moglabs

MWM wavemeter

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Preface

The MOGLabs MWM wavemeter provides a compact, high resolution and cost effective instrument for measuring the wavelength and spectrum of a laser. The instrument can be operated standalone, and easily controlled from a computer with a sophisticated host application or using simple text commands, via USB and ethernet. The low price makes is affordable even if you have just one laser to measure.

We hope that you find the MWM useful, and please let us know if you have any suggestions for improvement of the MWM or this document, so that we can make life in the lab better for all.

MOGLabs, Melbourne, Australia
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RoHS Certification of Conformance

MOG Laboratories Pty Ltd certifies that the MOGLabs MWM wavemeter does not fall under the scope defined in *RoHS Directive 2002/95/EC*, and is not subject to compliance, in accordance with *DIRECTIVE 2002/95/EC Out of Scope; Electronics related; Intended application is for Monitoring and Control or Medical Instrumentation*.

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Contents

1. Introduction

The MOGLabs MWM optical instrument is a high resolution diffraction grating spectrometer in Littrow configuration. Optical interference creates an image of a singlemode fibre core at a wavelength–dependent position on a semiconductor imaging sensor. The image is digitised at high spatial resolution and with high dynamic range and speed. The wavelength spectrum is determined from the digitised image and a fitting procedure determines the peak wavelength. It provides picometre (0.001 nm) accuracy and picowatt sensitivity, with up to 1250 readings per second. The relative accuracy, for example in measuring the difference between two laser wavelengths, is around 10 MHz (0.01pm).

The device can be operated standalone (without a host computer, see fig. 1.1) or via a web browser (fig. 1.2) or using the `mogwave` GUI application (chapter 4). Integration with data acquisition systems is straightforward using USB or ethernet (TCP/IP) communications and simple text–based commands.


```
W06200400 v0.6.11
770 nm to 792 nm



22.5 C 1010 hPa 5.30 ms
IP 10.1.1.127:7802
```
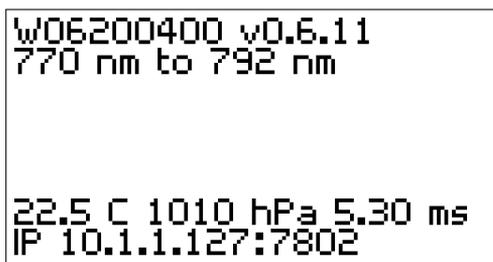
Figure 1.1: Wavemeter on–device display, showing serial number, firmware version, wavelength range, temperature, pressure, exposure duration and IP address.

1.1   Basic setup

1. Connect a 5 V 500 mA power supply via the USB interface. Some computer USB ports will provide sufficient power but in general a

Figure 1.2: Web interface homepage.

dedicated power supply or USB hub is recommended.

2. Second and third generation (Rev 2 and later) instruments have power on/off via the OK pushbutton. To power on or off, hold the OK button down for 2 to 3 seconds.

3. If possible, use a network connection for improved response times and faster data acquisition. Connect to an ethernet switch and the MWM will attempt to determine an IP address via DHCP. If that fails, it will default to an internal IP which will be shown on the instrument display. See chapter B for more information on configuring communications parameters.

4. The MWM must be coupled to the light source via a single–mode optical fibre. Multimode fibre is *not* suitable. The instrument sensitivity is very high and so the fibre mode diameter need not be well matched; for example, a 480 nm fibre can be used to measure 780 nm light and vice versa, though best accuracy and stability are achieved if the fibre is matched to the wavelength. Fibres with FC/PC (preferred) or FC/APC connectors can be used, and standard or polarisation– maintaining fibre.

Note: Your device has been configured and calibrated using a fibre with either FC/PC or FC/APC connector, usually with FC/PC at the wavemeter. Please refer to the test data provided with your device.

If you use a different connector type, you will need to reconfigure and recalibrate. Please see section 4.8.

Caution: The fibre tip is an integral part of the instrument. Unclean or damaged fibre tips will give unsatisfactory results.

5. The target laser should be directed into the other end of the fibre patch cord. Note that a lens is not needed; the bare fibre will normally couple sufficient light. A few nanowatts is good, though when first setting up, a few microwatts will make life much easier.

6. The device can operate standalone, but initially it is best to use a Windows^{TM} computer and the mogwave software application, as described in chapter 4.

1.2   Software installation

The MWM can be used directly from many standard laboratory data acquisition systems such as python, matlab or LabVIEW, via simple text commands. A simple example is included in chapter C. We also provide a standalone GUI application, mogwave, which runs under Microsoft Windows^{TM}.

To install the mogwave application, run the appropriate installer, for example mogwave_setup.exe, available from the MOGLabs website:
http://www.moglabs.com/wavemeter.html

1.2.1   USB drivers

When you connect the MWM, your computer should automatically find and install USB drivers from the Windows^{TM} update service. If not, in the install directory (typically c:\Program Files (x86)\MOGLabs) you should find the USB_VCPdriver folder which will contain setup programs for 32-bit and 64-bit systems.

If you have problems connecting with USB, in particular no driver found:

1. Ensure the device is connected to your computer via USB cable.

2. Double-click the appropriate 32-bit or 64-bit driver from the `USB_VCPdriver` folder in the install directory, typically
   `c:\Program Files (x86)\MOGLabs.`

3. Once installation is completed, restart your computer.

4. When your computer is finished booting, disconnect the USB cable from your wavemeter, and then reconnect.

2. Standalone operation

For full functionality, the MOGLabs MWM should be used with the `mogwave` Windows^{TM}–based application package provided (see chapter 4), but it can also be operated as a standalone instrument using the pushbuttons and on–screen menu system. The MWM also offers a web interface (see chapter 3) for operation with a web browser, for example on a smartphone.

2.1 On–device measurements

There are currently four modes of measurement operation which can be selected using the pushbuttons.

Off   The MWM is waiting for commands via ethernet/USB or the web interface, or for pushbutton activation of one of the other measurement modes.

On   The MWM measures and displays the wavelength ten times per second. The measurement units can be adjusted via the menu system (see below). The MWM automatically adjusts exposure time, and uses one–dimensional measurement of the spectral peak location.

PID with display The MWM measures continually at maximum speed, and activates PID control to vary the output voltage via the SMA connector to lock a laser to a wavelength that can be specified through the menu system. The measured wavelength is displayed on the device LCD screen.

PID no display As above, but the LCD screen shows the desired setpoint wavelength and is not updated with the actual measured wavelength. This allows the MWM to measure much more rapidly, at over 1250 measurements per second.

2.2 Front panel display and buttons

The pushbuttons can be used to start on–device measurements, access on–device menus, and initiate firmware upgrades.

2.2.1   Pushbuttons

There are four pushbuttons to the right of the LCD display, to select the measurement mode or to step through the menus.

$(\leftarrow)$ Stop measuring, if device-based measurement is active.
Activate firmware upgrade if held down during startup.

$(\uparrow)$ Enable device-based measurement with on-screen display, and step upwards through measurement modes.
If held down during startup, load network configuration from hard-coded definitions instead of EEPROM.

$(\downarrow)$ Enable device-based measurement with on-screen display, and step downwards through measurement modes.

(OK) Activate on-screen menus.
For MWM Rev 2 and later, the OK button acts as a power switch. Hold down for 2 to 3 seconds to power on or off.

$(\text{OK}) + (\downarrow)$ Hold both down to reset.

2.3   Measuring

The LCD display images below show the three different measurement modes in operation. On the left is the normal mode with ten measurements per second.

The middle image is with PID control activated, measuring and displaying as quickly as possible. The number shown below the units (i.e. 1170/s) is the number of measurements per second. The right-hand image shows the third mode of operation, where the displayed number is the setpoint

rather than the actual measured wavelength. That allows slightly faster operation (up to 1250 measurements per second).

The horizontal bar shows the input power: if the bar is short, the power is low. If the bar fills the width of the screen the input power is near maximum. If the detector saturates, the bar will be replaced with a warning message recommend reducing the input power.

```
W06200400 v0.6.11
775.549    nm (vac)
!!! REDUCE INTENSITY !!!
21.8 C 1010 hPa 0.06 ms
IP 10.1.1.126:7802
```

2.4 Device menus

2.4.1 Home screen

```
W06200400 v0.6.11
770 nm to 792 nm


22.5 C 1010 hPa 5.30 ms
IP 10.1.1.127:7802
```

The default screen on power-up, showing firmware version number, device serial number, wavelength range, temperature, pressure, exposure time and TCP/IP or USB connection. Press the $\circledcirc$ button to enter the menu system.

2.4.2 Main menu

```
Main menu 0.6.1
Measure off
Measure on
PID with display
PID no display
Settings >
```

Main menu, allowing selection of the measurement mode or entry into the sub-menus detailed below.

The $\uparrow$ and $\downarrow$ buttons select a different measurement mode (see 2.1) or Settings sub-menu. Use the $\circledcirc$ button to select the currently highlighted (as inverted text) sub-menu. Use the $\leftarrow$ button to exit the menu system.

2.4.3   Settings

The Settings menu offers selection of a number of sub-menus.

2.4.4   Units

The MWM measures wavelength in ambient conditions, but uses measured temperature and pressure to estimate the wavelength in vacuum, in air at standard temperature and pressure, or as a frequency or wavenumber. *Column* returns the sensor pixel number corresponding to the spectral peak, for diagnostic purposes.

2.4.5   PID

The MWM can output a PID control signal on the SMA connector for laser wavelength stabilisation (see 4.3.4). The PID menu allows display and adjustment of the PID setpoint, gain coefficients, offset voltage and limits. These values would normally be entered using mogwave or other interface but it may be useful to display and make small changes on the device.

To alter the static values, select the desired item using the up/down arrow keys, then press ⓞⓚ. The value will be highlighted as inverted text and can be altered using the up/down arrows. Use the ← button to move the cursor to the left. The cursor cannot be moved right; instead, keep pressing ← until the cursor wraps around.

Press ⓞⓚ when finished editing the value.

To save the new values, move down the menu to *Save to eeprom* and press ⓞⓚ.

2.4.6   Ethernet

```
Ethernet          Ethernet
Now      10.1.1.80   Gate      10.1.1.1  ^
Static   10.1.1.180  DHCP      Enabled
Mask 255.255.255.0   Port         7802
Gate      10.1.1.1
DHCP      Enabled    Save to eeprom >
Port         7802 v  Save + restart > v
```

The ethernet sub–menu shows the current IP address, and stored (static default) values for static IP address, netmask, gateway DHCP and TCP/IP port.

To save and activate the new values, move down the menu to either *Save to eeprom* or *Save and restart* and press ⓞⓚ. Both *Save* options copy the new values to EEPROM. The *Save and restart* option will also reboot the device with the new values.

2.4.7   Other

```
Other
Row          484
Max exp      400
P correct      1
Contrast      14

Save to eeprom >   v
```

Row is the sensor row used for measuring wavelength. The maximum exposure time (in milliseconds), pressure measurement correction, and screen contrast can also be changed. Note that there is no value range checking; consult the command language in appendix D for more information. Alter values as above.

2.4.8   System voltages

On-board power supply voltages, for debugging technical problems in consultation with MOGLabs.

2.4.9   About

Provides information including serial number and firmware version.

3. Web interface

With the MWM connected to your network, the device web server (see figure below) provides real–time wavelength readings to any web browser including mobile phones, desktop and laptop computers. Simply enter the device IP address, as shown on the LCD display (e.g. 10.1.1.128) into your web browser and you should see a webpage similar to that below, provided your computer/phone is on the same subnet as the MWM device.
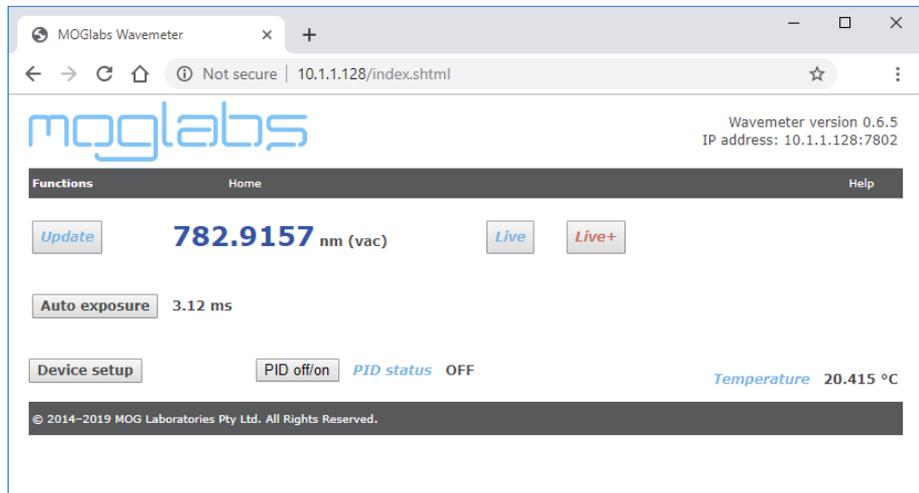

Figure 3.1: Web interface homepage, showing the wavelength, exposure time and device temperature. Buttons allow switching to real–time wavelength display, auto–adjust of exposure time, enabling PID, and jumping to a device setup page.

Web page common features

All device web pages have some common elements:

- The device firmware version, IP address and IP port number are shown at the top right of each page.

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- The MOGLabs logo can be clicked to access the MOGLabs website.

- The menu bar provides access to several key Functions, the device Home page, and to a Help page which provides a link to this user–manual via the MOGLabs website.

3.1   Home page

The home page shows a single wavelength reading (in the device default units), the exposure time, the device temperature, the status of the PID servo (on or off), and several clickable buttons.

Update Updates the displayed wavelength, exposure, temperature and PID status.

Live   Links to a new web page with live display (see below).

Live+ Links to a new web page with live display of just the wavelength, in large font. Particularly useful for use on small screens such as smart phones, or to view the readout from across the lab.

Auto exposure Recalculates the optimum exposure time.

Device setup Links to a new web page for configuring the device; see below.

PID off/on Toggles PID status between on and off.

3.2   Live view

Live view is very similar to the home page, but the wavelength and other readings change in real time. The *Static* button switches back to the static home page.
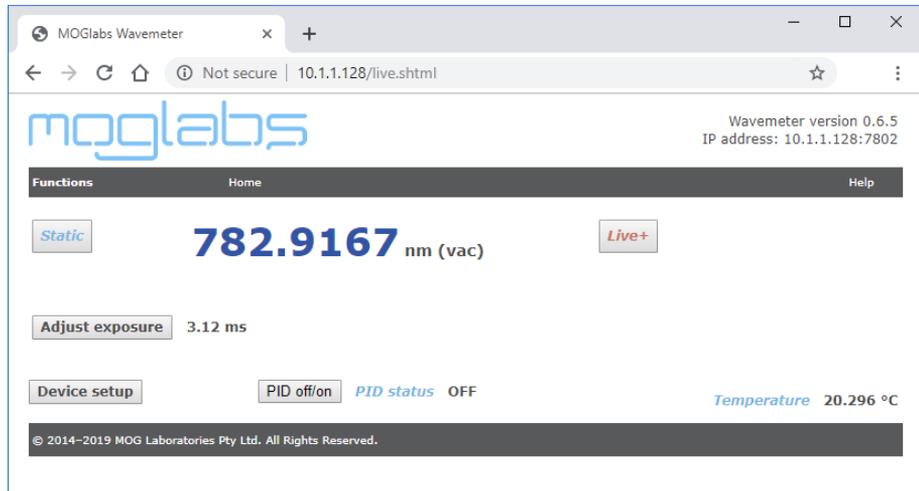

Figure 3.2: Live view, showing the wavelength, exposure time, device temperature, and PID status in real time.

3.3   Live+

Live+ shows just the real–time value of the wavelength, in the largest font that will allow the number to fit within the current window. Change the browser window size to enlarge or reduce the display. Use your browser back–button to return to the previous web page.

Figure 3.3: Live view, showing the wavelength in real time.
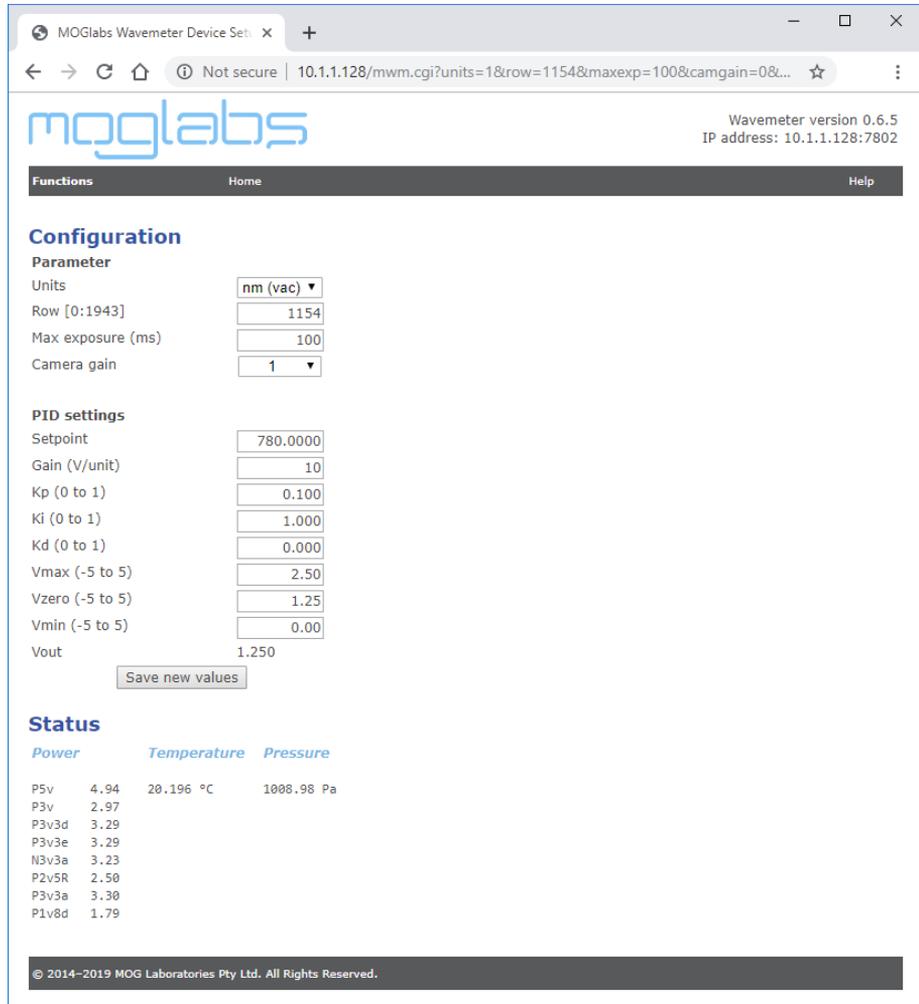
3.4   Device setup

The device setup page can be accessed from the menu bar (*Functions, Setup*) or by clicking on the *Device setup* button on the home page. The lower section of the screen shows the temperature, pressure and power supply voltages for diagnostics and fault–finding, but the main purpose of the page is for displaying and altering key device parameters.

3.4.1   Configuration

Units   Drop-down list of measurement units including `nm (raw)`, `nm (vac)`, `nm (air)`, `THz`, `cm-1` and `col`; see units in appendix D for details.

Row   The imaging sensor row used for acquisition of spectra. The default row will be set when the device is calibrated, or using `mogwave`.

Max exposure The maximum exposure time that will be allowed when automatic exposure control is used. Exposure times up to ten seconds (10,000 ms) can be used for measuring the wavelength of extremely weak lasers, but for

Figure 3.4: Device setup page.

most situations, a maximum exposure time of 100 ms is more than sufficient and ensures good responsiveness from the device.

Camera gain Drop-down list of analogue gain on the imaging sensor. The default is 1, but higher values can be used to reduce exposure times and thereby

increase measurement rate, particularly for frequency locking with the PID servo.

3.4.2   PID settings

The internal PID parameters can be adjusted, though in general it is probably easier to use `mogwave`; see section 4.3.4. `Vout` shows the current value of the DAC output voltage.

Save new values Saves any changed values to EEPROM on the device.

3.5   Software

The *Software* page provides a link to the wavemeter software support section of the MOGLabs website.

3.6   Update firmware

The *Update firmware* page provides a facility to enable updating the device firmware. Please see appendix G for full details.

4. MOGWAVE

The host software `mogwave` provides a graphical user interface that allows measurement and calibration functions. See appendix E for information on starting `mogwave` and configuring default parameters.

4.1 Device discovery

By default, a device discoverer (Figure 4.1) is initiated when `mogwave` is started. The discoverer scans the USB ports of the host computer looking for an MWM device, and then scans the local network subnet. Starting the application is then as simple as selecting the device to communicate with and clicking *Connect*.
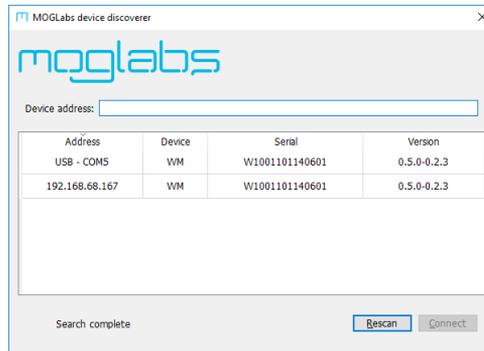
Figure 4.1: Example of the *device discoverer* window.

If the network does not permit device discovery and/or your MWM does not appear in the list, it is possible to enter the IP address of the unit in the *Device address* box and connect regardless.

The discoverer will not start if the connection is specified in the default configuration file or on the command line or equivalent shortcut link (see appendix E).

If using USB, or you have multiple MWM devices, or the network is a little

slow, and the application does not find your device, you can either edit the shortcut link which was created during the install process, to provide command–line parameters that specify the device address, or edit the `default.cfg` file. Further details are provided in the `mogwave` chapter 4, or in appendix E.

4.2   Main display

The primary window of `mogwave` is shown below. Note that the window size can be altered dynamically by simply stretching from a corner. To adjust the font size for small or large displays, change the `wmfontsize` parameter in the configuration file (appendix E.2).
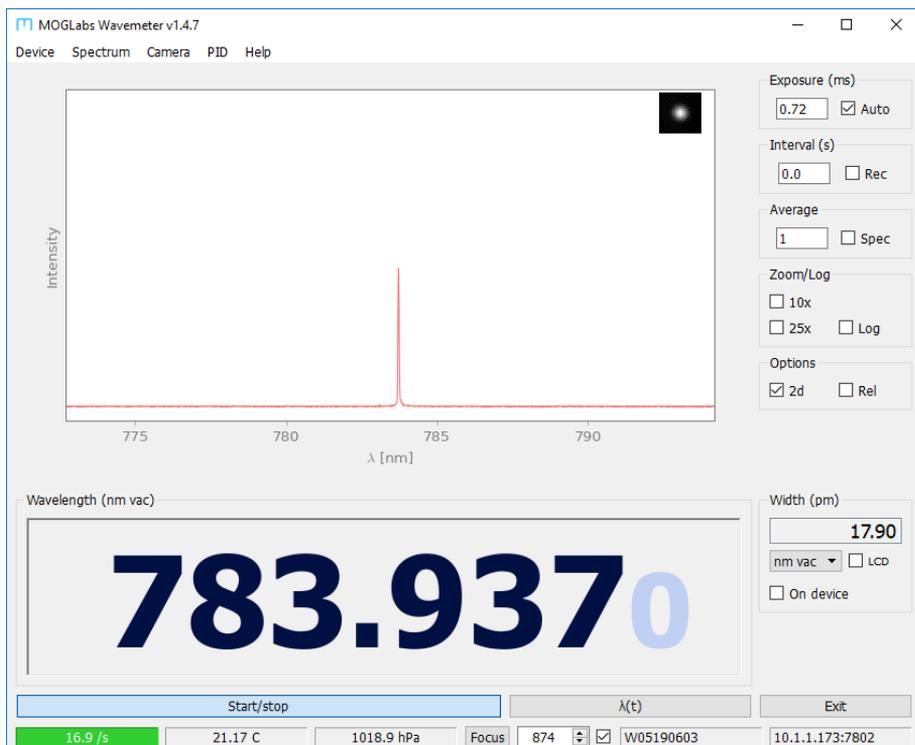
Spectrum The largest area shows the most recently acquired spectrum, or an av–

erage of a set number of spectra (see below). The display can be zoomed into an area around the highest peak using 10x and 25x zoom functions, and the spectrum can be shown in linear or log form.

2d image inset The inset shows a 2d image of the area around the highest spectral peak, which should be approximately Gaussian and symmetric. If the laser is multi-mode, the main peak will become distorted or even show two distinct spots.

Wavelength The calculated wavelength of the highest peak is shown. The wavelength is measured in ambient conditions (air temperature and pressure) and converted to vacuum equivalent wavelength, frequency or wavenumber by selecting the appropriate units. The rms width, fwhm width, or statistical uncertainty of the wavelength measurement is shown; click on the number to change which is displayed. The widths are calculated assuming the spectral peak is Gaussian in shape.

Status bar The status bar shows temperature and pressure inside the device, the device serial number, and the communications channel: IP address and port (if using ethernet) or USB port. Within the status bar, there is a coloured indicator region which can be red, yellow or green, a Focus button, a row number, and an auto-row toggle; these are described in greater detail below.

4.3   Menu

4.3.1   Device

Device network settings To configure the wavemeter network connection settings (IP address, mask, gateway and port). Particularly useful for configuring the network settings via USB.

Device command This opens a new dialog for interactive command access to the device, similar to `telnet` but this approach will work via USB. Type a command into the command line window, and hit `Enter` to send that command to the device (see appendix D); the response will appear in the box below the command line window. Some commands are not permitted (for example `spectrum`) due to the large amount of response data generated, particularly when communicating via USB.

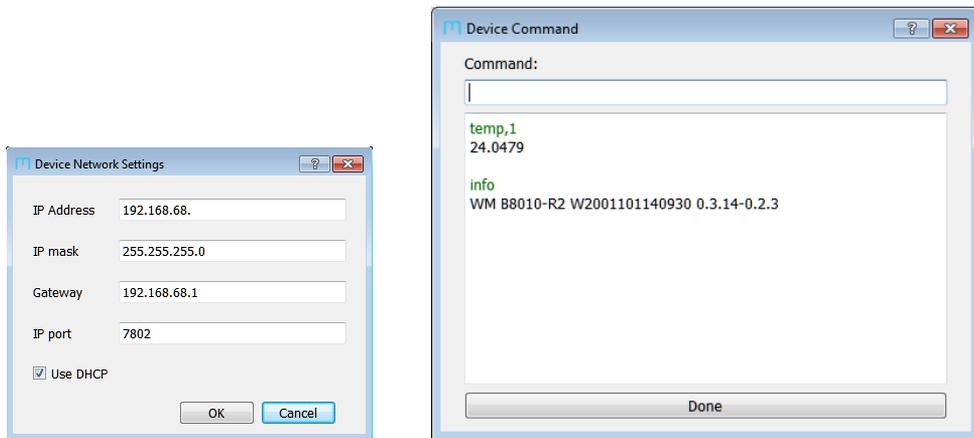
Figure 4.2: Network settings and device command windows.

Console Opens a new window with `mogwave` console text output; that is, the text that is normally displayed in the console if `mogwave` is started from a console window uch as a Windows^{TM}`cmd` window.

Error log Opens a new window for `mogwave` error messages; that is, the text that is output when software errors occur.

LCD Screen Opens a window showing the current LCD image on the MWM device (see below). Right–click in the image to close the window, or left–click to save the image to a .PNG file.
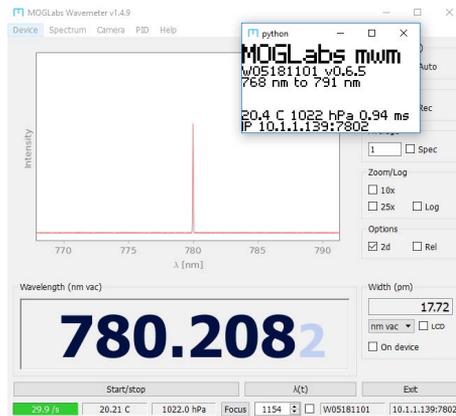
4.3.2 Spectrum

Save spectrum The current spectrum can be saved to a tab–separated `.dat` file using the `File` menu at the top of the window.

Save screenshot Saves currently displayed spectrum as a .pdf file.

HDR spectrum Experimental. Opens a new window (see below) for acquiring high dynamic range (HDR) spectra. A sequence of spectra are obtained at increasing exposure times and combined to form a single high dynamic range spectrum. The result is qualitative, but can provide information on spectral purity and ASE (amplified spontaneous emission).

Background images must be obtained before generating HDR spectra. The first time an HDR spectrum is acquired, a dialogue box will pop up asking you to block the light into the fibre, and to press OK. A sequence of background measurements will be acquired and stored.

Single Generates a single HDR spectrum. If background data has not been obtained, you will be prompted to block the light into the fibre so that the
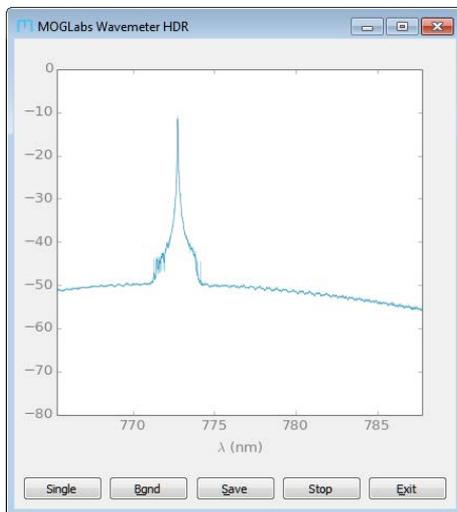
background noise can be determined.

Bgnd Acquire new background measurements.

Save Save current HDR spectrum. Saves all separate exposure time spectra and background measurements, with calculated HDR spectrum and a smoothed spectrum.

Go/Stop To generate HDR spectra in real time. The main application must be actively collecting spectra (if not, press the Start/Stop button in the main application). The spectrum and background images each require about 1 second of collection time so the main application response rate will be severely reduced.

Exit Close the HDR window.

Calibrate For device calibration; see following chapter.

4.3.3   Camera

Camera gain adjust Select electronic gain on imaging sensor (1x, 2x, 4x, 8x, 16x). Allows faster measurement with extremely weak signals. For best results

use higher power to keep exposure times below 1 ms at 1x gain.

Acquire full image Captures a full image from the sensor. Due to limited memory on the device, the image is captured in bands. Acquisition will take about 2 minutes using USB and five or six seconds on fast (100 Mb/s) ethernet.

4.3.4 PID

PID The MWM can output an analogue signal on the SMA connector, either a fixed value or a PID control signal that attempts to drive the wavelength of a laser towards some set wavelength. The dialogue box allows configuration of the setpoint wavelength, analogue output, and PID loop parameters.

PID servo control is described in detail in chapter 5. Below are some comments on the `mogwave`-specific aspects of configuring the PID servo controller.

PID servo output can be calculated and controlled by the host computer and `mogwave`, or from the MWM device operating standalone. The PID dialogue window (see below) shows both parameters for the `mogwave` PID controller and for the MWM on–device controller.

Copy parameters Click on the appropriate arrow to copy parameters from the

mogwave controller to the device controller (arrow points from MOGWave to Device) or vice versa (arrow points from Device to MOGWave).

Output (V) Shows the PID feedback signal $V(t)$. Can be edited to set a fixed output voltage, if PID ON is not enabled.

Setpoint λ_0 Defines the reference wavelength λ_0. Click on the *Set* button to use the currently measured wavelength. The setpoint units are the currently active *measurement* wavelength units set in the main mogwave window.

Gain (V/unit) Defines the gain, G. The gain is in volts per measurement unit. A typical value is 10 V/unit if units are nm. A negative gain can be used to invert the sign of the output voltage.

The gain and output voltage do not change if the current measurement units are changed in the main window of mogwave.

Units The drop-down unit selector will change the measurement units on the device. Use the main mogwave window to set units for PID using mogwave. No attempt is made to adjust the setpoint value or gain for a change in measurement units.

kp, ki, kd Proportional, integral and differential coefficients, each limited to a range of 0 to 1.

V_{max}, V_{min} These set the upper and lower output voltage limits, and also the integrator windup limits.

V_{zero} The offset voltage; that is, the output when the laser is at the correct wavelength, $\lambda = \lambda_0$. For MOGLabs DLC controllers, set $v_{zero} = 1.25$.

PID ON Enables PID calculation and output. Disable and re-enable to reset the PID controller (set the integrator to 0). Either the mogwave or MWM device PID controller can be activated. It can be helpful to start with the mogwave controller and once that is working, copy the coefficients across (see above), then activate the device controller, and then for highest bandwidth, stop mogwave; the device-based controller can then run at full speed.

The mogwave PID controller will be stopped when the PID dialogue box is

closed, but the MWM device–based controller will remain running if it was enabled. `mogwave` must also be acquiring measurements for the `mogwave` PID controller to work, but the main display interval does not affect actual measurement speed and thus PID response.

4.3.5   Help

Debug   Toggle debug on/off. Enables saving additional debug information with data recordings (see 4.4 below).

Settings Opens a new dialog for adjustment of some settings.
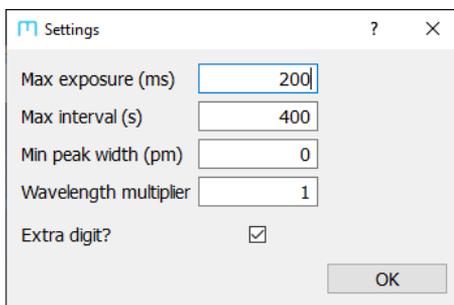
Max exposure (ms) The maximum exposure time that can be entered. The maximum can be up to 20 s (20000 ms). The auto–exposure algorithm will adjust the exposure time up to one quarter of the value entered, but longer exposure times, up to the `Max exposure` value, can be entered if auto–exposure is disabled. Long maximum exposure times can be tedious, and the MWM is very sensitive, and so a `Max exposure` value of 400 ms is recommended.

Max interval (s) The maximum allowed time between recorded measurements. The maximum value that can be entered is 86400 (one full day).

Min peak width (pm) The instrumental spectroscopic peak width. If a non–zero value is entered, it will be subtracted from the measured width, when in fwhm mode (see section 4.6 below).

Wavelength multiplier The measured wavelength is multiplied by this constant, which can be useful for example if you are working with a frequency dou-

bled or parametric downconverted source. Thus you might measure the wavelength of a 1064 nm laser but your experiment uses the 532 nm doubled output. If `wave_mult` is set to 0.5, the value displayed would be 532 nm even though the MWM is measuring 1064 nm. Allowed values are from 0.25 to 4.0.

Extra digit? The wavelength measurement is accurate to around 6 digits, but if this is enabled, an extra digit is displayed, which can be useful for observing small changes in wavelength.

Manual (local) Opens the user manual installed with the software.

Manual (online) Links to the MOGLabs website where the latest user manual can be found.

4.4   Acquisition

Exposure Sets the exposure time, in milliseconds. If the `Auto` button is pressed, the software will attempt to find an optimum time. The maximum time is currently 100 ms.

Interval Defines a dead-time between measurements. Can be anything up to 15 s.

If the `Record` box is checked, measurements are recorded in a tab-separated file until the `Record` is unchecked. A new file is created each time recording is started. The filename is generated automatically based on the current time.

Average The displayed numerical wavelength is the average of the most recent n measurements, where n is the number in the `Average` field.

If the `Spec` box is checked, then instead n spectra are averaged, and the wavelength calculated from the spectrum average.

Zoom The 10x and 25x reduce the wavelength range, to show greater detail of the peak and increase the measurement rate. The wavelength range is determined automatically to be centred on the spectral peak.

The Log button changes the display to show $20 \log_{10}$ of of the measurements, relative to 0 dB at the saturated pixel value.

4.5 Options

2d   Select to operate in high accuracy 2d mode. Unselect to operate in faster 1d mode.

Rel   When selected, the current wavelength is saved as a reference. The reference is subtracted from future measurements so the displayed wavelength shows the change relative to the reference value.

4.6 Wavelength

Wavelength The primary wavelength measurement is shown in a variable size (stretchable) text window. The last digit is slightly smaller and in grey text as a reminder that its value is imprecise. Click on the number to cycle through the different units.

(nm, vac) The in-vacuum wavelength, converted from the measured value using measurements of the air pressure and temperature.

(nm, air) The in-air wavelength, converted from the measured value using corrections for pressure or temperature.

(nm, raw) The raw in-air wavelength, as measured by the MWM, without corrections for pressure or temperature.

(THz)   The frequency, converted from the measured in-air wavelength, using measurements of the air pressure and temperature.

(cm^{-1}) The wavenumber; that is, the number of wavelengths per cm, in vacuum, converted from the measured in-air wavelength using measurements of the air pressure and temperature.

Uncertainty/Width Shows the peak width as an rms or full width at half maximum (fwhm), or the statistical uncertainty of the wavelength measurement. Click on the number to cycle through the options. The uncertainty is just a guide to indicate the reliability of the measurement and should not be used for quantitative purposes. The rms and fwhm widths are calculated assuming a Gaussian peak shape.

The instrumental resolution width can be subtracted automatically, by setting the *Min peak width* value through the Help/Settings menu, or the `mwmwidth` value in the `default.cfg` file; see appendix E.

LCD If the LCD toggle is on, the measured wavelength will be displayed on the device LCD screen, in current units. This can be helpful for tuning a laser, if the MWM is close to the laser and far from the host computer.

On device Normally the displayed wavelength is calculated by `mogwave`. If On device is selected, the displayed wavelength is that calculated by the device using a simpler algorithm.

wave_mult The `wave_mult` parameter, defined through the Help/Settings menu or the config file, can be used to multiply the measured wavelength by a constant, for example if you are working with a frequency doubled or parametric downconverted source. Thus you might measure the wavelength of a 1064 nm laser but your experiment uses the 532 nm doubled output. If `wave_mult` is set to 0.5, the value displayed would be 532 nm even though the MWM is measuring 1064 nm.

4.7   Functions

Start/stop Starts and stops acquisition and display of spectra and calculated wavelength.

Exit To quit `mogwave`.

$\lambda(t)$ Opens *Time Series*, a new graphing window, which displays the wavelength measurement as a function of time.

Time Configures the horizontal (time) axis range. The range will dynamically update to show all data acquired from when the Time Series window is opened, or the most recent measurements for a fixed duration if `Fix` is selected.

Fix If selected, show only most recent measurements, defined by value in Time spinbox.
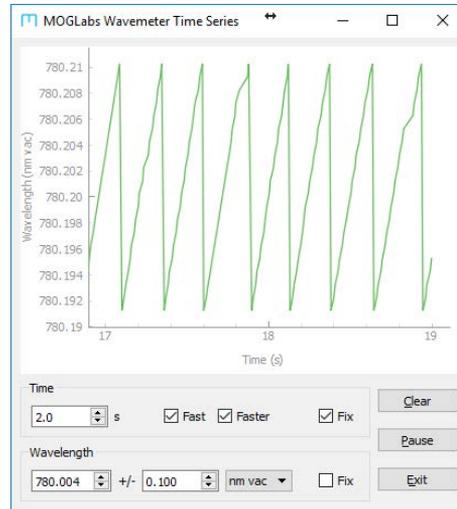
Fast When selected, the main spectrum is only updated once per second, thus allowing faster update of the Time Series plot.

Faster Select device-based wavelength measurements, indicated by cyan coloured status bar. Device-based measurements are much faster, allowing much more rapid updates of the Time Series plot. Also reduces the rate of update of the main wavelength numeric display. *Fast* and *Faster* can both be selected for fastest possible Time Series update rate.

Device-based measurements are less accurate than can be achieved with full mogwave analysis, particularly when the default in-device imaging row is different to the optimum row determined by mogwave.

Wavelength The vertical (measurement) axis can be configured to display in any of the allowed units. The range will dynamically update to show all measured data, or the axis can be fixed.

Clear Clears all measured data.

Pause Suspend plotting of measurements. Note that measurements can continue in the main mogwave window.

Exit Close the Time Series window.

4.8   Status bar

The status bar shows secondary information including the measured air device temperature and air pressure, the serial number, and the communications channel including IP address and port number if communicating by TCP/IP, or the USB port number. There is also the ability to change sensor row used for acquisiton of spectra.

Status   A colour indicator shows green when the main peak is properly acquired, red otherwise, indicating the displayed wavelength is not valid. The number (if shown) is the number of measurements per second.

Temperature The temperature measured near the sensor, typically several degrees above ambient. The colour will be green if within 1°C of the temperature when calibrated, orange within 2°C, and red if the difference is greater than 2°C.

Pressure The ambient air pressure, used to convert from in-air to in-vacuum wavelength.

Focus   The focus button will open a new window showing the sensor area around the current peak (typically 160 x 160 pixels), to allow convenient optimisation of the focus (see calibration in the next chapter). It can also be useful for finding the optimum pixel row (see below). The row number should be adjusted until the laser spot is at the centre of the focus window.

To centre the diffracted spot in the focus window, put the cursor as close as possible to the spot and click with the *left* mouse button. The row number will be changed such that the location of the cursor becomes centred. If the spot is off the focus window, click as close as possible (e.g. top or bottom of the focus window) and repeat until the spot becomes visible.

Note that the row number is not recorded on the device: the next time `mogwave` is started it will start at the row number saved in the device EEPROM. To set the current row as the device default, click the *right* mouse button anywhere in the focus window.
Warning: changing the default row on the device will affect the calibration. Recalibration is recommended.

Ctrl-focus Hold the Ctrl key down, and click on Focus, to open a very wide but not very high focus window. This is useful for adjusting the diffraction grating angle for different wavelengths (see calibration chapter).

Row The imaging sensor has many pixel rows. At the factory, the MWM is aligned and focussed and the optimal sensor row is determined and saved in the device EEPROM.

The row can change, due to thermal drift or if the fibre is changed, in particular if changing from FC/PC to FC/APC or vice versa. The row is tracked automatically but the row must initially be close, to within about 10 pixels of the centre of the spectral peak.

The row can be set via the up/down arrows, typed in numerically, or using the mouse inside the focus window as described above. Again, note that the initial starting value of the row is programmed in the device EEPROM but can easily be updated as described above.

Auto-row The automatic tracking of the row for the main spectral peak can be enabled or disabled via the check-box.

5. Signal out and PID

The MWM can output an analogue signal on the SMA connector ($V_{\text{out}} = -5$ to $+5\,\text{V}$). That signal can be a fixed value, a signal proportional to measured laser wavelength, or a PID control signal that attempts to drive the wavelength of a laser towards a set wavelength.

The MWM implements servo feedback control via a standard PID (proportional integral differential) function:

$$V(t) = Gk_p e(t) + Gk_i \int_0^t e(\tau)d\tau + Gk_d \frac{de}{dt} + V_{\text{offset}}$$

where $V(t)$ is the feedback response, limited to $[-2.5 \ldots + 2.5]\,\text{V}$. The error is calculated as $e(t) = (\lambda - \lambda_0)$ where λ, λ_0 are the most recent wavelength and setpoint wavelength. G is an overall gain, and V_{offset} is a constant voltage offset. The PID coefficients k_p, k_i, k_d are floating-point values in the range $[0, 1]$ which correspond to proportional, integral and differential terms respectively. Typical values are $k_p = 0.03 - 0.8$, $k_i = 0.01 - 1.00$ and $k_d = 0$. The offset allows the MWM to control unipolar devices (e.g. MOGLabs DLC controllers which have 0 to 2.5 volt control input range).

When optimising a PID control loop, it should be kept in mind that the achievable loop bandwidth is limited by the propagation delay of the entire signal processing chain, including the measurement time, which depends on exposure time, and any delays in the laser response. A locking bandwidth up to $100\,\text{Hz}$ is feasible.

5.1   MOGLabs DLC laser controller

If using the MWM with a MOGLabs laser and DLC controller, connect the MWM SMA output to the DLC SWEEP input and set DIP 9 on (external piezo stack control); see figure below. Set both the offset and windup parameters to 1.25 V. Use the DLC SPAN knob as a master gain on the PID feedback. The SCAN/LOCK and fast lock should be off (up); only slow (piezo) feedback will be active through the SWEEP control.
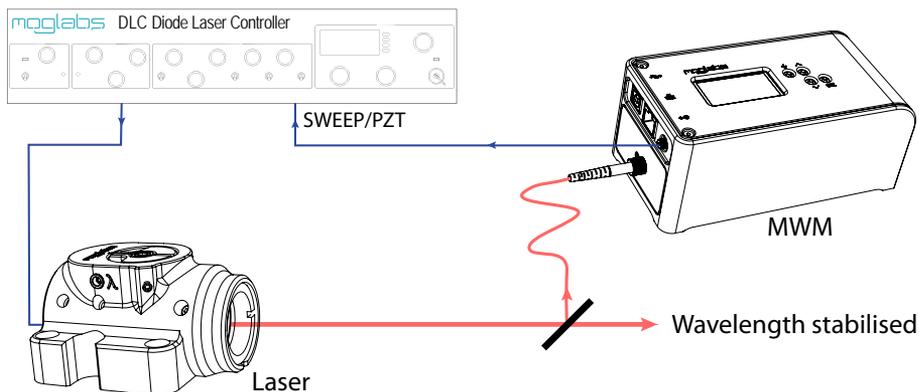
Figure 5.1: Stabilising a laser frequency with the MWM and PID. The SMA output of the MWM should be connected to the SWEEP/PZT input on the rear of the MOGLabs DLC controller.

5.2   PID parameters

PID servo output can be calculated and controlled by the host computer and mogwave, or from the MWM device operating standalone. In the latter case, the parameters can be set using the on-device menus with LCD display and pushbuttons, or using the web interface (see chapter 3), or using the mogwave PID menu action.

Setpoint λ_0 Defines the reference wavelength λ_0, for the the currently active *measurement* wavelength units set in the main mogwave window or on the device.

Gain (V/unit) Defines the gain, G. The gain is in volts per unit, where the units are the currently active measurement units if operating using the MWM standalone PID controller, or via the drop–down unit selector in the `mogwave` PID menu. The gain and output voltage do not change if the current *measurement* units are changed. A typical value is 10 V/unit if units are nm. A negative gain can be used to invert the sign of the output voltage.

kp, ki, kd Proportional, integral and differential coefficients, each limited to a range of 0 to 1. Set $k_i = k_d = 0$ to use the analogue output as a measure of laser wavelength, where k_p and the gain G define the relationship between the output voltage and the measured wavelength relative to the setpoint wavelength λ_0.

V_{max}, V_{min} These set the upper and lower output voltage limits, and also the integrator windup limits. See section below regarding windup.

V_{zero} The offset voltage; that is, the output when the laser is at the correct wavelength, $\lambda = \lambda_0$. For MOGLabs DLC controllers, set $v_{zero} = 1.25$.

5.3   Integrator windup

Integrator windup is caused by saturation of an output actuator. Once the MWM output voltage reaches the maximum (or minimum) value defined by V_{max} or V_{min}, the integrator will continue to accumulate error ("wind up"), but the actuator is not able to respond to an increased control voltage. For example, on MOGLabs DLC controllers, the piezo control voltage is limited to 0 to 2.5 V range and output voltages exceeding that range will not have any additional effect. If the actuator (laser) finally returns to within range, the "wound up" integrator has to reset from a value far from where it should be for the existing actuator value. That recovery can introduce a long time lag in the response, or prevent the servo controller from ever reaching stable equilibrium. The solution is to stop integrating when the integrator reaches the saturation limit. For MOGLabs DLC controllers, set $V_{max} = 2.5$, $V_{min} = 0$.

5.4   Examples

5.4.1   Analogue output of wavelength

With $k_p = 1$ and $k_i = k_d = 0$, the SMA output voltage will be directly proportional to the measured wavelength relative to the setpoint. Figure 5.2 shows an oscilloscope trace of V_{out} for an MWM measuring the wavelength of a rapidly scanning laser, for example to optimise the laser mode–hop–free tuning range.
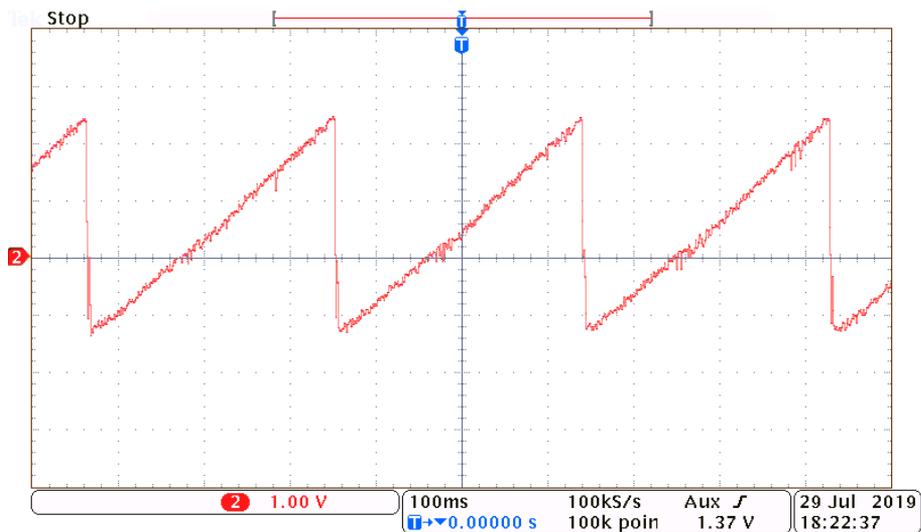
Figure 5.2: Wavelength measurement of a scanning laser. The gain was set to 200 V/unit with units on THz, thus 0.2 V/GHz, so that the ramp amplitude of 3.5 V corresponds to 20 GHz.

5.4.2   Wavelength stabilisation

To control the laser wavelength, the output signal should be connected to the frequency control input of the laser, usually a piezo control, as in figure 5.1. The figure below shows the response for a 780 nm Toptica DL–Pro laser connected to a MOGLabs DLC controller.

The DLC control voltage is 0 to 2.5 V, corresponding to laser frequency change of around 20 GHz (0.04 nm). If the frequency change is positive for positive change in control voltage, a negative gain should be used for negative feedback control. It would then seem logical to use an overall gain of $-2.5/0.04 = -62.5$ V/nm, with each DAC output step (2.4 mV) corresponding to $0.0024/62.5 = 0.04$ pm or approximately 20 MHz. With that gain value $G = -62.5$ and $k_p = 1$, the system would have unity feedback gain at all frequencies, which would be unstable. The proportional gain should be much lower, either by reducing $k_p << 1$ and/or by reducing G. Start with $k_p = 0$ and use integration (e.g. $k_i = 1$) to achieve high gain at low frequencies.
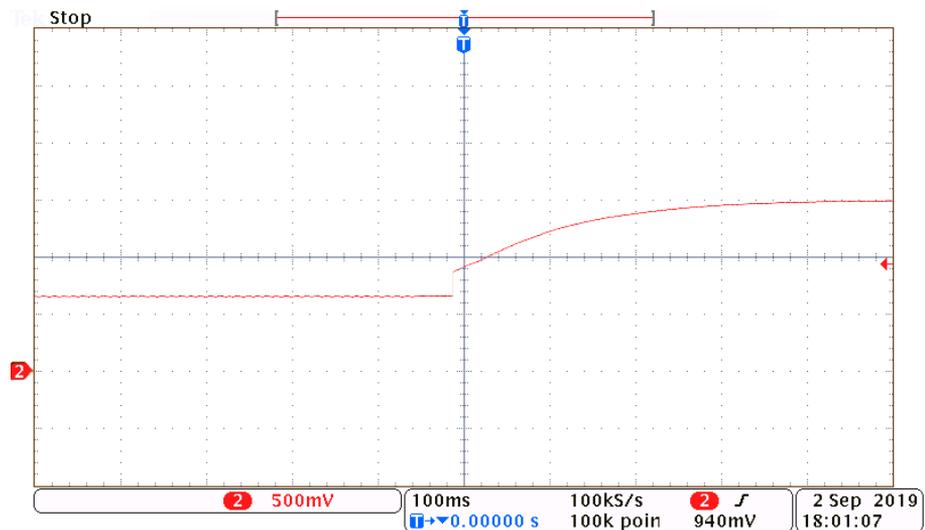
Figure 5.3: MWM output signal when PID is enabled for laser wavelength stabilisation. The setpoint wavelength was changed by 0.004 nm (about 2 GHz) causing a rapid change in the control signal, which then integrates more slowly until the new setpoint was reached. Gain -200 V/nm, $k_p = 0$, $k_i = 1.0$, $k_d = 0$.

The SPAN control on the DLC provides an adjustment of the overall gain, which can be used to maximise the effective resolution. For example, if the expected drift in the laser will be much less than the 0 to 2.5 V swing

(20 GHz), a higher PID Gain setting can be used with reduced gain via the SPAN control. The net feedback gain will be the same but more of the DAC output range will be used.

6. Calibration

Recalibration of the MWM can be required due to drift and metal creep, accidental mechanical shock, or to change the operating wavelength. Usually it is a very simple process of measuring a known laser wavelength and clicking one button. Multi–point calibration across the operating wavelength range will improve the accuracy.

Calibration consists of measuring a tunable light source using the MWM. The location of the diffracted spot on the imaging sensor is recorded, along with an independent wavelength measurement of the light source. A best-fit polynomial fit is calculated, translating imaging pixel location to wavelength.

6.1   Existing wavelength range

Here we describe recalibration, if the operating wavelength is unchanged.

From the `mogwave` application, select the `Spectrum` menu, then `Calibrate`, to start the calibration application. The normal wavelength measurement program will continue to run, so that you can see the measured wavelength using the current calibration data.

The calibration process requires measuring the wavelength of a light source, and entering the known wavelength for that source. Before entering data, please make sure that the units are the same in both the normal and Calibrate windows, typically (`nm, vac`). Avoid using (`nm, air`) because the measurements are subject to arbitrary variations in pressure and temperature.

The Calibration window shows two graphs. The upper graph shows the entered (known) wavelength against spectrum channel or bin which is effectively the uncalibrated wavelength. The lower graph shows the difference between the entered (known) wavelength and the calculated wavelength using the old calibration.
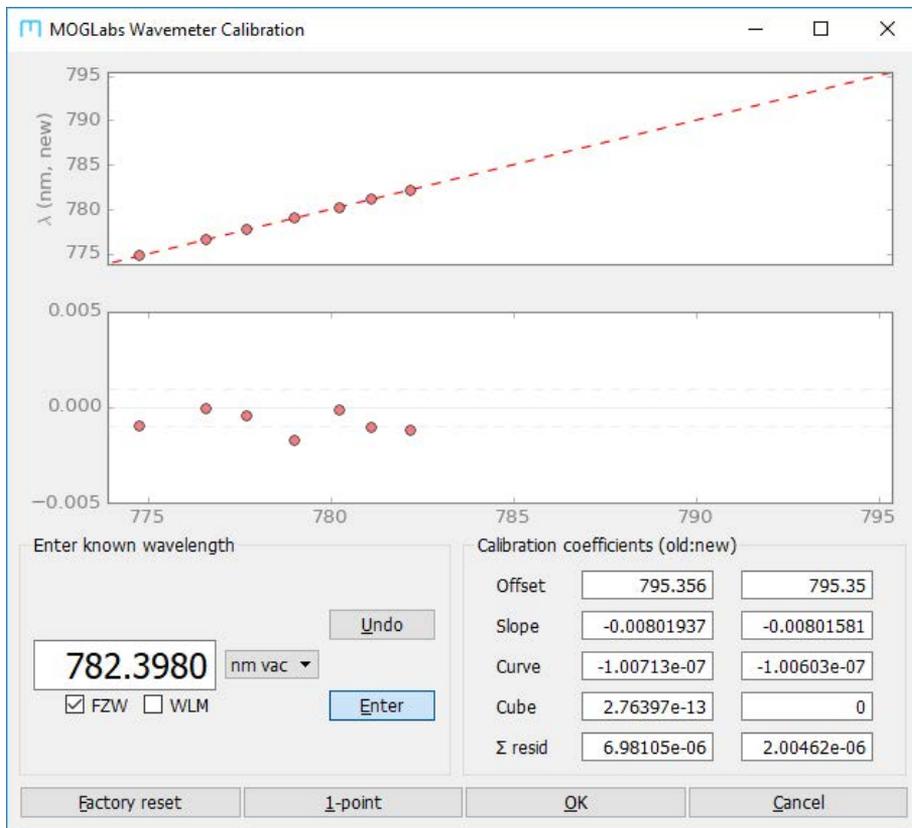
To calibrate, simply enter the known wavelength for your light source. Repeat at as many different wavelengths as desired, across the measurement range of the device, typically every one or two nm. The sum of the residuals can provide an indication of whether the new calibration coefficients are more precise than the old. If an error is made in entering a calibration point, the Undo button can be used to remove it. Repeated use of Undo can remove all entered data points, in reverse order.

If doing a single point measurement, click on the 1-point button. The offset will be corrected, and a new slope will be calculated based on the new wavelength.

If more than four calibration points have been entered, then press the OK button to calculate the full cubic calibration function. If three or two points are entered, the calibration will be limited to a quadratic or linear function.

NOTE It is important that the calibration wavelengths extend over the largest possible fraction of the operating range of the wavemeter. If you cannot tune your calibration source across a large range, use lower fit order (see below), or single-point calibration.

If the wavelength range of entered calibration points is less than half the full range, a new dialog will open, allowing adjustment of the fit order. Choose the highest order for best accuracy within the range of calibration
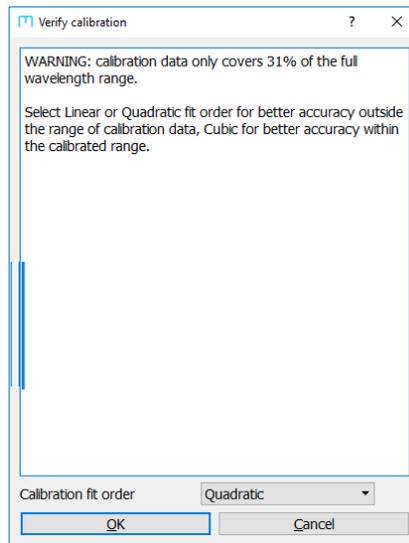
data, or a lower order for better stability outside the calibration range. For example, a typical MWM is calibrated for 775 nm to 796 nm; a range of 22 nm. That device might then be re-calibrated over a limited range such as 775 nm to 780 nm. If a cubic fit order is selected, the accuracy will be best within that range of 775 to 785 nm but can be very poor outside that range. A lower fit order, such as quadratic, will be more stable across the

full range of the device, but may be less accurate within the calibration range.

Both single and multipoint calibrations will save the new calibration co-efficients on the device. They also save all calibration points (measured and known wavelengths) to a `.csv` file.

To avoid reprogramming the device with new calibration data, hit the `Cancel` button.

6.2   Calibrating with MOGLabs FZW wavemeter

If you have access to a MOGLabs FZW Fizeau wavemeter, you can auto-matically load the known wavelength from the FZW measurements in real time, making calibration very fast. The FZW must be connected by USB to the same computer that is running `mogwave`, or accessible via ethernet.

Click on the FZW button just below the wavelength-entry window, and the *Device discoverer* window will pop up, listing accessible devices. Select the FZW and the FZW measurements will appear in the wavelength-entry window.

Note that `useFZW` must be set true in the config file (appendix E):

```
[wavemeter]
useFZW = True
```

Alternately, use the `-f` command-line option (see section E.1).

6.3   Calibrating with HighFinesse wavemeter

If you have a HighFinesse wavemeter, you can automatically load the known wavelength from the HighFinesse measurements in real time.

Start the HighFinesse application and ensure that it is successfully mea-suring your laser wavelength. Then click on the `WLM` button underneath the wavelength-entry window.

Note that `useWLM` must be set true in the config file (see appendix E):

```
[wavemeter]
useWLM = True
```

Alternately, use the `-w` command-line option (see section E.1).

6.3.1 Multiple HighFinesse wavemeters

HighFinesse wavemeters require a separate installation of device-specific software for each different HighFinesse device. If you have installed more than one on your computer, the default `wlmData.dll` may not be the correct version for the device you are trying to use. In that case, copy the correct `wlmData.dll` file to the `mogwave` installation.

The `wlmData.dll` file is typically in the `Com-Test` folder of the HighFinesse application for the device you will be using, for example

```
C:\Program Files (x86)\
   HighFinesse\Wavelength Meter WS6 1234\Com-Test\wlmData.dll.
```

Copy this to `C:\Program Files (x86)\MOGLabs\mogwave\mogwave`.

From time to time, HighFinesse change the way they store and load `wlmData.dll`, and the above may not work for your system. Contact MOGLabs if you are having difficulty.

6.4 New wavelength range

Reconfiguring the device to operate at a new wavelength, outside the range of the imaging sensor, is a quick and simple process.

1. Remove the top plastic cover and the bottom aluminium cover of the device.

2. Loosen the λ screw holding the grating (see below) for Rev 1 and 2 devices (serial numbers starting with W1 and W2).

For Rev 2 devices, release the three locking screws holding the grat–
ing in place at the bottom of the device, inside the optical chamber.

For Rev 3 and later, slightly release the two axial locking screws,
above and below the MOGLabs logo. The latter is hidden behind an
M4 flat head socket screw which must first be removed (see fig. 6.2).
Please take care that the grating holder does not fall out of the
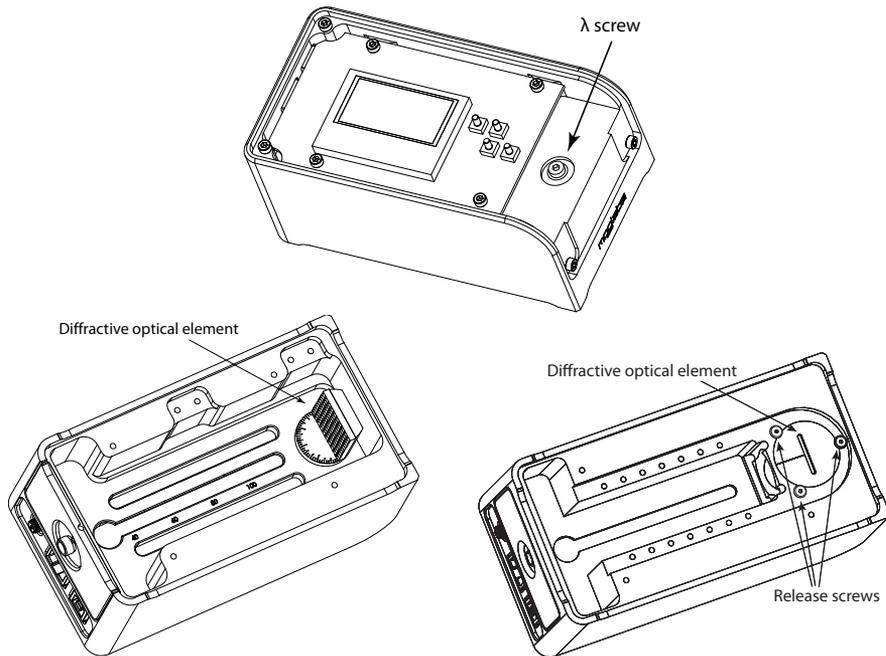wavemeter.

Figure 6.1: Adjustment of wavelength range; Rev 1 device at left, Rev 2 at right.
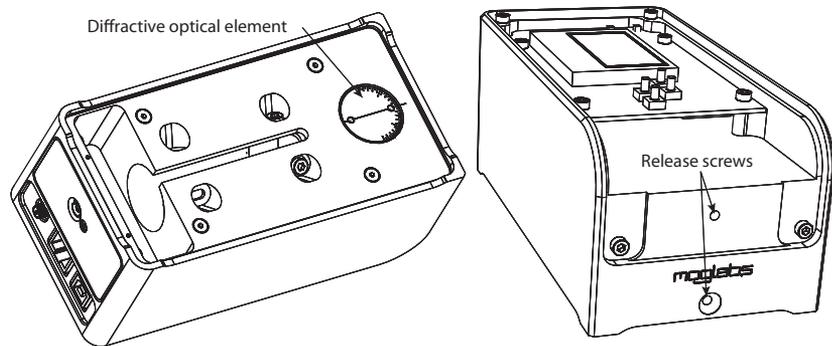
Figure 6.2: MWM Rev 3, showing location of grating (diffractive optical element) and axial locking screws. Note that the lower screw is normally hidden behind a protective M4 flat head screw which should be removed.

3. Couple light into the MWM, preferably with plenty of power (a few microwatts) exiting from the fibre endface (at the MWM end). If the source is tunable, set it to a wavelength that you want to be in the middle of the spectral range.

4. Run the `mogwave` program, and rotate the grating (see below) until a spectral peak is seen. On Rev 2 devices, the indicator line on the grating holder should point towards the fibre such that the surface of the grating is exposed to the light.

   To find the peak as the element is rotated, it can be helpful to use the Focus or Ctrl-Focus feature to see a large area of the sensor.

   If no spectral peak appears, then vertical tilt of the grating has moved the diffracted spot outside the focus window. In that case, try gently tightening the locking screws to restore the vertical alignment, or see the following section (New fibre).

5. When the spectral peak is at a suitable horizontal position, for example in the middle of the spectrum, firmly retighten the screws holding the optical element in place and replace covers.

6. Calibrate as above.

6.5   New fibre

If a diffracted spot cannot be found with `mogwave`, it can be necessary to acquire a complete sensor image. Typically this occurs when changing the calibration wavelength outside the initial range, or when changing to a new fibre. The wavemeter relies on the precise location of the fibre core. Some fibre patchcords (e.g. Diamond Fibre Optics) have highly repeatable fibre core locations, but most require some correction. Also changing between PC and APC terminations requires correction. The corrections are determined by taking a full sensor image and finding the appropriate diffraction spots.

Ensure light is diffracted onto the sensor. Acquire a Full Image, with exposure time of 10 ms or longer. Open the `fullimageYYMMDD_hhmmss.tiff`

file, normally saved in the folder in which `mogwave` is installed, with an image viewer (e.g. `IrfanView` or `ImageJ`). You should see one bright spot, and may also see one or two additional secondary spots depending on which generation of wavemeter you have (contact MOGLabs if unsure). Find the x,y location of the main spot; for example, in `IrfanView`, click on the spot, and while holding the mouse button down, at the top left of the `IrfanView` window you will see the x,y location.

The location should be programmed into the device. Enter the row number into the row-number box at the bottom of the `mogwave` button. Make sure the auto-row checkbox is not checked. Open the Focus window and follow the instructions in section 4.8.

Alternately, the row number can be programmed into the device using the `mogwave` Device Command option, using the following command:

```
set,row,mainY
```

where `mainY` is the y location of the main spot.

Reset the device, then calibrate as above.

A. Specifications

Parameter	Specification

Wavelength	
Wavelength	350 nm – 1100 nm
Range	23 nm at 780 nm
Min input power	1 pW ex fibre
Max input power	30 nW ex fibre (780 nm)
Accuracy	± 1 GHz (± 0.001 nm) at 780 nm (at time of calibration)
Precision	100 MHz (0.1 pm) at 780 nm

Electronics	
Power	+5 Vdc 350 mA via USB port
Display	In-device LCD or host computer
Battery	External via USB
PID feedback	12-bit DAC output, ± 2.5 V (1 mV resolution)
Exposure time	60 μs to 20 s
Readout rate	Up to 100 Hz, dependent on user computer

Sensors	
Imaging	Up to 2750 $\times$ 2004 2.2 μm $\times$ 2.2 μm pixels
Sensitivity	In fibre: min 1 pW, saturation 30 nW
Damage threshold	50 mW in fibre
Spectral response	See below

Parameter	Specification

Temperature	Resolution $\pm0.008°$C
	Range $10°$ to $+40°$C
Pressure	Resolution ±1 Pa
	Range 260 hPa – 1260 hPa
Aux ADC input	0 to $+5$ V, 12-bit (1 mV)

Interface	
Ethernet	10/100 TP RJ45
USB	USB1.1, plug type USB-B
SMA	12-bit DAC output, ±2.5 V
	(1 mV resolution)
Optical input	FC/APC or FC/PC single-mode fibre

Software	
mogwave	Windows-based GUI
API	Text commands via TCP/IP or USB
	python, Labview examples provided

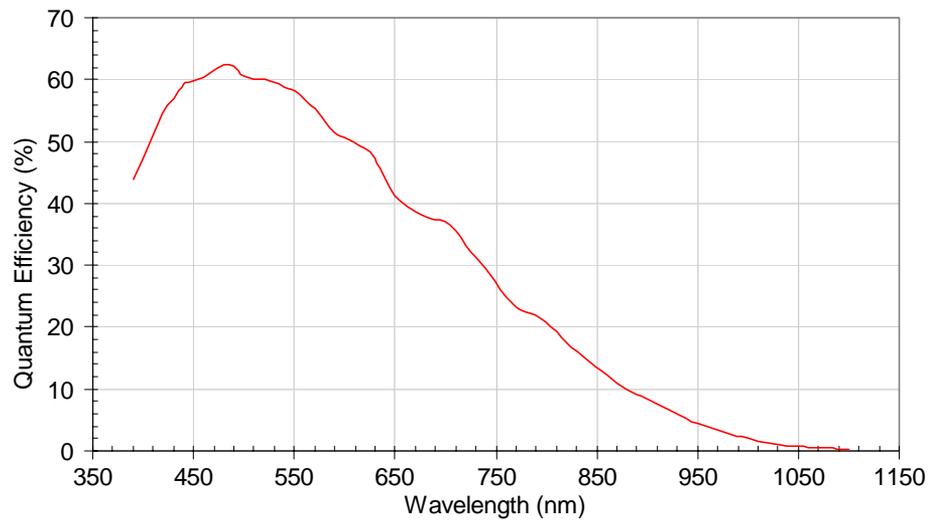| Dimensions	
Dimensions	165 mm $\times$ 85 mm $\times$ 70 mm
Weight	1.5 kg

Figure A.1: Typical detector spectral response.

B. Communications

The MWM can be connected by USB or ethernet (TCP/IP). From the user and device perspective the two are equivalent, but if possible, use a network connection for improved response times and faster data acquisition.

B.1 TCP/IP

When ethernet is connected, the MWM will attempt to obtain an IP address by DHCP. If DHCP fails, an internally defined address will be used. In both cases, the address will be shown on the device display, something like:

```
10.1.1.180:7802
```

The dotted–quad number (10.1.1.180) is the device IP address; you can type that into the address bar on your web browser and you will see a simple webpage for the device (via the standard `http` port 80).

The second number (7802) is the TCP/IP port number. This port provides full access to device functionality. It is through this port that your control software should access the device. Simple commands can be sent to the device using the `telnet` protocol, for example:

```
telnet 10.1.1.180 7802
disp,rgb,100,100,100
```

Here the `telnet` command line sepcifies IP address 10.1.1.180 and port 7802. You can also use a GUI `telnet`, in particular on Windows^{TM} we recommend PuTTY available at `www.putty.org`. Specify the `Host Name` as 10.1.1.180, `Connection type` as Telnet, and the `Port` which is normally 22, should be changed to 7802.

The above example sends the `disp,rgb` commmand to the device (to set the display backlight intensity). The full suite of commands is described in appendix D.

You can also access the device indirectly through a socket server established by `mogwave` on your host computer. The `mogwave` server provides fully calibrated wavelength measurement, allowing `mogwave` to act as an API for data acquisition systems, for example `matlab` or `LabVIEW`. See appendix F for more information.

B.1.1   Changing IP address

If you do not have a DHCP server to define the device IP address, and the default is not suitable, you will need to manually change the IP address. This is most easily done using the on-device menu system described in chapter 2. Network settings can also be changed by connecting via USB, and using the `mogwave` application to configure the device settings. The `mogwave` application is described in further detail in chapter 4, but two specific functions are documented below in relation to establishing communications.

Device network settings To configure the device network connection settings (IP address, mask, gateway and port), particularly useful if the device is connected by USB.
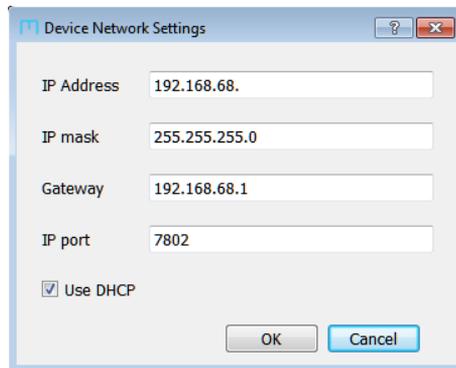
Device command This function (`File menu, Device command`) opens a new dialog for interactive command access to the device, similar to `telnet` but this

approach will work via USB. Type a command into the command line window, and hit `Enter` to send that command to the device (see appendix D); the response will appear in the box below the command line window. Some commands are not permitted because they require complex data flow.
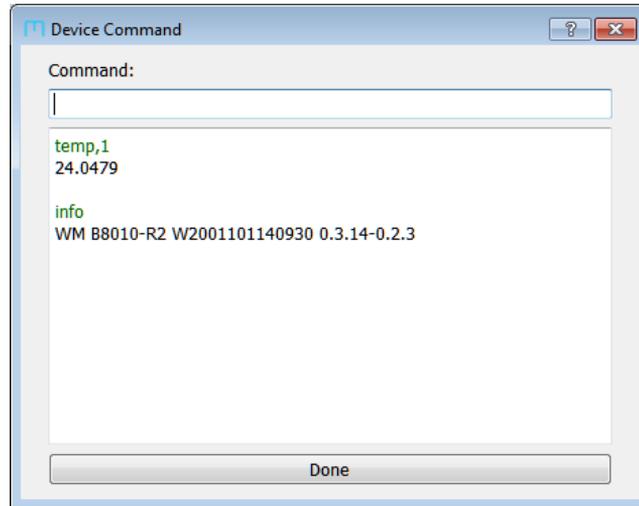
B.1.2 Configuration in alternate subnet

Another approach is to plug the device into a network which is in the same address space, then send the appropriate commands by `telnet`, and reconnect in the desired address space. For example, if the MWM default address is 10.1.1.180, and you want the device to work in the 192.168.1.xxx space:

1. Use a network patch cable to connect the MWM directly to a computer ethernet socket, not via a network switch or hub.

2. Configure the computer network settings to have an address in the same address space as the MWM; for this example, you can set the computer IP address to 10.1.1.189.

3. Telnet to the MWM, for example address 10.1.1.180 and port 7802, and use the `set` command to reconfigure the network settings:

```
telnet 10.1.1.180 7802
set,ipaddr,"192.168.1.100"
set,ipgw,"192.168.1.1"
reset
```

After reset, the device will default to the new settings. If using PuTTY (www.putty.org) as a `telnet` client, set the `Host Name` to 10.1.1.180, `Connection type` to Telnet, and the `Port` which is normally 22 should be changed to 7802.

B.2   USB

The MWM will appear as a VCP: a virtual COM port; that is, a fast serial port like an RS232 connection. When the device is connected to a Windows^{TM} computer, the computer will normally automatically download and install the STM32 Virtual COM Port Driver. Your software can then communicate as with any normal COM port.

To determine which port number is required, go to Device Manager (Start, then type `Device Manager` into the Search box). You should see a list of devices including "Ports", and within that,

```
STMicroelectronics Virtual COM Port (COMxx)
```

where xx is a number, typically 4 or 15 (see figure below), the USB port number.
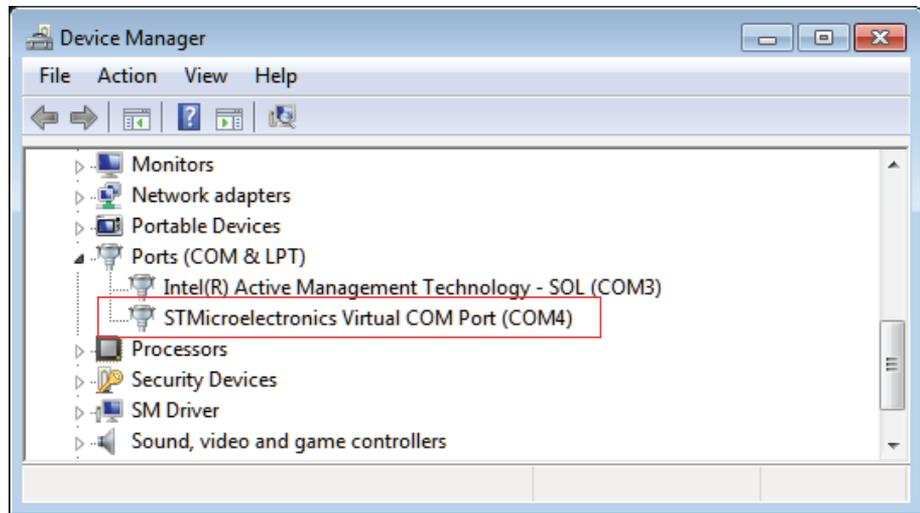
B.2.1 USB driver

If you do not see a virtual COM port under "Ports" in the `Device Manager` then manually install the USB driver. The driver install package should be in `c:\Program Files (x86)\MOGLabs\USB_VCPdriver`.

1. Run the USB driver setup program. This will copy the drivers to your computer, typically in

   `C:\Program Files (x86)\STMicroelectronics\Software\Virtual comport driver`

   Currently there are folders `Win7` with drivers for Windows 7 and `Win8` with drivers for Windows 8 to 10.

2. Ensure the wavemeter is connected to your computer via USB cable.

3. Double-click the appropriate 32-bit (`dpinst_x86.exe`) or 64-bit (`dpinst_amd64.exe`) driver for your version of Windows.

4. Once installation is completed, restart your computer.

5. When your computer is finished booting, disconnect the USB cable from your wavemeter, and then reconnect.

Look again for the virtual COM port within `Device Manager`. If you see
`STMicroelectronics COM Port (COMxx)` and the device is not connecting
then you need to tell the software (`mogwave`) which port to use. This is
most easily done by editing the default configuration file,
`C:\Program Files (x86)\MOGLabs\mogwave\configs\default.cfg`.
Change the two lines

```
# usb_port = COM15
# usb = False
```

to

```
usb_port = COMxx
usb = True
```

where xx is the COM port shown in Device Manager.

You can also specify USB and the port via command-line options for `mogwave`.
Edit the shortcut link to add `-u` to force USB, and `-p xx` to specify the
port number.

1. Right-click on the `mogwave` desktop shortcut and select `Properties`.

2. Edit the `Target` to add `-u -p xx` at the end (see figure below). It
   should be something like
   `C:\Program Files (x86)\MOGLabs\mogwave\mogwave\mogwave.exe -u -p 15`.

3. Select `Apply` to save the new shortcut.
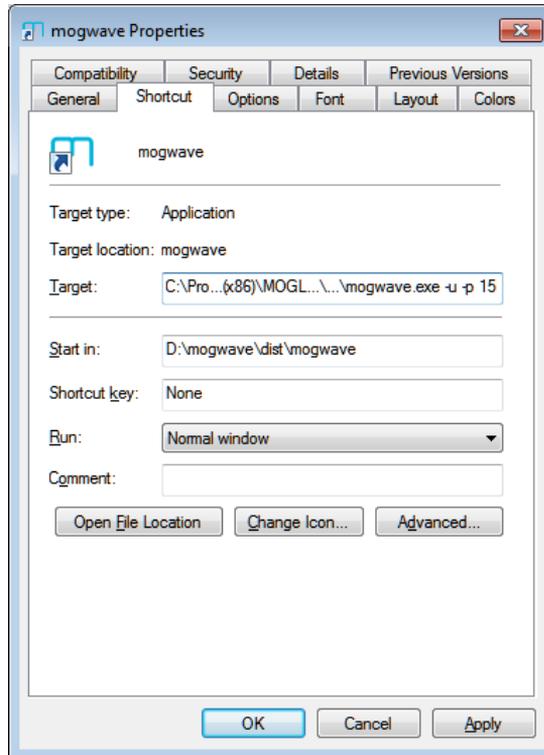
Figure B.1: mogwave shortcut properties, edited to add USB port number. Note that the Target has been abbreviated here.

C. Programming

The MWM is controlled via simple text commands of the form:

```
DISPLAY,LINE,0,0,"Hello"
```

Each command begins with a text key; only the first three letters are required but the full command can be used. Some commands will have a sub-command, and/or parameters including integers, floating-point numbers, and text strings. Each command will return a requested value, or a default "OK".

These commands can be sent to the device via TCP/IP (for example, using `telnet`) or USB. A full list of commands is provided in Appendix D.

Watchdog timer

The MWM has a watchdog timer that resets the device if any internal function or operation fails to complete within approximately 5 seconds. Thus if your application fails to receive an expected response then it can attempt to re-establish a connection after that time.

C.1 `python` example

A simple program involves opening the communications channel, configuring the imaging sensor, optimising the exposure time, and then either acquiring the spectrum or the calculated wavelength. An example, written in `python`, is outlined below. Further examples will be provided for `matlab` and `LabVIEW`.

```
#------------------------------------------------
# MWM wavemeter python example
# (c) MOGLabs 2020
# Using python driver from moglabs.com
```

```
#------------------------------------------------------
from mogdevice import MOGDevice
import sys
import matplotlib.pyplot as plt

# connect to the device
dev = MOGDevice('10.1.1.32')

#----------------------------------------
# Demonstrate simple command
#----------------------------------------
print('Device info:', dev.ask('info'))

#----------------------------------------
# Find optimum exposure time
# cam,atime,<max> finds optimum but with
# maximum of <max> milliseconds
#----------------------------------------
shutterStr = dev.ask('cam,atime,400\n')
shutterTime = float(shutterStr)
print('Exposure time: %.2fms' % shutterTime)

if (400-shutterTime < 1):
  print('Insufficient input power')
  sys.exit()

#----------------------------------------
# Acquire spectrum
#----------------------------------------
buflen = 0
cols = 2592 # sensor width
bufsize = cols*2 # two bytes per pixel
maxy = 2*4096 # 12-bit sensor, two rows added
bindata = ''
dev.send('spe\n')
# deal with fragmented tcp/ip packets
while buflen<bufsize:
    chunk = dev.recv(bufsize-buflen)
    chlen = len(chunk)
    bindata += chunk
    buflen += chlen

image = []
```

```python
# convert to list
for i in xrange(0,bufsize/2):
    word = ord(bindata[2*i])+(ord(bindata[2*i+1])<<8)
    image.append(word)
y = image[0:cols]

#-----------------------------------------
# Plot spectrum
#-----------------------------------------
plt.clf()
plt.ylim(0,maxy)
plt.xlim(0,cols-1)
plt.plot(y,'-')
plt.show()

#-----------------------------------------
# Report measured wavelength
#-----------------------------------------
wavelen = dev.ask('wavelength\n')
print('Wavelength:␣',wavelen)

# measure again
wavelen = dev.ask('wav\n')
print('Wavelength:␣',wavelen)
dev.close()
```

D. Command language

The MWM is controlled via simple text commands of the form:

```
wavelength,vacuum
```

Each command begins with a text key. Only a few letters of the text key are required, just enough to uniquely identify the command against all other valid commands. Some commands will have a sub-command, and/or parameters including integers, hexadecimal integers (e.g. `0xf31b`), floating-point numbers, and text strings. Each command will return a requested value, or a default "OK".

D.1   Wavelength measurement

WAVELENGTH `wave,<units>,<num>` or `wave,<num>,<units>`

Acquire image at current field of view and exposure time, and return calculated wavelength or frequency (defaults to units specified on device). The value is returned as a floating-point string.

`<num>` = 1..150 optional repeat count. Values are space-separated.
`<units>` optional unit specifier as for the `units` command below.

UNITS   `units,raw`   raw (as measured) wavelength [nm]

`units,vac`   in-vacuum wavelength [nm]

`units,air`   wavelength for NTP conditions [nm]

`units,thz`   frequency [THz]

`units,num`   wavenumber $[\text{cm}^{-1}]$

`units,col`   peak location as column number.

Set display units for wavelength when device is operating standalone, initiated by pressing the ↓ (DOWN) button. Note that the device measures wavelength in air for ambient temperature, pressure and humidity, given by the *raw* result. The *air* result is corrected for normal temperature and

pressure (NTP, 20°C and 1 atm. 101.325 kPa). Returns current units if no argument given.

D.2   PID control

set   `pid,set,val`
Set the desired wavelength sepoint. The current value is returned if no `val` is given. `val` should be a floating-point number in whatever units the MWM device will be measuring. There is no provision for providing units or for conversion if the display units are changed after setting the PID setpoing.

For example, to lock the laser frequency to the rubidium-85 D2 line at 780.243 nm (in vacuum), 384.230 THz. If the device is displaying in `nm` (vac), the set value should be 780.243. If the display units are later changed to `THz`, the MWM will initially display 380.230 THz but the PID controller will drive the laser towards 780.243 THz; thus the setpoint should first be changed to 380.230.

kp, ki, kd `pid,kp,val` or `pid,ki,val` or `pid,kd,val`
Set the PID coefficients k_p, k_i, k_d (see chapter 5). The current value is returned if no `val` is given, for example, `pid,kp`. `val` should be a floating-point number from 0 to 1.0.

min, max `pid,min,val` or `pid,max,val`
Set the minimum and maximum output limits from the SMA connector, in volts. The current value is returned if no `val` is given, for example, `pid,min`. `val` should be a floating-point number from -5 to $+5$.

offset   `pid,offset,val`
Set the output offset voltage; that is, the voltage on the SMA connector when the measured wavelength matches the setpoint. The current value is returned if no `val` is given. `val` should be a floating-point number from -5 to $+5$.

gain   `pid,gain,val`
Set the output gain in volts/unit. For example, if the MWM is displaying in `nm` (vac), driving a moglabs laser system with DLC controller, a reasonable

value would be −10 V/nm. Changing display units will not change this value. `val` can and often should be negative.

enable `pid,enable`
Resets and then activates the PID controller. The SMA output will initially be set to the PID offset (see above) and then vary according to the algorithm described in section 5.

disable `pid,disable`
Disables the PID controller. Note that the SMA output voltage will not be changed: it will remain at the most recent value set by the PID controller.

output `pid,output`
Returns the current value of the output of the PID controller, which should be the voltage on the SMA connector.

D.3   General functions

RESET Reset, equivalent to power off and back on. Note that the communications link will be closed.

CLOSE, QUIT, EXIT Close communications channel.

HELP, ? List commands.

INFO Report device serial number.

VERSION Report firmware version.

FRESET Restore configuration from factory defaults.

STATUS Report status of the unit. Currently not supported.

SER, STR Conversion of serial numbers between string and integer.

SERialtostr `ser,u32`
Convert unsigned 32–bit code to serial number string.
u32 must be a hexadecimal number.

STRtoserial `str,str`
Convert string to unsigned 32–bit serial number (8–digit hex).

D.4   Display functions

DISPLAY Commands to control the on-device LCD display.

line   `display,line,x,y,str`
Display string `str` at location `x,y`.
$0 \leq x \leq 16$; $0 \leq y \leq 7$

bigline `display,bigline,x,y,str`
Display string `str` at location `x,y`, using large font.
$0 \leq x \leq 16$; $0 \leq y \leq 7$

blank `display,blank`
Erase the display.

clear `display,clear,y`
Clear one line of text at `y`.
$0 \leq y \leq 7$

contrast `display,contrast,val`
Adjust display contrast.
$0 \leq$ val ≤ 63 (default is 14)

rgb   `display,rgb,r,g,b`
Set backlight intensity for colours `r,g,b`.
$3 \leq r, g, b \leq 254$
Note that most models have white backlights, which respond only to the
`r` value.

dump `display,dump`
Returns a binary dump of the LCD bit pattern.

D.5   Auxilliary measurements

ADC   `adc,chan`
Read voltage on ADC input, 0 to +5V unipolar, 12-bit.
Use `adc,3`. Allowed values are $1 \leq$ chan ≤ 8 but other channels are not

implemented in current models.

DAC `dac,v`

Set voltage on SMA connector, $\pm 2.5\,\text{V}$ 12–bit.

v can be an integer: $0 \le v \le 4095$ corresponding to $-2.5 .. + 2.5\,\text{V}$
or a floating–point number $-2.5 \le v \le +2.5$ but in that case must include a decimal point. For example `dac,2` will be interpreted as an integer (equivalent to approximately $-2\,\text{V}$) but `dac,2.` and `dac,2.0` will be interpreted as floating–point $(2.0\,\text{V})$.

POWER `pow`

Report power supply voltages.

TEMP `temp,chan`

Report temperature. `chan=1,2` for main unit and imaging sensor respectively.

PRESSURE `press`

Report pressure in hPa.

`press,Pactual`

Define actual pressure (hPa). The value will be used to recalibrate the pressure sensor.

PRAW `praw`

Report raw pressure in hPa. Pressure correction stored in EEPROM will be programmed into pressure sensor.

WDG `wdg,wdtime`

Set the watchdog time, in seconds. `wdtime = 3..16` (default 3 s).

The watchdog timer automatically resets the device if the device firmware freezes. For example, if the watchdog time is set for 1 second, and a 2 second exposure is initiated, the watchdog timer will reset the device halfway through the exposure. This facility allows automatic restart after interruptions or if there are software or firmware bugs.

ONTIME `ontime`

Time in seconds since last reset or power-on.

TBOOT `tboot`
>   Temperature at last reset or power-on.

D.6 Imaging

SPECTRUM `spectrum`
>   Acquire currently defined field of view using currently defined exposure time, sum first two rows and return sum in binary. Thus for typical 2592 columns, return 2592 16-bit integers, two bytes each, least significant byte first. Each integer has a maximum value of $2^{13} - 1 = 8191$.

SFIRST `sfirst`
>   As above, but returns only the first (even) row. Returns 16-bit integers (two bytes each, least significant byte first). Each integer has a maximum value of $2^{12} - 1 = 4095$.

SSECOND `ssecond`
>   As above, but returns only the second (odd) row. Returns 16-bit integers (two bytes each, least significant byte first). Each integer has a maximum value of $2^{12} - 1 = 4095$.

CAMERA Commands to control the imaging sensor. The imaging sensor is typically 1944 rows of 2592 columns, and each pixel can have a 12-bit value (0..4095).

>   **snap** `cam,snap`
>   >   Acquire new image and return image data as plain text. The values are output as four-character hexadecimal numbers separated by spaces. Because of limited data packet size, the `snap` command is limited to image sizes of 300 pixels.

>   **bsnap** `cam,bsnap`
>   >   Acquire new image and return image data as binary data, two bytes per pixel. The maximum image size is 10 rows of 2592 columns, and the data is sent as two bytes, least significant first (little-endian).

>   **expose** `cam,exp`
>   >   Acquire new image but do not return image data. Acquired data can be

used for wavelength determination with `wavelength` command.

fov   `cam,fov,rowstart,colstart,nrows,ncols`
Define the field of view (i.e. the imaging area).
$0 \le$ `rowstart` ≤ 1944 and must be even.
$0 \le$ `colstart` ≤ 2592 and must be multiple of 4.
$0 \le$ `nrows` ≤ 1943 and must be odd.
$0 \le$ `ncols` ≤ 2591 and must be odd.
Note that the actual number of rows acquired is one greater than `nrows` and similarly for `ncols`. The maximum number of pixels, i.e. `nrows+1` $\times$ `ncols+1`, must be less than 25,920.

time   `cam,time,u20`
Set exposure time. The value is 20-bit unsigned. The exposure time is approximately (`u20` $\times$ `ncols`$/48 - 8.5$) microseconds.

atime   `cam,atime,max`
Automatically set exposure time, with a maximum of `max` milliseconds. The exposure is adjusted until an interference peak is between 30 and 80% of the maximum pixel value, up to a maximum of `max` milliseconds.

bin   `cam,bin,binx,biny`
Sum neighbouring pixels to improve dynamic range. Untested.
`binx, biny` can each be 0, 1 or 3 for 1x, 2x or 4x binning.

gain   `cam,gain,d,m,g`
Set imaging sensor digital gain, multiplier and analogue gain.
$0 \le$ d ≤ 120
m $= 0, 1$; set to 1 for a factor of 2 in digital gain
$8 \le$ g ≤ 63

vars   `cam,vars`
Report imaging sensor field of view, exposure time, binning and gain settings. The values are tab-separated. They are:

`rowstart`   first row
`colstart`   first column
   `nrows`   number of rows - 1

        `ncols` number of columns –1

      `swu,swl` exposure time

   `binx,biny` binning (0, 1 or 3 for 1x, 2x or 4x)

        `gain` gain

D.7   Configuration settings

SET, GET Set and report EEPROM configuration values. Each `set` command described below has a corresponding `get` command to report the relevant parameter.

sid `set,sid,u32`
  Binary serial number, unsigned 32-bit `u32`.

serial `set,serial,str`
  Serial number string `str`.

iapversion `set,iap,u16`
  Boot code version, unsigned 16-bit `u16`.

wmversion `set,wmv,u16`
  Firmware version, unsigned 16-bit `u16`.

flash `set,flash,u16`
  Flags to communicate between IAP and WM, in particular set bit 0 for firmware upload on next restart.

ipaddr `set,ipaddr,"xxx.xxx.xxx.xxx"`
  Set IP address based on dotted–quad string, for example
  `ipmask,"10.1.1.180"`. Each number should be base 10 (normal decimal).

ipmask `set,ipmask,"xxx.xxx.xxx.xxx"`
  Set IP mask based on dotted–quad string, for example
  `ipmask,"255.255.255.0"`

ipgw `set,ipgw,"xxx.xxx.xxx.xxx"`
  Set IP gateway based on dotted–quad string, for example
  `ipgw,"10.1.1.1"`

mac `set,mac,"xx.xx.xx.xx.xx.xx"`

Set ethernet MAC address. The device is factory configured with a MAC address reserved by MOGLabs from the IEEE REgistration Authority. It should not be necessary to change the default MAC address.

ipport `set,ipport,u16`

Set the TCP/IP port number to unsigned 16–bit `u16`. The device will respond to `telnet` queries on that port. Note that if the command is being sent via TCP/IP, and the port number changes, the communications link will be closed.

dhcp `set,dhcp,u16`

Enable or disable DHCP. Zero or −1 (0xffff) disables; any other value enables.

pcorrect `set,pcorr,int`

Correction value for pressure, signed 16–bit `int`.

camvars `set,camvars,rowstart,colstart,nrows,ncols,swu,swl,binx,biny,gain`

Set imaging sensor field of view, shutter time, binning and gain.

avgcnt `set,avgcnt,u16`

Number of measurements to average when calculating and displaying wavelength on the device.

row `set,row,u16`

Defines row of imaging sensor used for acquiring interference pattern, calculating spectrum and wavelength.

$0 \leq \mathtt{u16} \leq 1943$, should be even.

maxshutter `set,max,u16`

Maximum exposure shutter time in milliseconds, unsigned 16–bit integer. Default is 100. Note that the device will self–reset if suspended for more than about 16 seconds, imposing a hard limit on the exposure time.

qcal `set,qcal,double0,double1,double2,double3`

Calibration coefficients used by mogwave. Each coefficient is a double–precision real number.

scal `set,scal,double0,double1,double2,double3`
Calibration coefficients used for device-based measurement. Each coefficient is a double-precision real number.

grating `set,grating,double`
Defines grating frequency (per mm), at calibration temperature.

tco `set,tco,double`
Grating temperature coefficient.

ctemp `set,ctemp,double`
Device temperature (in °C) at time of calibration.

cpressure `set,cpress,double`
Barometric pressure (in hPa) at time of calibration.

focal `set,foc,double`
Focal length of lens.

rgb `set,rgb,r,g,b`
Set backlight intensity. Three unsigned integers should be provided, but most devices have one colour (white) backlights and their intensity is defined by the r value.
$3 \leq r, g, b \leq 254$.

contrast `set,contrast,int`
Set LCD contrast; unsigned integer between 0 and 64. Values between 8 and 20 work well. Best value depends on viewing angle.

userid `set,userid,str`
Defines the user ID for firmware upload. Default value is "moglabs". When uploading new firmware, you will be asked for a user ID and password. This command allows you to set the user ID to limit access to firmware changes.

password `set,pass,str`
Defines the password for firmware upload.

D.8   EEPROM access

EEPROM Low-level commands to set and retrieve EEPROM values.

read   `eeprom,read,addr16`
Read single byte at address `addr16`.

rword   `eeprom,rword,addr16`
Read 16-bit word at address `addr16`.

rlong   `eeprom,rlongaddr16`
Read 32-bit long at address `addr16`.

seq   `eeprom,seq,addr16,num16`
Read `num16` bytes starting at address `addr16`.

double   `eeprom,double,addr16`
Read a double-precision floating value at address `addr16`.

write   `eeprom,write,addr16,val`
Write single byte `val` at address `addr16`.

wword   `eeprom,wword,addr16,val16`
Write 16-bit `val16` at address `addr16`.

wlong   `eeprom,wlong,addr16,val32`
Write 32-bit `val32` at address `addr16`.

page   `eeprom,page,addr16,num,str`
Write `num` characters from string `str` to address `addr16`. String should be
in double-quotes, for example
`eep,page,4,16,"W1001101140602"`
Warning: data must fit within 128-byte page boundary.

str   `eeprom,str,addr16`
Write string `str` to `addr16`.
Warning: data must fit within 128-byte page boundary.

freset   `eeprom,freset`
Restore configuration from factory defaults.

fset   `eeprom,fset`
Copy current configuration to factory default preservation area.

E. `mogwave` **configuration**

`mogwave` can be configured via command-line options for some critical set-
tings, and more generally through a configuration file. Note that command-
line options override values set in the configuration file.

E.1   Command-line options

To change the command-line options, edit the shortcut link to `mogwave`,
typically the desktop link created during installation.

1. Right-click on the desktop or `Start` menu shortcut, then select `Properties`.

2. Edit the `Target` to add the appropriate command-line options, for
   example:

   ```
   C:\Program Files (x86)\MOGLabs\mogwave\mogwave\mogwave.exe
   -u -p 15
   ```

   to specify USB on port 15.

3. Press `OK` to save the shortcut changes.

The shortcut should then start your software appropriately.

You can also specify network connection, for example:

```
...   mogwave.exe -ip 10.1.1.18
```

where the IP address should match what shows on the device screen.

Additional command line options:

```
-h    help
-c    configuration filename
-d    debug options
-ip   IP address
-l    enable logging of errors
-m    maximum exposure time (ms)
-p    TCP/IP port or USBCOM channel
-r    sensor row
-s    simulation wavelength
-t    timeout multiplier
-u    USB enable
-f    FZW for calibration (y/n)
-w    HighFinesse for calibration (y/n)
```

-c The configuration filename; see below. `mogwave` will first try to open the file within the current working directory (the directory where `mogwave` is located, or the "`Start in`" directory specified in the shortcut link). If not found, it will search for the file in the default configs directory within the `mogwave` directory.

-d Debugging flags. Integer value; set odd to save etailed measurements when recording data.

-m The maximum exposure time is by default 100 ms. Longer times can make the software unresponsive but may be useful for measuring very low-power lasers or pulsed lasers with low pulse rate.

-r The sensor row specifies the pixel row on the sensor to use for data acquisition. The default is set in the factory but adjustments may be needed when changing fibres or after mechanical disturbance.

-s Floating point wavelength in nm. `mogwave` can simulate measurement if no laser light is available. Value must be within wavelength measurement range.

-t The timeout multiplier is used to make the software a little more pa-tient in waiting for responses from the wavemeter device, particularly where the network connection is slow.

-f Enable MOGLabs FZW wavemeter reading for calibration (see sec-tion 6.2). Values are y, yes, n or no.

-w Enable HighFinesse WLM wavemeter reading for calibration (see section 6.3). Values are y, yes, n or no.

See Chapter B for more information on communications options and Chap-ter 4 for more information on the `mogwave` application.

E.2   Configuration file

Default values for communications and other useful parameters are defined in a configuration file. The default location is in the `configs` directory within the `mogwave` home directory, and the default file is `default.cfg`, for example

```
C:\Program Files (x86)\MOGLabs\mogwave\configs\default.cfg
```

The config file is in plain text, in the Microsoft `.ini` format, with a number of sections, and within each section, a number of options. The default data type is string. The default config file includes comments on the meaning of the different parameters.

Important parameters include the font size, default directory (folder) for saving data files, default TCP/IP address, USB port, maximum shutter time, measurement interval, and the spectrum plot colour.

F. `mogwave` **server**

`mogwave` provides a server that can be accessed via TCP/IP, providing an API so that wavelength measurements are accessible to other applications such as `matlab` or `LabVIEW`. To use the server, you should start `mogwave` and ensure that it is making sensible measurements. You can then stop `mogwave` and make single measurements on demand through the server, or leave `mogwave` running and access the most recent measurement from the server as needed.

F.1   Enabling the server

The server is accessed via TCP/IP on the host computer that is running `mogwave`. When `mogwave` starts, it will establish a TCP/IP socket on the host computer. The TCP/IP port is defined in the `default.cfg` file (see E.2); if 0, the server is disabled. A typical port value would be 7803.

F.2   Communication with the server

Communication with the server is via TCP/IP, with a simple command/re-sponse `telnet` protocol. For example, if the host computer running `mogwave` has IP address of `10.1.1.21`:

```
telnet 10.1.1.21 7803
help
```

Here the `telnet` command line sepcifies IP address 10.1.1.21 and port 7803. You can also use a GUI `telnet`, in particular on Windows^{TM} we recommend PuTTY available at `www.putty.org`. Specify the `Host Name` as 10.1.1.21, `Connection type` as Telnet, and the `Port` which is normally 22, should be changed to 7803.

The above example sends the `help` command to `mogwave`, which will report back something like:

```
mogwave running wavemeter W2001101140930
Wavelength range 766.2 to 788.9nm, difference 22.7nm
Valid commands: wave, last, close, start, stop, die, kill
```

F.3   `mogwave` **commands**

The `mogwave` server is controlled via simple text commands of the form `wave`. The commands must match exactly, with no abbreviations or extensions. For example, `wave` is good, but `wav` and `waver` are not.

Each command will respond with "OK:" if valid, or "ERR:" if invalid or some error occurred, followed by values or further information.

START `start`

Start continuous measurement.

STOP `stop`

Stop continuous measurement.

WAVE `wave[,units]`

Returns most recent measurement if acquiring; initiates a single new measurement if not.

units Units for return value; can be `nm vac`, `nm air`, `nm raw`, `THz`, `cm`. If no units specified, return value is raw measurement in nm.

The response includes the time of measurement, for example:

```
last,nm vac
OK: 16:59:08.8 779.984977
```

WIDTH `width[,units]`

Returns rms peak width of most recent measurement if acquiring; initiates a single new measurement if not. Note that the values returned by `wave`

and `width` are not necessarily associated with the same instantaneous spectral measurement. See above for optional units specification.

UNCERT `uncert[,units]`

Returns the statistical uncertainty for the most recent measurement if acquiring; initiates a single new measurement if not. Note that the values returned by `wave` and `uncert` are not necessarily associated with the same instantaneous spectral measurement. See above for optional units specification.

SPECTRUM `spectrum[,units]`

Returns most recently acquired spectrum, in text format, tab-separated wavelength and intensity values. Use the `wave` command to acquire a spectrum if not running acquisition continuously. See above for optional units specification.

EXPOSURE `exposure[,value]`

Control the sensor exposure time. If `value` is omitted, returns the current exposure duration in milliseconds.

value `auto` or `fixed` to enable/disable auto-exposure, or numerical value to set the exposure time in milliseconds.

PEAK `peak`

Return position and height of peak. Height is the largest integer value in the raw spectrum, and position is the integer number of the highest value (use `wave` to find calibrated wavelength).

TWOD `twod[,state]`

Switch between high accuracy 2d mode and faster 1d mode.

state State should be `True` or 1 to enable 2d mode, `False` or 0 to return to normal mode. If no state specified, defaults to `True`.

CLOSE, EXIT `close` or `exit`

Close the TCP/IP socket (i.e. disconnects).

KILL, DIE `kill` or `die`

> Terminate mogwave.

G. Ugrading firmware

1. Connect power and ethernet connection.

2. Use a web browser (e.g. `firefox`) to load the device webpage, based on the IP address shown on the device display.

3. On the web browser, select `Functions`, `Update firmware`.

4. Click on `Reboot to firmware upload mode`.

5. Watch the device display until it shows the IP address, then open your web browser at that address.

6. At the prompt, enter your user ID and password. Initially these are `moglabs` and `wavemeter`.

7. Select `Browse` and then select the new `MOG-WM.bin` firmware file.

8. Click on `Upload`.

9. Watch the device display, and when all packets have been uploaded, reset the device (disconnect from power and reconnect, or hold down the ⓞⓚ button until the unit powers off, and again to power up).

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