospheric turbulence (*ART, 2008*).

Some advantages of SODAR over other wind measurement techniques include:

- Possibility to measure the wind profile over the whole rotor,
- Ground based instrument makes it is faster, easier and cheaper to use relative to cup anemometers mounted on met masts,
- SODAR is generally cheaper than LIDAR.

Some drawbacks of SODAR include:

- The limited experience in the use of the instrument,
- Decrease in performance with height,
- Dependence on the prevailing atmospheric conditions,
- Need for a rigorous well established “absolute” calibration method.

(*InternationalEnergyAgency, 2007*).

### **4.5.2 History of SODAR**

Acoustic scattering has been in development for the last 50 years. The primary reason for this technology was to study the structure of the lower atmosphere. Like many new technologies SODAR emerged from the United States during World War II. Here scientists used acoustic backscatter in the atmosphere to examine low-level temperature inversions as they affected propagation in microwave communication links.

It wasn't until the 1970's that the idea of designing acoustic sounders was seriously pursued once researchers had shown experimentally that atmospheric echoes could reliably be obtained to heights of several hundred meters.

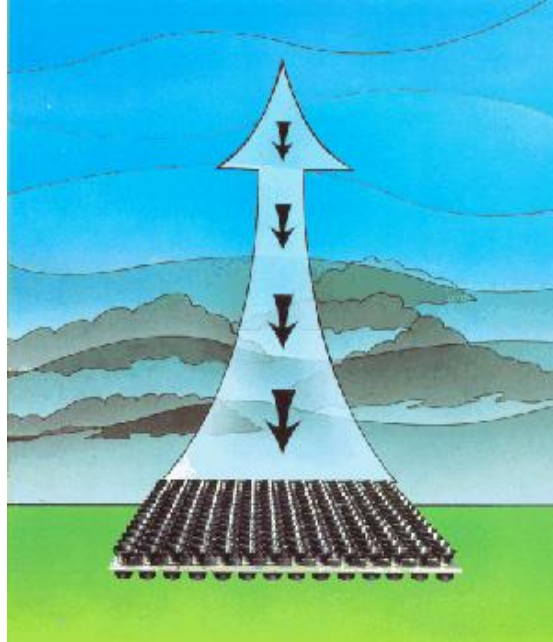
The first two commercial systems were the Model 300 developed by AeroVironment and the Mark VII developed by N.O.A.A. (National Oceanic and Atmospheric Administration). They were used to measure the turbulent structure of the atmosphere up to several hundred meters. The design of both devices was based around a parabolic dish and a facsimile recorder used to provide an Analog record of backscatter data (*ART, 2008*).

The first digital based acoustic sounder was developed in 1975 at the University of Nevada at Reno and at Scientific Engineering System, Inc. (S.E.S.). This was achieved by incorporating a microcomputer into the system. Further developments from both S.E.S. and N.O.A.A. saw the original single parabolic dish evolve into three axis digital based SODAR system which was able to measure the Doppler shift and backscatter intensities in real time. This system allowed the newly modified device to determine the vertical profile of the horizontal wind speed and direction. This commercial Doppler system was made available in the late 1970's by S.E.S. and was named Echsonde. By the early 1980's other companies such as Radian Corporation were using the technological advancements that S.E.S. had made in Echsonde as the basis for developing a microcomputer based three-axis Doppler SODAR system (*ART, 2008*).

The 1980's saw continued developments by various companies interested in improving this technology. These include Xonics Inc. and AeroVironment Inc. as previously mentioned. Xonic's device (Xondar), could measure wind profile and turbulence. AeroVironment's Invisible Tower (AVIT) again was based on three adjacent parabolic dishes operating in sequence however one was pointed vertically and the other two tilted 30 degrees from the vertical in horizontally orthogonal directions (*ART, 2008*).

Outside of the U.S.A., other organisations in Europe and Australasia produced commercial Doppler SODAR systems. One company in particular, Remtech in France, was one of the first to commercialise phased array SODAR systems which were capable of measuring Doppler shifts as well as turbulence parameters at heights of up to and over 1000 meters. They were also the first company to apply multiple frequency coding which helped to extend the altitude performance in SODAR. **Figure 14** shows Remtech's arrayed Doppler SODAR

device which measures the frequency shift of the echo that varies according to the wind speed, i.e. the Doppler shift, and the echo intensity, which varies according to thermal turbulence and structure.



**Figure 14: Remtech arrayed SODAR**

*(Remtech, 2009)*

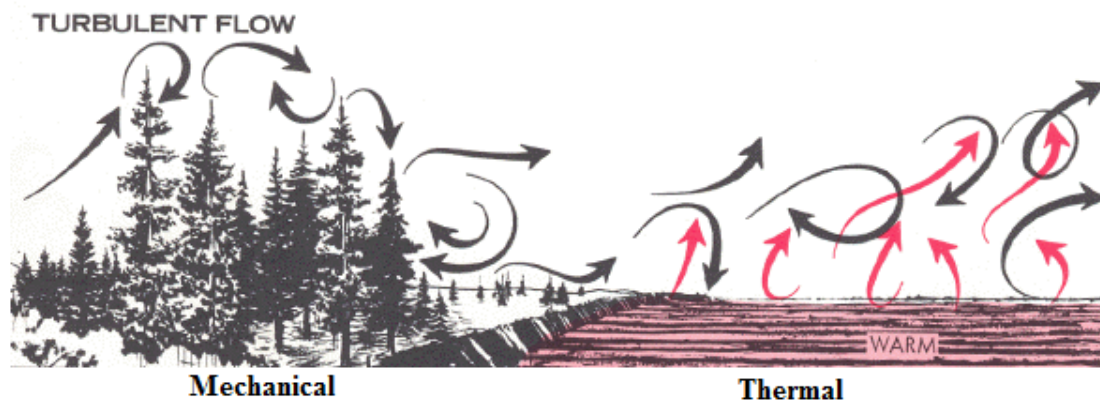
More recently, by the 1990's phased array Doppler SODAR systems utilise a laptop computer for much of the system control and operation. This has resulted in great simplification in comparison to earlier systems which required significant electronics and computer systems. Nowadays SODAR systems can be battery powered and extremely portable within an enclosed trailer (A.R.T., 2008). More details of the apparatus used in this project and work undertaken will be discussed later in this report.

### **4.5.3 Theory of SODAR**

The basic theory of SODAR functionality was mentioned previously in the Doppler effect of sound propulsion. Further discussion will analyse these operational and theoretical methods.

In order to comprehend this technology it is first necessary to understand the medium in which SODAR operates: The Atmosphere. Atmospheric motion is based on wind flow and turbulence. Turbulence is caused by one of two forces, namely thermal and mechanical

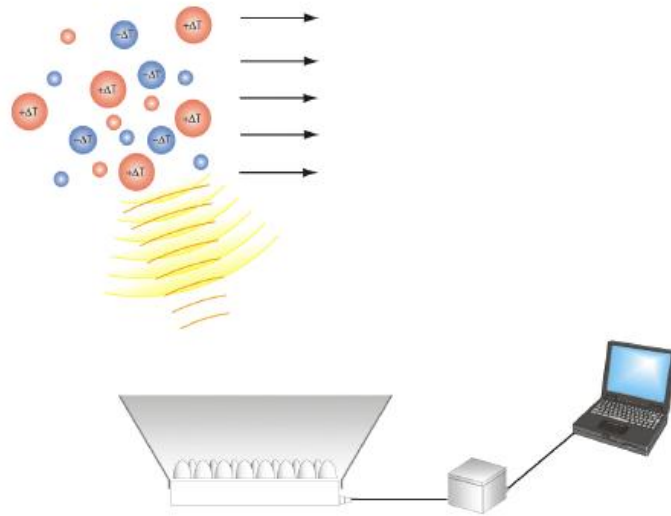
(**Figure 15**). A thermal turbulent force is caused by temperature differences in the atmosphere (hot air rises causing wind currents). A mechanical turbulent force is caused by air movement over natural or man-made obstacles. This interactive mechanical turbulent force is due to the earth's rough variation in surface smoothness and is less prominent over flat seas. The impact of turbulence from both mechanical and thermal sources is the formation of eddies. In the case of mechanical turbulence the size of the eddy is directly proportional to the size of the obstruction and speed of the wind.



**Figure 15: Graphic description of Mechanical and Thermal Turbulence.**

*(Buck, 2008)*

When a sound pulse, is transmitted from the SODAR device through the atmosphere it meets an eddy and its energy is then scattered in different directions (See **Figure16**). The scatter pattern that thermal and mechanical turbulence produce is different. However, there is almost always a proportion of acoustic energy reflected back towards the source of sound. This backscatter or atmospheric echo is then measured using a monostatic SODAR system. Logically, as the acoustic pulse is reflected as backscatter the angle between the eddies and the antenna is  $180^\circ$  as it returns directly towards the source. This detected backscatter is only caused by thermally induced turbulence and mechanical turbulence is generally not detected in a monostatic system (*ART, 2008*).



**Figure 16: Principle of SODAR shown with phased array**

*(SCINTEC, 2004)*

Bistatic SODAR systems have transmitting and receiving antennas at various locations. Because of this scattering angles other than  $180^\circ$  can be detected. As well as that, the increase in range of angles allows both thermal and also mechanical turbulence to be picked up. It also increases the complexity of the device in design and application.

The shift in frequency of the returned signal relative to the frequency of the transmitted signal is thanks to the Doppler Effect as discussed. It is this difference that allows us to calculate the measure of air movement at the position of the scattered eddy. If the target or reflected turbulent eddies are moving in the direction of the SODAR antenna, it will have a higher frequency than that of the transmitted signal. The opposite also applies in that when the target is moving away from the antenna, the returned frequency will be lower. It is this characteristic that allows Doppler SODAR systems to measure atmospheric winds and turbulence.

The thermal structure and radial velocity of the atmosphere at varying distances from the transmission antenna can be determined by measuring the intensity and the frequency of the returned signal as a function of time after the transmitted pulse. By sending consecutive pulses, one in the vertical and two in orthogonal directions at angles slightly tilted from the vertical we can obtain even further information. This can be done by conducting geometric

calculations to obtain vertical profiles of the horizontal wind direction and both horizontal and vertical wind speeds (*ART, 2008*). Some of these calculations will be looked at later in **Section 4.5.5**, however, first it is important to understand the transmitted pulse properties and some of its influencing factors.

#### **4.5.4 SODAR Pulse Properties**

A Transmitted sound pulse that is delivered by SODAR is scattered by fluctuations of the refractive index of air and by eddies as discussed. Other factors that cause these fluctuations include variation in temperature and humidity of the air as well as wind shear.

Turbulent fluctuations move with the wind. Therefore, the Doppler Effect shifts the sound frequency during the scattering process. This level of frequency shift is proportional to the velocity of the scatter in the beam direction. For example, if the beam is directed vertically, the vertical wind speed  $w$  can be calculated directly from the Doppler shift. In order to calculate the horizontal components it is necessary to tilt the beam also by a small angle  $\theta_0$  from the vertical into two horizontally perpendicular directions whose wind components can be named  $u$  (East) and  $v$  (North). Now three Doppler shifts are obtained from each transmitted pulse, which are a function of the wind components  $u$ ,  $v$ , and  $w$  (*Ioannis Antoniou, 2003*).

The transmitted pulse is assumed to be confined to a conical beam of half-angle  $\theta$ . For a system having pulse duration  $\tau$  and with speed of sound  $c$ , the pulse is spread over a height range of  $c\tau$ . As the pulse is scattered, it is detected at any one time from a volume ( $V$ ) where:

**Equation 1: Volume of pulse detected**

$$V = \pi(z\theta)^2 \frac{c\tau}{2}$$

Where  $\frac{c\tau}{2}$  is the height range and  $\pi(z\theta)^2$  is the horizontal extension with  $z$  being the height above the antenna array.

The ratio between received and transmitted powers at a height of a 100 m above ground and for a 4500 Hz SODAR is typically of the order of  $10^{-14}$ . Therefore absorption in the atmosphere is an important factor restricting the range that is the maximum height from

which scattered signals can be detected. The ratio of received to transmitted power is proportional to the absorption term as shown in **Equation 2**:

**Equation 2: Ratio of Received to Transmitted Power Proportional to Absorption**

$$\frac{P_R}{P_T} \propto e^{-2\alpha z}$$

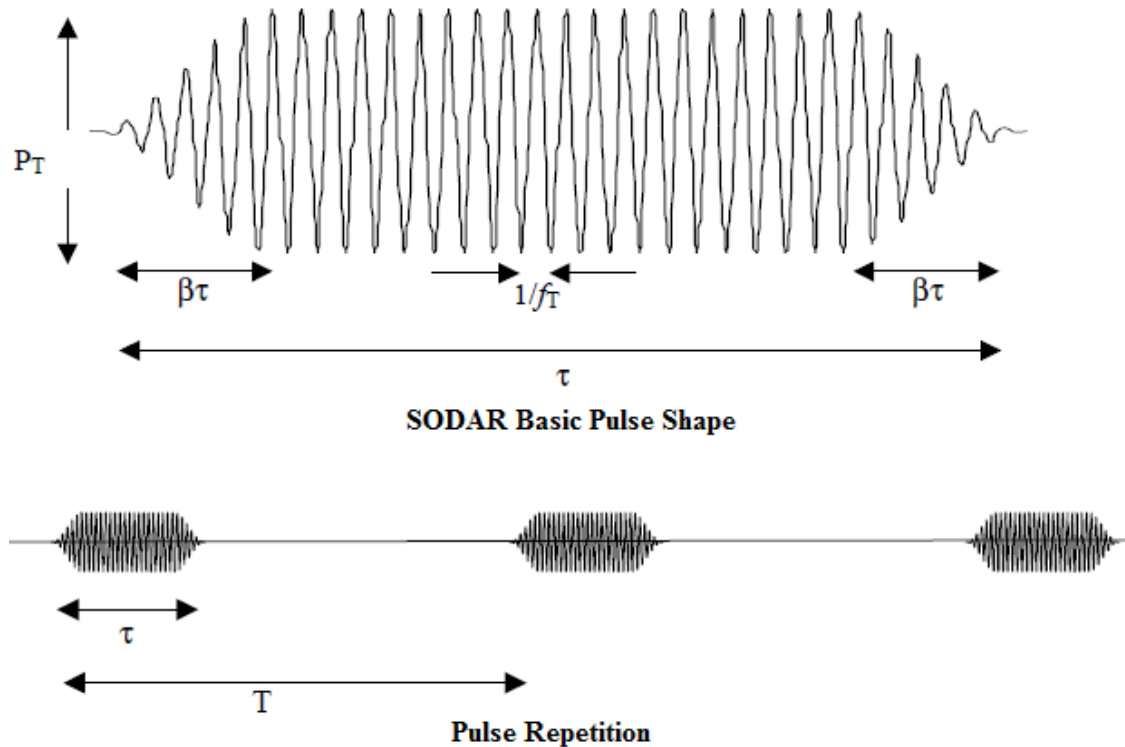
Where the absorption coefficient  $\alpha$  is the sum of classical absorption,  $\alpha_c$ , and molecular absorption,  $\alpha_m$ . Classical absorption is due to viscous losses when sound causes motion of molecules, and is proportional to frequency squared. Molecular absorption is due to water vapour molecules colliding with oxygen and nitrogen molecules and exciting vibrations, which are dissipated as heat. At low humidity there is little molecular absorption (*Ioannis Antoniou, 2003*). At high humidity  $O_2$  and  $N_2$  molecules are fully excited without acoustically enhanced collisions, and there is again little extra absorption. Absorption also depends on temperature and pressure since these affect collisions. The resulting equation shows a complicated dependence on the mentioned parameters as well as on the sound frequency. However, in the frequency range of interest for SODARS that is between 1 and 10 kHz the following rule is valid: The higher the frequency of a SODAR the more limited its range due to absorption (*Salomons, 2001*).

### **Sending Beam signal**

Parameters that effect how the SODAR sends the beam include:

1. Transmit frequency (fT)
2. Transmit power (PT)
3. Pulse length ( $\tau$ )
4. Rise time (up and down) ( $\beta\tau$ )
5. Time between pulses (T)
6. The tilt angle

Some of these parameters and the relationship between them are shown in **Figure 16**. Shown is the basic pulse shape emitted from one transmitter and the repeated pulse with a time interval between. A brief description of each parameter and its effects follows.



**Figure 17: Relationship between SODAR parameters**

*(Ioannis Antoniou, 2003)*

### Frequency

The frequency of a standard phased array SODAR is decided in the design process and cannot be altered much once assembled. Choosing the frequency is based on two factors, overcoming background noise and absorption in the atmosphere. Because absorption also depends on temperature ( $T$ ) and relative humidity ( $RH$ ), the frequency must be chosen carefully as it is the only independent design parameter.

### Power

The most important factor relating to power is to make sure the speakers are not damaged by the voltage signal. This can be clearly seen from the SODAR equation:



**Equation 3: SODAR equation, Power received.**

$$P_R = P_T G A_e \sigma_s \frac{c\tau}{2} \frac{e^{-2\alpha z}}{z^2}$$

$P_R$  = Power received from the atmosphere

$P_T$  = Transmitted power

$G$  = Antenna transmitting efficiency

$A_e$  = Antenna effective receive area

$\tau$  = Pulse length

$z$  = Height

$\alpha$  = Absorption of air

$\sigma_s$  = Turbulent scattering cross section

$c$  = Wind speed in air ( $\pm 340$  m/s)

If more power is put into the beam, more power will be received back. For this reason it is necessary to consider how much power the speakers are able to deliver without being damaged (*Ioannis Antoniou, 2003*).

**Pulse length**

The pulse length is the length of the pulse as shown in **Figure 17**. It is measured in milliseconds or in meters. The effective pulse width with respect to power output is used in calculations. This is the pulse width without the rise time plus half the rise time (up and down). So a pulse length of 100 ms with a rise time (up and down) of 15% will have an effective pulse length of 85 ms.

The pulse length has an impact on the following parameters:

1. Power received from the atmosphere,

Looking again at **Equation 3** it can be seen that a longer transmit pulse means more received power.

**Equation 4: Pulse width is proportional to received power.**

$$\frac{P_R}{P_T} \propto \tau .$$

2. Frequency resolution,

**Equation 5: Relationship between frequency and Pulse length**

$$\Delta f_V = \frac{1}{\tau}$$

3. Height resolution,

**Equation 6: Relationship between height and pulse length**

$$\Delta z = \frac{c\tau}{2}$$

## Rise time

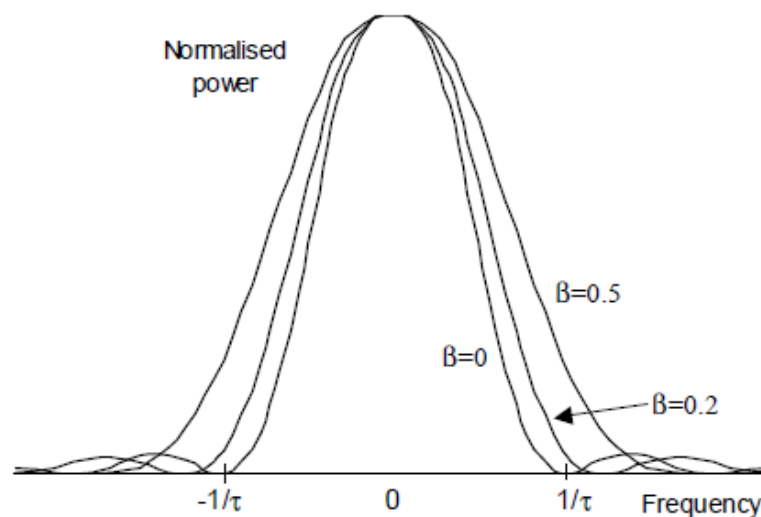
The reason that there is a rise time in the signal is because it passes through a Hanning filter first. This gives the signal a ramp up and down at the beginning and the end and helps to protect the speakers from too quick a rise in voltage, which could cause them harm (*Ioannis Antoniou, 2003*).

By assuming a pulse shape  $p(t)$  and duration  $\tau$ , determining the Hanning shape is defined as follows:

**Equation 7: Calculating Hanning shape**

$$(1-\beta)p(t) = \begin{cases} \frac{1}{2} \left[ 1 - \cos\left(\frac{\pi}{\beta\tau}t\right) \right] & 0 < t < \beta\tau \\ 1 & \beta\tau < t < \tau(1-\beta) \\ \frac{1}{2} \left[ 1 - \cos\left(\frac{\pi}{\beta\tau}\{\tau-t\}\right) \right] & \tau(1-\beta) < t < \tau \end{cases}$$

The frequency spectra for three pulse shapes are shown in **Figure 18** below.



**Figure 18: Hanning Shape pulse frequency spectra for different ramp times**

*(Ioannis Antoniou, 2003)*

For an ideal pulse  $\beta=0$ , all the energy would be in the main lobe of the sine function around the y-axis and decay to zero with no ripples. This is not practical as unwanted ripples are introduced to the frequency. By increasing  $\beta$ , the pulse becomes broader and deeper with fewer ripples due to more of the energy being in the main lobe. This is a more desired effect, however broadening the main lobe causes the transmit frequency to be less well defined, for this reason a balance must be reached between ripples, pulse power and a well defined transmit frequency.

### Time between pulses

Time between pulses and the maximum height the SODAR attempts to measure have a direct relationship. It is critical that any measure of backscatter must be finished before the next pulse is sent therefore the maximum height is  $cT/2$ .

For phased array SODAR it is important to make sure backscatter from other pulses have been completely detected before sending out another pulse, otherwise it could effect the measurements and have an undesired effect.

### The Tilt Angle

The tilt angle  $\theta$  is defined by the loud speaker spacing  $d$  of the antenna array, by the number of speakers  $N$  and by the transmit frequency  $f$  (or wave number  $k$ ). The resulting intensity pattern can be compared to optical interference patterns:

**Equation 8: Intensity of loudspeaker array of N speakers**

$$I \propto \left[ \frac{\sin\left(Nk \frac{d}{2} \sin \theta\right)}{\sin\left(k \frac{d}{2} \sin \theta\right)} \right]^2$$

In theory it is possible for the beam to be steered by a variable phase-shift between 0 and  $\pi/2$  between two respective loudspeaker groups. Manufacturers of SODAR fix the progressive phase-shift at  $\pi/2$ , which helps to simplify the design. In practice this leads to tilt angles of  $16^\circ$  -  $30^\circ$  for higher to lower transmit frequencies respectively. The practical limit on the beam tilt angle is:

**Equation 9: Limit on beam tilt angle**

$$\Delta\theta_{ilt} \leq \frac{2\pi}{4dk}$$

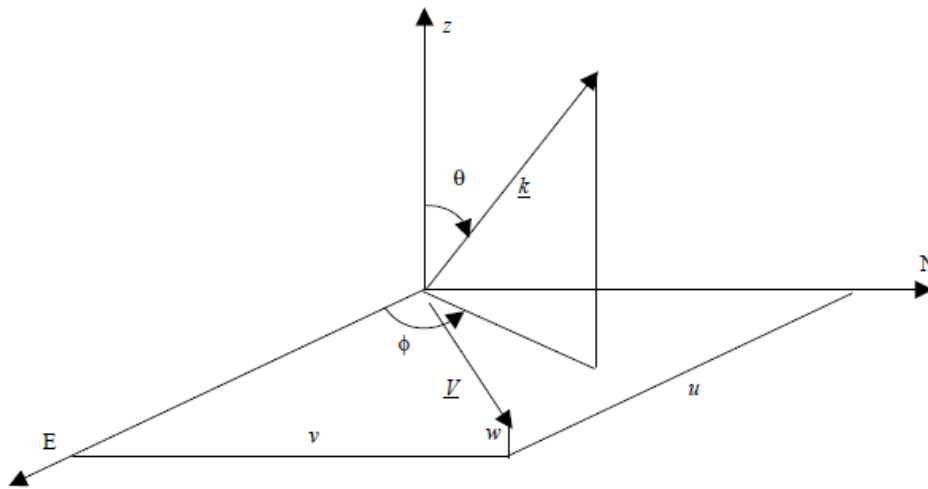
(Ioannis Antoniou, 2003)

### 4.5.5 Calculating Wind Component from SODAR

Having reviewed some of the parameters of the signal beam, it is important to understand how the returned signal is used to calculate relevant wind data. If three beams  $w, v$  and  $u$ , as described in section 4.5.4 were sent into the atmosphere the returned scatter data can be analysed. The signal transmitted from a SODAR is a travelling wave with components like  $\sin(\omega t - kz)$  or  $\cos(\omega t - kz)$ . The sound wave is scattered by turbulent effects and the return signal has a different frequency due to the Doppler Effect. The total Doppler shift is:

$$\Delta\omega = -2\mathbf{k}\mathbf{w}$$

If the SODAR beam (**Figure 19**) is tilted at a zenith angle  $\theta$  from the vertical, and directed at azimuth angle  $\phi$  with respect to East, and the wind has components  $V = (u, v, w)$



**Figure 19: Orientation of the SODAR beams**

*(Ioannis Antoniou, 2003)*

It follows then that:  $\Delta\omega = -2k(usin\theta \cos\phi + vsin\theta \sin\phi + w\cos\theta)$

The easterly wind component is  $u$  and the northerly wind component is  $v$ , so an easterly or northerly wind gives a lower frequency. SODARs are typically designed so that they direct two tilted beams in orthogonal planes, say with  $\theta_1=\theta_2=\theta_0$ ,  $\phi_1=0$  and  $\phi_2=\pi/2$ . A third beam is vertical with  $\theta_3=0$ . Then, at each range gate height, three Doppler shifts are recorded:

**Equation 10: Doppler shifts for 3 beams**

$$\Delta\omega_1 = -2ku \sin \theta_0 - 2kw \cos \theta_0$$

$$\Delta\omega_2 = -2kv \sin \theta_0 - 2kw \cos \theta_0$$

$$\Delta\omega_3 = -2kw$$

Solving for  $u$ ,  $v$ , and  $w$  gives the three wind components:

**Equation 11: Wind components**

$$u = -\frac{\Delta\omega_1}{2k \sin \theta_0} - \frac{w}{\tan \theta_0}$$

$$v = -\frac{\Delta\omega_2}{2k \sin \theta_0} - \frac{w}{\tan \theta_0}$$

$$w = -\frac{\Delta\omega_3}{2k}$$

Since  $w$  is usually much smaller than  $u$  or  $v$ , the  $w$  component in the tilted beam Doppler shifts is sometimes simply ignored in calculating  $u$  and  $v$ . For example, if  $w = 0.1 \text{ ms}^{-1}$ , then for  $\theta_0 = \pi/10$  the error in  $u$  is  $0.3 \text{ ms}^{-1}$ . This compares with a typical measurement uncertainty in  $u$  of  $0.5 \text{ ms}^{-1}$ .

Each tilted beam also has finite width  $\delta\theta_0$ . This causes an extra spectral broadening in the Doppler signal of

**Equation 12: Extra spectral broadening**

$$\frac{\delta\Delta\omega_1}{\Delta\omega_1} = 2 \frac{\delta\theta_0}{\tan \theta_0}$$

(ignoring the  $w$  term). Typically  $\delta\theta_0 \sim \pm\pi/40$ ,  $\theta_0 \sim \pi/10$ , so if  $k=80 \text{ m}^{-1}$  and  $u=5 \text{ ms}^{-1}$ , then  $\Delta\omega_1 = 250 \text{ rad s}^{-1}$  ( $\Delta f_1 = 39 \text{ Hz}$ ), and  $\delta\Delta\omega_1 = 160 \text{ rad s}^{-1}$  ( $\delta\Delta f_1 = 26 \text{ Hz}$ ).

It is also possible to calculate the wind speed and direction for each measurement taken.

$$\text{WindSpeed} = \sqrt{u^2 + v^2}$$

$$\text{WindDirection} = \tan^{-1} \frac{u}{v}$$

This is specific to each individual measurement taken and it is more beneficial to find the averaging of power spectra and averaging winds to obtain wind energy for that particular site (Ioannis Antoniou, 2003).

## **Chapter 5: Mobile SODAR unit**

### **5.1 Introduction**

So far, the majority of information reviewed is not directly related to the experimental work conducted, however, it was felt that it was important to have a firm understanding of the ‘bigger picture’, such as; the energy crisis, wind energy resource, wind measurement techniques and lastly SODAR, the remote sensing device used in conjunction with this project. Such information is not of critical importance to the work carried out, however, it reflects the complete learning and comprehension of ideas and concepts taught on this course. The following information presented will focus on the control aspects of powering the SODAR device and other electrical units in the trailer. First a description of the SODAR used as part of this project is given.

### **5.2 SODAR device**

The type of SODAR device used as part of this project is a Wind Finder AQ500 developed by AQS Systems, a remote sensing company situated in Stockholm. It is based on the monostatic technique, i.e. the same loudspeaker driver is used both for transmitting of sound pulses and receiving of the echo signals. The antenna has three separate loudspeaker drivers used for each wind component  $u$ ,  $v$  and  $w$  as described in section 4.5.5. See **Figure 20** for an internal view of the SODAR device. A graphical description of the interface used in conjunction with the device is also displayed in **Figure 21**.

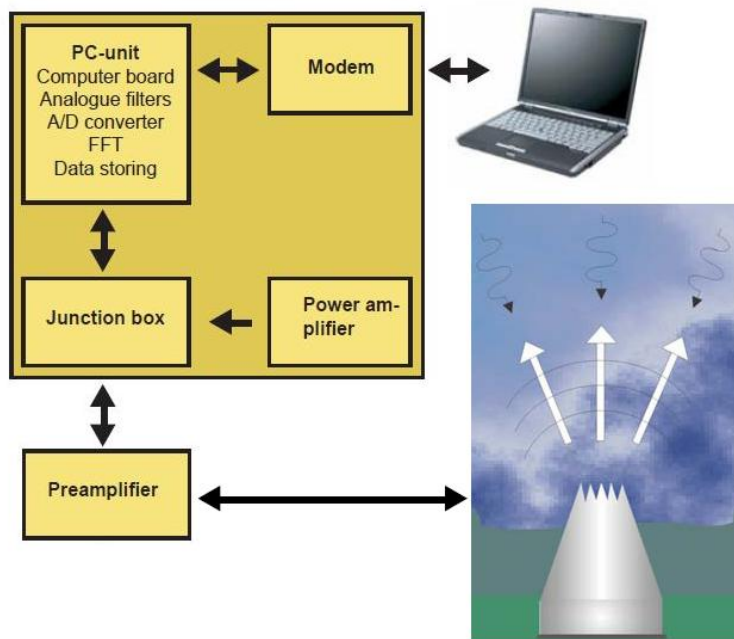


**Figure 20: Internal view of SODAR device**

*(AQSystem, 2008)*

**Table 2: SODAR internal components**

<b>A</b>	Speaker
<b>B</b>	Parabolic Dish
<b>C</b>	Speaker Membrane



**Figure 21: Functioning Description of SODAR interface.**

*(AQSystem, 2008)*



The system is controlled from a separate P.C. unit. There is also an analog board which has filters and an A/D (Analog/Digital) board for sampling data. The P.C. unit contains a flash memory used for storing programs and retrieved data. The A/D board is provided with a D/A output which is used for generation of a digital tone pulse.

The digital tone pulse is filtered on the analog board and connected to the Power amplifier. The Loud speaker drivers are transmitting in a cycle depending on the measuring mode. Long tone pulses are used for measuring wind data at high altitudes and shorter tones are used measuring at lower altitudes.

As one loudspeaker transmits a signal or pulse it immediately follows that it works as a microphone to detect the reflected weak echo signal. While this occurs the other subsequent inactive loudspeakers are too acting as microphones to detect background noise. Once signals are received they are transmitted back and amplified through the preamplifier into the electronic unit. The signals then connect into the analog board where they undergo correction and filtering. Filtered signals then are sampled by the A/D converter and the frequency spectra for the three channels, one with the echo signal and two with the background noise. They are calculated by a FFT algorithm with 1024 points. As the background noise is considered interference and of no use in the acquisition of useful data it is subtracted from the channel with the spectrum of the echo signal (*AQSystem, 2008*).

The P.C. unit is then able to calculate required information such as the horizontal wind speed and direction together with component sigma values, max value, min value and the vertical wind speed. This is done by analysing the detected Doppler shift of the returned echo signals.

### **5.3 SODAR Deployment Considerations**

The main goal of this project was to prepare the SODAR unit for deployment in the field and to ensure it is capable of operating at a potential site for a wind farm or at an existing site while retrieving data for review. Before successful testing at various sites can be conducted, it is first necessary to ensure that a number of factors are considered to allow the device to operate remotely without human assistance. These include:

- Power availability
- Weather conditions
- Remote communication
- Data acquisition

The main experimental aspect of this project was based around data retrieval and control functionality. Other aspects will be discussed briefly as they all feature in the mobile unit that was used.

### **5.3.1 Power availability**

In order to deploy the SODAR unit at a site, one of the first critical requirements that must be made available is a consistent power supply. This is achieved by the presence of a generator in the mobile trailer which is used to charge batteries which in turn power the SODAR, data logger and lighting inside the trailer. The type of generator used in this case is a Fischer Panda AGT 4000 connected to a Yanmar L48V diesel engine. The Generator supplies a 12V charge to four 12V batteries, which provide power to the SODAR. It also charges a 12V starter battery which is used to start the generator, power the data logger, and is also used for part of the SODAR unit. The generator has a number of operational sensors installed. These include:

- Oil pressure sensor
- Motor temperature sensor
- Low fuel level
- Low battery level

Most of these operational aspects are linked in with the data logger and will be discussed in greater detail in **Chapter 7**.

### **5.3.2 Weather Conditions**

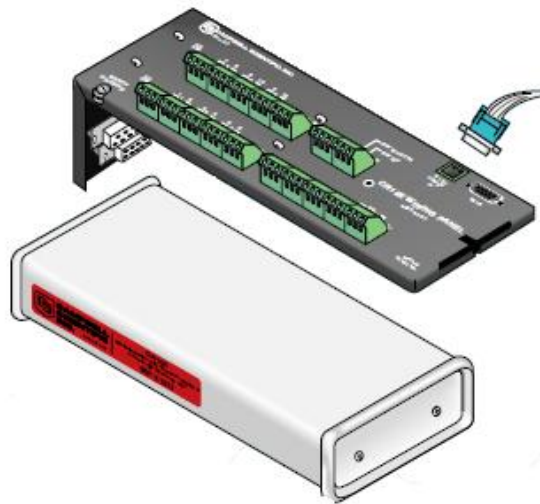
The exterior of the trailer has some weather probes attached that can also be linked in to the data logger. These include:

- Rain detection probe
- Frost detection probe
- Dew/condensation probe
- Temperature probe

The collection of data by the SODAR unit can be severely impacted by the presence of bad weather such as heavy rain, snow and icing conditions. Rain and snow can cause invalid data to be returned to the SODAR particularly in the reflection of vertically sent sound pulses. These probes also draw power from the battery contained in the mobile unit and are connected into the data logger.

### **5.3.3 Data Acquisition**

This was the primary focus of this project. All data monitored in the mobile trailer unit was to be collected and stored by a Campbell Scientific CR10X data logger shown in **Figure 22**. The CR10X is a fully programmable data logger and controller in a small, rugged, sealed module. The data logger requires a 12V D.V. power supply and can be powered by the battery used for the generator start up. The data logger comes with a detachable wiring panel (black with green in/outputs **Figure 22**) which connects via two D-type connectors located at the end of the module. The Wiring Panel has a 9-pin serial I/O port which is used when communicating with the data logger and it also provides terminals for connecting sensor, control and power leads to the CR10X. It also provides transient protection and reverse polarity protection. Communication with the data logger can be established through the use of a portable CR10KD keyboard display or with a computer terminal (*CampbellScientific, 2002*).

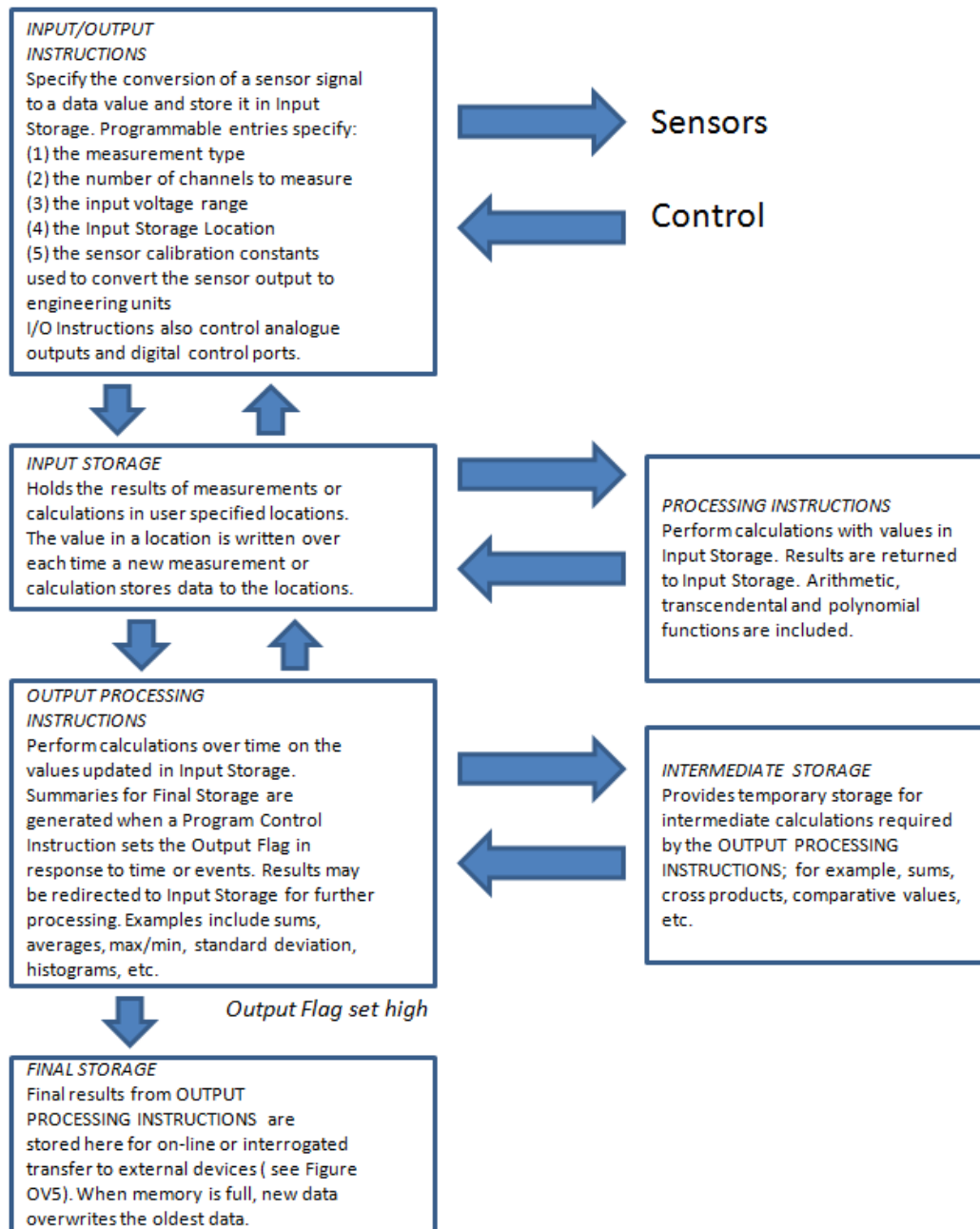


**Figure 22: CR10X data logger and wiring panel**

*(CampbellScientific, 2002)*

Further information in relation to initial communication will be discussed in section **6.4**.

**Figure 23** shows how the data logger processes input information and carries out instructions. The storage areas are outlined and some example output processing instructions are given that are sent to final storage. This gives a good understanding of how a data logger operates to produce useful output data from signals received.



**Figure 23: Processes, Instructions and storage areas**

*(CampbellScientific, 2002)*

### **5.3.4 Remote Communication**

Both the data logger and the SODAR device used in this project allow for remote communication through the use of an external modem. The computer board that is supplied with the SODAR comes with a serial port (COM1) that allows for connection of a GSM modem. There is also a GSM antenna that is of significant enough length so that a sufficient signal can be detected. The software that is used for this is SODWIN 6.0-COM. It needs to be installed on the laptop being used to communicate with the remote modem. This software is capable of collecting the set SODAR parameters that are currently set and it also allows for update and alteration of new input parameters. The same software is used for communication via a telephone modem. The modem also allows for retrieval of data obtained by the SODAR device for analysis off site (*AQSystem, 2008*).

The data logger used in this project has an I/O port which can act as a 5V DC power line and can be used to power a modem. Using a modem in conjunction with a data logger allows for remote communication and collection of data. Retrieval of data via modem can be done under program control or by regularly scheduled polling of the data logger. Campbell Scientific's data logger support software automates this process. Telecommunications are part of the programming command language and can be found on the prompt sheet attached in **Appendix A** under instruction 97 and instruction 99. More details of this will follow in the description of the code functionality later in section **7.5.5**. The diagram in **Figure 24** shows all possible communication methods that can be used with the CR10X data logger. These include direct connection with the device itself via a SC12 cable and then through a SC32A, SC929 or RS232 type interface cable. These can then be connected to a laptop using an SC-USB cable.

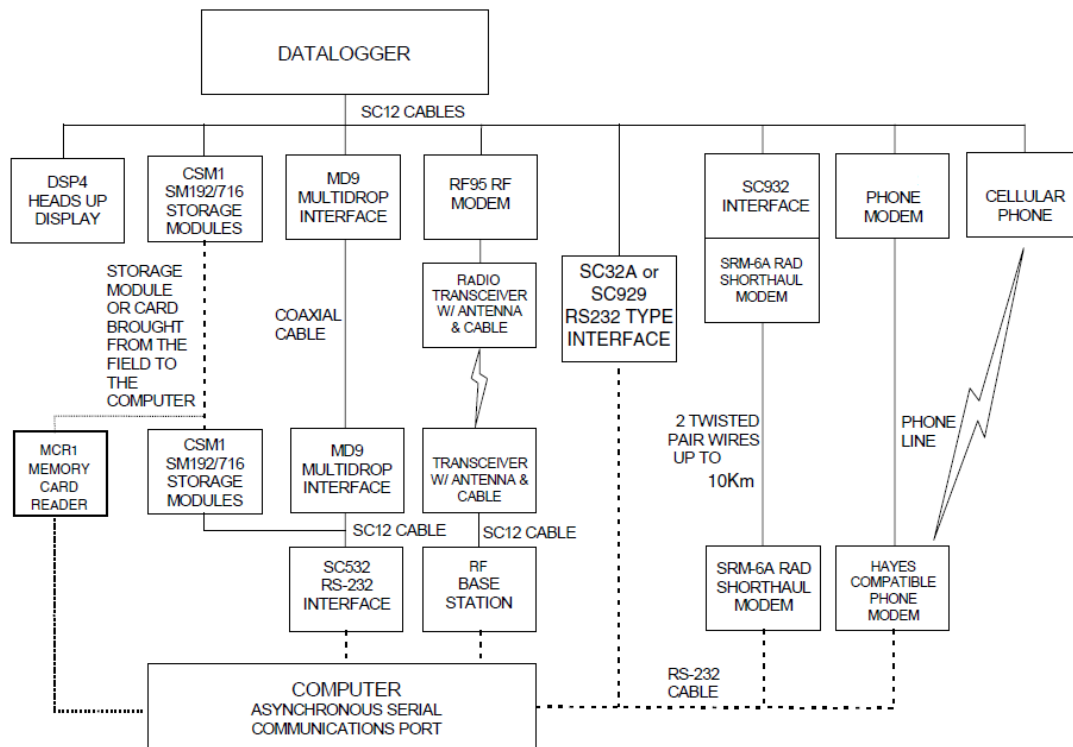


Figure 24: CR10X communication options

(CampbellScientific, 2002)

## Chapter 6: Using the Data Logger

### 6.1 Introduction

The project was split into two separate research areas; Repair and operation of the SODAR device on University campus, while powering it of the electricity mains, which was conducted by my colleague Roger Carter. The other aspect, which I was dealing with, was preparation of the mobile unit for deploying the device for operation in the field. In **Chapter 5**, some of the field considerations are discussed. This chapter deals more so with the experimental work undertaken with the data logger to achieve the required goals. The two most important apparatus that were used consist of the diesel generator and the data logger as described in section **5.3.1** and **5.3.3** respectively, the latter which will be discussed next.

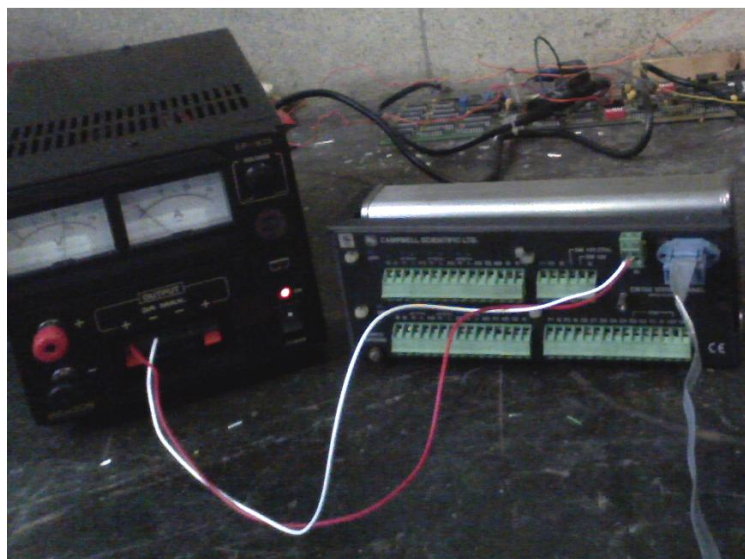
## **6.2 Initial Retrieval**

The data logger was disconnected from the wiring panel initially and was located in the trailer. The wiring panel was connected to several wires which were set to conduct various operations that became clearer later in the project following detailed research. Initially it was necessary to disconnect the wiring panel from all wires and remove the data logger with it from the trailer into a lab where experimental work could be conducted on it.

The actual Campbell Scientific CR10X data logger is quite rugged and robust however some slight damage was discovered to the D-type connection used to connect into the wiring panel. It appeared to be bent and would not fit correctly to the wiring panel, possibly due to an impact sustained. Luckily after the damaged pins were straightened manually using a set of pliers, connection with the wiring panel could be re-established. Had the impact to the connector been more severe the device may have needed to be sent to Campbell Scientific for repair.

## **6.3 Powering the data logger**

The data logger was powered in the laboratory by wiring it up to a 12V D.C. supply voltage. The supply voltage was provided by the mains and converted to D.C. in a power supply unit which allowed for adjustable voltage control. This however was fixed at 12V as required by the data logger. **Figure 25** shows the data logger in the lab with a variable D.C. voltage supply. Note the data logger is the ‘can’ shaped rugged silver metallic unit connected to the wiring panel on the front of it on the right hand side of the photograph.



**Figure 25: Data logger and supply voltage**

## **6.4 Establishing Communication**

### **6.4.1 Setting up the apparatus**

The data logger came with a blue SC12 cable in the trailer (which can also be seen in **Figure 25**), and it was thought that by connecting this to the CS I/O port on the wiring panel and then to a SC-USB cable before plugging it into a laptop, that it would be possible to communicate to the logger. A number of factors needed to be considered first:

- Installation of the software for the SC-USB cable and establishing which COM port the cable operated under.
- Downloading of PC200W, free software available from the Campbell Scientific website used to program and communicate with data loggers.

Having completed all this it was still not possible to connect with the logger. A voltmeter was used to ensure that power was running through the wiring panel by checking that there was a voltage between the 5V supply and ground inputs available on the panel which can be used to power a modem or other device as discussed in section **5.3.4**. This was present, meaning that the data logger was receiving power and that the internal battery was not dead. Following this inspection, a contact was established within Campbell Scientific, Franco Casule, who was familiar with this particular device. Having sent a number of pictures of the setup configuration it was made clear that the SC12 cable being used could not be used to communicate with the logger as the interface was not SC-USB Interface, but a USB to Serial Interface. The blue SC12 cable that was originally used is just a through cable and not an interface. For this reason it was necessary to purchase an interface which could be used to connect into a computer or a laptop. The most inexpensive SC929 cable was chosen and ordered for delivery.

### **6.4.2 Connecting to the Data Logger**

Upon delivery, once everything was set up correctly, it was found that the data logger appeared to be password protected from previous usage and would not allow connection. This particular model allows for three levels of password security on the device and this is explained in detail in the user manual however it is not of significant importance at this stage. The existing code that was on the data logger would not allow connection unless the password was entered correctly and it was not possible to override without re-setting the



device. As the password was not available the only solution was to re-set the logger. This was achieved by uploading a new operating system using the device configuration utility hardware configuration function (See **Figure 26**) on PC200W software. Having successfully re-set the data logger it was then possible to conduct preliminary simulations.

## **6.5 Preliminary Programming**

### **6.5.1 Software description**

As mentioned previously, the software used in the initial stages of this project was PC200W. It is designed for collecting data and is in comma-separated format ready for easy importation into data analysis packages such as MS Excel. It can also be used for setting the data logger clock, checking measurements and graphically displaying input locations in real-time. An inbuilt function within PC200W is an option to create a program using an application called Short Cut (See **Figure 26**). With Short Cut you can select sensors, choose output data, and create wiring tables. The steps involved using Short Cut for building data logger programs are as follows:

- Select Scan interval (time between measurements taken),
- Select sensor from a built in library,
- Select measurement outputs (Max, Min, Average etc.),
- Automatically generate an appropriate data logger program (in .DLD code),
- Review wiring tables, data label tables and output lists.

**Figure 26** shows a screen shot of PC200W and the location of some the functions described.

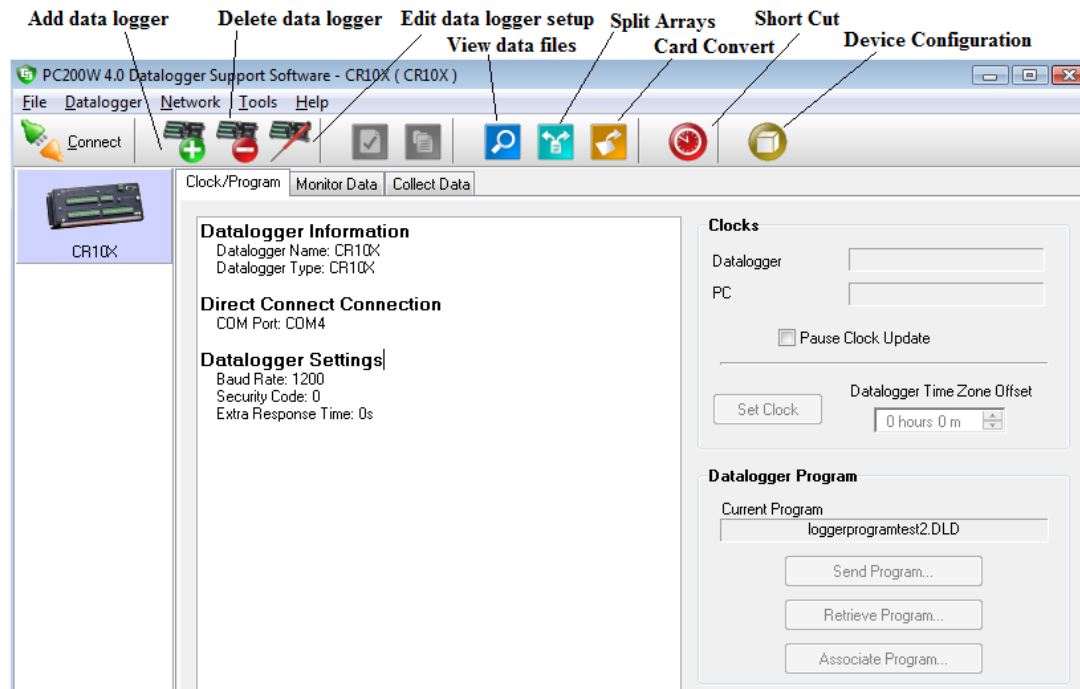


Figure 26: Screenshot of PC200W

### **6.5.2 Program Tests**

As no external sensors were available for the data logger that matched any of those in the inbuilt library some basic programming tests were conducted using sensors built into the logger and some external wiring connected to the wiring panel.

#### **Data logger Internal Temperature**

The first measurement that was carried out was the internal temperature of the data logger using a thermistor that is located inside the device on the analog board. The scan interval was set for every 10 seconds and the output measurements included the Max, Min, Average and Standard Deviation. The results obtained were as expected and do not require any discussion as the experiment is only part of the familiarisation process of operating of the data logger. The results can be found in **Figure 27** and in **Table 3** in section **6.5.3**.

### **Data logger Battery Voltage**

The next measurement that was taken and logged into the data logger's memory was the voltage supplied to the device. The CR10X operates at a nominal 12V DC. Below 9.6V or above 16V the CR10X will not operate correctly. Again the scan interval was set for every 10 seconds. Similar to before, the output measurements included Max, Min, Average and Standard Deviation. As the power supply used to convert the mains electricity was variable it was initially set to 12V and lowered in five intervals until the logger failed to operate. It was not increased for fear of damaging internal components. The results displayed the decline in voltage until the CR10X stopped working. These results can also be found in **Figure 27** and in **Table 3** in section **6.5.3**.

### **Single Ended Voltage**

The final preliminary measurement that was taken with the data logger using PC200W was a basic single ended voltage. Two wire sensors (signal and ground) were used to measure the voltage on a single-ended channel relative to ground. The scan interval was again set for every 10 seconds. A multiplier was used to convert the result from milliVolts to Volts. The two wires used to make measurements were connected to the data logger into input locations 1H and AG. The other ends of the wires were connected to a simple 1.5V battery to the positive and negative terminals. More details on wiring the data logger will be given later on for more complex experiments. Again, the results can be found in **Figure 27** and in **Table 3** in section **6.5.3**.

### 6.5.3 Preliminary Programming Results

As discussed, PC400W shortcut function automatically generates the DLD code necessary to take measurements that is uploaded to the data logger. The results of the basic measurements taken are displayed in **Figure 27** and **Table 3**.

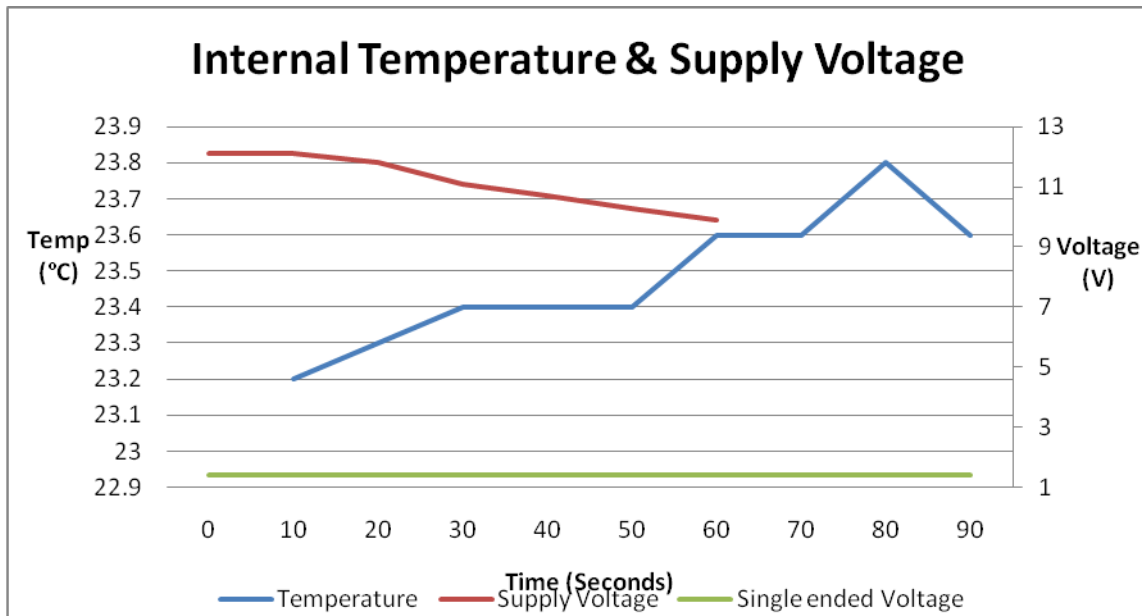


Figure 27: Preliminary data logger results

Table 3: Preliminary measurements logged

	Average	Max	Min	Standard Deviation
Internal Temperature	23.48	23.8	23.2	0.175119007
Supply Voltage	10.98333	12.1	9.9	0.854205284
Single ended Voltage	1.4	1.4	1.4	-

### 6.5.4 Discussion of Results

The results obtained were as expected. The internal temperature rose slightly with time however it appeared to level off. The Supply voltage dipped according to the five incremental reductions as outlined in 6.5.3. The Single ended voltage logged a voltage from a 1.5V battery that appeared to be drained by 0.1V.

It is possible to retrieve the DLD code that was uploaded to the data logger for each individual program and analyse it using the prompt sheet (see **Appendix A**) which is also available from Campbell Scientific. As PC200W is limited to developing programs that are restricted to sensors contained in the built in library that is part of Short Cut, the functionality of the data logger is limited and does not allow it to reach both its full potential, and to conduct the objectives required as part of this project. For this reason, more advanced programming Campbell Scientific software was obtained on a free 30-day trial to achieve the required results. This is known as LoggerNet 4.0.

## **Chapter 7: Applying the Data Logger**

### **7.1 Introduction**

As discussed in section 5.3.1 one deployment consideration for operating a SODAR device is the availability of power. The presence of the Yanmar diesel engine synced with a Fischer Panda generator overcomes this issue. The combined apparatus is controlled with the presence of the CR10X data logger which is wired to monitor the performance and conduct control operations. Before it was possible to implement the data logger to conduct the necessary functions, the generator and diesel engine needed to be inspected and repaired accordingly.

### **7.2 Engine Maintenance**

#### **7.2.1 Replacing the battery**

The engine used in this project requires a 12V heavy duty battery connected in order to start it up. The supply voltage is used to power the control panel which consists of the main on/off switch, operation counter, generator start button, motor temperature light, oil pressure light, operating state display, and battery charging control light. The battery also supplies power to the fuel pump and actuator which are part of the start up process (*FischerPanda*). The original battery that was removed read a voltage of around 6V. Having connected it to a charger adjusting the input voltage and current supply, it was felt, after reviewing the readings, that a number of cells inside the battery were more than likely exhausted. An alternative newer battery was acquired and charged for twenty four hours until a 12V reading was detected. The battery was then connected to the generator and the control panel light up once the switch

was flicked on. The generator started once the start button was pressed and the speed control temporarily adjusted.

### **7.2.2 Changing the Oil**

Given that the number of operational hours read 1950, and it was not clear when any maintenance was last carried out on the diesel engine, it was considered necessary to do some to make sure no other issues were encountered. Using the Yanmar operational manual a step by step guide was followed to change the oil and clean the oil filter (*Yanmar, 2005*). First of all the oil was drained using the connected hose at the base of the engine. Next the oil filter was removed and cleaned thoroughly removing any dirt accumulated. Finally the two dip sticks and oil filter were put back in place before re-sealing the hose. Clean Castrol Magnatec SAE 15W-30 oil was then put into the engine. The generator was started up and allowed to run for 5 minutes before being shut down and the oil level checked and modified accordingly.

### **7.2.3 Adjusting the throttle**

Initially when the start button was pressed the engine would only turn over repeatedly but not run completely until the speed control throttle was pushed temporarily. Having identified this issue it was deemed necessary to permanently modify its position so that the engine would start solely by hitting the start button. This was carried out using a spanner to loosen the bolt and adjust its position before retightening it.

The diesel engine and generator were then operating smoothly and delivering a consistent power supply. This meant that the next stage of the project required reconnecting the data logger and programming it to conduct control operations and monitor performance.

## **7.3 Control and Operation Requirements**

The data logger is used in conjunction with the engine and the generator. Circuitry is wired up accordingly and will be discussed at a later stage. The presence of a GSM modem also allows alarm messages to be sent out to inform the operator via txt message to a mobile phone. First the control functions of the data logger will be discussed.

The data logger is implemented to retrieve, process and store data, and also perform operations. The data collected includes:

- Outside temperature (Max, Min, Average)
- CR10X and Generator start up 12V battery Voltage

- Generator Run time (Max, Min)
- The Number of failed modem attempts.

Operations carried out include:

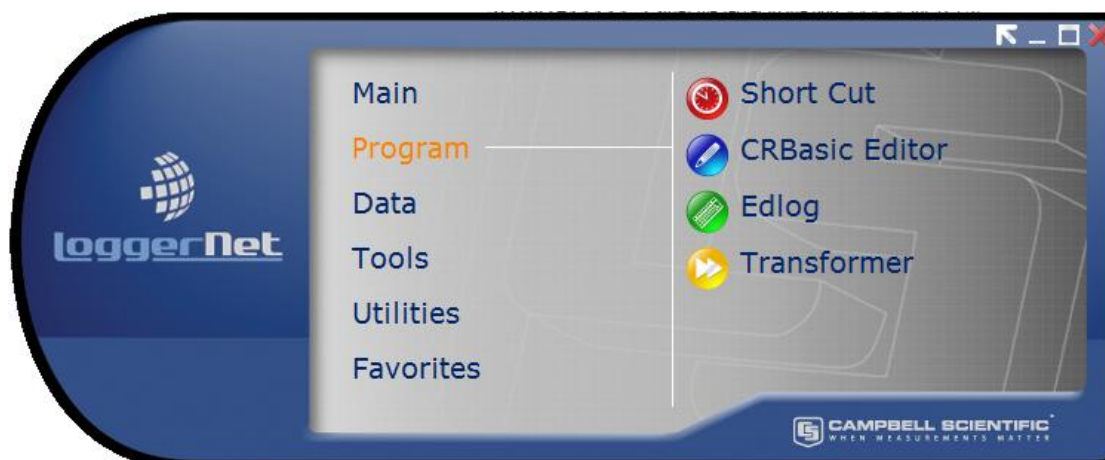
- Generator operation intervals
- Monitor fuel level
- Monitor battery levels
- Send alarm signals.

More detail of the program used to achieve this and a description of the wiring diagram follows.

## **7.4 Programming Software**

### **7.4.1 LoggerNet 4.0**

LoggerNet is a more advanced version of PC200W that allows increased logger capabilities. The software has a very user friendly interface that is easily navigable. It enables users to set up, configure, and retrieve data from a network of Campbell Scientific data loggers and share this data over an Ethernet communications network. Some of the functions included allow multiple remote monitoring and control of several separate data loggers. There are also powerful built in data analysis tools. As well as Short Cut, (the built in function used to create programs described in 6.5.1) there are advanced functions included that allow the development of programs for specific needs. These are known as CR Basic Editor, Transformer and Edlog as shown in **Figure 28**.



**Figure 28: Logger Net user interface**

### **7.4.2 Edlog**

Edlog is a tool to create and edit data logger programs for all Campbell Scientific data loggers. Instructions are available for sensor measurement, intermediate processing, program and peripheral control, and data storage. The CR10X instruction and parameter prompt sheet attached (**Appendix A**) can be used in conjunction with it to assist with inputting values according to requirements. The built-in pre compiler provides error checking and warns of potential problems in the program. Edlog produces a DLD file type that can be uploaded to the logger to carry out the necessary functions. Edlog was used in conjunction with LoggerNet to write the code necessary to perform functions and take measurements as outlined in **section 7.3.1**.

## **7.5 Programming Description**

### **7.5.1 Introduction**

The program created is based on the original however it is modified and commented in more detail. The program does not consider the presence of the SODAR device as in this instance it was not ready for connection in the mobile trailer for a number of reasons. For one, the batteries that powered it appeared to be exhausted and need to be replaced and also the circuit was simplified to try and obtain some measurements and results. This section describes some of the processing instructions that are taking place within the data logger that may be dependent on input signals and measurements.

### **7.5.2 Digital I/O Ports**

Terminals C1 to C8 on the data logger are digital input/output ports. They are generally used for reading the status of an external signal. They are either set in a high or low state. High and low conditions are:  $3V < \text{high} < 5.5V$ ;  $-0.5V < \text{low} < 0.8V$ . They can also be configured as output ports and supply control (on/off) of external devices, in this case the generator and the modem. Ports 1-5 that are used in this project are described in **Table 4**. The code that is referred to is the program uploaded to the logger to carry out such functions and can be found in **Appendix B**.



**Table 4: Ports used on data logger**

<b>Port</b>	<b>Type, Input/output</b>	<b>Name</b>	<b>Function/Description</b>	<b>Code Line</b>
<b>C1</b>	O/P	Start Generator	Starts generator at intervals of 1 hour, then turns the engine off for 2 hours before restarting the loop. Ensures batteries receive charge.	5,6: Table 1 program
<b>C2</b>	I/P	Generator Run	Measures Max and Min time generator runs every 30 mins.	21-25: Table 1 program
<b>C3</b>	I/P	Fuel Low	Low fuel signal is detected at this port and calls subroutine 1 to send alarm signal "Fuel Low"	12-14: Table 1 program
<b>C4</b>	I/P	Battery Low	Low battery is detected (24V) at this port and calls subroutine 2 to send alarm signal "Batt Low"	15-17: Table 1 Program
<b>C5</b>	O/P	CR10X GSM ignition	Initiates GSM modem ignition and shut down	10,11: Table 1 Program

### **7.5.2 Flags**

Flags are signals that are generated as a result of readings detected through the digital input/output ports. They are either set as high or low. In this project, the remote data logger is programmed to detect when the specified flag is set high. When the flag is set high, measurements and processes are carried out and the flag is set low once they have been completed. If the data logger detects that the flag is low, it collects data from the specified input locations and reviews incoming information before it can change to high again. The flags outlined in this project are given and described in **Table 5**.

**Table 5: Flag description**

<b>Flag Name</b>	<b>Function</b>	<b>Code Line</b>
F1-Low Fuel	Re-set modem if high disabling communication for sub-routine 1	2,3,12 : Table 3 subroutine 1
F2-Low Battery (24V)	Re-set modem if high disabling communication for sub-routine 2	16,17,26 : Table 3 subroutine 2
F3-Low Battery CR10X	Re-set modem if high disabling communication for sub-routine 3	30,31,40 : Table 3 subroutine 3
F5-Re-dial Low Fuel	Allows for subroutine 1 to be called and communication initiated if high. Impacted by C3	2,13: Table 1 13: Table 3 Subroutine 1
F6-Re-dial Low Batt(24V)	Allows for subroutine 2 to be called and communication initiated if high. Impacted by C4	3,16: Table 1 27: Table 3 Subroutine 2
F7-Re-dial Low Batt (CR10X)	Allows for subroutine 3 to be called and communication initiated if high. Impacted by measured voltage <12V	4,19: Table 1 41: Table 3 Subroutine 3

Flags 1-3 have a default setting of low until after communication has been carried out to prevent the modem from contacting the mobile phone in succession. The modem is limited to two calls every twenty four hours. Flags 5-7 are initially set high to allow subroutines to be called and communication alarms if necessary. However, they are set low once the corresponding subroutine has run again to prevent constant re-dial.

### **7.5.3 Run Generator**

The program signals to run the generator at intervals of one hour on and two hours off. This makes sure the batteries receive adequate charge consistently. Also If C2 is set high the generator detects an input signal in the form of Z which also signals the generator to operate. See code lines 5,6,20,21 (**Appendix B**).

### **7.5.4 Output processing**

The data is collected in the storage module of the memory every thirty minutes. The array ID is 501 and the time is logged with the information gathered. Although readings are taken every ten seconds, it is the processed result of that data that is stored. The data included in the output array is listed in **Table 6**, a screenshot of the final storage information collected taken from Edlog.

**Table 6:Final Storage data**

<b>Array ID</b>	<b>Output Instruction</b>	<b>Line Number</b>	<b>Final Storage Label</b>
501	Set Active Storage Area (P80)	162	<b>501</b>
501	Real Time (P77)	167	<b>Year_RTM</b>
501			<b>Day_RTM</b>
501			<b>Hour_Minute_RTM</b>
501	Sample (P70)	171	<b>battery</b>
501	Average (P71)	176	<b>Temp_AVG</b>
501	Minimum (P74)	180	<b>Temp_MIN</b>
501	Maximum (P73)	185	<b>Temp_MAX</b>
501	Maximum (P73)	191	<b>genrun_MAX</b>
501	Minimum (P74)	196	<b>genrun_MIN</b>
501			<b>genrun_Hr_Min_MIN</b>

### **7.5.5 Subroutines**

Subroutine 1, 2, and 3 are almost identical except for the fact that they all deliver different messages. The Alarm message delivered by each subroutine is as follows:

- Subroutine 1: ALARM! FUEL LOW
- Subroutine 2: ALARM! BATT LOW
- Subroutine 3: ALARM! CR10 LOW

The subroutine begins by initiating communication with the GSM using instruction 97. The type of modem selected is generic with a 9600 baud rate. The model used is a Wavecom Fastrack supreme. The call time limit is set to 20 seconds and fast retry is set to 60 seconds in the case of a failed attempt. The number of failed attempts is stored in the data logger's memory. Communication is conducted with the modem through the use of American Standard Code for Information Interchange (ASCII), which is listed in Appendix E of the user manual for the CR10X data logger. Initial commands are sent to the modem prior to dialling out the required number. Once a response has been detected the modem then proceeds to sending a message which is different for each subroutine in this case as outlined. Further commands are conducted before communication is ceased and retried if unsuccessful, otherwise is successful, the flag 1 is set high to reset the modem and flag 5 is set low to prevent unnecessary redial.

## **7.6 Wiring the data logger**

The circuit diagram of the wiring diagram used to connect the data logger to all necessary devices used in this project and described in the code is given in **Appendix C**. The input port for each wire and a description of the colour used is given in this drawing. A complete comprehension of the circuitry used was required to understand where all input and output signals are coming from. At each input location there is a note on the signal being received. Displayed is:

- CR10X wiring panel with connected wires,
- Fuel gauge with corresponding relays
- Fuse connections for 12V and 24V supplies.
- Temperature Probe
- 12V logger battery
- GSM Modem
- SC12 and SC929 cables
- Laptop Computer

The wiring diagram is modified from the original one given as some of the apparent wiring outlined did not seem to be present although it was felt that there was enough to connect everything sufficiently to run the program that was created and uploaded to the data logger.

## **Chapter 8: Results and Discussion**

### **8.1 Introduction**

This chapter reflects on the work conducted and achievements obtained throughout this project. The experimental procedures undertaken have contributed to significant learning in the understanding and operation of the devices used.

### **8.2 Laboratory experiments**

A significant amount of time was spent understanding the theoretical operation and control capabilities surrounding the use of the data logger by studying the operation manual. Once connected and functional in the laboratory, basic measurements were taken, having established a form of connection, and acquired the software to do so. These results have already been identified and are discussed in section 6.5. The procedure of initial data logger use is well documented throughout **Chapter 6**.

The outcome of the laboratory experiments showed that the logger was functioning as expected producing predicted results. Also increased familiarity with the software and programming techniques led to the acquisition of a more advanced program compiler.

### **8.3 Generator Repair**

Prior to applying the logger for practical use and achieving the targeted control and operation requirements it was first necessary to identify and conduct repair to the engine and generator. Initially it was thought that the device was a standalone generator supplied by Fischer Panda. Upon further investigation it was discovered that a Yanmar diesel engine was synced in with the generator and operating via a control panel supplied with the generator. Some time was spent establishing the type of engine used to drive the generator and an operation manual was acquired to conduct service as necessary. The battery was also replaced to provide an electrical start capability to the control panel. All of the work described was clearly outlined in section 7.2 and carried out successfully.

The result of the work carried out led to increased familiarity with the combined engine-generator operation. It also meant that power was now available in the mobile trailer unit should any field testing of the SODAR be carried out in the future.

## **8.4 Data Logger Application**

### **8.4.1 Achieved Goals**

Having gained a complete understanding of operation, and applied the data logger experimentally the next stage was to apply it for use in the required scenario. The functionality goal of the data logger for use in this project has been clearly described in section 7.3. The process in achieving that goal is also described in detail and the steps undertaken to manipulate and develop instructions in Edlog are also well documented throughout section 7.5.

The result of this part of the project included:

- Successful development of the program to achieve necessary results
- Uploading the program to the data logger
- Understanding of necessary wiring to apply logger functionality
- Established direct communication and monitoring of data, flag and port status
- Sent out Alarm message via the GSM modem having detected low battery on the batteries used to supply the SODAR device.

All of these aspects were successful and described with the information used, modified and given in **Appendix A, B&C**. Some problems were encountered along the way however, which impacted the collection of useful data.

### **8.4.2 Identified issues**

Upon wiring the data logger accordingly to run on the uploaded program some issues were encountered. First of all the black and grey wires connected to the green plug used to supply power to the data logger through the wiring panel seemed to be delivering a very low voltage that was not significant enough to power it up. This was overcome by directly connecting the data logger to the 12V battery used for the generator start up.

Upon inserting all other necessary input wires, obtaining a power source and starting the generator, further issues were encountered. The readings that were being detected by the logger in the connect function of LoggerNet, upon direct connection through the use of an SC929 cable via an SC-USB to a laptop, appeared to be of no use and significantly inaccurate. Having successfully compiled the program and reviewed it thoroughly the suspected reason was believed to be in the mobile trailers circuitry. The data logger was shown to log information however it was not as predicted. This was assumed to be due to incorrect input signals being obtained. This proved to be quite disappointing and the remainder of the project focused upon checking the wiring of the trailer and making sure all fuses were functional and that signals were being sent and received accordingly. Efforts made were of no avail and therefore no data was successfully collected for report in this part of the project due to potential circuitry malfunction which could not be identified in time.



## **Chapter 9: Conclusion and Recommendations**

### **9.1 Conclusions**

Overall, this project focused on a very broad spectrum and global scale before being narrowed down to a specific aspect that contributes to its entirety. To recap on the development of issues and the structured process taken within this project the key areas and their relationship are as follows:

- Global environmental and economical issues,
- Identified solution in the form of wind,
- Wind energy history, market potential and possible constraints,
- Wind measurement techniques,
- SODAR and the technology,
- Applying SODAR in the field,
- **Control aspects of a diesel generator used to power a SODAR device,**
- Using a Campbell scientific data logger to achieve control and operational goals.

By reviewing such a wide variety of information, significant learning's were achieved and more specifically the outlined goal of the project title was achieved successfully in the form of theoretical application. Practical application was also achieved in the form of; successfully understanding how the data loggers operates, obtaining preliminary laboratory test results, successful repair of the generator used, modifying and developing the coding and instructions used to program the data logger, uploading the program and communicating with the data logger while connected to the circuitry described in **Appendix C**.

More complete practical application would see a return of useful data from the data logger and fully functional circuitry of the mobile trailer unit. However, unfortunately due to the time constraint that limited this project duration a solution could not be established that would produce the output data required prior to report submission. It was felt however, if further analysis of the circuitry could be conducted that the data logger was sufficiently programmed to produce the outlined output results and conduct the identified control operations, provided the input signals were valid.

Although it is believed that the program uploaded is comprehensive and fully functional if wired correctly, perhaps it proved to be a step too far as it is quite advanced coding. An alternative approach would have been to simulate the intended results in the laboratory through individual programs designed to produce an output for that particular parameter or control operation. This was overlooked due to the lack of practical application having successfully got the generator operational. It may however, be necessary to do in order to comprehend reasons for identified issues with circuitry in the future.

## **9.2 Recommendations**

The most important aspect that needs to be conducted to achieve a fully functional mobile trailer unit for the SODAR is to validate all existing circuitry. This would prove to be quite a significant task and was outside the scope of this project due to time constraints. If all circuitry is fully functional it would mean that the uploaded program could operate as required and produce valid results.

Also, as the SODAR is being used to measure wind data and potentially identify sites for a wind turbine, it would seem logical to look at potential renewable sources of power to keep in conjunction with overall sustainability. Such options could include Photo Voltaic Solar Panels that could be used to charge the batteries particularly in climates that may be suitable or during summer months.

If all circuitry was validated and the logger adequately operating in conjunction with the GSM modem, the given code could be modified to include the presence of the SODAR device, and the potential for a field test would exist. If this could be achieved, it would be possible to conduct accurate calibration and comparison of results with other remote wind measuring devices and cup anemometers at the test site discussed in section 4.1. This test site is fully commissioned and located in Worcestershire where they have a 90m met mast with an anemometer attached installed. This location would prove ideal to correlate results obtained from the SODAR, anemometer and potentially any LIDAR devices present if the data was made available. The results obtained at this remote location may prove to be more accurate than those from a rooftop in an urban canopy where the device currently lies on campus. This site in Worcestershire is fully accessible and open for use by any interested parties.

Identifying the necessary software, analysing the data logger operating methods, explaining the programming application and finally, conducting maintenance on the generator, has resulted in a solid basis for further advancement in achieving a fully functional mobile trailer unit for the SODAR device. All of these achievements discussed throughout the project will greatly assist in the deployment potential for the SODAR and allow for analysis of wind energy at multiple locations.

## **References**

- AQSystem. (2008, August 19). Wind Finder AQ500. Stocokholm, Mediavägen, Sweden.
- ART. (2008, May 24th). *Atmospheric Research & Technology LLC*. Retrieved June 18th, 2010, from About Sodar: [http://www.sodar.com/about\\_sodar.htm](http://www.sodar.com/about_sodar.htm)
- Bruns, E. (2002, 24 9). *Environmental issues of offshore wind farms*. Retrieved 11 25, 2009, from IEA WIND:  
[http://www.ieawind.org/Task\\_11/TopicalExpert/Summary\\_40\\_Offshore.pdf](http://www.ieawind.org/Task_11/TopicalExpert/Summary_40_Offshore.pdf)
- Buck, S. a. (2008, 11 14). *Forest Encycleopedia Network*. Retrieved July 28th, 2010, from Mechanical and Thermal Turbulence:  
<http://www.forestencyclopedia.net/p/p418/i/i32/view?showNav=n>
- BWEA. (2009). *Wind Energy in the UK, State of the Industry Report*. London: British Wind Energy Association.
- C.B. Hasager, P. A. (2007, April). *Riso National Laboratory*. Retrieved August 7, 2010, from Technical University of Denmark: <http://130.226.56.153/rispubl/reports/ris-r-1586.pdf>
- CampbellScientific. (2002). *CR10X Measurement and control module instruction manual*. Retrieved June 5, 2010, from Campbell Scientific Europe: <http://www.campbellsci.co.uk/>
- Daily, S. (2010, August 3). *Science News*. Retrieved August 13, 2010, from New Carbon dioxide Emmissions Model:  
<http://www.sciencedaily.com/releases/2010/08/100802110827.htm>
- EAI. (2010, July 10). *Internation Energy Outlook 2010*. Retrieved July 15, 2010, from U.S. Energy Information Administration: <http://www.eia.doe.gov/oiaf/ieo/pdf/highlights.pdf>
- ECORATER. (2010). *Wind Power Energy*. Retrieved July 5, 2010, from copyright ETSU for DTI 1999: <http://www.ecorater.co.uk/wind-power-energy.shtml>
- EWEA. (2010). *Wind Energy The Facts*. Retrieved July 10, 2010, from <http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-3-wind-turbine-technology/evolution-of-commercial-wind-turbine-technology/growth-of-wind-turbine-size.html>
- FischerPanda. (n.d.). *Fischer Panda Generator*. Retrieved June 12, 2010, from ATG 4000 DC Generator Operation Manual: [http://fischerpanda.com/Manuals/Panda%20AGT-DC%204000%20\(12V\)%20Operation%20Manual.pdf](http://fischerpanda.com/Manuals/Panda%20AGT-DC%204000%20(12V)%20Operation%20Manual.pdf)
- Gentry, B. (1999). *Atmospheric Remote Sensing Laboratory*. Retrieved July 10, 2010, from Wind Lidar: [www.ece.arizona.edu/~arsl/presentation2.ppt](http://www.ece.arizona.edu/~arsl/presentation2.ppt)
- Government, H. (2007). *Meeting The Energy Challenge*. Norwich: TSO.

InternationalEnergyAgency. (2007). 51st IEA Topical Expert Meeting, State of the art of Remote Wind Speed Sensing Techniques using Sodar, Lidar and Satellites. *Risø* (p. 32). Roskilde, Denmark: Sven-Erik Thor.

Ioannis Antoniou, H. E. (2003). *On the Theory of SODAR Measurement Techniques*. Roskilde: RISO National Laboratory.

MacKay, D. J. (2008). *Sustainable Energy - without the hot air*. Cambridge.

NaturalPower. (2010, August 10). *Natural Power News*. Retrieved August 12th, 2010, from <http://www.naturalpower.com/news/lidar-sodar-test-site>

Oldbaum. (2010, June 22). *Oldbaum Services*. Retrieved June 28, 2010, from <http://www.oldbaumservices.co.uk/AQ500.pdf>

Peinke, J. (2007). *Wind Energy*. Oldenburg: Springer.

Remtech. (2009, 12). *Phased Array Sodar Family for all Ranges and Applications*. Retrieved July 18, 2010, from <http://www.remtechinc.com/sodar.htm>

RenewableEnergyWorld. (2008, March 27). *Using LIDAR for Identification of Wind Parameters*. Retrieved July 16, 2010, from Renewable Energy World: <http://www.renewableenergyworld.com/rea/news/article/2008/03/using-lidar-for-identification-of-wind-parameters-51911>

SCINTEC. (2004, January). *Acoustic Wind Profilers*. Retrieved August 8, 2010, from Advanced High Performance Sodars for Wind and Turbulence: [http://www.scintec.com/PDFs/Product\\_Information\\_FAS\\_2007.pdf](http://www.scintec.com/PDFs/Product_Information_FAS_2007.pdf)

TelosNet. (2001). *Illustrated History of Wind Power Development*. Retrieved July 19, 2010, from TelosNet Web Development and Darrell Dodge: <http://www.telosnet.com/wind/early.html>

Yanmar. (2005). *Yanmar Italy*. Retrieved August 19, 2010, from LV Series Engine: [http://www.yanmaritaly.it/pdf/manuali\\_operativi/LV%20OperationManual.pdf](http://www.yanmaritaly.it/pdf/manuali_operativi/LV%20OperationManual.pdf)

## **Appendix A: Prompt Sheet**

CR10X INSTRUCTIONS AND PARAMETERS

Table with columns: INST, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14. Contains instruction details for CR10X including VOLT, AC, EXCIT, and various sensor and control instructions.

Option Codes

Table of Option Codes with columns: INST, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14. Lists various options like RANGE, EXCITATION, CONFIGURATION, and THERMOCOUPLE with their respective codes and descriptions.

PROCESSING INSTRUCTIONS

Table with columns: INST, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12. Contains processing instructions like SPA MAX, SPA MIN, RUNNINGS AVG, and various filter and averaging options.

Option Codes

Table of Option Codes for processing instructions, including MAX/MIN, OUTPUT, and AREA codes.

OUTPUT PROCESSING INSTRUCTIONS

Table with columns: INST, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10. Contains output processing instructions like WIND VECTOR, SAMPLE, AVERAGE, TOTALIZE, and HISTOGRAM.

Option Codes

Table of Option Codes for output processing, including AREA, OUTPUT, and D/LOC codes.

PROGRAM CONTROL INSTRUCTIONS
(F is fixed data (constant); X, Y, & Z are input locations)

Table with columns: INST, 01, 02, 03, 04, 05, 06, 07, 08. Contains instruction codes like IF CASE < F, BEGIN SUBR, DO, LOOP, etc.

FLAG DESCRIPTIONS:

- 0 Output flag
1-8 User flags
9 Interrupt processing disable flag
83-92 Command codes
93-96 SERIAL OUT
97 INITIATE TELE DEVICES
98 SEND CHAR
111 RUN FLASH
120 TST1 GOES
121 ARSOS
122 INMARSAT-C

88,89 COMP/Comparison codes:

- 1 = 3 >
2 = 4 <
91 COMP/Comparison codes
92 Time into Interval
96,98 DEVICES/baud codes:
Addressed Print Device
Printable ASCII
Comma separated ASCII
Binary Final Storage format

Option Codes

- Serial Printer or Computer
Printable ASCII
Comma separated ASCII
Binary Final Storage Format
Storage Module
Transfer Data to Other Final Storage Area
MODEM/baud codes:
RF modem
Short haul/Direct
Phone modem
Voice call-back, 1200 baud
Voice modem, data call-back, 300 baud
Voice modem, data call-back, 1200 baud
RF modem (SDC state)
y = Baud Rate Code; baud rate code 3 not valid for Inst. 97
(97 is followed by Inst. 63 or 68)

98 DEVICES/baud codes:

- 1y Addressed Print Device
4y Pin-Enabled Print Device
y = Baud Rate Code
(98 is followed by Inst. 63 or 68)
120 BUFFER
A Mode
0 - Binary
1 - ASCII
B Buffer
0 - Self-timed
1 - Random
C New data
0 - Appends new data to old
1 - Writes over old data
122 OPTION
0 Data Report
1 Clock Check
2 Message Check

BAUD RATE CODES
y= 0 300
1 1200
2 9600
3 76800

ERROR CODES

- 3 Program Table full
4 Intermediate Storage full
5 Final Storage Area 2 not allocated
8 CR10X was reset by watch dog timer
9 Insufficient input Storage
10 Low battery voltage
11 Attempt to allocate unavailable storage
12 Duplicate \*4 ID
20 Subroutine encountered before END of previous subroutine
21 END without IF, LOOP, or SUBROUTINE
22 Missing END
23 Non-existent SUBROUTINE
24 ELSE in SUBROUTINE without IF
25 ELSE without IF
28 EXIT LOOP without LOOP
29 IF CASE without BEGIN CASE
30 IFs and/or LOOPS nested too deep
31 SUBROUTINES nested too deep
32 Instruction 3 and interrupt subroutine use same port
33 Cannot use control port 0 as counter with instruction 15 or SDM
40 Instruction does not exist
41 Incorrect Execution Interval
60 Insufficient Input Storage
61 Burst Measurement Scan Rate too Short
62 N=2 in FFT
\*D Mode Errors
04 Program storage area full
06 Flash program does not exist
08 Addressed device not connected
97 Data not received within 30 seconds
98 Unrecoverable errors detected
99 Wrong file type or editor error

DAY OF YEAR CALENDAR

Calendar table with columns for months (JAN to DEC) and days (1 to 31). Shows day of year for each date.

Add 1 to unshaded values during leap years.



Copyright © 1987, 2000
Campbell Scientific, Inc.
Printed March 2000

CR10X PROMPT SHEET

This prompt sheet is intended for field use or as a reference by those familiar with CR10X programming; additional details and examples are in the CR10X Operator's manual. Computer-assisted programming is supported by EDDOG and Short Cut; communications is supported by GraphTerm and TELCOM (DOS) and PC208W (Windows).

CR10KD Keystrokes

CR10KD Keystrokes section containing detailed instructions for various menu options like BEGIN LOGGING, ENTER PROGRAM TABLE 1, CLOCK, INPUT STORAGE, FINAL STORAGE, MANUAL DATA DUMP, MEMORY ALLOCATIONS, CR10X STATUS-BOARD FIRMWARE, SECURITY, and STORE OR LOAD PROGRAMS.





## **Appendix B: Program Code**

### **Data logger Code Used to monitor and control Generator**

#### ***;Data logger ports:***

;C1 – O/P – Start Generator

;C2 – I/P – Generator Run

;C3 – I/P – Fuel Low

;C4 – I/P – Battery Low

;C5 – O/P – CR10X GSM ignition

;

;Scan rate 60 seconds

;averaging period – 30 minutes

;Temp – E1, SE1

;sms calls - +447581092131

;

#### ***;Flags used to initiate communication:***

;F1 – P97 comms mode reset – Low fuel

;F2 – P97 comms mode reset – Low battery – 24V

;F3 – P97 comms mode reset – Low battery – CR10X

;F5 – re-dial flag – Low fuel

;F6 – re-dial flag – Low batt – 24V system

;F7 – re-dial flag – Low battery on CR10X

; - set to ensure no more than two calls to each phone every 24 hours.

#### ***;Measurement taken every 10 seconds***

\*Table 1 Program

01:10 Execution Interval (seconds)

#### ***;Measure External Temperature***

1: Temp (107) (P11)

- 1: 1       Reps
- 2: 1       SE Channel
- 3: 1       Excite all reps w/E1
- 4: 1       Loc [ Temp]
- 5: 1.0     Mult
- 6: 0.0     Offset

***;Set re-dial flags 5,6 and 7 high***

2: If time is (P92)

- 1: 0       Minutes (Seconds --) into a
- 2: 720     Interval (same units as above)
- 3: 15      Set Flag 5 High

3: If time is (P92)

- 1: 0       Minutes (Seconds --) into a
- 2: 720     Interval (same units as above)
- 3: 16      Set Flag 6 High

4: If time is (P92)

- 1: 0       Minutes (Seconds --) into a
- 2: 720     Interval (same units as above)
- 3: 17      Set Flag 7 High

***;Charge batteries for 1 hour then wait 2 until next charge unless flagged***

***;Start Generator***

;5:    It time is (P92)

- ; 1: 0       Minutes (Seconds --) into a
- ; 2: 120     Interval (same units as above)
- ; 3: 41      Set Port 1 High

***; Stop Generator***

6: If time is (p92)

1: 60 Minutes (Seconds --) into a

2: 120 Interval (same units as above)

3: 51 Set Port 1 Low

***;Define initial Port settings***

7: Set Port(s) (P20)

1: 0007 C8..C5=low/low/low/output

2: 8887 C4..C1=input/input/input/output

***;Reset CR10X data logger GSM communication (1min reset)***

8: If time is (P92)

1: 5 Minutes (Seconds --) into a

2: 60 Interval (same units as above)

3: 45 Set Port 5 High

***;Turn modem off provided communications with GSM have ended***

9: If time is (P92)

1: 0 Minutes (Seconds --) into a

2: 60 Interval (same units as above)

3: 55 Set Port 5 Low

***;Check port and flag status and calls subroutines if high******;If low fuel is detected port 3 is high and therefore sets flag 5 high and calls subroutine 1 if necessary***

10: If Flag/Port (P91)

1: 43 Do if Port 3 is High

2: 30 Then Do

11: If Flag/Port (P91)

1: 15 Do if Flag 5 is High

2: 01 Call Subroutine 1

12: End (P95)

***;If low battery is detected (24V) port 4 is high and therefore sets flag 6 high and calls subroutine 2 if necessary***

13: If Flag/Port (P91)

1: 44        Do if Port 4 is High

2: 30        Then Do

14: If Flag/Port (P91)

1: 16        Do if Flag 6 is High

2: 02        Call Subroutine 2

15: End (P95)

***;Battery measurement taken and data logger low batt flag setting calls subroutine 3 if CR10X battery is low***

16: If (X $\leftrightarrow$ F) (P89)

1: 3        x Loc [ battery]

2: 4        <

3: 12       F

4: 30       Then Do

17:    If Flag/Port (P91)

1: 17        Do if Flag 7 is High

2: 03        Call Subroutine 3

18:    End (P95)

***;Runs generator if input signal detected in the form of F***

19:    If Flag/Port (P91)

1: 42        Do if Port 2 is High

2: 30        Then Do

20: Z=F (P30)

1: 1        F

2: 0        Exponent of 10

3: 2            Z Loc [genrun ]

21: Else (P94)

22: Z=F (P30)

1: 0            F

2: 0            Exponent of 10

3: 2            Z Loc [genrun ]

23:    End (P95)

***;Measures battery voltage***

24:    Batt Voltage (P10)

1: 3            Loc [battery]

***;Output processing of data and measurements***

***;Output storage format***

25: Serial Out (P96)

1: 71            Storage Module

***;Stores data every 30 minutes***

26:    If time is (P92)

1: 0            Minutes (Seconds --) into a

2: 30            Interval (same units as above)

3: 10            Set Output Flag High

***;Final storage area selected***

27: Set Active Storage Area (P80)^16581

1: 01            Final Storage Area 1

2: 501            Array ID

***;Storage time***

28: Real Time (P77)^3722

1: 1110        Year,Day,Hour/Minute

***;Battery Sample Stored***

29: Sample (P70)^1706

1: 1 Reps

2: 3 Loc [battery]

***;Temperature Average, Min, Max calculated and Stored***

30: Average (P71)^16989

1: 1 Reps

2: 1 Loc [ Temp ]

31: Minimum (P74)^24806

1: 1 Reps

2: 00 Time Option

3: 1 Loc [ Temp ]

32: Maximum (P73)^19768

1: 1 Reps

2: 00 Time Option

3: 1 Loc [ Temp ]

***;Max & Min Generator running time Stored***

33: Maximum (P73)^27526

1: 1 Reps

2: 00 Value with Hr-Min

3: 2 Loc [ genrun ]

34: Minimum (P74)^3123

1: 1 Reps

2: 10 Value with Hr-Min

3: 2 Loc [genrun ]

\*Table 2 Program

02: 0.0000 Execution Interval (seconds)

***;Subroutine 1,2, and 3. Communication with Modem.***

***;Subroutine 1, Low fuel message***

\*Table 3 Subroutines

1: Beginning of Subroutine (P85)

1: 01 Subroutine 1

2: Do (P86)

1:21 Set Flag 1 Low

***;Call back command is run once flag 1 is reset***

3: Initiate Telecommunications (P97)

1: 72 Generic Modem/9600 Baud; Use the Generic modem to send the string

2: 1 Disabled when User Flag 1 is High

3: 20 Seconds Call Time Limit ; Should be long enough with a 10 sec timeout

4: 60 Seconds Before Fast Retry ; just in case it fails

5: 2 Fast Retries

6: 60 Minutes before Slow Retry

7: 4 Failures Loc [number\_fail\_connection

8: 0000 Call-back ID

***;Number dialled +447581092131. ACII binary digital characters used to transfer data. Initially communication is established with modem commands made.***

4: Extended Parameters 4 digit (P68)

1: 87 Option

2: 100 Option

3: 69 Option

4: 24 Option

5: 65 Option

6: 84 Option

7: 43 Option

8: 67 Option

***;Number entered***

## 5: Extended Parameters 4 digit (P68)

- 1: 77      Option ;M
- 2: 71      Option ;G
- 3: 83      Option ;S
- 4: 61      Option ;=
- 5: 34      Option ;"
- 6: 43      Option ;+ it is best to enter the number in international format
- 7: 52      Option ;4
- 8: 52      Option ;4

## 6: Extended Parameters 4 digit (P68)

- 1: 55      Option ;7
- 2: 53      Option ;5
- 3: 56      Option ;8
- 4: 49      Option ;1
- 5: 48      Option ;0
- 6: 57      Option ;9
- 7: 50      Option ;2
- 8: 49      Option ;1

## 7: Extended Parameters 4 digit (P68)

- 1: 51      Option ;3
- 2: 49      Option ;1
- 3: 34      Option ;"
- 4: 13      Option ;Terminate with carriage return, then wait for response
- 5: 82      Option ; R – Rx chars – this waits for the "LF &gt; Space"
- 6: 3      Option ; 3 chars
- 7: 10      Option ;LF
- 8: 62      Option ;>;

***;Message sent once connection established : "ALARM! Fuel Low"***



## 8: Extended Parameters 4 digit (P68)

- 1: 32      Option ; space
- 2: 69      Option ;E – Tx with echo, now send the message
- 3: 15      Option ; 15 chars
- 4: 65      Option ;A
- 5: 76      Option ;L
- 6: 65      Option ;A
- 7: 82      Option ;R
- 8: 77      Option ;M

## 9: Extended Parameters 4 digit (P68)

- 1: 33      Option ;!
- 2: 32      Option ;
- 3: 70      Option ;F
- 4: 85      Option ;U
- 5: 69      Option ;E
- 6: 76      Option ;L
- 7: 32      Option ;
- 8: 76      Option ;L

## 10: Extended Parameters 4 digit (P68)

- 1: 79      Option ;O
- 2: 87      Option ;W
- 3: 84      Option
- 4: 1        Option
- 5: 26      Option
- 6: 87      Option
- 7: 100     Option
- 8: 82      Option

## 11: Extended Parameters 4 digit (P68)

1: 3        Option  
 2: 10       Option  
 3: 48       Option  
 4: 13       Option  
 5: 000      Option  
 6: 0000     Option  
 7: 0000     Option  
 8: 0000     Option

12: Do (P86)

1: 11        Set Flag 1 High

13: Do (P86)

1: 25        Set Flag 5 Low

14:    End (P95)

***;Subroutine 2, Battery Low on 24V System message***

15:    Beginning of Subroutine (P85)

1: 02        Subroutine 2

16: Do (P86)

1: 22        Set Flag 2 Low

***;Call back command is run provided flag 2 is reset***

17:    Initiate Telecommunications (P97)

1: 72        Generic Modem/9600 Baud ; Use the Generic modem to send the  
string

2: 2        Disabled when User Fag 2 is High

3: 20        Seconds Call Time Limit ; Should be long enough with a 10 sec  
timeout

4: 60        Seconds Before Fast Tetry ; just in case it fails

5: 2        Fast Retries

6: 60        Minutes before Slow Retry

7: 4        Failures Loc [no\_fails

8: 0000 Call-back ID

***;Number dialled +447581092131. ASCII binary digital characters used to transfer data. Initially communication is established with modem commands made.***

18: Extended Parameters 4 digit (P68)

1: 87 Option

2: 100 Option

3: 69 Option

4: 24 Option

5: 65 Option

6: 84 Option

7: 43 Option

8: 67 Option

***;Number entered***

19: Extended Parameters 4 digit (P68)

1: 77 Option ;M

2: 71 Option ;G

3: 83 Option ;S

4: 61 Option ;=

5: 34 Option ;"

6: 43 Option ;+ international format

7: 52 Option ;4

8: 52 Option ;4

20: Extended Parameters 4 digit (P68)

1: 55 Option ;7

2: 53 Option ;5

3: 56 Option ;8

4: 49 Option ;1

5: 48 Option ;0

6: 57 Option ;9

7: 50      Option ;2

8: 49      Option ;1

21: Extended Parameters 4 digit (P68)

1: 51      Option ;3

2: 49      Option ;1

3: 34      Option;"

4: 13      Option; Terminate with carriage return, then wait for response

5: 82      Option ; R – Rx chars – this waits for the “LF & SPACE” response

6: 3        Option ; 3 chars

7: 10      Option ; LF

8: 62      Option ; >;

***;Message sent once connection established : “ALARM! BATT LOW”***

22: Extended Parameters 4 digit (P68)

1: 32      Option ; space

2: 69      Option; E – Tx with echo, now send the message

3: 15      Option; 15 chars

4: 65      Option; A

5: 76      Option ; L

6: 65      Option ;A

7: 82      Option ;R

8: 77      Option ;M

23: Extended Parameters 4 digit (P68)

1: 33      Option ;!

2: 32      Option;

3: 66      Option; B

4: 65      Option; A

5: 84      Option ; T

6: 84      Option ; T

- 7: 32      Option ;
- 8: 76      Option ; L
- 24:    Extended Parameters 4 digit (P68)
- 1: 79      Option ;O
- 2: 87      Option; W
- 3: 84      Option
- 4: 1        Option
- 5: 26      Option
- 6: 87      Option
- 7: 100     Option
- 8: 82      Option
- 25:    Extended Parameters 4 digit (P68)
- 1: 3        Option
- 2: 10      Option
- 3: 48      Option
- 4: 13      Option
- 5: 000     Option
- 6: 0000    Option
- 7: 0000    Option
- 8: 0000    Option
- 26:    Do (P86)
- 1: 12      Set Flag 2 High
- 27:    Do (P86)
- 1: 26      Set Flag 6 Low
- 28:    End (P95)
- ;Subroutine 3, CR10X Data logger Battery Low message***
- 29: Beginning of Subroutine (P85)
- 1: 03      Subroutine 3

30: Do (P86)

1: 23 Set Flag 3 Low

***;Call back command is run provided flag 3 is reset***

31: Initiate Telecommunications (P97)

1: 72 Generic Modem/9600 Baud ; Should be long enough to send the string

2: 3 Disabled when User Flag 3 is High

3: 20 Seconds Call Time Limit ; Should be long enough with a 10 sec timeout

4: 60 Seconds Before Fast Retry ; just in case it fails

5: 2 Fast Retries

6: 60 Minutes before Slow Retry

7: 4 Failures Loc [no\_fails

8: 0000 Call-back ID

***;Number dialled +447581092131. ASCII binary digital characters used to transfer data. Initially communication is established with modem commands made.***

32: Extended Parameters 4 digit (P68)

1: 87 Option

2: 100 -- Option

3: 69 Option

4: 24 Option

5: 65 Option

6: 84 Option

7: 43 Option

8: 67 Option

***;Number entered***

33: Extended Parameters 4 digit (P68)

1: 77 Option ;M

2: 71 Option ;G

3: 83 Option ;S

- 4: 61      Option ;=
- 5: 34      Option ;"
- 6: 43      Option ;+ it is best to enter the number in international format
- 7: 52      Option ;4
- 8: 52      Option ;4

34: Extended Parameters 4 digit (P68)

- 1: 55      Option ;7
- 2: 53      Option ;5
- 3: 56      Option ;8
- 4: 49      Option ;1
- 5: 48      Option ;0
- 6: 57      Option ;9
- 7: 50      Option ;2
- 8: 49      Option ;1

35: Extended Parameters 4 digit (P68)

- 1: 51      Option ;3
- 2: 49      Option ;1
- 3: 34      Option ;"
- 4: 13      Option ;Terminate with carriage return, then wait for response
- 5: 82      Option ; R – Rx chars – this waits for the "LF &gt; SPACE" response
- 6: 3      Option; 3 chars
- 7: 10      Option ;LF
- 8: 62      Option ;>;

***;Message sent once connection established : "ALARM! CR10 LOW"***

36: Extended Parameters 4 digit (P68)

- 1: 32      Option ;space
- 2: 69      Option ;E – Tx with echo, now send the message
- 3: 15      Option ;15 chars

- 4: 65      Option ;A
- 5: 76      Option ;L
- 6: 65      Option ;A
- 7: 82      Option ;R
- 8: 77      Option ;M

## 37: Extended Parameters 4 digit (P68)

- 1: 33      Option ;!
- 2: 32      Option ;
- 3: 67      Option ;C
- 4: 82      Option ;R
- 5: 49      Option ;1
- 6: 48      Option ;0
- 7: 32      Option ;
- 8: 76      Option ;L

## 38: Extended Parameters 4 digit (P68)

- 1: 79      Option ;O
- 2: 87      Option ;W
- 3: 84      Option
- 4: 1        Option
- 5: 26      Option
- 6: 87      Option
- 7: 100     Option
- 8: 82      Option

## 39: Extended Parameters 4 digit (P68)

- 1: 3        Option
- 2: 10      Option
- 3: 48      Option
- 4: 13      Option



5: 000      Option  
6: 0000     Option  
7: 0000     Option  
8: 0000     Option  
40: Do (P86)  
    1: 13      Set Flag 3 High  
41: Do (P86)  
    1: 27      Set Flag 7 Low  
42:    End (P95)

End Program

***;Storage data input locations***

1 Temp      1 3 0  
2 genrun    1 2 2  
3 battery    1 2 1  
4 no\_fails   1 0 4  
6 \_\_\_\_\_ 0 0 0  
7 \_\_\_\_\_ 0 0 0  
8 \_\_\_\_\_ 0 0 0  
9 \_\_\_\_\_ 0 0 0  
10 \_\_\_\_\_ 0 0 0  
11 \_\_\_\_\_ 0 0 0  
12 \_\_\_\_\_ 0 0 0  
13 \_\_\_\_\_ 0 0 0  
14 \_\_\_\_\_ 0 0 0  
15 \_\_\_\_\_ 0 0 0  
16 \_\_\_\_\_ 0 0 0  
17 \_\_\_\_\_ 0 0 0

18 \_\_\_\_\_ 0 0 0  
19 \_\_\_\_\_ 0 0 0  
20 \_\_\_\_\_ 0 0 0  
21 \_\_\_\_\_ 0 0 0  
22 \_\_\_\_\_ 0 0 0  
23 \_\_\_\_\_ 0 0 0  
24 \_\_\_\_\_ 0 0 0  
25 \_\_\_\_\_ 0 0 0  
26 \_\_\_\_\_ 0 0 0  
27 \_\_\_\_\_ 0 0 0  
28 \_\_\_\_\_ 0 0 0

***Final Storage Labels, Output processed data***

0,Year\_RTM,

0,Day\_RTM

0,Hour\_Minute\_RTM

1,battery

2, Temp\_AVG

3,Temp\_MIN

4,Temp\_MAX

5,genrun\_MAX

5,genrun\_Hr\_Min\_MAX

6,genrun\_MIN

6,genrun\_Hr\_Min\_MIN

## Appendix C: Wiring Diagram

