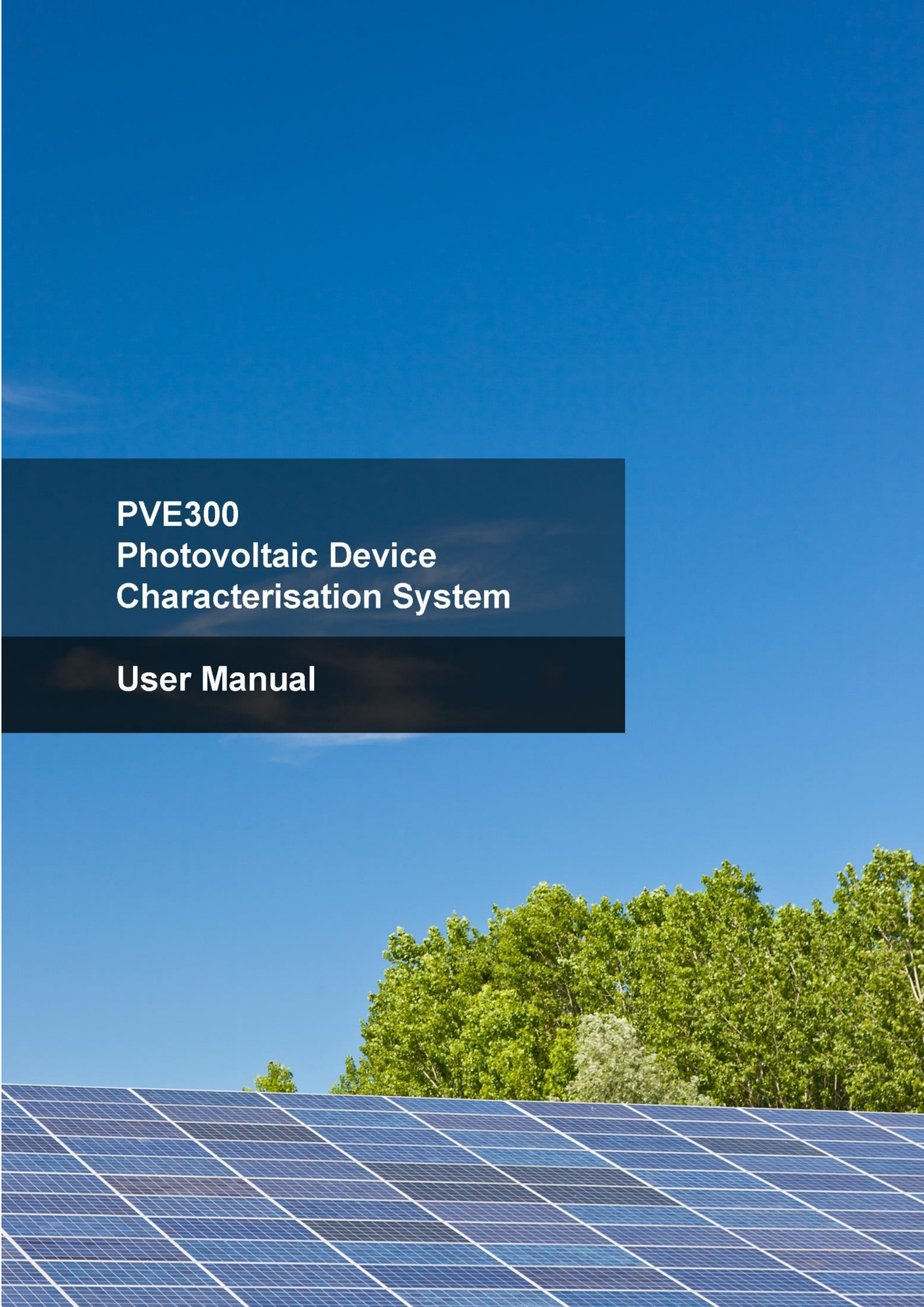
PVE300
Photovoltaic Device Characterisation System

User Manual



Contents

1. Introduction

This manual has been written to accompany the Bentham PVE300 photovoltaic characterisation system, and aid in the use of the system and the control software, BenWin+.

Sections 2 to 9 discuss the system component hardware, 10 the software, and in sections 11-14 is provided a guide to the measurement of spectral responsivity/EQE, and spectral reflectance/transmittance used in the determination of IQE.

A precautionary note and troubleshooting help is provided in section 15.

In the appendices are to be found background information deemed to be of interest, including a note on system installation.

1.1 System Configuration

A monochromatic probe source, 300-1800nm, is assembled from a dual xenon/quartz halogen light source.

This source, with appropriate accessories and reference standards, is used to determine the spectral responsivity, reflectance and transmittance of devices under test.

The conditions of measurement and signal recovery depends upon the material system under consideration, as discussed in §11.

A temperature controlled vacuum mount is provided to ensure that the measurement is made under temperature controlled standard conditions, and to set the device under test (and reference detector) at the measurement plane.

An integrating sphere is used to perform measurements of sample transmittance and reflectance.

2. Dual Light Source

2.1 Introduction

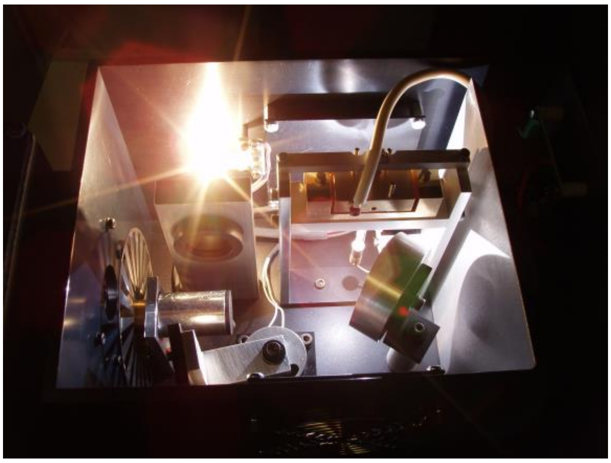


Figure 2.1: Dual Source

The probe light source here employed is a dual xenon/quartz halogen source having a computer controlled swing away mirror between them to permit selection as a function of wavelength and an arrestable optical chopper to provide an AC probe signal.

Whilst the xenon source provides higher output throughout the visible, this is accompanied with unstable line emission. The quartz halogen lamp, despite its lower output, represents a very stable source up to 3µm.

In effect, the system operates in a mode in which the instability of the xenon lamp is taken account, the recommended cross over point between xenon and QH lamp use is 800nm.

Note that the dual housing has a fan situated to one side. This fan should be connected to the 610 at all times and should be powered on when the source is in use.

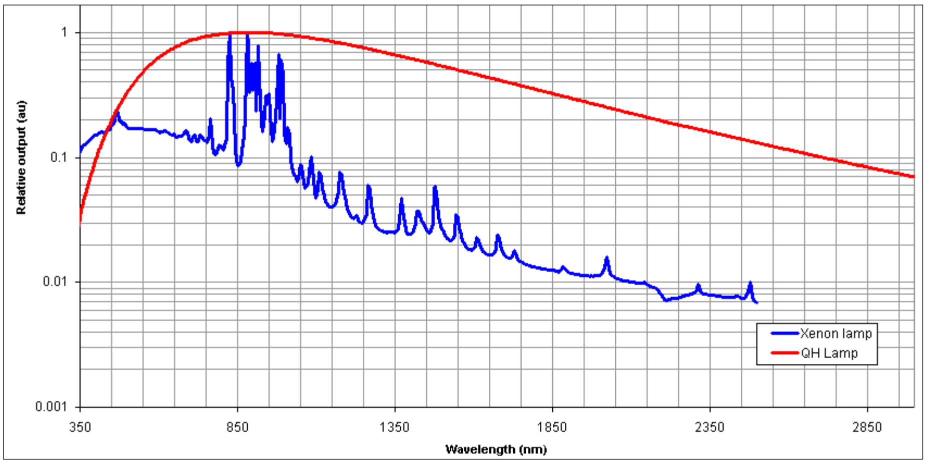


Figure 2.2: Relative output of xenon and quartz halogen lamps

NOTES:

1. **The lamp housing becomes hot during operation.**
2. **On powering up the xenon lamp, a starter drops a high voltage across the electrodes to commence the arc. It has been seen that this discharge can damage other electronics. It is recommended where possible to switch on all discharge sources first before monochromator and electronics.**

2.2 Xenon short arc lamp

The output from the 75W xenon lamp is coupled to the monochromator via an off-axis parabolic reflector. The output is coupled to the monochromator save when the SAM is activated to couple light from the QH lamp.

This lamp should be operated at 5.40A with a Bentham 610 supply. The 610 destined for use with this lamp is indicated. Lamp life is estimated at around 1000hrs.

2.3 Quartz Halogen Lamp

The output from the 100W quartz halogen lamp is coupled to the monochromator via an arrangement of condenser lenses. The output is selected when the SAM is energised, in which case the latter also blocks the light issued from the Xenon lamp from reaching the monochromator.

This lamp should be operated at 8.50A with a Bentham 610 supply. The 610 destined for use with this lamp is indicated.

2.4 610 Constant Current Supply

2.4.1 Introduction

A rotary switch provides 5 calibrated pre-set current settings; 4.00 A, 5.40 A, 6.30 A, 8.50 A, 10.40 A. Users also have access to a variable output ranging from 0 to 10.4 A, PC setting where users can control the unit via the USB port on the rear of the unit.

Figure 2.3: 610 supply

Temperature stability	30 ppm/°C	
Indications	Green LED= Power on Red LED = Lamp failure	
Front panel meter	Output voltage indicator	
Fan output	12V ac (typically 200mA)	
Mains input voltage:	Back panel switch to select nominal 110V or 220/240-V ac	
Mains frequency	50 or 60 Hz	
Mains input fuse	220/240V	2.5A Anti-surge
	110V	5A Anti-surge

Table 2.1: 610 specifications

A socket for lamp fan operation is situated on the lower right of the front panel.

2.4.2 Setting up mains voltage

Whilst the mains voltage is set up at Bentham according to where the device is sent, it is of good practice to verify before powering up the 610.

A toggle selector should be found underneath the mains connector to the rear of the 610. Please ensure that the voltage of the country in which the 610 is to be used is displayed.

Figure 2.4: Voltage selector displaying voltage in use

At Bentham, the appropriate fuse (plus a supplement) is fitted. Should the voltage setting be wrong, please ensure that the correct fuse is installed.

2.4.3 Lamp Operation

- Ensure fan is connected and power on
- Use the rotary switch on the 610 to select the current required
- Should the required current not appear as a pre-set value, use the adjustable dial on the right hand side and select that channel

Operating conditions are as follows:

Source	Current (A)
100W QH lamp	8.500
75W Xenon lamp	5.400
50W QH lamp (solar simulator)	4.000

Table 2.2: Lamp current settings

Depress the output button to illuminate/extinguish the lamp

2.4.4 Operation Notes

For correct lamp operation, please respect the following:

- Please ensure the correct polarity is respected at all times, connecting red to red and black to black from lamp to 610
- Always ensure that the fan is connected to the 610
- Do not touch bulb with bare fingers.

- Do not run the lamp at a current lower than that at which it is specified. Under-running a quartz halogen lamp can curtail lifetime by breaking down halogen cycle.
- The lamp requires approximately ten minutes warm-up time

Furthermore, it is of use to note the voltage displayed on the 610 LCD. This is for indication only, but can be used to determine lamp condition[1]. Quartz halogen lamps are operated at slightly under their nominal rating, and as such the voltage readings may be lower than nominal.

[1]One of the failure mechanisms of such lamps is "bridging" or short-circuit of part of the filament, leading to a correspondingly lower voltage and reduced light output.

3. Monochromator

3.1 Monochromator operation

No light source is truly monochromatic, i.e. does not contain light of solely a single wavelength. All sources contain contributions from a finite range of wavelengths, namely its' spectrum.

A monochromator is a device which permits the determination of the spectral output of a source by separation and measurement of the component wavelengths.

3.2 Wavelength Dispersion

The simplest means of resolving component wavelengths is that seen when, for example, sunlight shines through raindrops to create a rainbow.

The apparently "white" light from the sun, on travelling through the droplet is refracted, or bent. The amount light is refracted depends upon its wavelength. Here, blue light on one extreme of the visible spectrum is refracted more than red light on the other extreme, resulting in a rainbow. In effect the sun contains wavelength components from the UV to the infra-red (heat radiation).

Wavelength separation in an analogous manner, using a prism, may be employed in a monochromator, yet has practical implications, namely due to material absorption of the incident light and the limited wavelength range of operation.

The preferred means of wavelength dispersion is by use of diffraction gratings.

3.3 Diffraction from a grating

In Bentham monochromators, diffraction gratings are used for wavelength dispersion. Rather than using the refraction of light, diffraction gratings depend on the diffraction, or interference of light.

Diffraction gratings can come in two forms, reflection or transmission gratings. Since it is the former that are employed in Bentham monochromators, here shall be considered this specific case.

A diffraction grating is effectively a surface which, on the microscopic scale, contains a vast number of "terraces", or grooves, separated by a distance comparable to the wavelength of light to be considered. Bentham uses gratings with a "groove density" from 75- 2400 grooves per millimetre.

On shining light upon this surface, each terrace acts as a narrow slit-shaped source. It is the interference of the light from these sources that is of interest.

Diffraction can be visualised by the following, whereby light of wavelength λ is incident at an angle α to the normal of a diffraction grating of groove spacing, d. Light is diffracted along angles β_m into a number, m, of diffraction orders.

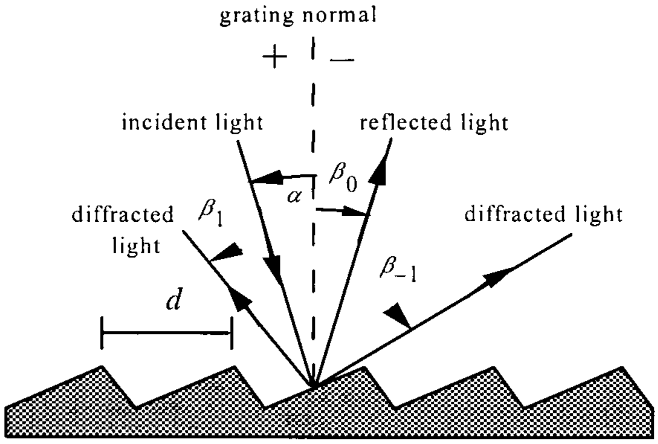


Figure 3.1: Plane reflection grating diffraction

Now, it is known that light in can behave like a wave. When two wave peaks are coincident, results a larger peak, the inverse in the case of troughs. In between these extremes, vary amounts of interference occur.

A sign convention exists for the definition of angles and orders. In general angles are measured from the grating normal to the incident wavefront. Should diffraction occur on the opposite side of the grating normal, then negative angles are used.

This view can be simplified to the following, where one can consider two adjacent grooves separated by a distance, d.

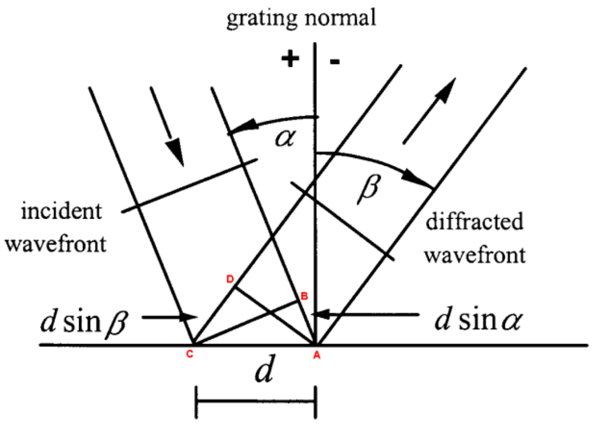


Figure 3.2: Path difference between neighbouring rays

The geometrical path difference, Δ, between the path of the incident wavefront between A and B and the diffracted wavefront between C and D is

$$\Delta = AB + CD = d \sin \alpha + d \sin \beta$$

Now, for constructive interference to obtain, adjacent rays must differ by integer number of wavelengths. This leads to the grating equation.

$$m\lambda = d(\sin\alpha + \sin\beta)$$

or

$$Gm\lambda = \sin\alpha + \sin\beta$$

where G is the groove density, G= 1/d.

For a given incidence angle α, there shall therefore be a set of discrete angles for which constructive interference shall be observed. At all other angles, there will be some measure of destructive interference. Here m is the diffraction order and is an integer.

Since the absolute value of the sine function cannot exceed unity, then:

$$| m\lambda / d | < 2$$

For a particular wavelength the above gives the possible diffraction orders present.

Specular reflection (α =β) always exists, this is the m=0, zero order position, where the grating simply acts as a mirror and the component wavelengths of the incident wavefront are not separated.

In Bentham monochromators, the grating is rotated as a function of wavelength,
about a pivot coincident with the central ruling, to scan through wavelengths. The direction of the incident and diffracted light remains therefore unchanged.

In this case, one refers to the angular deviation, 2K, between the incidence and diffraction directions, defined as:

$$2K = a - \beta = \text{constant}$$

Further defined is the scan angle, ϕ, measured from grating normal to the dissector of the beams

$$2\phi = a + \beta$$

Now, substituting, the grating equation becomes:

$$m\lambda = 2d\cos K \sin\varphi$$

For a given monochromator K is a constant, therefore one can determine select a wavelength by determining the required grating angle.

3.4 Diffraction orders

As noted above, the grating equation may be satisfied at a given angle by a number of wavelengths of different diffraction orders.

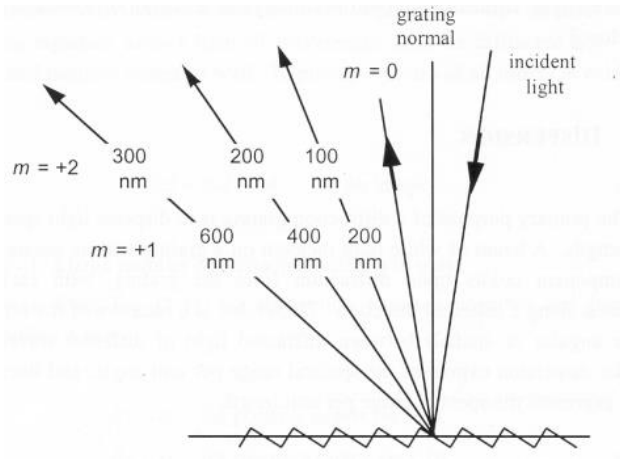


Figure 3.3: Existence of diffraction orders

This can lead to problems when attempting to measure light in a given diffraction order, when the detection system is capable of sensing the wavelength in the next diffraction order etc.

Order sorting is therefore required, and consists of the filtering of the monochromator input with long pass filters where higher diffraction orders might be present.

This also leads to on explanation for measurement in first order. The wavelength of light that diffracts along the direction of λ_1 in order m+1, is $\lambda_1+\Delta\lambda$, where

$$\lambda_1 + \Delta\lambda = \frac{m+1}{m}\lambda_1$$

Hence we define the free spectral range, the range of wavelengths over which overlapping of adjacent orders does not occur,

$$F_\lambda = \Delta\lambda = \frac{\lambda_1}{m}$$

3.5 Diffraction grating production

Gratings found in monochromators are replicas based on master gratings.

Master diffraction gratings are produced by one of two means:

1. Holographic exposure then chemical etch of grooves

2. Mechanical ruling of grooves

In the holographic technique a substrate is covered with a photoresist material whose properties change under light stimulation. Exposure to an interference pattern defines the grating outlay, chemical etching is then employed to selectively etch the substrate as a function of the photoresist.

This method produces almost sinusoidal grooves, but of very high surface quality.

The mechanical technique involves the mechanical inscribing, using a diamond tip in a "ruling engine" to define grooves on a metal substrate, a lengthy and difficult process.

This method yields very good, triangular grooves, resulting in gratings of very high efficiency. However, surface defects may have an impact in certain cases by introducing stray light into the monochromator.

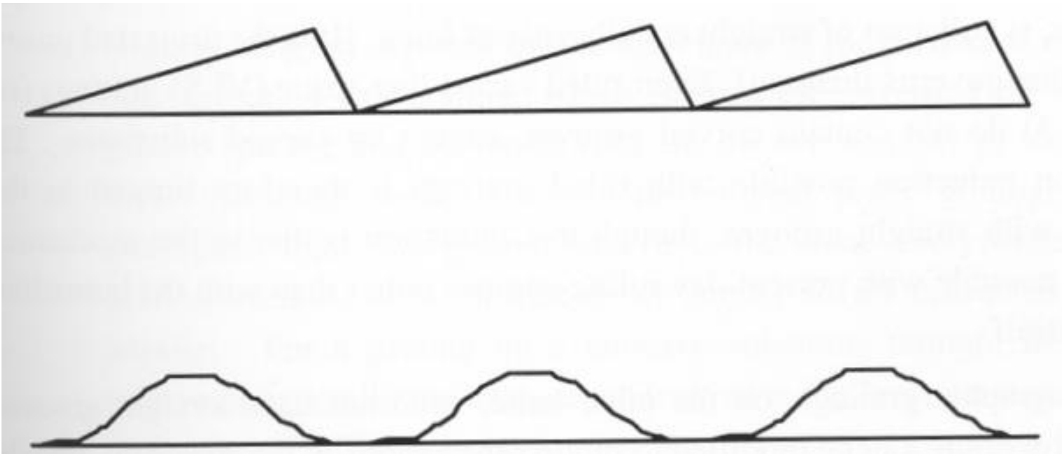


Figure 3.4: Groove shape obtained using ruling (upper) and holographic techniques

Replica gratings are resin casting of master gratings, on a glass substrate, which are then coated by a suitable metallic coating for the spectral range of use, such as aluminium.

Diffraction gratings may be produced on flat (plane) or non-flat (for example concave) substrates.

3.6 Diffraction grating efficiency

The efficiency of a grating is defined as the power of monochromatic light diffracted into a given order relative to that light incident.

In order to increase the efficiency of a grating at a given wavelength, the angle of the grooves is designed such that the specular reflection from the grating surface lies in the same direction as that wavelength in question.

This procedure is called blazing, the peak wavelength being the blaze wavelength.

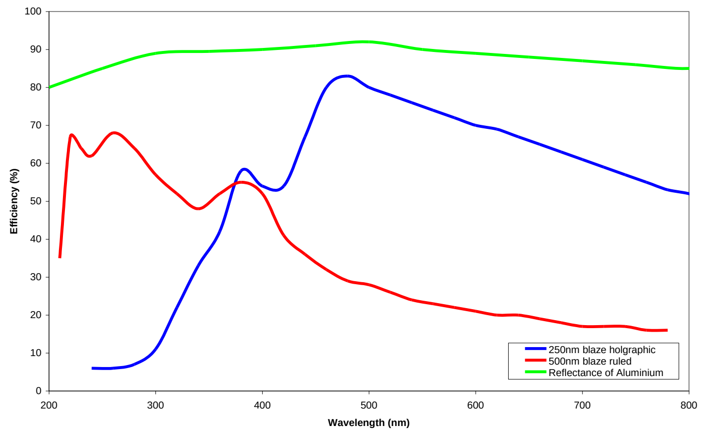


Figure 3.5: Example grating efficiency curves

The consideration of grating efficiency becomes more complicated when one considers polarised incident light, and in particular the case of TM polarised light in which case the electric field vector is perpendicular to the grooves, giving rise to anomalies, or abrupt changes in the grating efficiency curve.

3.7 Czerny-Turner Monochromator

The Czerny-Turner configuration, as employed in Bentham monochromators, uses a plane diffraction grating.

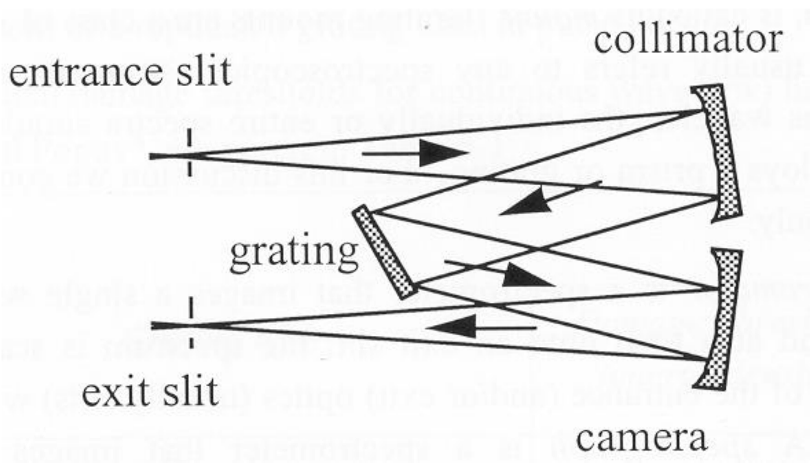


Figure 3.6: Czerny-Turner configuration

In order to control the location of diffracted light, the grating should be illuminated by collimated light. Incident light, diverging from an entrance slit is collimated by a first concave mirror. After diffraction from the grating, light is focussed to an exit slit by a second concave mirror. As a function of wavelength therefore, the grating is rotated to scan through a spectral range.

3.8 Stepping motor drives

It has been seen that in fixed angle monochromators, it is of question to move the diffraction grating through a range of angles in a repeatable manner. To this end, stepping motors are employed.

A stepper motor is a type of electric motor that moves in increments, or steps, rather than turning smoothly as a conventional motor does. The size of the increment is measured in degrees and can vary depending on the application. Typical increments are 0.9 or 1.8 degrees, with 400 or 200 increments thus representing a full circle. The speed of the motor is determined by the time delay between each incremental movement.

Inside the device, sets of coils produce magnetic fields that interact with the fields of permanent magnets. The coils are switched on and off in a specific sequence to cause the motor shaft to turn through the desired angle. The motor can operate in either direction.
When a current is passed through the coils of a stepper motor, the rotor shaft turns to a certain position and then stays there unless or until different coils are energized.
Unlike a conventional motor, the stepper motor resists external torque applied to the shaft once the shaft has come to rest with current applied. This resistance is called holding torque.
Stepping motors, combined with gear systems or sine-bar mechanisms are used to provide high precision and highly repeatable monochromators.

3.9 Double monochromators

When using a single monochromator such as that shown in figure 3.6, it is possible that light, entering from the entrance slit, be scattered off the walls and structures constituting the monochromator, reach the exit slit. Therefore, at a given wavelength, λ, an artificially high signal is measured.

This is termed stray light and is of concern where low light level measurements are performed where there exists a significant light component at other wavelengths. Classical examples are measurements of UV sources and high optical density filter transmission.

Consider for example the measurement of a quartz halogen lamp, a lamp often used as calibration standard. The following figure demonstrates the effect of scattered light in measuring the lamp UV output where there exists a significant amount of visible light.

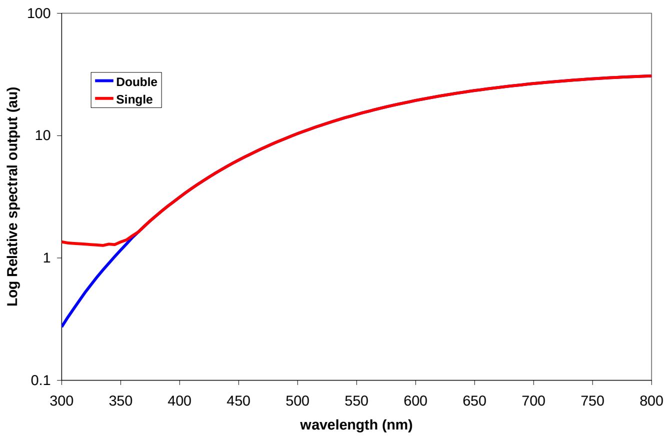


Figure 3.7: Measurement of QH lamp with single and double monochromators

A double monochromator situates a second single monochromator at the exit of the first.

Entering the first monochromator is all the light from the source to be measured; entering the second monochromator is the wavelength selected and a level of stray light, which one desires to reduce.

In the second monochromator, the desired wavelength re-selected; at the exit slit one finds that the level of the stray light has reduced to the square of the case of the single, for example a factor 10^3 down in a single, a factor 10^6 down in a double.

There are two possible configurations of double monochromator; with additive or subtractive dispersion.

With additive dispersion, the first monochromator is followed by a device of similar type. The band of light transmitted from the first to second is further dispersed, resulting in twice the dispersion of a single system; for a given required bandwidth therefore, the monochromator slits may be doubled in size with respect to a single monochromator, which increases the system throughput.

With subtractive dispersion, the second monochromator is operated in an inverse manner to the first in such a manner that at the exit slit there exists no net dispersion.

At the exit of the first monochromator, the light to be transmitted to the second monochromator is dispersed across the slit; at the exit of the second monochromator this dispersion does not exist and all the wavelengths are combined. The dispersion of a subtractive double monochromator therefore is the same as that of a single monochromator.

The subtractive configuration is often employed in such systems as primary transfer standard where the uncertainty of dispersion across the detector slit is unacceptable (yet for most applications of no real consequence).

A further important point is that of the slits of the double monochromator.

With additive dispersion, it is the entrance and exit slits which define the system bandwidth, the middle slit between the two monochromators being employed to reduce the stray light being transmitted to the second element. The middle slit should be at least twenty percent larger than the largest slit of the system to prevent tracking problems (beating) between the two component monochromators.

With subtractive dispersion, it is the entrance and middle slits which define the system bandwidth; the exit slit is employed to reduce the system stray light and again should be at least twenty percent larger than the largest slit of the system.

3.10 Wavelength calibration

The TM family of monochromators contain a turret (per monochromator) upon which can be mounted up to three diffraction gratings.

The turret is driven through a reduction gear from a stepping motor which is used in the micro-stepping mode, yielding an angular resolution of 0.00072° per step which corresponds to 500,000 steps per revolution of the turret

Each monochromator includes a two-stage encoder which allows the unit to be sent to a fixed point (negative limit) which is used as a datum. On software initialisation, the turret is sent to this “park” position.

For each grating, is provided two parameters; the first is the number of steps which must be made from the datum position to reach the nominal zero order position for that grating (zord), the second is a scaling factor (value near 1) which gives the best wavelength linearity (alpha).

For systems having multiple exit ports, by use of swing away mirrors (SAMs), setup involves ensuring the good calibration of all ports with one set of grating parameters.

The results of the wavelength calibration (zord and alpha per grating) is provided for all monochromator exit slits.

By far the most useful wavelength calibration source is the mercury lamp, the spectrum of which contains a large number of discrete emission lines in the UV- visible domain, the wavelength of which never change.

It is worth noting that in the case of high pressure mercury lamps, the lines may be broadened with respect to those emitted from a lower pressure lamp. Values are given in appendix 1.

In spectroradiometry, the first order contribution is most commonly used, however, for purposes of wavelength calibration, higher order contributions may be of use.

Furthermore, in the case of gratings for use in the infra-red, where there exists no useful contribution from the mercury lamp output, the zero-order position is used to set up gratings, in which case light incident on the entrance slit is transmits directly to the exit slit.

In effect the mercury spectrum is virtually omnipresent to a certain extent in the laboratory environment, overhead fluorescent tubes containing some of this vapour.

Alternative calibration sources are lasers or interference filters of known transmission, which may be suitable for certain wavelength regions, but do not have such wavelength coverage as the mercury lamp. Please see appendix 2 or information concerning checking the wavelength calibration.

3.11 TMc300 Monochromator

The monochromator of this system is a Bentham TM300, 300mm focal length monochromator.

In the TMc300 monochromator, up to three diffraction gratings are mounted on a turret to permit use over a wide spectral range.

The turret is driven through a reduction gear from a stepping motor which is used in the micro-stepping mode, yielding an angular resolution of 0.00072° per step which corresponds to 500,000 steps per revolution of the turret.

Figure 3.8: TMc300-FU monochromator

For each grating is provided two parameters, the first is the number of steps which must be made from the datum position to reach the nominal zero order position for that grating (zord), the second is a scaling factor (value near 1) which gives the best wavelength linearity (alpha).

The TMc300 includes a two-stage encoder which allows the unit to be sent to a fixed point (negative limit) which is used as a datum. On software initialisation, the turret is sent to this position.

A six position order sorting filter wheel is situated behind the entrance slit.

There exists in this monochromator two exit ports with a swing away mirror positioned between the two.

All ports are fitted with fixed slits to define system bandwidth.

3.12 Diffraction gratings

This system is fitted with the following gratings:

Line density (g/mm)	λ Blaze (nm)	Max λ range (nm)
1200 Ruled	500	300-1100
600 Ruled	1250	1000-2500

Table 3.1: Diffraction gratings installed

3.13 Order sorting filter wheel

The governing diffraction equation admits solutions for integer multiples of the wavelength in consideration, thus diffraction orders. Most spectroradiometry is performed on the first order contribution, it is necessary to avoid measurement of higher order signals for correct measurements.

A six position order sorting filter wheel is to be found on the inside of the monochromator exit port. The following filters are fitted:

Position	Filter	Insertion (nm)
1	Open	0
2	OS400	400
3	OS700	700
4	OS1250	1250
5	Open	-
6	Shutter	-

Table 3.2: Filter wheel content

A blank disk, in position six stops light from entering the monochromator during dark current and offset measurements.

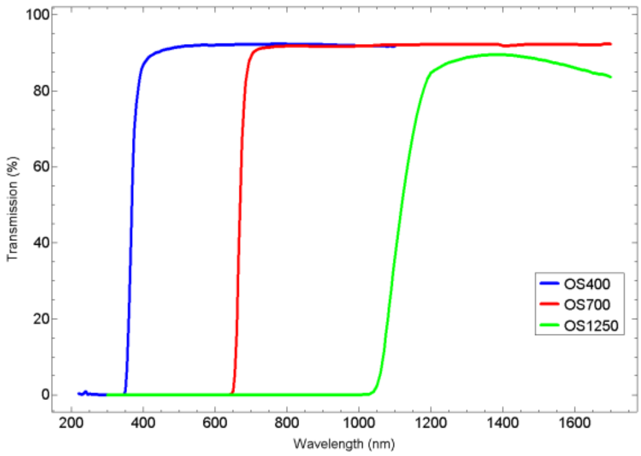


Figure 3.9: Typical OS filter transmission

3.14 Monochromator Bandwidth

The monochromator bandwidth, defined in nm, is the range of wavelengths seen by the detector at one time, and is directly linked to the monochromator slits in use.

This is an important quantity to take into account, particularly when measuring sources have fine spectral features such as line emission. For example, the measurement of a source having two spectral lines one nanometre apart with a system bandwidth of five nanometres, will result in the measurement of a single line. In many instances this is of no concern, since the power measured shall nevertheless be correct.

The effect of monochromator entrance and exit slits on monochromator bandwidth can be viewed in two manners.

In the first instance, the monochromator is an imaging system; the input port is imaged at the exit port; the dimension of the monochromator entrance slit defines the image size at the exit port.

Furthermore, since the light incident at the exit of the monochromator is dispersed one can imagine the wavelength axis running along parallel to the wall of the exit slit, and the size of this slit determines how many wavelengths can be seen at one time.

One can imagine therefore an infinite number of images of the entrance slit of incrementally differing wavelength presented parallel to the exit slit; whichever of the two are the largest, defines the bandwidth of the system.

In a double monochromator, a further slit is included, the middle slit (in the case of a system having additive dispersion). The purpose of this slit is to reduce the amount of stray light going from the first to second monochromators and should at all times be set to at least 20% larger than the largest slit in the system, else tracking problems between the component monochromators shall result.

The slit function of a monochromator provides interesting information with regards to the device performance and the system bandwidth; this may be determined by the measurement of a source of narrow spectral width, such as a laser.

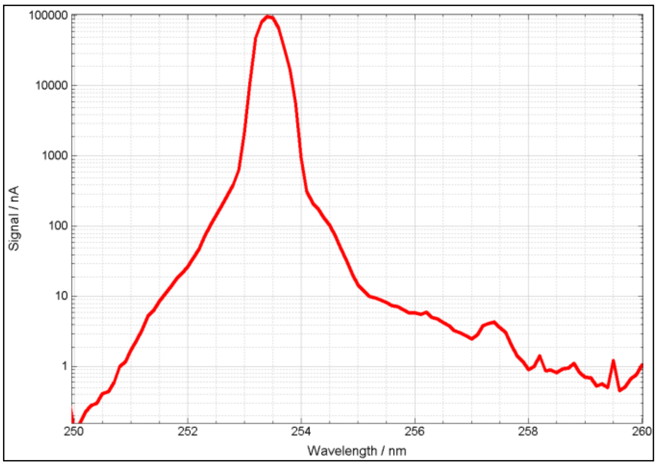


Figure 3.10: Example measurement of slit function

One should perform a measurement at smaller steps than the system bandwidth (for example 0.1nm), over a spectral range of around four times the expected bandwidth, centred on the expected wavelength of the emission line, for example 632.8nm for the HeNe laser.

The full width half maximum (FWHM) of this spectrum provides the bandwidth of the system. Inspecting the signal at one bandwidth, two bandwidths etc. relative to the peak, provides information of the stray light performance of the system.

If the entrance and exit slits are of the same dimension, the slit function shall have a triangular profile, otherwise, the function shall be flat-topped.

It is worth noting that care should be made in making this measurement as it is not sufficient to shine a laser in the entrance slit of the monochromator. This measurement should ideally be performed by filling the entrance slit, using an integrating sphere for example and illuminating the sphere with the source.

Finally, it follows that slit dimension has an impact of the light throughput of the monochromator. In certain instances where a reduction in signal is required, either the entrance or exit slit can be reduced, whilst maintaining the same system bandwidth. It is preferable that the slit to be reduced be the exit slit to avoid any conflict with the input optic.

It is important to remember that to perform a scan with a step size lower than the bandwidth obtained is satisfactory, on the contrary to step larger than the bandwidth results effectively in the loss of information.

For information, the following table shows the bandwidth obtained for the monochromator and gratings of this system with a range of slit widths, those supplied being highlighted.

Fixed slits are changed by the following method, see figure 3.11.

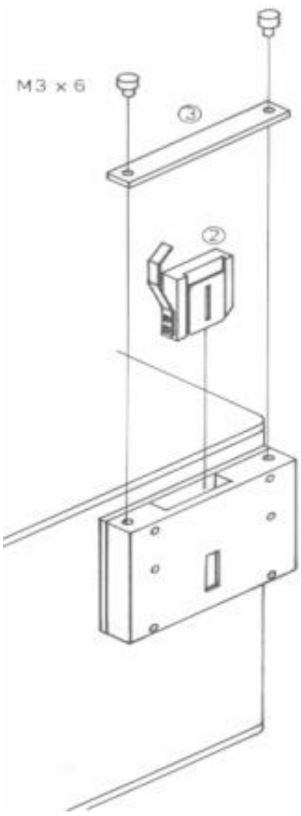
Removing slits:

- Remove fixed slit cover with M3 Allen key
- Using pincers, pull out slit in place

Inserting slits:

- Place slit in holder with **etched side facing away** from monochromator, **flat rear of slit against the monochromator**
- Push fixed slit down, firmly into place

It is important that the slits are installed in the correct orientation, else a wavelength error results.



Grating Groove Density (l/mm)		1200	600
Reciprocal Dispersion (nm/mm)		2.70	5.40
Slit widths (mm)	Part no. for pair of slits	Bandwidth produced (nm)	
0.05	FS (0.05)	0.14	0.27
0.1	FS (0.10)	0.27	0.54
0.2	FS (0.20)	0.54	1.08
0.37	FS (0.37)	1.00	2.00
0.4	FS (0.40)	1.08	2.16
0.5	FS (0.50)	1.35	2.70
0.56	FS (0.56)	1.51	3.03
0.74	FS (0.74)	2.00	4.00
1	FS (1.00)	2.70	5.40
1.12	FS (1.12)	3.03	6.05
1.48	FS (1.48)	4.00	8.00
1.85	FS (1.85)	5.00	10.00
2	FS (2.00)	5.40	10.81
2.78	FS (2.78)	7.51	15.02
3.7	FS (3.70)	10.00	19.99
4	FS (4.00)	10.81	21.62
5.56	FS (5.56)	15.02	30.05
8	FS (8.00)	21.62	43.23
10	-	27.02	54.04

Figure 3.11: Changing fixed slits along with a table of the slit widths and bandwidths that these produce

3.15 Setting mains voltage

The TMc300 is fitted with a switch mode power supply. However, prior to switching on the monochromator, please ensure that the line fuses selected are correct for the mains voltage in your region.

Whilst the housing is destined to have one orientation (and one fuse) for 110V and another for 240V, in practice, the same fuse for the destination region is included. Ensure that the white indicator arrow points to the appropriate setting.

Fuses are:
110 V- 1260mA anti- surge
220/240V – 630mA anti- surge

4. Probe Beam Optics

A mirror- based relay optic is employed to image the output of the monochromator at the sample plane. This optic provides a magnification of ~1.2. In practice, it is an aperture which is imaged to provide a controlled probe spot on the sample. Therefore, an aperture is placed in the exit slit of the monochromator instead of the usual rectangular slit.

One is limited here to the dimension of the aperture used (and therefore spot size), since, were the aperture larger than the entrance slit, it would define the system bandwidth, which may not be desirable.

This eventuality has been catered for in the use of an extended aperture box attached to the exit slit, and by mounting the monochromator on a rail.

In this manner, were for example a 5mm spot required, but the slit width used in the system be 1.85mm (corresponding to 5nm with the 1200g/mm grating), then the 1.85mm slit would be placed in the exit port, and a 5mm aperture would be placed in the aperture box.

The monochromator should be sent to a visible wavelength, using signal setup, and the position of the aperture in the aperture box adjusted such that the light output from the monochromator just overfills the aperture.

The position of the monochromator should then be altered to achieve a focussed image of the aperture at the sample plane, and locked into place.

5 Solar Simulator

5.1 Overview

The requirements of this system is for a ~1 cm^2 uniform solar simulator output at the sample plane, tuneable from 0.1-1 sun output (1000 Wm^{-2}) over the range 400-1100nm.

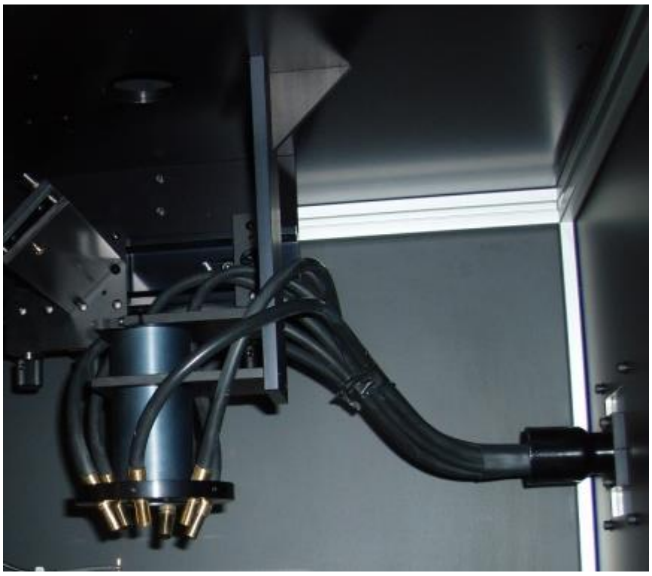


Figure 5.1: Coupling from solar simulator

The solar simulator comprises of 1 or 2 50W quartz halogen lamps, which are coupled by a rear reflector to a 6-branch glass fibre bundle, to achieve uniformity at the sample plane. This source should be operated at 4.00 A by the bias 610.

The source is fitted with a solenoid-based shutter, controlled via a swing away mirror control in the monochromator to apply or not the bias source as required. Holders for 50mm square filters are provided to permit filtering the solar simulator should this be required.

5.2 Mechanical

The solar simulator is mounted to the wall of the PVE300, at which place is adapted the six branch fibre to the source.

The six branches are connected to the sample optic by pushing through such that the ferrule is flush with the bottom of the holding plate, and are held by grub screw.

5.3 Setting Irradiance Level

The level of the bias can be adjusted by a bi-lateral variable slit, one turn of which equates to 0.5 mm. The levels can be measured and set, and the required micrometer setting recorded.

The position of the micrometer may be locked by the clockwise rotation of a collar at the base of the barrel; this should be loosened before proceeding to change. The level of bias can be measured directly as an irradiance measurement, or should one have access to a luxmeter, by measuring the illuminance in lux at the sample plane, one can use the following scaling factor to approximately determine the irradiance over the range 400-1100nm with no filter in place (*37.6 lx ≈ 0.523* Wm^{-2})

6. DTR6 Integrating Sphere

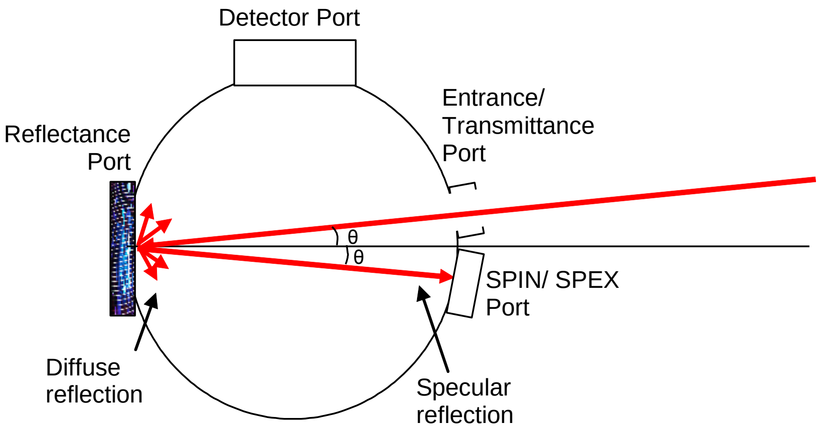


Figure 6.1: Geometry of DTR6

6.1 Overview

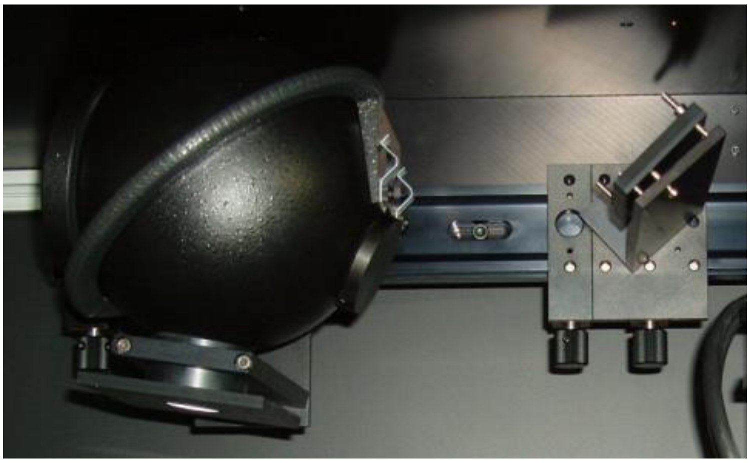


Figure 6.2: DTR6 installed in PVE300

The DTR6, situated on an optical rail to the top of the PVE300 system may be used by relaying the probe beam, via the moveable 45° mirror to the horizontal plane.

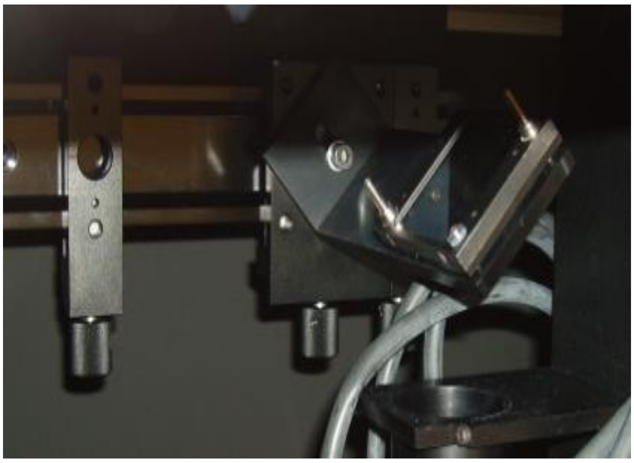


Figure 6.3: Relay mirror reflecting light toward DTR6

Used in one of two configurations, the DTR6 may be used for the measurement of transmittance or reflectance.

6.2 Integrating Sphere Theory

The integrating sphere is coated with Barium Sulphate, a highly diffusely reflecting material.

It is so called, since light impinging on the walls of the sphere is reflected in all directions such that the light is "averaged" over the surface of the sphere walls; placing a detector in a first consideration, should read the same result independent of position.

In practice this is not strictly the case since there shall exist entrance and exit ports in the sphere walls, and baffle structures are employed to prevent light from the source reaching the detector without being reflected off the sphere walls.

6.3 Measurement of reflectance

6.3.1 Measurement of reflectance

The measurement of sample reflectance is made with respect to a reference standard of reflectance. The sphere is positioned at such a position that the probe beam is focussed onto the plane of the reflectance sample port. It is important that this image under-fills this port.

6.3.2 SPIN/SPEX reflectance

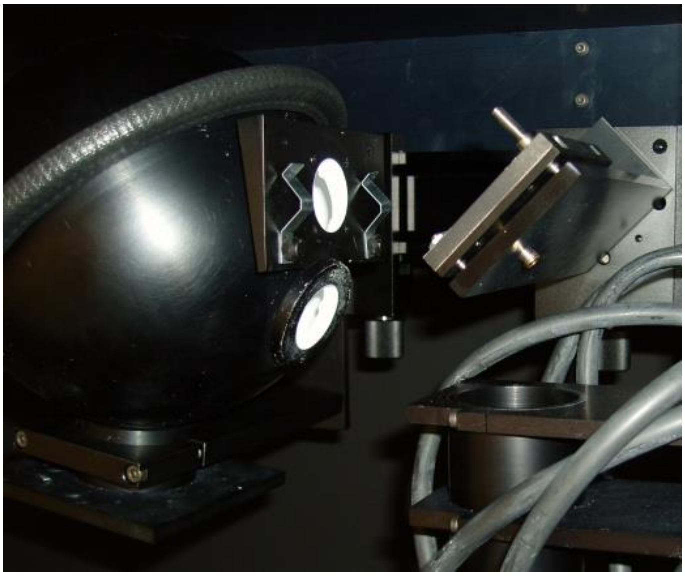


Figure 6.4: For measurement of reflectance sphere pushed against right hand stop

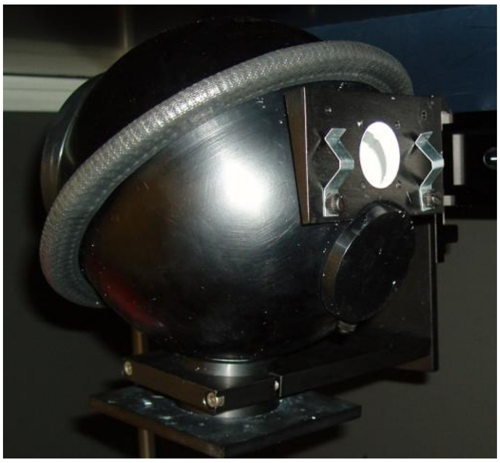
The integrating sphere captures all light reflected from the sample being measured. Here, one can distinguish between specular and diffuse reflection.

Specular reflection is that which occurs at the same angle of incidence, and can be suppressed by placing a light trap at the SPIN/SPEX port- this signal shall be attenuated and shall not contribute to the measurement of reflectance.

This is termed SPEX or specular exclusive reflectance.


Figures 6.5 & 6.6: Specular trap, and fitted to DTR6

On the contrary, SPIN (specular inclusive) reflectance is measured by placing a reflective plug at the SPIN/SPEX port.

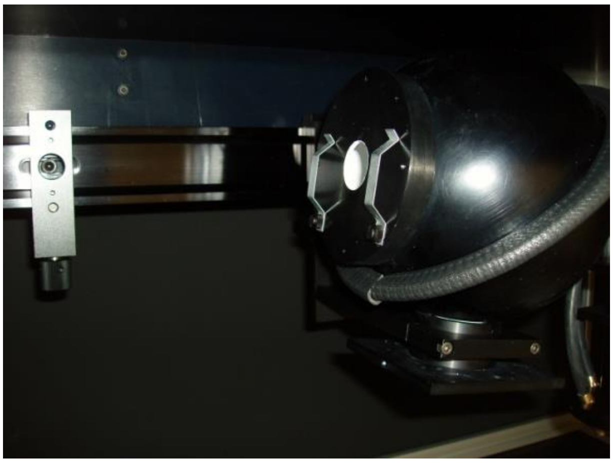



Figures 6.7 & 6.8: Specular "includer", and fitted to DTR6

Light is reflected back into the integrating sphere and therefore is included in the measurement.

6.3.3 Sample Port

Slide clips may be attached to the sample port to hold samples in place.



Figures 6.9: Sample port

Where the sample to be measured is smaller than the port size, port reducers are provided, which screw to the sample port side. It is important to ensure that the probe beam size is selected such that the beam be smaller than the port at all times.

Figures 6.10: Set of port reducers

Figures 6.11: Sample port reduced

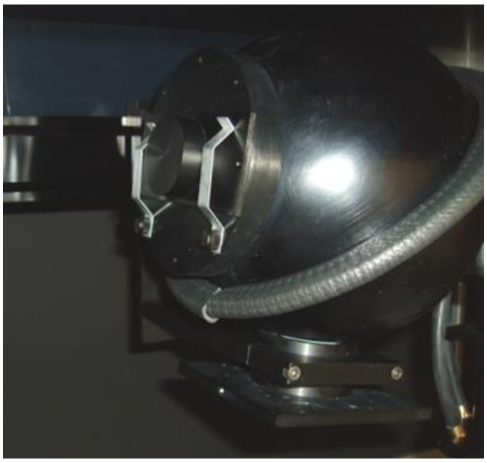
To aid visualisation of what is being measured at the sample port, is provided a viewer which attached to the specular port.

Figures 6.12: Sample port viewer

Figures 6.13: Sample port viewer installed

6.3.4 Reference Standard

A PTFE-based reference reflectance standard is provided to calibrate the system against a presumed reference level of 100%.



Figures 6.14: Reference standard in place

6.3.5 Detector

Light is detected by mounting the silicon-InGaAs sandwich detector at the detector port (lower). The output of this detector is coupled via the 498 amplifier to the lock-in amplifier.

6.4 Measurement of transmittance

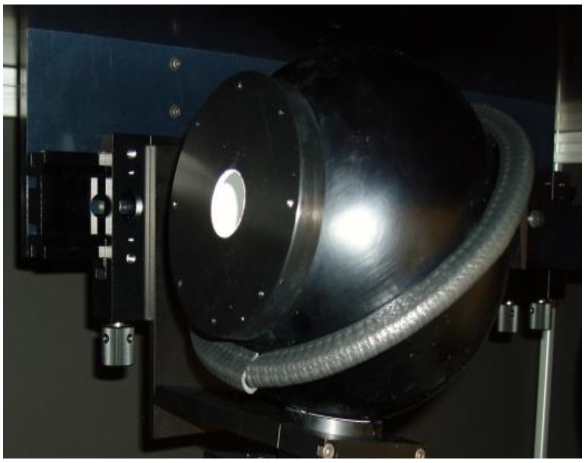


Figure 6.15: For measurement of reflectance

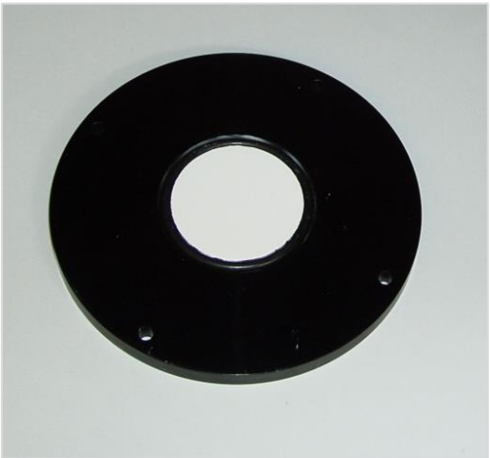


Figure 6.16: Reflectance port cover sphere pushed against right hand stop

The measurement of sample transmittance is made with respect to a system measurement with no sample in place. With a sample in place, any light that is transmitted may be diffused off the optical path. The integrating sphere collects all light transmitted through the 2π steradians behind the device. For this measurement, it is necessary to cover the reflectance sample port with the above cover.

7. X-Y Translatable Temperature Controlled Vacuum Mount

7.1 Overview

Measurements of spectral response being a function of sample temperature, the vacuum controlled temperature mount ensures stable sample temperature, even under operation of the one sun bias source.

The temperature controlled vacuum mount is in turn mounted on an X-Y stage to allow measurement across the area of the sample under test.

7.2 Temperature Controlled Vacuum Mount

The temperature controlled vacuum holder has been designed to accommodate samples of a number of sizes, having a water cooled Peltier heat pump system to maintain sample temperature at the desired 20°C.

There are three pipe connections to the mount, vacuum, water in and water out. A further electrical connection is provided for a temperature sensor embedded in the mount.

Two probes are provided for electrical connection to the sample, one for p-up devices, and one to provide a ground, having a shorting termination at its' BNC connector.

An earthing point is provided to the side of the mount, and an earth strap provided. This latter can therefore connect either the mount to a p-up probe, or interconnect the two probes.

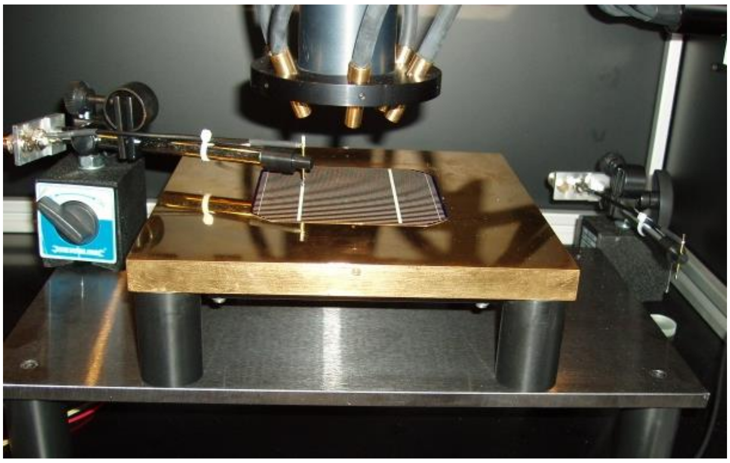


Figure 7.1: Vacuum mount with probe

The probes are mounted on magnetic base stands, and have a thumb screw adjustable mechanism for fine motion of the height of the probe. The electrical connections to the current amplifier being via co-axial cable, all connections to the detection electronics emanate from one probe.

7.3 Vacuum Mount

The vacuum sample holder is formed in a cross pattern to permit use with large and small samples. It may be found that when using small samples, optimal operation of the vacuum would be had by covering the unused holes.

The vacuum is connected via the chamber interface plate to the vacuum port of the controller. When switched on the air pump makes significant noise. It is recommended to minimise the length of the intervening pipe to obtain best vacuum performance.

7.4 Temperature Control

The temperature control comprises a water re-circulation system and Peltier cooler to provide only a cooling effect, with the desired set temperature of 20°C.

The water re-circulation system enters one side of the mount, exits the other, and along the depth of the mount there exists spurs, akin to the design of a radiator heater, to ensure even distribution of water.

The water circulation can be used on its' own if desired, the cooling does not operate if the circulation is not on.

A switch permits the selection of viewing on the LCD the actual mount temperature or the set temperature, the black rotary switch being used to define the temperature. This, when pushed in, is locked in place.

Once the mount is filled then it is only necessary to drain and refill when the water becomes contaminated, as seen via the filling chamber.

7.4.1 Filling the Water Re-circulation Circuit

The fill procedure is as follows:

- Using funnel fill reservoir
- Switch on pump for short time ensuring all pipes are connected
- Using an iterative process, switch on pump, and gently rock the vacuum mount to expel all air
- Ensure there is no air lock in the reservoir
- Top up reservoir
- When air is expelled from the system the pump runs more quietly
- Stop reservoir
- Ensure the pump is not run for any significant duration without water.

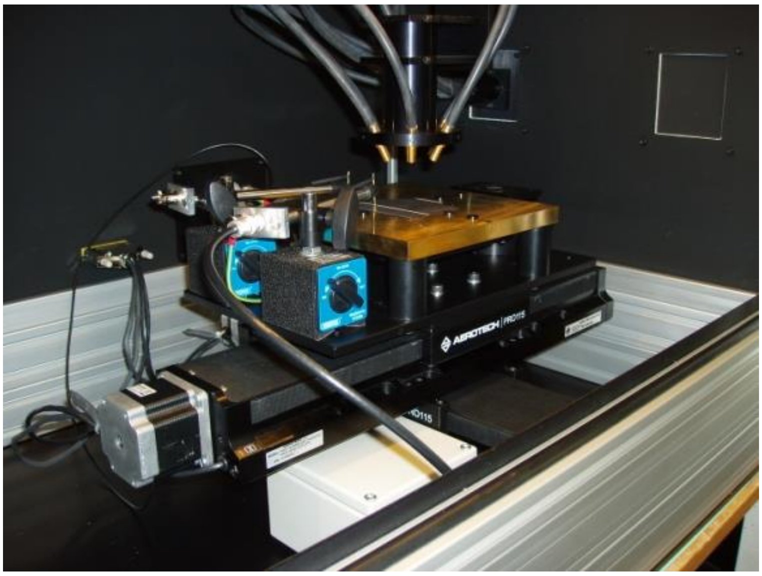


Figure 7.2: PVE300 vacuum mount on X-Y stage

8. PVE300 Chamber

The sample chamber is provided, with a door, to provide a means to perform measurement excluding all ambient light. The sample chamber has to the front right side a panel for making electrical connections to the inside of the box. At the rear right side of the chamber is provided a panel though which the connections to the temperature controlled vacuum mount are made.

To the upper of the chamber, an optical rail is situated for use with the integrating sphere based accessories to measure reflectance and transmittance. A translatable 45° mirror permits relaying the probe either to the vacuum mount for the measurement of EQE or the DT6 six for measurement of transmission and reflectance.

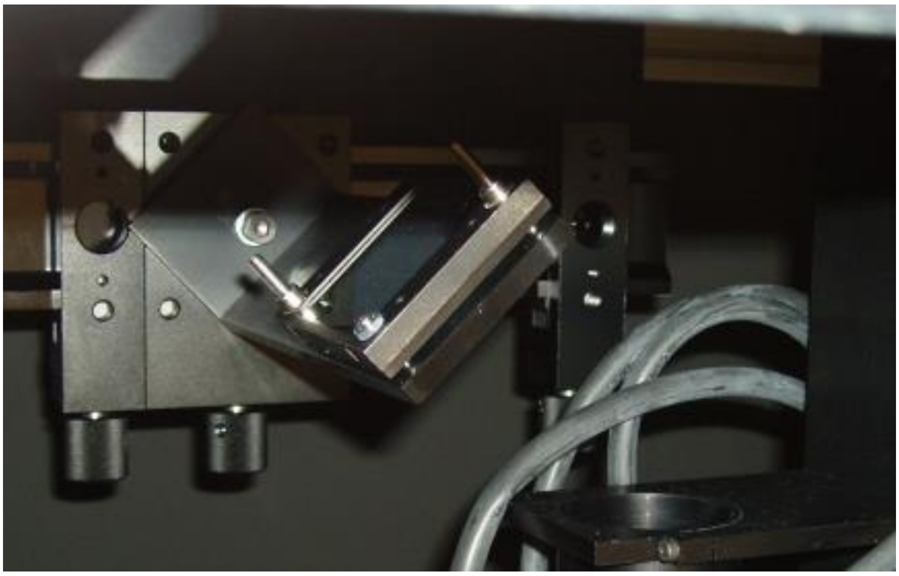


Figure 8.1: Relay mirror out of beam (EQE)

9. Detectors and Detection Electronics

9.1 Overview

The PVE300 has two modes of operation- with a DC probe or with an AC optical probe (10Hz-2kHz), often used in conjunction with a DC bias source. The conditions of measurement of spectral response and EQE, and signal recovery depends upon the material system under consideration, as discussed in §11.

The measurement of reflectance and transmittance may be performed in either mode, yet AC is the default. An arrestable optical chopper is located in the dual light source to modulate the probe on a known carrier wave for AC operation; arrested DC operation obtains.

9.2 System Detectors

This system comprises three detectors.

A calibrated 10x10mm silicon detector, and a calibrated 5mm diameter Germanium, both with calibration traceable to national standards, are used to calibrate the PVE300 for the measurement of spectral responsivity, by effectively determining the power in the probe beam as a function of wavelength.

These device should not be used with the bias source, because of issues of linearity.

An un-calibrated silicon-InGaAs sandwich detector is mounted to the DTR6 in the measurement of reflectance and transmittance over the range 300-1700nm.

9.3 Detection Electronics

9.3.1 Components

The detection electronics are housed in the 417 unit, to which is connected the controlling USB bus. The various components are as follows:

Electronics Module	Function
417	Electronics modules bin, power supply and display
474	Low noise pre-amplifier
498	AC pre-amplifier/DC amplifier and ADC
496	Phase insensitive lock-in amplifier and ADC
218M	Chopper control

Table 9.1: Installed modules

9.3.2 417 Bin

Figure 9.1: 417 control panel

The 417 bin provides power to and houses Bentham detection electronic modules.

The display section of the 417 can be used to display the analogue output of certain installed modules.

A rotary switch permits selection of displayed channel.

Switch Position	Function Displayed
A	Output of 496 (0-10V)

Table 9.2: Live display channels

A BNC socket provides output of the function selected by the rotary switch.

Whilst the mains voltage is set up at Bentham according to where the device is sent, it is of good practice to verify before powering up the 417.

A toggle selector should be found underneath the mains connector to the rear of the 417. Please ensure that the voltage of the country in which the device is to be used is displayed.

At Bentham, the appropriate fuse (plus a supplement) is fitted. Should the voltage setting be wrong, please ensure that the correct fuse is installed.

The fuse rating is as follows:

220/240V	630mA anti-surge
110V	1260mA anti-surge

Table 9.3: Fuses used for different local voltages

9.3.3 474 Transformer/Ultra-Low Noise Pre-amplifier

Figure 9.3: 474 Transformer and Transformer Pre-amplifier

The cell is operated in either short circuit or under voltage bias to perform measurements. From there the 474 transamplifier decouples the AC optical probe generated photocurrent from that generated by the DC bias source, whilst the amplifier provides a fixed 1000x gain to boost the signal coupled from the transformer. The input from the transformer and output to the lock-in amplifier are labelled.

9.3.4 498 AC Current Preamplifier/DC Nanoammeter and ADC

Figure 9.4: 498 Current Pre-Amplifier and Integrating ADC

The cell should be operated in short circuit. This programmable AC current pre-amplifier/DC nanoammeter and ADC includes six decades of gain and a 14-bit ADC. This is, in normal use controlled by BenWin+.

It is possible to use locally should the need arise. To use locally, push the RTL button. This permits using the two buttons to the right of the gain range LEDs to change current gain range and the lower button to change between inputs.

This amplifier is for use when no or little DC bias is employed, and saturates at 100mA. Overload of range in use is indicated by red LED. The output of the 498 is 0-10V.

In the DC mode, the 498 operates stand-alone, in the AC mode, the output of the current amplifier should be connected to input 1 of the 496 module. For details of the ADC, please see §9.3.6

9.3.5 496 DSP Lock-in amplifier and ADC

Figure 9.5: 496 DSP Lock-in Amplifier and ADC

The 496 combines a lock-in amplifier with an analogue to digital converter and is used to recover an optically chopped signal between 10-2000 Hz. Inputs to the 496 are either directly from a voltage generating detector or through the 474 or 498 amplifier.

Reference input, the output signal from the chopper control module is also required for use. To use locally, push the RTL button. Each gain range of the lock-in amplifier outputs 0-10V.

The 496 lock-in amplifier is a key component of the system when operating in AC conditions where the optical signal to be measured may be confounded with a background optical signal, whether from ambient lighting, or in the infrared, heat (or infrared radiation) emitted by instrumentation and the background.

To discriminate the two contributions, the optical signal to be measured is modulated on a known carrier wave by an optical chopper, the relative phase difference between these two waveforms must be taken account of. In the 496, the input and reference are digitised prior to determination of the components in two orthogonal states in order to take the vector sum of the two. Phasing intervention as is custom with traditional lock-in amplifier-based systems, is therefore not required.

For details of the ADC, please see §9.3.6

9.3.6 ADC

The ADCs uses a continuously running voltage to frequency converter to produce a pulse train whose frequency is proportional to the instantaneous input voltage. The pulses are accumulated in a counter.

At fixed intervals, 100ms, the contents of the counter is transferred to an output buffer and the counter reset to zero. The total number of pulses accumulated by the counter in any counting period represents the true average of the signal during that counting period. If the accumulated pulses from a number of counting periods are added and normalised then a true average over a longer period is obtained.

The ADC has two other special features which enhance its usefulness in light measurements systems. Firstly, the input to the ADC is offset giving the unit a small negative range. This ensures that negative going noise peaks, occurring in near zero signals, are correctly averaged while retaining most of the available resolution for positive going signals.

Secondly, the ADC provides information to the computer indicating that a transient overload has occurred at some point during the conversion period. This information is essential if accurate measurements are to be made on pulsed light sources such as CRT monitors.

The ADC provides 2000 counts per volt and has a maximum of 20000 counts.

Due to the quantum nature of light and the way in which optical detectors work, signals in light measurement systems are always accompanied by electrical noise. The limit of low light level detection is often imposed by the ability of the measuring system to distinguish between the signal to be measured and the associated electrical noise.

In most cases, where the noise is truly random, the signal to noise ratio can be improved by averaging. For a signal accompanied by random noise the signal to noise ratio will increase in proportion to $\sqrt{T}$ where T is the averaging period.

With dc systems the maximum period which can be used for averaging is limited by so called dc drifts (i.e. low frequency noise. The noise power in fact increases continuously as zero Hz is approached).

The ADC therefore behaves as a digital averager with the averaging period programmable in 100ms increments.

For DC systems the averaging period can be fixed for a particular experimental set-up or can be varied depending on the signal level to give a substantially constant signal to noise ratio for all signal levels.

Software schemes have been used where the averaging period is determined by looking at the variance between successive readings or, more simply, by linking the averaging period to the sensitivity range of the amplifier so that averaging period increases as the sensitivity required increases. This last approach is very useful in solar UV measurements where in a typical spectral scan from 280nm to 400nm the signal level changes by $\sim 10^6$.

Similarly, measurements which have included a transient noise pulse such as that produced by Cherenkov events in the window of a photomultiplier, can be recognised and repeated if required.

9.3.7 218 Arrestable Chopper controller

The optical chopper is controlled by the 218 unit, with connection between the controller and the chopper by an amphenol socket connector.

The dial shows the chopping frequency for a ten-slot chopper blade. This dial can be locked and unlocked by a small tab underneath the dial. The value should be scaled according to the blade fitted to a particular system.

This system is provided with a twenty slot blade only. It follows that the dial shows double the actual frequency applied. The system is set to 295Hz on the dial, resulting in a chopping frequency of 590Hz, used for all applications. Ensure that a BNC takes the reference output to the reference input of the lock-in.

An optical sensor on the chopper provides feedback to the controller to provide the reference signal. Ensure that the reference from the front of the controller goes to the lock-in amplifier reference input.

In this system, the chopper is arrestable via an electromagnet. To stall the chopper for use in the DC regime simply power off the chopper using the on/off switch on the front panel of the 218M module.

Figure 9.2: On/Off switch to use or arrest the chopper

Note that when returning to the AC mode, that the lock-in may take some time to re-find the reference. This can be speeded up by momentarily powering down the 417 electronics, closing BenWin+ and re-initialising.

10. BenWin+

10.1 Introduction to BenWin+

BenWin+ is a Windows software designed to control Bentham's range of monochromators, detection electronics and accessories.

On running the software, initiating an initialisation procedure establishes communication with the hardware.

BenWin+ then reads a file of type *.cfg, (entitled system.cfg by default). This file describes the elements of hardware to be controlled and their USB address (PID and VID)

By default a *.atr file of the same name as the *.cfg file used is looked for. This file describes the parameters of the instruments of the system. Groups of cfg, atr files and scan properties can be saved in a configuration to permit easy migration between setups. Configurations are saved in .xml files.

Features include:

- User initiated or time-delayed spectrum scanning (schedules)
- Easy system calibration, irradiance, radiance, detector responsivity etc
- Obtain spectrally integrated quantities (candelas etc)
- Instantly obtain colorimetric data
- Perform transmission, absorption and reflection measurements
- Perform simple arithmetic functions
- Add-on for control of translation stages, goniometers, data acquisition from other instruments etc
- Direct export of measurement data to excel, with capability of running macros
- The software can also be run in stand-alone mode to view measurement results at a later time

The following sections will be divided into configuration, measurements, analysis and menu reference.

10.2 System configuration

The drivers for both the TMc300 and the 417 are automatically recognised by windows. The process to add new hardware should be followed once for each instrument before using BenWin+.

- Connect the USB to the monochromator and power on
- Wait until windows finds new hardware
- Allow windows to search for the required drivers automatically
- Perform the same process for the 417

10.2.1 Installing BenWin+

- Insert BenWin+ CD into computer, and double–click on setup. This takes you through the setup process, select complete installation
- A Bentham\BenWin+ folder is created in C:\Users\Public\Documents
- A shortcut to BenWin+.exe shall be found also on the desktop
- This system is based on the use of configurations, it is necessary in the first instance to setup BenWin+ into configuration mode
- Run BenWin+
- Go to Tools Options and select "prompt for configuration on start up", hit apply
- Close window and close BenWin+
- Go to c:\program files\Bentham\BenWin+
- Delete the created file configuration.xml

Finally, ensure that in C:\Users\Public\Documents\Bentham\BenWin+\Calibration, the certificate files have been installed. These are the calibration files of the reference detectors. Should they not have installed, they can be directly copied from the CD accompanying the calibration certificates.

10.2.2 Getting the software started

- Run BenWin+ to be presented with the following window:

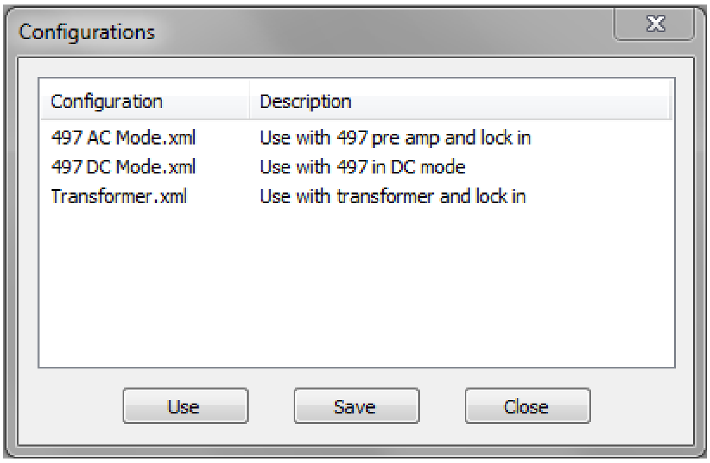


Figure 10.1: Configurations menu

- Double click on the required configuration to use
- If the window above does not appear go to Tools → Configurations… and select the configuration to use

10.3 Instrument attributes

To view the instruments in the system go to Instruments in the toolbar. This lists the system components, giving access to their properties.

Note that these properties are saved in the configuration file. On closing BenWin+, by default any changes made herein are saved. This default can be removed by going to Tools → Options and de-selecting “save instrument attributes to file on exiting the application”. Hit apply.

Should any problems be encountered, if in doubt reload the configuration files from the installation CD to re-establish the initial conditions.

10.3.1 TMc300 Monochromator

Selecting this page gives access to the parameters of the monochromator. Selecting Advanced>> gives access to the grating properties. For grating values of this system please see the calibration certificate

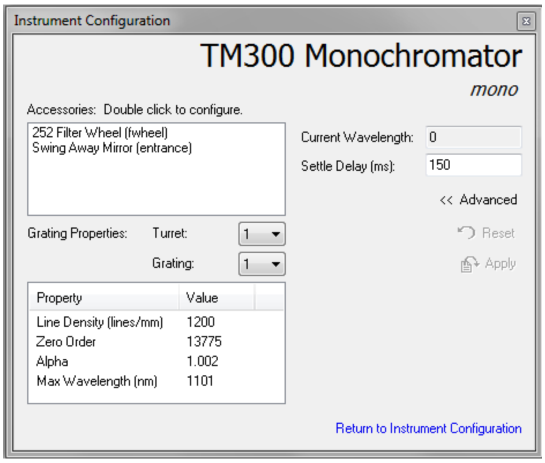
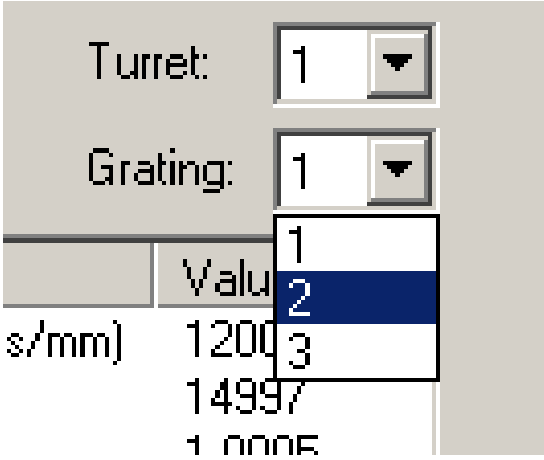


Figure 10.2: Monochromator settings

The pull down arrow permits toggling between turrets and gratings. The zord and alpha measurements are obtained from the calibration certificate.



10.3: Turret and grating drop down menu

Monochromator settle delay of 100ms should be sufficient.

10.3.2 Filter Wheel

The filter wheel has six positions. The filters in place are described in section 2.3, and are specified here by their wavelength of insertion.

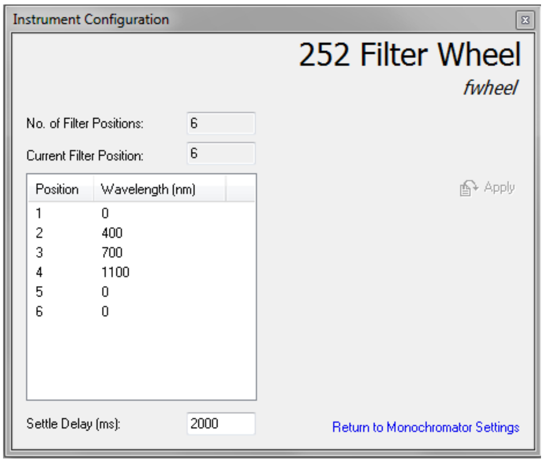


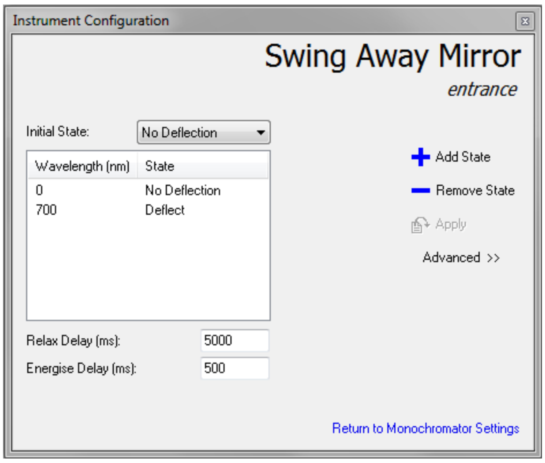
Figure 10.4: Filter wheel window

The settle delay is the pause taken by the system following each action. 1000ms is sufficient.

10.3.3 Swing Away Mirror (SAM)

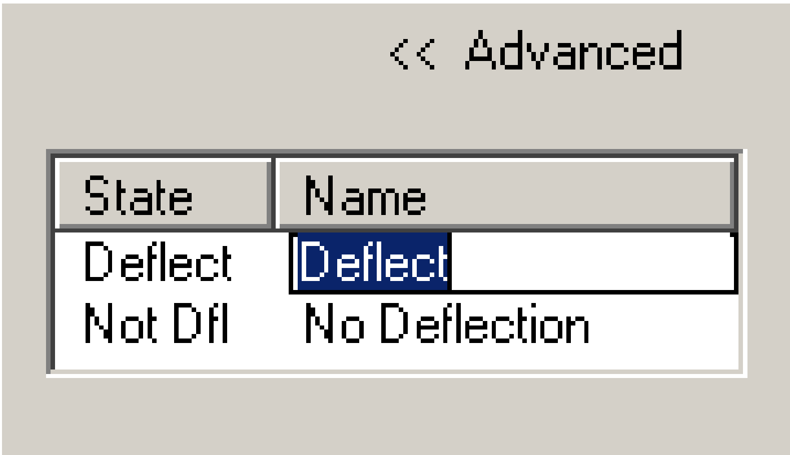
This page is accessed via a link in the monochromator page. The states of each SAM is as follows:

Deflect: Select Xenon source
No-deflect: Select QH source



10.5: Swing away mirror menu

Define states by the wavelength of insertion (inclusive), and the SAM state. In advanced>> can be named the two SAM states for easier setting up.



10.6: SAM states and naming conventions used

Settle delay of 1000ms is sufficient.

10.3.4 498 AC Pre-amplifier and DC Nanoammeter

This applies to the AC high-sensitivity, DC mode and DC chopped configurations. The properties page of the AC pre-amplifier and DC nanoammmeter are the same. The settings window is shown below.

Figure 10.7: 498 amplifier menu

All ranges are used, it is recommended to use range 1 as the start range. Setup 2 is not required in this application.

Settle delay of 1000ms is sufficient.

10.3.5 498 Analogue to Digital Converter (ADC)

The 498 ADC integrates over 100ms periods. One can choose how many of these periods shall be taken to determine the reading at each wavelength.

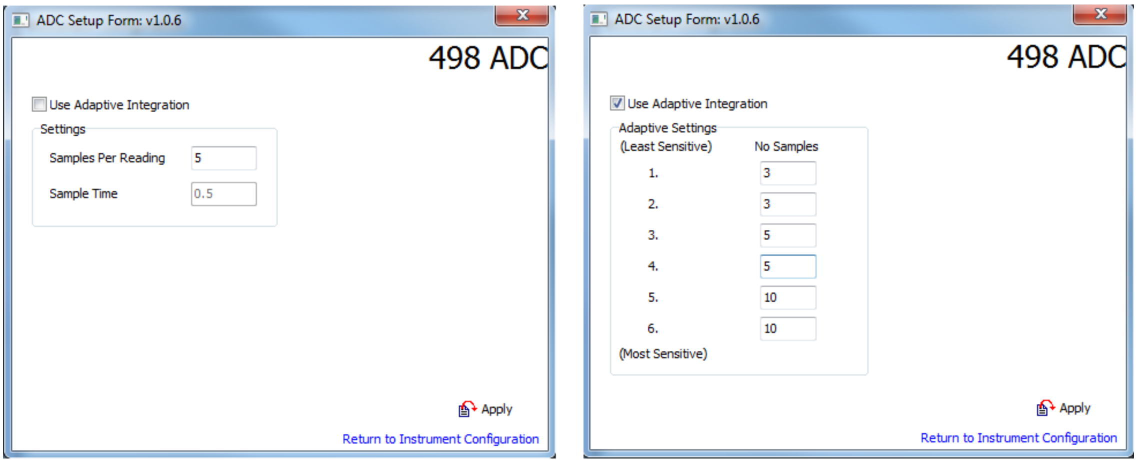


Figure 10.8: 498 ADC menu when (l) a single value of samples is used and (r) when adaptive integration is used

A good number to use for reasonable signal is 5 averages.

One may also select adaptive integration which permits varying the number of averages taken as a function of the gain range of the current amplifier, fewer averages in the low gain ranges and more in the higher gain ranges to smooth out noise.

10.3.6 496 Lock-in amplifier and ADC

The lock-in amplifier page permits definition and viewing of the gain, window function and integration time of the two inputs.

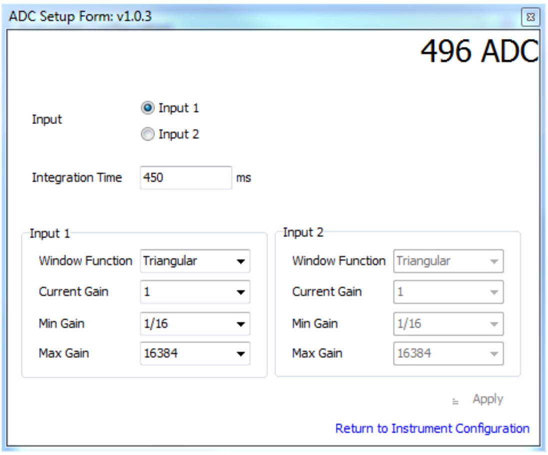


Figure 10.9: 496 DSP Lock-in menu

It is recommended to use 1/16 and 16384 as the minimum and maximum gains. Since this lock-in amplifier is completely autonomous users only need to select the input that they wish to be read, with no need to define the phase and offset of the signal.

The ADC operates as described above in 10.3.5. It is recommended that and integration time of at least 450 ms be used.

10.3.7 498 DC Lock-in

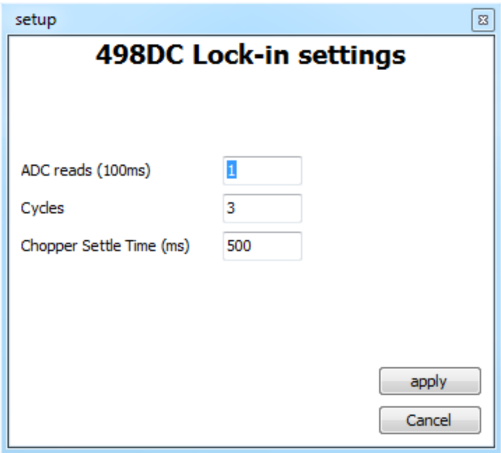


Figure 10.10: 498 DC Lock-in Settings

This window is only used in DC chopped mode and depicts the settings used in this mode. ADC reads is the number of readings taken for each point, while the number of cycles is the number of times the chopper cycles before moving on to the next wavelength. Chopper settle time is the time interval between the chopper movement finishing and a reading being taken.

10.3.8 Miscellaneous

The miscellaneous page is as follows. The dark integration time, the time over which dark current is integrated is factory set to 5 seconds and should be sufficient.

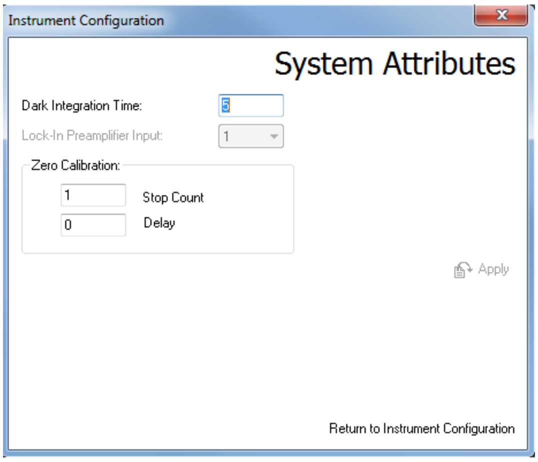


Figure 10.11: System attributes menu

10.4 Measurements and utilities

10.4.1 Introduction

BenWin+ is a general purpose spectroradiometer software, wavelength scans being its habitual use. Other functions include setting the monochromator to a given wavelength, timed scans at a given wavelength, scans according to a schedule, system calibration, and relative measurements.

Spectral scans involve the initial measurement of the system with respect to a reference. This reference may be a lamp of known output, a reflectance standard or a 100% "no-sample" measurement.

By comparing the measured signal obtained as a function of wavelength with the reference, can one determine the nature of an unknown sample.

The system therefore effectively measures the detector photocurrent under stimulation by the source, as a function of wavelength, which is therefore a convolution of the source output, the spectral response of the input optic, the monochromator (mirrors and diffraction grating) and of the detector.

As shall be seen in the next section, an advanced menu gives access to change items such as zero

10.4.2 Hardware operation

The initialisation procedure establishes communication with all hardware components, and moves the monochromator to a known reference point.

For M300 and DM150 monochromators, the gratings are moved to a maximum positive limit the corresponding wavelength of which should be input to the software at installation.

For TM300 and DTM300 monochromators, the procedure moves the monochromator moves the turret to a negative mechanical limit, the software being instructed via the system.atr file the number of steps from this point is the zero-order position of a given grating.

Now, in most systems there exists a filter wheel, in position six of which is a blank to shut off the input to the monochromator. This is used in the determination of the detector dark current, and to protect the detector from continual exposure.

When scans are launched, it is important to perform the zero-calibration procedure.

This procedure shuts the input to the monochromator. In the first instance sets the current amplifier to maximum gain range (ranging to a lower gain range if this range is in overload). When stable, the output of the ADC is read.

This constitutes the detector dark current. The current amplifier is then set to its' minimum gain range, and the ADC read. The signal measured does not come from the darkened detector at this point, what is registered is the offset of the detection electronics. The 20,000 count ADC has ~400 counts reserved for negative-going noise signals. With no stimulation therefore, the system should read ~400 counts. It is important to realise the importance of ensuring this offset is taking into account.

Consider for example a large signal in a higher gain range, say 18000 counts, ranging to a lower gain range, where the counts may be 1800.

The relative impact of not subtracting the 400 count offset leads to discontinuities in the spectrum should zero-calibration not be taken into account.

Should zero-calibration be not selected, provided that the system has performed at a previous point this routine, the same values shall be carried through at all times.

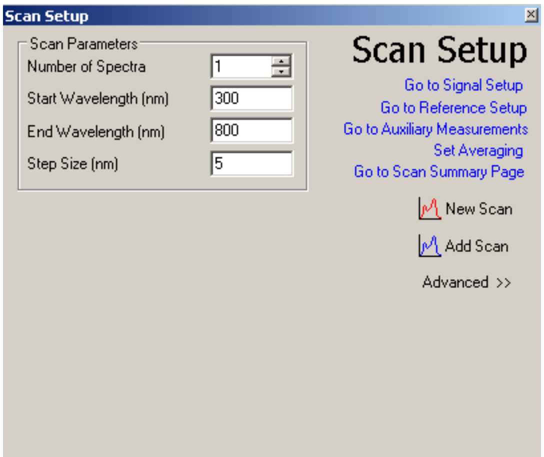
This is not recommended, particularly in the case of for example photomultipliers, whose response is very temperature and condition dependant.

In the scan parameters page, it is recommended that the zero-calibration routine be applied, that the amplifier be permitted to auto-range, that the shutter is closed post-scan, and that the monochromator is returned to the start wavelength for the next measurement.

Furthermore, where add-on modules are employed, ensure that appropriate pre- or post-scan module fields are selected.

10.4.3 Scan setup

Spectral scans are initiated by going to the Scan menu and selecting Scan setup to reveal the following:



10.12: Scan setup menu

- Enter the wavelength range required
- Select bandwidth required
- Select number of scans required
- Click on advanced>> for further features:

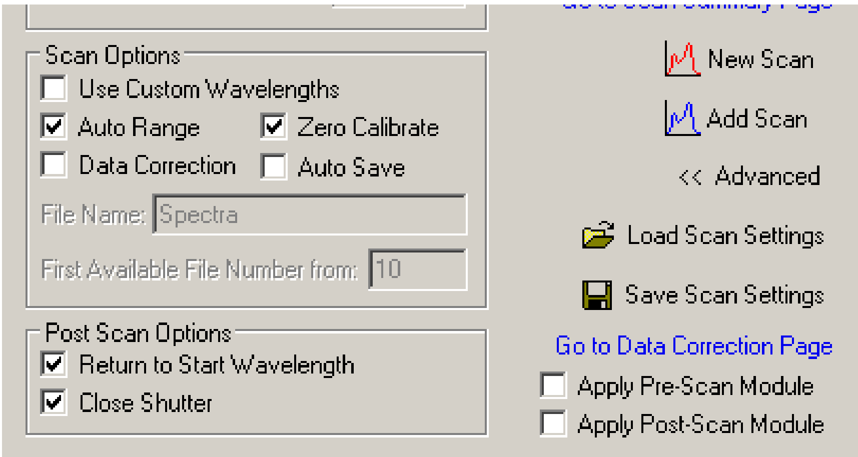


Figure 10.13: Advanced setting within the scan setup menu

- Ensure that zero calibration is selected. This determines ADC offset and dark current at beginning of scan
- Ensure that autorange is selected, permitting the amplifier, to change gain range where appropriate

- It is of good practice to have close shutter and return to start wavelength selected.
- Should it be desired that all spectra are saved, select auto save and define file name prefix and number suffix
- Click on new scan for measurement

When performing initial measurements of a calibration standard, ensure that data correction is not selected- this uses the calibration mode of the software not required at present, the y-axis of the scan window once launched should read Signal (nA). Having performed measurements of the calibration standard, and having implemented a correction (see below), ensure that data correction is selected to determine the corrected output of unknown sources.

The following window shall be seen in the foreground, detailing the progress of the scan, whilst a spectral plot will appear in the background.

The shape of the uncorrected scan will vary depending upon source, gratings, etc, but it is normal that there be relatively sharp features, with loss of response towards the ends of the spectrum.

Furthermore, a slight discontinuity may be seen at the insertion of order sorting filters. All of these features “calibrate out”.

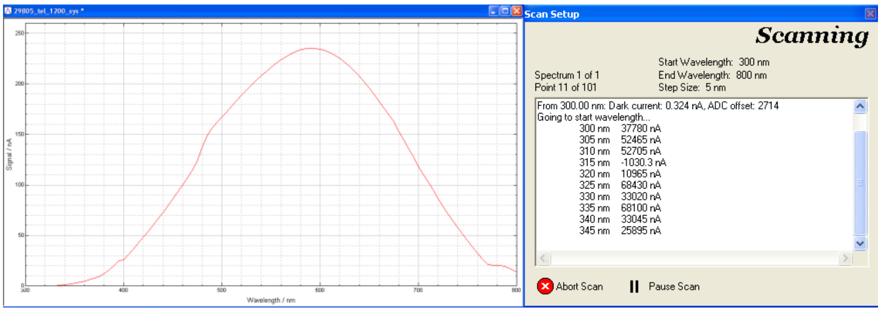
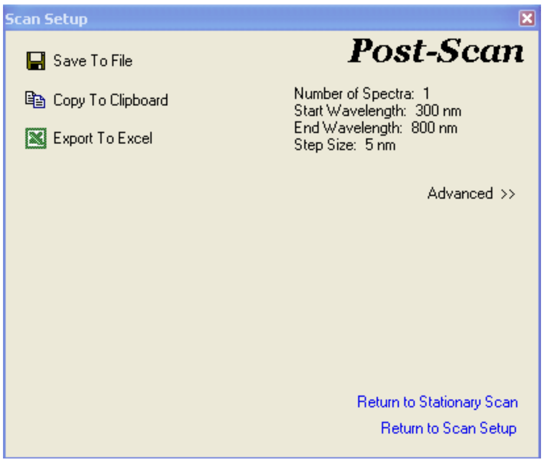


Figure 10.14: Graph and scan window during measurement

At the end of a scan, you shall be presented with the following screen. At this point one may, if desired choose to export the spectrum to excel (either for viewing, to perform calculations or to run macro which may be specified), or one may simply close this window. Please see §10.5-10.8. If autosave should not be selected, ensure that the current spectrum is saved.



10.15: Post scan menu

10.4.4 System Calibration

System calibration refers to the calibration of sources or detectors against standards. For measurements against reflectance etc standards please see section §10.4.6.

The measurement of any unknown source with a spectroradiometer, or the response of an unknown detector means nothing without comparison to a standard such as those obtained or compared with scales as defined for example by the National Physical Laboratory.

Such measurements require a first scan of a standard prior to measurement of the unknown device. An example of this can be seen in the following figure, the irradiance of a lamp being required.

The upper scan is the throughput of the monochromator system when viewing the unknown lamp, having actual irradiance displayed in the lower spectrum.

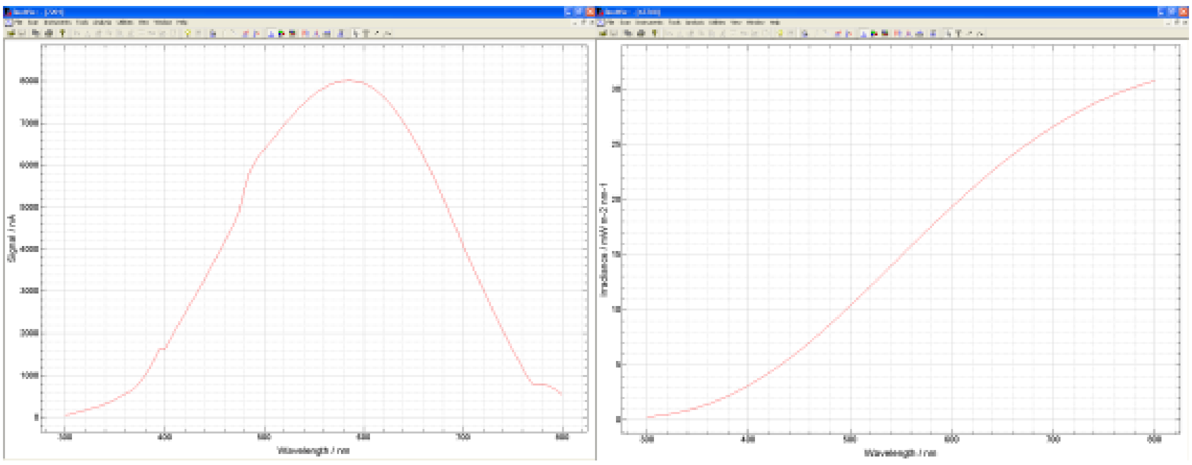


Figure 10.16: Raw scan and calibrated scan data

The ratio of the calibration data showing the true device spectrum, to the system measurement, yields a wavelength dependant system correction factor. All future measurements ought to be multiplied by this correction curve to yield a true reflection of the source unknown device spectrum.

This rationale applies for the determination of detector responsivity.

It is also of importance to reflect the quantity of the calibration measurement, whether it be irradiance, radiance etc. This correction, and subsequent presentation of data in correct quantities and units, is implemented in BenWin+ via the data correction page.

Firstly to apply data correction two files are required:

1. A *.bcf Bentham certificate file of the source calibrated results with measured quantities and units
2. A *.ben, system file, measurement of the unknown device in the same step

The procedure is as follows:

- Perform scan over desired spectral range of standard source
- Ensure that data correction is not selected and that the units of the measurement are in nA
- Save scan
- Go to Scan → Data Correction page

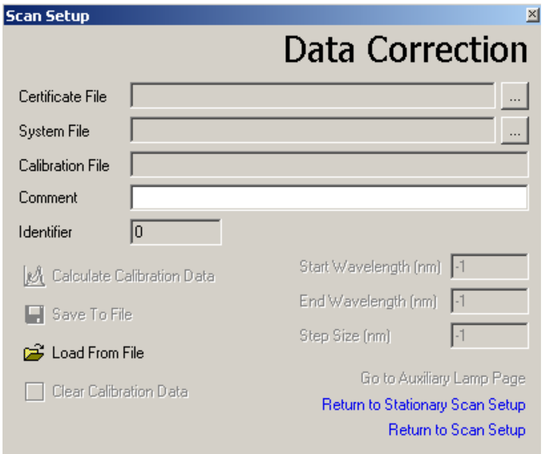


Figure 10.17: Data correction menu

- Using … button select appropriate *.bcf file for device
- Select just-saved scan as system file
- Hit Calculate calibration data
- Save to file
- When prompted do you wish to apply data correction click YES
- Return to scan setup, and then scan as normal

Note that the y-axis should reflect the correct quantity to be measured. Ensure that the next time that a comparison to standard be performed, that data correction is NOT selected.

One may view the *.bcf file by selecting open/all files and find the .bcf files in the BenWin+ calibration folder.

If you have no .bcf file, you can create one by the following process.

- Prepare your calibration standard data as a two column ASCII file with no header nor footer, wavelength in the left column, measurement in the right
- Save this file
- Go to BenWin+ → File → Import

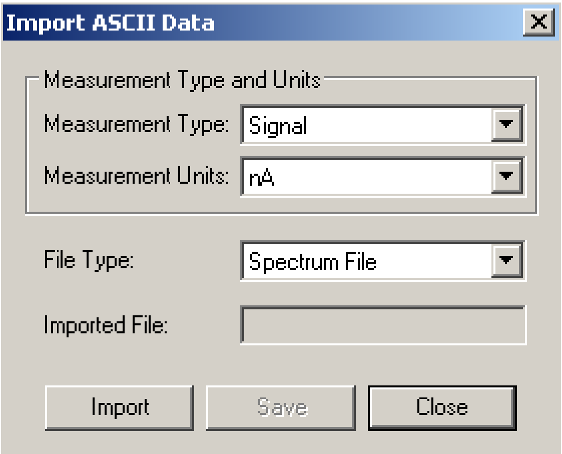


Figure 10.18: Import data menu. This can be used to create certificate files

- Select units and quantity of measure, select certificate file and import
- Chose the file of your data and save in the BenWin+ calibration folder

10.4.5 Reference Measurements

The reference setup can be found in the scan menu. This permits the direct measurement of transmission, reflectance and absorbance of samples.

No calibration correction is applied here. Of interest is the comparison of the raw measured signal with either no sample (for transmission and absorbance) or a standard (for reflectance) in place, and then with the sample under test in place.

In the case of reflectance, the standard used may be presumed to have 100% reflectivity, or one can specify a calibration file with the true reflectance of the standard. This file should be in absolute units.

The measurement procedure follows:

- Go to scan/scan setup
- Ensure in advanced>> that data correction is NOT selected
- Perform scan over required spectral range
- Save file
- Go to scan/reference setup

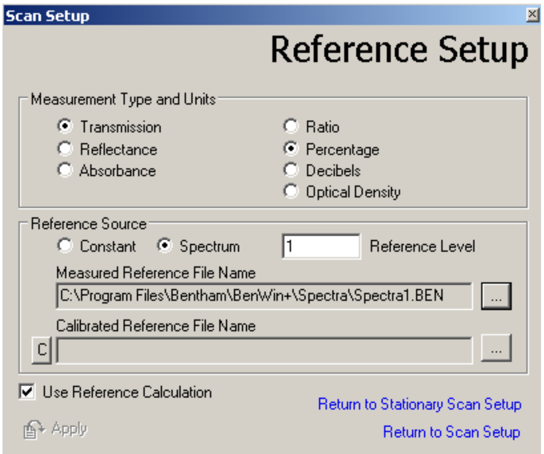


Figure 10.19: Reference setup menu

- Select required measurement type and unit
- Select reference to apply , constant (inputting reference level) or spectrum
- Use "…" to load just saved reference spectrum
- In the case of reflectance, should a calibration file be held for the standard, load this file using the …
- Select use reference calculation
- Return to scan setup
- Perform scans in the usual manner
- To use another reference file, use the … button to select other file
- To perform a new reference level, ensure that "use reference calculation" is switched off
- To switch of calibration correction, hit C button to remove file

10.4.6 Stationary Scans

It is possible to perform time-based scans at a fixed wavelength. This is particularly useful when for example monitoring a lamp to determine warm- up stabilisation period, or for example to measure the transmission of a photochromic material during or after activation.

Go to Scan → Stationary Scan setup to reveal the following:

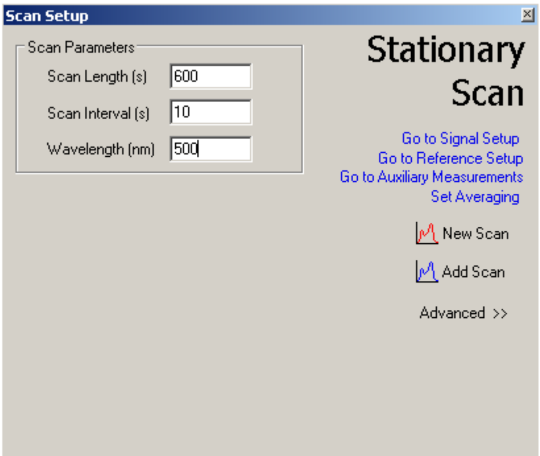


Figure 10.20: Stationary scan menu

Define scan length, scan interval and monitor wavelength. It is sometimes useful to perform a spectral measurement of an unknown source beforehand to determine the spectral output, and therefore to determine the wavelength of monitoring.

In advanced, one can select whether data correction be applied or not. Ensure that auto ranging and zero calibration are selected for correct measurement. The scan interval should not be less than the ADC read interval.

10.4.7 Signal Setup

The signal setup page permits moving the monochromator to a given wavelength, of use for certain measurements, and also useful when aligning optics.

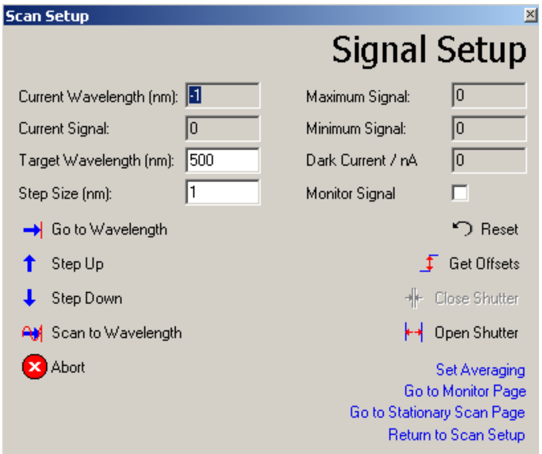


Figure 10.21: Signal setup menu

Input the desired wavelength in Target Wavelength and hit Go to wavelength. Note that one might monitor the zero order contribution by typing 0 for the wavelength.

Note that here there may be a large signal which may be of consequence with the detector in use (particularly if a bi-alkali photomultiplier is used, for which high signal stimulation might cause hysteresis effects).

Once at the given wavelength, the filter wheel opens the shutter. Selecting the monitor signal box ranges the amplifiers to determine the current signal.

One might also define a step size, and manually scan over a spectral range by hitting the scan up and scan down buttons. Note that the monochromator control is designed such that a given wavelength be reached in one direction only, that of increasing wavelength.

This is to ensure the best wavelength calibration. When scanning down the wavelength scale, the system goes beyond the wavelength selected to approach in the increasing direction.

10.4.8 Signal monitor

The signal monitor opens the shutter and monitors the signal at the current wavelength. A graphic with auto-ranging y-axis shows the current signal and is update as fast as possible.

10.4.9 Set file information

One can associate information with each scan by going to Scan → File Information. Here one can define a number of fields hitting the + button, double clicking on the field entry on each line to edit to, for example, Operator, Lamp type etc. One can pre-define the file information to prevent re-typing information common to each measurement. Highlight and hit the – button to delete a field.

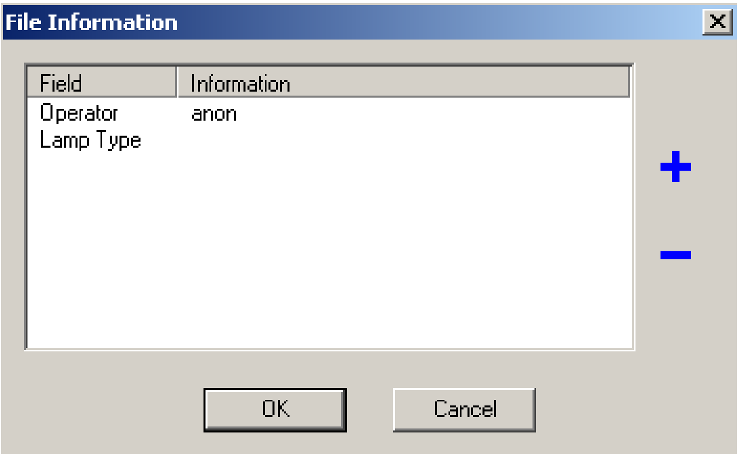


Figure 10.22: File information window

With Use file information selected, on starting a new scan a window prompts for the entry of the required file information values. File information is saved with scan data.

10.4.10 Add-ons

In order to increase the flexibility of a given system, add-on modules permit the interfacing of for example the control of further instruments, as part of BenWin+, or specific data analysis post-scan.

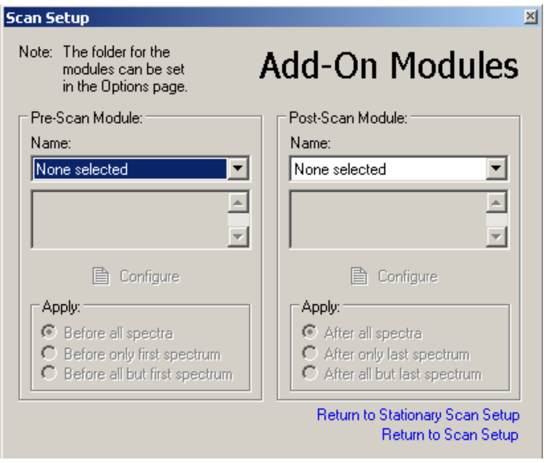


Figure 10.23: Add-on modules menu

Add-on module dlls should be placed in the BenWin+/Add-ons folder. They can be implemented via the add-on modules page, and selected as either pre- or post- (or both) add-on modules. Pre-scan modules are used in instances where control or measurement during scans is required, post-scan modules when calculations are involved.

10.4.11 Auxiliary measurements

It is possible to collect data from a source other than the principal monochromator detector. This source might be obtained via either a Bentham two input current amplifier or relay unit, or via an add-on.

Should a calibration factor be associated with this auxiliary measurement, this may be defined via this page.

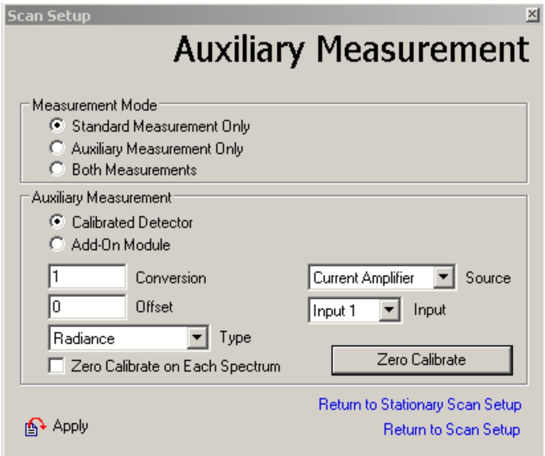


Figure 10.24: Auxiliary measurement menu

- Define whether standard, auxiliary or both measurements are to be performed
- Define whether a calibrated detector or add-on module is employed
- Data are acquired at each point in the ranged defined as a scan

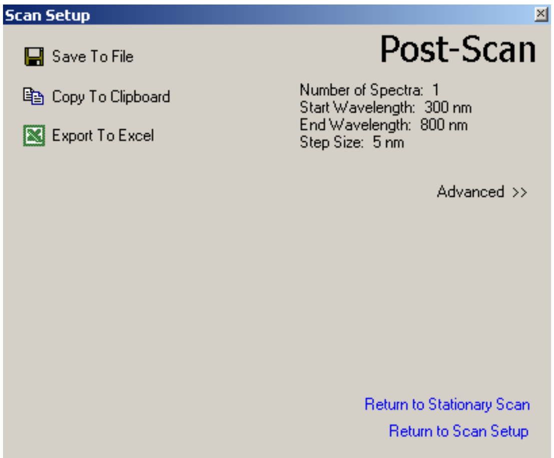
Should a calibrated detector be employed, it is of question to define the source, input, conversion factor, offset and measurement type. Covering the detector, one can hit the zero calibrate button to take the dark current of the source.

The measurement type can be either:

- Radiance – mW sr^{-1} m^{-2} nm^{-1}
- Radiant Intensity – mW sr^{-1} nm^{-1}
- Irradiance – mW m^{-2} nm^{-1}
- Radiant Flux – mW nm^{-1},
- Detector response – A W^{-1} nm^{-1}

10.4.12 Post-scan

A scan having finished, one is presented with the following window:



10.25: Post scan menu

If autosave was not selected, save the file now. In the following sections are given information on the three BenWin+ data views, and the direct exportation of results to Excel.

10.5 Spectrum View

10.5.1 Introduction

This default view presents a view of the spectral distribution of the source, as a function of wavelength (or as a function of time in the case of time-based scans).

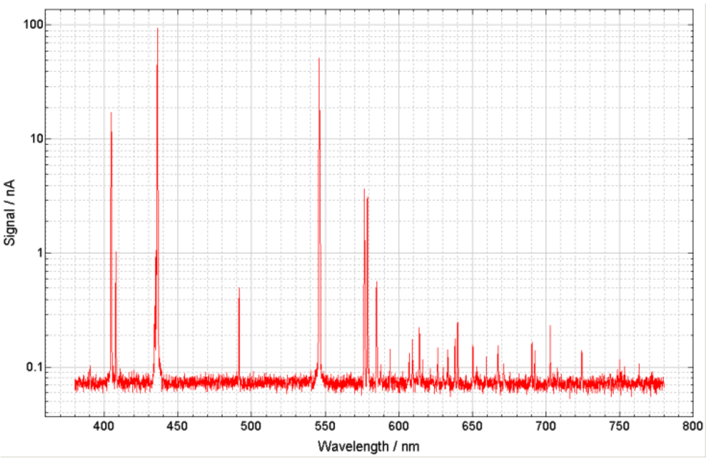


Figure 10.26: Xenon spectrum

Having performed a scan, within this view the data may be analysed via functions in the analysis menu, or using a right mouse key short cut button.

These functions follow, starting with the analysis menu.

10.5.2 Set spectrum names

In Analysis → Set spectrum names. One may either autoset file names or change each entry manually.

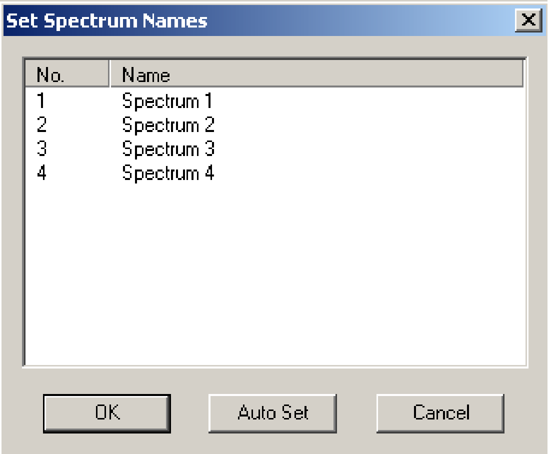


Figure 10.27: Set spectra names menu

10.5.3 Overlay spectra

One can overlay different spectra by going to Analysis → Overlay spectra. Having more than one spectrum window open, it is possible to superimpose selected scans into a given window.

Those available spectra are found in the left hand window, may be highlighted and the → arrow used to place the spectrum in the list to superimpose. Hit OK to apply.

10.5.4 Delete spectra

One may delete spectra from a multiple-spectrum window by going to Analysis → Delete spectra. Check off spectra for deletion, hit OK.

10.5.5 Interpolate

One might apply a cubic spline to interpolate or extrapolate given spectral data.

- Go to analysis →interpolate
- Modifying the start or stop wavelengths truncates the scan
- Enter the desired step size.

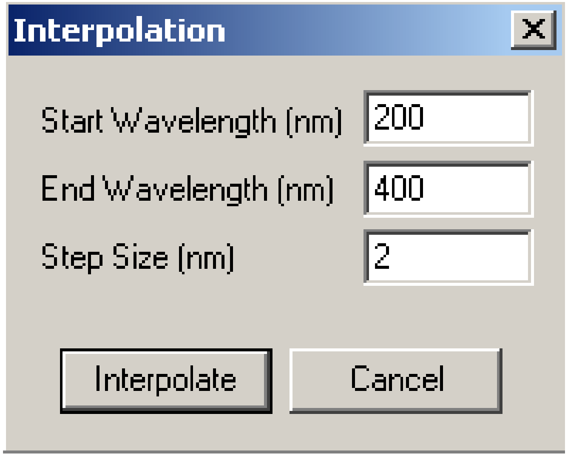


Figure 10.28: Interpolation window

10.5.6 Cut

- Go to Analysis → Cut
- Check off from the list the spectra desired to truncate
- Define the lower and upper limits, then hit OK

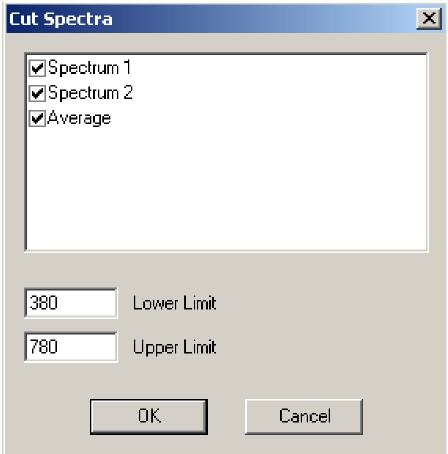


Figure 10.29: Cut spectra window

10.5.7 Concatenate

One can concatenate two spectra, to obtain a single spectrum.

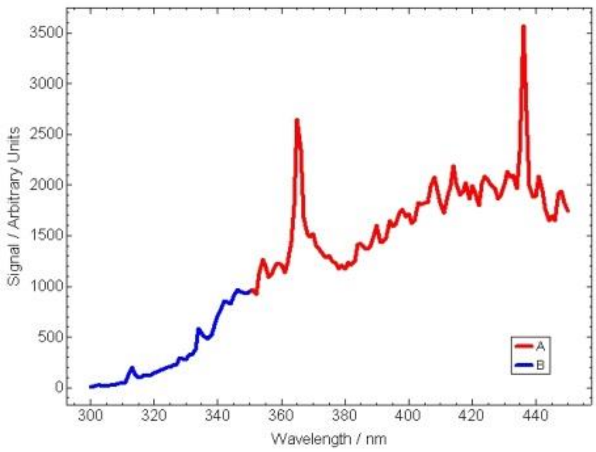


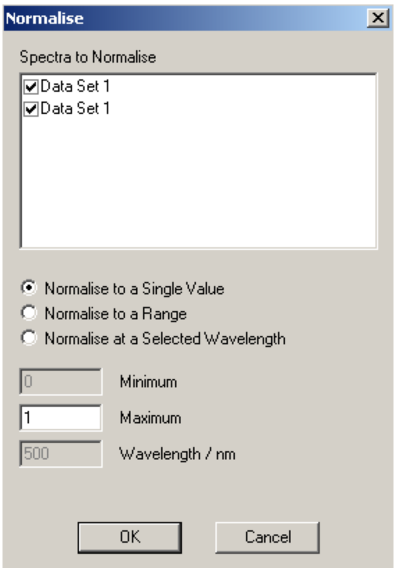
Figure 10.30: Two spectra to be concatenated

The spectra need not be continuous, but where a sub-set of the values are not exclusive, the latter sub-set is not modified, the remainder of the set being concatenated.

10.5.8 Invert

Select to obtain a mirror image in the plane of the x-axis of a given spectrum.

10.5.9 Normalise



10.31: Normalise spectra window

One may normalise selected spectra to:

1. A single value, defined as the maximum, set usually to unity
2. A range, define maximum and minimum limits
3. A selected wavelength, define the wavelength and the maximum wavelength

10.5.10 Spectral arithmetic

Having one or more scan windows open, one can perform simple arithmetic, either multiplying a spectrum by a constant or another spectrum.

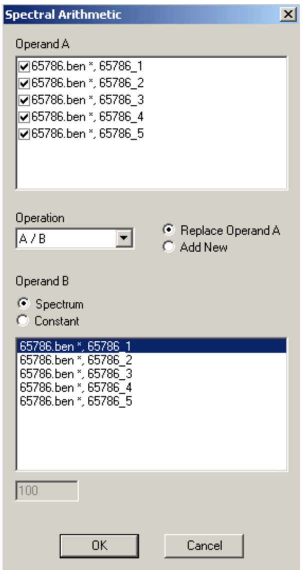


Figure 10.32: Spectral arithmetic window

- With the window of the first spectrum active, go to Analysis → Spectral Arithmetic
- Select the spectrum (or spectra) for Operand A, the operation required, and for Operand B select either a constant (defined lower) or another spectrum
- Select Replace or add new spectra, then OK

10.5.11 Spectral average

Having performed a number of scans of a given source, one can perform a spectral average, determining also the standard deviation and two spectra based on the minimum and maximum values at each point. These results are labelled accordingly, and are presented on the active spectrum window.

10.5.12 Quantum efficiency

In the case of detector responsivity (A W^{-1} nm^{-1}) the responsivity results may be converted to quantum efficiency, defined as the ratio of electrons extracted for the number of incident photons. This process is non-reversible, ensure that the original detector responsivity has been previously saved.

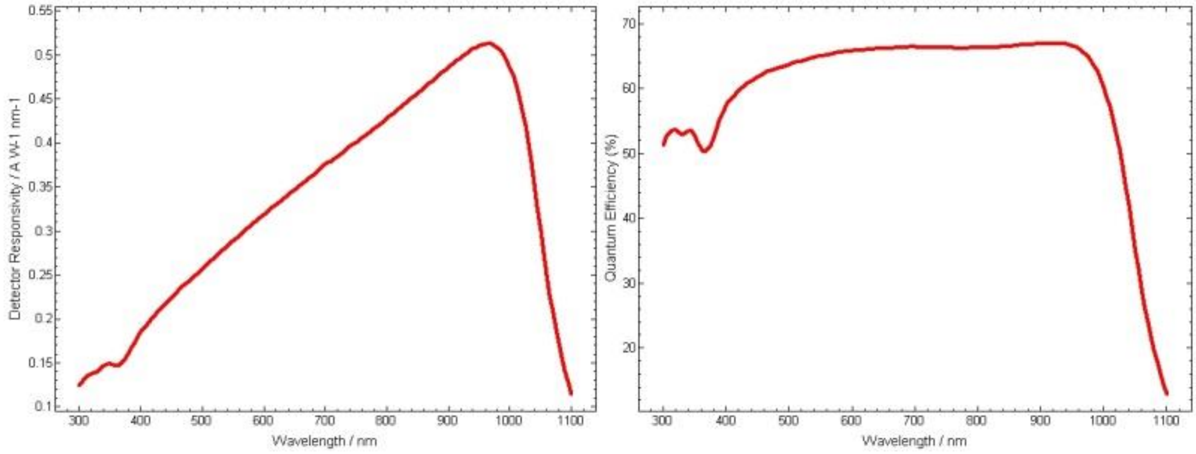


Figure 10.33: (l) Detector responsivity and (r) Quantum Efficiency

10.5.13 Peak picker

Having performed for example a scan of a line source, the peak picker function may be used to determine the wavelength position of these peaks**.**

Typically using the auto-settings function should find the peaks present. The results are noted on the graph, a measurements window to the right of the spectrum window also displaying the results.

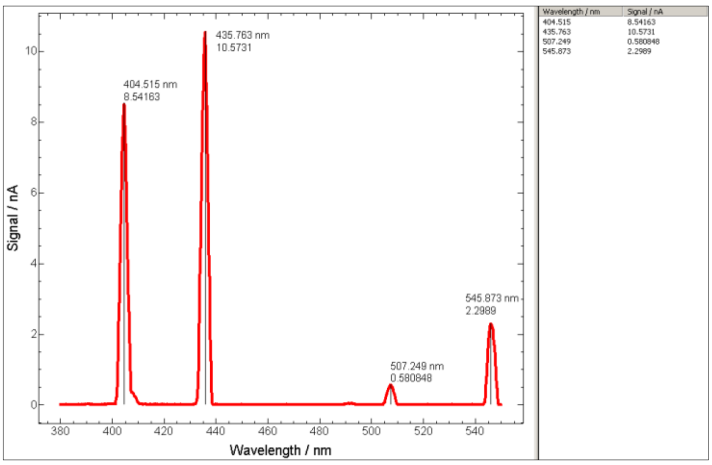
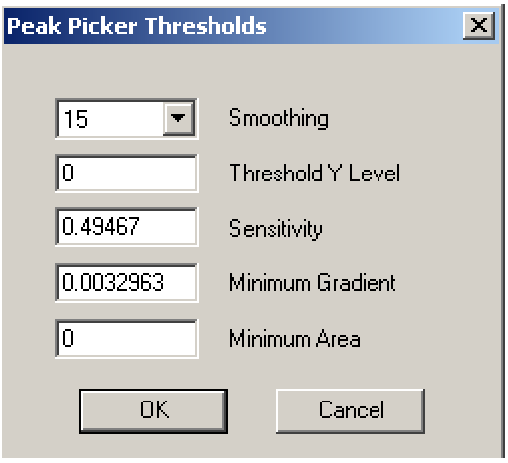


Figure 10.34: Xenon spectra with peaks denoted by the peak picker

Should certain peaks not be found using the auto settings, then the set thresholds window can be accessed.



10.35: Peak Picker window

The functions are as follows.

Using the auto-settings function overwrites all changes to thresholds.

Smoothing: Reduces errors due to a noisy spectrum. Broad peaks should be smoothed with a larger number of sample, the converse for narrow peaks.

Threshold Y Level: Enables the rejection of peaks whose height above a local baseline is below that value.

Sensitivity: The Sensitivity threshold allows the user reject peaks whose absolute height is less than a set value.

Minimum Gradient: The Minimum Gradient (Value >0) threshold is used to define the peak edges. Points at which the absolute gradient are greater than the Minimum Gradient are considered to be peaks.

Minimum Area: Peaks with an area less than the Minimum Area are rejected. This discounts delta-function peaks such as caused by cosmic events.

10.5.14 Spectral Integrals

Spectral integrals and action spectra can be applied in the Analysis → Set spectral integral.

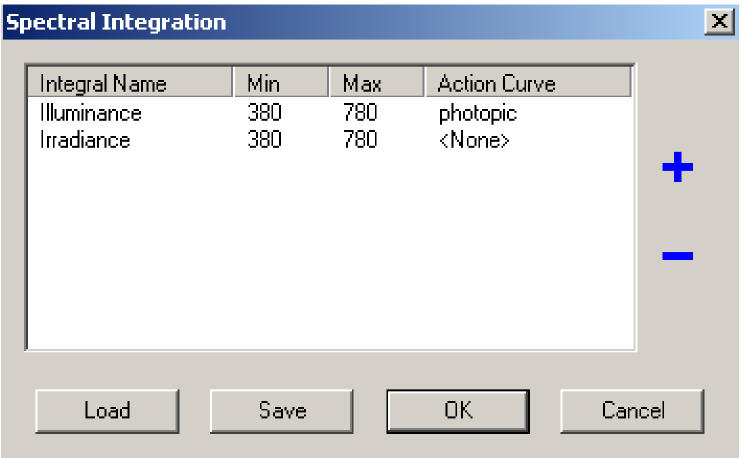


Figure 10.36: Spectral integration window

+ add integrals, define name, spectral range, and action spectra. Action spectra are two-column ASCII files (wavelength, value) saved as *.ACTION in BenWin+ folder.

One may define a group of integrals and save for use later.

For the first time go to Analysis → Calculate spectral integrals to view results.

Thereafter, BenWin+ will present results automatically. The data are also saved in the *.ben file.

10.5.15 View menu

Through the view menu, one can toggle to further views as described in the following sections, as well as looking at spectral data and viewing or adding markers and cursors to determine the positions of features.

Markers may be automatically positioned using the peak pickers function or via cursors.

One can view the numerical data by selecting View → Spectral Data. Re-select to remove the measurement data.

One can place up to two cursors on the canvas of the spectrum to manually probe the measurement results.

The cursors are accessed via View → Cursors.

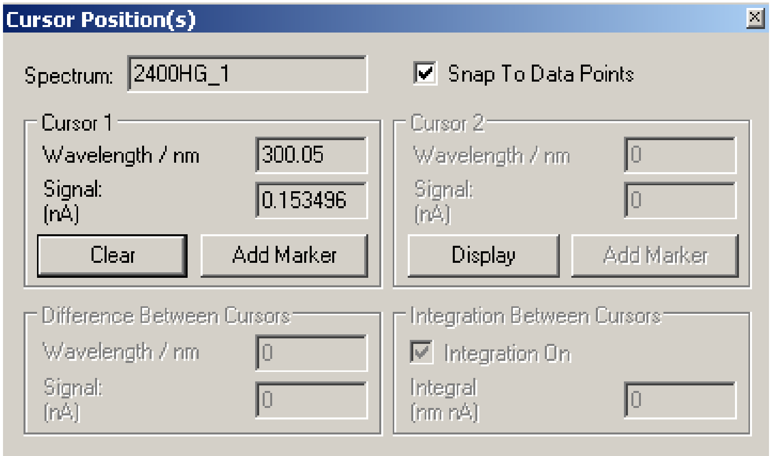


Figure 10.37: Cursor position window

Controls of the two cursors are on either side of the window.

Hit display to obtain the cursor which may be dragged in place with the mouse. The wavelength and signal of the cursor position is displayed.

One may choose to add a marker at that position. When two cursors are active, the lower section of the cursor window shows the difference and integration between the cursors.

When multiple spectra are present in a given window, the keyboard up or down arrows selects the curve under consideration.

Hit clear to remove the cursor from the graphical view.

Going to View → Marker List provides the user with a list of extant markers in a window.

10.5.16 Further features

Further menu features, including short-cuts to some of the above are obtained from a menu activated with right mouse click over a spectrum window.

These items are as follows:

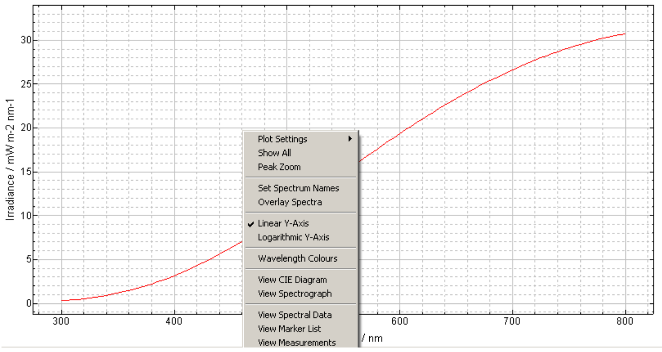


Figure 10.38: Graph with spectrum window shortcuts

Plot settings: Define the aesthetic aspects of the graph, line colours, labels etc.

Show All: A zoom is provided by pushing left mouse button, holding down the button one can create a zoom box whilst moving the mouse to view a particular region of the spectrum. Show all returns to a view of all data.

Peak Zoom: Automatic finding and viewing of peaks

Set spectrum names: See §10.5.2

Overlay spectra: See §10.5.3

Linear/Logarithmic axis: Set y-axis as linear or logarithmic axis

Wavelength colours: Superimposes wavelength colours to a scan over the visible region.

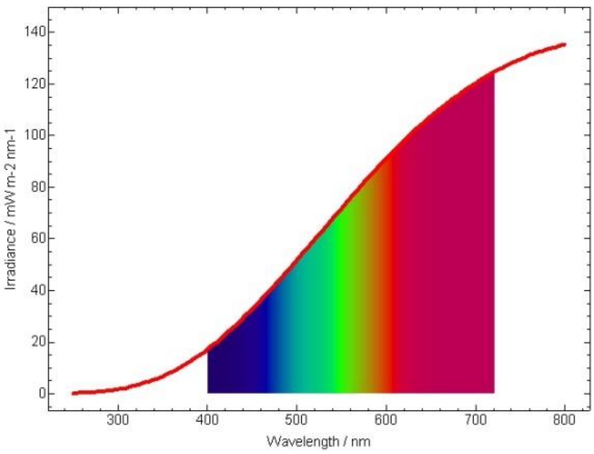


Figure 10.39: Spectrum with the wavelength colours overlaid

View CIE/spectrograph: Toggle between views

View spectral data/marker list/measurements: Presents to right of spectrum window spectrum values, markers and calculated measurement values (spectral integrals)

10.6 Export to Excel

It is possible to export scan results to Excel, either at the end of a scan or via the scan menu. Via the post-scan page in Advanced >>, one can edit the Excel export settings.

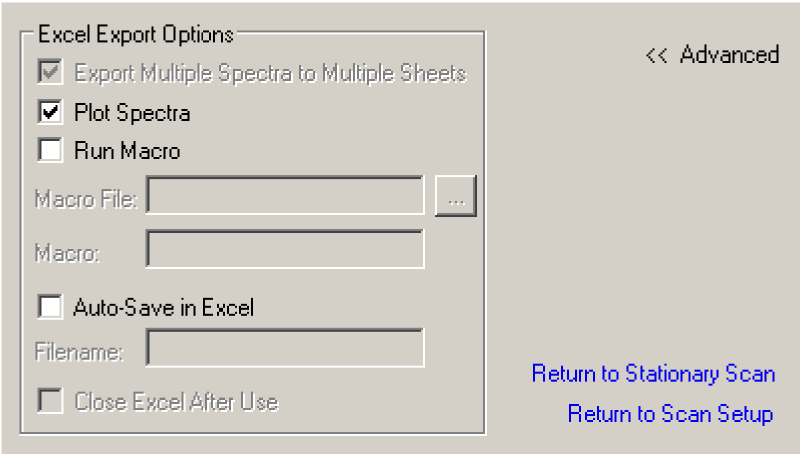


Figure 10.46: Excel export settings

Having performed multiple scans in one window, the Export Multiple spectra to multiple sheets button becomes active. This permits the choice of exporting each spectrum to an individual worksheet, or placing all in one worksheet.

One may choose whether or not to plot the spectrum on exporting to Excel. Should a macro be required, select "Run macro" to run pre-defined macro (see appendix 4 for information on writing macros). Define the macro file using the "…" button to select, and define the name of the required macro. One may choose to autosave in Excel, in which case a filename is required. Else, one can export via File → Export → Export to Excel

10.7 Use of BenWin+ on Desk Computers

It is possible to install BenWin+ on a desktop computer to view measurement results extra-laboratory.

- Load BenWin+ software CD into computer.
- Double click on the set-up launcher icon, which shall take you through the set-up process.
- You may now run BenWin+ for use to load saved spectra etc.
- Initialising will not however work

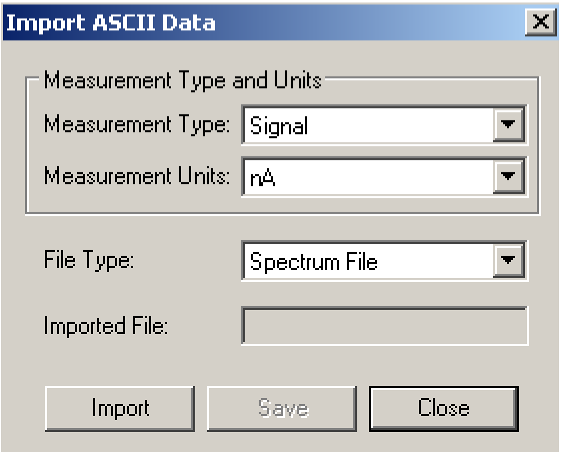
10.8 Menu reference

The following is a reference of those BenWin+ specific menu items.

10.8.1 File

An expanded menu is available when a spectrum opened.

Import ASCII data: Import ASCII two-column ASCII file wavelength in left column, values in right, for preparation as BenWin+ spectrum, certificate or calibration file.



10.47: Import ASCII Data window

Using pull down menus, define measurement type, units and file type.

File types are:

1. *.ben: BenWin+ spectrum file
2. *.bcf: BenWin+ certificate file. When applying data correction, the certificate file must be in this format

Import Colorimetry data: Import data from ASCII file.

Export to ASCII: Export spectral results to two-column ASCII file (*.dat)

BenWin+1.0 file: BenWin+ spectrum files contains not only spectral file information, but colorimetry, dark current, integral values etc. Now, BenWin+ 2.0 saves files in binary format, version 1.0 in ASCII format. Export to version 1.0 file to extract required values in ASCII format.

Export to Excel: Export spectral results to Excel

Graphics File: Export graph in a number of image formats. Having chosen file name and format, the user is then presented with a window to define resolution.

Measurements to ASCII: Where spectral integrals of an add-on processes further the spectral data, this permits exporting these values to ASCII

Copy: Copy spectral values or measurements (integrals or add-on values) to paste as text.

Properties: Provides details of spectral measurement, including spectral range, correction factors, file information and summary of scan events.

10.8.2 Scan

- Scan setup: See §10.4.3
- Signal setup: See §10.4.7
- Stationary scan setup: See §10.4.6
- Signal monitor: See §10.4.8
- Set averaging: Short-cut to Instruments → ADC page. See §10.3.5/10.3.6
- Scan summary: Provides a summary of actions performed by the system over the defined spectral range in scan setup page
- Data correction: See §10.4.4
- Reference setup: See §10.4.5
- Add-on modules: See §10.4.10
- Auxiliary measurements: See §10.4.11
- Set file information: Allows the users to determine data fields that are attached to each scan
- Use file information: Allows the user to change data within each field that is attached to each scan
- New scan: Initiate new scan in a new scan window, given scan parameters in scan setup page.
- Add scan: Initiate new scan given scan parameters in scan setup page, adding scan to active spectrum window.

10.8.3 Tools

Initialise: Initialises the system using the configuration last selected

Advanced Initialisation: The standard initialise button establishes communication with hardware based on a default system.cfg file (or the latest *.cfg file used on the computer). The advanced initialisation page permits definition in the first place of a specific *.cfg file to employ.

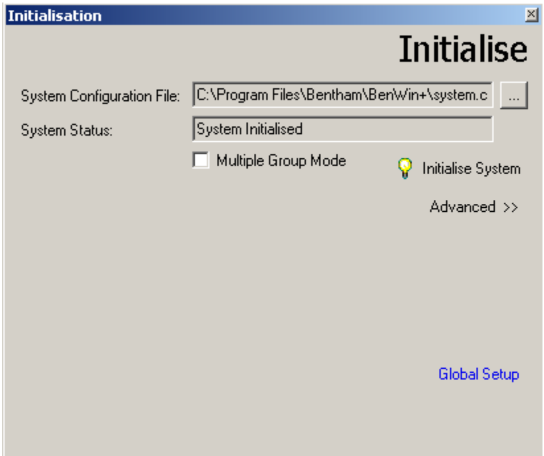


Figure 10.48: Advanced initialisation window

Here can also be defined instrument group set ups and mode of operation.

It is for example possible to define two groups of detection electronics, operated in ratiometer mode, or a wavelength switched system permitting for example the use of DC electronics in the ultraviolet and visible spectral regions, and AC electronics in the infra-red.

Create custom wavelength file: When measuring for example a line source, rather than performing scans over the entire spectral range, full of barren land, it is possible to define a custom wavelength file limiting scans only to those regions of interest.

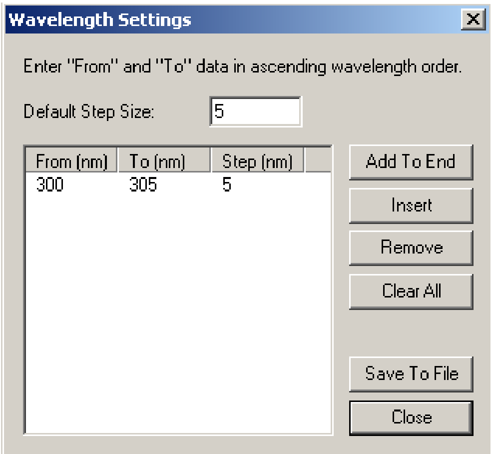


Figure 10.50: Users can create a custom wavelength file in this window

One can define a default step size, start and stop ranges, and add, insert or remove as appropriate. Having defined a custom wavelength file, save. This file might be implemented going to Scan → Scan Set Up and in Advanced>> selecting "Use custom wavelengths" and hitting the "Load custom wavelengths" button to select the appropriate file.

Schedule mode: Allows the user to determine an autonomous programme of scans. Upon loading a schedule they system will perform the measurements as directed in the schedule window

Options: Relates to specific operation options of BenWin+. Certain recommended items are pre-selected.

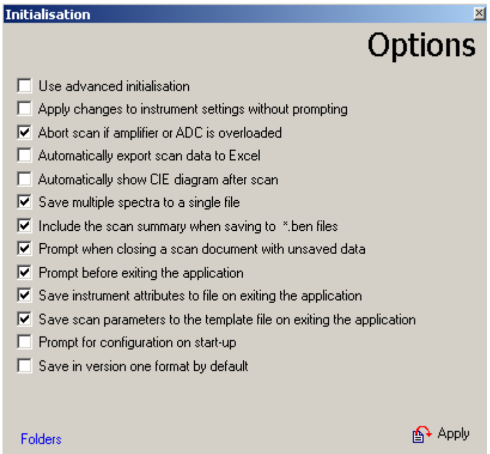


Figure 10.51: Options window

The default file locations may be modified by following the Folder link bottom left and use the "…" button to navigate to new folder location.

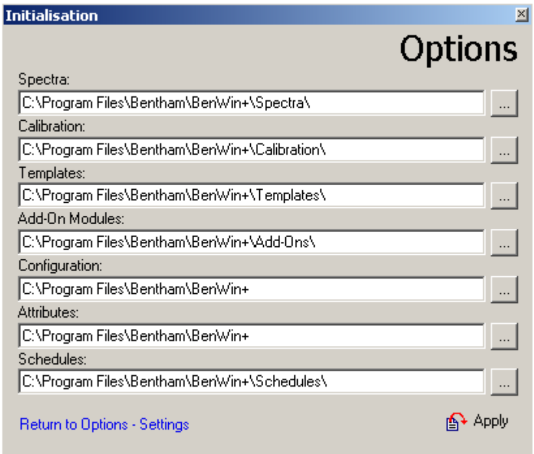


Figure 10.52: Folder locations window

10.8.4 Analysis

Set spectrum names: See §10.5.2
Overlay spectra: See §10.5.3
Delete spectra: See §10.5.4
Interpolate: See §10.5.5
Cut: See §10.5.6

Concatenate: See §10.5.7
Invert: See §10.5.8
Normalise: See §10.5.9
Spectral arithmetic: See §10.5.10
Spectral average: See §10.5.11
Quantum efficiency: See §10.5.12
Peak picker: See §10.5.13
Set spectral integral: See §10.7.14
Calculate spectral integrals: See §10.5.14
Calculate add-on measurements: See §10.4.11

10.8.5 View

Spectrum: See §10.5
Spectral data: Hit this button to present the numerical spectral data to the right of the spectrum window
Marker list: Shows presently set markers in right hand list
Measurements: Shows spectral integral results in right hand list
Vertical split: Position spectral data, measurements etc window to right of spectrum window
Horizontal split: Position spectral data, measurements etc window under spectrum window
Wavelength colours: §10.5.16
Cursors: See §10.5.15
Markers: §10.5.15
Toolbars: Toolbars are as follows.

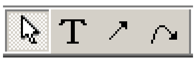
Hardware

Initialise | Configuration

Main

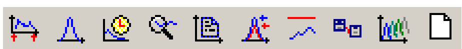
Open | Save | Copy spectral data | Print |Help

Mouse Mode



Cursor | Add text | Draw straight arrow | Draw curved arrow

Scan

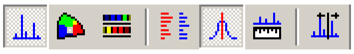


Scan setup | Signal setup | Stationary scan setup | Signal monitor | Scan summary | Data corrections | Set reference | Add-on modules | Set averaging | New scan

Analysis

Peak picker | Spectral integrals | Set spectrum names | Overlay spectra | Normalise

View



Spectrum view | CIE diagram | Spectrograph | Spectral data | Marker list | Measurements | Cursors

Status bar: Lower screen status bar showing hardware mode, system status, current wavelength and dial reading

Show auxiliary measurements: where a system is taking auxiliary measurements select to present or not the auxiliary measurement results

11. Device dependent detection

11. 1 Overview

In general, standard techniques require that the spectral response of solar cells be tested under light biasing at 1000 Wm^{-2} to simulate use conditions†. This presents the problem of discriminating the photocurrent generated by the monochromatic probe from that generated by the solar simulator. In most cases, this situation may be circumvented by optically chopping the monochromatic probe and recovering the AC signal with a lock-in amplifier having either a transformer or trans-impedance amplifier front-end. Whilst the former input stage is preferred- since it does not pass the DC signal, the AC signal can be given maximum possible gain- it only functions at elevated frequency, incompatible with certain types of cell. Indeed, in the case of certain DSSC cells, with particularly slow electron transport, recourse is made to the use of a DC monochromatic probe and detection. The following are the recommended routes for testing the solar cells of today.

Probe source and signal detection operates in the AC regime permitting the use of a DC bias source to operate the device under test under standard conditions in the measurement of spectral response.

There exists three methods of signal recovery; via a transformer, for those devices requiring the standard one sun bias, via a high current sink current amplifier, or via a high gain pre-amplifier for the measurement of less efficient devices, where higher sensitivity is required and where no or little bias shall be employed.

With the addition of a few further elements, the presently unused monochromator port next to the dual light source may be used to permit the measurement of solar simulator irradiance.

11. 2 Semiconductor and Organic Solar Cells

474 Transformer & 496 Lock-in Amplifier

The fast electron transport mechanisms in most semiconductor and some organic cells permit exploitation of the preferred transformer coupling method.

The monochromatic probe beam is optically chopped at a frequency of 600 Hz and the cell under test illuminated with a one sun solar bias.

The solar cell output is coupled by the 474 transformer, which passes only the optically chopped signal. This signal is amplified and passed to the lock-in amplifier. The device is operated under short circuit conditions.

This technique is recommended for all semiconductor (c:Si, mc:Si, a:Si, µ:Si, CdTe, CIGS, CIS, Ge, tandem, multi-junction, quantum well, quantum dots) and some organic cells.

11. 3 Organic and DSSC Solar Cells

477/498 Pre-amplifier & 496 Lock-In Amplifier

Where device response is slow, recourse is made in the first instance to reduced chopping frequency and the use of a trans-impedance amplifier front-end to the lock-in amplifier.

The monochromatic probe beam is optically chopped at a frequency of >10 Hz and the cell under test illuminated with one sun solar bias (or less to improve signal to noise).

The solar cell output is passed through the 477 or 498 trans-impedance amplifier prior to being passed to the lock-in amplifier. The device is operated under short circuit conditions.

This technique may be applied to organic and some DSSC cells.

11. 4 DSSC Solar Cells

498 and DC chopper

Due to carrier transport mechanisms at play in DSSC cells, it may be found necessary to operate these cells at much slower chopping frequencies or in the DC regime.

The monochromatic probe beam is either run DC or optically chopped up to 2Hz, and the cell illuminated with a reduced level of solar bias.

The solar cell output is passed through a trans-impedance amplifier and the cell response recorded as a shutter in the dual source switches on and off the monochromatic probe. The device is operated under short-circuit conditions.

This technique may be applied to DSSC technologies.

12. Measurement of Spectral Responsivity (Transformer)

12.1 Introduction

The measurement of spectral responsivity involves the comparison measurement of a detector of known responsivity with a device under test.

To determine absolute (AW^{-1}) responsivity, samples in both occasions must be underfilled by the probe beam, ie the light from the probe must be entirely seen by the detector.

If this is not the case, only measurements of relative spectral response can be performed.

With the calibrated detector underfilled and knowing its AW^{-1} responsivity, one can effectively determine the optical power in the beam.

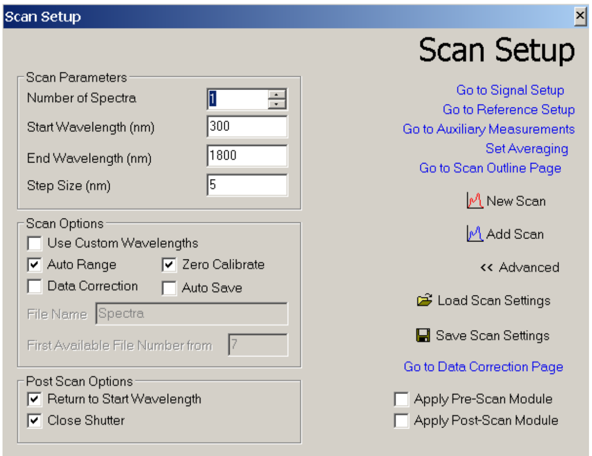
Measuring then the photocurrent response of the device under test one can determine the responsivity of the latter, and from there the quantum efficiency.

12.2 System setup

- Ensure USB connected
- Power on the Xenon source 610
- Power on all remaining devices after red lamp failed light of Xenon source extinguishes
- Let lamps warm up for ten minutes

12.3 System calibration

- Run BenWin+, select Transformer mode
- Ensure reference detector connected via the thick, short BNC cable, to the input of the transformer, the output of the transformer to the input of the 474 amplifier and the output of the 474 amplifier to input 2 of the 496 lock-in amplifier
- To position reference detector central to the beam, go to wavelength box and input visible wavelength (eg. 555nm)
- Go to Scan → Scan setup
- Define start, end and step wavelengths, for example 300-1100nm in steps of 5nm
- Go to advanced>>, ensure that data correction is NOT selected



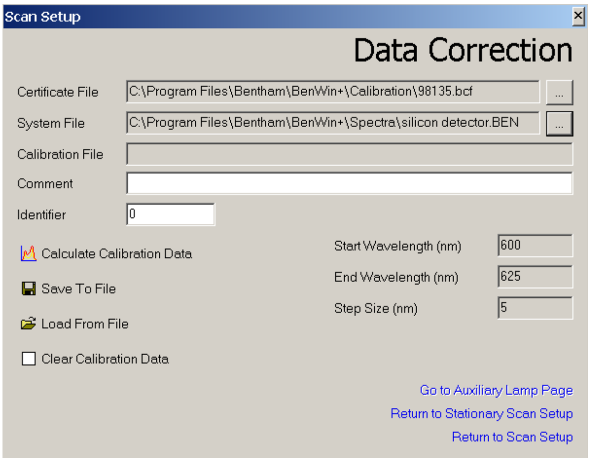
12.1: Scan setup page with settings used for the initial calibration measurements

- Hit new scan
- The y-axis should read signal (nA)
- At the end of the scan, save, giving appropriate name
- Multiple scans can be performed, the average taken using the function in the Analysis menu, and all but the average spectra deleted using this analysis menu item
- Save result
- Calibrate the system 300-1100nm with the silicon detector and 800-1800nm with the germanium detector, ensuring that where a calibration over the full range is required, an overlap region is provided

12.4 Applying calibration

Where the measurement range encompasses the range of only one reference detector, to implement data correction:

- Go to Scan → Data correction
- For certificate file load .bcf file of calibrated detector
- For system file, select just saved measurement



12.2: Data calibration window

- Hit calculate calibration data
- On prompt say YES to the application of data correction
- For future use, hit save to file, and give appropriate name

Where the measurement range encompasses the range of both reference detectors, to implement data correction:

Go to Utilities → Correction Calculator

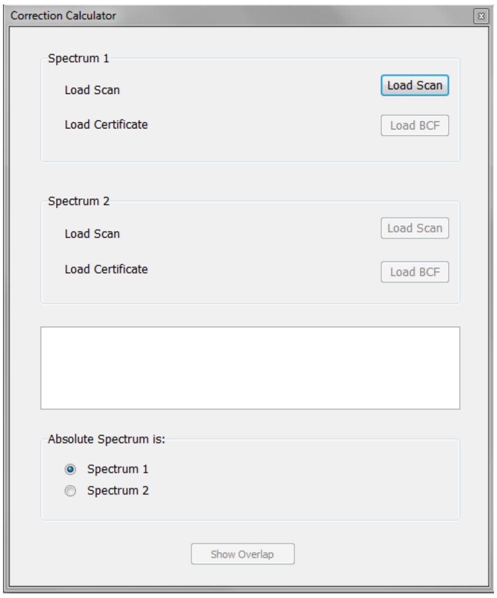


Figure 12.3: Correction Calculator window

For spectrum 1:

- Load measurement of silicon detector (300-1100nm)
- Load certificate of silicon detector

For spectrum 2:

- Load measurement of germanium detector (800-1800nm)
- Load certificate of germanium detector

Set absolute spectrum as spectrum 1.

One of the correction factors are taken as absolute, the other normalised to ensure a continuous correction function. Given the larger area of the silicon diode it is more likely that the beam power measurement be performed correctly with this device.

- Hit show overlap
- The correction curves for both devices are shown in the overlap region and there deviation noted
- Typically the crossover point is taken automatically ~950nm. Given the reduction of response of silicon in the region of its band edge, this is the most stable location
- Hit save to file
- Go to Scan → Data Correction
- Hit load from file
- Load just-saved correction file
- On prompt say YES to the application of data correction

12.5 Measurement of solar cells

From the above, the system is now calibrated in spectral responsivity.

- Ensure sample device connected via the thick, short BNC cable, to the input of the transformer, the output of the transformer to the input of the 474 amplifier and the output of the 474 amplifier to input 1 of the 496 lock-in amplifier
- Position sample cell, using lock-in amplifier page to select wavelength, to check position with respect to probe beam
- Check phasing of lock-in amplifier

Where the use of a bias source is required, go to utilities → PV bias control to switch on/off as required:

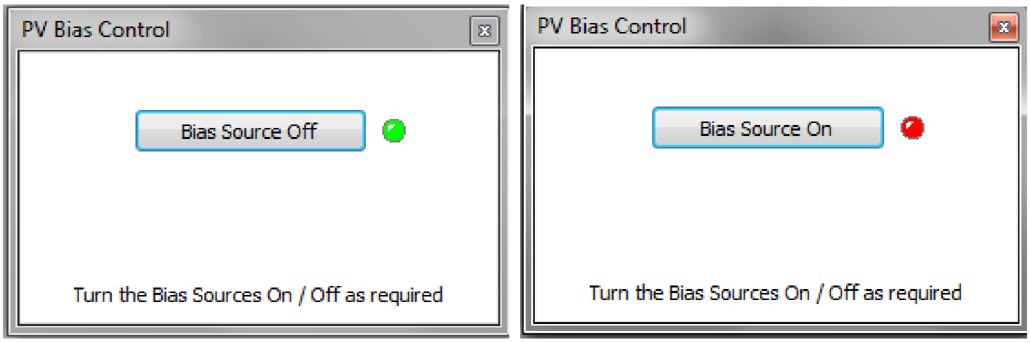


Figure 12.4: PV bias control

- Perform spectral scans ensuring data correction selected
- Save results with appropriate name

12.6 Results analysis

At the end of the scan, one is presented with the spectral responsivity of the device, such as:

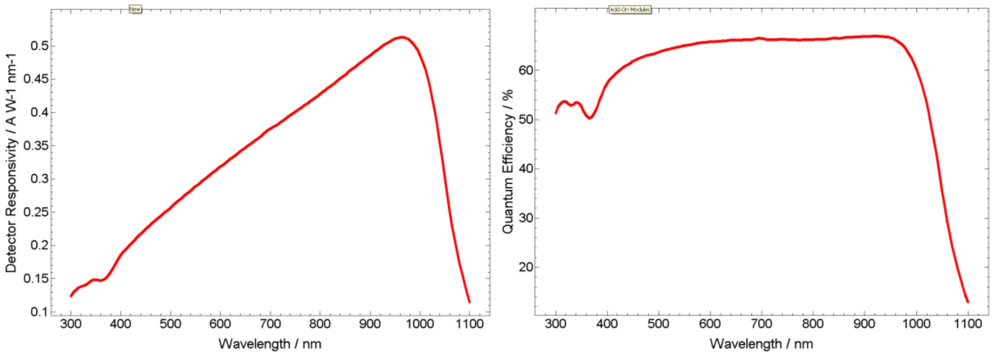


Figure 12.5: Detector responsivity and external quantum efficiency

If desired, one can inspect the (external) quantum efficiency of the device by going to the Analysis → Quantum Efficiency menu item. One can return to the responsivity view via Analysis → Detector Responsivity. Do not forget to save the device results.

13. Measurement of Spectral Responsivity (498 Preamplifier-AC mode)

13.1 Introduction

When the response of the cell is slow it may be useful to use this mode as the probe beam can be chopped to as little as 10 Hz. Please note that the 498 amplifier saturates at 100mA, and should therefore be used with little or no bias.

It should be further noted that the 498 is a DC and AC amplifier, the presence of a large DC bias-generated photocurrent will lead the amplifier to operate on a low gain level, which means of course that the probe signal shall receive little gain and the signal to noise ratio shall deteriorate.

13.2 System setup

- Ensure USB connected
- Power on the Xenon source 610; the lamp failed light shall show whilst the starter circuit is charging, and extinguish when the lamp illuminated
- Power on all remaining devices after red lamp failed light of Xenon source extinguishes
- Let lamps warm up for ten minutes

13.3 System calibration

- Run BenWin+, select 498 AC mode configuration
- Ensure reference detector connected directly to input one of the 498 amplifier and the output of this to input 1 of the 496 lock-in amplifier
- Users can then follow the instructions detailed in §12.3

13.4 Applying calibration

The process of applying the calibration should be the same as the process described in §12.4

13.5 Measurement of solar cells

Users can then follow the same instructions as §12.5. Please note that the PV bias should not be used in this mode

13.6 Results analysis

Again users should follow the steps detailed in §12.6

14. Measurement of spectral responsivity (498 Amplifier/ADC-DC mode)

14.1 System setup

- Ensure USB connected
- Power on the xenon source 610; the lamp failed light shall show whilst the starter circuit is charging, and extinguish when the lamp illuminated
- Power on all remaining devices after red lamp failed light of Xenon source extinguishes
- Let lamps warm up for ten minutes
- Power off optical chopper on 218M module

14.2 System calibration

- Run BenWin+, select 498 DC mode configuration
- Ensure reference detector connected directly to input one of the 498 amplifier
- Following this, the procedure is the same as stated in §12.3

14.3 Applying calibration

To apply the calibration users should follow the instructions detailed in §12.4

14.4 Measurement of solar cells

From the above, the system is now calibrated in spectral responsivity and users can now measure the cell

- Ensure device under test connected directly to input 1 of the 498 amplifier
- Users can then follow the instructions detailed in §12.5

14.5 Results analysis

To analyse the results the user can follow the instructions described in §12.6

15. Measurement of Reflectance

15.1 System setup

- Ensure USB connected
- Power on the Xenon source 610
- Power on all remaining devices after red lamp failed light of xenon source extinguishes
- Let lamps warm up for ten minutes
- Run BenWin+, select 498 AC high-sensitivity configuration
- Connect detector via interface panel to 498 input 1
- Go to scan → signal setup
- For target wavelength choose 0nm
- Move the 45° mirror fully to the right so that light enters the sphere, then fix in place
- Placing the reflectance standard at the reflectance sample port, adjust sphere position to obtain probe focussed at this plane, fix in place sphere
- Depending on spectral range of consideration, mount silicon/germanium sandwich detector at detector port

15.2 System calibration

- In Scan → Reference setup, ensure "use reference setup" not selected
- In Scan → Scan Setup → advanced ensure that data correction is not selected
- Go to Scan → Scan setup
- Place reflectance standard at sample port
- Ensure SPIN/SPEX trap has reflectance plug in place
- Ensure detector connected directly to input one of the 498 amplifier and the output of this to input one of the 496 lock-in amplifier.
- Go to Scan → Scan Setup
- Define start, end and step wavelengths, for example 300-1100nm in steps of 5nm
- Go to advanced>>, ensure that data correction is NOT selected

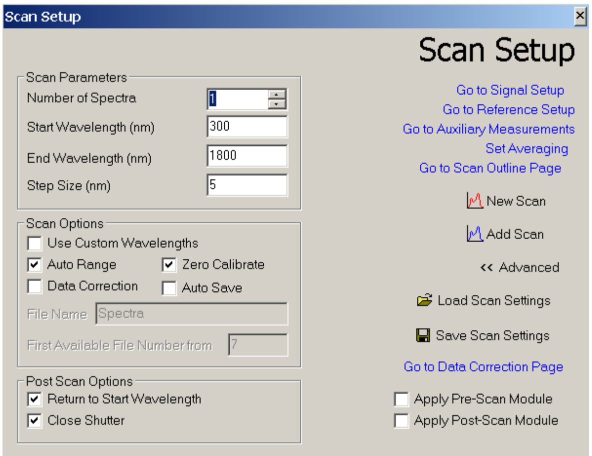


Figure 15.1: Scan setup window with settings used for initial scan of the reflectance piece

- Hit new scan
- The y-axis should read signal (nA)
- At the end of the scan, save, giving appropriate name

Multiple scans can be performed, the average taken using the function in the Analysis menu, and all but the average spectra deleted using this analysis menu item. Save result.

15.3 Applying calibration

This is implemented via the reference setup. To implement correction:

- Go to Scan → Reference setup

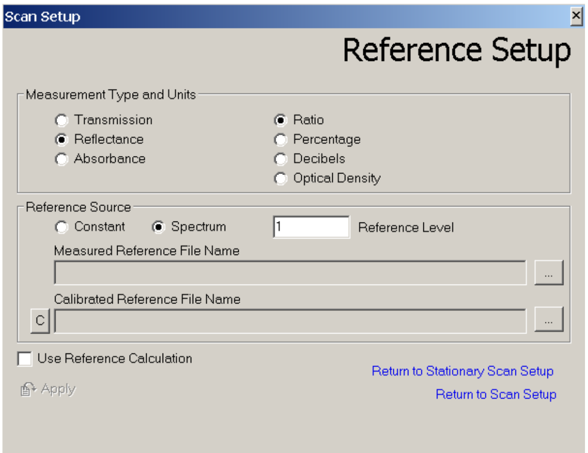


Figure 15.2: Reference setup window used in reflectance measurements

- Select reflectance
- Select ratio
- For measured reference, hit … button to load just saved file

- For calibrated reference file name, hit … button and load calibration values of reflectance standard
- Check the “use reference calculation” box
- Return to scan setup proceed to measure

15.4 Measurement of Reflectance of Solar cells

From the above, the system is now calibrated in SPIN reflectance.

- Place the sample to test at the reflectance sample position
- Perform scan over the required spectral region
- Save results with appropriate name

16. Measurement of Transmittance

16.1 System setup

- Ensure USB connected
- Power on the Xenon source 610
- Power on all remaining devices after red lamp failed light of Xenon source extinguishes
- Let lamps warm up for ten minutes
- Run BenWin+, select the 498 AC high-sensitivity configuration
- Go to Scan → Signal Setup
- For target wavelength choose 0nm
- Probe beam shall be transmitted to PVE300 chamber
- Displace 45° mirror to relay light toward DTR6, fix in place
- Placing a target at the entrance port, adjust sphere position to obtain probe focussed at this plane, fix in place sphere
- Depending on spectral range of consideration, mount Silicon or Germanium detector at detector port
- Connect detector via interface panel to 498 input 1
- Place reflectance standard at reflectance port to close this aperture

16.2 System calibration

Users should follow the steps described in §15.2

16.3 Applying calibration

To implement the calibration via the reference setup, users should follow the steps shown in §15.3

16.4 Measurement of the Transmittance of Solar Cells

From the above, the system is now measured in terms of transmittance. TO perform this users should follow §15.4

16.5 Results analysis

Based on the results of transmittance and reflectance, the EQE may be modified to determine the IQE via the following:

$$IQE = \frac{EQE}{1 - R - T}$$

Where IQE and EQE are in absolute units or percent, and the reflectance, R, and the transmittance, T, are in absolute units. A utility exists to permit the calculation of the IQE, in Utilities → EQE IQE Calculator.

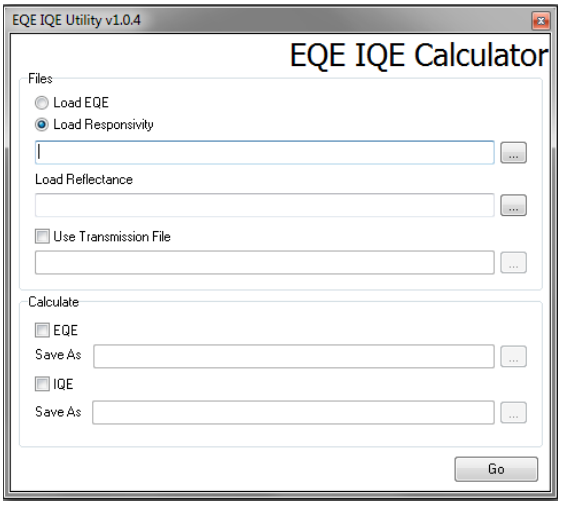


Figure 16.1: EQE IQE Calculator

17. Precautions & Troubleshooting

17.1 Precautions

This section deals in the first instance with those precautions that should be observed in using this system, then with the cases where something goes wrong

The following is a list of specific precautions aimed to preserve for good use this system.

Light Source

- Ensure correct bias applied to correct lamp at all times
- It is recommended to power on the Xenon lamp first before all other electronics

Monochromator

- Do not touch gratings nor optics
- Do not subject monochromator to violent physical shock- this may invalidate wavelength calibration
- Always switch on Xenon sources prior to monochromator

17.2 Trouble Shooting

The following is a list of some more common problems encountered with spectroradiometer systems, by no means exhaustive, please contact Bentham should any other problem arise.

Problem	**Possible Error/Solution**
"Jumps" seen in spectra at decades	Ensure zero-calibration is selected
On scanning no signal seen	Ensure detector connected to 487 Ensure correct channel used.
BenWin+ does not initialize	Ensure all units switched on and USB connection OK
Nonsensical scan obtained	Ensure data correction switched on/off as appropriate Ensure reference calculation on/off as appropriate

Appendix 1: Verification of Monochromator Wavelength Calibration

Wavelength calibration is usually checked using a mercury lamp the output of which consists of discrete lines at defined wavelengths. The presence of mercury in overhead fluorescent tubes can act as a good replacement for a specific lamp.

The following describes calibration with a mercury lamp but in the case of this system, the same can be performed using the emission lines from the xenon lamp, or by simply viewing the zero order contribution of each grating in turn.

The following table shows the position of the mercury lines. Those marked in red are particularly strong lines, leading therefore to higher orders with a measurable contribution.

1st Order	2nd Order	3rd Order	4th Order	5th Order	6th Order	7th Order
184.91						
194.17						
226.22						
237.83						
248.2						
253.65	507.3	760.95	1014.6	1268.25	1521.9	1775.55
265.2						
280.35						
289.36						
296.73						
302.15						
312.57	625.14	937.71	1250.28	1562.85		
313.17						
334.15						
365.02	730.04	1095.06	1460.08	1825.1		
365.44						
366.33						
404.66	809.32	1213.98	1618.64			
407.78						
434.75						
435.84	871.68	1307.52	1743.36			
491.6						
496.03						
546.07	1092.14	1638.21				
576.96						
579.07						
690.7						
1013.98						

Table A1.1: Xenon lines along with their nth order

It is of course important to ensure that whilst observing the higher order lines, the order sorting filters of the monochromator are de-activated. This is done by going to Instruments → Filter wheel and resetting the true insertion wavelengths with 0nm.

Use the Tools → Create Custom Wavelength file facility of BenWin+ to define a scan around desired emission lines rather than scanning over the full range.

Go to Tools → create custom wavelength file, to view the following, left. Set default step size, insert the number of lines required, double click on values to edit and finally save to file.

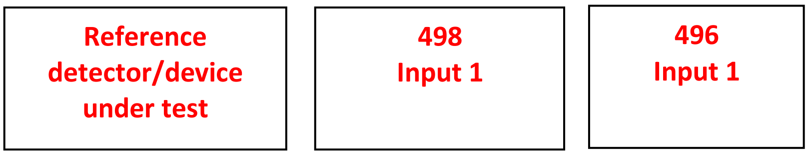
Choose a step size of minimum 0.15nm to view lines. Scans using this file are initiated by going to Scan → Scan Set, select custom wavelength file and load file required, then scan as normal.

Please be aware of the slits presently in system. Having for example 5nm slits present and looking at the lines around 365nm, one will effectively see several lines which can distort the result and wrongly show lack of calibration.

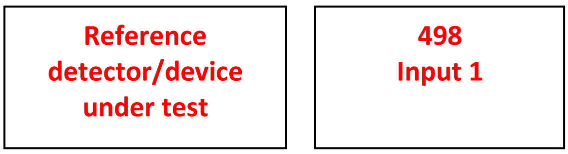
In the case of infrared gratings where this procedure is of no use, gratings are set up with the zero-order position.

Appendix 2: Electrical Connection for Transformer Configuration

Appendix 3: Electrical Connection for 498 Pre-Amplifier AC Configuration



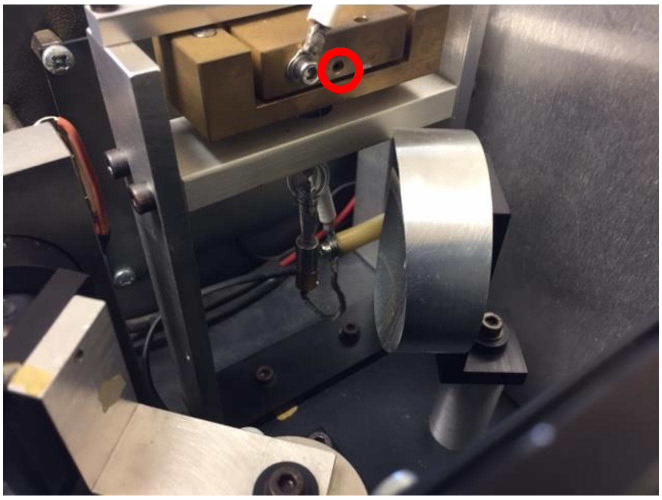
Appendix 4: Electrical Connection for 498 Amplifier-ADC DC Configuration



Appendix 5: Dual Light Source Lamp Replacement

Xenon Lamp Replacement

- Remove the lid of the dual light source by removing the 8 screws that hold the lid onto the source, the lid can then be removed
- Undo the grub screw that holds the top of the bulb in the brass holder. This will release the top of the bulb



A5.1: Grub screw that releases the top of the xenon lamp

- Gently pull the bulb out of the brass holder and place it so that the top rests on the floor of the source, by the xenon mirror. Now undo the screw that holds the base of the bulb to the main support
- The bulb can now be removed from the source entirely. Rest the bulb on a soft surface and gently release the wired collar from the base of the bulb
- The new bulb can now be inserted following the reverse procedure. Ensure that polarity is observed, and that the collar is placed onto the correct end of the bulb

A5.2: Remove this screw to remove the cable connecting the xenon lamp

Alignment of Xenon Lamp

- The system should be started up in reflection mode (using the 498 and 496), but with the silicon detector (DH-Si) connected rather than the sphere and the mirror which deflects the beam towards the sphere out the way so that the beam falls onto the DH-Si.
- Now the system is set so that the probe beam strikes the silicon detector. To do this the lock-in amplifier page is opened by opening the Instruments → Lock in amplifier page from the top

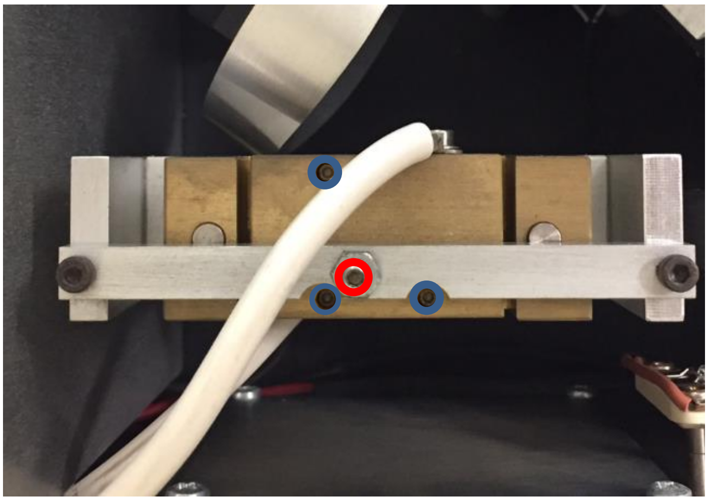
of BenWin+. The wavelength is set to 555nm and the “Start” button is pressed so that the probe beam is falling onto the DH-Si. There will now be values in Channel 1, Channel 2, theta and resultant.

- The bulb can now be aligned until this resultant value is as high as possible. There are 2 alignments to be performed on the bulb which should be repeated until the resultant is as high as possible.

The 2 alignments are the height of the bulb and the tilt of the bulb. These 2 are controlled in the following way.

Height: At the top of the light source is a central screw held in place with a nut onto the central aluminium bar (red circle). This nut can be loosened so that an Allen key can be inserted in the top of the grub screw. As this grub screw is rotated the bulb will be moved vertically in the mount. The resultant value should be watched and the height of the bulb adjusted until this is a maximum value.

Tilt: There are three other grub screws present which screw directly into the brass block (blue circles). Each of these adjusts the tilt of the xenon bulb. Each of these should be adjusted so that a maximum resultant value is seen. It may be found that after all 3 have been adjusted, the first can be adjusted further to gain even more signal, therefore this process should be done iteratively until no more gain in signal can be achieved.



A5.3: Grubs screws used to adjust the height (red) and tilt (blue) of the xenon lamp

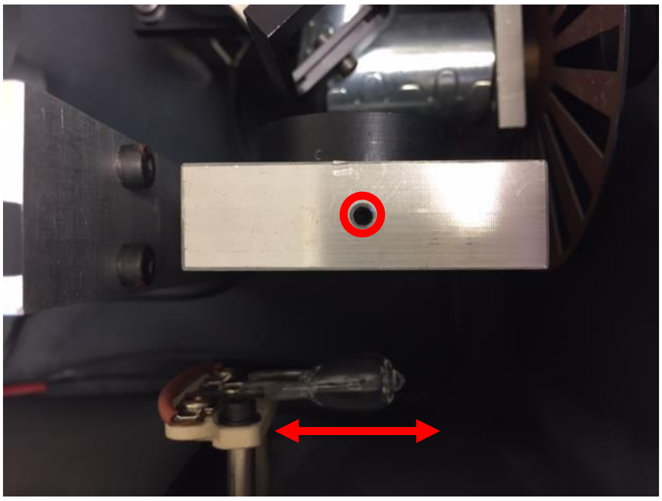
Both the height and tilt alignments should be done iteratively until no more signal can be gained. The xenon bulb signal should finally be roughly 4 times higher than the Quartz Halogen signal. Once complete the nut on the height control should be tightened.

Quartz Halogen Lamp Replacement

Replacement of the quartz halogen (QH) lamp is a relatively easy procedure. Simply remove the expended lamp and replace with a new 100W lamp. There is no need to observe polarity on the lamp.

Alignment of the Quartz Halogen Lamp

The QH lamp should be fitted such that the slits of the monochromator are centrally located on the image of the filament. Although under normal circumstances, there is no need to focus the lamp as this should already be set. However, should users need to, undoing the grub screw that secures the lens and then move this back or forward until the signal is maximised in the same way as the xenon lamp.



A5.4: Moving the QH lamp left or right allows the user to centre the filament on the slits, while the lens allows focussing

Appendix 6: Overview of System Installation

The following notes provide the user with a guide to the installation of the PVE300 system.

Shipped Items

The measurement enclosure with monochromator, light source, relay optic and bias light source is shipped as a single unit in a wooden crate. Power supplies, vacuum mount, detection electronics, integrating sphere, detectors and accessories are packaged separately.

As a guide, the anatomy of the system, is provided overleaf.

PVE300 Enclosure

Site the main PVE300 enclosure in a suitable location. On optical bench is not required. For the moment the only addition to the enclosure is to find the power supply with 3-pin connector for the LED illumination of the chamber; connect to mains and connect 3-pin to socket in right hand wall of PVE300

Power Supplies

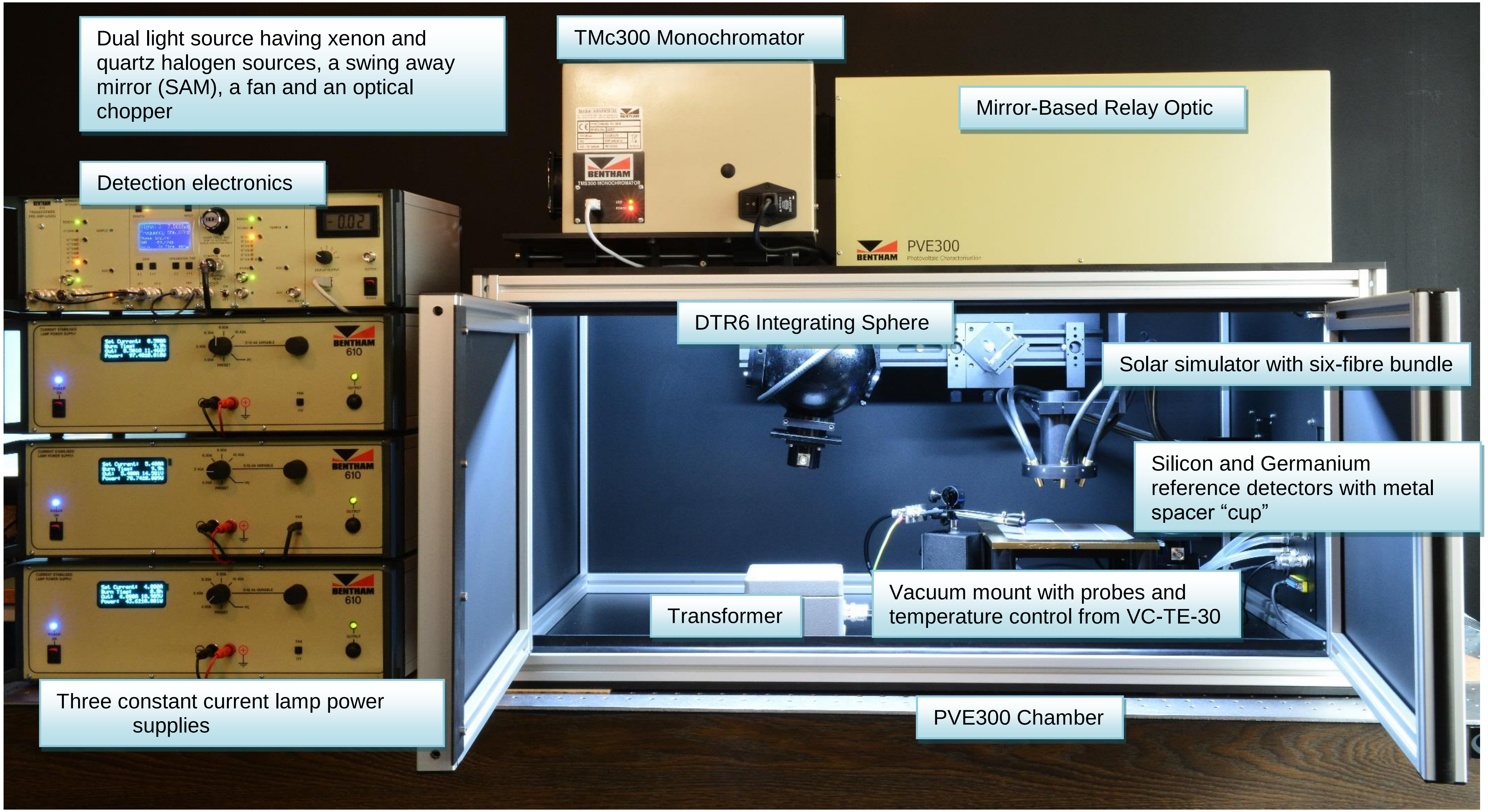
Two power supplies are required for the dual light source and one for the solar simulator. The 610 power supplies current is set via a key switch with the etched arrow pointing to the set current. These are pre-set and the key kept to the side for safe keeping.

Place the 610s set to 8.500A and 5.400A to the left hand side of the enclosure (dual light source), and that set to 6.300A to the right hand side of the enclosure.

Detection Electronics
Place the detection electronics on top of the 610 to the right hand side of the enclosure

Electrical Connections

- Locate red and black cables to connect 610 to light sources
- Connect 610 set to 8.500A to the quartz halogen lamp in the dual source
- Connect 610 set to 5.400A to the Xenon lamp in the dual source
- Connect 610 set to 6.300A to the solar simulator to the right of the enclosure
- Connect black 3-pin connector cable between fan input on dual source and either of the dual source power supplies
- Connect black 3-pin connector cable between fan input on solar simulator and its power supply
- Connect black 3-pin connector cable between SAM port on dual source and SAM port on left hand side of monochromator
- Connect black 3-pin connector cable between SAM port on solar simulator and SAM port on right hand side of monochromator
- Connect black 5-pin connector cable between chopper input on dual source and 218M output of the 417 detection electronics
- Connect output of transformer, through the interface panel on right hand wall of enclosure, to the input of the low noise amplifier with thin BNC cable
- Connect short piece of thick BNC cable to input of transformer- to be connected to either reference detector or electrical probe
- Connect USB between controlling computer and monochromator (windows will recognise on power-on) (pass from rear under monochromator)
- Connect USB between controlling computer and detection electronics (windows will recognise on power-on)
- Connect mains to monochromator (pass from rear under monochromator), detection electronics and power supplies



A6.1: PVE300 setup

DTR6 Integrating Sphere

- Mount silicon/germanium detector to detector port using screws provided (lower port in picture below)
- Mount sphere to optical rail in chamber as shown below, clamp in place

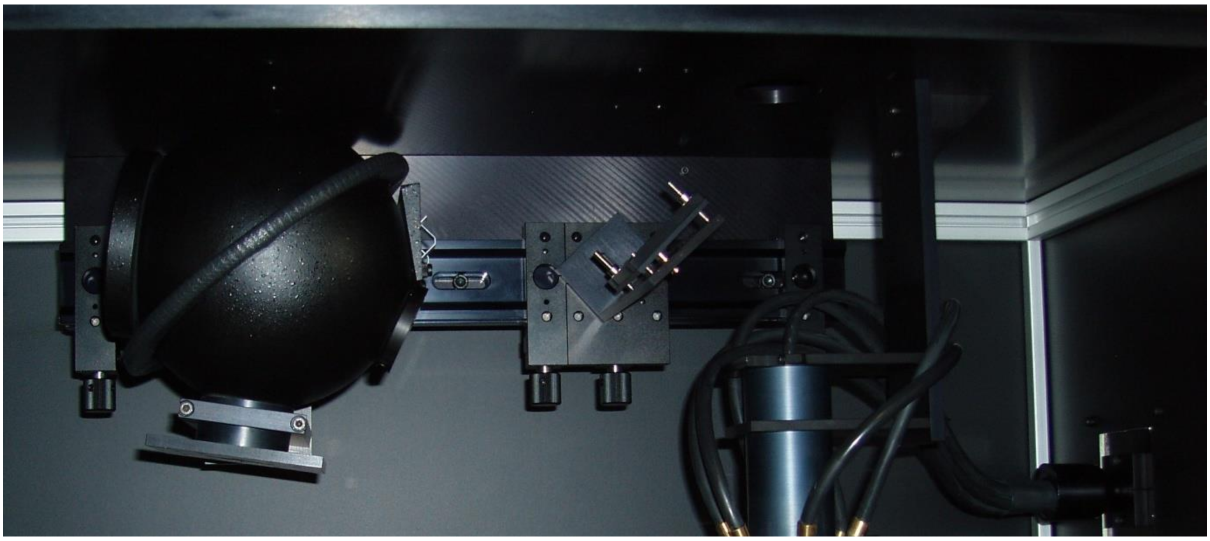


Figure A6.2: DTR6 and 45° Mirror

Vacuum Mount

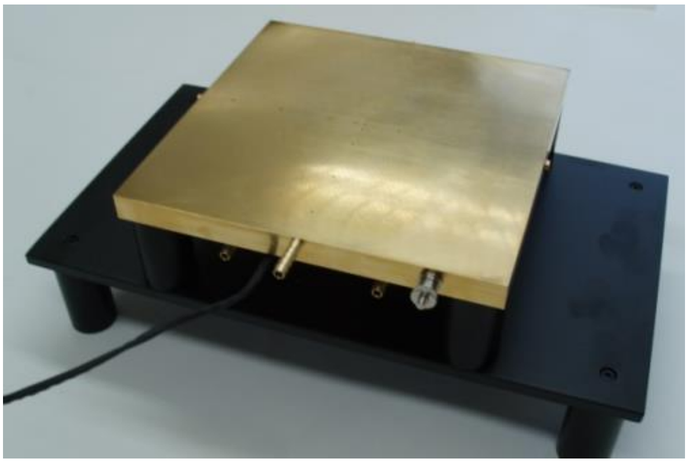


Figure A6.3: PVE mount

The 200x200mm vacuum mount is mounted on a stand for placement of the electrical probes.

Vacuum points are disposed in a cross formation to improve thermal contact during operation. "Pennies" are provided to stop unused holes where required to improve the vacuum.

Below the stage are situated the temperature-controlling Peltiers with the associated water cooling of the latter. To the rear of the device is located a port for the vacuum air feed and two circulation ports for the water cooling system.

- Locate the vacuum mount in the chamber
- Locate the VC-TE-30 to the right hand side of the chamber. If stacking the electronics, it is recommended to place this unit to the bottom to avoid water spilling over other electronics

Figure A6.4: Front panel of VC-TE-30

The VC-TE-30 houses the water cooling controller, the drive to the Peltiers and a vacuum pump. An on-off switch is located to the rear of the unit next to the mains input. At the front are two ports for the water re-circulation system, a reservoir, a vacuum port, and electrical connection to the Peltier devices.

A toggle switch powers off/on the water circulation, vacuum and the temperature control. A protection mechanism prevents the temperature control to be powered on without water circulation.

A front panel LCD display shows the current and target temperature of a transducer situated inside the mount. Below the LCD a toggle switch switches the view of the LCD between target and actual. The target temperature can be modified by pulling out the black knob, modifying the set point, and locking the position by pushing back in the knob.

To set up the mount:

- Locate clear piping
- The vacuum port on the mount is the upper port- it should be connected to the vacuum port of the VC-TE-30 through the right-wall interface plate

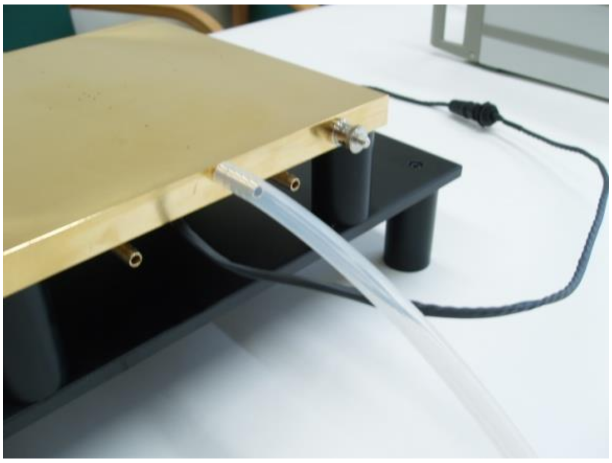


Figure A6.5: Rear of the mount showing the connection to the vacuum

- The Peltier electrical control should be connected to the VC-TE-30. Note that the intermediate connection should be attached to the wall of the PVE300 system
- The water re-circulation ports should be connected each to the VC-TE-30 providing input and output to the mount.

Figure A6.6: (l) Water flow into the mount and (r) Peltier intermediate connection

There should remain some water in the mount so getting the system running should be easy. Have ready distilled water and remove the lid from the reservoir. Power on the VC-TE-30 and power on the water flow for short periods, say 20 seconds. Top up the reservoir ass required as air in the circuit is replaced with water. Rock the VC-TE-30 and the mount gently to help rid of air locks therein. When the system is free of air locks, no significant bubbles should be seen inside the reservoir.

Electrical Probes

Locate the probes on the pedestal to the side of the vacuum mount; two probes are provided, with output via BNC. Should the mount be used as the ground plane, a fly lead permits connecting the probe to a grounding point on the mount, the probe connecting to the other pole of the device under test.

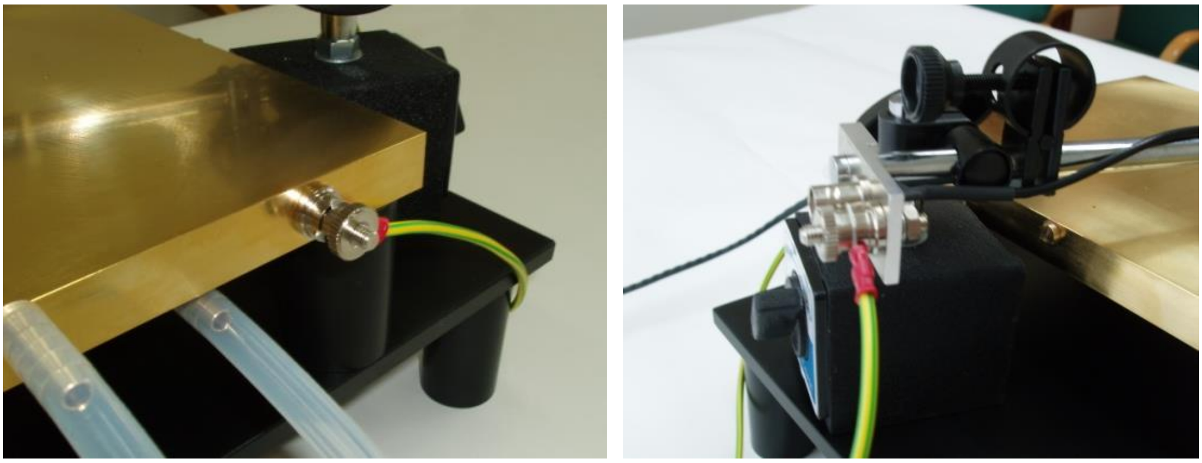


Figure A6.7: (l) Earth connection on the rear of the mount and (r) earth connection to probe for front to rear connections

Where the device under test is insulated from the mount, two probes are required. In this instance, the fly lead should connect both probes, and a stub should be placed on the BNC port of the second probe to short the probe to the opposite pole of the BNC.

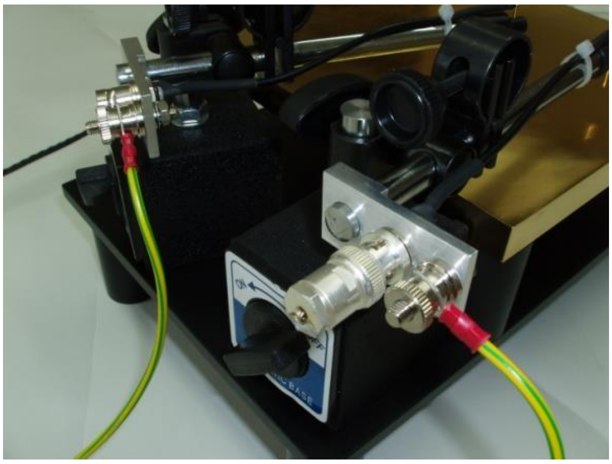


Figure A6.8: Earth connection between two probes for front to front connections

Software

- Insert BenWin+ CD into computer and let autorun open
- Install BenWin+ or select from drive setup.exe
- Hit OK to end
- Copy from calibration certificate CDs the bcf files of each calibrated detector and paste in c:\Program Files (x86)\Bentham\Benwin+\Calibration
- Starting Up System

System Start Up

There is no particular start up sequence save from the suggestion of powering on the xenon lamp first. On power on, the red lamp failed light illuminated whilst the starter circuit charges up. After thirty seconds, the arc is struck and the lamp operates. It is possible, but very unlikely, that interference from this start up procedure damages live electronics. As a precaution powering on and waiting for the start of this lamp before powering on the rest of the system avoids any doubt. There is no particular order for power-down.

The system is now ready for measurement for examples see section 11.

Guarantee

BENTHAM INSTRUMENTS warrants each instrument to be free of defects in material and workmanship for a period of **one** year after shipment to the original purchaser. Liability under this warranty is limited to repairing or adjusting any instrument returned to the factory for that purpose.

The warranty of this instrument is void if the instrument has been modified other than in accordance with written instructions from BENTHAM, or if defect or failure is judged by BENTHAM to be caused by abnormal conditions of operation, storage or transportation.

This warranty is subject to verification by BENTHAM, that a defect or failure exists, and to compliance by the original purchaser with the following instructions:

1. Before returning the instrument, notify BENTHAM with full details of the problem; including model number and serial number of the instrument involved.

2. After receiving the above information, BENTHAM will give you shipping instructions or service instructions. After receipt of Shipping instructions, ship the instrument "carriage paid" to BENTHAM. Full liability for damage during shipment is borne by the purchaser. It is recommended that instruments shipped to us be fully insured and packed surrounded by at least 2 inches of shock-absorbing material. Specific transit packaging as used in monochromators etc. must be installed.

BENTHAM reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of BENTHAM, and BENTHAM neither assumes, nor authorises any other person to assume for it, any liability in connection with the sales of BENTHAM'S products.

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WEEE statement

Bentham are fully WEEE compliant, registration number is WEE/CB0003ZR. Should you need to dispose of our equipment please telephone 0113 385 4352 or 4356, quoting account number 135419.