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The Renovation and Re-commissioning of an AQ500 SODAR System for Use in the Assessment of Urban Wind Energy Applications

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Signed: Date: 07/09/10

Abstract

The technology of remote wind monitoring is at the forefront of wind resource assessment. The use of SODAR systems for rural wind resource measurements is relatively well established; however their use within the urban environment is yet to be fully explored. The wind flow within an urban environment proves to be considerably more complex than its rural counterpart due to building interactions and increased sources of turbulence. An old AQ500 SODAR system is to be re-commissioned for use on an urban rooftop. The process of renovation is documented, and the fault finding process outlined, to provide a fuller knowledge of system operation and to eliminate any faults present. The proposed site for the system is fully assessed with regard to expected air flows caused by its own topography, and that of the surrounding area. Boundary Layer theory and the urban heat island phenomenon are examined in order to assess the air flow in and around cities. The current and future states of urban wind energy are discussed, and the position of SODAR systems within the field is evaluated. Future applications of SODAR and remote wind sensing techniques are presented.

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Introduction

As our ever increasing energy demand continues, the future of our energy generation to meet this demand is taking shape in more new and novel ways. The anthropogenic impact upon our climate due to the burning of fossil fuels is becoming widely accepted as the reason for a global warming and an increased frequency of extreme weather events[1]. With global and governmental targets to reduce carbon emissions and minimise the human reliance upon carbon intensive, finite fossil fuels, the necessity to move towards more sustainable energy generation is gathering pace.

The economic cost of exploiting the remaining fossil fuels is also rising. This is due to expensive exploration in remote environments and the deeper drilling that is often required. Along with this cost comes an increased direct environmental risk. This greater risk was highlighted by the recent oil spill disaster in the Gulf of Mexico. A costly mistake whilst deep water drilling led to unprecedented amounts of oil spilling into the ocean and onto American shores[2]. The devastating impact this had upon the local environment has not surprisingly caused attention to focus once more upon greener, more sustainable, renewable energy generation techniques.

The most developed of these generation techniques and the fastest growing energy sector in the UK is wind energy[3]. Previously confined to areas to areas of well-known large wind resources, the industry is now pushing the boundaries of economic feasibility in areas of a lower or perhaps unexpected wind resource. This is due the availability of suitable wind resources being spatially finite, and the drive to minimise environmental impact. With the majority human dwellings and energy consumption coming from the urban environment[4] there is a strong case for developing this low carbon energy generation within this environment.

However as the move towards wind energy development in urban areas has progressed, new issues with regard to the wind resource have arisen. Urban wind is not comparable to its rural counterpart, possessing rather more complex and volatile characteristics, due to the large amounts of human construction. Therefore the development of wind energy within an urban environment requires new skills and poses new research possibilities in order to be successful in harnessing the full potential.

In order to take full advantage of an available resource, the characteristics of that resource must be fully understood. The analysis of the wind resource has developed as the industry has grown and demanded more detailed, accurate, and readily available knowledge. This has led to advancement in technology towards more sophisticated wind monitoring devices, capable of stand-alone operation and able to deliver large amounts of high quality data.

One of these devices is a Sonic Detection and Ranging system (SODAR), capable of detecting wind flow at a great distance and with great speed and accuracy using sonic pulses.

This thesis will document the restoration process of re-commissioning an old SODAR system with the intention of successful deployment and wind analysis within an urban environment. This documentation will provide the basis for future research using the system. Along with this there follows an in-depth analysis and review of, the current state of the urban wind energy industry and the position of SODAR systems within it.

Objectives, Scope and Methodology

The objectives for the thesis have been split into primary and secondary status. Among these objectives the scope and methodology of the work is discussed.

Primary objectives

The main objective for this thesis was to successfully renovate an old AQ500 SODAR system and re-commission it for use within an urban environment. This process will involve identifying and isolating the essential components of an old system that is installed within a road trailer. The system will need to be brought back into a successfully working condition and renovated to a state where it can operate from a single mains supply. In order to achieve this, a sufficient fault finding methodology is necessary to identify the key areas where the system may not be operating as required. This methodology consists of employing a bottom-up approach, where the operation of the smaller components of the system is confirmed before integrating all of the components together. To identify the faults within the system a process of elimination is employed to determine the components that require attention and those which are in working order. Using this approach it is intended that the system be restored to original working order. By undertaking this process of restoration a fuller understanding of the operation of the system can be gained, and thus documented for further use.

Along with this renovation process a system specific user manual can be created that outlines the basic operation of the system and highlights areas of common problems. This can provide a troubleshooting document that can be applied during future use of the system. Thus the scope of this thesis goes far beyond the initial work required in order to re-commission the SODAR system as it can be used for further research using this device.

Secondary objectives

The secondary objectives for this thesis were dependent upon the timescale that was required to fully restore the system to a successful working condition. Should the system be working with sufficient time remaining to take a period of measurement data it was intended to assess these results with respect to the local application of a wind turbine. The data could be validated and used to assess the site of the SODAR with regards to its wind resource and ultimately model and predict the output of various wind energy applications. However, if the renovation was not completed in time, the secondary objectives are set to analyse research from the topic area and provide an insight into the kind of results that could be expected from the SODAR at a given site whilst providing the basis for further use of the system.

The characteristics of the site of the SODAR as a wind resource are to be assessed along with the various technologies that could be applied to harness this resource in this site. Through research into basic wind flow principles and the surrounding area, an estimation of the wind resource can be produced. An investigation into the current state of urban wind energy will provide an insight in the technologies suitable at the site in question and the applicability of a SODAR system in predicting their output.

Research into the field of remote wind monitoring will provide a basis for the classification of SODAR systems within the renewable energy sector. The advantages and disadvantages of the system can be compared in order to assess its versatility, suitability and prospective future within this fast moving industry.

The boundary layer

In order to begin the measurement of the urban wind flow, an understanding of its basic principles must be gained. The flow of air over an urban surface is determined by the aerodynamic principles of a boundary layer. These principles apply to boundary layers on both a small scale (such as flow very close to a surface) and on a larger scale (such as flow over a city).

The boundary layer is described as a layer of aerodynamic flow where frictional effects are dominant[5]. This can be found when a fluid, such as air, travels across a surface and the friction of the surface causes turbulence to occur in the air flow close to that surface. This effect occurs on a large scale when the surface friction of the earth causes wind flow to slow and even back in the opposite direction. The layer that is created here is called the planetary boundary layer. When compared to the frictionless flow that is present at higher altitudes, away from sources of friction, a layered effect is caused. The uppermost layer, where frictionless flow occurs, is often termed the *laminar* layer. In this layer a parallel flow exists. The lowermost layer, which is dominated by turbulence, is termed the *turbulent* layer. The flow in this layer can diverge in chaotic eddies due to frictional forces. Finally, the area of interaction between the two layers is the termed the *transitional* zone. A simplified diagram of the boundary layer and the associated frictional air flow effects is shown in Figure 1.

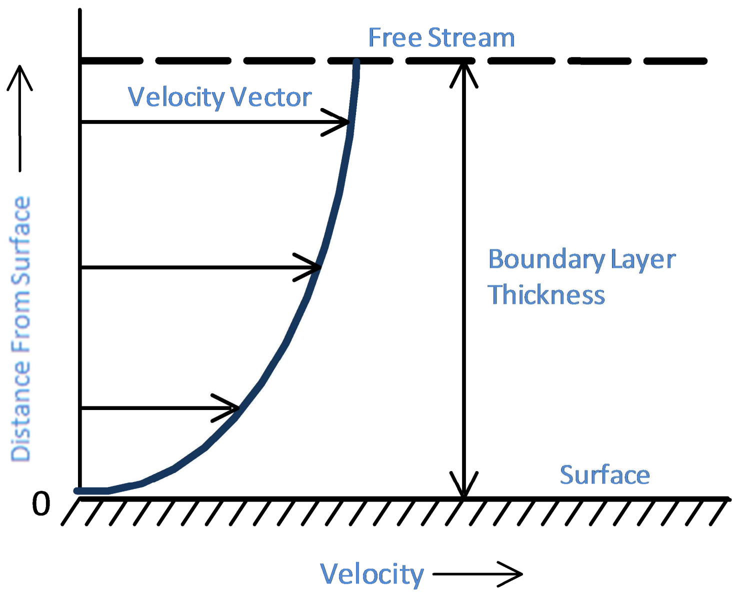


Figure 1 - Boundary Layer

It can be seen that due to the surface friction the velocity of air flow decreases as the proximity to the frictional surface increases. The velocity decreases in a roughly logarithmic fashion until finally at the surface the resultant velocity is zero.

The frictional force that slows the air will also cause an energy transfer from kinetic to heat energy to take place. A thermal conduction transfer will also be present if the surface is hotter than the fluid. In this case, as air temperature rises, so too does viscosity. The density however decreases with rising temperatures.

In a rural scenario the frictional effects, and thus the boundary layer, are caused by landscape topographies such as mountains, trees, and valleys. The overall surface is relatively smooth and the boundary layer is therefore smaller than over a rough surface as the air flow is less disturbed and can return to a laminar flow more easily. An example of the effects of a simple hill on the flow of air and the resulting boundary layer are shown in Figure 2.

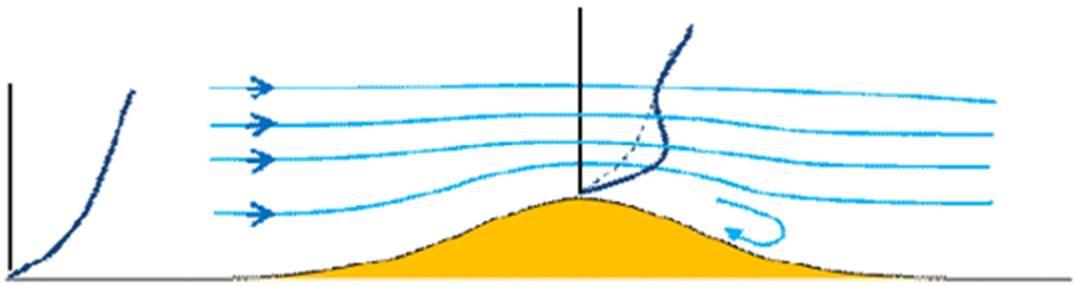


Figure 2 - Air flow over a Guassian Distribution shaped hill[6]

The typical boundary layer shape can be seen on the approach to the hill. On the peak of the hill, the air acceleration in the lower boundary layer can be seen. This is caused by the increase pressure as the air moves over the raised surface. The result as the air slows due to this change in surface as it moves past the hill is turbulent back eddies appearing in the lee of the hill. This turbulence is caused by the frictional effect of this changing surface.

In the urban scenario, there is an increased frictional component due the construction, height and layout of a large amount of buildings. Many of the buildings are tall with an un-aerodynamic box shape, and are erratically spaced in conjunction to one another. There is also an increased thermal component due to the materials dominant within city construction. The common stone buildings will store radiant heat from the sun and release it again into the nearby atmosphere. So in this scenario, the boundary is increased, and its qualities become more unpredictable. This boundary can be broken down into subcomponents which are highlighted in Figure 3.

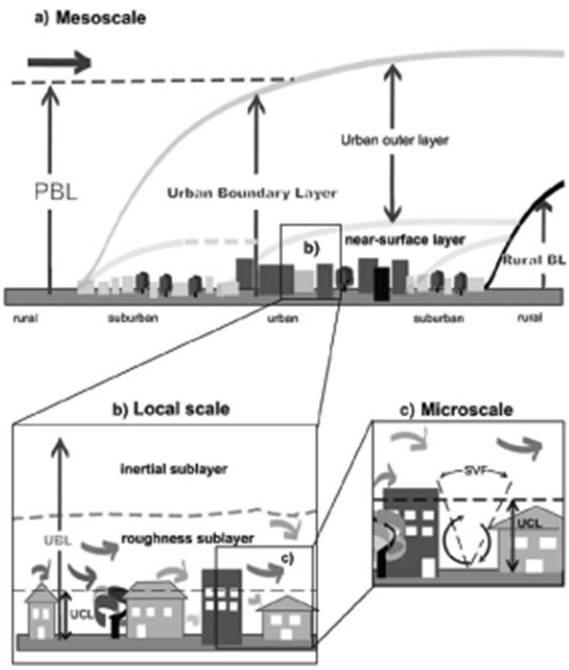


Figure 3 - Urban boundary layer structure and sub-layers[7]

If a line were drawn across the rough outline above the highest rooftops of the city, then this would give the boundary of the so called 'roughness sub-layer'. This layer is effectively the meso-scale frictional component and in most cities will increase in height as air travels up over the suburban area and up over the main urban district (which is generally composed of higher buildings), and will then decrease again back over suburban areas, and decrease finally as the transition back to a rural surface is complete. The final transition back to a rural surface downwind can take longer however. This is due to the time taken for the turbulence to resettle into normal flow. There appears to be no specific height for this layer but *Raupach et al.(1991)* estimate the height to be around 2-5 times the height of the roughness element measured from the ground[8]. Beneath this roughness sub-layer is an area known as the urban canopy layer, which *Oke (*1976; 1984) classifies as the area beneath the mean building height[9]. The air flow here is extremely chaotic between buildings due to back eddies and street channelling effects. It will therefore vary largely depending upon site characteristics. Above the roughness sub-layer, and up to the planetary boundary layer, is known as the inertial sub-layer. The thickness of this layer will vary as the roughness sub-layer does. Another graphical representation of the layers is shown Figure 4.

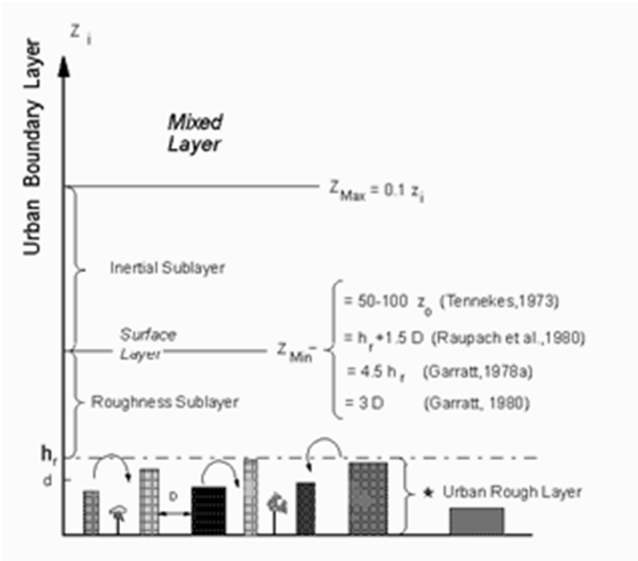


Figure 4 - Urban boundary layer structure[10]

The urban wind therefore varies dramatically with height and is primarily affected by the significant surface roughness, and the heat island phenomenon. Wind within the boundary layer is governed by temperature and pressure gradients, diurnal heating and cooling, and surface topography. The flow of wind over varying surfaces and the resulting boundary layer as observed by *Santamouris* is shown in Figure 5. It can be seen that the height at which the air flow reaches its undisturbed flow has more than doubled as the air has moved over the urban surface.

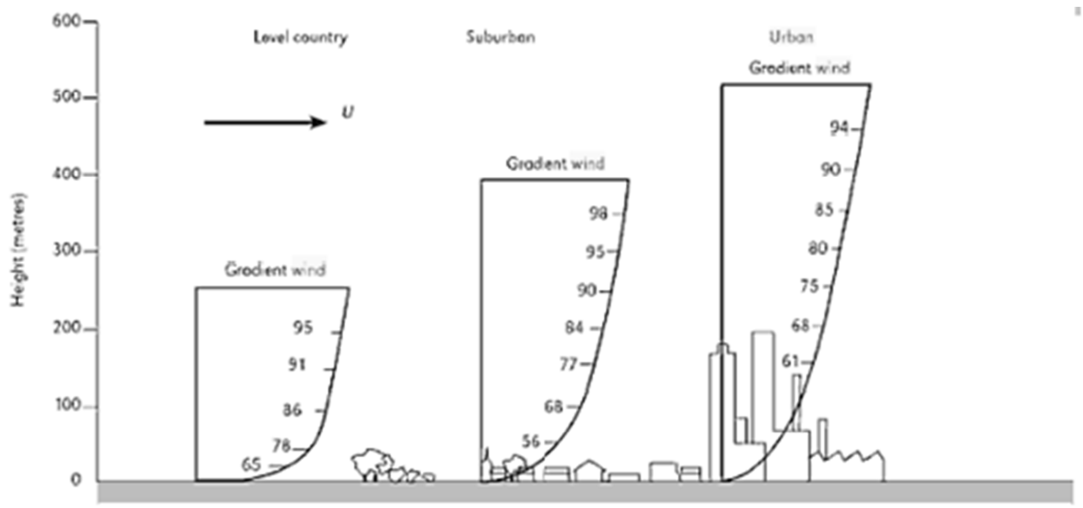


Figure 5 - Wind profile over urban surfaces[11]

During periods of light winds, the depth of the urban boundary layer will be affected by surface generated thermal convection. During stronger winds, the area above the rooftops has a wind structure with a logarithmic decay profile due to the strong winds stabilising the temperature structure.

Heat Islands

As previously mentioned, there is an increased thermal component to consider in an urban environment. Due to the construction of the buildings, and the large amounts of paved areas, the overall albedo of the urban surface has a lower reflectivity than surrounding rural areas. These surfaces therefore absorb a greater amount of incoming solar radiation. When this is coupled with the heat capacities of construction materials such as concrete or asphalt, there is a large amount of heat storage in an urban area. This storage, coupled with the increased energy consumption and excess heat from human life in urban areas leads to the phenomenon of a heat island. An urban greenhouse effect is also caused by the polluted air absorbing more of the outgoing radiation and re-emitting it. A heat island is therefore a consequence of anthropogenic heat and pollution.

The increased heat storage leads to increased heat release and to higher temperatures in city centres. The temperature difference between urban and rural is largest during summer nights, when solar energy absorbed during the day is released again at night. These changing temperatures have diurnal and seasonal effects on the thickness and profile of the boundary layer.

The air quality in heat islands is often poor. This is due to the increased amount of pollution emitted in an urban environment, coupled with the aforementioned occurrence of back eddies in the urban canopy layer, which effectively ‘trap’ air within a city. This recirculation of trapped air leads to the build-up of pollutants and a reduced air quality.

If the isotherms around a city are plotted on a surface weather map, then the resulting effect would resemble the topographic contours of an island[12], giving rise to the term ‘heat island’. This effect is highlighted in an example from St. Louis in Figure 6.

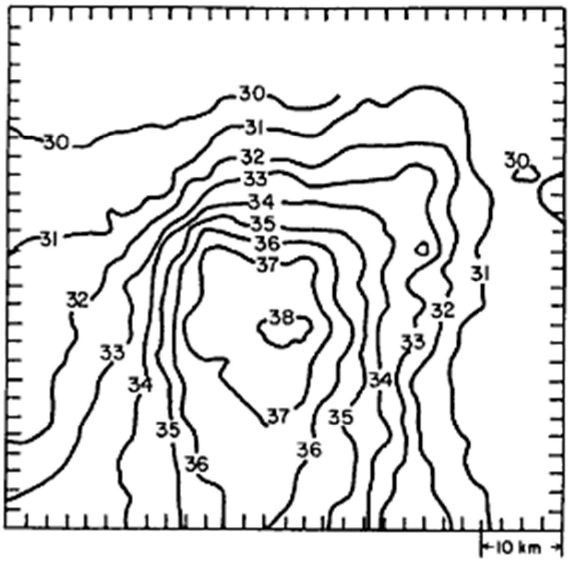


Figure 6 - Surface map of isotherms over St. Louis metropolitan area[11]

This microclimatic state is formed due to three main factors. The climatic zone, the surrounding topographic features and the specific layout of the urban features present within a city. The urban features would take into account the size and height of buildings, along with their positioning and thermal composition. The expansion of urban areas has altered the urban climate and ultimately reduced the quality of the urban environment. In general an urban climate is warmer and less windy than a rural climate, thus leading to stagnation and a lack of recirculation. There can be increased discomfort due to a poorly designed urban environment, including high temperatures, wind tunnelling effects and buffeting turbulence.

As previously mentioned, this radiative heating has a seasonal and even diurnal effect on the composition of the urban boundary layer. Measurements recorded over a two year period in Moscow by *Yushkov, V. P.* (2004) highlight these variations in a graphical format in Figure 7.

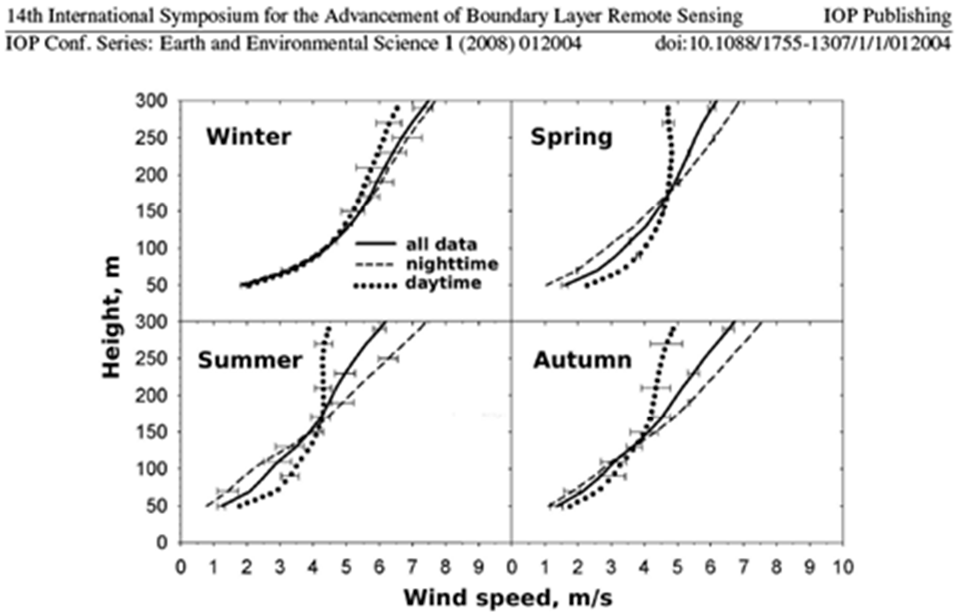


Figure 7 - Seasonal mean wind profiles over two year period in downtown Moscow[13]

It can be seen that due to the increased heating present during the spring and summer months, the thermal storage of the city is causing a significant change to the boundary layer profile between night and day. There are lower mean wind speeds at low levels present during the night in all scenarios. The daytime boundary can be seen as having a more obvious logarithmic shape. So it can be seen that there is large degree of variability in the characteristics of the boundary layer within an urban environment as the frictional and thermal components are greatly increased.

Wind shear

The stability of the atmospheric boundary layer will affect the wind shear in the first few hundred metres above the ground. The wind shear is determined as the difference in wind speed and direction, in both horizontal and vertical components, over a relatively short distance in the atmosphere. The stability is usually described in terms of stable, unstable or neutrally stable, and it is primarily affected by changes in vertical temperature gradients. These gradients are caused by the radiative heating of a surface and the resulting convective flows. The rate of change of this temperature gradient is known as the lapse rate. So the wind shear has an increased affect in the urban environment due to the aforementioned heat island effects.

In order to quantify these effects and the characteristics of the urban boundary layer profile there are a variety of techniques that can be employed.

Wind Monitoring

There are a variety of devices that can be used for wind monitoring. The most conventional and well known device is likely to be the spinning cup anemometer. However there are variations of this device and also other varying techniques of measuring wind characteristics. Some of the most important wind monitoring device characteristics that are desired have been outlined in Table 1.

Characteristic	Explanation
Error	The difference between the measured and true value
Accuracy	The mean difference between the measured value and the true value of wind speed.
Precision	The dispersion of measurement values about that mean
Time Constant	The time taken for a sensor to respond to a 63.2% (1-1/e) change in wind speed
Distance Constant	The time constant multiplied by the mean wind speed. Thus giving the length of air flow required to cause a response to 63.2% change in wind speed
Sampling Rate	The frequency of the measured signals
Resolution	The smallest unit of measurement that can be reliably obtained

Table 1 - Wind Monitoring Characteristics

It is obviously desirable to obtain measurements that give a true representation of the wind resource and thus high levels of accuracy and precision are desirable. The capability of a device to handle changeable conditions is defined by the values of time and distance constants and will vary significantly from one device to another. Some devices will excel in individual characteristics making them more suitable for specific types of measurements. Overall reliability of any device must also be considered. This is the capability of the device to continually produce results to the same degree of accuracy over a long period of time. This can be affected by issues such as weather and the elements, calibration errors or simply device wear and tear.

Cup Anemometer

This is the most common and well known method of wind monitoring. The wind pushes the cups around and the rotation will produce a small voltage. The voltage varies with the rotational speed and can be measured to produce a value for the wind speed. This device has significant benefits due to its simplicity and its lack of need for a power source as the measurement signal is generated simply from the speed of the spinning of the cups. The dimensions of the device can be altered to measure specific wind aspects such as mean wind or turbulence as the time and distance constant will vary with the size of the cups. As these devices have moving parts they can be prone to fouling due to dust or ice. They do however only measure wind speed in situ and in a mono-directional scalar quantity.

Propeller Anemometer

The propeller anemometer is similar to the cup anemometer in principle however it consists of a propeller that is kept facing the wind by a wind vane. This has the added advantage of the detection of wind direction with no need for a separate wind vane. The addition of another rotor on a vertical mount will allow for a measurement of the vertical wind component also. The propeller anemometer suffers the same problems due to moving parts as the cup anemometers. These issues can be tackled by expensive device heating (requiring a power source) or regular maintenance.

Ultrasonic Anemometer

Ultrasonic anemometers were first developed in the 1970s, these devices use ultrasonic pulses (usually around 40kHz) transmitted across perpendicular planes to assess wind speed and direction. The moving mass of air within the wind causes the pulses to accelerate or slow dependent upon the flow direction. It is the time difference that is measured against the relative speed of sound in order to determine the characteristics of the wind. The speed of the ultrasonic pulses leads to the capability of a high sampling rate (20Hz) thus these devices are extremely useful in the high resolution detection of turbulence within a short time frame. They can have considerably smaller time and distance constants when compared to conventional cup anemometers.

Met Masts

All of the previously mentioned devices measure instantaneous wind speeds at a given height. This data can be combined to produce an average for a given site. As has been shown previously, there can be a large variation in wind speed with height, especially in complex topographies such as an urban environment. In order for these conventional measurement devices to obtain data at various heights, multiple units are required to be mounted at the desired heights. This leads to the construction of a met mast. A met mast is a semi-permanent structure that is usually held in place with guy wires, and that can be moved from site to site. Met masts are used widely within the wind turbine industry. They are often deployed on a prospective development site for up to 2 years before a decision is made from the collected data as to whether the wind resource at the site is suitable for a wind turbine. This can result in maintenance issues with instruments on the mast that have moving parts. The height of measurements is limited by the height of the tower and any wind speeds required above this height must be extrapolated using estimations. The physical footprint of these masts can be large due to the guys required for stability.

Due to this large physical footprint and their required height they impose a striking visual impact, bringing with them the connotations of the proposal for the site to be developed into a wind farm. This can cause speculation in the surrounding area of the intentions of the installers of the mast. This in turn can cause unrest among a community that does not welcome a wind farm development. In this case the installers of the met mast will have already created tension between themselves and local residents. In the most extreme cases, met masts have been torn down or vandalised by local residents who are opposed to the development of a wind farm in their area. Even though a development may not even be intended for the site of the met mast, this is the connotation that it brings. Further issues of met masts include the requirement of planning permission for installation (which may not always be granted) and the high associated costs of transportation and deployment.

Remote wind Monitoring

Advancement in technology and the requirement of wind measurements at greater heights (due to increasing wind turbine hub heights), along with the desire for a smaller footprint and ease of transport has led to the development of remote wind monitoring devices. These devices are often referred to as wind profilers due to the resulting wind speed profile across a range of heights that is produced. The graphical output that would be expected would be similar to that of Figure 1. There are several different types of wind profilers, each utilising a different medium for the measurement signal.

LIDAR – Light (laser) Detection and Ranging

A LIDAR device uses an infrared beam to illuminate natural aerosols and particles and causes a proportion of this light to be reflected back towards the source. It is through the measurement of the frequency of the light, which is altered by the motion of particles in the air along the light beam, that a Doppler shift can be determined. From the Doppler shift, the motion of the particles can be determined. The conical scan pattern of a LIDAR system facilitates multiple readings of air motion to be taken at different angles. Through the accumulation of measurements around this disc of air, a deduction of the wind vector can be obtained. In a very short period of time, due to the speed of light, enough measurements can be taken to determine the desired qualities of the measured wind, such as horizontal and vertical components, along with direction. This process is then repeated at numerous heights by focussing of the transmitted beam. LIDAR provides a very high resolution, along with a high sampling rate. The most favourable weather to obtain accurate LIDAR data is during clear air days with dry conditions. However precipitation, snow and low clouds can cause errors.

RADAR- Radio Detection and Ranging

A Radar wind monitoring device works in a similar fashion to a LIDAR device except that electromagnetic radio waves are used as the beams to detect backscattering. RADAR wind profiling is less common than other remote wind monitoring devices but has a favourable output in low cloud base conditions, and fog.

SODAR – Sonic Detection and Ranging

The operation of this device is again similar in principle to the previously mentioned wind profilers. The SODAR system however uses sound waves as the medium for detection and ranging. The SODAR will however be discussed in more detail due to its relevance to this thesis.

SODAR Operation and Background

Atmospheric turbulence is caused by fluctuations in horizontal and vertical wind flow. Temperature gradients within the atmosphere cause thermal air flow and air movement over natural (or man-made) obstacles cause mechanical flow. Both of these sources cause turbulent air parcels of various sizes, called eddies, to occur. Should an acoustic pulse be transmitted through the atmosphere and encounter an eddy, its energy will become scattered in all directions. This scattering causes reflection of the acoustic waves and a proportion of these will be reflected back towards the source. This is called backscattered energy.

A SODAR device transmits sound pulses up from the ground into the atmosphere. These pulses become scattered by atmospheric turbulence and some the backscattered energy is received again by the SODAR.

The SODAR system in question is the AQ500 SODAR and is shown in Figure 8.

Figure 8 - AQ500 SODAR[14]

This three component Doppler device is based on the mono-static technique and consists of three speakers. This means that the same speakers are used as transmitters and receivers. The transducers transmit the sound pulses, and then switch to receiving mode and are capable of receiving the backscattered echo signals. Most SODAR systems are mono-static due to the simpler and more practical design[15].

There is however a bi-static version. In the case of a bi-static SODAR system the transmitter and receiver are spatially separate. This leads to a more complex deployment, which has led to its less common status. The benefits of a bi-static system are an improved signal-to-noise ratio and an increased ability to measure in neutral conditions.

In the case of the mono-static system there are three speakers, one for each wind component. These individual components are often labelled u, v, and w. Longer tone pulses are used for higher altitude readings and shorter tones are used for the lowest height measurements. This is due a larger signal being required to minimise signal attenuation over a longer distance, and a small signal being required for the shorter distance as the return time will be very short. In the case of the AQ500 there are 3 long pulses (one from each speaker) followed by 3 short pulses. Figure 9 highlights the configuration of the transmitted pulses and their trajectories.

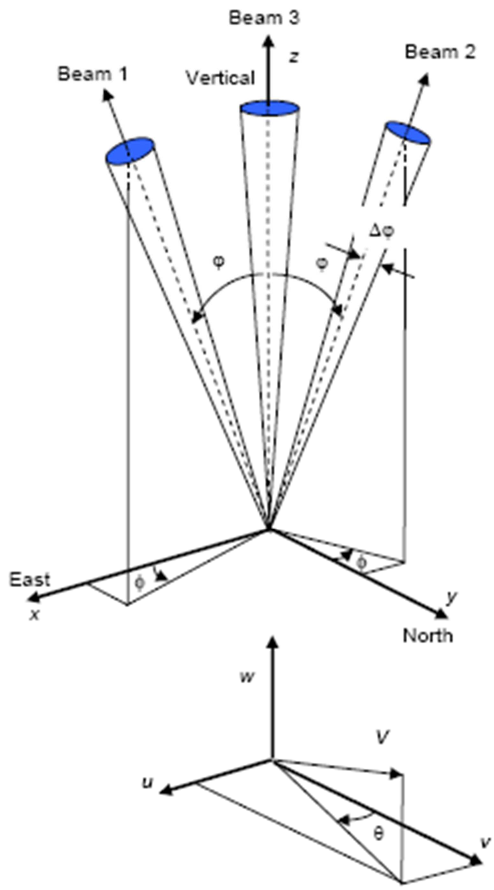


Figure 9 - SODAR beam trajectory[16]

Once one speaker has transmitted a pulse it switches function and immediately acts as a receiver for the backscattered energy signal. At the same time, the other two speakers are detecting background noise. These signals are then pre-amplified for correction and filtering, and frequency spectrums of the received signals are produced using a Fast Fourier Transform of 1024 points. The frequency spectrum of the background noise is then subtracted from the spectrum of the echo signal in order to obtain the true received signal. This process occurs for each speaker to obtain the 3 components.

From the three return signals, which each act as a vector component, the intensity and Doppler (frequency) shift are obtained in order to calculate both wind speed and direction, along with the turbulent character. This is done for every height gate in order to obtain a vertical profile. The intensity of the returned signal is affected by the thermal structure and the atmospheric stability. It is proportional to the C_T^2 function which is characterised by the thermal structure that is present[15]. Thermal structure variations include; convective columns or thermals, sea/land breezes, ground-based radiation inversions, and temperature different air masses. The measured Doppler shift yields information about the air movement at the position of backscattering. The frequency of the returned signal will change dependant on whether the turbulent eddy is moving towards or away from the transmitted acoustic pulse. Along with the intensity and frequency, the radial velocity and thermal structure can be determined. With the additional data from the orthogonal beam directions, as well as the vertical plane, geometric calculations are used to determine wind velocities, both horizontally vertically, along with direction.

Data comparison

Measurement data is provided in mean format due to the method of sampling over a volume and multiple points in time and space. This means that a vector measurement of the wind at the site is recorded, compared to the scalar measurement from conventional cup anemometers. Since the reading is integrated over a 10 minute period the vector wind measurement takes into account directional variations in the wind and is therefore more representative of the available power within the air flow. For example, in a frequently shifting wind with extreme variations (±180°) the scalar measurement of the average speed may be high but the power available will be reduced due to the inability of a modern wind turbine to orientate itself to harness the full potential of the wind. Whereas a vector measurement from a SODAR will show a much lower measurement of average wind speed due the volumetric measurement of air flow being integrated over the 10 minute period.

An Investigation into the comparison of results between a cup anemometer met mast and an AQ500 SODAR system was undertaken at a site at Dalwinston in Dumfries and Galloway by Airtricity[17]. Although a clear correlation of results is seen, there was also an average reading from the SODAR system of 4% less than the met mast. It is not clear from the report whether the effect of vector measurements has been taken into account. Further studies, using several systems in conjunction with met masts do however confirm that measurements from a SODAR system are now as reliable as those from a conventional met mast[16].

When compared with a LIDAR system, which is probably its closest counterpart in the remote wind sensing field, the findings from one report do state that the SODAR has a larger standard deviation in error readings and a lower accuracy. This report was focussing on the projection of power curves for multi MW turbines[18]. These detrimental results from the SODAR could be attributed to the relative age of the system in question when compared to the LIDAR systems used.

If the system is accurately calibrated however, a lower measurement from a SODAR system (when compared with a met mast on the same site) should in fact provide a more realistic value for the average wind speed in a constant direction and therefore provide a more accurate projection for the available power that could be utilised by a modern wind turbine. A vector measured wind is therefore always lower than a scalar measured wind, but can be more representative of the available wind resource.

In order to explore the capabilities of the AQ500 SODAR the system specifications are examined.

Specifications

The AQ500 SODAR in question has the following characteristics;

Antenna Specification

Power Source	Battery, Solar Panel, Diesel Generator
Transmission Frequency	3144Hz
Speakers	3
Pulse Power (max)	300W
Weight	70kg
Dimensions (Width and Height)	1.0m x 1.4m

Antenna Ambient Conditions

Humidity	10-100%
Operating Temperature	– 40°C to +60°C

Measurement Specification

Max Height	150m
Min Height	15m
Resolution	5m
Averaging Time	10min
Horizontal Speed Range	0-50m/s
Accuracy of Horizontal Speed	≤0.1m/s
Vertical Resolution	0.05m/s
Vertical Speed Range	±10m/s
Accuracy of Wind Direction	2-3 degrees

Table 2 – Specifications

One main difference between SODAR and the conventional cup anemometer was the need for a constant power source. There are multiple power sources available for a SODAR system. The AQ500 has been designed to be powered by a diesel generator with back-up batteries. Some modern systems have been adapted to include a Solar panel to aid in power generation. This is a positive development as it is using a renewable technology to power the analysis required to implement further renewable technologies; whereas previously the system itself had a larger carbon footprint due to the reliance upon diesel fuel.

The operational frequency of the system is 3144Hz and this lies in the lower range of the audible spectrum.

The system weighs around 70kg, which is quite heavy but the relatively compact dimensions allow for transportation within a road trailer.

The operating conditions can handle extreme temperatures and the speakers themselves incorporate a heating system to avoid icing.

Some of the main advantages and disadvantages of SODAR systems are outlined as follows;

Advantages

- The systems can be installed in a fraction of the time taken to install a met mast. Once installed, the physical footprint will also be significantly smaller than that of a met mast, as will the visual impact.

- They are generally cheaper than other wind profiling devices (for example LIDAR) and can be transported just as easily.

- The height range of wind readings from a single system is significantly higher than conventional wind measurement devices or met masts. Wind measurements can also be taken as low as 10 metres from the ground.

- They can have a very high accuracy of horizontal wind speed. (see Table 2)

Disadvantages

- There can be a lack of valid data during periods of heavy precipitation due to unwanted backscattering from water droplets.

- Excessive background noise can cause the signal to be undistinguishable. The frequency of the transmitted pulses is around 3-4 kHz and is therefore in the audible spectrum and susceptible to interference from everyday background noise. This becomes increasingly apparent in a noisy urban environment.

- Ground clutter can affect the signal so suitable positioning of the system is crucial. Due to the upwardly expanding beam trajectory care must be taken to avoid side lobe energy radiating from buildings, trees, towers etc. as this can cause zero-biasing of the return signal.

SODAR in an Urban Environment

As previously mentioned a SODAR system is subject to interference from background noise due to the operational frequency lying within the audible range. This becomes an increased issue when a SODAR is considered for use in an urban environment due to the considerable amount of extra noise from people, cars, music etc. when compared to a rural environment. Ground clutter from nearby buildings causing disruptive echoes may also overwhelm the return signal. The weaker the return signal, the more likely the signal is to be lost in the background noise. This will lower the height from which data can be measured successfully and increases the possibility of biased data. Corrective algorithms may be used to enhance the filtering of the background noise, and the availability of data could also be increased by altering the scan rate, FFT size and number of averages taken. Failing this, positioning of the SODAR away from direct noise sources may be required in order to achieve reliable measurements. Data from a SODAR system in an environment with complex terrain such as the urban surface may differ when compared to the data from a met mast in the same position due to the increased levels of turbulence that may be present.

The audible spectrum noise emission from the SODAR system itself during normal operation my also become an issue if it situated close to public or residential areas. Any work undertaken near the SODAR cone during operation requires ear protectors due to the noise intensity. However, positioning the system on a roof or enclosed area away from busy public places could help to tackle this issue.

Powering the system becomes easier as it closer to many direct mains sources. Although the system may require some form of protection in order to comply with public safety regulations.

There has been a limited amount of easily available research found on the operation of SODAR within an urban environment. As it has been used for wind resource analysis, this has mainly taken place within a rural environment.

Wind Energy

Knowledge of the characteristics of the wind resource at a particular site is essential for assessing its potential for wind energy utilisation. *Stankovic et al* highlight this in the statement "assessing on-site resources in the appropriate manner is vital for any turbine feasibility assessment and its importance cannot be emphasized too strongly"[19].

The selection of a suitable turbine for a site requires knowledge of the average wind speed that is expected along with associated characteristics of direction, standard deviation, turbulence and any extreme wind occurrences. An average speed of above 5.5ms^{-1} on a site is usually considered suitable for wind energy application (NREL)[19]. Energy prediction from a chosen site leads towards a performance evaluation of the site based upon the expected output and economic value of the turbine in the expected wind conditions. Detailed knowledge of the site specific wind patterns will also influence the siting of turbines with respect to the surroundings and also any other turbines within a wind farm. The characteristics of the wind resource also provide information to allow effective load management, along with turbine maintenance predictions. SODAR systems can be used to collect all the necessary data required to make such an assessment.

The basic equation for the available energy from a wind resource is proportional to the cube of the wind velocity 'U' and it this becomes the dominant factor in determining the possible energy available. The other determining factors are also outlined within Figure 10.

$$P = {}^{1}/_{2}\rho A U^3$$

P = Power
ρ = Air density
A = Swept area
U = Wind velocity

Figure 10 - Wind Energy Equation[20]

A SODAR system measures a volumetric average wind speed over a ten minute period and thus gives an accurate estimate of the available wind energy resource with respect to a wind turbine. This is because conventional measurement techniques are from a point source, whereas the SODAR measurement is averaged over an area. As can be seen from the above equation, the output power is proportional to the swept area and thus a volumetric measurement gives a more accurate representation of the average wind speed and the potential power available over that area. As was previously seen from boundary layer wind profiles, the wind speed can vary greatly over a vertical distance, thus proving the need for a measurement that is accurate over a range of heights instead of a singular point.

The use of SODAR remote measurement technology is relatively established within the development of rural wind resource assessments for wind turbine applications. Wind speed probability density functions can be created from the average wind speed measurements over a period of time and thus a distribution of expected wind speeds can be created. This plot will outline the likelihood of certain wind speeds occurring over the specified time period. This distribution is likely to similar to the form of a Weibull distribution as shown in Figure 11.

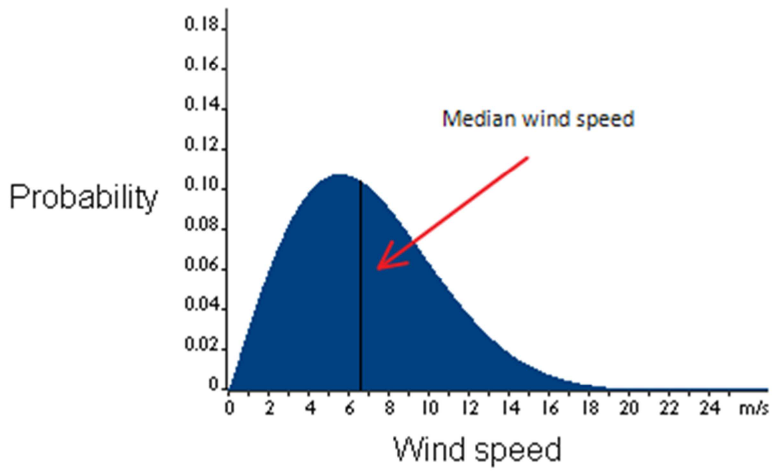


Figure 11 - Example Weibull distribution

The median speed has been highlighted and is evidently slightly greater than the most common wind speed. This is due to commonly lower speeds that have been outweighed by significantly larger, but less common, high wind speeds.

From this distribution a velocity exceedence curve can be deduced. This curve provides an estimated projection to the number of days of which specific wind speeds will be exceeded. This curve is used to aid in the choice of turbine as associated cut-in, cut-out, and rated power values for the chosen turbine can be assessed against the amount of days in which these values are likely to occur. From this curve and the characteristics of the chosen turbine, the associated power output curve can be plotted and integrated with respect to the limits of cut-in, cut-out and rated power to produce an estimated power output for the turbine at the site. This process has been simplified in this explanation due to its relative acceptance within the industry of wind turbine development. SODAR systems are accepted as suitable wind resource measurement devices for such a wind turbine development assessment.

The prediction of the expected power output from turbines in more complex, and perhaps turbulent, locations is less well developed however. The application of SODAR systems in such environments is yet to be fully explored.

Urban Wind Energy

The future of the onshore siting of wind turbines is likely to move increasingly towards areas of high roughness, as there are limited areas of low roughness that can be utilised. This leads towards more turbine development in extreme landscapes such as cliffs, mountains and forested areas, but also in urban or industrial areas. The move towards urban wind energy has the benefit of the generation of power at the point (or nearer to the point) of the consumption of the power. This minimises the need for large amounts of energy to be transmitted over long distances. This not only reduces the expensive transmission costs, but minimises the power that is lost to heat in transmission. This power loss is relatively small in high voltage lines, but becomes more significant as lower voltage distribution networks are utilised. The development of wind energy in the urban environment can also be considered to have less environmental impact as it is being implemented in already built up areas. There is therefore a lower biodiversity impact and the need for access roads and construction of added transmission lines is negated.

The development of wind energy in the urban environment has not been as successful as that in rural areas however. This is primarily due to the generally lower wind speeds and a lack of understanding of the unpredictability of urban wind flow, thus causing turbines to produce a lot less power than initially predicted. Manufacturers are quoting turbine power outputs that are not being met due to the poorer wind resource that is available in many urban locations. This leads to disgruntled customers and a negative image for the applicability of urban wind energy.

Very small home mounted turbines require a considerable amount of prior knowledge and understanding of the available resource to avoid complications or relatively poor energy yield. Structural issues can also occur with the retrofitting of existing buildings and the associated planning permission can also cause setbacks. Normally they only produce a small amount of energy due to their generally smaller size. Dealing with this production of smaller amounts of energy can also raise efficiency issues if a grid connection is sought. The smaller size is a consequence of the lack of available space, the aforementioned structural and planning issues and also the need for the turbine to be able to react to quickly changing wind directions. A conventional horizontal axis wind turbine is less efficient during changeable wind directions as it does not operate to its output capacity whilst it is adjusting to a face a new wind direction. The expected output will only occur if a constant air flow is present directly onto the face of the blades. High levels of turbulence within the urban canopy layer often causes the output of home mounted turbines to fall below expectations. Research during the Warwick wind trials[21] was conducted into 30 sites of small scale urban wind application and found the output to be poorer than was originally thought due to low wind speeds and high levels or turbulence. Some capacity factors were found to be as low as 0.85%. This is astonishing when compared to capacity factors of around 10-30% that would be expected from a good turbine site.

Ineffective home mounted turbines run the risk of becoming nothing more than an aesthetic gimmick and this could in turn be detrimental to the image of urban sustainability and small scale energy generation.

A novel approach to an urban wind energy that is more suited to changeable wind directions is the vertical axis wind turbine. An example of a VAWT is shown in Figure 12.

Figure 12 - Vertical Axis Wind Turbine[22]

This style of turbine is able to harness lift from the wind from multiple directions allowing for energy generation more of the time as it does not need to spin to face the wind. The performance is therefore improved in turbulent urban conditions. They incur less maintenance due to fewer and slower moving parts and they emit less noise. These qualities perhaps make them more suitable for urban deployment, however there is added cost due to the greater amount of material required per metre of swept area.

As has been previously discussed, the average wind speed in the built environment is generally low and this is a significant factor hindering the development of urban wind energy. However the wind may be channelled by urban topography, thus increasing its potential in certain areas. Certain sites may benefit from wind acceleration due to surrounding buildings and any turbine situated there would become a Building Augmented Wind Turbine (BAWT)[23]. In most cases the area that benefits from the accelerated wind is considerably smaller than the area of building surface required to produce that accelerated flow. By careful positioning of the turbines they can be best placed to take advantage of this higher speed augmented wind.

Rooftop wind turbine

In order to develop BAWTs the airflow around structures must be understood so that the maximum potential from a site may be realised. Many tall urban buildings have a standard box shape due to simplicity and structural stability. However, this shape is not particularly aerodynamic and blocks the flow of air forcing the air around the sides and over the top. This causes an accelerated wind flow in some areas as *Mertons* has shown in Figure 13.

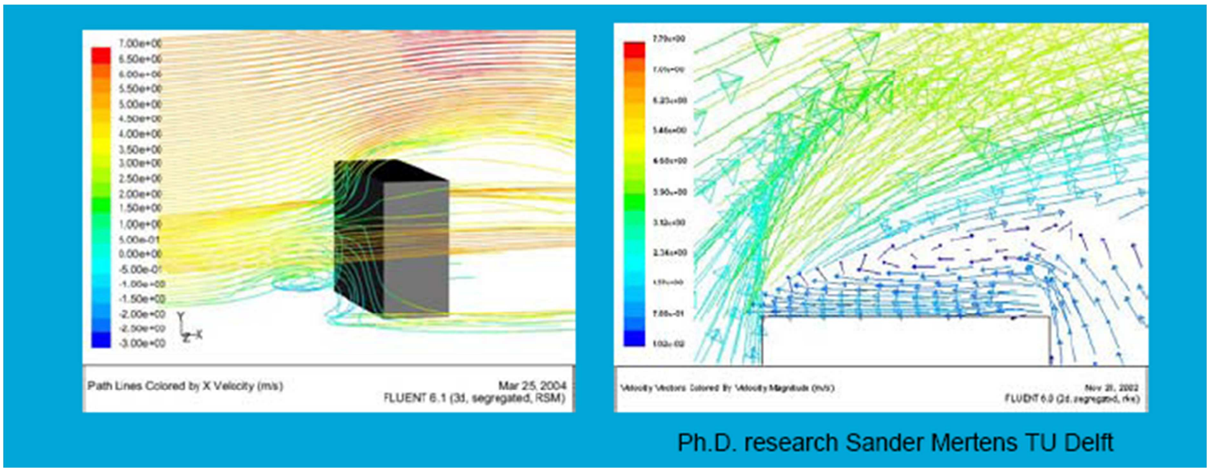


Figure 13 - Air flow around box building[24]

The accelerated wind flow over the leading edge of the roof can be seen clearly in Figure 13, as can the associated back eddies on the surface of the roof caused by sheltered areas where there is a lack of air pressure. When this is considered with more similar surrounding buildings (a typical urban environment) there will be more turbulence present as the flow incident upon the building will not be purely laminar as is shown in Figure 13. When considering a standard rooftop for wind turbine application the height of the turbine hub must be great enough to overcome the area of back eddies. The height must also be great enough to overcome turbulent areas and take advantage of the higher velocity wind flow present at higher altitudes. The angle of the wind flow over the rooftop also has a significant vertical component due to the early separation on the upwind building edge. This will decrease with the height of the turbine installation but is unlikely to be factored out due to height restrictions. The aforementioned VAWT, or a HAWT with the face angled towards the flow would be best suited to utilise this upwards wind flow.

The installation of turbines upon rooftops however leads to added issues in which vibration transference from the turbine to the building occurs. Should the vibrations that are transferred match the Eigen-frequency of the building then structural damage could occur. A high tower will also incur greater effort with regards to tower erection and maintenance, and will have a more striking visual impact. The greater yield from stronger and less turbulent winds at higher altitudes will however be significant if properly implemented as the wind energy equation of Figure 10 highlights the cubic impact of velocity upon energy available.

If the leading edge of the building were to be smooth and rounded, there would be added natural wind acceleration due to the reduced frictional component and therefore a reduced resultant vertical wind component[19]. There would also be less turbulence as there would be less flow inhibition. This would mean that a lower turbine hub height could be implemented without compromising the output performance as the detrimental effects at lower altitude would be improved by the rounded surface.

Building integrated wind turbines

Further research into BAWTs has also led towards buildings that have turbines at the heart of their structure and design. Whereas retrofitting is essentially an afterthought, in these cases the building has been designed in order to capture the air flow and direct it towards a turbine that is part of the building. This inherently has a greater output potential. One of the first large scale commercial example of this would be the world trade centre in Bahrain which incorporates three 225kW turbines in between two sail shaped structures that act as wings to increase the wind flow. The building is shown in Figure 14.

Figure 14 - BAWTs at Bahrain World Trade Centre[25]

This design takes advantage of the prevailing winds at the site and the structure accelerates the wind flow through the turbines which are part of the building itself.

The relative immaturity of such designs means that their productivity and efficiency is yet to be fully understood. They are very site specific to the local wind conditions and their applicability is therefore currently limited.

Environmental impacts

The issues concerned with the placement of urban wind turbines are relatively similar to that of rural applications. There are, however, some features that demand more attention. Public safety is of greater concern due to increased proximity to a large amount of people. This must be considered during both construction and operation. Failure of either the tower or the blades that results in the shedding of parts could cause considerable damage to anything nearby. Although the amount of turbine failures is generally small, the risk to human life is considerably increased within an urban environment.

The noise created from the operation of turbine must also be considered. This noise will be both mechanical and aerodynamic and its effects on nearby residents or public areas will need to be assessed prior to construction.

Since turbines are likely to be installed in higher and more exposed areas of urban regions they visual impact becomes significantly greater. Planning permission becomes a greater issue in the instances where the visual impairment or nationally or locally designated buildings or monuments is considered. The effect on local property values will also be factored into this assessment.

The output of a turbine that has been successfully designed as part of a new building will be significantly higher, as will its aesthetic appeal and sustainable image. Indeed this may have a positive impact on the surrounding area.

As well as the environmental impact of the increased application of BAWTs, there also arises a social impact. The significant amount of investment required in design, and the return on investment from sustainable power generation potentially creates new legal issues. Should the surrounding area be altered in any way that results in the reduction in performance of an already installed turbine, the question of liability for economic loss could arise. This is a complicated area of law that is constantly evolving.

Position of the SODAR unit

In order to the assess the initial positioning of the SODAR unit for the application of urban wind energy, basic analysis was undertaken of some of the key factors of the site and the surrounding area.

The SODAR was installed on the roof of the University of Strathclyde's James Weir building. The aim of this siting was to assess the wind flow in the urban canopy and also identify the components of the urban boundary layer. Since the minimum height measurement that can be observed by the current program in the AQ500 is 20m, any accurate assessment with regard to wind turbine placement would have to consider a turbine with a minimum hub height of 20m. This is considerably larger than most urban wind turbine developments for rooftop application but provides a baseline for research within this area.
The height of the building is thought to be around 70-80m. The shape of the building is square sided, so it is relatively similar to the model in Figure 13.

Using an urban model that has been created by Glasgow City Council gives an accurate impression of the topography of the city centre area. The urban model tool is a 3D digital representation of the city centre of Glasgow that has been developed in order to allow the public to have greater access to, and understanding of, the structural development of the city[26]. The model can be downloaded for free from the website. Through its use, a greater understanding of the physical characteristics of the city centre was gained. Analysing the tool proved useful in assessing the surface topography of the area surrounding the deployment position of the SODAR system.

The average height of the city centre buildings (as deduced from the urban model) is around 45-50m and therefore defines the urban canopy layer height for the area. This would lead to the formation of the roughness sub-layer for the area to be around 150m according to *Raupach et al*. This gives a comparative measurement to relate results from the SODAR against. Even though the siting of the SODAR will be on the edge of this location and considerably higher in altitude, the relevance and accuracy of the model is extremely useful. The James Weir building is to the north of the city centre east (as shown on urban model) and will have a greater height than most surrounding buildings due to the steep slope of the

Montrose Street hill and the height of the James Weir building itself. The view from the rooftop to the east and west respectively is shown in Figure 15.

Figure 15 - Views from rooftop

It can be seen that this is obviously one the tallest buildings in the area and thus should extend slightly above the standard urban canopy layer for the area. This should in turn result in a slightly less turbulent and stronger wind flow than over surrounding buildings, but it is likely still to be dominated by turbulent flow.

The kind of flow that may be expected around the site of the SODAR (this has been deduced from *Mertons* wind flow information) is shown in Figure 16 where thicker arrows indicate a stronger wind flow.

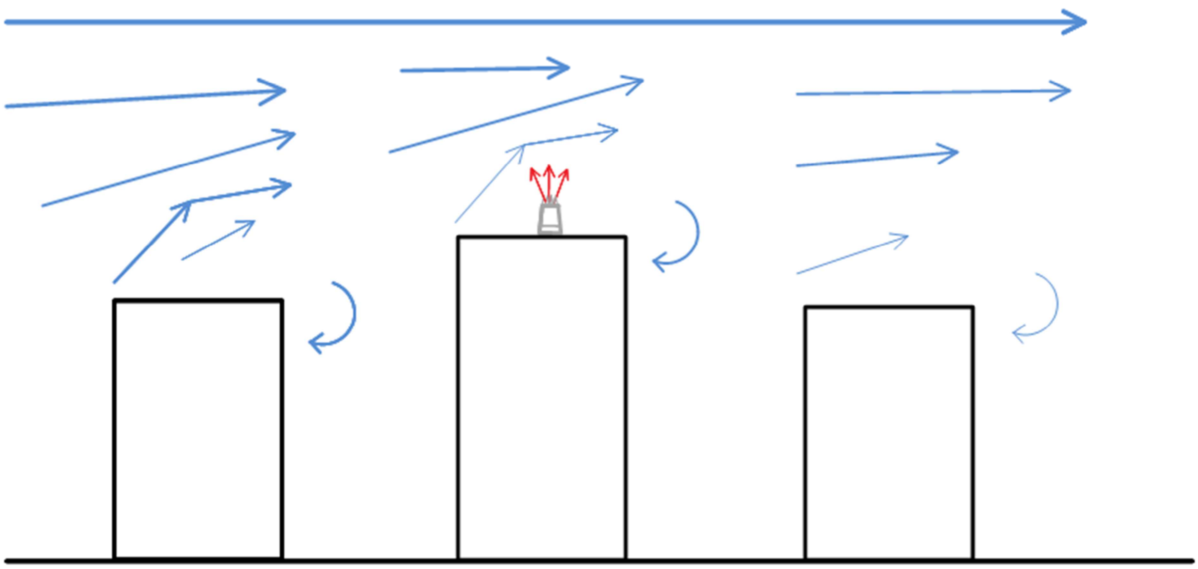


Figure 16 - Relative position of the SODAR system

It can be seen that there is expected to be a significant vertical component to the wind flow due the shape and position of the James Weir building. The flow should return to laminar flow at higher altitudes. This simple analysis has been conducted purely from site inspection, analysis of the topography of the surrounding area, information of the wind flow over square sided buildings and knowledge of the composition of the urban boundary layer.

Using the Government Department for Climate Change's wind database tool[27], rough average wind speeds for the area can be found. This database has been put together through a culmination of data from weather stations and wind resource assessments throughout the UK. It gives a very rough average expected wind speed for an area. For the grid reference that covers the SODAR position the average wind speeds are shown in Table 3.

DTI Wind Database

Height (m)	Wind Speed (m/s)
45	7.1
25	6.4
10	5.6

Table 3 - Average Wind Speeds for Site

Although this database does not take into account the complex nature of the urban surface topography it does provide a baseline for the average wind speeds that could be expected in this area. Although the value of 7.1m/s is expected at 45m, due to this being the average height of buildings in the area, the profile of the boundary layer is expected to be pushed upwards due to the friction of the urban canopy layer. This means that lower values would be expected for the heights stated. However, due to site specific effects from urban wind channelling this may not always be the case as augmented wind may cause acceleration. Extra turbulence created by the surface topography is also likely to alter the values stored in the database.

With the proposed site of the SODAR unit explored and assessed for expected outcomes, the next step was the renovation process.

Renovation and re-commissioning

The main part of the project was the renovation and re-commissioning of an old SODAR system, with the aim of taking measurements from the roof of the James Weir building. The SODAR system was acquired by the university from RES Scotland having reached the end of its commercial working life. The system was installed in a trailer and powered via a diesel generator and back up batteries. The intention of this thesis project was to bring the system back into operation and power it from a single mains source so that it could be positioned on the roof and used for urban boundary layer analysis. Although the system had been working previously, there were components removed and the contents of the trailer were obviously well used and not in good condition.

During this practical part of the project, there was regular communication with the project supervisor, Dr Matt Stickland, and there was also secondary communication with Andy Oldroyd of Oldbaum Services, who has significant experience in the practical operation of SODAR systems. There was also some email communication with Kalle Wikmyr of AQSystems, Stockholm.

Initial configuration

The first step was to study the circuit diagrams that were provided with the system in order to establish where the system could be isolated to a single power source. The documentation that was provided was edited and added to and by no means correlated to what was present within the trailer; this is likely to be due to the age of the system. The system components were identified through research into similar devices and through analysis of the supplied documentation and service manuals. A point power source was identified where the main system was powered from a combination of a diesel generator and back-up batteries. The required components of the system were isolated from the rest of the system and the trailer at this point. The components that were removed from the trailer to the room M4 where they could be worked upon were as follows;

- PC Unit – holds the program for the operation of the system, handles the inputs and outputs, and computes the required calculations for the production of results

- Power Amplifier – amplifies the outgoing pulses and the received signals

- SODAR Junction Box – provides the interface between the PC unit, the power amplifier and the SODAR cone

- Communication Cables – long cables that allow the SODAR cone to be positioned some distance away from the main system and power source

- SODAR Cone and Speakers – the main baffle that houses the speakers and provides sound and wind protection

Appendix A shows the initial email that was sent to AQSystems to ask for advice for connections and highlights the various components of the system in picture format. At this stage the components that were removed did not match the supplied documentation. Hence there was initially a degree of doubt over the connection configuration and the required power supply. After establishing the connection configuration through the study of the relative components in the operation manual the following set up was achieved as shown in Figure 17.

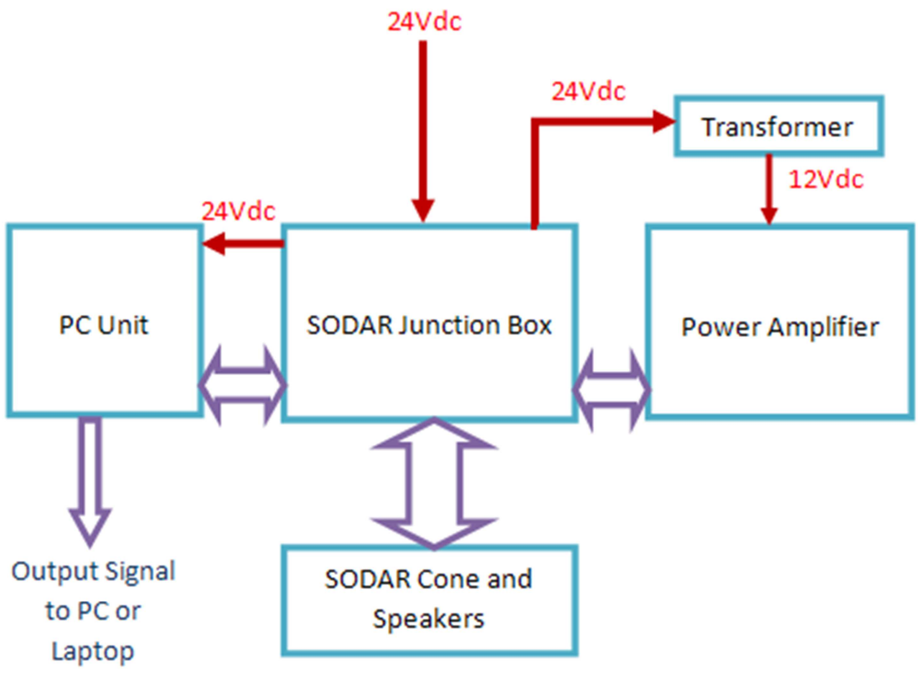


Figure 17 - SODAR system block diagram

It can be seen that a single power supply is connected to the SODAR junction box at 24Vdc. This is then stepped down by the transformer to 12Vdc to power the amplifier. A more detailed circuit diagram highlighting these connections is shown in Figure 18. It is annotated to highlight the variations between the supplied documentation and the actual system.

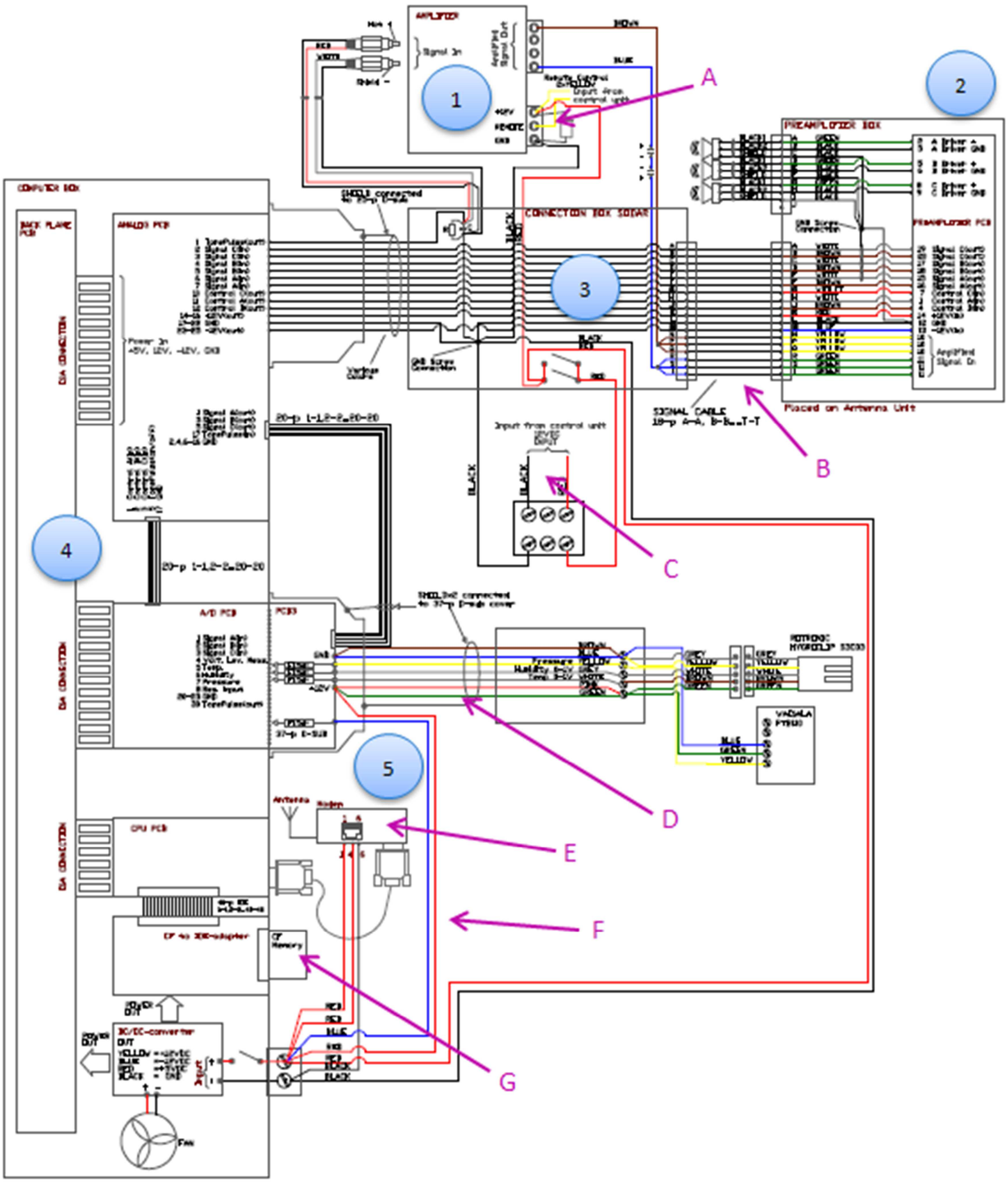


Figure 18 – System circuit diagram[6]

The system circuit diagram is labelled as follows;

1 Power Amplifier

2 SODAR cone and speakers

3 SODAR junction box

4 PC unit

5 Output signal to PC or laptop

The differences between the circuit diagram and the actual system configuration are highlighted as follows;

A) This power source to the amplifier is labelled as a direct 12Vdc connected from the SODAR junction box. However, on the system it is supplied from a 12Vdc output transformer that is located directly underneath the amplifier and is supplied with 24Vdc from the SODAR junction box.

B) What is labelled is an 18 pin signal cable is in fact two signal cables. One of which is a 10 pin cable and the other is a 6 pin cable.

C) This single point power source for the system is labelled as 12Vdc. The actual power source required for the system in question is 24Vdc.

D) This serial connection does not exist. It was originally used for temperature, pressure, and moisture sensors.

E) This is the serial connection for the modem and its antenna. This can also be used for a direct serial connection. There was no modem with the system when it was removed from the trailer.

F) This external power cable for the original sensors does not exist.

G) This is the slot for the Compact Flash drive but an internal connection directly to the PCB can be obtained.

With the correct connection configuration obtained the system was ready to be powered up. This was done using 24V, 2A desktop power supply unit (PSU).

Power up

When the PC unit was initially powered up it emitted 4 short beeps. After inspection inside the unit, the model of the BIOS was obtained to be AMIBIOS 586. Research into the pattern of beeps coming from the particular BIOS found that this was likely to be a RAM error. By removing and replacing the RAM card, the beeps disappeared and the PC unit powered up with no beeping. It is expected that a loose connection between the RAM card and the printed circuit board (PCB) had caused this error, perhaps due to it being dislodged during transit of the system. A boot failure error was now displayed on start-up; by ensuring within the BIOS menu that the system boots from the compact flash drive the program will run.

With the system connected as shown in Figure 17 and powered by a 24V PSU the SODAR speakers began to emit random pulses. At this stage in the project the expected output from the speakers was not clarified.

In order to examine the program operation a PC screen was connected to the PC unit via a VGA cable, and a standard PC keyboard was also connected to allow navigation. The screen in Figure 19 was seen.

Figure 19 - Program Screen

This was confirmed, by Andy, to be the expected output that is likely to be seen during a standard program. The next step in the SODAR manual supplied by AQSystems was to collect the SODAR parameters by using the supplied SODWIN 5.1 software and obtain a serial connection via an RS232 serial cable. This would determine the parameters that were stored in the system, but more importantly it would prove the existence of a successful serial connection to the system.

Initial attempts at collecting the SODAR parameters from a PC via serial connection resulted in a 'runtime error' message. Research into the specific error found that the message meant that 'the handle is invalid'. By installing the software on another PC this problem was bypassed. By ensuring that all files are copied over during installation (including files that are older than system files) then this error is avoided.

Serial connection

With the software running on the PC and the program running on the SODAR PC further attempts were made to collect the SODAR parameters and obtain a successful serial connection. The resulting message from the SODWIN software was 'Updating Failed'.

Consulting the AQSystems manuals recognised this message as a connection error but offered no diagnosis of the issue so a fault finding process of elimination was undertaken. The first area to examine was that of the serial port configuration. The PC was swapped to ensure that there was not a faulty serial port on the original PC. This had no effect so the serial ports were assumed to be operational. This also was confirmed by using another serial device on the PC.

Using the port configuration suggested in the manual had borne no success so multiple combinations of baud rate, parity, flow control, data bits, stop bits and buffer levels were attempted, with no successful connection obtained. The voltage level of each pin was checked to determine the high or low status of each pin and the status configuration matched that of a standard 'ready to transmit' serial port.

The next step was to examine the serial cable itself to ensure its compatibility. RS232 null modem cables have 9 pins and are sold in a number of formats and pin configurations so that they can be compatible with numerous devices. The supplied cable was found to be the 'full handshaking' configuration. This pin configuration is shown in Figure 20.

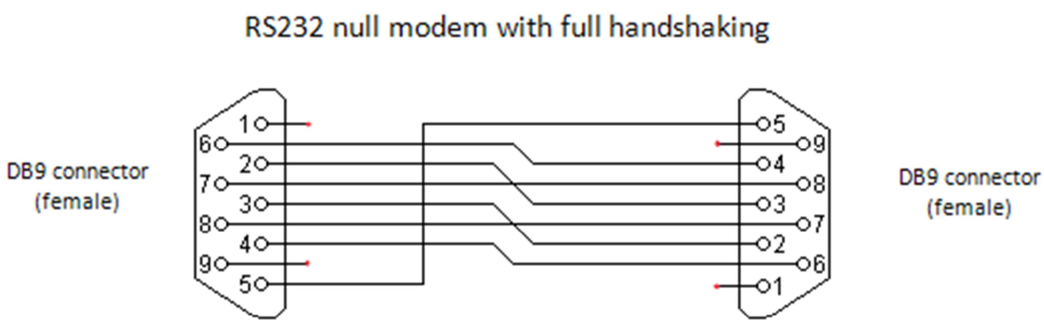


Figure 20 - Serial cable configuration

The handshaking modes determine how the two devices in question initially communicate with each other in order to secure a connection. Initial attempts at purchasing different cables from local suppliers were unsuccessful so in order to test the connection with varying pin configurations a sample cable was made. The cable consisted of 9 separate wires and a solderless breadboard interface so that connections between the pins of the two serial ports could be altered. Multiple serial connections were tested using different handshaking modes such as loop-back, partial and no handshaking but did not result in the desired connection; ‘Updating Failed’ was still shown upon attempting a connection. It was ruled out then that the serial cable and the associated port settings were not the source of the connection error.

In order to check that the error did not lie within the SODAR PC unit, the decision was taken to transfer the program to another PC unit. The A/D card and the bespoke AQSystems analog card were transferred to the backplane of an old Intel 486 PC. The two cards can be seen in their original position within the SODAR PC unit in Figure 21.

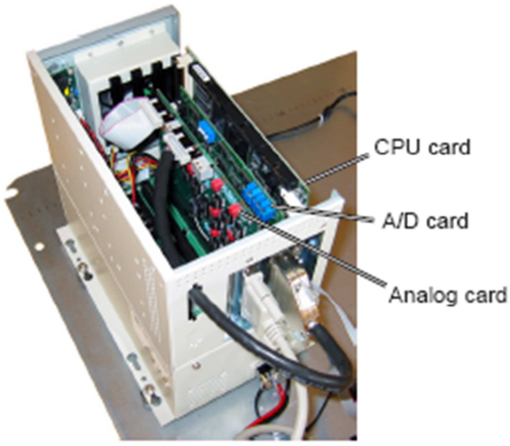


Figure 21 - Cards within SODAR PC unit[14]

Along with the physical cards, it was also required to transfer the SODAR program across to the 486 PC. The MS-DOS platform was used to run the program. This involved altering the autoexec.bat and config.sys files within the 486 PC to match the files within the SODAR PC unit. This was done using the DOS edit command within the root drive of the PC. These files contain the necessary information to execute the required programs within MS-DOS and also ensure that the operating system runs as expected. By altering the autoexec.bat file to include the batch file that initiates the SODAR program, the 486 PC will attempt to run the SODAR program when it is booted up. By copying the full SODAR program from the compact flash drive onto a floppy disk and ensuring the correct file structure was maintained, it was then possible to run the program on the 486 PC from the floppy disc. This was an extensive process requiring low level DOS manipulation that ultimately resulted in the successful transferral of the SODAR program and operational structure to a separate machine. With the program running as expected on the 486 PC another attempt from a PC was made to obtain a serial connection and collect the SODAR parameters. This attempt was again met with the response ‘Updating Failed’.

This led to the conclusion that the connection problem did not lie with either of the communication ports, the SODAR PC unit, or indeed with the null modem cable.

It was thought then that the problem may lie with the SODAR program itself on the compact flash drive. Two more programs were acquired from Andy. These were not of the compact flash format but of the DiskOnModule format. By disconnecting the compact flash drive from the CPU card within the SODAR PC unit, and attaching the new program cards directly to the CPU card, the new programs can be run in the same way as previously. This was confirmed by the DOS screen that could be seen on the output of the SODAR PC unit being similar to that of Figure 19. Attempting a connection with one of the program cards yields the response ‘Updating Failed’. However, with the other card a connection was obtained and the response ‘Parameters Ok!’ was seen on the screen. This was the first stage of connection and identified that it was a compatibility issue between the SODWIN software and SODAR program that was initially causing connection issues.

Modem Connection

With the direct serial connection established the next step was to explore the possibility of obtaining a modem connection so that data could be collected remotely. This would negate the need for a direct connection and make the system suitable for deployment where direct access was not always required.

A Wavecom Fastrack Supreme 10 modem was acquired. This model can be seen in Figure 22.

Figure 22 - Wavecom modem

This modem connects to the serial port of the SODAR PC unit via a VGA to RS232 adaptor and can be powered in parallel with the power amplifier by the 12Vdc output from the transformer. A standard GSM aerial is also connected to the modem. The first attempt to dial the modem was made by inserting a standard mobile phone SIM card (with pin code disabled) into the modem and phoning the number from a mobile phone. A ring tone was heard, but after one ring it was disconnected. This proved that the modem could receive incoming calls on a voice SIM card but that a different approach was needed in order to obtain a secure connection.

It was found during further research that in order to use the modem for data transfer, a data specific SIM card is required. The first attempt was to take the SIM card out of a commercially available wireless internet dongle. However, the format of this SIM card was 3G and the Wavecom Modem does not support data transfer in the 3G format, so the connection was unable to be established. Further research into data transfer SIM cards, and contact from AQSystems led to the conclusion that a Circuit Switched Data (CSD) card was required. The SIM card service provider was contacted to see if this option could be activated on either the voice SIM or the 3G SIM but apparently it was not available. The commonly used General Packet Radio Service (GPRS), which used to be standard within the mobile phone network, did also not seem suitable for the required connection for data transfer. After contacting most of the major mobile network service providers it became apparent that only 3G data SIMs were now commercially available as this is the current standard for data transfer.

In order to obtain a CSD enabled card it seems that a contract would need to be undertaken with a Machine-2-Machine company that specialises in computers communicating with each other over a mobile network. This niche area of the market seems to be expanding in industrial applications, and as remote sensing increases in wind resource assessment it is likely that these SIM cards may become more widely available.

It was decided that the project should go ahead without using a modem connection to retrieve data, but simply use a direct serial connection to retrieve data when required. Although this hinders any remote placing of the system, this does not prove to be an issue if the system is placed on the roof and certainly does not affect any results obtained.

Another area of research into this area would be utilising a 3G modem and SIM card for data transmission however this data transfer rate is way above the specifications required for the relatively small amount of data that is being transferred.

Preparation for stand-alone operation

This research into the modem connection was done in parallel with the renovation of the SODAR cone. The side of the cone baffle required structural reinforcement with a metal panel that was screwed into place where it had split at the join. Also, the re-attachment of a rubber joining strip on the base of the cone, using industrial strength glue, to allow a proper fit between cone baffle and the base was required. The completed repairs to the cone can be seen in Figure 23.

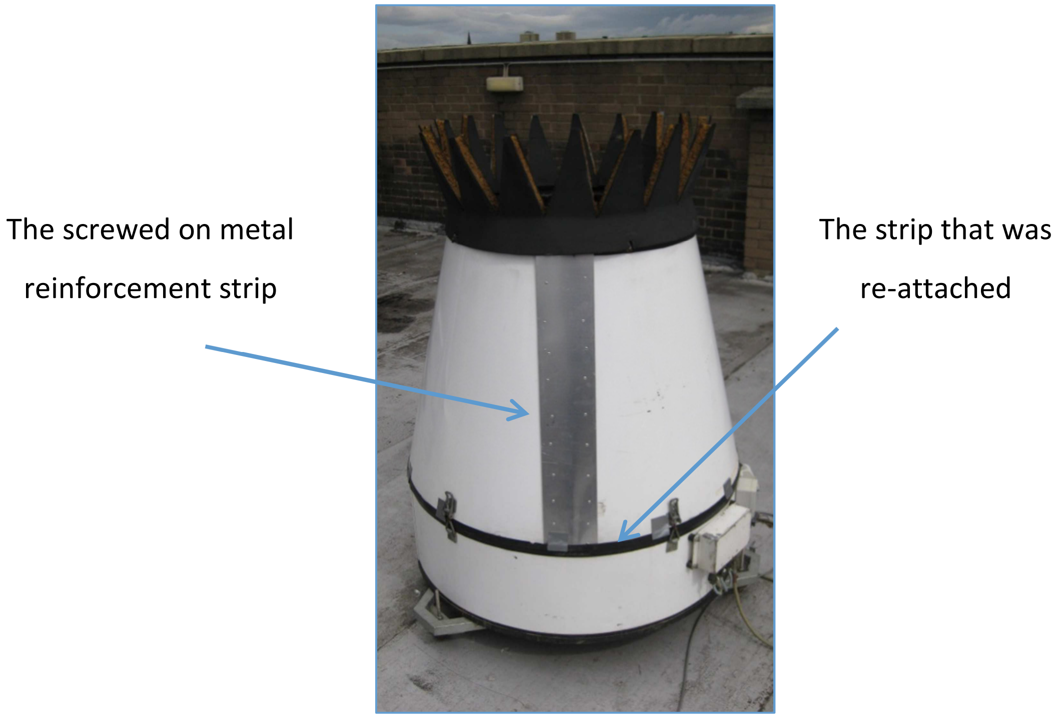


Figure 23 - Cone Repairs

The solid metal box that held the electronics of the system within the trailer was removed so that the necessary components could be housed securely within it whilst in position on the rooftop.

The system was now ready to be moved on to the roof of the James Weir building. The siting of the system, next to a LIDAR device, can be seen in Figure 24.

Figure 24 - Siting on the roof

The two systems were positioned close enough that they are measuring roughly the same air flows, but not close enough to interfere with each other. It is intended that the LIDAR data can be used in conjunction with the SODAR data to compare the output of the two systems for the same area.

The main system components of the SODAR were housed within an outbuilding on the roof for protection from the elements.

When the system was first tested on the roof the series of pulse tones that could be heard was erratic. Upon consultation with Andy it was confirmed that the pulse pattern should be 3 short tones followed by 3 long tones. This sequence allows for the lower altitude readings with short pulses and higher altitude readings with the longer pulses. A relay clicking sound could be heard from the system, and a dimming light could be seen on the amplifier, on each pulse. It was assumed from this that the system was struggling for power, thus causing the relays to switch the amplifier on and off, and consequently not producing the required pulse output. The standard pulse power of the system is set at 300W and if this is supplied at 24V then a current of 12.5A will be drawn. The PSU used to power the system has a capacity of around 2A at 24V; obviously this is well below what is required. Since there was no readily available, large enough transformer, the solution to this was to connect two PSUs in parallel to provide more amperes. In addition to this, the two 12V back-up batteries from the trailer were connected in series (to make 24V) with the PSUs to provide a buffer. Since the pulses only require a high ampere output for a short period of time, the fully charged batteries can help to absorb these spikes in power. The pulse power is also adjustable within the SODAR parameters. With the configuration described, and the pulse power set to between 50-100W the system can output the correct pattern of pulses. Although this is below the standard output, the system should still be fully functional at this power, but may result in a lack of data if there is large amount of background noise present.

It was thought that there may be a suitable transformer located within the SODAR trailer, however after an extensive search this was not found. For future use of the system at its full rated power, a suitable transformer that can supply 24V from a standard 240V mains power source and handle 12.5A current spikes should be purchased.

Retrieval of suitable data

With the system set up on the roof and producing the required pulse sequence, the next step was to collect and retrieve data. After allowing the system to run for 10 minutes so that one batch of integrated data could be recorded, an attempt was made to transfer the data file from the SODAR PC Unit to the Laptop PC used to collect data on the roof. The file transfer process could not be completed however due to an unknown error. The correct process of file retrieval was completed but no file was received in the folder on the laptop. This led again to the conclusion of incompatibility between the SODWIN software and the SODAR program. A newer version SODWIN (SODWIN 6) was acquired from Andy. This required copying a newer executable file into the existing SODWIN program folder and replacing the parameter files with the newly supplied ones. With the new program a direct serial connection could not even be obtained. It was decided that all three of the supplied program cards should be examined for their compatibility with both versions of the SODWIN program. This involved taking the PC unit apart to insert each card, reconnecting the whole system back together and then analysing the connection that is possible from the laptop. The results of this are shown in Figure 25.

Program card	Format	SODWIN Version	Parameter collection?	Current data collection?	Spectrum collection?	File list collection?	File Transfer?
Original Flash card	Compact Flash	5.1	✗	✗	✗	✗	✗
Original Flash card	Compact Flash	6	✓	✓	✓	✓	✗
Disk with no sticker	DiskOnModule	5.1	✓	✓	✓	✓	!
Disk with no sticker	DiskOnModule	6	✗	✗	✗	✗	✗
Stickered disk	DiskOnModule	5.1	✗	✗	✗	✗	✗
Stickered disk	DiskOnModule	6	✓	✓	✓	✓	✓

Figure 25 - Compatibility comparison

As can be seen in Figure 25 the only program that allowed a full connection was the DiskOnModule stickered disk, and only when accessed with the SODWIN version 6 software. The file transfer of from the disk with no sticker using SODWIN 5.1 has been highlighted, this is because the files transfer sometimes but are 0kb.

The contents of each program card were examined using DOS commands as they were each installed respectively on SODAR PC unit. The program cards contained similar files, some of which only vary with respect to the company involved; such as tempdRES and tempdNEL which contain ANSI data prior to conversion. The individual program files were identified by the format AQLC####.EXE. On examining the file structure of the compact flash drive in comparison to the other program cards it was found that there was a program within a folder named 'new prog'. Since this was not in the root drive like the other program cards, it was thought that it was not in use. It was copied into the root drive, from which the existing equivalent program file was removed, using DOS commands. This new program however still had connection issues.

So it can be seen that the only suitable option was to use the stickered disk and access the files using the SODWIN 6 software.

In order to examine the signals received by the system, and to check that the system was operating correctly, the frequency spectrum was examined. The frequency spectrum displays the individual spectrums that are received from each speaker at each height gate. There should be a correlating spectrum that varies in amplitude for the various height gates. However, on analysis of the retrieved spectrum files, it became evident that only one of the spectrum components was present. When viewing the spectrum with the software, only the first channel showed any data. This can be seen in Figure 26. It did however show a similar spectrum for each height gate.

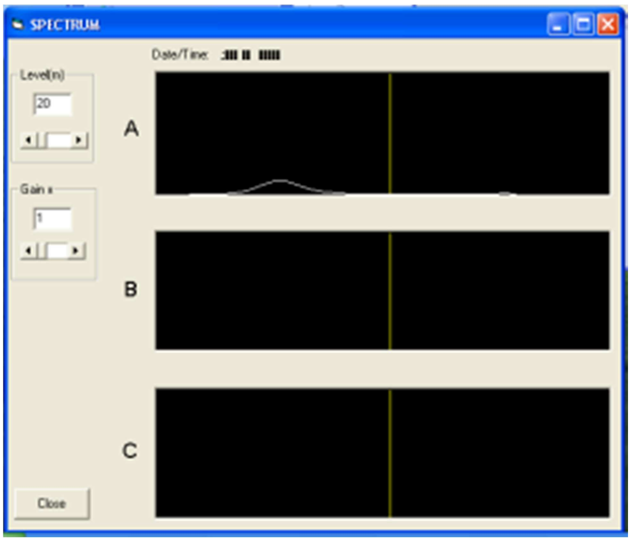


Figure 26 - Spectral Output

The graphical format on occasion showed an output that was comparable to an expected spectral output (a Gaussian distribution similar to that of component 'A' in Figure 26) but this was erratic as sometimes the spectral output was sporadically spread. The data collected did however show some boundary layer characteristics that were expected of valid data.

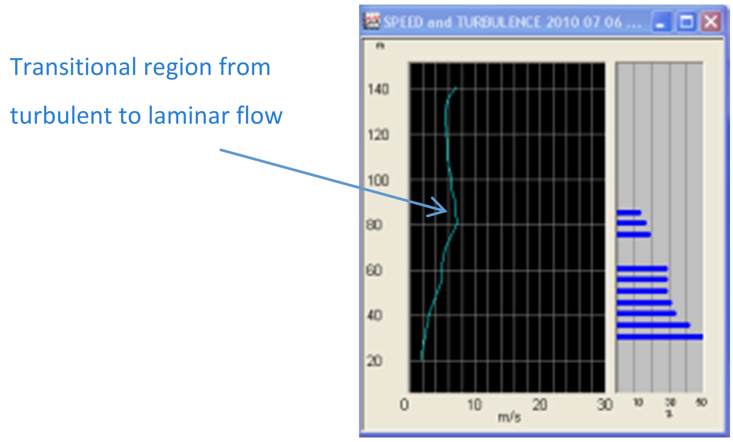


Figure 27 - Single spectrum wind profile

It can be seen from Figure 27 that the resulting wind profile shows an increasing average wind speed from 20-80m. At 80m a clear transition can be seen from an increasing average to a steadier average between 6-8ms^{-1} at heights above 80m when a return to laminar flow occurs. Given the height of the building at around 70-80m this seems to display the formation of the roughness sub-layer at around 150-160m. This correlates with the expected height range of 2-5 times mean building height as estimated by *Raupach et al* given that the mean building height is around 50m. Although this was thought to be a promising output, the lack of a full spectral input meant that this was likely to be only one vector component of the desired data. The fact that the average wind speed at 20m was only 2ms^{-1} and it was very windy on the roof at the time of measurement backed up this theory further.

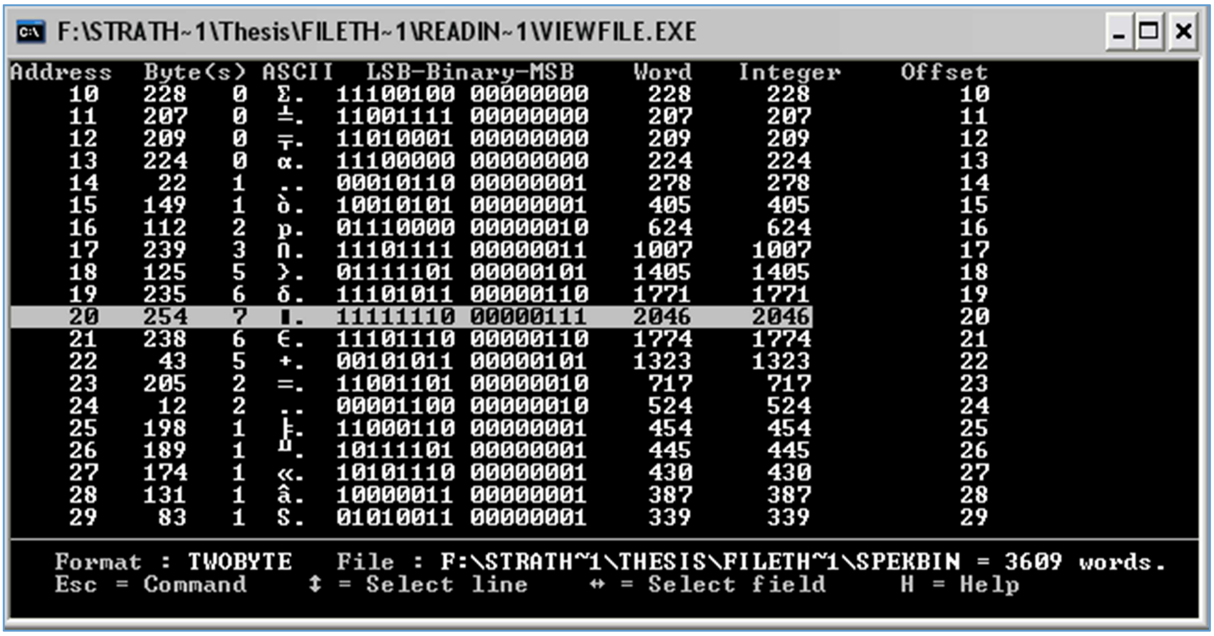
Due to presence of only one spectral component it was thought that perhaps only one of the speakers was working correctly. In order to examine this, the speaker membranes were replaced. Two replacement speaker membranes were provided with the system. Changing a membrane involves removing the back of the speaker using a hex key, and the replacement of the membrane with great care due to their thin film and fragility. This process is highlighted within the AQSystems service manual. In order to ensure that all membranes in question were working, the two membranes of the supposedly non-working channels were swapped with the spare membranes, but also the membrane of the working channel was swapped with the other two channels. The result of this process was that the output was unchanged. The same channel (channel ‘U’ as denoted by the mark on the speaker) remained as having the only spectral output. It was then deduced that the problem did not lie with faulty speaker membranes.

The next check was to the transmission cables connecting the SODAR PC unit to the SODAR cone. The wired connections between the two ends of the cables were checked using a voltmeter and were found to all be functional.

Some of the SODAR parameters including pulse power and gain were altered, and periods of data collection undertaken, to assess any effect on the resulting spectral output, but this was to no avail.

Raw data files

In order to assess whether the error was in the translation of the raw data into a readable format by the SODWIN software, the raw data files were to be examined. Within the SODWIN program files folder the raw data exists in ANSI format before it is translated into a readable format. For the spectrum data, the file named ‘spekbin’ contains all three components in ANSI code before being translated into the files named ‘uspek’, ‘vspek’ and ‘wspek’. On inspection of these converted files, only uspek contains any values, whereas the other two files contain only zeros. This is expected after the spectral output showing only one component. In order to examine the spekbin ANSI file, a piece of specialist software called ‘viewfile’ that exposes the raw data within a file in numerous formats was utilised. The output of this program is shown in Figure 28.



F:\STRATH~1\Thesis\FILETH~1\READIN~1\VIEWFILE.EXE

Address	Byte(s)		ASCII	LSB-Binary-MSB	Word	Integer	Offset
10	228	0	Σ.	11100100 00000000	228	228	10
11	207	0	±.	11001111 00000000	207	207	11
12	209	0	╤.	11010001 00000000	209	209	12
13	224	0	α.	11100000 00000000	224	224	13
14	22	1	..	00010110 00000001	278	278	14
15	149	1	ò.	10010101 00000001	405	405	15
16	112	2	p.	01110000 00000010	624	624	16
17	239	3	∩.	11101111 00000011	1007	1007	17
18	125	5	}.	01111101 00000101	1405	1405	18
19	235	6	δ.	11101011 00000110	1771	1771	19
20	254	7	■.	11111110 00000111	2046	2046	20
21	238	6	ε.	11101110 00000110	1774	1774	21
22	43	5	+.	00101011 00000101	1323	1323	22
23	205	2	=.	11001101 00000010	717	717	23
24	12	2	..	00001100 00000010	524	524	24
25	198	1	╞.	11000110 00000001	454	454	25
26	189	1	╜.	10111101 00000001	445	445	26
27	174	1	«.	10101110 00000001	430	430	27
28	131	1	â.	10000011 00000001	387	387	28
29	83	1	S.	01010011 00000001	339	339	29

Format : TWOBYTE File : F:\STRATH~1\THESIS\FILETH~1\SPEKBIN = 3609 words.
Esc = Command ↕ = Select line ↔ = Select field H = Help

Figure 28 - Viewfile spekbin output

It can be seen that integer values increase to peak value (highlighted) before decreasing again. This pattern was consistent throughout the first third of the file, following the expected spectral output. The first third contained numerical integer values stored in two-byte packets, whereas the remaining two thirds merely contained zeros. This matches the output pattern shown within the individual ‘spek’ files. It could be concluded from this that it was not this conversion process from ANSI to decimal that was faulty and causing erroneous data.

The ANSI format data file was also examined using the viewfile program. The integer values within this file did not exactly match the values displayed within the SODWIN converted data files, however there was some correlation. This leads to the conclusion that either the SODWIN translation is incorrect or the method used to view the data with the viewfile software is not correct. From this conclusion the translation process was to be further examined by Andy.

It was at this point that the re-commissioning process was ceased due to time constraints. It was decided that Andy would be brought in to analyse the system in order to solve the final compatibility issues.

In order to discuss the method of operation of the current system and any common problems encountered, a user manual has been created.

User Manual

The power source for the system is currently connected as outlined in Figure 29.

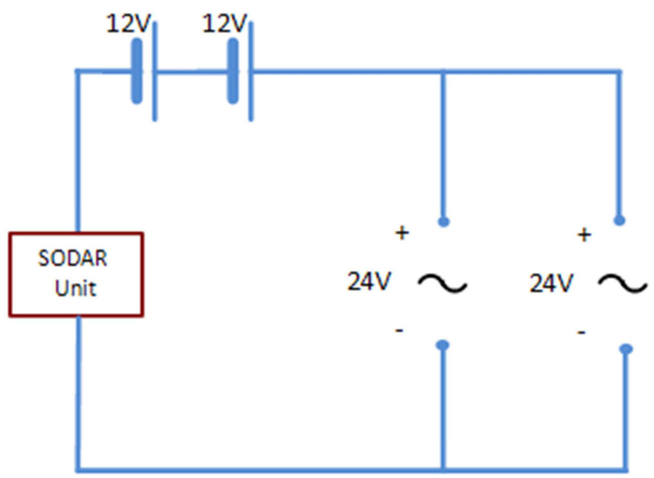


Figure 29 - Power supply set-up

With the power supply connected to the SODAR junction box, the system is powered up via the switch on the SODAR junction box. As the system powers up the speakers will begin to emit pulses that gradually increase in power until the specified pulse power is reached. The pulses should emit in the pattern of three long pulses followed by three short pulses.

With a laptop connected to the SODAR PC unit via the serial cable, the SODWIN program should be started. The setup tab should be accessed and the communications should be viewed. Ensure that the correct com port and baud rate are set to match the laptop being used for communication. Typically this will be com1 and 9600 baud. Direct connection, along with no automatic collection should be selected. In the same tab, the path for data files can be viewed and should be set to the desired destination for the SODAR data files.

The SODAR parameters can be collected through the SODWIN software by accessing the tools tab and manual connection menu and selecting SODAR parameters. A description of the parameters is shown in Table 4.

Parameter	Description
Integration Time	10min for wind energy
	15min for air pollution
Antenna Orientation	input compass direction during set-up
Measuring Modes	defines height gates *typical 2*
Frequency	pulse frequency
Limit Wind	factory set, either 20,21,22
Store Spectrum	'y' to store spectrum
Gains u,v,w	range 0.05-0.3 *typical 0.15*
Pulse Power	standard 300W
Pulse Power Control	'n' to define using Pulse Power value
Noise Limit Wind	range 3000-8000 *typical 6000*
Noise Reduction	'y' to activate background noise
	subtraction
Reduction Figure	range 0.1-1.0 *typical 0.8*

Table 4 - SODAR Parameters

The list of SODAR parameters will be updated with the values stored in the current program. On the first set-up of the system the antenna orientation should be updated. The method for calibrating this can be found in the AQS manual. The measuring mode will usually be linked to the program card in use. The operating frequency need not be changed unless there is constant source of noise nearby around the same frequency, as this may result in signal interference. The pulse gain and power can be altered dependent upon available power and higher values should be selected in areas of high background noise to ensure that a strong signal is obtained.

If the serial connection has now been confirmed, check that the speakers are transmitting and receiving correctly by collecting the frequency spectrum. This is collected via the same menu as the SODAR parameters. On viewing the collected spectrum there should be a frequency distribution present on each channel. The distributions should resemble typical Gaussian shape. With the spectrums identified the SODAR system should now be left running for 10 minutes to acquire the first integration period data. After the first 10 min integration period there will be a data set stored in the SODAR PC unit. This can be viewed using the ‘collect current data’ command and can be viewed in either tabular of graphical format. The graphical format will resemble something similar to that of Figure 27. The system can now be left to collect data for the required period. The data will be stored in daily files and can be accessed using the File List command. In order to transfer the files from the SODAR system the file list must be collected and the desired files selected. The files names will start with WA and will then be followed by the date in numerical year/month/day format. After selecting the desired files they should be transferred and will appear in the folder selected in the communications tab. The transferred files will appear in numerical format, their ANSI counterparts can be found in the SODWIN root folder. The numerical data files can be viewed in notepad. Once saved in a notepad file, they can be opened from the notepad file in Microsoft Excel. Upon opening the file, delimited formatting will have to be selected with commas selected as the limiters. The file can then be viewed in Excel. There may be no headings for the data columns however a sample data set is shown in Figure 30.

Date/Time	Interval	mode	Voltage	Temp	Null	Press	spd20	dir20	std20	vert20	std v20	s/n20	spd25	dir25	std25	vert25	std v25	s/n25	spd30	dir30	std30	vert30	std v30	s/n30
							cm/sec	deg					cm/sec	deg					cm/sec	deg				
20080516 9:10	10	1	1330	-400	0	600	245	87	92	13	56	95	272	87	86	12	55	104	281	97	83	4	48	118
20080516 9:20	10	1	1330	-400	0	600	245	82	95	30	64	88	267	83	92	33	58	89	275	85	89	32	61	87
20080516 9:30	10	1	1330	-400	0	600	193	75	9999	40	55	105	285	77	95	41	56	107	303	76	94	34	59	105
20080516 9:40	10	1	1330	-400	0	600	205	78	78	29	51	103	315	78	91	30	52	100	325	79	98	30	55	94
20080516 9:50	10	1	1330	-400	0	600	204	57	9999	62	75	98	293	58	104	61	78	103	302	58	113	64	78	100
20080516 10:00	10	1	1330	-400	0	600	223	43	86	6	64	101	251	44	92	5	67	102	261	44	95	6	60	100
20080516 10:10	10	1	1330	-400	0	600	287	75	95	9	55	101	317	74	96	8	52	95	326	76	98	11	55	100
20080516 10:20	10	1	1330	-400	0	600	273	64	95	23	61	116	357	65	96	24	60	113	364	64	97	24	64	106
20080516 10:30	10	1	1330	-400	0	600	334	82	99	21	64	97	386	81	104	21	64	95	399	78	107	22	67	103
20080516 10:40	10	1	1330	-400	0	600	281	75	94	23	61	90	362	75	100	26	63	92	368	76	102	25	68	86
20080516 10:50	10	1	1330	-400	0	600	337	77	91	15	61	103	358	78	93	15	62	100	359	79	92	17	64	90
20080516 11:00	10	1	1330	-400	0	600	298	84	83	13	50	109	318	83	87	15	52	107	320	85	90	15	57	101
20080516 11:10	10	1	1330	-400	0	600	236	79	73	21	54	88	335	78	82	23	54	91	341	79	85	21	54	103
20080516 11:20	10	1	1330	-400	0	600	244	70	86	11	55	100	345	69	88	12	52	108	350	70	89	16	57	109
20080516 11:30	10	1	1330	-400	0	600	260	69	98	23	70	88	288	69	97	22	72	82	295	69	98	19	66	90
20080516 11:40	10	1	1330	-400	0	600	197	36	77	18	49	103	217	37	79	20	51	109	226	37	84	23	57	113

Figure 30 - Sample data set

The date and time for each measurement period can be seen at the start of each row. With the temperature and pressure sensors not connected the values of -400 and 600 are shown in these cells. The data is set into separate height gates, starting at 20m then increasing in steps of 5m up until 150m. Data availability may vary at this height due to weather conditions or pulse power. For each height gate there are values for average horizontal wind speed, the direction, and the standard deviation about the mean. There is also the average speed of the vertical wind component and the standard deviation about that mean. Finally there is a signal to noise ratio which outlines the amount that the data has been influenced by background noise. Data in this format can be easily plotted in excel by selecting the desired columns for analysis of the wind resource.

Troubleshooting

This section will outline a troubleshooting method that incorporates a process of elimination.

Powering up

If upon powering up the system there is a clicking sound coming from the amplifier in time with the pulses, then it is likely that the pulse power is too high for the power supply. This can be easily reduced in the SODAR parameters menu down to a value of 50W. Lower values will however result in a higher signal to noise ratio and thus reduce the data availability. This could become more of an issue in an urban environment due to the greater amount of general background noises. Another cause of a lack of data availability could be during periods of heavy precipitation as this causes extra unwanted backscattering from water droplets in the air.

If there is no clicking and the correct pulse sequence is not heard then it is likely to be one of three causes.

1. There is an inadequate connection between the SODAR cone and the control box for the system. The two connecting leads should be checked to ensure that they are fitted correctly, and wired a connection should be confirmed using a voltmeter.

2. One or more of the speaker membranes may be damaged. There are two spare membranes currently with the system. They can be replaced by removing the back panel of the speaker using a hex key. The membrane is delicate and must be handled with care.

3. The PC unit is not functioning or the program is not running. Connect a PC monitor to the PC unit and ensure that the screen in Figure 19 is seen. If this is not case then the program is not running, this could either be due to a lack power to the PC unit (check connection), a lose connection somewhere in the system (a BIOS error may be heard or the program card may not be connected properly), or the DOS program not loading

from the specified path (ensure that the correct drive is selected in the PC unit setup menu).

Connection issues

If when trying to access the SODAR PC unit through the SODWIN software a serial connection is unable to be obtained then there are a few possible causes.

1. The correct RS232 null modem cable should be used. The cable currently with the system is of the full handshaking variety.

2. The correct communication settings should set for the selected com port. This includes 9600 baud and the default com1 port settings for no parity, hardware flow control, 1 stop bit and 8 data bits.

3. The correct program card should be selected so that it is compatible with the version of SODWIN in use for communication.

If using a modem to obtain a remote connection, great care should be taken in order to ensure the suitability of the SIM card and modem. The SIM card should be CSD-enabled to allow the data transfer. This is likely to require a contract from a specialist provider as most commercial network operators have progressed exclusively into 3G data transmission. A suitable modem should also be chosen that supports the CSD format.

Intended research

As previously mentioned, it was intended to use the SODAR system to collect data concerning the air flow over the roof of the James Weir building. From this data an analysis of the possible output from a wind turbine at this site could be conducted. The intention was to create a probability distribution function from the wind speeds present at the site. This could in turn be used to analyse the projected outputs from various turbine heights and sizes.

The work would have also taken into consideration an analysis of the urban boundary layer throughout various weather conditions and time frames. This could be used to predict the flow rates under varying circumstances.

The results would be compared against those of the LIDAR system positioned at the same site and would give a representation of the validity of the results and information regarding the operation of the SODAR system in an urban environment.

However, due to the many obstacles encountered along the experimental restoration process, and a continual reliance upon external sources for advice and information, the project did not reach completion.

What has been created however, is a documented progress report and a base from which the intended future research can be conducted. With the system near completion towards a fully working state, input from an expert in the field should see it producing reliable results. It can then be used for analysis of the wind flow over the rooftop and an investigation into potential turbine installations could be conducted.

Further Application of SODAR

With the government's ever increasing targets of the percentage of the nation's power that should come from renewable sources, there will undoubtedly be a large amount of wind power as it is already the most developed renewable technology. As the application of wind power continues so too will the use of remote wind sensing techniques such as SODAR. The benefits of a SODAR system over conventional wind monitoring techniques have been highlighted throughout this paper. But there are areas where there is further potential available for the application of SODAR that have to be fully examined.

Upstream wind predictions

The ability of SODAR to measure vertical wind components gives rise to the possibility of mounting a system horizontally near, or even upon, a wind turbine hub. The originally vertical components would then produce a horizontal wind speed cross section as it approaches the sensor. This would allow a sensing technique that could be used to measure the actual wind speed upstream and track its progress before it reaches the turbine itself. This would be useful in the operation of a turbine to ensure that it is set up correctly in order to maximise the potential energy captured from the incoming wind. The speed range of the vertical component on the current system is only 10m/s so this would have to be adapted in order to accommodate a greater range. Issues may also occur with the backscattering of signals from the ground at readings of greater distance due to the radial trajectory of the pulse beams. Noise and vibration transference between the system and the turbine would also need to be taken into consideration.

Resource assessment for BAWTs

The issues regarding the use of SODAR systems within an urban specific environment have been discussed. In order for a system to produce useable results it is likely to need to be positioned on a rooftop or away from any sources of side lobe interference. The minimum height gate measurement of around 15-20m also potentially limits its use for the wind resource assessment for turbines with a hub height of around this value.

But an approach that incorporates these facts may warrant further research as the development of BAWTs continues. Should the wind resource assessment be conducted by a SODAR system on the site of a potential new building, then a wind profile of the expected winds above and around the site of the new building could be created. Armed with the knowledge of the air flows above the potential site, this profile could be used in conjunction with the designing of the building to model the expected flows around the building. This would ensure that any integrated wind turbine technology should perform to expectations. This becomes increasingly suitable for SODAR systems as the height of most modern urban buildings will outstrip the measurement capabilities of a conventional met mast. Also the large footprint of a met mast may not be suitable if the plot of available land is restricted. With the measurements from SODAR systems being volumetric, the values should also be more representative of the available wind power resource due to the associated accountability for directional variations resulting from large amounts of turbulence. Not only could the design of BAWTs be enhanced and include more radical wind augmentation that utilises this fuller understanding, but the design of any natural ventilation systems planned within the building could also benefit from the knowledge of the expected air flows.

Should a SODAR system be used in this way then any sources of background noise would have to be considered. Even if a similar LIDAR system were to be considered instead, there may be issues with regard to significant urban light pollution.

Conclusions

The conclusions have been spilt into their primary and secondary objectives as described in the initial methodology.

Primary objective

The process of restoring an old AQ500 SODAR system to a working condition that can be powered from a mains supply is almost complete. Although issues remain with regards to the final compatibility of the system and the access software, a considerable amount of diagnosis work has been undertaken. This work has resulted in a documented investigation into the main components of the system and their respective operation.

In addition to this, a substantial amount of practical work was required in the removal of the system from its old state to bring it to its current state, and into its new position. A significant amount of fault finding analysis was undertaken in order to determine the areas of fault within the system. This has resulted in the creation of a troubleshooting step-by-step manual that outlines key areas of possible concerns.

Although it was felt that the significant amount of reliance on external sources has hindered the progress at some stages, this could not be helped, as such is the nature of an experimental project. Even though there was no opportunity to obtain any analysable data, what has been created is the basis for further research both with the SODAR system in question and into the topic area. It is hoped that the detailed analysis in the operation of individual parts of the system and the system as a whole can be used to provide a deeper understanding for future researchers.

The successful renovation and relocation has been achieved and the proposed work needed in order to bring the system into full operation has been outlined.

Secondary objectives

The global scene has been set for the continued development of our renewable energy generation techniques. Wind energy is currently at the forefront of this development but it by no means being utilised to its full potential.

An analysis into the field of urban boundary layers has been conducted. The results of which clearly highlight the important characteristics of the various layers and corresponding wind profiles that would be expected to be encountered in a number of urban scenarios. The influence of topography and surface friction upon the air flows have been discussed, along with the effects of the phenomenon of the urban heat island. The urban heat island is an anthropogenic consequence of city construction that ultimately dictates thermal structure and the thickness of the various levels within the urban atmospheric boundary, thus in turn affecting the air flows within it.

The main methods of wind measurement have been discussed in relation to each other and to the wind energy industry. The conventional cup anemometer met masts are slowly giving way to more modern and powerful remote wind monitoring devices. The advantages of the remote sensing techniques are numerous, mainly being their increased accuracy, mobility, subtlety, and inherently more representative vector measurements. The place of SODAR systems within the field of remote wind monitoring is established, although older systems may not have the same accuracy as a more sophisticated LIDAR system they can match the accuracy of met masts and the reduced economic cost of the systems make them attractive to wind energy researchers.

The conventional method of wind resource assessment has been outlined, along with the different challenges that apply to wind energy application in urban environment. The need to develop in regions of greater surface roughness will increase as areas of available lower surface roughness become depleted. The air flows within the urban region are significantly more complex and turbulent. Although this hinders wind energy application it should be seen as an area of emerging potential and one which is very different from its rural counterpart.

Various methods of wind harnessing within the urban environment exist and are evolving all the time as the understanding of this area in increasing. Although initial attempts at urban wind energy have been somewhat unsuccessful, progress is being made with newer, novel devices. One of the most promising areas is that of building augmented wind turbines which utilise the potential for air flow acceleration within the urban environment.

The proposal for assessing the current site of the SODAR for wind energy application required the assessment of the local topography. By understanding the air flow around similar objects, and the topography of the surrounding surfaces, a depiction of the expected characteristics around the site has been created. Although very small home mounted turbines have experienced very little success, the application of a larger turbine here, perhaps tilted towards the prevailing flow may result in an improved output.

The suitability of SODAR within an urban environment has been discussed with regards to the potential issues of background noise and side lobe interference. Although such systems have been rarely used in an urban context due these issues and the minimum height that can be measured, cases for the application of SODAR have been proposed. The use of wind profiling at a prospective site before any building design has been created allows for the significant integration of wind turbines into or around the building itself. This in turn provides a better prospect for the turbine to produce a larger output and hence increase the sustainability of the building and its projected image.

The environmental impacts of SODAR are minimal due the small physical footprint. However, the energy consumed during operation should be factored into any embodied carbon assessment for a wind turbine. The application of solar power may also improve this. The environmental impact of urban wind development is thought to be lesser than its rural counterpart due the reduced need for transmission, and the already developed installation sites. The implications of building accelerated winds must be fully assessed of course, as their impact on residents and the local ecosystems may be significant.

To conclude, the basis for future research has been created through considerable fault analysis and documentation along with research into the topic area of urban wind energy in an applied theoretical manner.

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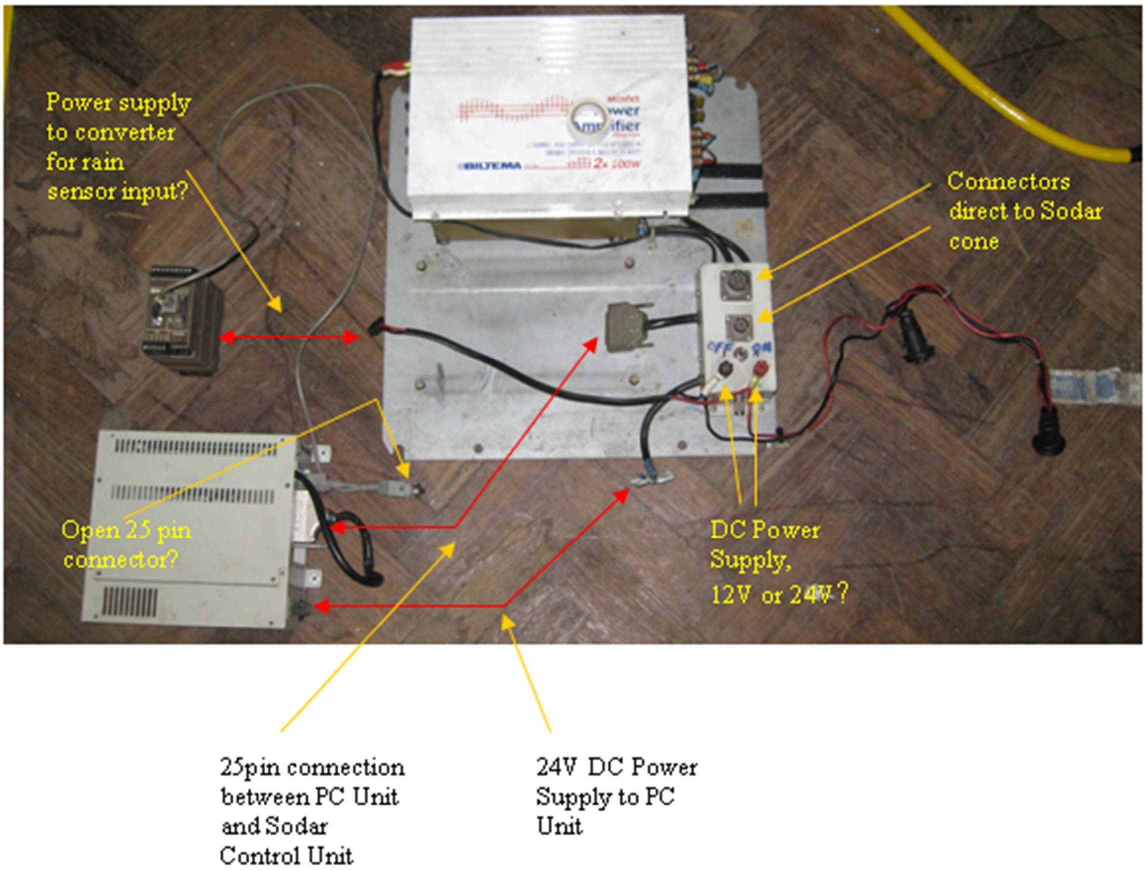
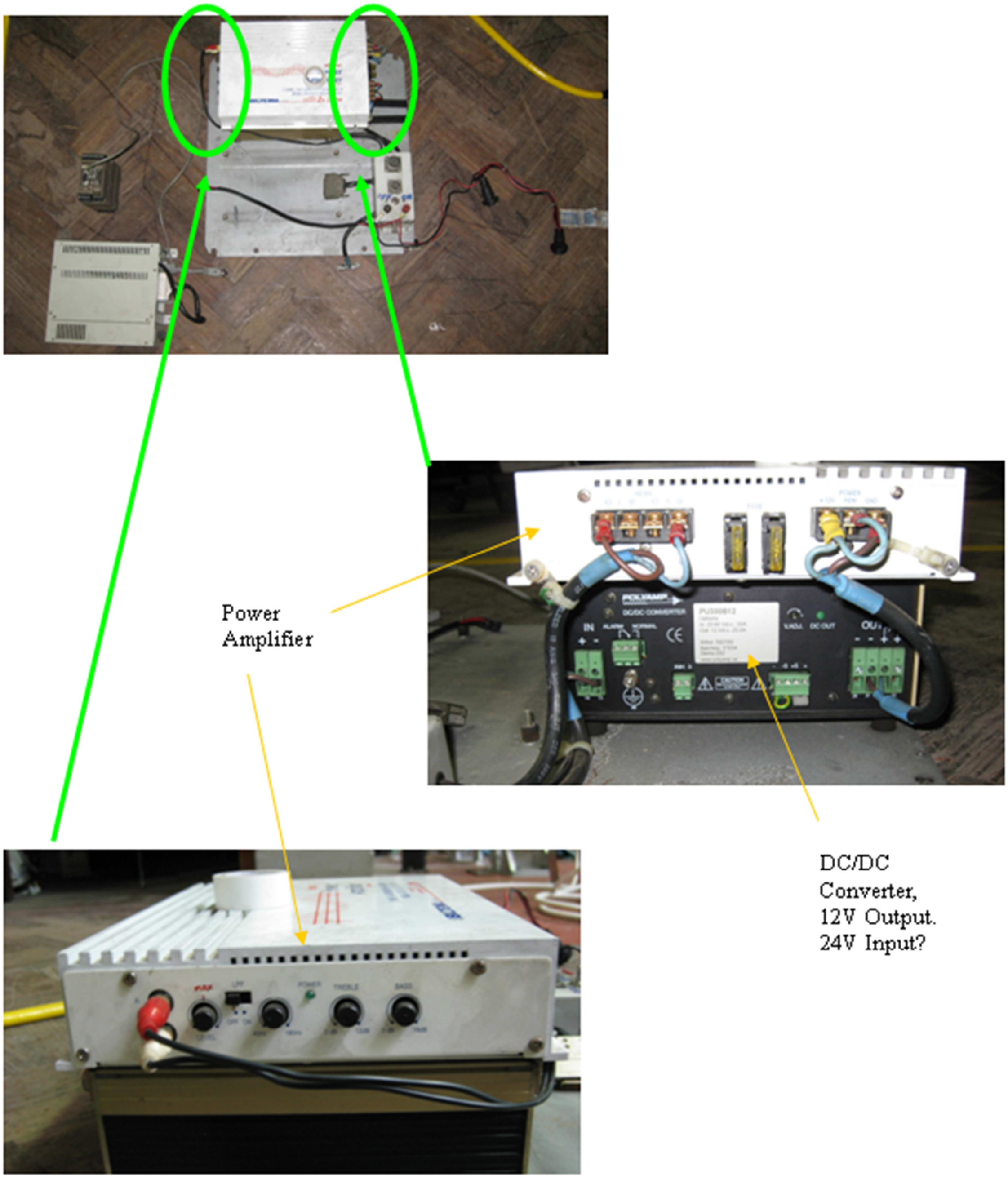
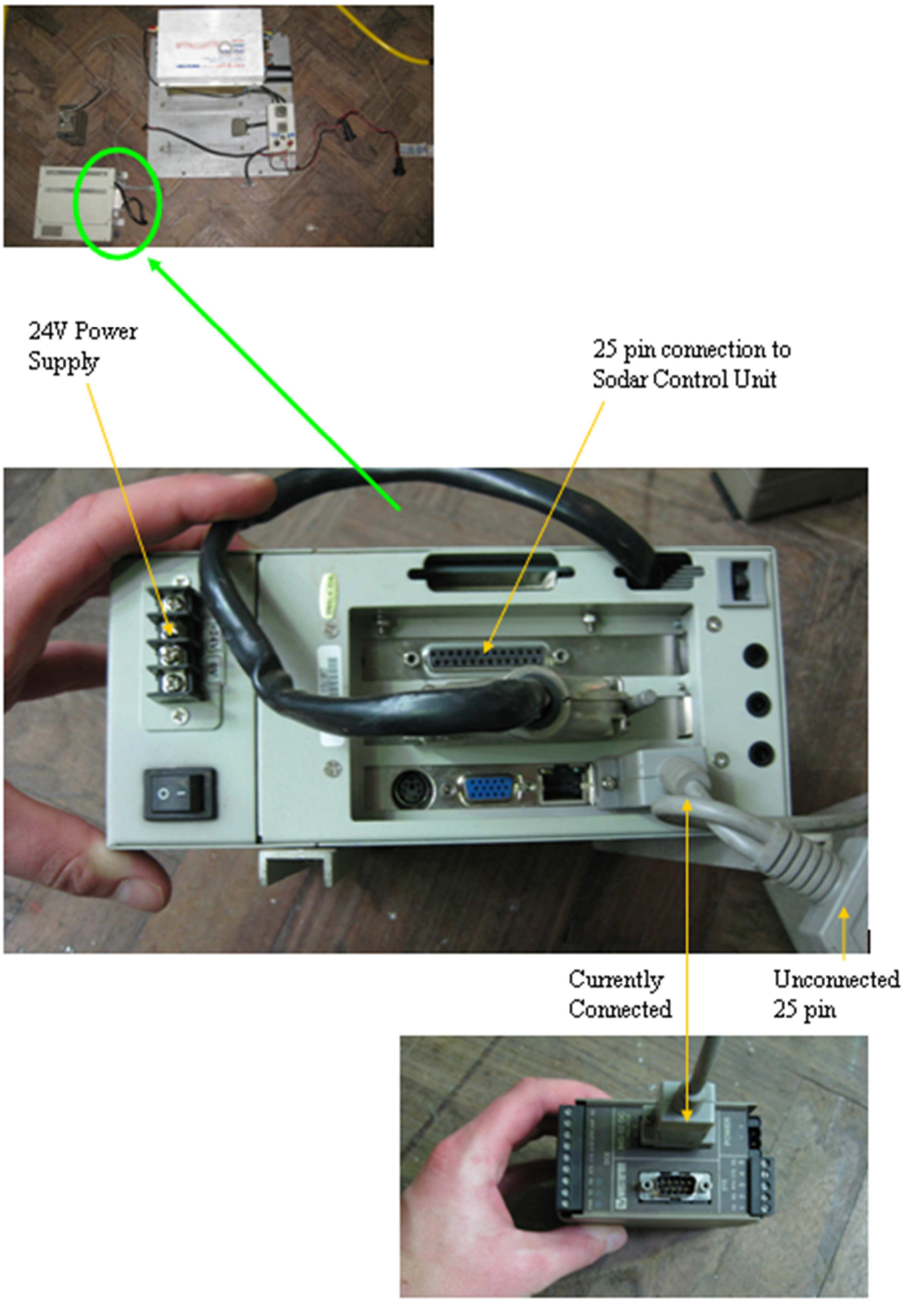
Appendix A

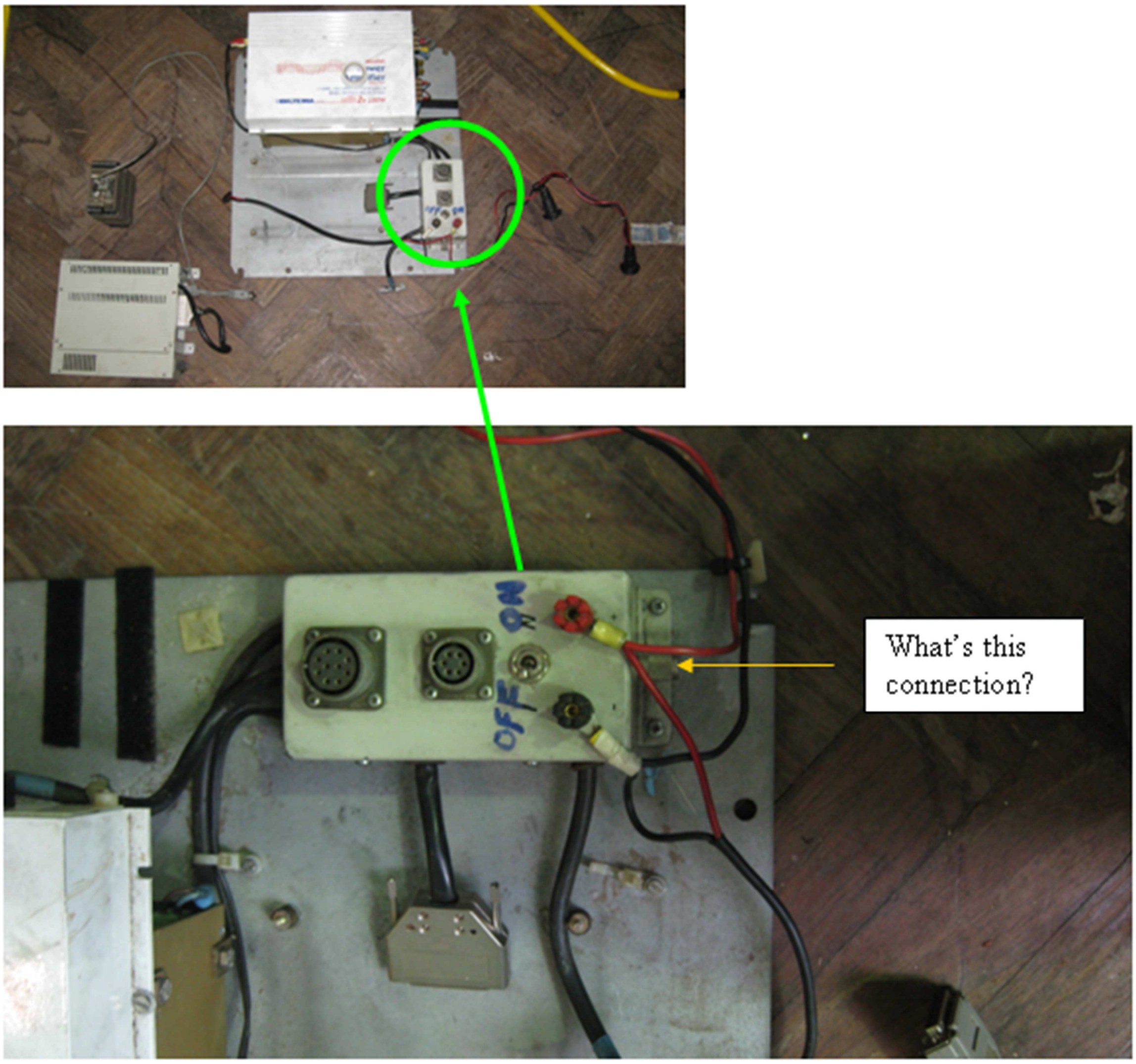
This is a copy of the email that was sent to AQSystems once the components were initially removed from the trailer. At this stage the configuration of the system was unclear, hence the questions within the pictures.

Here is the system I have, separated from the diesel generator, batteries and associated circuitry. There are also two cables to the SODAR cone (highlighted in diagram below).




Power
Amplifier
DC/DC
Converter,
12V Output.
24V Input?


24V Power Supply
25 pin connection to Sodar Control Unit
Currently Connected
Unconnected 25 pin


ON
OFF
What's this connection?