

Build and operating procedure for the Gonio RAdiometric Spectrometer System (GRASS)

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ABSTRACT

This document provides the build and operating procedures for the Gonio RAdiometric Spectrometer System (GRASS). Within this guide, the operator find information on how to construct the instrument, take measurements and also guides to the analysis of the data.

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Approved on behalf of NPLML by Ian Severn, Business Leader

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1 Scope

This document aims to provide information on how to construct the GRASS instrument and how to operate it. This will include measurement procedures that should be followed, planning tips and also how to analyse the data acquired. The document also contains details on the traceability of the instrument and how it was validated. In essence this should provide a comprehensive guide to the instrument and provide references to other work or documents that support the development and use of the instrument.



2 Introduction

To perform vicarious calibration for the validation of satellite sensor data products, field instrumentation is used to provide the *in-situ* data. The theory behind the application of field spectroscopy is based on the following basic behaviours of electromagnetic radiation, such that when the light radiates a surface it may be reflected, absorbed or transmitted. This is dependent on the nature of the surface and the wavelength of the incident radiation. For example, the light can be reflected from a surface (e.g. a mirror), or scattered in different directions (A and B in Figure 1) and the light can also be either absorbed or transmitted, (C and D in Figure 1).

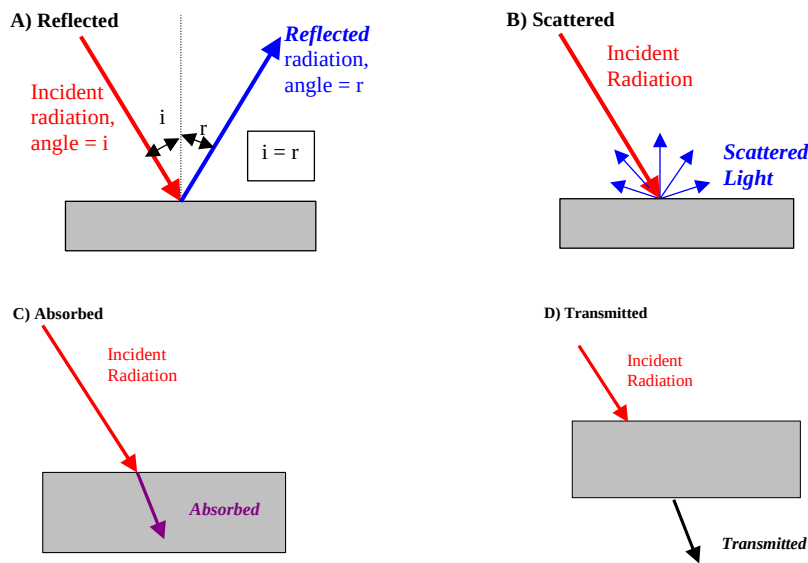


Figure 1: Schematic representation of reflected, scattered, absorbed and transmitted light. (Gibson, 2000)

Remote sensing of the earth involves a combination of these effects. For example, Figure 2, shows the incident radiation, (i.e. from the Sun), can be scattered from the top of the atmosphere, absorbed, or transmitted to the surface, where the light can also be reflected or absorbed. Since all surfaces have different properties, they can reflect and absorb different amounts of light at different wavelengths.

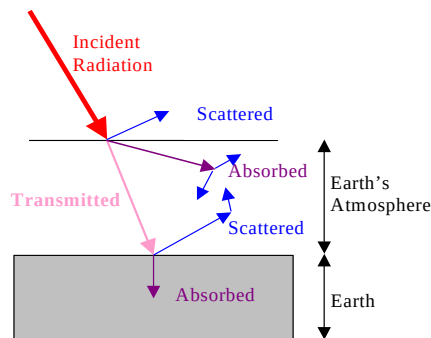


Figure 2: Schematic representation of the Earth - atmosphere system and the light interactions.

To perform vicarious calibration a variety of instruments are used to measure and quantify the various reflectance and absorption effects. The use of field instruments to provide *in-situ* data

is a suitable method for the validation of satellite sensor data. However, as previously mentioned, its accuracy is limited by the ground measurement process and the validity of the atmospheric radiative transfer models, the main errors being in the aerosol model and the directional reflectance effects (Dinguirard, et al., 1999).

2.1 Directional Reflectance

Directional reflectance effects are due to a natural target being non-Lambertian. Due to their macro- and microphysical construction, terrestrial surfaces reflect light with different intensities in different directions (Diner, et al., 1999). This is because on a micro scale a surface is rough, and, therefore, the light is reflected in different directions, the intensity of which is wavelength and directionally dependent. For example, depending on the viewing and illumination angles a surface can appear brighter or darker – for example a mown lawn or a forest canopy, Figure 3. This interaction of the light is of key interest in developing an understanding of the reflectance characteristics of the natural environment.

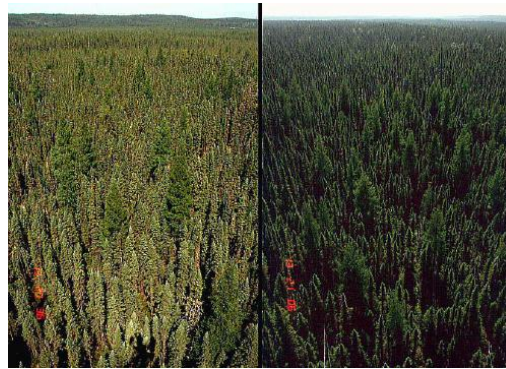


Figure 3: A black spruce forest in the BOREAS experimental region in Canada. Left: backscattering (Sun behind observer), Right: forward scattering (Sun opposite observer), note the shadowed centres of trees and transmission of light through the edges of the canopies. (Lucht, et al., 2006).

The bidirectional reflectance distribution function (BRDF) was defined by Nicodemus *et al* (1977), and it describes the scattering of a parallel beam of incident light from one direction in the hemisphere into another direction [Equation 1]. It describes infinitesimally small quantities and as such cannot be measured. The BRDF describes the intrinsic reflectance properties of a surface, from which many other quantities can be derived.

$$BRDF_{\lambda} = f_r(\theta_i, \phi_i; \theta_r, \phi_r; \lambda) = \frac{dL_r(\theta_i, \phi_i; \theta_r, \phi_r; \lambda)}{dE_i(\theta_i, \phi_i; \lambda)} [sr^{-1}]$$

Equation 1

Where $dL_r [Wm^{-2}sr^{-1}] = \text{Radiance}.$

$dE_r [Wm^{-2}] = \text{Irradiance}.$

Reflectance factors are defined as the ratio of the radiant flux reflected by a sample surface to the radiant flux reflected into the identical beam geometry by an ideal (loss-less) and diffuse (Lambertian) standard surface.

An ideal Lambertian surface reflects the same radiance in all view directions, and its BRDF is $1/\pi$. Thus, the Bidirectional Reflectance Factor (BRF) (unit less) of any surface can be expressed as its BRDF [sr^{-1}] times π [Equation 2].

$$BRF = \pi \cdot f_r(\theta_i, \phi_i; \theta_r, \phi_r)$$

Equation 2

2.2 Definitions

Different beam geometries can be defined following the definition of reflectance factor: these include: bidirectional reflectance factor (BRF), hemispherical-directional reflectance factor (HDRF), the biconical reflectance factor (conical-conical reflectance factor – CCRF), and the hemispherical – conical reflectance factor (HCRF).

Since BRDF and other reflectance nomenclature were defined by Nicodemus *et al.* (1977), the use of the terminology has been misunderstood, misapplied or ignored, as demonstrated by Schaepman-Strub *et al.*, (2006), such that terms used within the scientific literature do not always accurately describe the measurements that have been undertaken.

The above nomenclature was adapted by Martonchik *et al.*, (2000), to apply specifically to remote sensing applications, and more recently the review by Schaepman-Strub *et al.*, (2006), which contains case studies highlighting the issues surrounding the misuse of the nomenclature, show the importance of using the established definitions for all remotely sensed data.

The following table [Table 1] summarises the different definitions, which relate the incident and reflected light distributions. The table is adapted and summarised from the Schaepman-Strub *et al.*, (2006) and Martonchik *et al.*, (2000) papers.

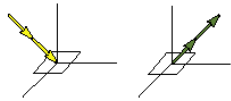
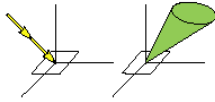
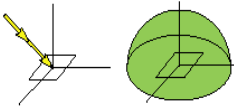
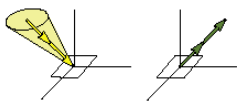
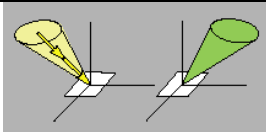
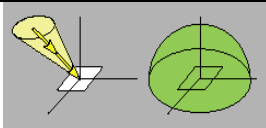
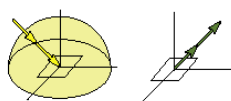
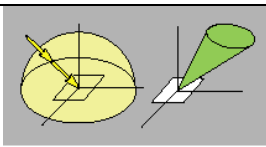
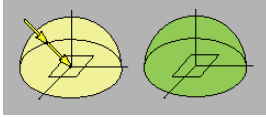
Case	Relation of incident and reflected radiation.	Description of terminology.
Case 1	Bidirectional  BRDF BRF	BRDF - Describes the scattering of a parallel beam of incident light from one direction in the hemisphere into another direction in the hemisphere. It is the intrinsic property of the surface.
Case 2	Directional - Conical 	Integration of the BRDF over the solid angle
Case 3	Directional - Hemispherical  DHR Black-sky albedo	DHR - Ratio of the radiant flux for light reflected by a surface into the view hemisphere to the illumination radiance flux, when the surface is illuminated with a parallel beam of light from a single direction. Integration of the BRDF over the hemisphere. Inherent property of the surface, which is independent of atmospheric conditions.
Case 4	Conical - directional 	
Case 5	Biconical  CCRF	This is the most general quantity, because its expression contains all other special ones; for $\omega=0$ the integral collapses and we obtain the directional case, and for $\omega=2\pi$ we obtain the hemispherical case.
Case 6	Conical - hemispherical 	
Case 7	Hemispherical - directional  HDRF	Similar to the BRF (case 2), but includes irradiance from the entire hemisphere.
Case 8	Hemispherical - conical  HCRF	For large IFOV sensor measurements performed under ambient sky illumination, the assumption of a zero interval of the solid angle for the measured reflected radiance beam does not hold true. The resulting quantity is the HCRF
Case 9	Bi-hemispherical  BHR Albedo	Ratio of radiant flux from a unit surface area into the whole hemispheres to the incident radiance flux of hemispherical angular extent. For the special case of pure isotropic incident radiation (e.g. a situation that may be closely approximated in the field by a thick cloud or aerosol layer, the resulting BHR is reported as white-sky albedo . Inherent property of the surface, which is atmospherically dependent.

Table 1: Definitions of the reflectance quantities in optical Remote sensing, adapted from Schaepman-Strub *et al*, (2006) and Martonchik *et al*, (2000)

Table 1, contains the definitions for the different combinations of the illumination and reflected beam geometries. Each picture gives a brief illustration of the definition. However, only the pictures surrounded in grey can actually be physically measured, as described by Schaepman-Strub *et al*, (2006). The other quantities, such as BRDF can be determined, but not physically measured. An example of the data processing chain, using the reflectance nomenclature is shown in Figure 4.

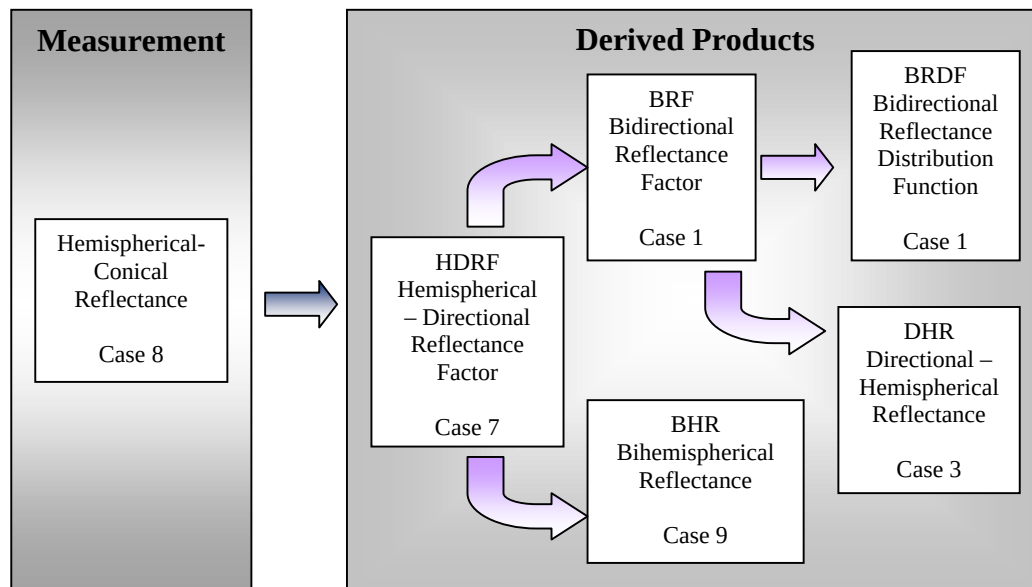


Figure 4: Conceptual data processing chain of airborne and satellite measurements to convert a spectrodirectional measurement (case 8) into BHR, BRDF and DHR respectively, adapted from Schaepman-Strub *et al*, (2004).

Understanding the BRDF characteristics of different surfaces is becoming increasingly important as more satellites have the capability of measuring surfaces at multiple angles. As the data products from these instruments become more readily available for investigations into the bidirectional reflectance distributions of various surfaces, it is vital to validate the satellite sensor data with field instrumentation that can also measure at multiple angles. The data from field spectroscopy instruments is also becoming more important as the demand for more accurate, traceable data grows. The BRDF determined from measurements made by field instruments can be used in a variety of applications such as inputs for atmospheric models and satellite sensor data validation (vicarious calibration). Other examples include (Sandmeier, 2000);

- o Validate currently available bidirectional reflectance distribution function (BRDF) models and support the development of new models
- o Investigate the physical mechanisms of BRDF effects
- o Study relationships between bio geophysical parameters and BRDF effects
- o Development of spectral libraries (Clark, *et al*., 2002)

3 Terminology for GRASS parts

To avoid confusion through the document, the different elements of the design have been named, and are shown in Figure 5. For ease of referencing elements of the design, the fiber and lens combination was dubbed a ‘camera’ and therefore the element of the structure to which they would be attached was named the ‘camera holder’. Table 2 lists the parts and provides a small description of the part and gives the quantity of the parts used within the whole structure.

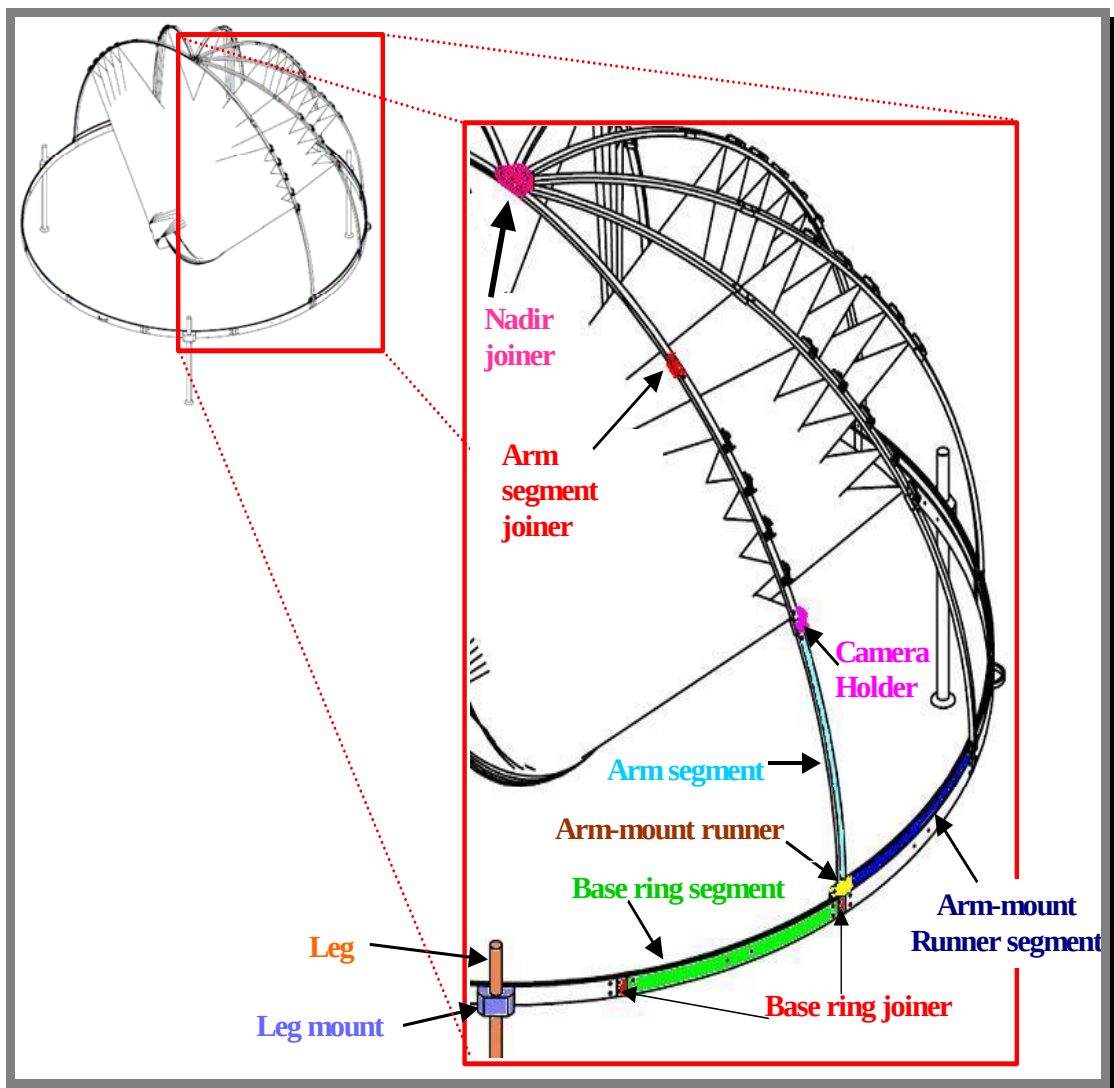


Figure 5: Names of the various parts of the structure of the GRASS.

Part name	Description	Quantity
Base-ring segment	The segments make a full circle and form the base of the structure. They are marked at 1° intervals all the way around the structure.	12
Base-ring joiner (Figure 6)	Joins each of the base-ring segments together	12
Leg	The structure stands on these.	6
Leg mount	The leg mount is attached to the base ring segments, and are evenly spaced around the structure. They have a clamp system to attach the leg to the structure, and also vary the height of the legs.	6
Arm-mount runner segment	These segments form a semi-circle, which the arms are then mounted on.	6
Arm-mount runner joiner (Figure 8)	These join the arm-mount segments together. On their underside they have PTFE blocks, which fit into the slot on the upper side of the base-ring. This allows the arm-mount runner semi-circular section to rotate on top of the base-ring.	7
Arm segment	The arm segments join together and form the arch on which the fibers and lenses can be mounted.	3 per arm (= 21 in total)
Arm segment joiner (Figure 9)	The arms segments are joined together with this joiner.	2 per arm (= 14 in total)
Camera holder	The camera holder has a mount for the lens (and diffuser) to which the fiber is attached. The holder is attached to arm segments, which have a slot to accommodate a PTFE block on the side of the camera holder. This PTFE block means the camera holders can be moved to any part of the arm, this can be at any point along one of the arm segments or at the arm joiner, as they both have slots to accommodate this movement and positioning.	5 per arm (= 35 in total)
Nadir joiner	Where the arm segments come together at the top, the nadir joiner clamps each arm together to complete the structure and make the arms rigid. This nadir joiner also has a mount for a lens (and diffuser) so that a fiber can be mounted at the nadir.	1

Table 2: Names of the parts of the structure, description of each part and quantity.

The base ring is made of 12 curved segments that would be joined together by the 80 mm joiner (Figure 6). This small part has two joiner bars running through it, and the curved sections would attach to the joiner bar (Figure 7).

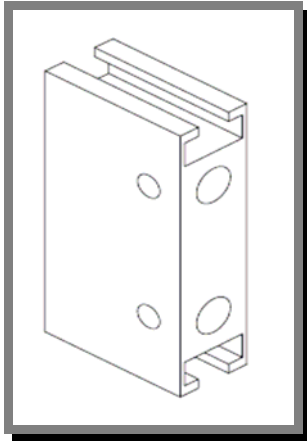


Figure 6: Base Ring Joiner (80mm joiner)

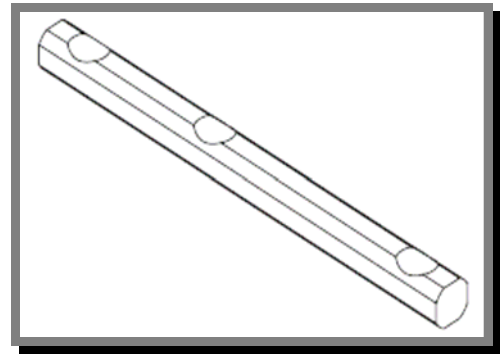


Figure 7: Joiner bar

Similarly the arm-mount runner (Figure 8) and the arm-segment (Figure 9) joiners work in the same manner by having the joiner bar run through them to connect the arm-mount runner segments and the arm-segments respectively.

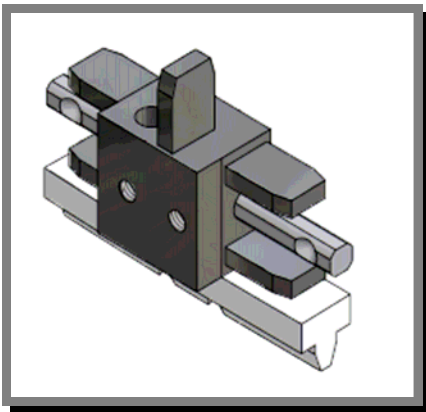


Figure 8: Arm-mount runner joiner (40mm joiner)

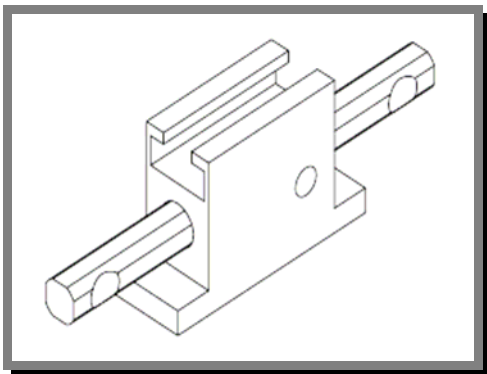


Figure 9: Arm-segment joiner (30mm joiner assembly)

Figure 10 and Figure 11 depict the two different measurement set-ups. Figure 10 shows the radiance set-up, where the lens is used and therefore looking down at the target.

Figure 11 shows the irradiance set-up, where the curved section is on a hinge and can be flipped over and secured such that the diffuser can be attached to the end of the fiber to enable irradiance measurements to be conducted.

The movements to show the changes between the irradiance and the radiance set up are shown in the pictures in Figure 12.

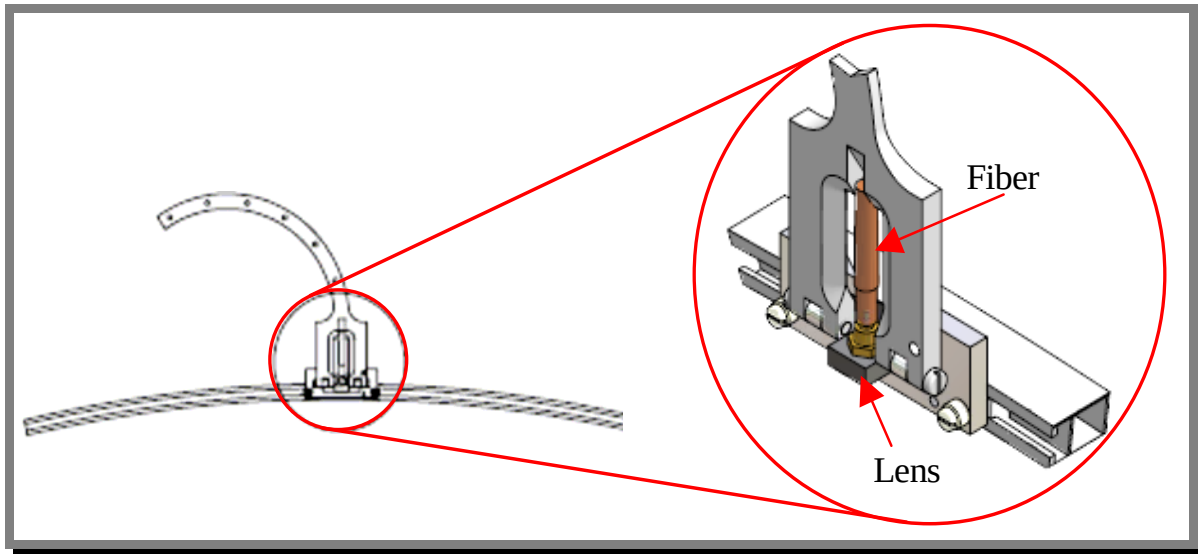


Figure 10: Camera holder in Radiance measurements set-up

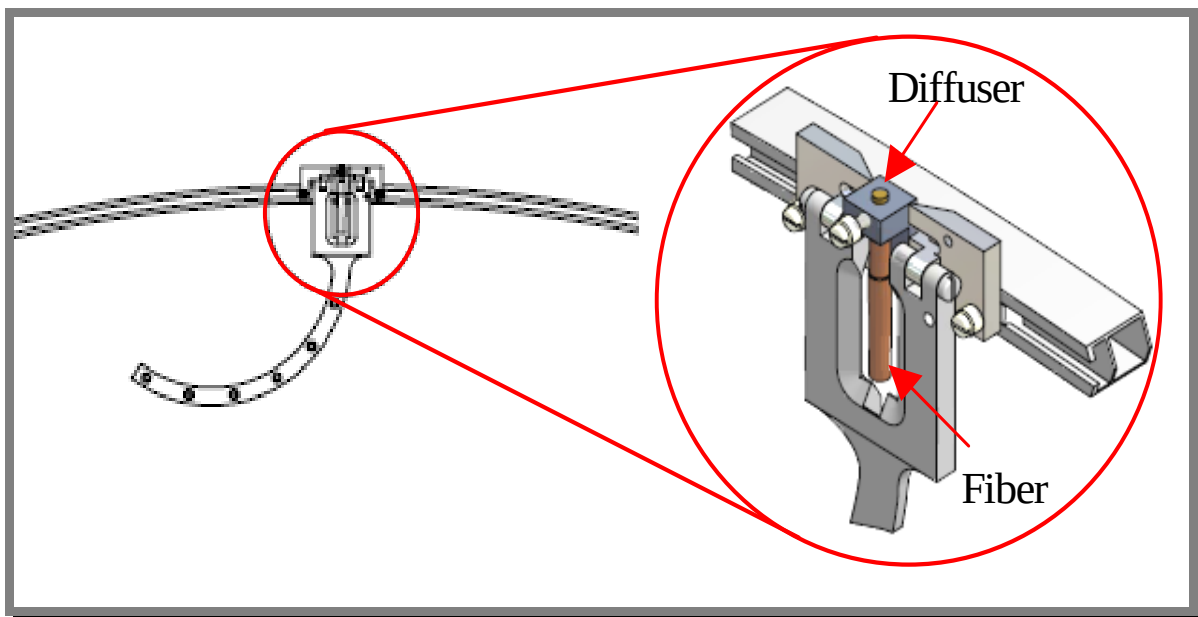


Figure 11: Camera holder in irradiance measurement set-up

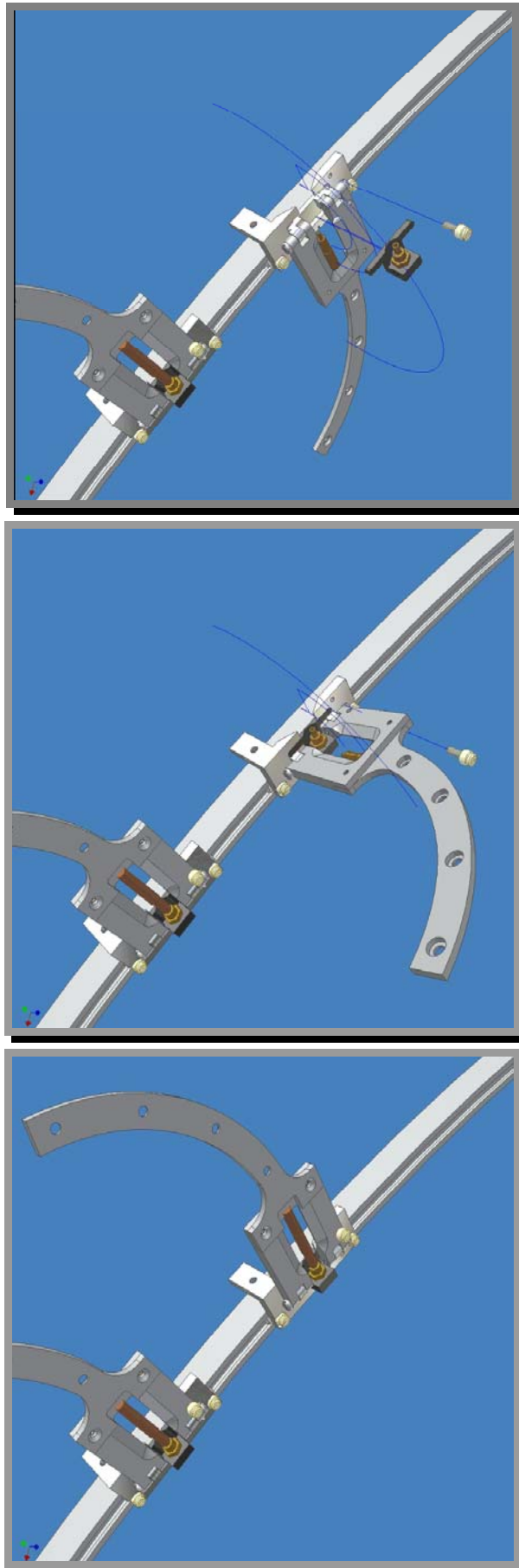


Figure 12: Movements required changing from irradiance to radiance set-up for the camera holder.

A fibre also needs to be mounted at the nadir, so that both radiance and irradiance measurements can be conducted at the nadir position as well. This means that the nadir joiner needs to incorporate a similar mechanism to the other camera holders to be able to mount the lens or the diffuser and also support the fibre in this position. The design was built into the nadir joiner and is shown in Figure 13.

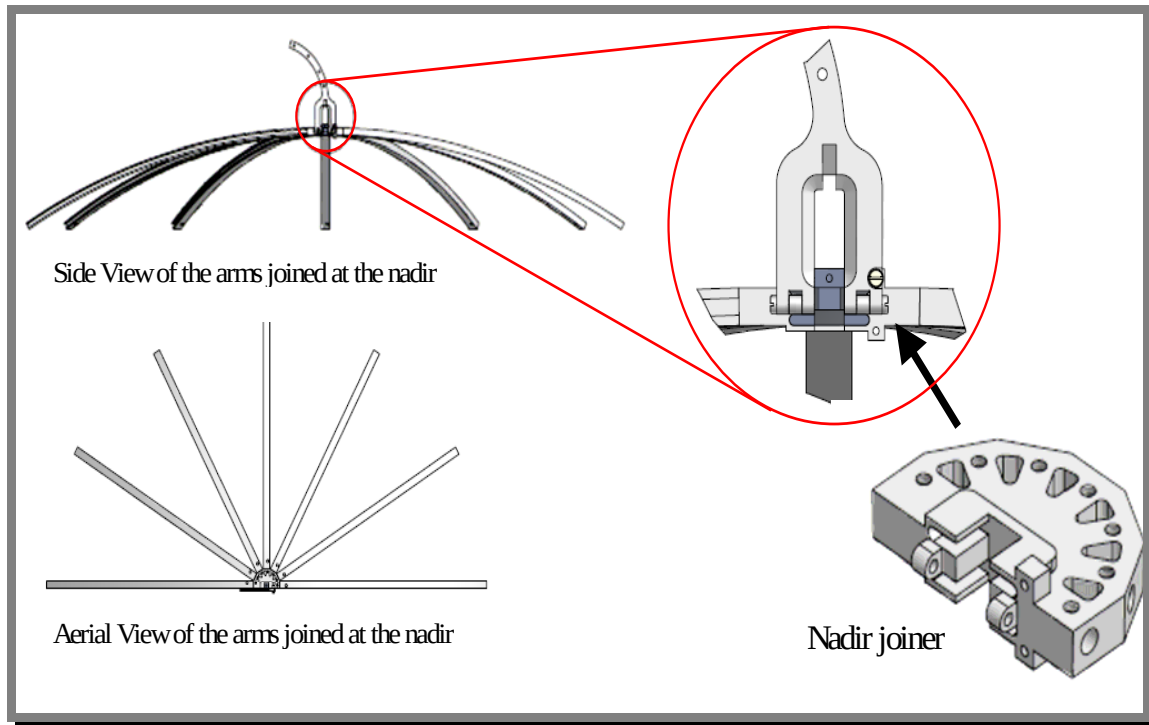


Figure 13: Nadir joiner and camera holder

To aid with the build the instrument a naming convention has been determined; this is shown in Figure 14 and detailed in Table 3.

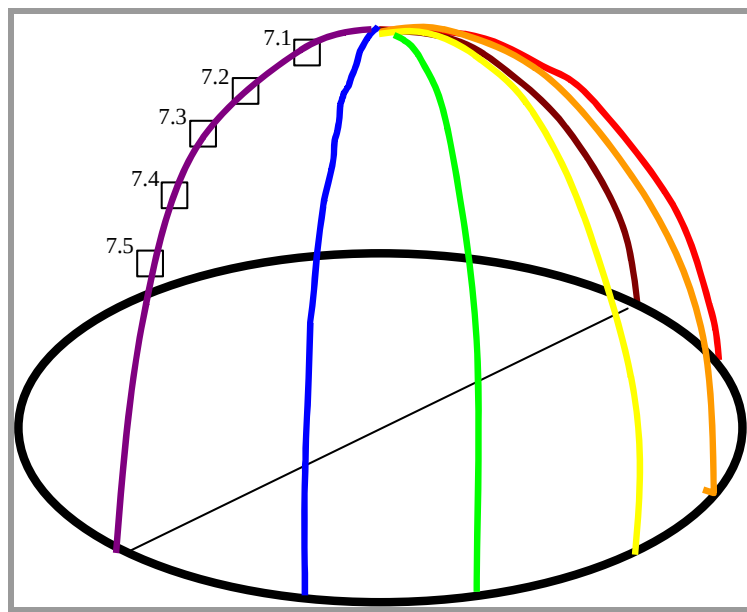


Figure 14: Naming Convention for GRASS – an example of the camera names are shown for arm 7.

Item	Label	Position
Main Multiplexer	4(16)	Yellow tag at the back
Section Multiplexers	1(16) 2(16) 3(16)	Yellow tag at the back
Arms	1 (brown) 2 (red) 3 (orange) 4 (yellow) 5 (green) 6 (blue) 7 (purple)	Arm number (colour)
Fibres	1.1 ... 1.5 (brown) 2.1 ... 2.5 (red) 3.1 ... 3.5 (orange) 4.0, 4.1 ... 4.5 (yellow) 5.1 ... 5.5 (green) 6.1 ... 6.5 (blue) 7.1 ... 7.5 (purple)	Heat shrink labels Arm number. Position number (colour)
Camera holders / Lenses / Diffusers	1.1 ... 1.5 2.1 ... 2.5 3.1 ... 3.5 4.0, 4.1 ... 4.5, 5.1 ... 5.5 6.1 ... 6.5 7.1 ... 7.5	Engravings Arm number. Position number

Table 3: Naming Convention

4 GRASS parts list

Figure 15 shows the full structure of GRASS with all the structural parts labelled. Table 4 lists all the parts with their quantity, serial numbers etc that complete the system.

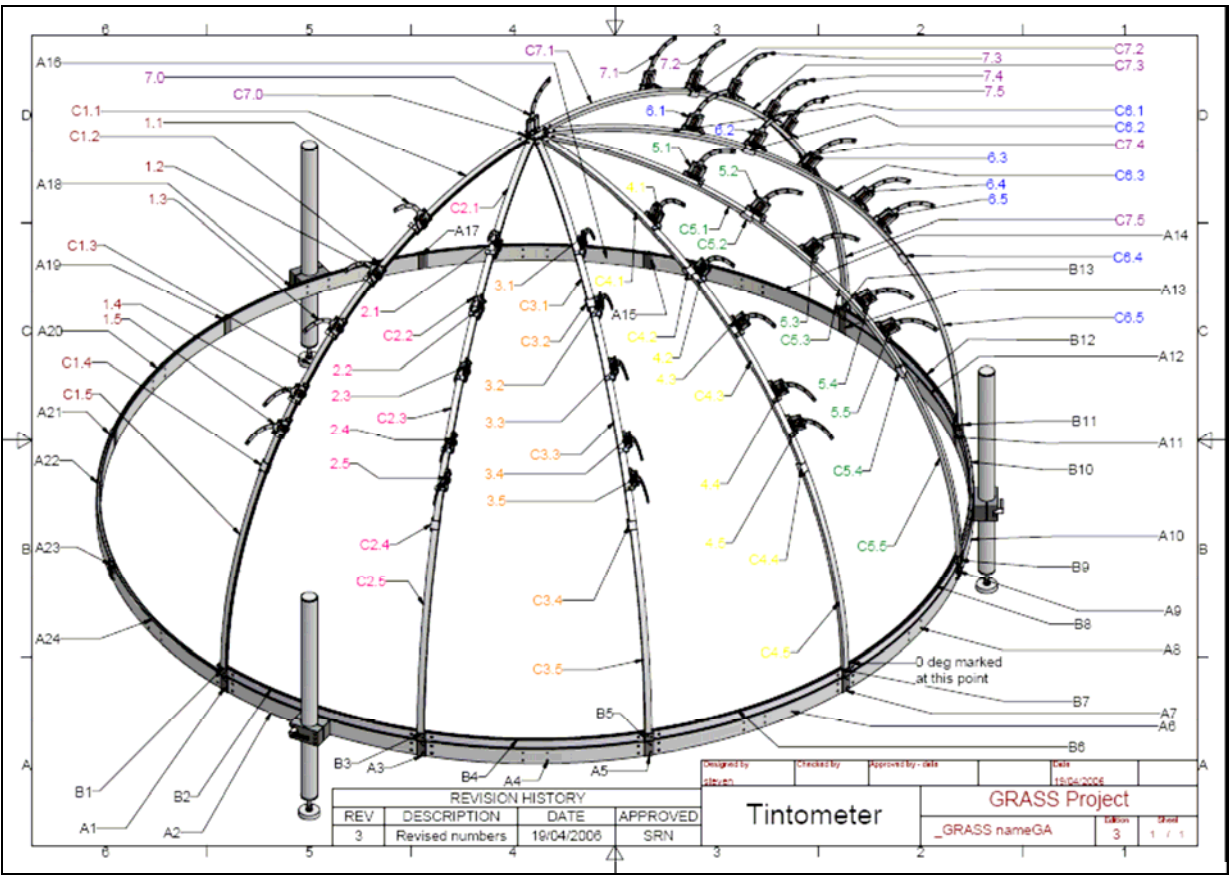


Figure 15: Diagram of GRASS with all the parts names.

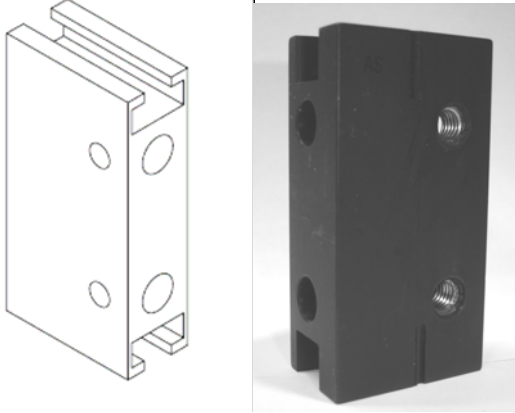
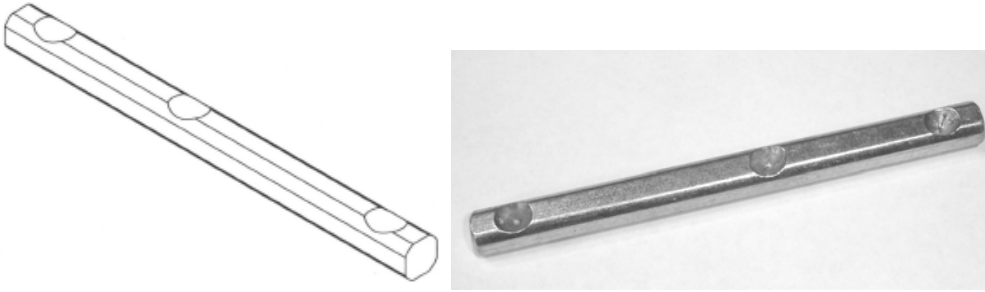
Item	Description	Serial Number	Quantity	Notes	Country of Origin	Box
1	UV/VIS Collimating Lens, 200 nm-2 microns	N/A	36	 The 74-UV has an f/2 fused silica lens for 200-2000 nm. When focused for collimation, beam divergence is 2° or less, depending on fiber diameter.	USA	NPLGRASS 1
2	Cosine Corrector with opaline glass diffusing material	N/A	36	 Our Cosine Correctors couple to optical fibers and spectrometers for relative and absolute spectral intensity measurements, for emissive colour applications, and for evaluation of light sources such as LEDs and lasers	USA	NPLGRASS 1

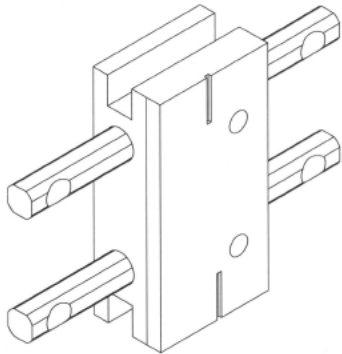
3	400µm Premium Grade. Fiber, VIS/NIR, 5 m - BX metal Sl.	As shown in Table 3	36		USA	NPLGRASS 1
4	Fiber Optic Multiplexer; 1 input to 16 output fibers, UV, 150ms switch time MPM-2000-VIS400-1x16	(Serial Numbers 039180018 039180019 039180020)	3	 Includes the unit power and signal cables.	Germany	NPLGRASS 1

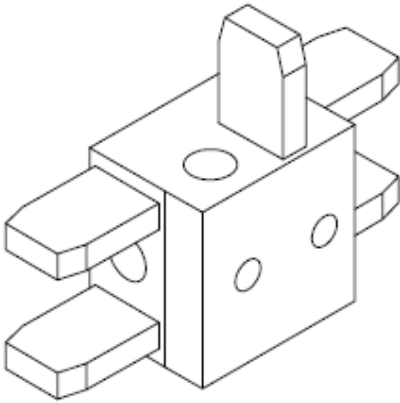
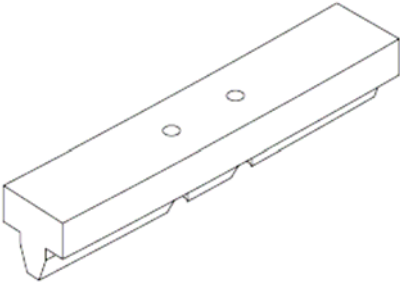
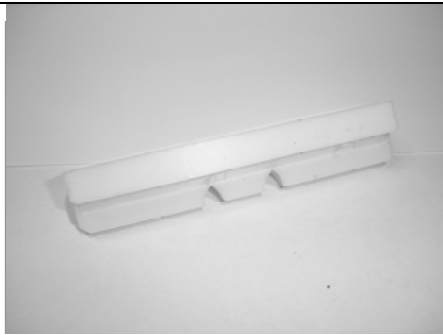
5	400µm Premium Grade. Fiber, VIS/NIR, 2 m - BX metal Sl.	N/A	4			USA	NPLGRASS 1
6	Fiber Optic Multiplexer; 2 input to 8 output fibers, MPM-2000-VIS400-2x8	(Serial Number 050460014)	1	 Includes the unit power and signal cables.		Germany	NPLGRASS 3

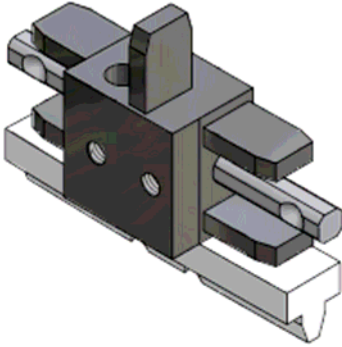
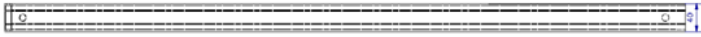
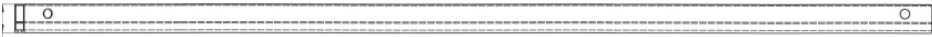
7	National Instruments 4-port USB to RS-232 converter NI ENET-232/4	(Serial Number E9A17F)	1	 The National Instruments Ethernet serial interfaces provide additional RS232 ports to your computer through standard Ethernet networks. Includes USB Cable	USA	NPLGRASS 3
8	Panasonic Laptop Computer	(Serial Number XXXXXX)	1		China	NPLGRASS 3
9	Reference Panel	(Serial number xxxxxx)	1	600 mm x 600 mm Spectralon panel, Labpshere	USA	NPLGRASS 4

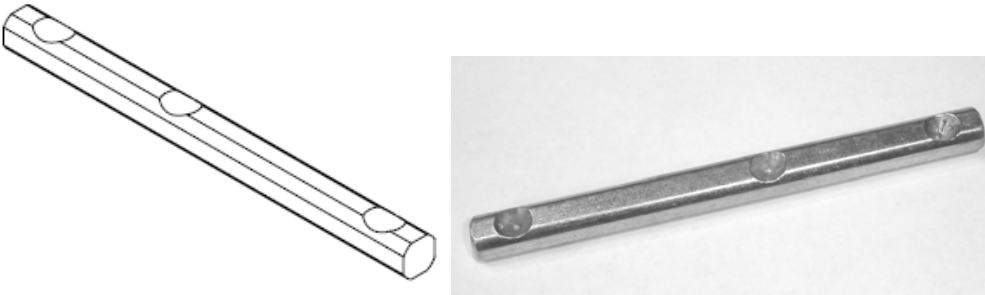
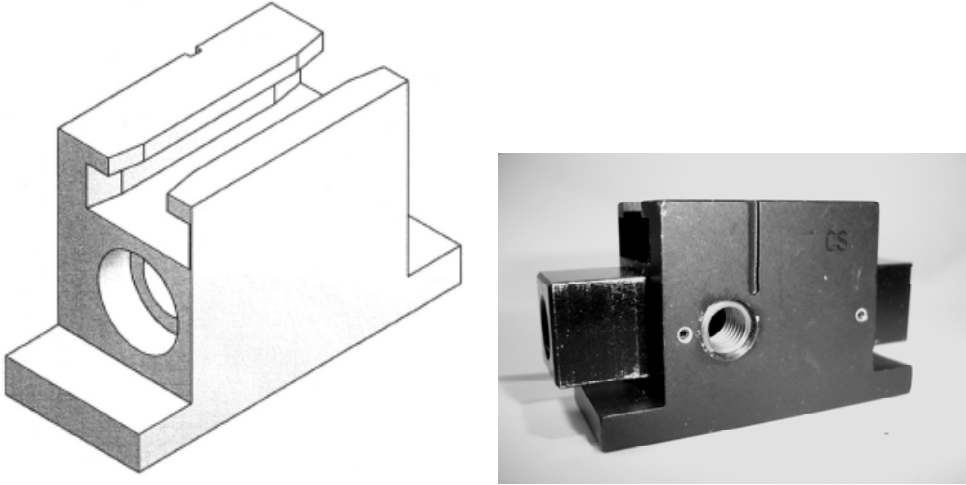
10	USB 2-Port Hub	No Serial Number	1		China	NPLGRASS 3
11	Reverse Illumination source	Serial number S/N 141578-1	1	 Visible fiber Optic fault locator (Class 2 laser) OzOptics Ltd FODL-45-635-1, Laser Class 1	Canada	NPLGRASS 3

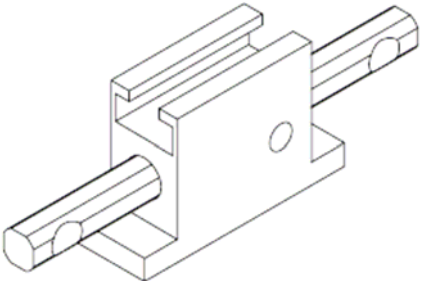
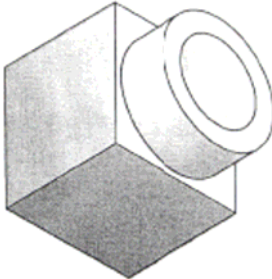
12	80mm joiner	Part numbers: A1, A3, A5, A7, A9, A11, A13, A15, A17, A19, A21, A23	13		UK	NPLGRASS 1 NPLGRASS 2
13	Joining bar	No Part Number	53		UK	NPLGRASS1 & 2

-	80mm joiner GA	N/A	13	Assembly diagram [Consisting of 1 of 80mm joiner and 2 joining bars]   Assembly joined to the 80 mm curve.		
14	80mm curve	A2, A4, A6, A8, A10, A12, A14, A16, A18, A20, A22, A24, AS	13	 	UK	NPLGRASS 1 NPLGRASS 2

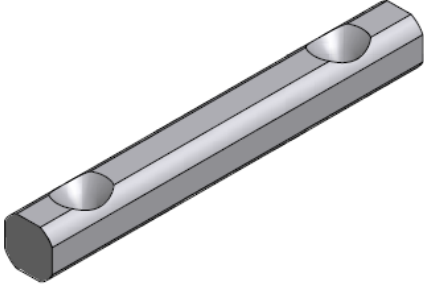
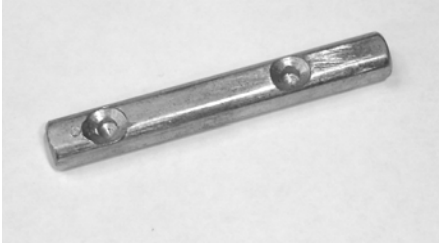
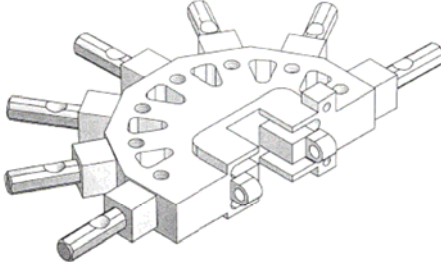
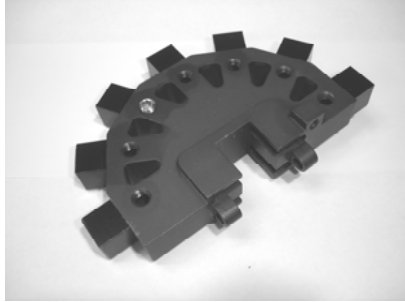
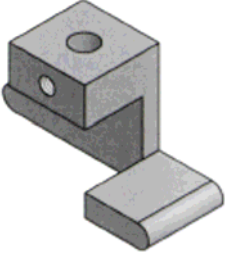
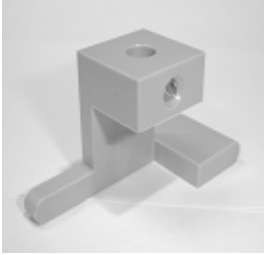
15	40mm joiner -2	B1, B3, B5, B7, B9, B11, B13	8	 	UK	NPLGRASS 2
16	40mm joiner runner-2	No Part Number	8	 	UK	NPLGRASS 2

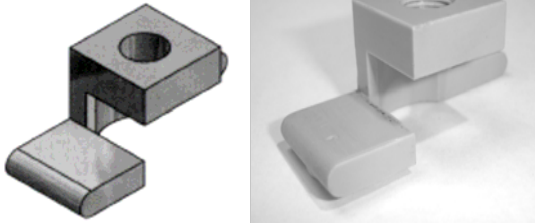
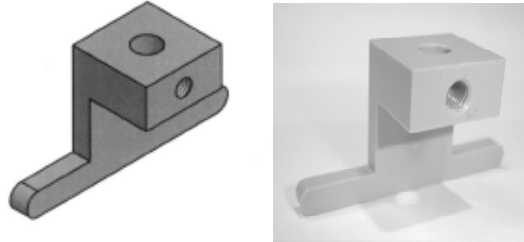
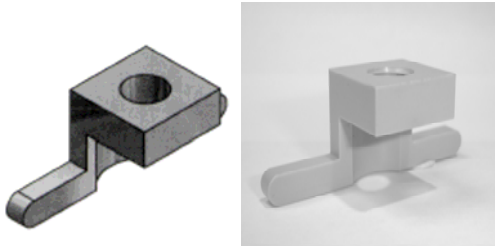
-	40mm joiner-1	N/A	8	Assembly diagram [Consisting of 1 of 40mm joiner –2, 1 of 40mm joiner runner-2 and a Joining bar]  		
17	40 curve	B2, B4, B6, B8, B10, B12, BS	7		UK	NPLGRASS 2
18	30 curve-short	C1.1, C2.1, C3.1, C4.1, C5.1, C6.1, C7.1, CS1	8		UK	NPLGRASS 2
19	30 curve	C1.3, C1.5, C2.3, C2.5, C3.3, C3.5, C4.3, C4.5, C5.3, C5.5,	15		UK	NPLGRASS 1 NPLGRASS 2

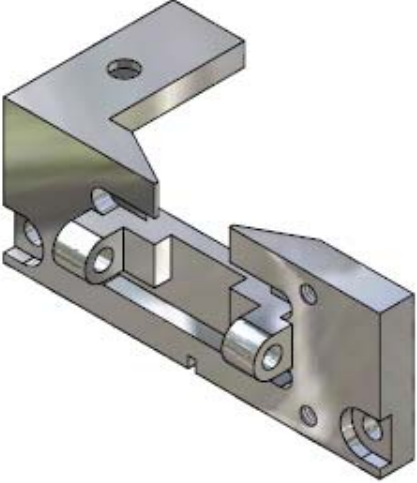
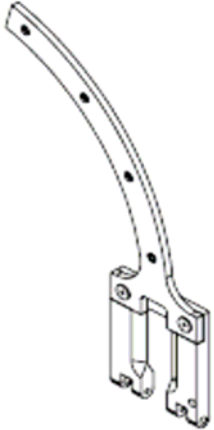
		C6.3, C6.5, C7.3, C7.5, CS3.5				
20	Joining bar	No part number	50		UK	NPLGRASS
21	30mm arm-joiner-V2	C1.2, C1.4, C2.2, C2.4, C3.2, C3.4, C4.2, C4.4, C5.2, C5.4, C6.2, C6.4, C7.2, C7.4	15		UK	NPLGRASS 1 NPLGRASS 2
	30mm joiner assembly	N/A	15	Assembly diagram [Consisting of 1 of Joining bar and 1 of 30mm arm-joiner-V2]		

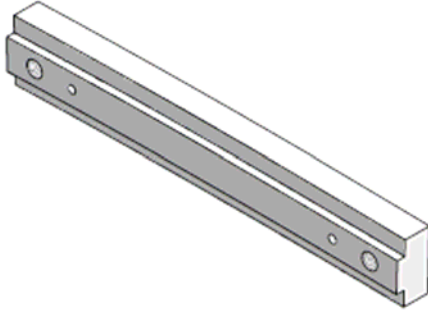
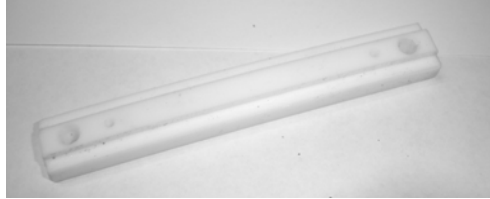
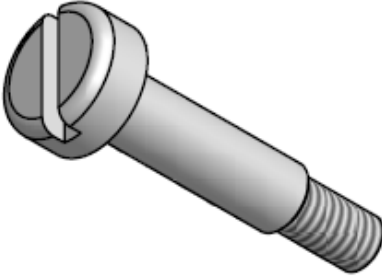
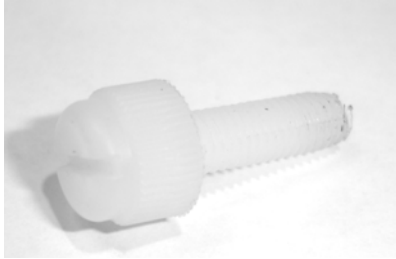
							
22	Joiner fix	No Part Number	44			UK	NPLGRASS 1 & 2

-	30mm joiner assembly Fix	N/A	15	Assembly diagram [Consisting of 1 of Joining bar, 1 of 30mm arm-joiner-V2 and 2 of Joiner Fix] Assembly attached to the 40mm curve.		
23	5 Nadir	No part number	2		UK	NPLGRASS 2

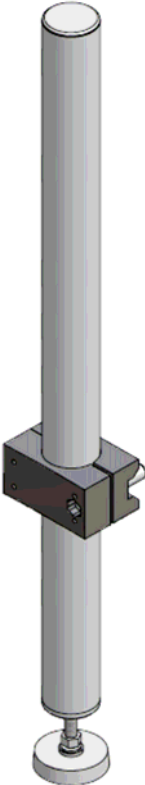
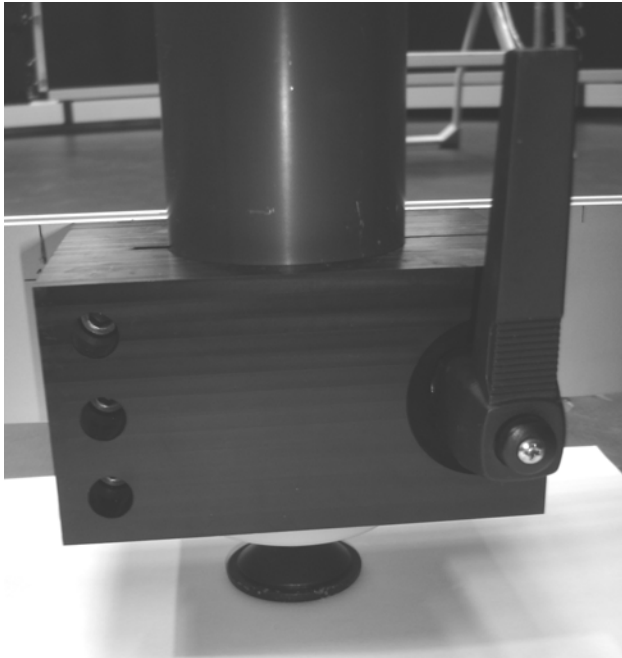
24	Nadir joiner	No part number	8	 	UK	NPLGRASS 2
-	Nadir mod GA		2	Assembly diagram [Consisting of 1 of nadir, 7 of nadir joiner and 7 of joiner fix]  		
25	5 camera cosine holder nadir	No part number	2 each	  Cosine Holder	UK	NPLGRASS 1

				 Camera Holder		
26	5 camera cosine holder	No part number	36 each	 Cosine Holder  Camera Holder	UK	NPLGRASS 1

27	5 lens holder	1.1, 1.2, 1.3, 1.4, 1.5, 2.1, 2.2, 2.3, 2.4, 2.5, 3.1, 3.2, 3.3, 3.4, 3.5, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1, 5.2, 5.3, 5.4, 5.5, 6.1, 6.2, 6.3, 6.4, 6.5, 7.1, 7.2, 7.3, 7.4, 7.5, 4.0	36		UK	NPLGRASS 1
28	5 fibre holder 2 part	No part number	36		UK	NPLGRASS 1

29	5 lens runner	No part number	36	 	UK	NPLGRASS 1
30	5-screw	No part number	74	 	UK	NPLGRASS 1

-	5 camera holder	N/A	36	Assembly diagram [Consisting of 1 of lens holder, 1 of lens holder part 2, 1 of camera holder, 1 of 400μm premium grade fiber, 1 of lens runner and 3 of screws]. A 3D CAD model showing the assembly of the camera holder. It includes a lens holder, a lens holder part 2, a camera holder, a 400μm premium grade fiber, a lens runner, and three screws. The components are shown in a exploded view, with the fiber optic cable running through the lens holder and lens holder part 2, and the camera holder mounted on the lens runner. A photograph of the assembled camera holder from the underside. The assembly is mounted on a red surface. The camera holder is black and has a lens runner attached to it. The lens holder and lens holder part 2 are visible, and the 400μm premium grade fiber is running through them. The assembly is secured with three screws. The background is a clear blue sky. Assembled view from the underside
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31	Leg Assembly	No part number	6	  Bottom of the leg assembly	UK	5 in NPLGRASS 1 1 in NPLGRASS 2
	GRASS name GA			Assembly diagram (see Figure 15)		

-	Grub screws	N/A	Numerous			Germany	All boxes
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Table 4: Parts list for GRASS (for the assembly diagrams please contact NPL).

5 Reverse illumination source

Fiber Optic Fault Locator (FODL) manufactured by Oz Optics Ltd, Canada was selected to check the pointing direction of the cameras. It has a connector suitable for the Ocean Optics optical fibre used with GRASS. If the cameras are viewing strong reflecting surfaces such as snow or desert, we recommend the user switches to chopped mode (MOD) with a frequency of 2 Hz. Pulsed light is easier to visualise. Another option is to cover the surface viewed by the cameras with a black canvas to achieve a better contrast.

It is recommended to cover the exit with the protective cap when a fibre is not connected to the FODL and insert into the protective blue bag.

Optical specifications:

Laser type: Fabry-Perot, **Class 1**
Central wavelength: 635 nm +/-10nm
Output power: 0.8-1.0 mW
Connector type: SMA 905

Power supply:

2AA Batteries

Environmental specifications

Operating temperature: -10° to 50°C
Storage temperature: -20° to 60°C
Humidity: <90%, non-condensing

Applications

1. To determine the pointing area of each camera and eventually to adjust their pointing direction
2. To detect any break of the optical fibre attached to each camera.



For more details, please refer to the manual provided by the manufacturer.

1 Building and operating GRASS

The following sections describe how the instrument should be constructed and operated.

1.1 Requirements

It takes two people to construct the structure (though a third pair of hands is useful) and it takes approximately 3 hours to set it up and start the measurements, where one hour is recommended to warm up the spectroradiometer before starting any measurements. This section describes the overall construction and the detailed elements to the build.

As an introduction the photos in Figure 1 to Figure 4, show the different elements of the construction of the instrument; detailed instructions are to follow.



Figure 1: The base ring is assembled first, and is shown mounted on the legs. The semi-circular arm mount runner segments are then constructed on top of the base ring. There are now 6 legs.



Figure 2:The next phase involved constructing the arms. Arms 1 and 7 are built first, to form an arch using the nadir joiner. Arm 4 is then added to stabilise the structure.



Figure 3:The rest of the arms are then constructed. This completes the structural aspects of the system.



Figure 4: If required the structure can be been raised on its legs so that it is about 1m off the ground.

Figure 5 shows two base-ring segments connected together with the base-ring joiner, with the arm-mount runner joiner, with its PTFE block on top.

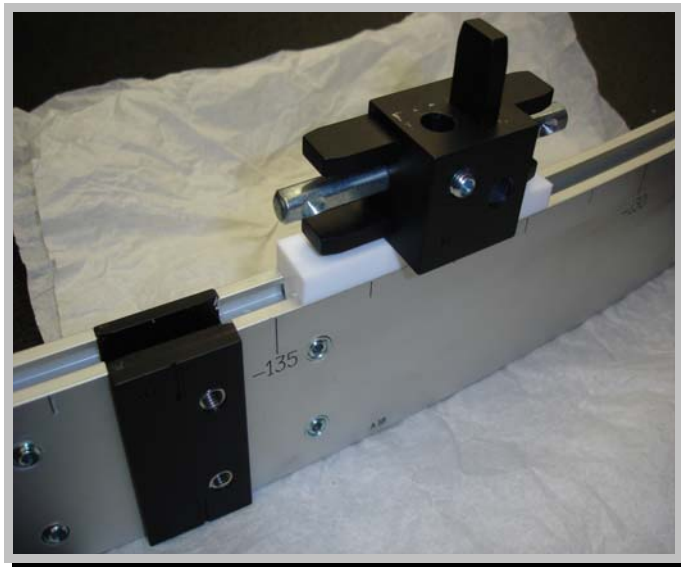


Figure 5: Photograph of the arm-mount runner joiner with the PTFE slider attached, mounted onto the base ring.

The arms were constructed as shown in Figure 6. The joiner bar goes into the arm segment joiner, and then the arm segments attached to the either end of the joiner bar. The PTFE block in Figure 6 is what the camera holder mounts onto, to allow it to move to any position along the arm.

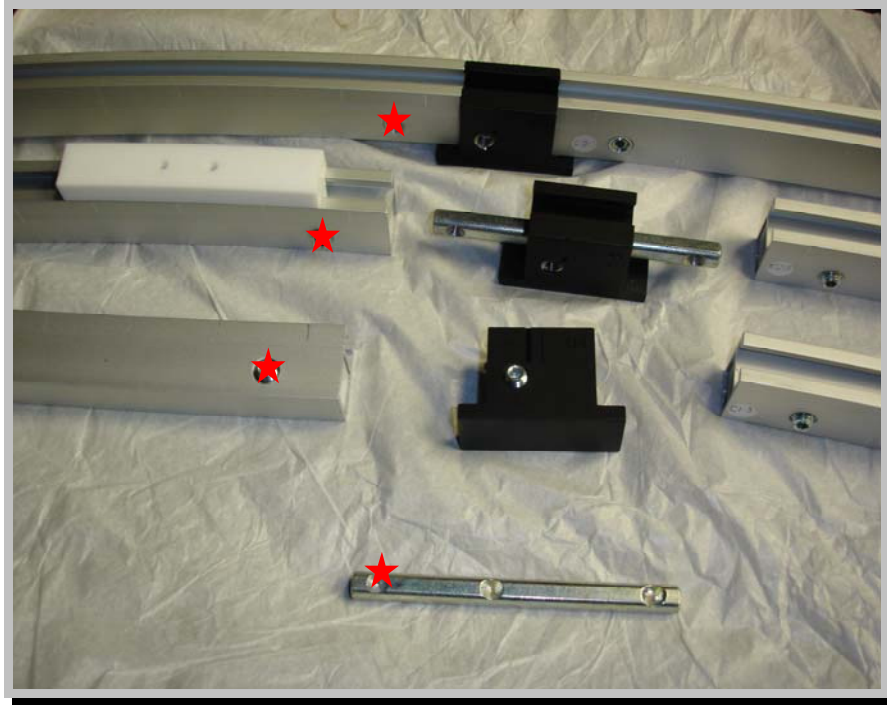


Figure 6: Photograph of construction of one of the joints in an arm.

1.2 Construction procedure

To aid the operator various parts are already assembled, and therefore when disassembling the same should be done. This makes the process quicker and less complicated. The parts have also been packed into the boxes such that the order they come out is the order in which they should be assembled (this may alternate between boxes), but they should be packed away in the same order within each box to ensure they fit within the boxes safely, and also to aid the assembly for the subsequent uses of the instrument.

DO NOT PLUG ANYTHING IN TO ANY POWER
SOURCE OR TURN ANYTHING ON UNTIL
INDICATED IN THE FOLLOWING
INSTRUCTIONS

Step 1: Base Ring

- Open boxes.



Figure 7: Packing boxes with all the GRASS parts inside

- Layout the legs in pattern on the floor so that they alternate between the small and large feet.

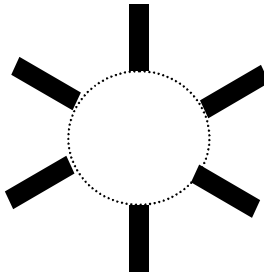


Figure 8: How the legs should be distributed on the surface before starting to build the GRASS

- Layout the base-ring sections, these should follow in order if they have been put away correctly, they are marked from -180° to $+180^\circ$. They should also alternate sections with and without the leg mount. They are also numbered from 1 to 12, so that when you are standing in the middle, they increase in number in a clockwise direction.



Figure 9: Base rings

- Firstly attach the legs to the relevant sections – they should alternate around the ring with the small and large feet.
- Then connect all the base-ring sections to form the circle. The two joiner bars should be pushed into the white square parts on the inside of the base-ring segment. Check that there are grub screws available, this need to be loose to allow the joiner bars to slide in.



Figure 10: The joiner of the base rings

Problems that might occur:

Check that there are grub screws in the joints you are about to make.

It is possible that the joiner bar pushes the white plastic inside across the hole.

The end of the segment should look like this, where you can see a hole.



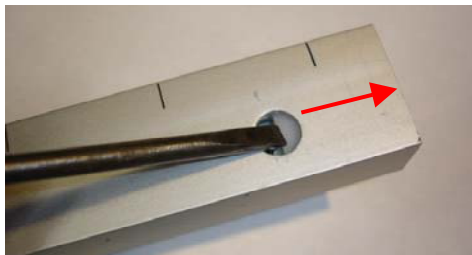
However if the white plastic inside moves it may start to cover the hole.



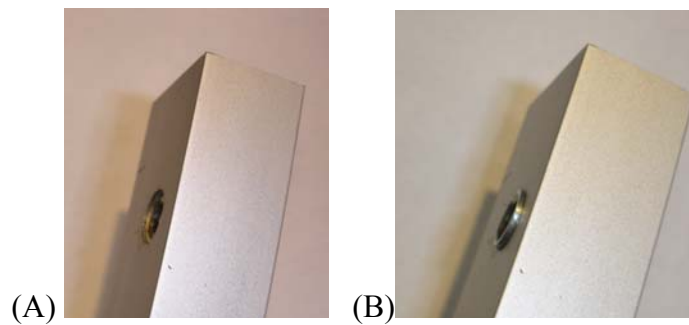
Or even fully cover the hole.



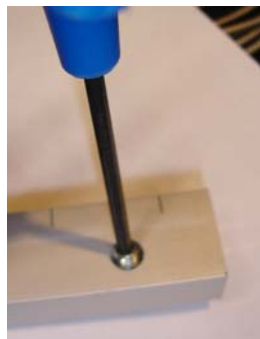
To resolve this, a screwdriver can be used to push it back. Tilt the screwdriver and push towards the end of segment, as shown by the red arrow.



It should also be checked that the silver ring from the hole, is proud of the segments surface, in picture (A) the ring is below the surface, but is proud of the surface in picture (B).



To make the ring proud, a screwdriver can be used from the inside of the segment to push it out, or with a grub screw in the hole, an Allen key can be used to pull it out by wiggling the grub screw from side to side and also pulling it outward.



Step 2: Arm mount runners

- Firstly attach the arm-mount runner joiner on the end of one the sections (look for the right numbers on the parts – they should run in sequence).
- Place the arm mount runner sections on the base-ring. Then continue to add each section until it fills half the circle.



Figure 11: The arm-mount runners are mounted on the base-ring

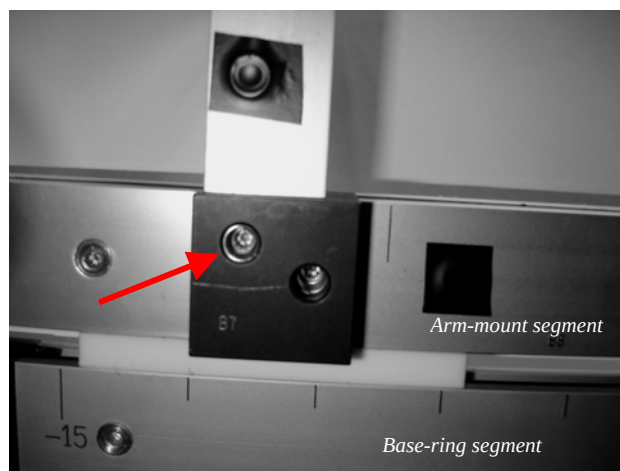
Step 3: Bottom of the arms

- Next carefully take the bottom sections of the arm runners, which the fibers are attached to and connect, to the arm mount runner joiners.
- Care should be taken not to put any fingers on any of the lenses.

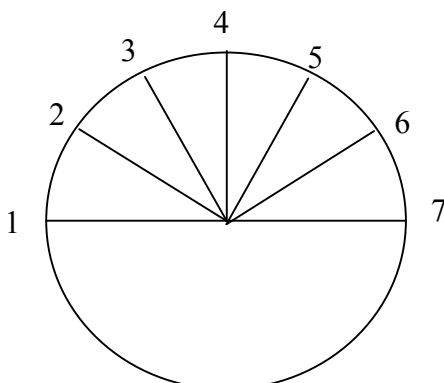


Figure 12: The Cameras and the Optical fibers are on the bottom sections of the arm runners

- The grub screw indicated by the red arrow should be tightened.



- They should be attached such that they are ordered 1 to 7 in a clockwise manner, when viewed from inside the circle.



View from above of the layout of the arms

- Once all the bottom arm runner segments are attached, they should look something like this.



Figure 13: The bottom arm runner are attached to the base-ring

- NOTE: If assembling in a laboratory or a confined space, care should be taken to check that there is adequate space to accommodate the camera holders sticking out from each of the arm locations.
- The fibers should be in boxes that need to be opened and the fibers laid out on the floor



Figure 14: The optical fibers should be kept in the protection box before coupling them to multiplexers

Step 4: Top of the arms

- The next layer in the box should be the rest of the arm segments.



Figure 15: The upper segment of the arms

- Firstly find the sections for arms 1 and 7. Attach the middle arm sections.
- Then find the nadir joiner, attach the top arm section to the nadir joiner. This forms the top of the arch.
- With two people at either end of the top piece of the arch, hold in place and attach to the arms sections already there. This will complete the arch between arms 1 and 7.
- Then complete the rest of the arms, attaching the middle sections first and then the top sections (which attach to the nadir joiner).



Figure 16: The GRASS structure is built

- This then completes the structure.

Step 5: Fiber alignment

- The next part involves sliding all the cameras up the arms to the positions that are required.
- For the irradiance set-up the cosine diffuser should be attached and positioned looking outward.



- For the reflectance set-up the lens should be attached and looking towards the centre of the hemisphere.



- To align to a particular angle there are markers on the arm runner segments, which indicate the zenith angle. The notch on the underside of the camera holder should be aligned with the marker on the arm runner segment. The example in Figure 17 is set to 36° .

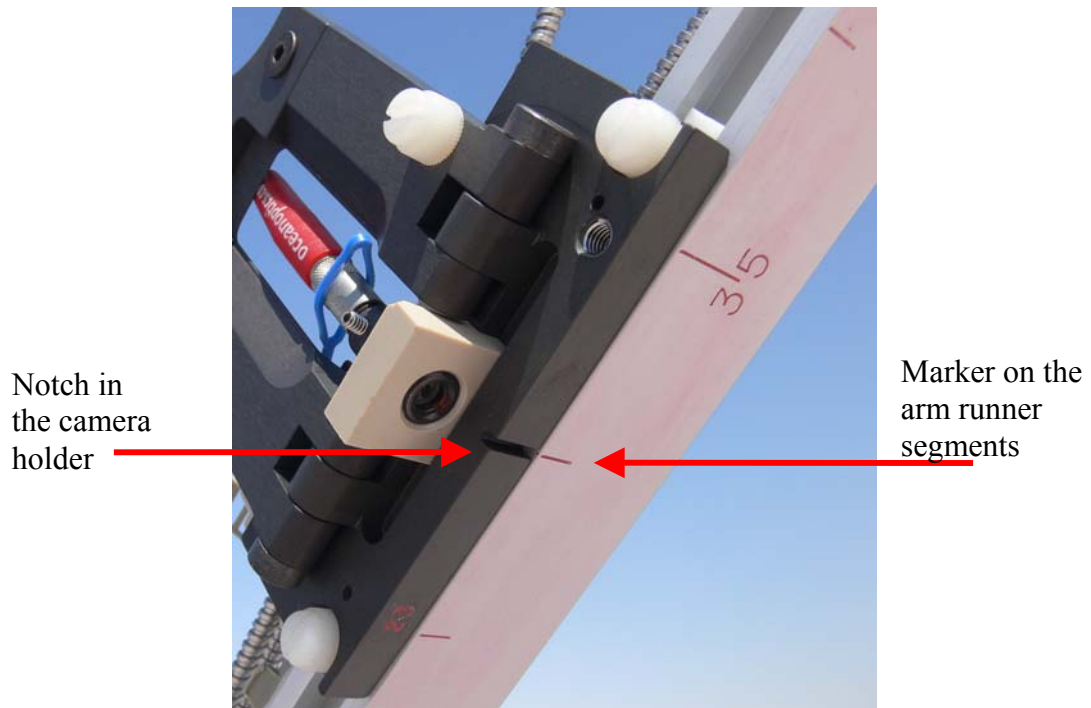


Figure 17: Setting the cameras at a 36degrees viewing angle.

- Make sure the PTFE screws are tightly in place.
- Once all the cameras on each arm are positioned at the required angles, the fibers should be clipped into the fasteners to stop them moving around.
- Care should also be taken to make sure that the bends in the fibers are not too tight!

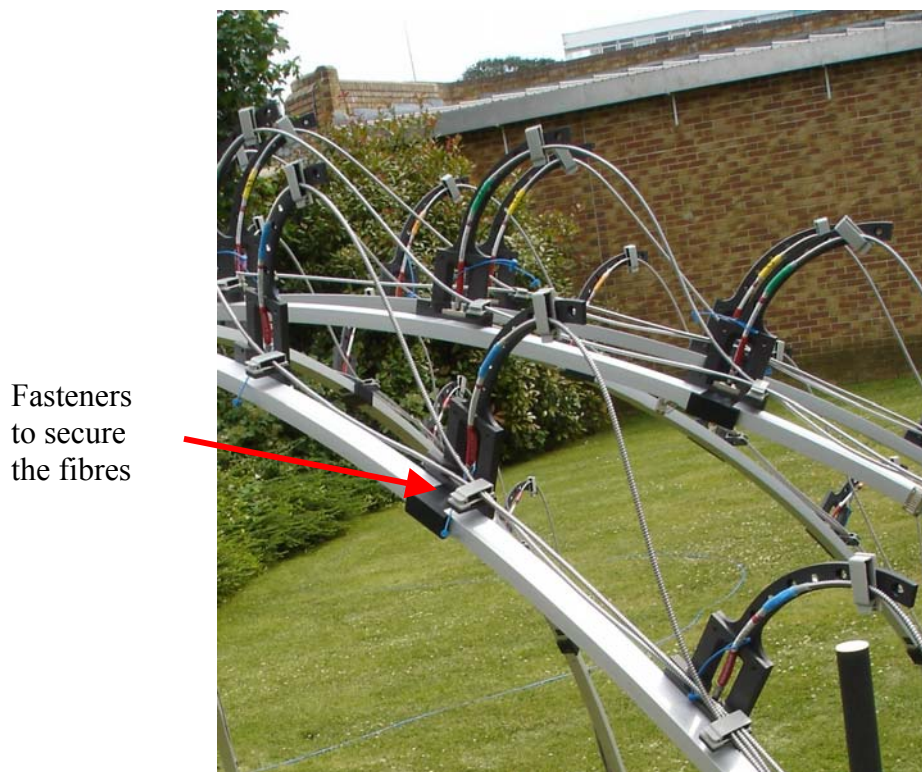




Figure 18: The optical fibres should be fastened to the structure to avoid any bends that could damage them

Step 6: Multiplexers

- The base plates for the multiplexers should be attached to the arm-mount runner sections as per Figure 20.
- They should be placed at the bottom of arms 3, 4 and 5 respectively. They must be located as shown in the picture below so that all the fibres and leads will reach.
- The multiplexers should then be placed on these base plates, with the backs of them facing arm 4. They should be labelled as to where they should be positioned.

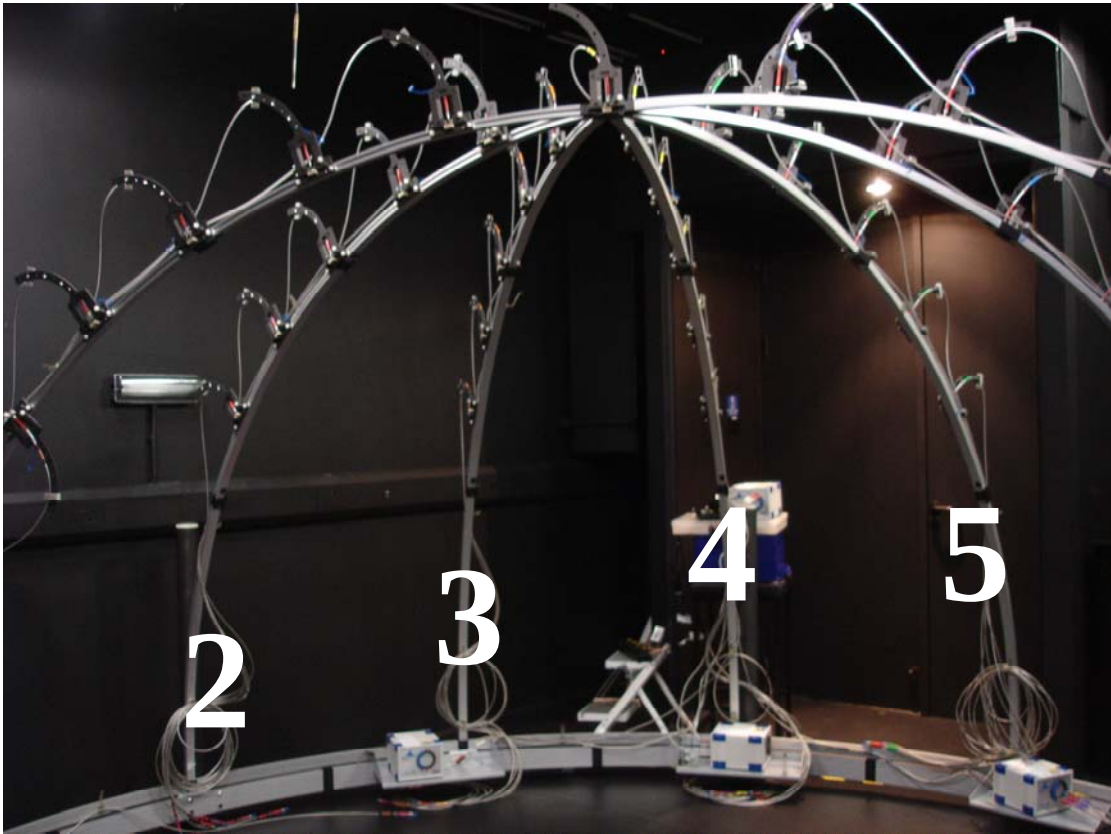


Figure 19: The optical fibre are connected to multiplexers which are placed on the base plates

- These then need the power and signal cables to be connected. This now requires the upright box to be opened.
 - The clips should be undone and the front panel removed.
 - Lift the lid.
 - At the back of the top section there is a black board (that covers the hole in the back) this should be removed and stored somewhere for safe keeping;
- There should be a bundle of cables on the right hand side. These wires should be unwound, and the ends put through the hole in the back.
- The black electrical wires can be attached to the multiplexers in any order (though their length should dictate this), but the white serial cables must be connected in the right order. These are all colour coded, the cable marker should match the sticker on the back of each of the multiplexers. The serial cables require the small flat head screwdriver to secure them.

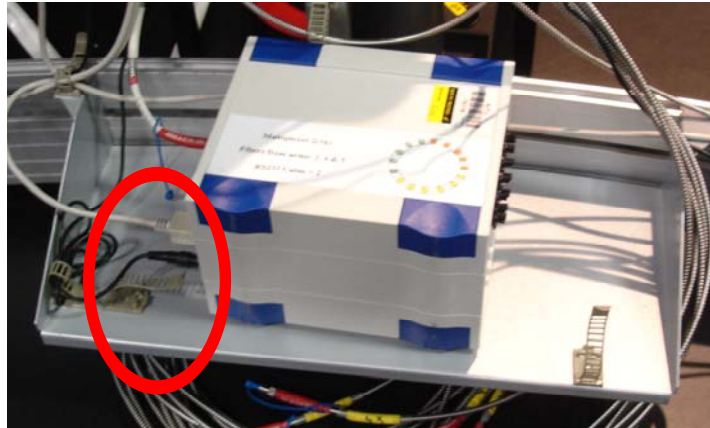


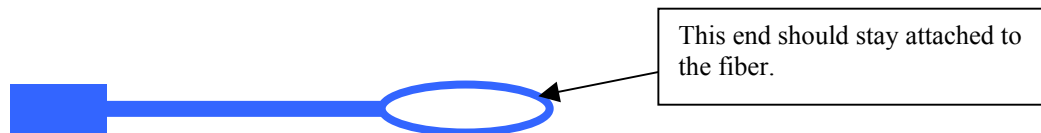
Figure 20: The base plates for the multiplexers should be attached to the arm-mount

The fibers and electrical cable should be attached to the outside of arm 4 – such that they will go over the top of the legs when the structure is rotated.



Step 7: Fiber connections

- All the fibers should then be attached.
- They should follow the plan on the multiplexer (they are colour coded – see Appendix A).
- All the blue caps should be collected into one of the trays from the toolbox. Preferably the caps should only be removed just before a fiber is inserted so to avoid any chance of material getting into the multiplexer. When all the fibers are installed, the tray of the caps should be stored carefully in the tool tray for use when packing away.
- On the fibers themselves, there should be a plastic blue cap. These should stay attached to the fiber via the use of the ring on the opposite end to the cap.



- The fibers from each arm should run down their respective arm, and then coiled up at the bottom. However it should be checked that the ends that are to be connected to the multiplexers can reach. This is sometimes easier to do one fiber at a time. Connect the end to the relevant position on the multiplexer and then feed the fiber back along the arm-mount runners and secure at the bottom of the arm, using the cable ties attached to the structure.

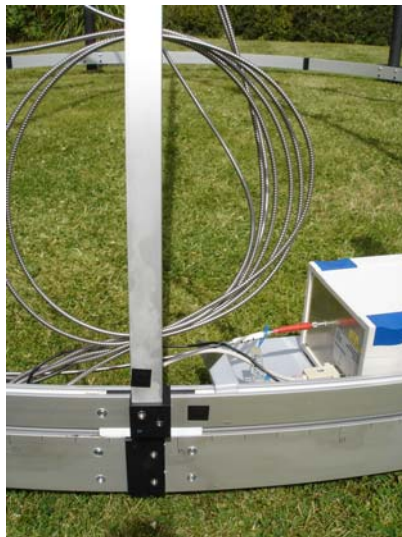


Figure 21: The optical fiber should be clear of the floor in order to rotate the system.

NOTE: Please note that the fibers should be clear of the floor so that the system can be rotated. The fibers should also only be secured to the upper ring as the base ring is fixed.

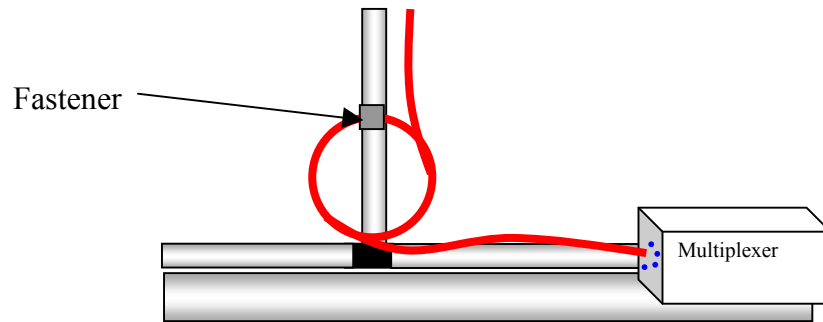


Figure 22: Schematic of how the fiber should be wound up and secured at the bottom of the arm.

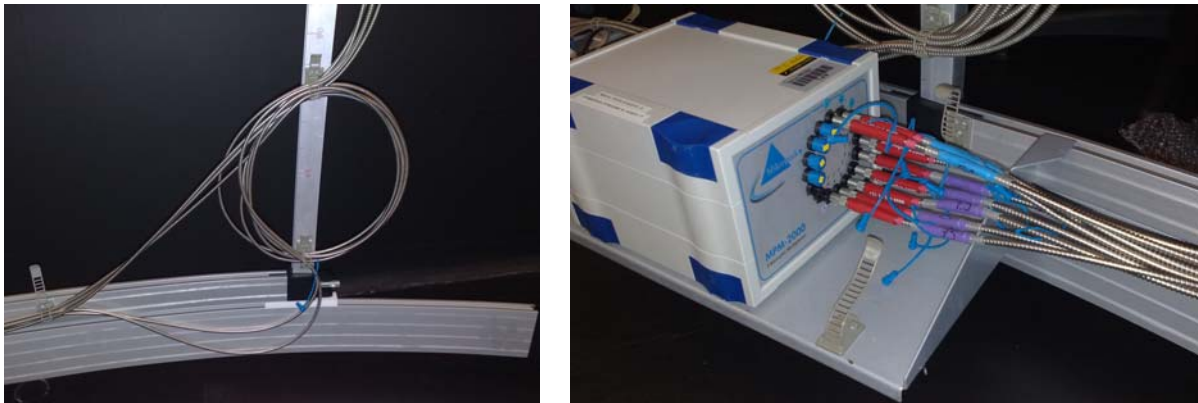


Figure 23: Left - Photograph of the fibers wound up at the bottom of the arm. Right - photograph of the fibers plugged into the multiplexer.

- There should also be three fibers (short ones that have white heat shrink on), these are labelled and should be connected to the back of the multiplexers in the correct order. They are labelled [1→4, 2→4, and 3→4], the first number relates to the multiplexers on the structure (which are numbered 1,2,3). The second number is the 4th multiplexer, which is in the upright box.
- The front of the 4th multiplexer in the upright box faces the bristles. There are three of the blue caps that should be removed, which are labelled 1,2, and 3. They can be easily accessed with the lid open.
- Once the three fibers are attached to the multiplexer in the upright box, the other ends should be attached to the multiplexers on the structure following the numbering. The multiplexers are numbered 1, 2 and 3.

Step 8: Electrical connection

- The next steps require all the electrical and computer connections to be made – but care must be taken through this process that they are turned on in the correct order otherwise there can be irreversible damage caused to the ASD hardware.

DO NOT TURN ANYTHING ON

**THIS MUST BE DONE IN THE
CORRECT ORDER**

Step 9: ASD connection

- The electrical connections should be checked within the box.

The Serial cable to USB connector should have 4 serial cables in the back and one USB Connector.

The multiplexer should have a serial cable and a power cable connected in the back at the bottom.

The four small black units, which are labelled 'MUX P/S', should all have connectors in the back.

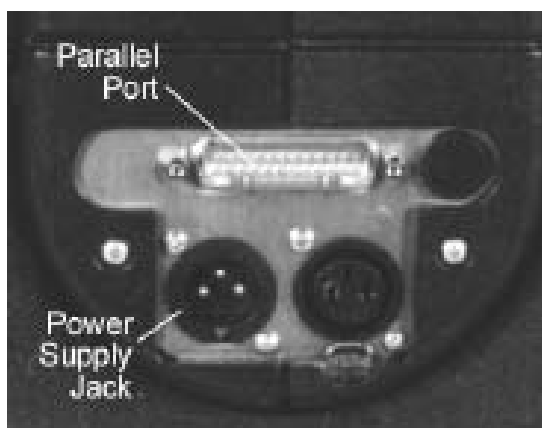


The distribution board on the left should have the laptop power supply plugged into it.

The power supply for the ASD should also be plugged into the distribution board and the power supply unit should sit on the shelf.

The distribution board on the right hand side should have 4 plugs in it, which are all labelled 'MUX P/S'

- Nothing should be connected to any power supply yet.**
- The ASD Field Spec Pro should have all its connections made as follow:
- The back of the ASD looks like this.



- This plug is the power supply jack.
- It should be carefully aligned and pushed in.



NOTE: If you are used to the normal ASD connections – please be aware this where it differs. To enable the GRASS operating software to work in connection with the ASD Field Spec Pro, an Ethernet adapter is required.

- The Ethernet adapter gets its power from the ASD; the cables should be connected as shown in this diagram below. [These should be set up in the box prior to transportation, but these connections should be checked].

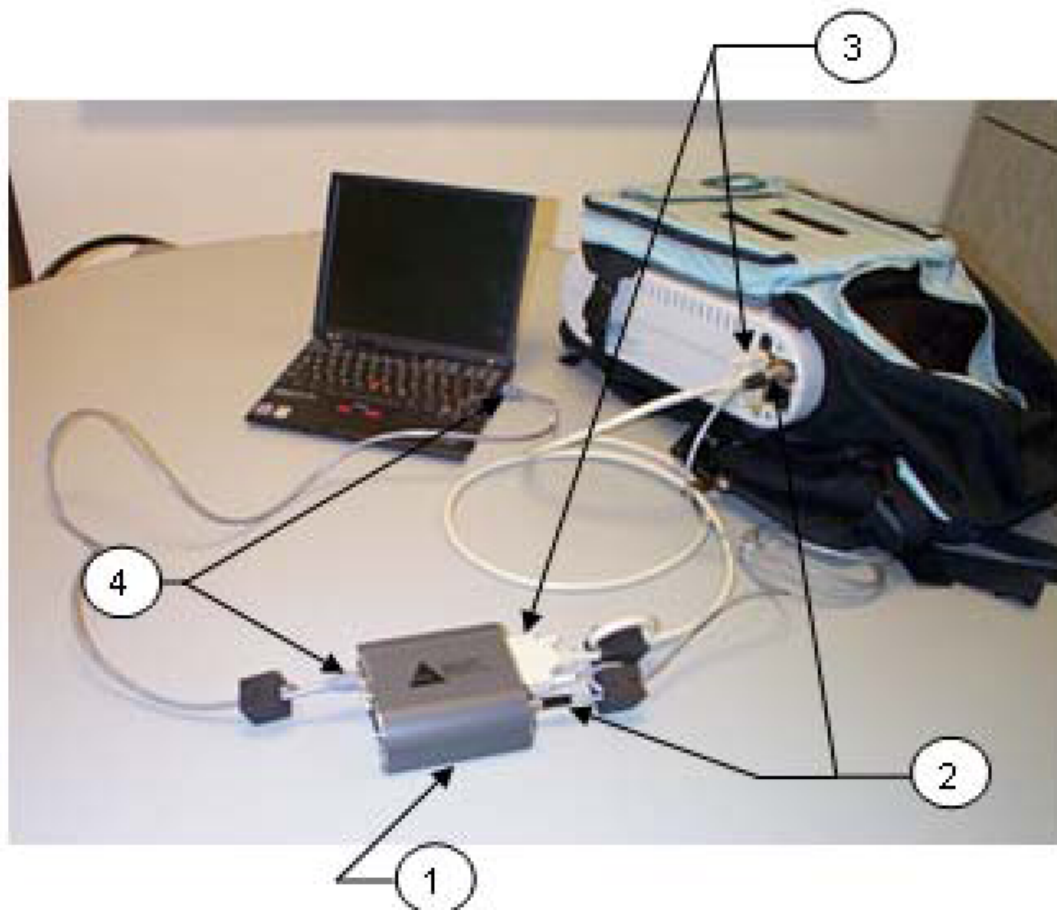


Figure 24: Connections order for the ASD radiometer, when the old version is used

1. Smart Ethernet adapter
2. Grey power cable
3. White parallel cable
4. Grey cross over cable.

- The optical fiber from the ASD should be put in place carefully. It should be unwound carefully from the ASD compartment.
- The end of the fiber should be slid into the back of the multiplexer that is in the top of the upright box. It should be secured in place with cable ties.
- The black power cable for the laptop, the USB cable and the grey cross over cable should go out through the hole in the back of the upright box.
- The lid should be shut now, and the laptop positioned on the top. The power cable, USB cable and the grey cross over cable should be connected to the laptop (**BUT DO NOT** switch it on).
- The GPS USB cable should be connected to the laptop
- An optical mixer manufactured by ASD will be used to improve the connection between the ASD optical fiber and the GRASS optical fibers. (The two optical fibers have different core diameters.)

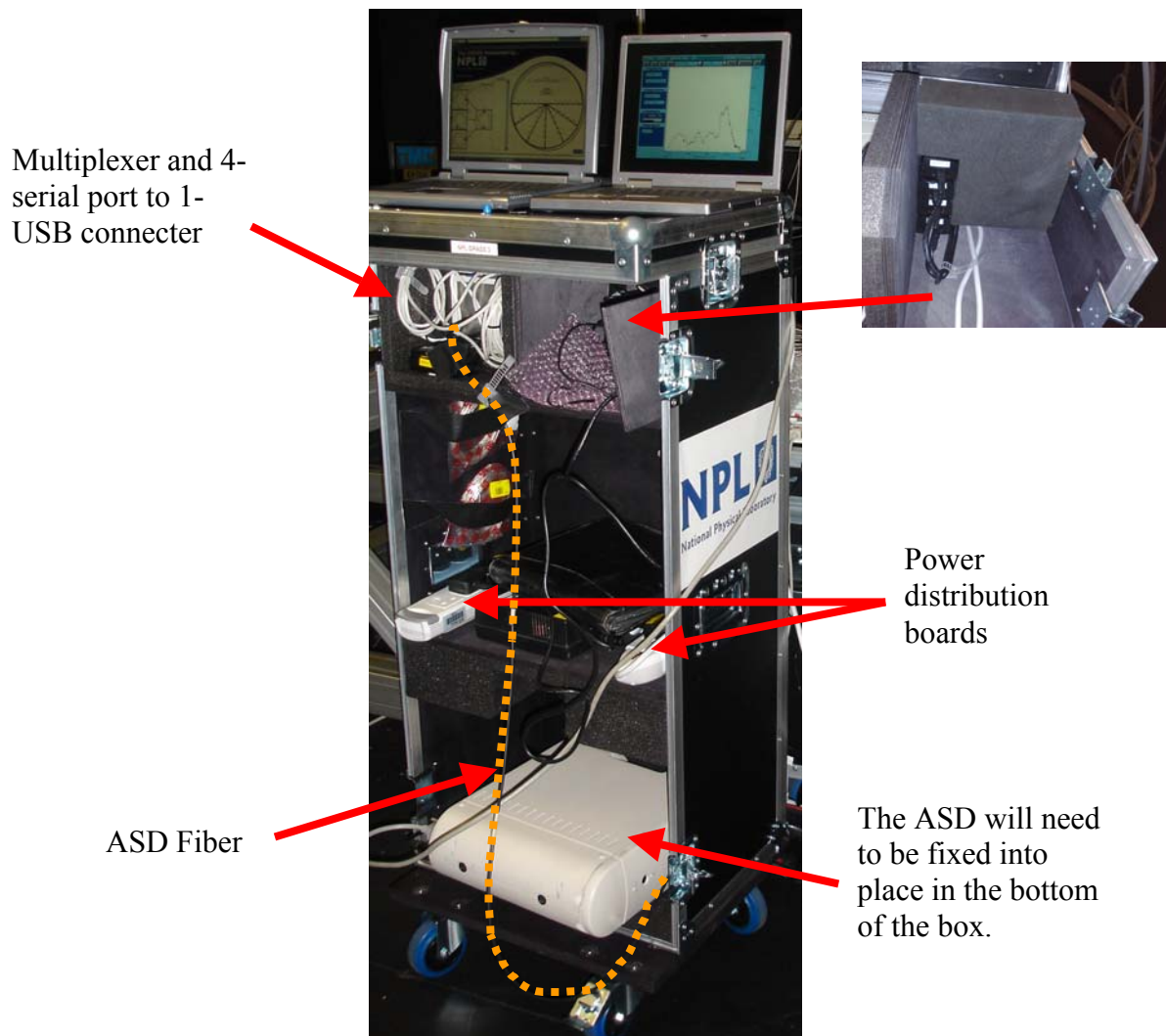


Figure 25: View over the final positions of all items: radiometer, laptop, multiplexers and power distributions boards

Step 10: V-SWIR connection

The NERC V-SWIR instrument is connected to the GRASS laptop with a USB cable. The instrument driver is available from NERC. The USB driver creates a virtual COM port for connection to the spectrometer.

More information about V-SWIR can be provided by NERC, University of Edinburgh.

1.3 Operating software and Data acquisition

The software has been written to run the GRASS optical components with the ASD and the NERC V-SWIR field spectrometers. If using an ASD instrument the software relies on having the ASD RS3 software installed initially. There are 3 versions of the GRASS operating software:

1. GRASS2 ASD... GRASS with ASD spectrometer and full multiplexer suit (4 units)
2. GRASS2 NERC VSWIR... GRASS with the NERC V-SWIR instrument and full multiplexer suit (4 units)
3. 1Mux GRASS2 NERC VSWIR... GRASS with the NERC V-SWIR instrument and 1 multiplexer

1. GRASS2 ASD

Initial Installation For ASD Only

For each ASD FieldSpec Pro, the software for that particular ASD must be installed on the GRASS laptop. This is to ensure that the software is the current up-to-date version for use with the instrument. This process will only need to be completed when it is a new ASD spectrometer that is being used with the GRASS optics. Once installed, and the software checks are complete this phase can be skipped.

- Switching on the GRASS laptop starts the installation process; this should not be connected to the ASD.
- Insert the USB pen from the ASD. This pen drive will contain the operating software for the ASD.
- Open the USB folder - there should be a file called 'FieldSpec 3 Software Install'.
- Open this folder

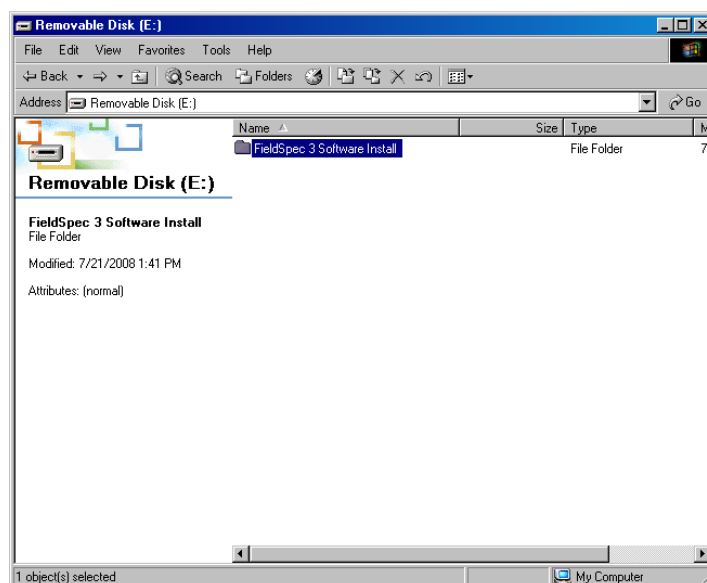
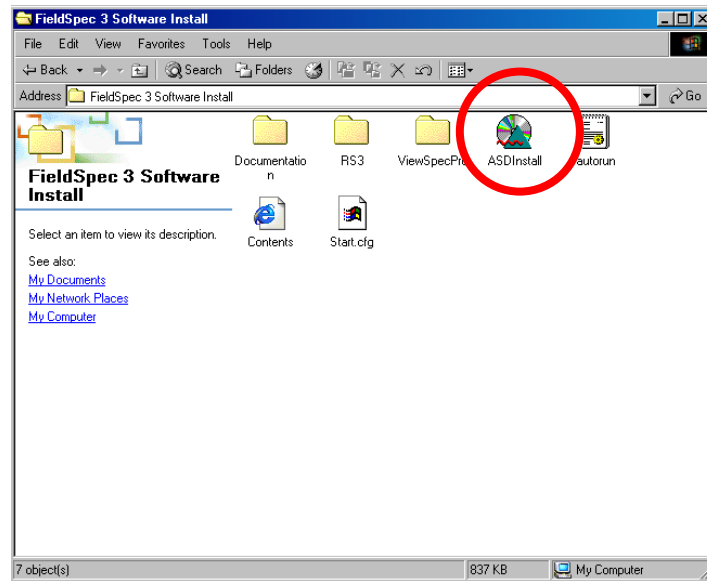
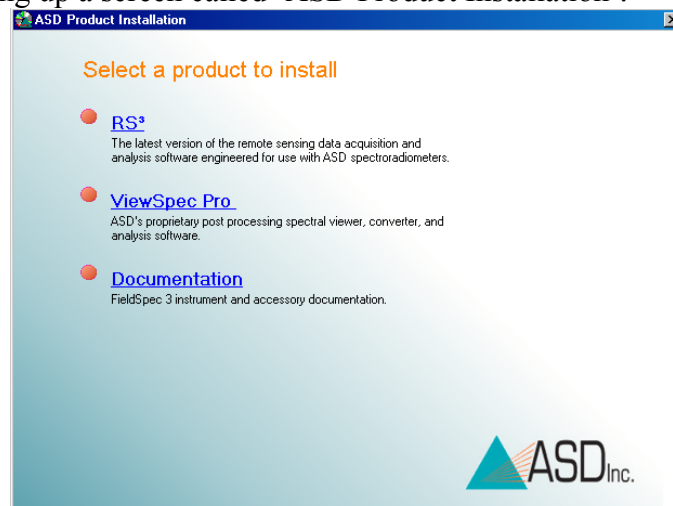


Figure 26: Folder with the ASD software to install

- In that folder there should be an icon called 'ASD Install'. Click on this icon.



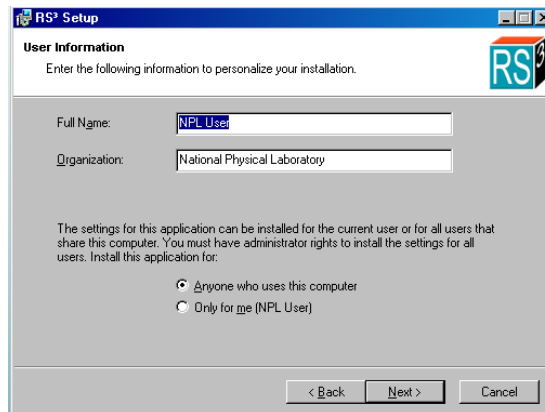
- This will bring up a screen called 'ASD Product Installation'.



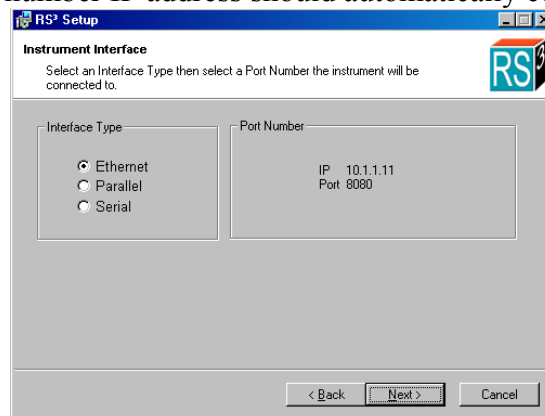
- There are 3 pieces of software to be installed; these include the RS3, ViewSpec Pro and the Documentation.
- If you click on the RS3 first – this will start an installation wizard.
 - Please note: it may take 20-30 seconds for the installation to start – so be patient.
 - Also it may say that the RS3 is already installed, and that you are required to uninstall the current software to enable the new one to be installed. Say 'yes' to uninstalling the old version, and follow commands to uninstall and restart the computer. Once the computer is on again, follow the first few steps above and click on RS3 link on the ASD Product Installation screen. This will then bring up the following wizard.
- Close any other programs and click next.



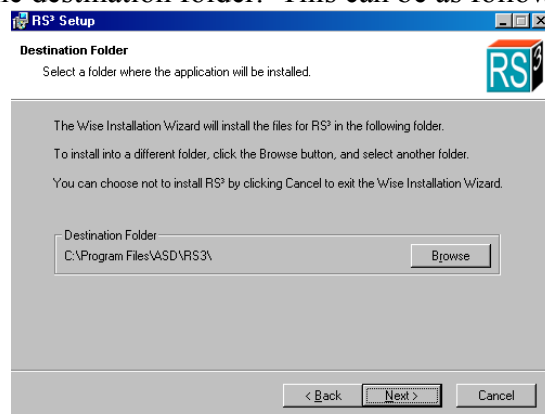
- It will ask for user information – this can be as follows – then click next.



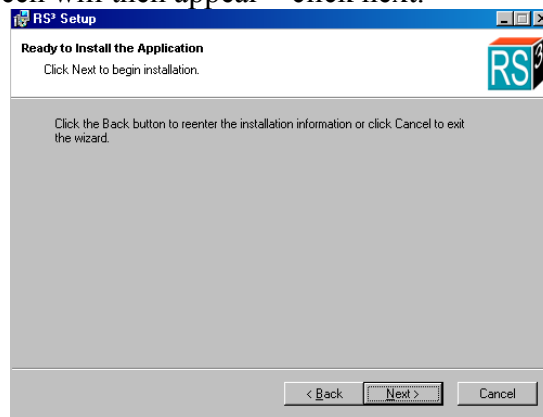
- It will then ask you about an Instrument Interface. The Ethernet option should be chosen. The port number IP address should automatically come up as follows.



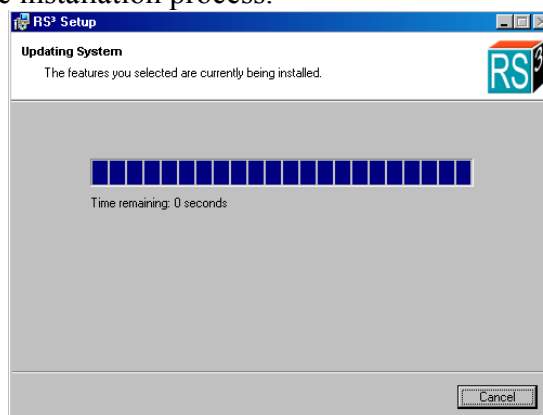
- The next step is the destination folder. This can be as follows



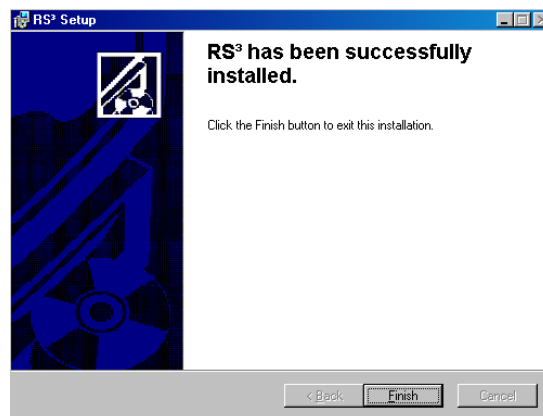
- The following screen will then appear – click next.



- It will then run the installation process.



- It will then tell you when the RS3 has been installed, where you can then click on finish.



- Once back at the ASD product installation screen, the other two pieces of software can be installed. This will follow a similar process to the installation of the RS3 software.



- Once all the software has been installed the following icons should appear on the desktop.



- The laptop must now be switched off.

1.3.1 Turning on sequence

- Once the laptop is switched off, the various connections between the ASD and the laptop and the GRASS instrument can be made
- The next phase is turning everything on this must be done in the correct order.
- Firstly the power cable that comes out of the upright box (which will provide the power to everything) can be connected to the mains (or a generator).
- Once connected to the mains the multiplexers should all turn on. You should hear them initiate, and they should all then have a green light on the front. Also the 4-serial port to 1 USB connector (which is on top of the multiplexer in the upright box) should also have a series of green lights on.

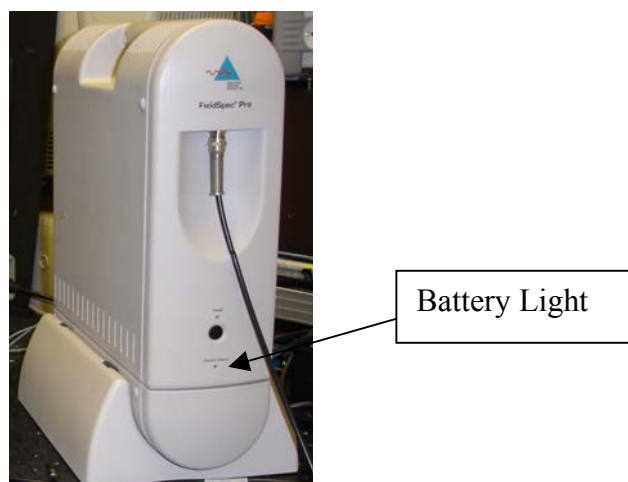
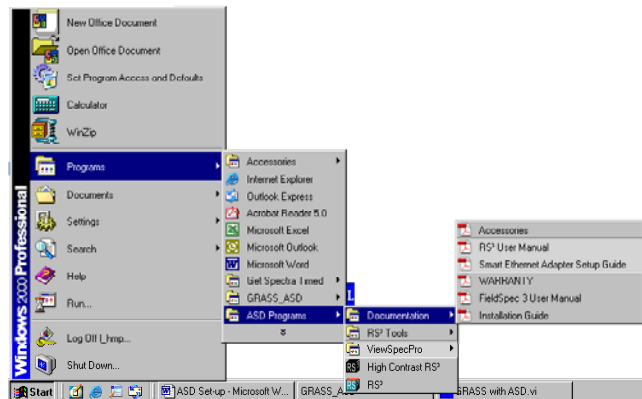


Figure 27: ASD radiometer and the light indicating that the instrument is on.

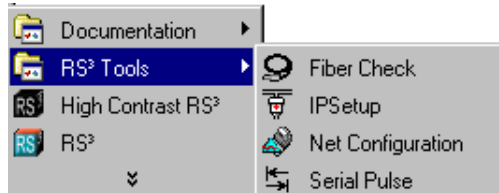
- The ASD should then be switched on first. The fans on the instrument should turn on and a green light on the front panel should also come on.
- The laptop can now be switched on.
- The ASD software can be accessed in various ways. On the desktop there should be the icons for the ViewSpecPro, and RS3 programs. Also these can be accessed from the

Start menu>programs>ASD Programs

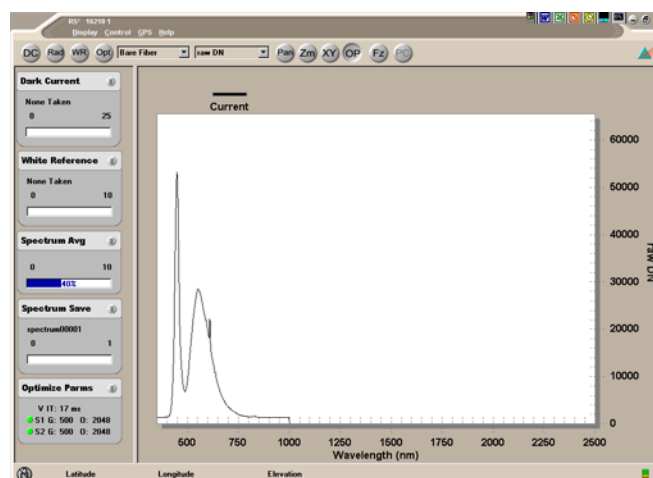
>Documentation
 >RS3 tools
 >ViewSpecPro



- Under the RS3 tools, there are options which include a Fiber Check (for new instruments), and an IPSetup option that may be required if you are experiencing any connection problems.



- To check that the ASD is working correctly, it is worth using the ASD software to check the connections. Click on the RS3 icon on the desktop, and the following screen should appear.



- In the bottom right hand corner of the screen it will check connectivity, and if successful will stay green in the corner. If there are problems with connection it should tell you, but you should then follow checks for the IP set-up.
- Once the particular instrument is set-up and working with the laptop and connections are made, it will not be necessary to check the ASD with the RS3 software every time the instrument is turned on. But it may be useful if any problems are encountered.
- Assuming the ASD software shows it is all connected and working the GRASS_ASD software can then be started.

All 3 GRASS software programmes operate in a similar manner. The following section uses the GRASS2 NERC VSWIR application as an example.

- Note: It should be checked that the USB cable from the upright box is plugged into the laptop. This should be done before the laptop is turned on.
- The following screen should appear for GRASS2 NERC V-SWIR only.

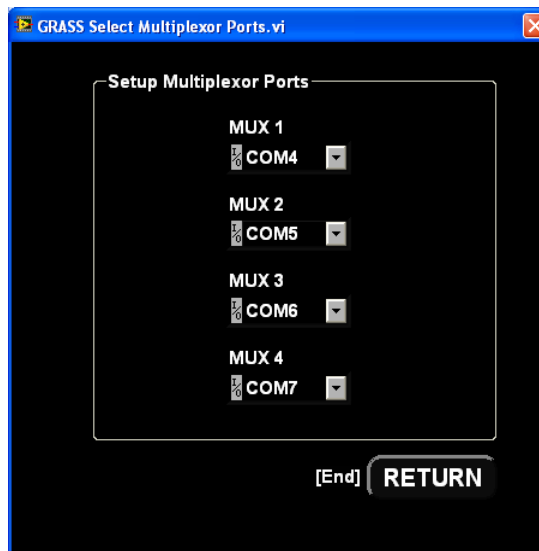


Figure 28: First screen of the Operating software, the correct COM ports for each multiplexers are selected at this stage

The user should select the correct COM ports for the multiplexers connected. Clicking on the grey down arrow provides a list of port options, select the correct port for the multiplexer. For the single multiplexer version only one MUX control is shown. Pressing the [RETURN] button will proceed to the main screen shown below Figure 30, if there is an error communicating with the multiplexers the following message is displayed:

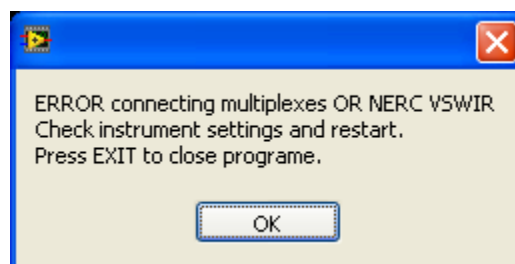


Figure 29: Error message if there is no communication with the multiplexers.

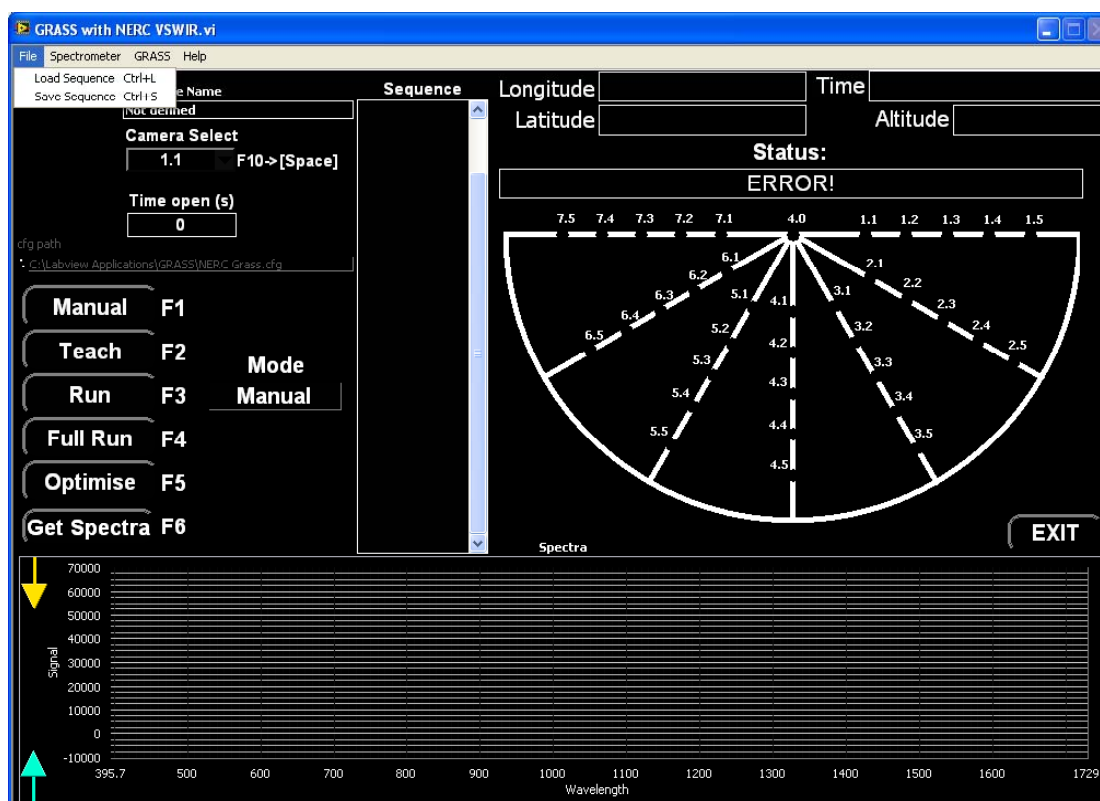


Figure 30: Main screen, which allows the selection of the operation mode.

There 6 modes for the GRASS operating software these are selected by clicking the buttons on the left of the screen or pressing the function key on the keyboard:

- Manual [F1]
- Teach [F2]
- Run [F3]
- Full Run [F4]
- Optimise [F5]
- Get spectra [F6]

The current mode is displayed to the right of the buttons under the title Mode (in Figure 30 the mode is shown as manual.)

- **Manual** – while this is showing (which is the default), each individual camera can be selected one at a time. Use the camera select control to choose the camera required. This control can be selected by clicking on it with the mouse, a list of cameras is displayed, move the mouse to the camera required then click again to select. An alternative method is to press the [F10] button then the [Space bar] to activate the list then use the cursor keys to navigate through the list then press the [Enter] key to select the camera highlighted.
- **Teach** – (Figure 31) under this heading you are able ‘teach’ a sequence of cameras for a measurement sequence. In this mode when you select a camera, using the technique described above, it is added to the sequence. The delete button, or the [DEL] key, can be used to remove the highlighted camera if a mistake is made.

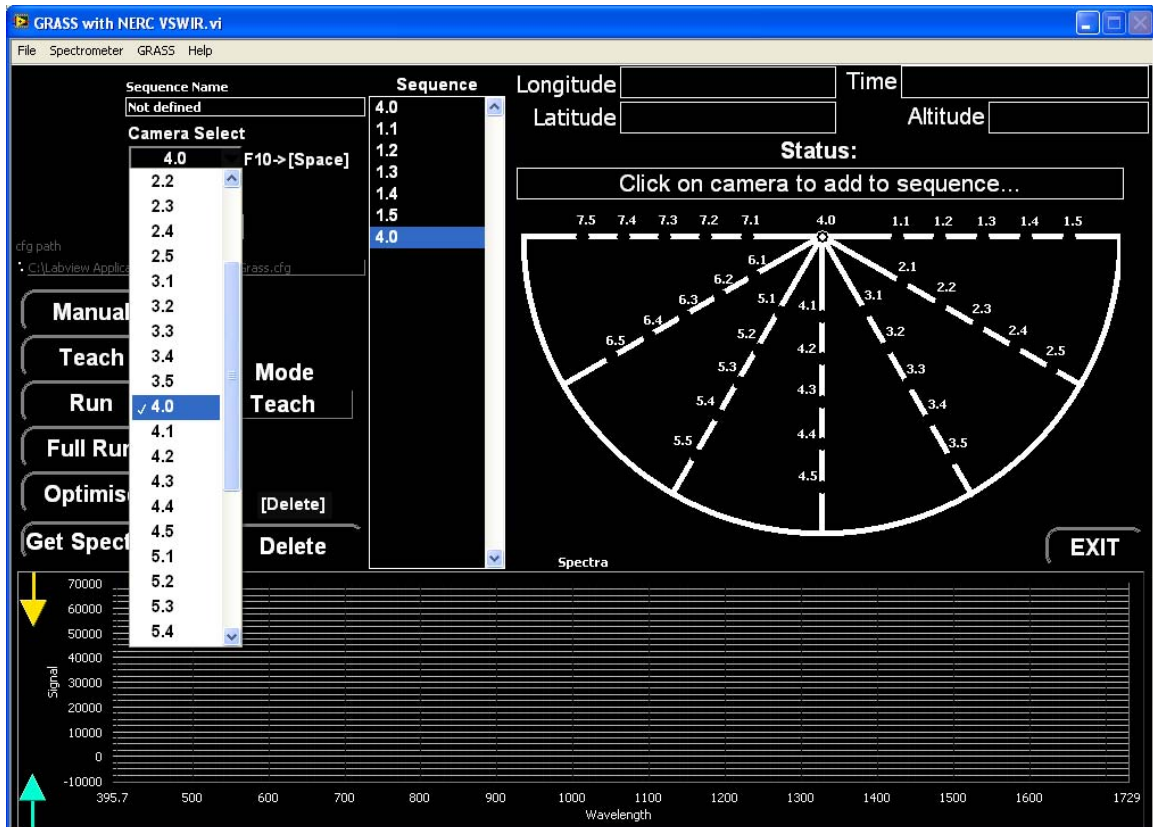


Figure 31: The teach screen

- The sequence can also be saved. By clicking on 'File>save sequence', (Ctrl+S) it will bring up a dialogue box to allow you to name and save the sequence you have created.
- Similarly by clicking on 'File>Load sequence' (Ctrl+L) it will bring up a box to allow you to select a previously saved sequence. Once this is selected it will list all the cameras in the sequence box on the main screen.
- **Run** – once a sequence has either been selected, or loaded, it is possible to start the measurement sequence.
- **Full Run** – this option will allow to record the signal over all 36 cameras.
- **Optimise** – This is the function that will ensure that the spectrometer is fully optimised and is used for the ASD only. Once the GRASS system is set up and the target is illuminated, select the nadir camera and click on optimise. This will initialise a sequence within the spectrometer to optimise its integration time and also take a dark signal reading. The settings of the spectrometer will remain at these optimised settings for any subsequent measurements, until the optimise button is pressed again. **The ASD should be optimised before any measurements are taken.** The NERC V-SWIR does not require the optimise phase. See the section on spectrometer settings for the NERC V-SWIR options.
- **Get Spectra** – If you want to check the signal levels, or just want an individual spectral measurement, the 'Get Spectra' option can be used. It will take a measurement and then ask if you would like to save it.

- **Spectrometer Menu** – Spectrometer setup measurement (Ctrl+M) *NERC V-SWIR only*. See Figure 32. This screen allows for the adjustment of the spectrometer measurement characteristics. These settings are important to get the best out of the measurement campaign. Discuss with NERC the best settings for the type of measurement you are making. The port that the spectrometer is connected to is set using the Set Instrument Port (Ctrl+N) menu option.

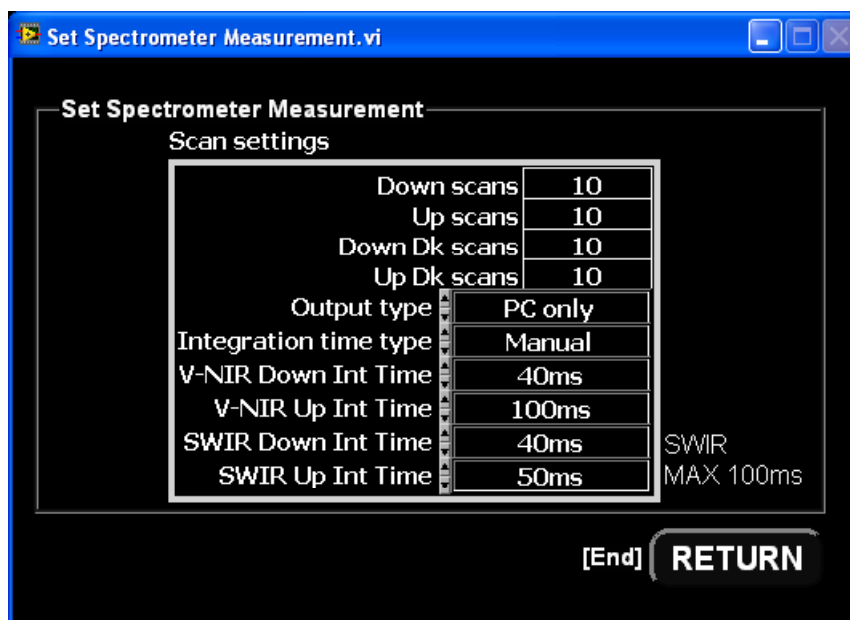


Figure 32: Spectrometer Measurement

- **GRASS menu** – Selecting the GRASS>Set Camera Angles (Ctrl+C) menu option opens the screen shown in Figure 33. This screen is where the current angles of the cameras must be set. The analysis software uses this data. Incorrect data in this screen will cause errors in the analysed data. Returning from this screen saves the data in a file, so if the angles are not altered then this screen requires only setting once. This menu also allows you set the port that the GPS device is connected to (Ctrl+P). Press [F1] then type the word COM# (#=the port number to which the GPS is connected). Click on the Return button or press the [End] key to continue.

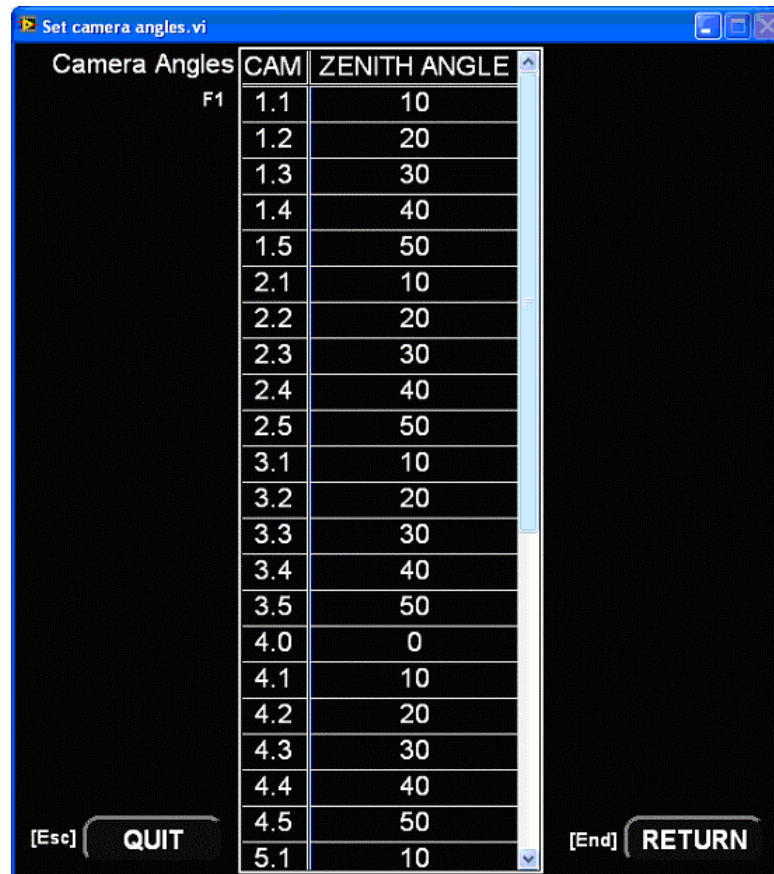


Figure 33: Camera angles

Exit the software – Click on the Exit button to close down the GRASS software application. Not exiting in this way may cause some setup data to be lost or corrupted. Also shuts down the connected instruments in a controlled manner.

1.3.2 Start Measurement Sequence

Once the 'Run' option has been selected a dialogue box appears giving the option to continue or cancel the run. When ready to start the measurement sequence click on ok. The system then requires the entry of the Solar Principle Plane and the marker on the GRASS base ring (Figure 34). Press [F1] and type in the Solar Principle Plane figure, press [F2] and type in the Marker value then press the [End] key to continue. The values are remembered so if they are correct just press the [End] key to continue.

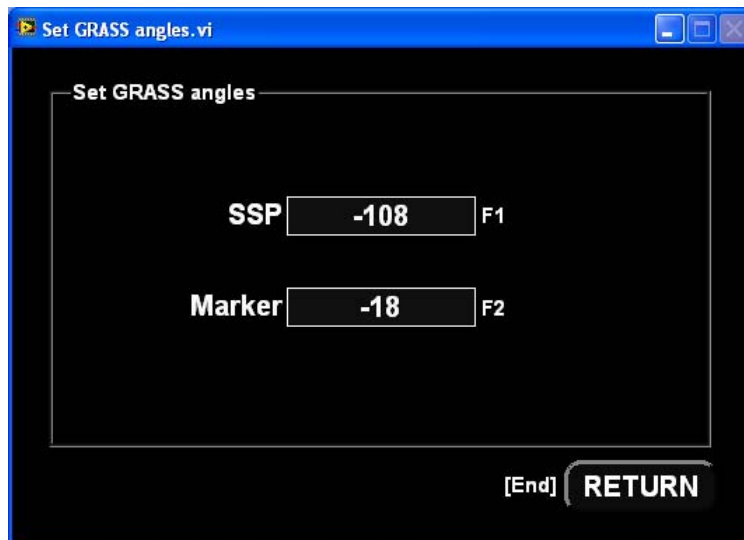
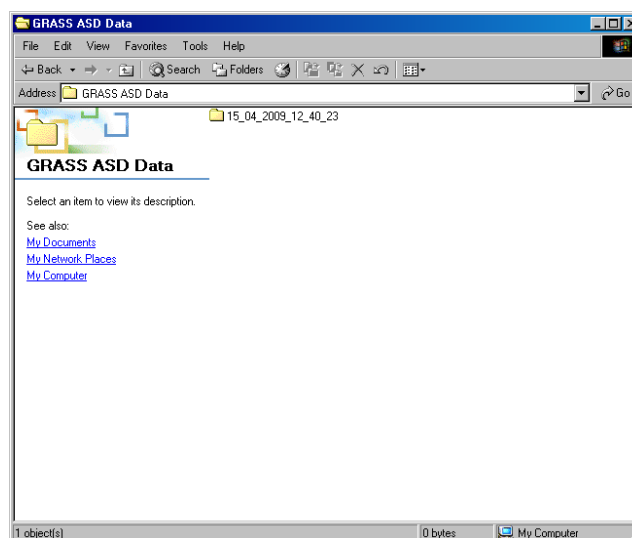
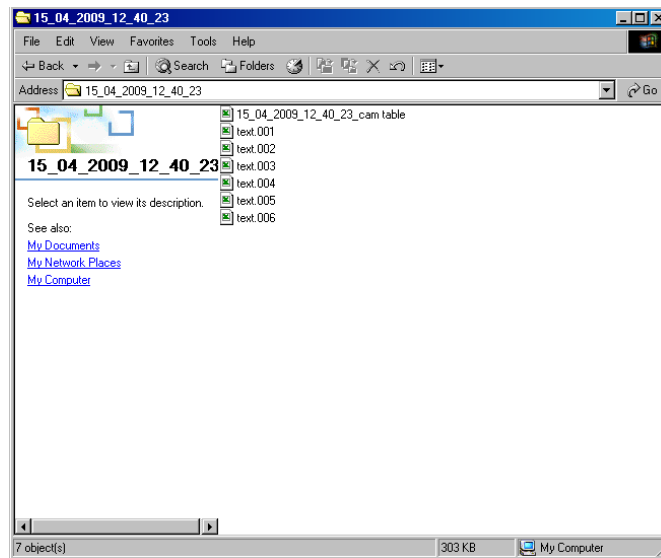


Figure 34: Set GRASS angles dialogue

- If at any time you want to stop the measurement sequence the 'STOP' button can be clicked on. The button appears where the delete button is in Figure 31
- During the sequence the spectra for each of the cameras will be displayed on the graph at the bottom of the screen. The camera that is being measured will be the one highlighted in the sequence box.
- At the end of the sequence a small box will appear to say 'Sequence End'. Click on ok to continue.
- The data from the sequence will automatically be saved in the following folder c:\GRASS ***** Data (***** = type of spectrometer). The results from each individual sequence will be saved in a unique folder which is uses a date and time stamp e.g. 15_04_2009_12_40_23.



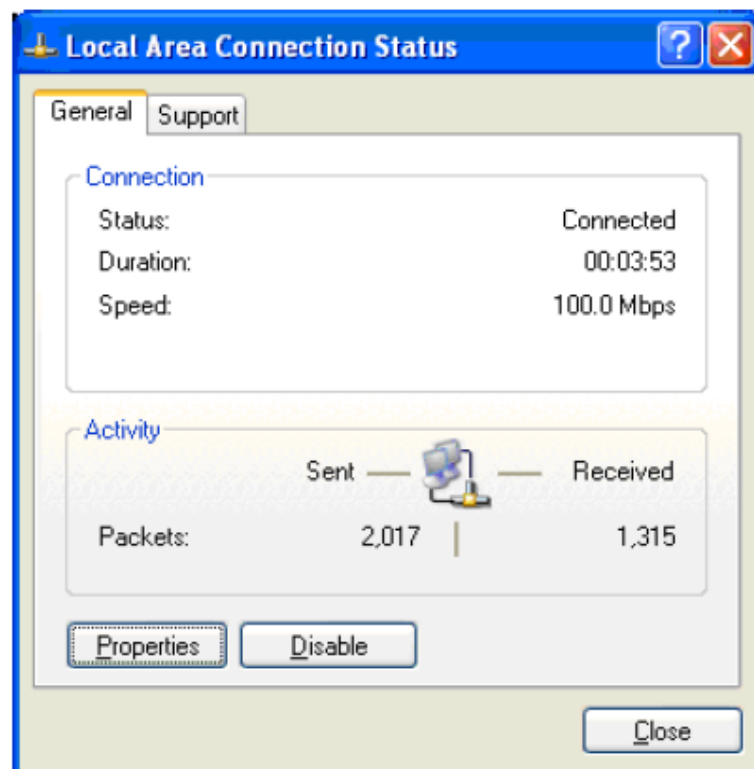
- Within the folder there will be a file which will be date and time stamped as the main folder followed by ‘.._cam table’. This file will contain the details of which of the saved files is associated with which camera in the sequence.
- The number of other files in the folder will depend on the number of cameras in the sequence. In this example there were only 6 cameras in the sequence, therefore there are only 6 data files.



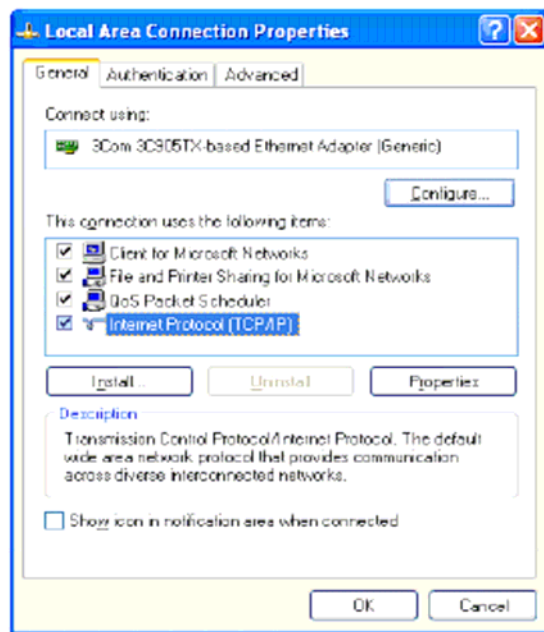
1.3.3 Network IP address set-up

If there is trouble with the connection with the ASD, then the network should be checked. To set it up, follow these instructions.

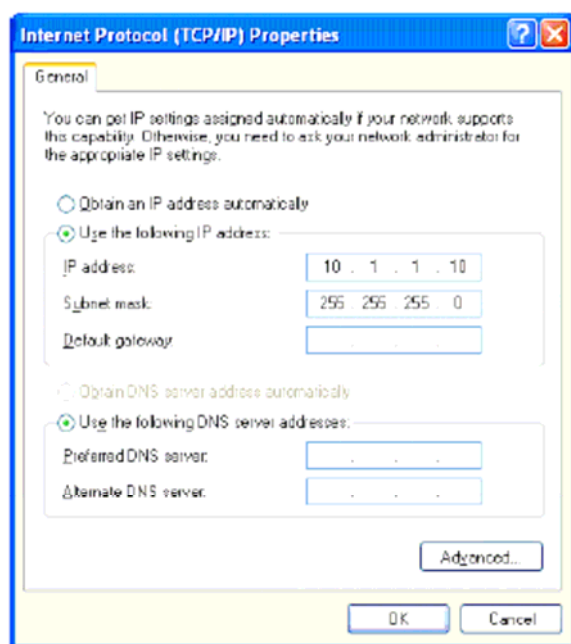
1. Click on the **Start** button
2. Click on the **Control Panel**.
3. Click on **Network and Internet Connections**.
4. Click **Network Connections**.
5. Click on the **Local Area Connection (LAN)**. The status dialog box for this connection will be displayed.



6. Click on the **Properties** button from the **Local Area Connection Status** dialog box. This opens the Local Area Connection Properties dialog box.



7. In the **Local Area Connection Properties** dialog box, select **Internet Protocol (TCP/IP)** from the list of components and then click on the properties button. The Internet Protocol (TCP/IP) properties dialog will be displayed.

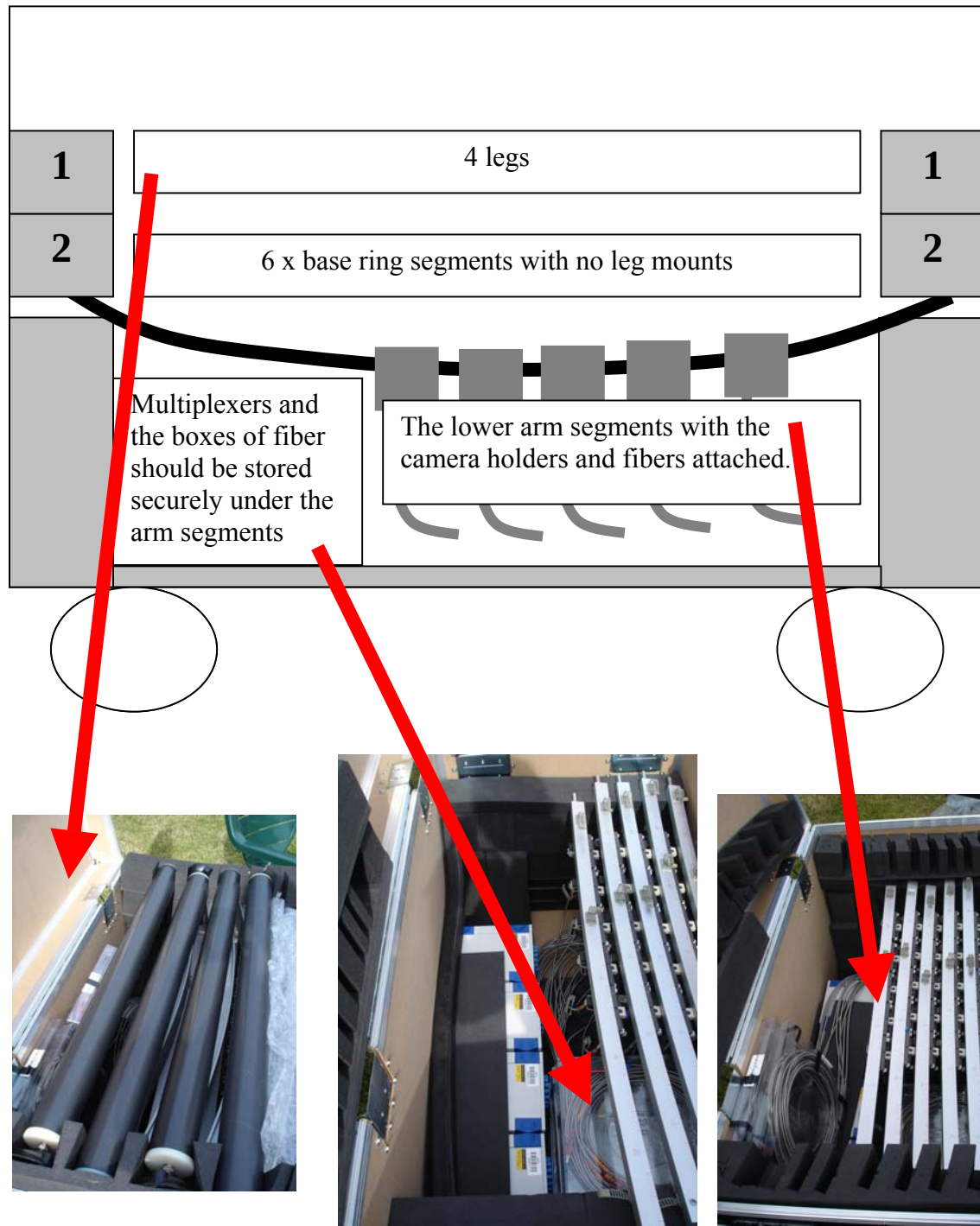


8. Within the **Internet Protocol (TCP/IP) Properties** dialog box, use the following settings to set a static IP address
 - **IP address:** 10.1.1.10
 - **Subnet Mask:** 255.255.255.0
 - **Default gateway:** (leave blank)
 - **Preferred DNS Servers:** (leave blank)
 - **Alternate DNS Servers:** (leave blank)
9. Select **OK** to save the setting of the **Internet Protocol (TCP/IP) Properties** dialog box.
10. Select **OK** from the **Local Area Connection Properties** dialog box.
11. Select **Close** from the **Local Area Connection Status** dialog box.

1.4 Packing the instrument away

The instructions essentially need to be followed in reverse to pack the instrument away. Below are some pictures to help with the process as to what parts go into which box.

NPL GRASS 1



NPL GRASS 2

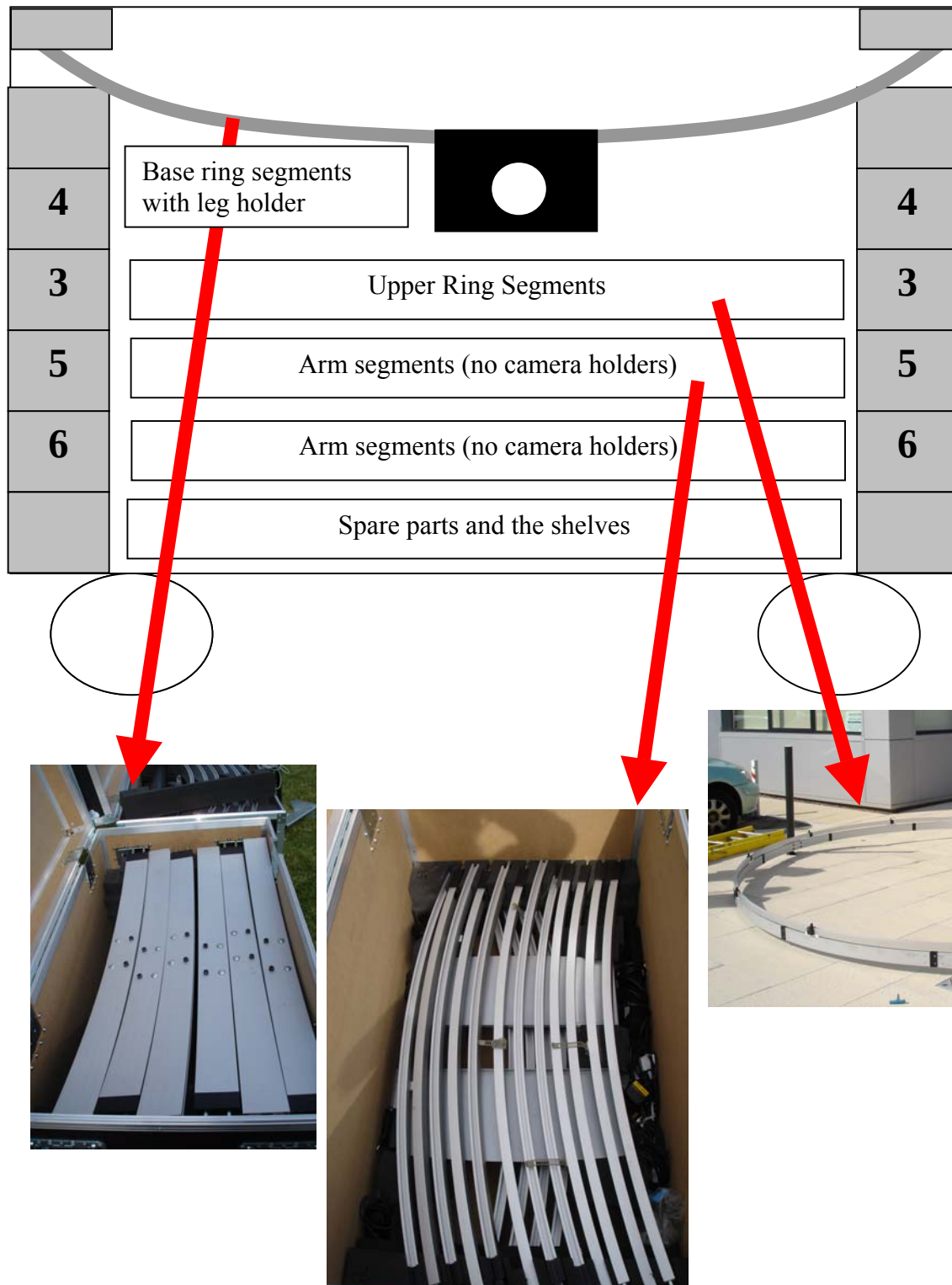


Figure 36: Position of all parts in the box NPL GRASS 2

2 Measurement Protocols

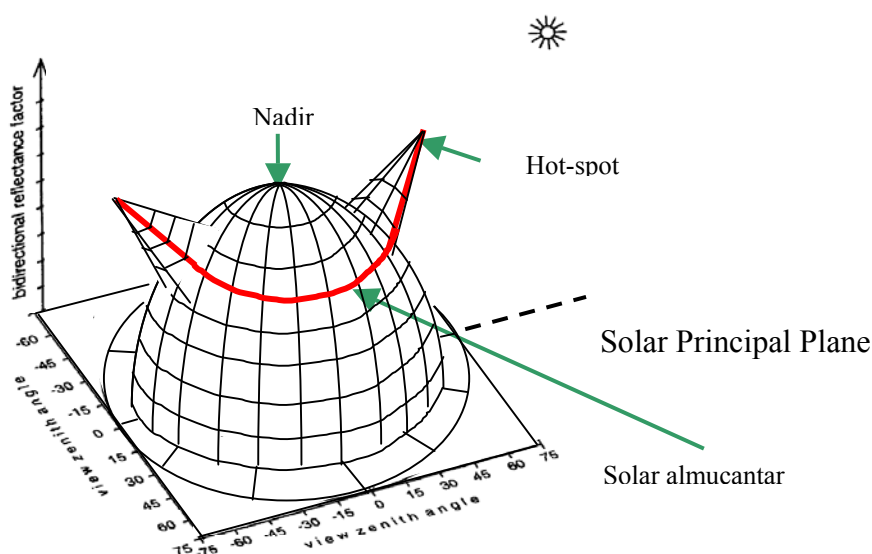
Some initial key steps:

- Make sure the laptop is set to UTC
- If ASD is used, it should be optimised at the beginning of a measurement sequence.

2.1.1 Definitions

Before describing the measurement protocol for the GRASS, it is opportune to list some definitions.

Below is an exaggerated plot of the reflectance of a surface.



Nadir:	Is the point looking perpendicularly down on the surface.
Hot-spot:	Is the back-reflection of the solar radiation, which is around the solar zenith and azimuth angle.
Solar Principal Plane:	Is the azimuth plane at which the sun is positioned during measurements.
Solar almucantar:	Is the 360° plane around the hemisphere at the same zenith angle as the sun.

The way the measurements are done is such that the angular data is referenced to the solar principal plane, rather than geographical north.

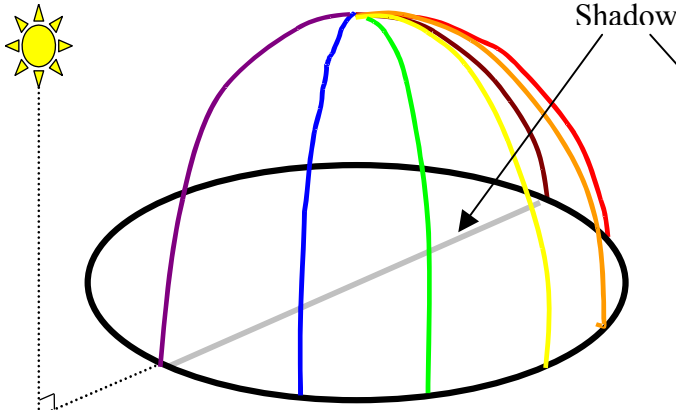
To determine the angle of the SPP, the structure can be used. Essentially the sun will cast a shadow across the centre of the measurement area. As shown in the diagram below, arm 7 will cast a shadow across the centre of the measurement area, which will align with arm 1 and this will be inline with the solar principal plane. At this point, the red marker of the upper base ring should be in line with a degree indicator on the base ring. This angle should be recorded.

To take radiance and diffuse irradiance measurements, the structure should be set up as follows:

Arm 1: Diffuse
Arm 3: Radiance
Arm 5: Radiance
Arm 7: Diffuse

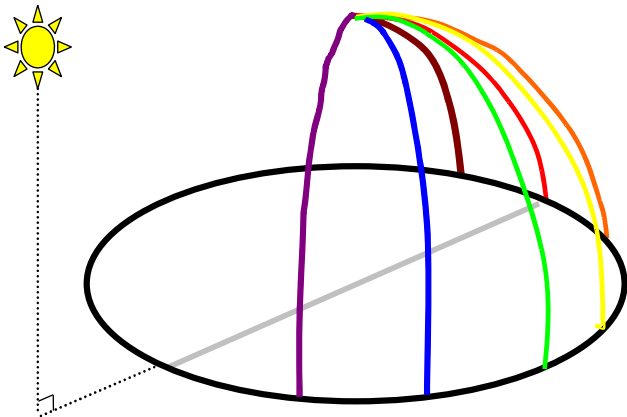
Arm 2: Radiance
Arm 4: Diffuse
Arm 6: Radiance

With the structure aligned with the SPP, this will be the starting point for the measurements. In this position the diffuse measurements can be taken. It can then be rotated in an anticlockwise direction for the measurements. The following boxes show the series of positions that the structure should be aligned to, followed by the measurements to be taken in that position, and then the amount the structure should be rotated to put it into the correct position for the next set of measurements.



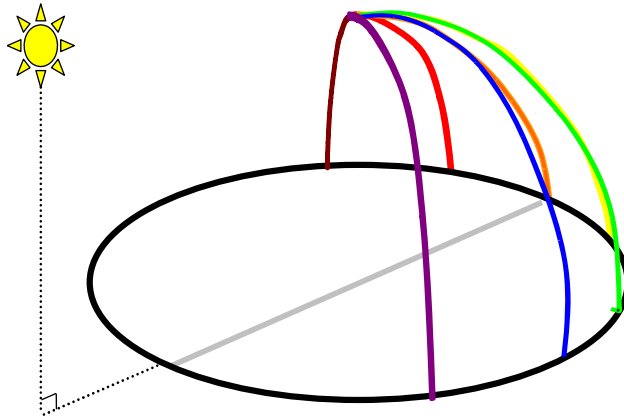

Position 1:

- Position 1 Measurements
Radiance: None
Diffuse: All cameras.
- Rotate 30°

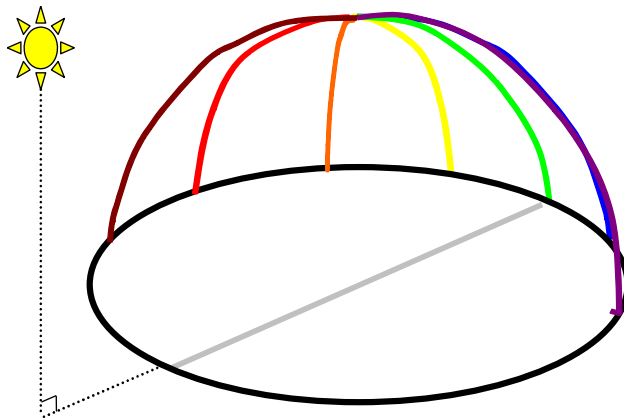


Position 2:

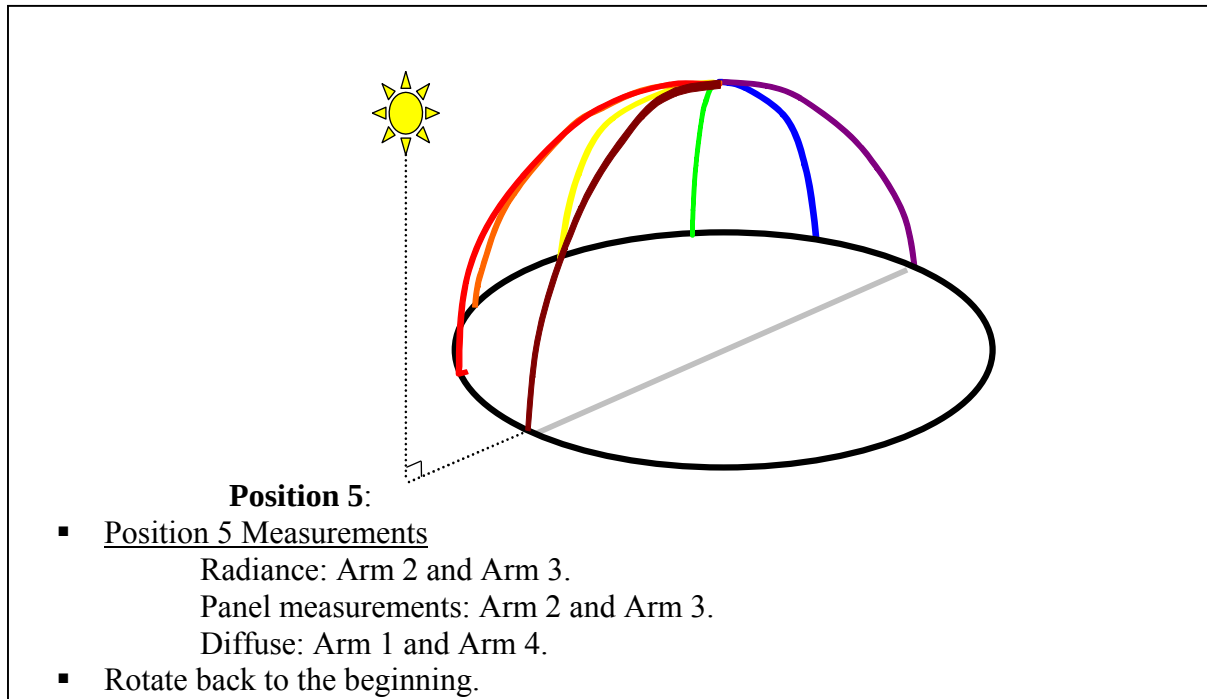
- Position 2 Measurements
Radiance: All cameras.
Panel measurements: All cameras.
Diffuse: All cameras.
- Rotate 30°

**Position 3:**

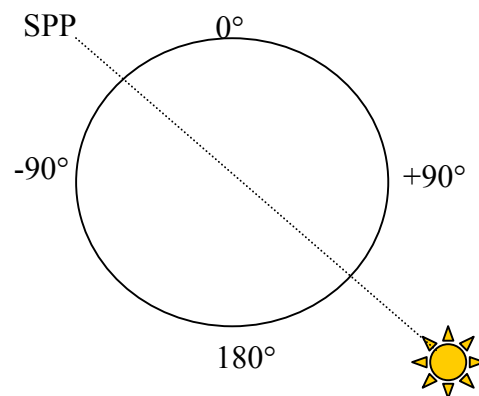
- Position 3 Measurements
 Radiance: Arms 2 and 5.
 Panel measurements: Arms 2 and 5.
 Diffuse: All cameras.
- Rotate 60°

**Position 4:**

- Position 4 Measurements
 Radiance: Arms 2 and 3.
 Panel Measurements: Arms 2 and 3
 Diffuse: Arm1.
- Rotate 60°

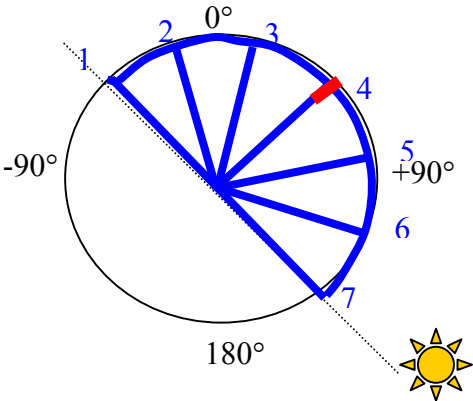


When using the operating software it should ask you to enter the angle of the solar principal plane. The base ring has markers from -180° to 0° to $+180^\circ$. In the example below the SPP would show -45° on the base ring. This point is now the reference point and defines 0°



The arms of GRASS have a red marker at the bottom of arm 4, for each measurement the angle on the base ring on the marker should be entered. In the case below it would read $+45^\circ$. However the angle relative to the SPP for each arm should be entered, so

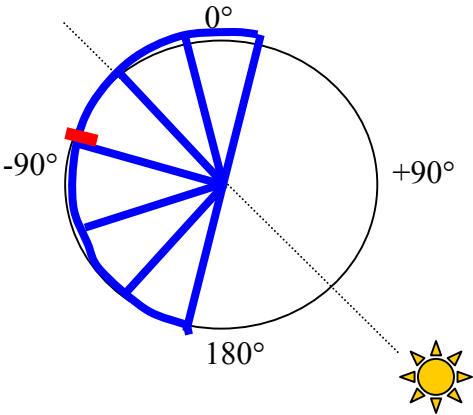
Arm 1	Arm 2	Arm 3	Arm 4	Arm 5	Arm 6	Arm 7
0°	30°	60°	90°	120°	150°	180°



When the structure moves the red marker should be read, which in the case below would read = -75°

Therefore the arms should be:

Arm 1	Arm 2	Arm 3	Arm 4	Arm 5	Arm 6	Arm 7
240°	270°	300°	330°	0°	30°	60°



But note these may not be round number such as 30°, or 60°, but could be more 57° or 62°.

Over the course of the day the SPP will change, but the positions of the arms will change lot. At least this will only require two angles to be entered. They should be entered at the point just before the start of a measurement sequence.

2.1.2 Data Analysis

Analysis of measured data is performed using MADAT software. There is a dedicated manual describing the inputs and outputs of this software as well as its capabilities and limitations (Louise Wright, “MADAT software manual v5.0”). Here below is a summary of this software, which was developed with the aim to analyse data recorded with an ASD or a V-SWIR radiometer.

Input:

The input files are .txt files, which are organised in two datasets, one contains the DNs measured over the Spectralon panel and the other one the DNs measured over the target using all cameras of the GRASS system. The input files resulted from both instruments are in the ASD format. The header contains information data read by the GPS such as: latitude, longitude and UTC time. MADAT uses this information to calculate the sun zenith angle of the measurement. The operator will have this information on a GUI interface and it has the possibility to change the sun zenith angle if it is incorrect.

Output:

The RF of each camera at different viewing and azimuth angles is calculated from the two DNs datasets and the RF of the reference panel. The reference panel is calibrated by NPL with traceability to SI standards prior to each measurement campaign. This calibration is performed for a range of illumination angles, which were selected accordingly to the range of the sun zenith angles related to the planned field measurements. This means that the users of this software should check that the right RF of the Spectralon panel is uploaded in the software.

Saving Data

The RF of all cameras can be saved in one Excel file as it is described in the manual (p. 27).

Standard Uncertainty estimation

For a full sequence recorded with the ASD radiometer, there are seven datasets measured over nadir. These data could be saved in an Excel as per figure 25 (MADAT manual) and further used in the calculation of standard uncertainty Type A (repeatability and reproducibility) over nadir. An example is given in Appendix C: BRDF Type A standard uncertainty.

Graphical representations

Data can be represented as spectral RF over the 350 to 2500 nm for each camera and Analysis of measurements recorded with GRASS can be performed using the MADAT representations of RFs and it will allow to compare the backward and forward scattering of the measured target. If one wavelength is selected, the RF data could be represented in polar coordinates.

Please, refer to MADAT manual for more information.

3 Evaluation of Performance

3.1.1 Traceability

At NPL all optical radiation measurement is traceable to the cryogenic radiometer, as shown in Figure 37. The cryogenic radiometer is used to calibrate solid-state detectors as transfer standards. These detectors in effect establish a spectral responsivity scale, forming the top of the calibration chain. Usually the transfer standard calibrated directly against the cryogenic radiometer is a trap detector (Fox, 1991). Trap detectors are used to calibrate filter radiometers and photometers.

The filter radiometers are then used to measure the temperature of a high temperature blackbody (up to 3500 K) and this, through Planck's law, provides a known source of spectral radiance. The Spectral Radiance and Irradiance Primary Scales (SRIPS) facility can then be used to transfer the scale from the blackbody to lamp and integrating sphere sources through an intermediate spectrometer. These sources are then used to calibrate spectrometers, which can be used in the field.

The NPL National Reference Reflectometer (NRR) is a goniometric instrument capable of illuminating a sample at any angle and detecting the reflected or transmitted light at any point on a 360° arc. Its principal uses are to realise NPL scales for diffuse reflectance, regular reflectance, gloss and haze. The light source is a tungsten ribbon lamp, which is either filtered or passed through a monochromator depending on the type of measurement. A suite of detectors allows measurements to be made from 350 to 2500 nm. The NRR provides traceability to SI for reflectance measurements.

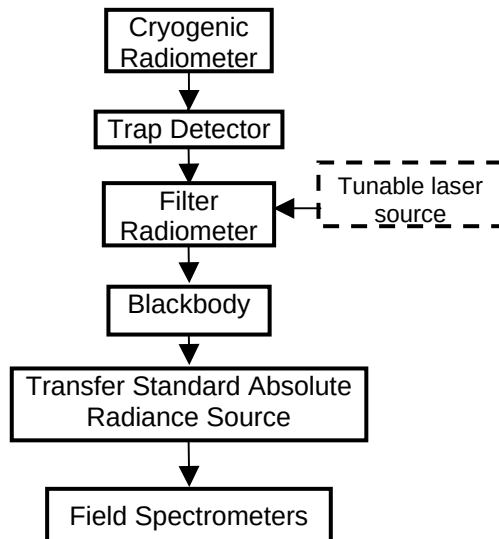


Figure 37: Traceability chain to the NPL Primary standard cryogenic radiometer

The reference panel will be calibrated prior to each measurement campaign for a range of illumination angles matching the variability of the sun zenith angle for this site and this period of the year. The reflectance factors of the reference panels measured for this range of sun zenith angles will be introduced in the MADAT software in order to calculate the BRDF effects of the site.

GRASS is calibrated against a transfer standard absolute radiance source (TSARS), which is traceable to the NPL primary standard. This calibration is applied to the data in the MADAT software for the analysis.

This radiometric calibration can be done by removing the optical elements of the structure, such as the lenses and multiplexers in combination with the spectrometer. A measurement of the TSARS can then be made with each of the optical fibers using the GRASS_ASD software. This will then provide the spectral responsivity for each of the camera positions, which will then need to be put into an array for the MADAT analysis software. The linearity of the system can be checked using two power levels of TSARS.

However, GRASS structure is probably not rigid enough to keep the same position of cameras optics and optical fibers after each dismantling, packing, shipment and new building of the whole structure. The radiometric calibration performed in the lab is mainly lost after each dismantling and build of the structure. In this moment it is not recommend to use GRASS for absolute radiometric measurements.

3.1.2 Field of View

The field of view of lenses has been set to 4°. This was achieved by using a laser to back illuminate each of the optical paths and adjusting the position of the lens to create a defined illuminated area at a set distance. All of the lenses were adjusted to these positions and should not be changed.

Reverse illumination source

A reverse illumination source (laser Class 1, 635 nm, a Visible fiber optic fault locator manufactured by OzOptics, see the technical details in Part 1, Chapter 5) is provided together with GRASS. It is used to check the area viewed by each of the 36 cameras. This will give an idea about the patch size viewed by each camera and check that all cameras are pointing over the surface of the 600 mm x 600 mm (300 mm x 300 mm) reference panel used for such measurements.

The source is a class 1 Laser, however if one follows the recommendations of the manufacturer it is safe and does not require a special training. However it is recommended to avoid viewing the source directly.

3.1.3 Directional Accuracy

Using the same laser illuminating the system whilst the structure is fully assembled, the directional accuracy of the cameras could be assessed. The laser would form a series of illuminated patches on the target surface, and the offset from the centre could be measured. The distance from the centre was less than 4° angular offsets for all of the cameras.

3.1.4 Sources of uncertainties

In field based measurements of BRDF it is important to note that one of the principle sources of uncertainty relates to the timing of the experiment and not simply the instrumentation or method itself. For example, errors can be introduced due to changes in the solar irradiance over short timescales. This, therefore, means that the errors are dependent on the measurement sequence, and time-delay between successive measurements of the target and reference measurements. Careful consideration and good documentation is required to minimise these systematic uncertainties. A common approach is to restrict the field measurements to a period around solar noon when the solar geometry is changing least and when the uncertainty due to the angular response of the reflectance panel is at a minimum. Alternately the method established by ONERA (The French Aerospace Laboratory) using an artificial light source during night time conditions, instead of the Sun can provide the necessary data.

- A single point instrument can be used to measure the angular variability. The uncertainties associated with these measurements will arise due to the accuracy of the method of acquisition. For example, if a sensors physical location is constant, but the orientation of the sensor is changed to capture multi-angular radiance, the area of the target that is measured is assumed to be spatially and spectrally uniform. Any non-uniformity will introduce errors that can be difficult to determine. Where the sensor is mobile, the errors are associated with the mechanism of the sensor and the uncertainties associated with tilting the sensor and geo-location of the sequential measurements.
- Determining the angular reflectance characteristics of a particular surface can be difficult in the natural environment, due to effects such as the atmospheric conditions and illumination angle of the Sun, which are constantly changing. It is, therefore, critical that the time taken to perform a full set of measurements is kept to a minimum. By reducing the measurement time, the uncertainties associated with the changing environmental conditions can be reduced.
- The angular field-of-view of the sensor should also be kept as small as possible to ensure that the BRDF measured is a good estimate of the true BRDF at the specified geometries. The 4° FOV should fulfil this requirement.
- A particular problem in the field is the diffuse radiation that is produced from skylight and scattered light. The light is hard to quantify as its intensity can vary over the hemisphere and with time due to atmospheric changes. These errors can be reduced if considered carefully, but crucially they should be documented, otherwise the data can be devalued and the diffuse contribution can become a significant source of uncertainty.

There are a few methods for calculating the diffuse irradiance contribution, which include conducting measurements under different conditions (e.g. clear skies/hazy skies). By occluding the solar disc, the difference between the direct and diffuse irradiance can be determined, or the complete sky irradiance can be measured.

Example: Type A Standard uncertainty

Appendix C presents an evaluation of the Type A standard uncertainty as calculated from GRASS datasets during the Tuz Golu measurement campaign in August 2009. This standard uncertainty is associated with the repeatability and reproducibility of measurements taken over nadir in a frame of 10 minutes using an ASD radiometer.

The MADAT software allows saving the data recorded at nadir in an Excel file and for a full sequence over 7 arms there is a dataset of 7 measurements at nadir. The same measurements were repeated in the lab using a floodlight to check if the illuminations conditions are the cause of the variability of data over nadir.

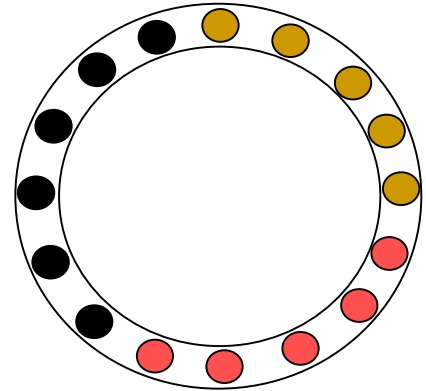
Appendix A : Multiplexers identifiers

These are the labels that are used to identify which fibers connect to the different ports on the multiplexers.

Multiplexer 1(16)

Fibers from arms: 1 & 2

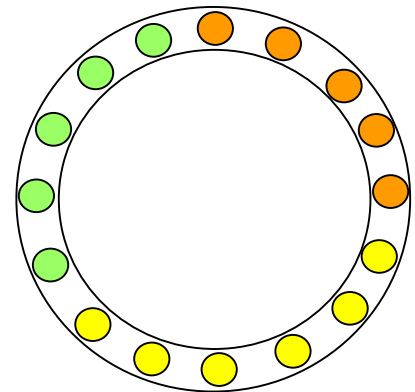
RS232 Cable = 3



Multiplexer 2(16)

Fibers from arms: 3, 4 & 5

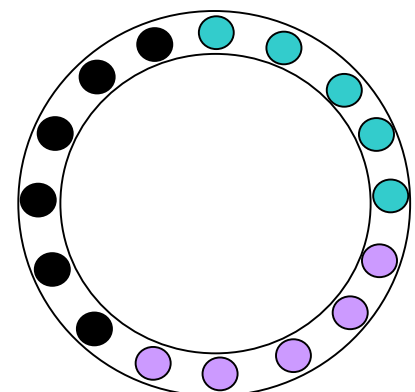
RS232 Cable = 2



Multiplexer 3(16)

Fibers from arms: 6 & 7

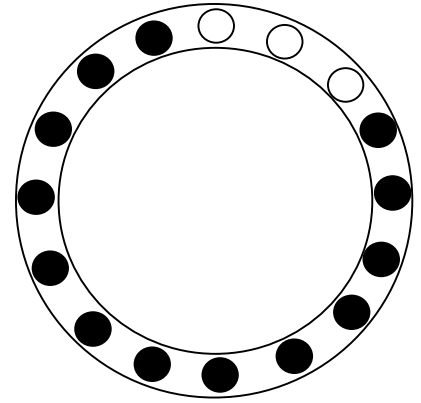
RS232 Cable = 1



Multiplexer 2(8)

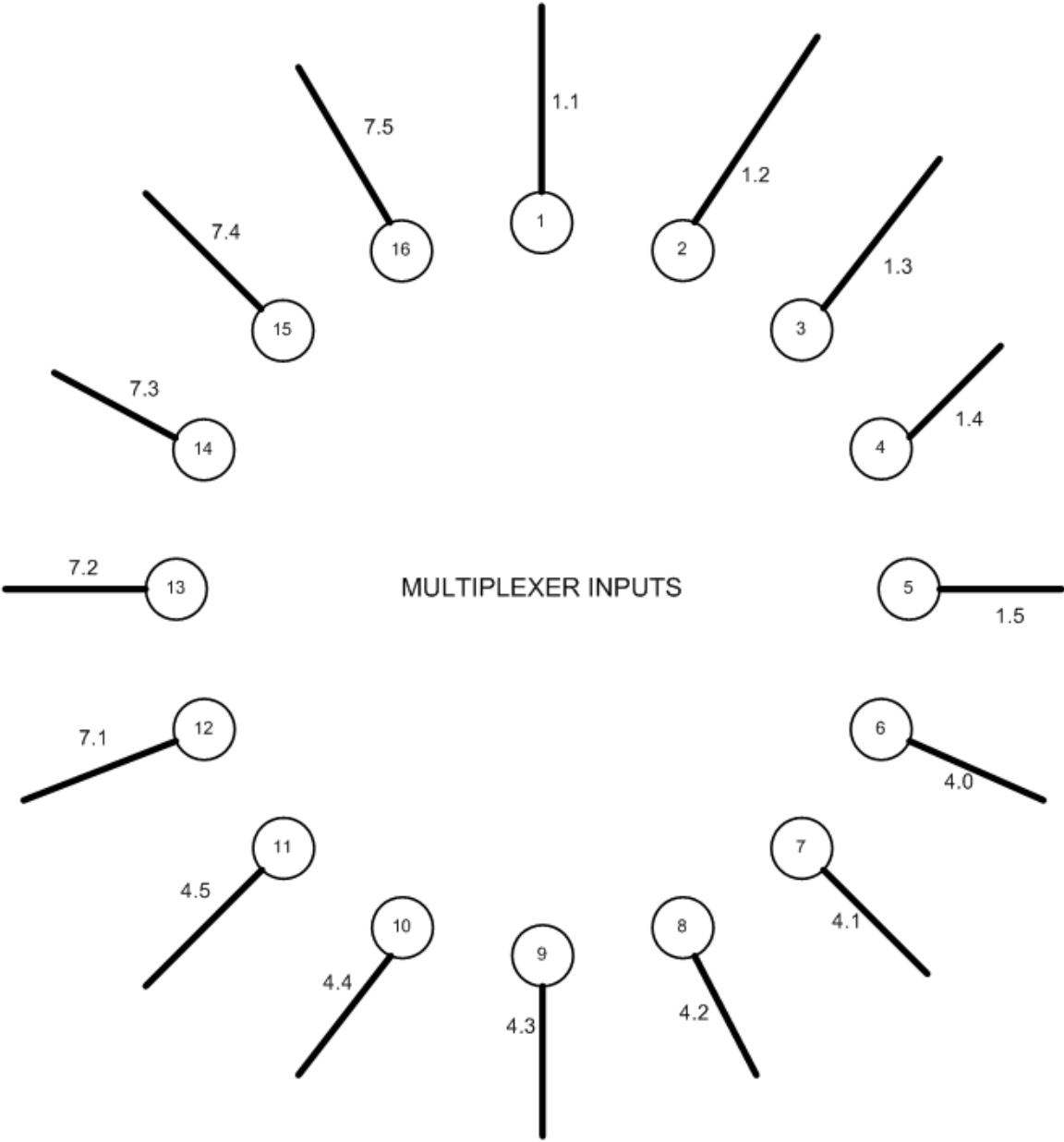
Fibers from other multiplexers

RS232 Cable = 4



Appendix B: 1 Multiplexer

Camera input arrangement for the single multiplexer GRASS system.



Appendix C: BRDF Type A standard uncertainty

Measurements were recorded with GRASS over three days: 25th, 27th and 28th August for the same sun zenith angle: 35 degree over the slat lake (Tuz Golu, Turkey). This dataset was used to estimate the standard uncertainty associated with the repeatability and reproducibility (Type A standard uncertainty).

The values at nadir for these 3 days at 35deg sun zenith angle show a particular feature: values are decreasing with time for 25th, 27th and 28th August (Figure 38 and Figure 39). The timeframe of a full GRASS sequence over half of hemisphere takes only 10 minutes. This could be explained by changing illumination conditions during the measurements. This wasn't monitored in August 2009.

Lab experiments using a floodlight confirmed our hypothesis. A series of measurements using a reference panel and an artificial target proved that for stable illumination conditions the values measured over the nadir camera are constant and they don't change in value over 10 minutes as was the case for field measurements (Figure 41 and Figure 42).

We consider that these datasets are not enough for a complete standard uncertainty analysis. These first results with a standard uncertainty Type A of 0.5% (Figure 40) will be further confirmed with the analysis of more datasets from August 2010.

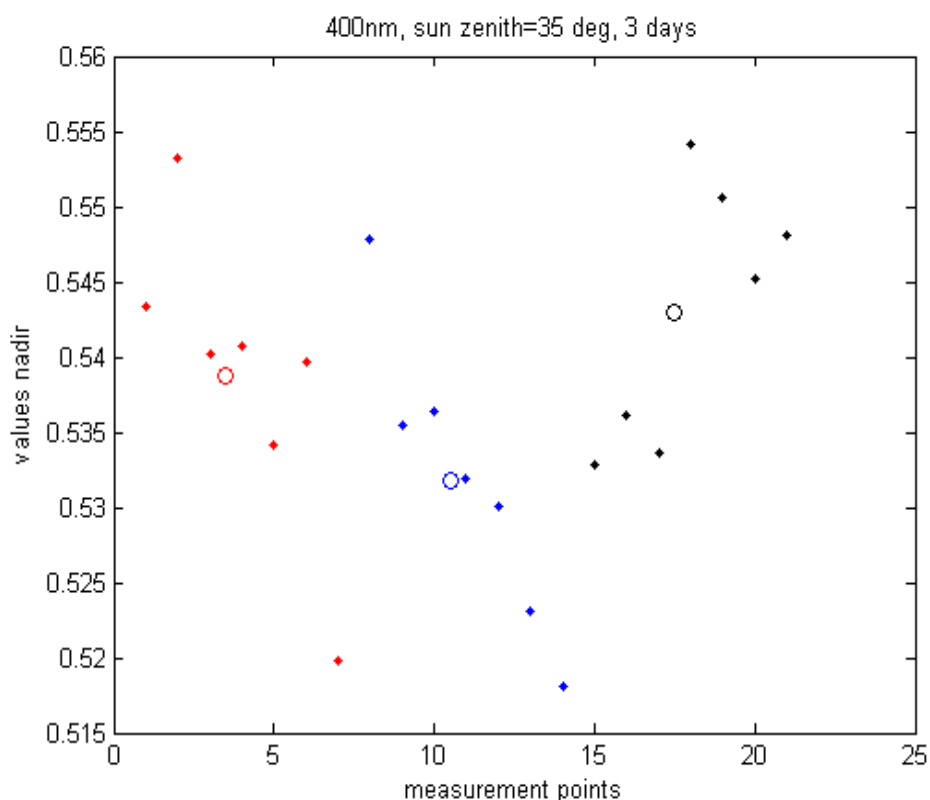


Figure 38: DN values recorded with an ASD radiometer over nadir at 400nm and for a 35° sun zenith angle, in Tuz Golu, Turkey on 25th, 27th and 28th August

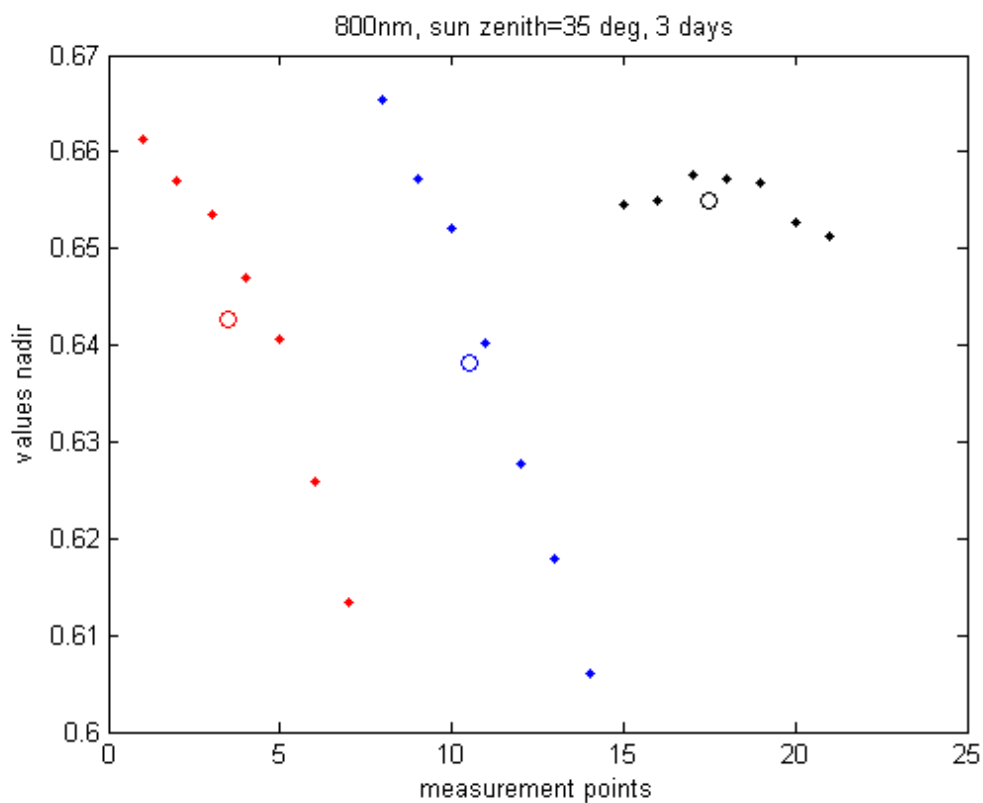


Figure 39: DN values recorded with an ASD radiometer over nadir at 800nm and for a 35° sun zenith angle, in Tuz Golu, Turkey on 25th, 27th and 28th August 2009.

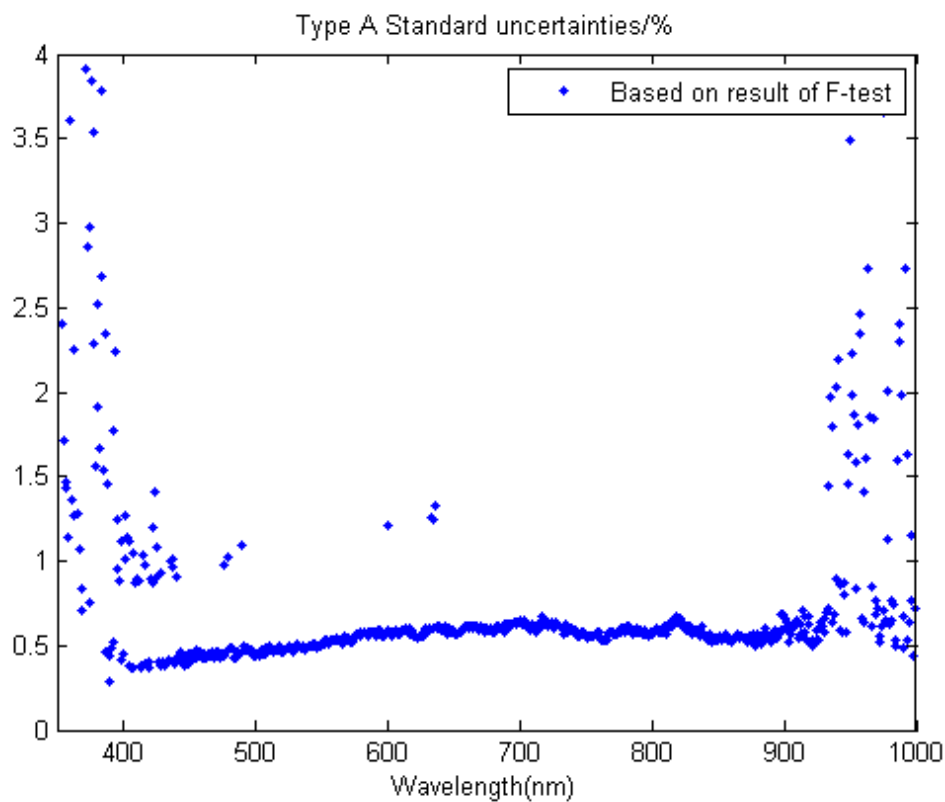


Figure 40: Standard uncertainty Type A associated with the nadir measurements for a 35° sun zenith angle, in Tuz Golu, Turkey on 25th, 27th and 28th August 2009.

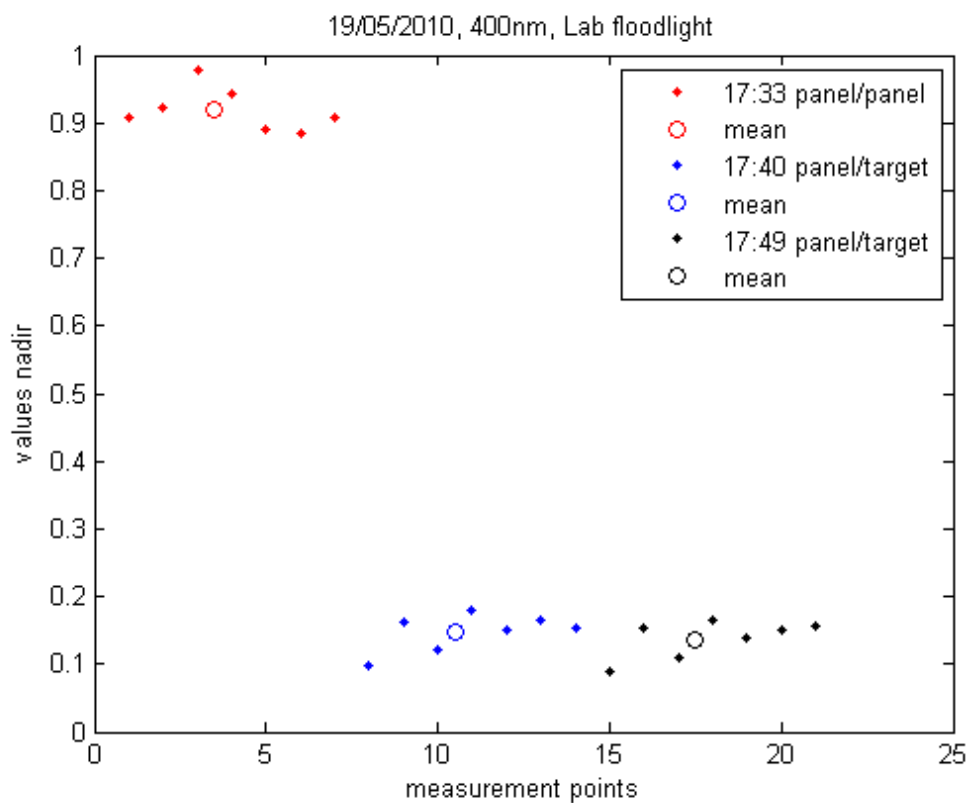


Figure 41: DN values recorded with an ASD radiometer over nadir at 400nm and for a 45°-illumination angle of a floodlight, in the NPL laboratory.

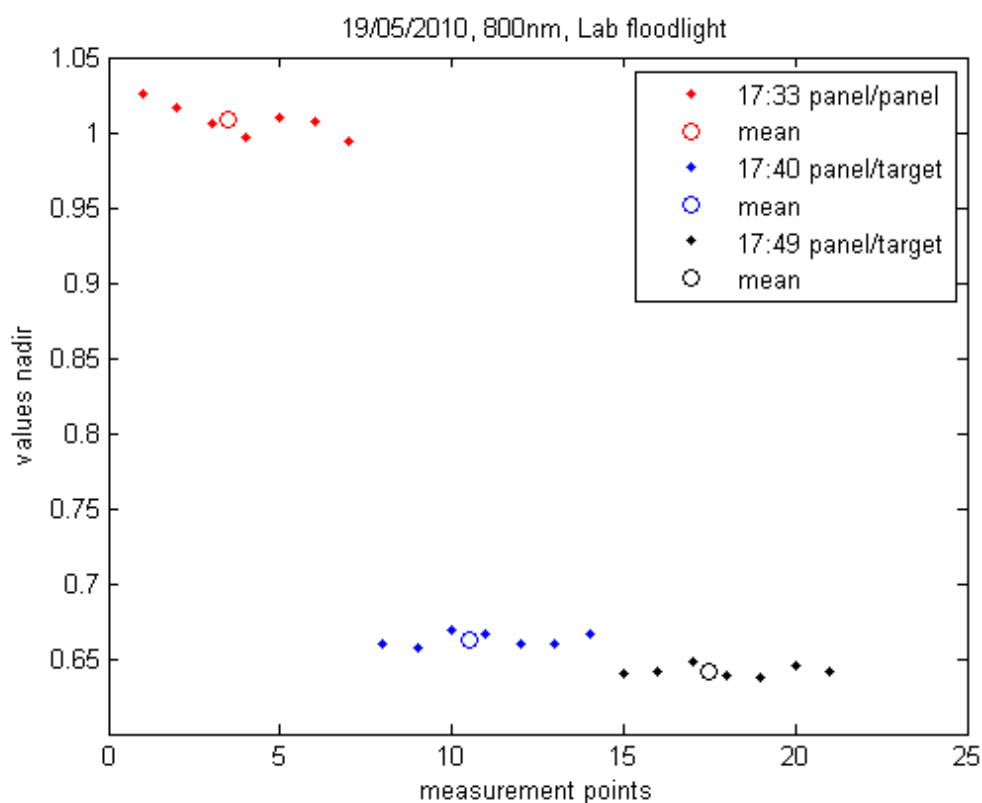


Figure 42: DN values recorded with an ASD radiometer over nadir at 800nm and for a 45°-illumination angle of a floodlight, in the NPL laboratory.

References

- Clark, R. N., G. A. Swayze, K. E. Livo, et al., (2002). Surface Reflectance Calibration of Terrestrial Imaging Spectroscopy Data: a Tutorial Using AVIRIS, Proceedings of the 10th Airborne Earth Science Workshop, 21pp.
- Diner, D. J., G. P. Asner, R. Davies, et al., (1999). New Directions in Earth Observing: Scientific Applications of Multiangle Remote Sensing, Bulletin of the American Meteorological Society, 80, 2209-2228.
- Dingirard, M. and P. Slater, (1999). Calibration of Space-Multispectral Imaging Sensors: A Review, Remote Sens. Environ, 68, 3, 194-205.
- Fox N. P. (1991). "Trap detectors and their properties", Metrologia, 28, p. 197-202.
- Gibson, P., (2000). *Introductory Remote Sensing, Principles and Concepts*. Routledge, London.
- Lucht, W. and C. Schaaf (2006). BRDF Explained, <http://www-modis.bu.edu/brdf/brdfexpl.html>, 25th June 2007.
- Martonchik, J. V., C. J. Breugge and A. Strahler, (2000). A Review of Reflectance Nomenclature used in Remote Sensing, Remote Sensing Reviews, 19, 9-20.
- National Bureau of Standards, US Department of Commerce, (1977). *Geometrical Considerations and Nomenclature for Reflectance*. Washington, D.C.
- Sandmeier, S. R., (2000). Acquisition of bidirectional reflectance factor data with field goniometers, Remote Sensing of Environment, 73, 3, 257-269.
- Schaepman-Strub, G., T. H. Painter, S. Huber, et al., (2004). About the Importance of the Definition of Reflectance Quantities - Results of Case Studies, Geo-Imagery Bridging Continents, XXth ISPRS Congress, Istanbul, Turkey, 361-366.
- Schaepman-Strub, G., M. E. Schaepman, T. H. Painter, et al., (2006). Reflectance quantities in optical remote sensing - definitions and case studies, Remote Sens. Environ, 103, 27-42.