Fizeau Wavemeter

FZW600

Version 0.1.2, Rev 2 hardware

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Getting started

1. **Connect to +5 V power** via the USB port or the DC barrel jack.

   When powering with USB, it is important that the host can supply up to 600 mA. Some older computers may detect this as a short-circuit and power down the device; USB-3.0 compliant hubs are recommended.

2. **Power on** using the rocker switch on the rear.

3. **Connect fibre** using the supplied fibre patchcord. Typically this is FC/PC (black) on one end and FC/APC (green) on the other. The FC/PC side must be connected to the FZW.

   If the device was ordered with the FC/APC option (as indicated on the chassis), the supplied fiber is FC/APC on both ends and either end can be connected to the FZW input.

   Single-mode fibres are strongly preferred, although small-core multi-mode fibres (up to 62.5 µm) can be used at the expense of reduced accuracy.[1]

4. **Input light** with the supplied free-space to fibre adapter. Typically the FZW only needs a few microwatts to operate, so high coupling efficiency is not required. The *saturation* (Figure 1) is a measure of the power reaching the detector

   The auto-exposure algorithm tunes the exposure time to match the input power and optimise the measurement rate. In some cases it may be preferable to set the exposure time manually, such as when performing maintenance on the source laser and the laser output power tends to fluctuate rapidly.

That's it: with a coupled fiber you should be able to read the wavelength within two seconds of power-on. It is recommended to

[1] Absolute accuracy specifications are only valid when using single-mode fibres.

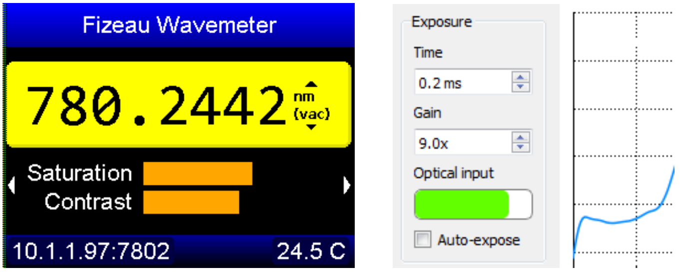


Figure 1: Both the built-in wavemeter display (left) and host software (right) provide saturation indicators that measure the optical power reaching the detector.

periodically inspect the measured interference fringes for correct structure (§4.1) to ensure reliable measurement.

Typically the FZW will reach thermal equilibrium and full accuracy within 15 minutes of being turned on. The most accurate results will be obtained in a well-stabilised lab environment. It is recommended that the FZW not be in thermal contact with any other equipment to prevent formation of thermal gradients.

Host connection

The recommended mode of operation is using the Windows™ host application (chapter 3) which provides a simple interface for controlling device functionality. Instructions for connecting via ethernet and USB are provided in Appendix D.

1. Introduction

1.1 How it works

The FZW is a high-precision device that measures laser wavelengths using a set of Fizeau interferometers. A Fizeau interferometer is formed by two planar surfaces with a small wedge angle between them, which generates spatially-varying interference fringes as the optical path length changes (Fig. 1.1). Both the fringe spacing and phase of the resulting interference pattern are related to the wavelength of the incident light, so analysing their structure allows precise determination of the laser wavelength.

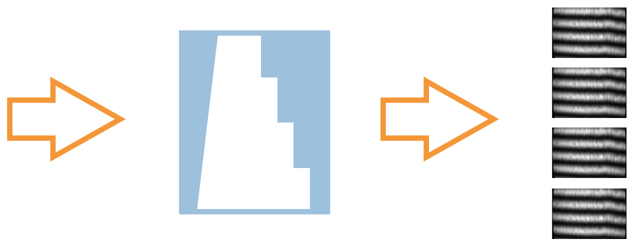


Figure 1.1: Collimated monochromatic laser light and Fizeau etalons create interference patterns on an imaging detector. The wavelength is calculated by combining measurements of the fringes from four different etalons.

A rough estimate of the wavelength is obtained directly from the fringe spacing, to an absolute accuracy of one part in 100. This initial estimate is then improved by the phase of the fringe pattern. Multiple etalons with different free-spectral ranges (FSRs) are used to refine the wavelength measurement without sacrificing absolute accuracy. The MOGLabs FZW uses four such stages, with the FSR of the final etalon being 7.5 GHz. This enables the wavelength to be determined to an absolute accuracy of one part in 10^7.

1.2 Features

The MOGLabs FZW has no moving parts, and very high sensitivity semiconductor imaging, enabling high measurement speed (up to 350 per second) and measurement of pulsed sources with only a few microwatts of light.

Long lifetime is assured as there are no mechanical parts to wear out. The etalons are optically-contacted fused silica, with a low thermal expansion coefficient, making the instrument incredibly robust, reliable, and stable. High precision MEMS-based sensors are used to make small corrections for environmental variations. Recalibration is not required to maintain the stated accuracy; in fact, the FZW is more stable than the neon lamp used in some other wavemeters as a calibration source.

The FZW also integrates a modern 32-bit microprocessor and high-resolution compact colour display. Wavelength calculation is performed automatically on the device so that no host computer is required. It is compact and can be powered from USB or even a rechargeable battery, so you can move it around your lab and measure wavelength right where you are adjusting your laser.

Fast ethernet and USB communications combined with a sophisticated software suite enable display on your lab computer or your smartphone. Multiple FZW devices can be easily run from a single computer, and integration with common data acquisition systems is simple using text-based commands over standard protocols, with simple bindings to `LabVIEW`, `MATLAB`, and `python` provided. PID frequency feedback locking is also included with every device, also without requiring a host computer.

2. Connections and controls

2.1 Front panel interface

The FZW front panel (Figure 2.1) includes an interactive colour screen with push-button interface, and a number of status indicator lights. This allows autonomous usage of the wavemeter independently of a computer.

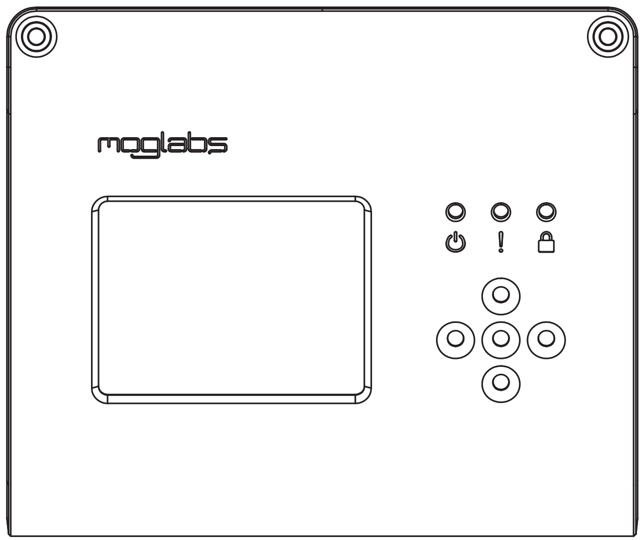


Figure 2.1: MOGLabs FZW front panel layout.

The buttons are arranged as a "directional pad" with up, down, left and right buttons, and an additional **OK** button in the centre. In wavelength display mode, the up/down buttons change the display units, and the left/right buttons swap between different diagnostic modes (see §3.1). Pressing **OK** opens the menu system.

The display includes a *sleep mode* which reduces the brightness when not in use. Where this feature is undesirable it can be disabled by setting the sleep time to zero in the menu system.

The LED indicators display the current state of the device, as listed in the table below.

Indicator	Colour	Status
PWR ⏻	**Off**	Unit is powered off
	Green	Normal operation
	Blue	Firmware update mode
ERR !	**Off**	No measurement in progress
	Green	Normal operation
	Yellow	Measurement error
	Red	Critical device error
LOCK 🔒	**Off**	PID/analog output disabled
	Green	PID locked
	Yellow	PID engaged but not locked
	Red	PID output saturated
	Blue	Analog output error

2.1.1 Menu system

The menu system allows for interactive control of the device without a computer interface (Figure 2.2). It is started by pressing the **OK** button from the measurement display mode, and exiting by pressing the left directional button.

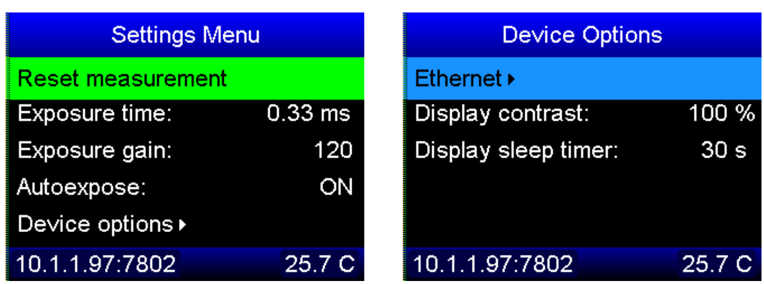
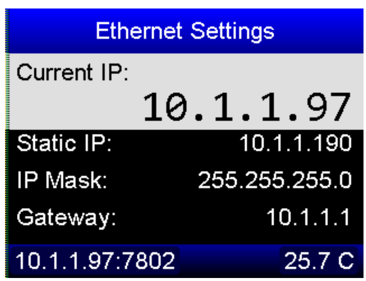


Figure 2.2: Primary settings menu, showing measurement options (left) and device settings (right) which includes display settings.

Within the menu system, the up and down buttons control the selected item. Pressing **OK** on a selected item activates it to allows editing the value, entering the submenu, or executing the command. Pressing the left button returns to the previous menu, or exits the menu system.

When a value is selected for editing, a digit will be highlighted. Using the up/down keys modifies this digit, and using the left/right keys changes which digit is selected. Pressing **OK** again exits editing mode.

In particular, it is useful for configuring the Ethernet settings in an networking environment where DHCP is disallowed (Figure 2.3). In this situation, an appropriate static IP should be allocated to the unit, the gateway set as required by the network configuration, and DHCP set to OFF.



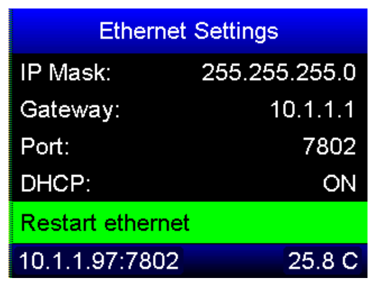


Figure 2.3: The Ethernet settings menu provides control of connection settings (left), including DHCP and static addresses. Any changes only take effect once the Ethernet controller is restarted (right).

2.2 Rear panel controls and connections

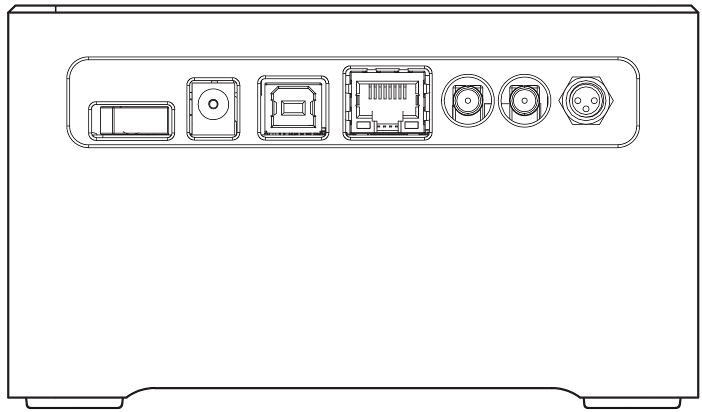


Figure 2.4: MOGLabs FZW Rev3 rear panel layout.

From left to right, the features of the rear panel (Figure 2.4) are:

Power switch Switches the unit on/off.

DC supply 2.1mm centre-positive barrel-jack connector for supplying power the unit. Not required if power is supplied over USB. Use of a floating (unearthed) "plugpack" power supply is not recommended.

USB Standard USB type-B connector for powering and/or communicating with the device. When used to power the device, must be connected to a USB port capable of supplying 600 mA.

Ethernet RJ-45 jack for 10/100 MB/s TCP/IP communications, which is the recommended interface for computer control and monitoring.

SMA output Analog output port for wavelength monitoring or PID control of laser wavelength (see §4.7). 16-bit resolution with ±2.5 V output range.

TRIG input Active-low TTL input for synchronising the wavemeter measurement to an external trigger (see §4.5).

Shutter control M8 connector for interfacing with the FSW4/FSW8 multi-channel optical switcher (see chapter 5).

3. User interface

3.1 On-board UI

The FZW includes an integrated user interface for operating the wavemeter independently of a host computer. The primary display shows the currently measured wavelength (Figure 3.1) in units that can be selected via the up/down buttons.

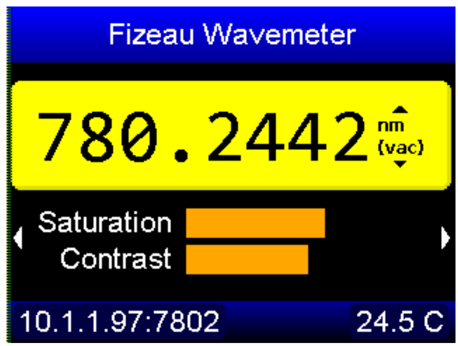


Figure 3.1: Primary wavelength display showing the measured wavelength, saturation and contrast, as well as the device IP address.

The *saturation* is a measure of the optical power reaching the detector, and the *contrast* is a measure of fringe quality. In general, higher saturation is preferred as this permits faster measurement, however oversaturation (as indicated by the bar turning red) will degrade measurement accuracy.

Pressing the left/right buttons changes to an alternate display mode (Figure 3.2), permitting diagnostic of the fringe pattern as explained in §4.1, as well as displaying a rudimentary time-series of variations in the measured wavelength over time. Pressing the central OK button opens the menu system (see §2.1.1).

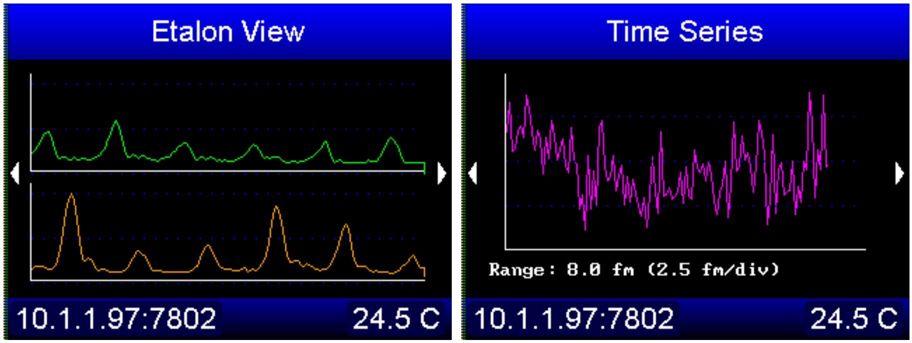


Figure 3.2: Diagnostic modes of the FZW on-board UI: etalon display (left) permits verification of fringe quality, and time-series display (right) shows variation in the measured wavelength over time.

3.2 Web UI

The FZW includes a simple web interface for monitoring the device remotely through a web browser, such as using a smartphone. Navigating to the device IP address displays the currently recorded wavelength, which is automatically updated (Figure 3.3). At present this interface doesn't provide control options, but increased functionality will be provided in future firmware updates.

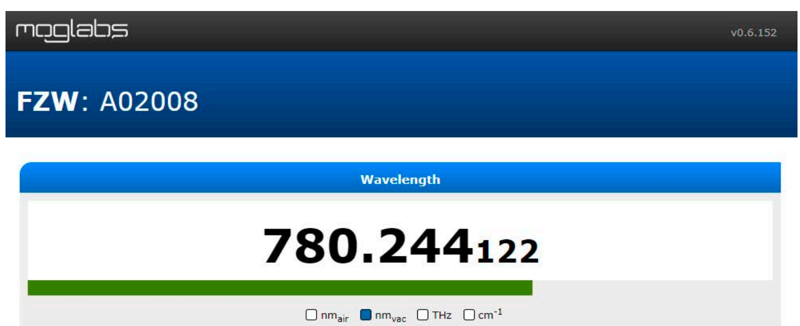


Figure 3.3: Demonstration of the integrated web interface showing measured wavelength and saturation (represented by the coloured bar).

In environments where embedded devices running web servers constitute a security concern, the web interface can be disabled using the command `ETH,WEB,0` or through the Menu System by selecting

Options→Ethernet→Web server→OFF.

3.3 Software UI

A fully-featured control and diagnostic program suite for Windows™ operating systems is available from the MOGLabs website.

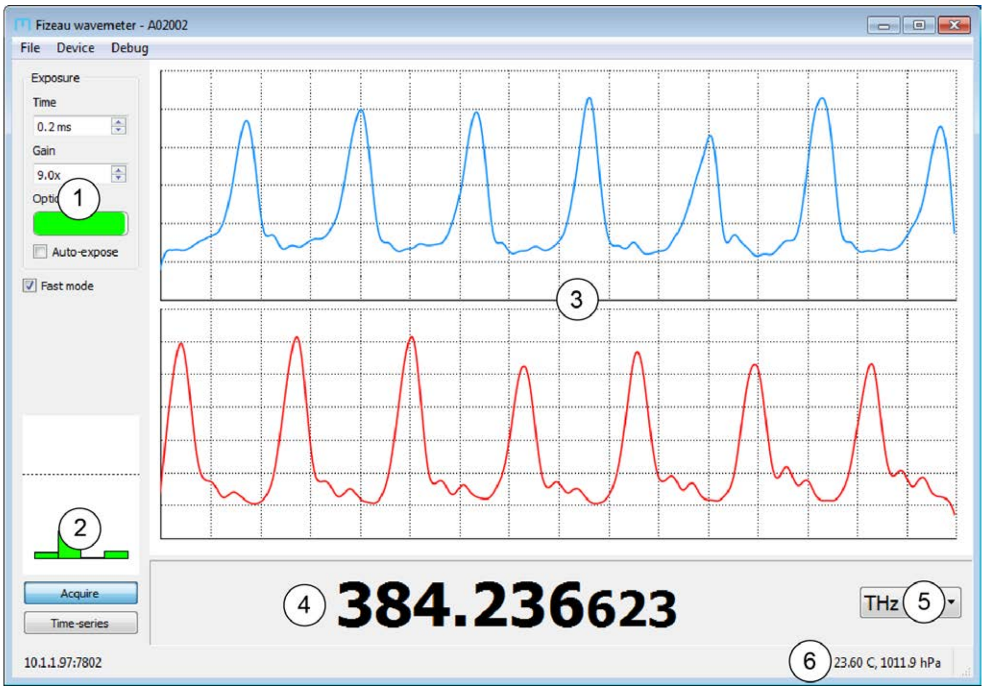


Figure 3.4: Demonstration of the host software interface, showing exposure controls (1), convergence monitor (2), interference fringes (3), measured wavelength (4), display units selector (5), and device diagnostics (6). The font size of the measured wavelength can be enlarged by dragging the splitter bar vertically.

Most of the user interface is dedicated to displaying the etalon fringes, which are important for measurement diagnostics (see §4.1). The wavelength display box has selectable units, and can be resized to increase the font size and make the measurement easier to read from a distance.

The exposure controls on the left-hand side include a scale bar showing the optical saturation. Both the exposure time and camera gain can be manually adjusted, although in most scenarios the auto-exposure algorithm will optimise these values.

The *convergence monitor* on the lower-left indicates how stable the iterative measurement is. In most situations the bars should remain below the dotted line, indicating that the iterative algorithm is converging reliably. In situations where the laser wavelength is changing rapidly, or the calibration has been perturbed, the bars may exceed the indicated region indicating the reliability of the measured value is reduced.

3.3.1 Time-series measurement

Clicking the *Time-series* button on the lower-left of the window brings up a dialog that shows how the measured wavelength is changing over time (Figure 3.5). This can be beneficial for measuring long-term drifts in laser wavelength, such as diagnosing laser locks.

3.3.2 Scan-range measurement

The time-series feature can also be used to display rapid measurements, where the *measurement interval* is set to zero. This can be useful, for example, to measure the mode-hop free scan range of a tunable laser (Figure 3.6). Note that at the end of the laser scan, the wavelength changes very rapidly and can cause the wavelength to vary non-trivially *during* the camera exposure, which may cause a “jump” in the measured wavelength at this point.

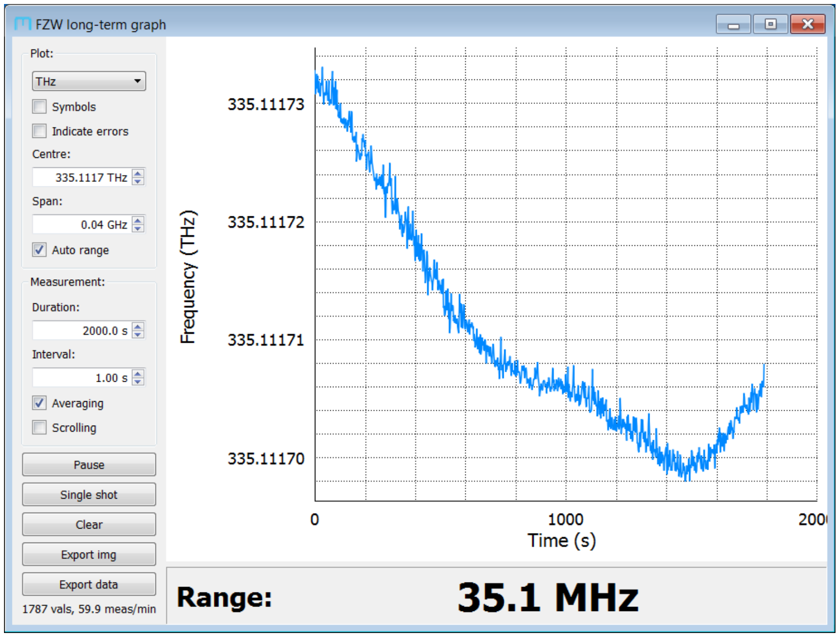


Figure 3.5: The time-series window shows how the wavelength measurement is changing over time, for measuring drift. The graph displays *Duration* seconds of data, with a datapoint collected every *Interval* seconds. When *Averaging* is enabled, the wavelength measurements during each interval are averaged to enhance the measurement precision.

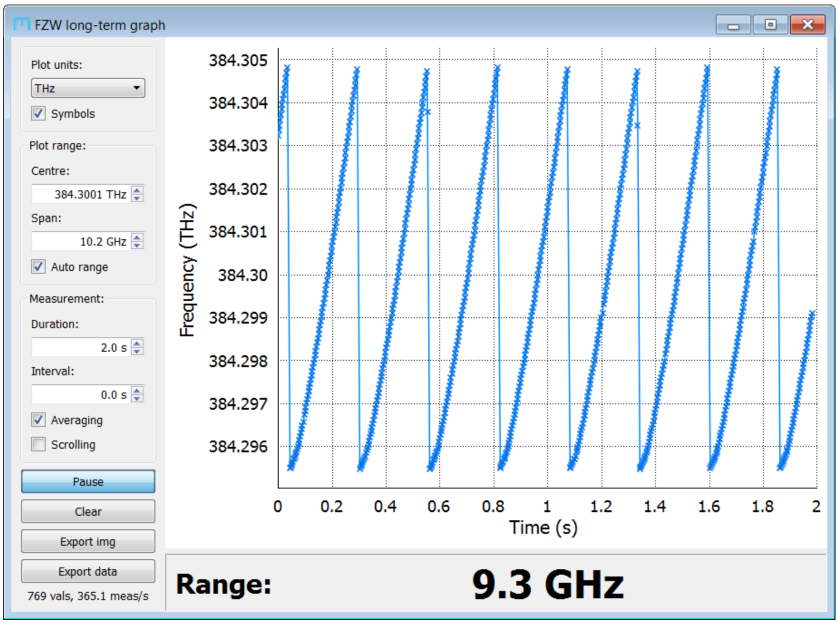


Figure 3.6: When configured for maximum measurement speed, the FZW can be used to measure the mode-hop free scan-range of a laser. Setting the *Interval* to zero ensures measurements are recorded as rapidly as possible, as indicated by the label in the bottom left.

3.3.3 PID configuration

The application also includes a window for adjusting the constants used for the PID control loop (§4.7). This provides a convenient interface for optimising the gain values, and verifying the state of the control loop. When the control loop has saturated at one of its limits, the box will be highlighted in magenta.

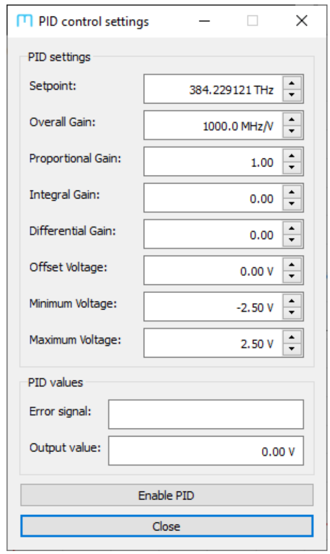


Figure 3.7: Interactive window for adjusting the PID constants, including display of the instantaneous PID error value (in MHz) and the output value (in Volts) for diagnostic purposes.

4. Operation

4.1 Fringe identification and optimisation

The host software includes a prominent display of the interference fringes used to compute the laser wavelength. Understanding the fringe structure is important in ensuring that the wavelength measurement is accurate. The two primary causes of reduced measurement reliability are laser multi-moding, and poor spatial profile of the light emitted by the fibre.

The presence of multiple frequency components during a measurement can change the structure of the interference pattern and cause the measurement to fail. Typically this is evident by the presence of secondary peaks in the fringes, a significant widening of the peak widths, and/or a significant reduction in the amplitude of the fringes compared to the background level (Figure 4.1). Multimode behaviour may be evident in only one of the etalons (Figure 4.2) so it is important to periodically verify the fringe shape.

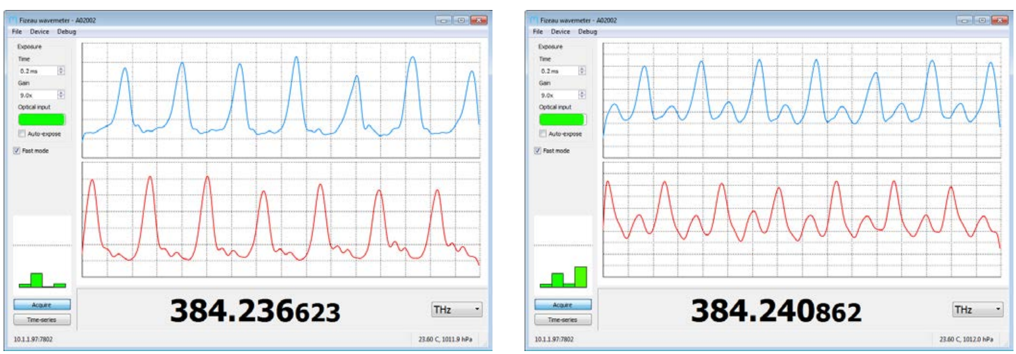


Figure 4.1: Examples of fringes measured with a single-mode laser (left) and multimode laser (right). The presence of secondary peaks and reduction in contrast indicate the laser is not single-mode.

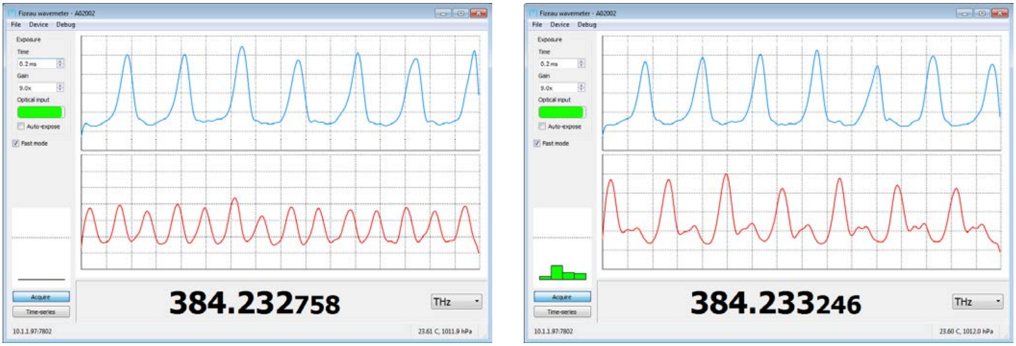


Figure 4.2: A multimoding laser might only be evident in one of the interference patterns. In some circumstances this will be clear from an obvious change in fringe spacing (left), whereas at other times the secondary peaks might be smaller amplitude (right).

Note that while the wavemeter may be able to produce a value for the wavelength of the strongest frequency component of a multimoding laser, the accuracy of this value should not be relied upon.

In many situations, multi-mode optical fibres are convenient for achieving good coupling efficiency quickly. However, they produce a non-Gaussian beam shape that introduces bias and reduces accuracy of the measurement. Single-mode fibres are therefore strongly preferable where accurate measurements are required.

With multimode fibre, the structure of the fringes fluctuates with both the fibre-coupling alignment and mechanical strain on the fibre, as can be seen by fluctuations in the measured wavelength when disturbing the fibre. Wherever possible the fibre should be restrained to the table and the coupling alignment should be optimised to make the peaks as close to equal height as possible (Figure 4.3).

Fibres with very large core diameters (e.g. >100 μm) should be avoided as the increased core size causes distortion in the interference fringes to the point where interpretation of the fringes becomes impossible (Figure 4.4).

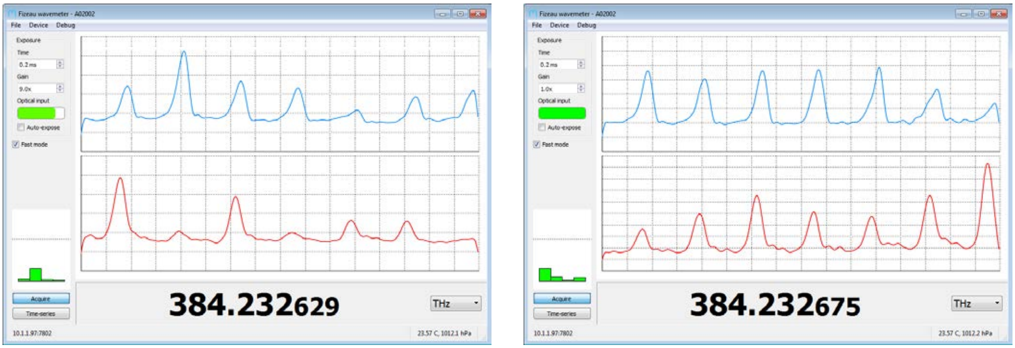


Figure 4.3: Example fringes measured with a 62.5 µm-core fibre demonstrating envelope structure that causes measurement bias (left). Adjusting the input coupler alignment can give more uniform fringe heights (right) and more reliable measurement.

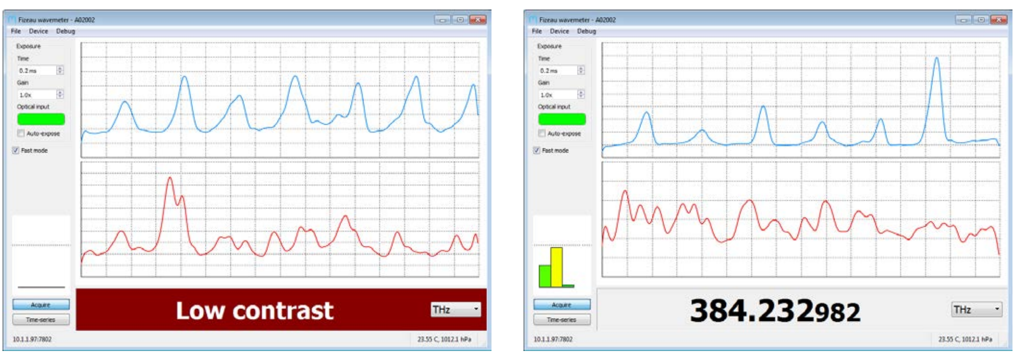


Figure 4.4: Examples of fringes measured with a 200 µm-core fibre. The mode shape makes reliable readout almost impossible (left) although in some situations a low-accuracy measurement can still be achieved (right).

In this scenario the unmeasurable etalons are ignored, and it may still be possible to extract a wavelength estimate with vastly reduced accuracy (~ 20 GHz uncertainty). In some applications this estimate may be sufficient, but smaller core fibres are strongly recommended.

4.2 Auto-exposure algorithm

The FZW has an auto-exposure algorithm that rapidly adjusts the exposure time to match the intensity of the incident beam to prevent over- or under-saturation. The algorithm is generally stable, but assumes that the optical power does not fluctuate much. In situations where the optical power is not constant (such as with pulsed lasers, or ramping lasers with a large bias current) it may be necessary to disable the auto-expose feature.

4.3 Wide and fast modes

The default measurement mode is suitable for most applications and provides a good general-purpose trade-off between measurement speed and accuracy. However, in some situations it may be preferable to deliberately reduce the device accuracy, to increase the measurement rate or reduce susceptibility to unstable or high-linewidth input lasers.

Engaging *fast mode* causes the wavemeter to read only the final etalon, which increases the measurement rate but can make the measurement unable to detect sudden perturbations such as mode-hops.

Engaging *wide mode* prevents the wavemeter reading the longest etalon, which reduces the overall accuracy of the measurement by an order of magnitude, but makes the measurement more robust against sudden changes. Wide mode may be necessary for unstable or high-linewidth lasers, which can otherwise result in “low contrast” errors.

These two options can be enabled simultaneously to achieve the highest possible measurement rate (> 1200 meas/s for short exposure times).

4.4 Pulsed laser measurement

The FZW uses an electronic rolling shutter when reading out the CCD camera to ensure each pixel in the camera is subjected to the laser for an identical exposure time. However, when operating with pulsed lasers this introduces the possibility that the pulse occurs while the shutter is rolling, causing it to be measured by some pixels and not others. Enabling *pulsed* mode changes the camera to a global shutter configuration to prevent this scenario from ocurring.

Note however that global shutter mode is not recommended for CW lasers as it tends to result in distortion from an effective overexposure towards the bottom of the CCD.

4.5 Externally triggered mode

The FZW includes a TTL input for externally-triggering an acquisition. This is particularly useful when measuring pulsed lasers with low repetition rates, which can help ensure that each acquisition captures the same number of laser pulses.

This also permits the auto-exposure algorithm to be used even in pulsed mode, and prevents errors arising from acquisitions occurring without any incident light.

The FZW begins a measurement whenever the TTL input is low. Holding the input low will immediately trigger a second measurement once the first is complete, so it is recommended to hold the input high when not in use.

4.6 Measurement averaging

The FZW is capable of several hundred wavelength measurements per second, which can provide valuable realtime feedback when tuning lasers. Alternatively, these measurements can be automatically averaged to produce higher precision measurements at a slower rate.

The Allan deviation is a useful measure of the improvement achieved by increased averaging, as the influence of measurement noise is reduced but the influence of drift increases. A typical Allan deviation measurement (Figure 4.5) shows that the measurement precision can be improved by up to 250 ms of averaging. The limiting factor which causes drift on longer timescales is small fluctuations in the device temperature (at the 0.05°C level).

The internal averaging can be configured using the `MEAS,AVERAGE` command. Setting the value to zero disables the internal averaging, resulting in instantaneous values being displayed.

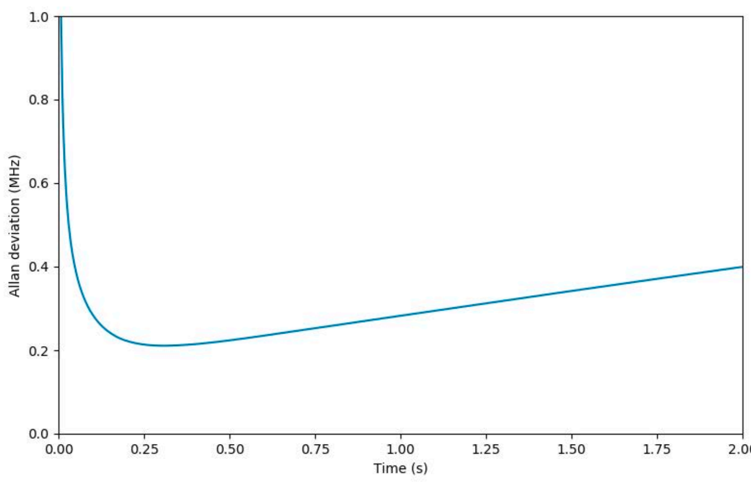


Figure 4.5: Measurement of the Allan deviation of the FZW measuring a locked laser, demonstrating that substantially improved precision can be achieved by averaging over 250 ms.

Note that operating the FZW in environments with poor ambient temperature control may experience much more rapid drift, and the benefit of data averaging is greatly reduced.

4.7 PID control

The FZW includes an SMA output that provides an analog voltage $V(t)$ that can be used for locking a laser at an arbitrary wavelength typically by feeding back to the piezo through the laser controller.

The FZW implements a standard PID algorithm that includes proportional, integral and differential control responses with adjustable gains, as represented by the expression

$$V(t) = G\left[K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt}\right] + V_0,$$

where $e(t) \equiv f(t) - f_0$ is the "error function", the difference between the measured laser frequency and the setpoint frequency (in MHz).

The PID constants are in the range $[-1, 1]$ and G represents an overall gain in MHz/V. These values can be set using the `PID,GAIN` command as shown in the example below, or using the software interface (see §3.3.3).

The range of the analog output is $\pm 2.5\,\mathrm{V}$, with an offset voltage V_0 that may be useful for interacting with some laser controllers. It is recommended to ensure that appropriate minimum and maximum output values be set in accordance with the device being controlled.

```
# define the desired lock point (in THz)
PID,SET,384.22924169
# set the gain to 100 MHz/V
PID,GAIN,100
# define the PID gains
PID,KP,1
PID,KI,0.1
PID,KD,0
# set the PID to average over 100ms
PID,AVERAGE,100
```

```
# set the output range to be 0—2.5V centred at 1.25V
PID,MIN,0
PID,MAX,2.5
PID,OFFSET,1.25
# activate the PID
PID,ENABLE
```

Listing 4.1: Example script to configure the PID controller

The front-panel interface includes a multi-colour LED which indicates the status of the lock at a glance. The indicator is green when the lock is stable, yellow when the lock is engaged but the error signal has not converged to zero, and red when the output has saturated indicating the lock has failed (see also §2.1).

Note that setting $K_p = 1$ and $K_i = K_d = 0$ produces the error signal $e(t)$ on the analog output, which can be used for monitoring purposes, or in combination with external servo controllers.

4.8 Calibration adjustment

The FZW operates over a very wide range of wavelengths (400–1100 nm) and its absolute accuracy over this range is limited by a variety of broadband effects. The FZW does not include an internal calibration source because the inherent stability of the FZW across the full wavelength range is better than the accuracy of compact references such as a neon lamp.

However, often the accuracy of a wavemeter is only critical around a particular wavelength of interest, and it is desirable to improve the calibration of the device around this wavelength, even though this negatively impacts the absolute accuracy at other wavelengths.

To calibrate at a single wavelength, connect a reference laser of stable wavelength to the FZW using a single-mode fibre. The reference laser wavelength must be known to at the least the precision required from calibration. Then access the recalibration function through the “Device” menu of the host software (Figure 4.6) and enter the

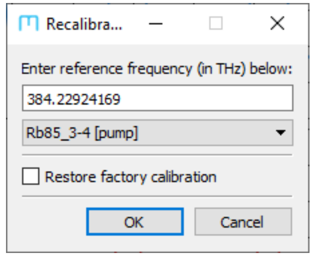


Figure 4.6: The recalibration window of the host software allows correction of the device calibration using a known reference. A standard reference can be selected from the dropdown box, or a custom reference frequency can be entered.

known laser frequency in THz. This calibration correction can also be applied programmatically using the `MEAS,CORRECT` command.

Note that when adjusting the calibration, it is recommended to use a well-known reference (e.g. atomic transition) with an appropriate amount of averaging.

The calibration can also be reverted to the factory-provided calibration by ticking the appropriate box in the software interface, or using the command `MEAS,CORRECT,RESET`.

5. Optical switcher

5.1 Overview

The FSW4 and FSW8 are optional extra components that integrate with the FZW that provide 4- or 8-channels of optical multiplexing, allowing a single wavemeter to be used for monitoring or feedback of up to 8 lasers (Figure 5.1). The optical switcher is only available with FC/APC-connectorisation.

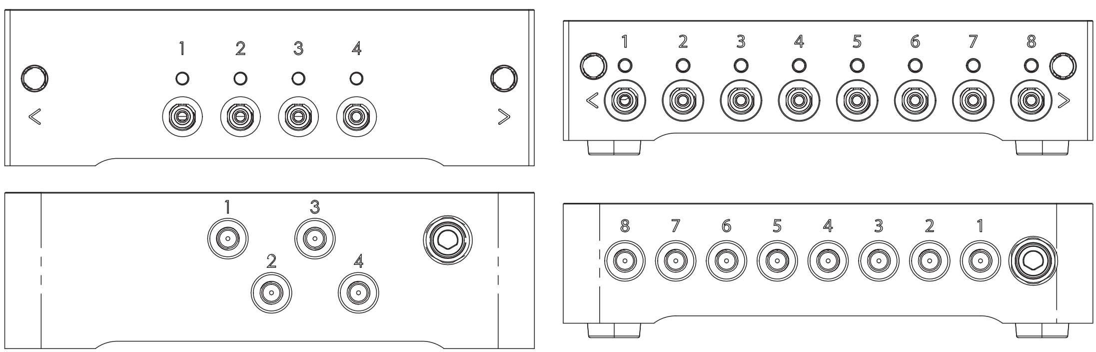


Figure 5.1: FSW4 (left) and FSW8 (right) optical switchers. The front-panels (top) have the fiber inputs and LED indicators, while the back-panels (bottom) have the SMA outputs for monitoring and PID control. Pressing the front-panel buttons cycles between the input fibers.

The switcher can be controller through software commands or with the physical push-buttons, permitting both standalone and automated operation. LEDs on the front indicate the active channel, and separate SMA outputs on the back provide individually-configurable PID outputs for each channel (§5.4).

The switcher has connectors to receive a number of FC/APC input fibers, and a single FC/APC output fiber for connection to the FZW. It has indents on the top for the feet of the FZW, so the two can be carried together as a single unit. Care should be taken to ensure the output fiber is not accidentally sheered as it could break.

5.2 Operation

The FSW4 and FSW8 contain a MEMS mirror arrangement that

5.3 Software UI

When connecting to a FZW that has an optical switcher attached, the interface will show a tabbed view for the different switcher inputs. Names can be assigned to the inputs by double-clicking the tabs. !

5.4 Simultaneous PID

!

A. Specifications

Parameter	Specification
Accuracy	
Measurement range	400 – 1100 nm
Absolute accuracy[1]	<600 MHz
Measurement precision	10 MHz (full-speed), 1 MHz (100-sample average)
Minimum optical power[2]	500 μW (300 meas/s), 10 μW (100 meas/s), 100 nW (10 meas/s)
Maximum optical power	10 mW
Exposure time	100 μs to 1 s
Measurement rate	Up to 350 meas/s
Number of etalons	4
Smallest etalon FSR	7.5 GHz
Electronics	
DC jack power input	+5 V (Rev 1–3) or 9–24 V (Rev4+), as labelled on device
Power usage	< 3 W
Display	Integrated colour LCD screen
Analog output	12-bit DAC output, ±2.5 V range

[1]Absolute accuracy as measured in a temperature-stabilised laboratory environment using a spectrally-narrow laser coupled into single-mode fibre.

[2]Stated optical powers are indicative for 780 nm light; actual optical power limits scales with detector responsivity (Figure A.1).

Parameter	Specification
Interface	
Ethernet	10/100 RJ45
USB	USB2.0 device with USB-B plug
Optical input	FC/PC or FC/APC as labelled on device
Control software	Integrated on-device menu system Windows™ software suite Integrated web server
Language bindings	Examples provided for `python`, `MATLAB`, `LabVIEW`
Mechanical	
Dimensions	W×H×D = 146 × 120 × 81 mm
Weight	1.5 kg

Optical switcher specifications

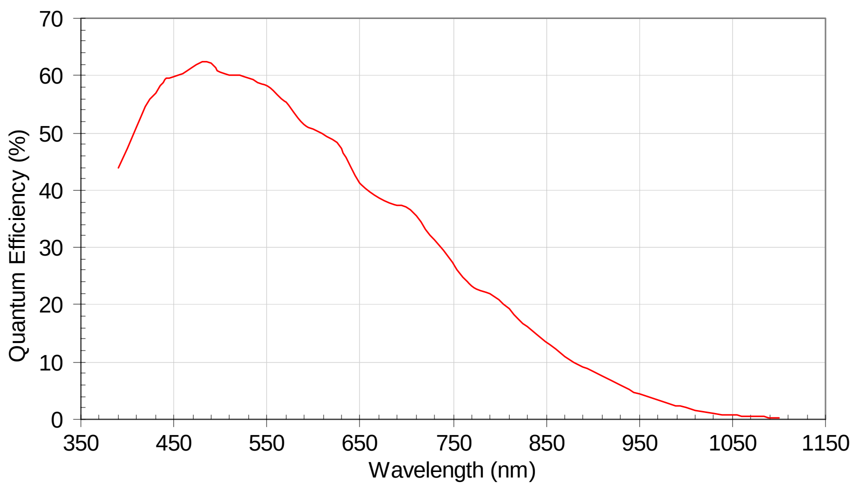


Figure A.1: Typical detector responsivity.

B. Firmware updates

From time to time, MOGLabs will release updates to the device firmware which improve the device functionality. This section contains instructions on how to apply firmware updates to your device using the "Firmware Update Tool" available from the MOGLabs website as part of the host software suite.

WARNING: Do not attempt to communicate with the device while a firmware upgrade is being applied, and do not interrupt an upgrade (or factory reset) in progress.

1. Running the application will display diagnostic information about your device (Figure B.1). Ensure the serial number matches the device.

2. Press the "Select" button to choose a firmware package to use, as downloaded from the MOGLabs website.

3. The package is compared against the currently running version to determine which upgrades are required (Figure B.2). Up-to-date components are shown in green, upgrades are shown in yellow, downgrades in purple and conflicts in red.

4. Click on *Update all* to install all detected upgrades in sequence. Individual components can be installed by clicking the *Upload* option next to each item.

5. The device will reboot after every individual component upgrade, to ensure the upload was successful before moving on to the next component.

6. A dialog box will indicate the upgrade was successful and the device will be ready to use.

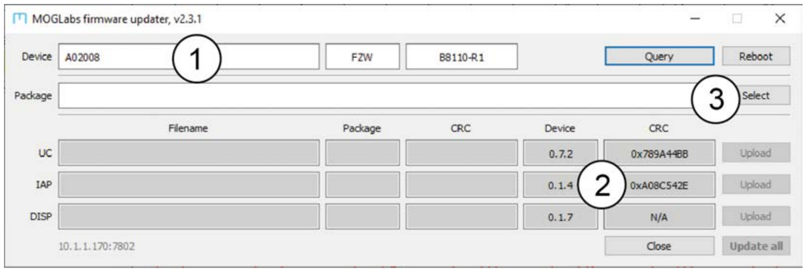


Figure B.1: The firmware update application connected to a FZW unit, showing the device serial number (1) and current firmware versions (2). Click the *Select* button (3) to open a firmware package for upload.

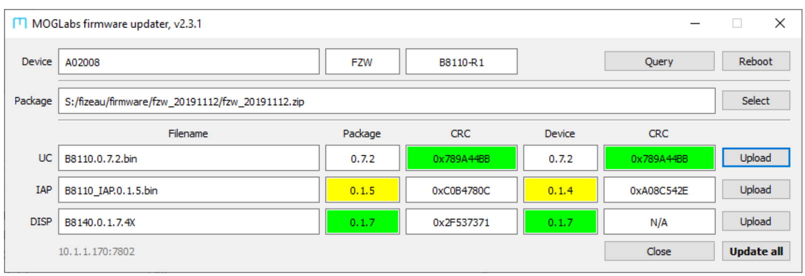


Figure B.2: The firmware update application with a loaded package. The versions running on the device are compared against the selected package, in this instance showing that an update is available for the IAP (yellow) and the other components are up-to-date (green).

C. Command language

The FZW can be controlled over USB via a virtual serial port, or over Ethernet using TCP/IP. The syntax follows a text-based request/reply architecture with messages delimited by CRLF. Failed queries are replied to with the string “ERR” followed by an explanation of the issue. It is strongly recommended to check for the response before sending the next command.

> **Please note:** The command language is being continuously updated across firmware releases to improve functionality and add features. When upgrading firmware, please refer to the most recent version of the manual available at `http://www.moglabs.com`

Some commands accept values with units. The following units are recognised for returning measurements or defining setpoints:

nmv, vac Wavelength in vacuum, in nanometers.

nma, air Wavelength in air, in nanometers as measured within the interferometer. May differ from expected standard temperature and pressure (STP) value due to environmental conditions.

THz Frequency, in terahertz.

wav, pcm Wavenumber, in per centimetre.

C.1 General functions

INFO Report identification information about the unit.

VER Report versions of firmware currently running on device.

Please ensure to include both the `INFO` and `VER` information in any correspondence with MOGLabs.

TEMP Report measured temperatures.

C.2 Display settings

CONTRAST `DISP,CONTRAST[,val]`
Sets the contrast of the display, which is either a percentage value, or an integer between 0 (off) and 15 (full brightness).

SLEEP `DISP,SLEEP[,val]`
Sets the sleep timer of the display, which is the time in seconds after the last button press that the display is dimmed. Setting the timer to zero disables the dimmer behaviour.

C.3 Measurement settings

WAVELENGTH `MEAS,WAVELENGTH[,units]`
`MEAS,WL[,units]`
`MEAS,FREQ`
Returns the most recently measured value of the wavelength, in the specified `units`.

UNITS `MEAS,UNITS[,units]`
Set the default units for measurement readback, as well as the units used by the integrated LCD display.

SAT `MEAS,SAT`
Returns the measurement saturation, which is a number in the range $[0, 100]$ that measures the optical power reaching the detector. Typically the saturation should be in the range 50–90 to ensure enough light for rapid measurement, but with a substantial margin before oversaturating the detector.

CONTRAST `MEAS,CONTRAST`
Returns the measurement contrast, which is a number in the range $[0, 100]$ that measures the fringe quality.

WIDE `MEAS,WIDE[,onoff]`
Enable or disable “wide” measurement mode (see §4.3).

FAST `MEAS,FAST[,onoff]`
Enable or disable “fast” measurement mode (see §4.3).

PULSED `MEAS,PULSED[,onoff]`
Enable or disable "pulsed" measurement mode (see §4.4).

TRIG `MEAS,TRIG[,onoff]`
Enable or disable externally triggered mode, where a measurement will only occur when the associated rear-panel SMA input is low (see §4.5). The special argument keyword `SOFTWARE` will generate a software trigger.

RATE `MEAS,RATE`
Returns the current rate at which wavelength measurements are being calculated, in measurements per second.

AVERAGE `MEAS,AVERAGE[,val]`
Specify the wavelength measurement to average over `val` milliseconds for improved measurement precision at the expense of measurement rate. If `val` is zero, no averaging is performed.

CLEAR `MEAS,CLEAR`
Reset the measurement averaging and internal verification, for use in combination with an external optical switch or shutter.

CORRECT `MEAS,CORRECT,val`
Apply a correction to the device internal calibration using the currently-supplied laser as an absolute reference. The reference value `val` should be specified ***in THz*** and as many significant figures as practical. Perturbing the calibration in this way will improve the absolute accuracy of the device around the reference wavelength, at the expense of the absolute accuracy far from the reference wavelength.

Specify `val` as the string "`RESET`" or "`FACTORY`" will revert the calibration to the factory-provided values.

C.4 Camera settings

AUTO `CAM,AUTO[,value]`
Enable or disable the auto-exposure algorithm to dynamically adjust the exposure time to match the input (see §4.2).

EXPP `CAM,EXP[,value]`
Set/query the camera exposure time to `value` milliseconds. If `value` is specified, the auto-exposure algorithm is disabled unless `value` is the string "`AUTO`".

MAXEXP `CAM,MAXEXP[,value]`
Set/query the maximum permitted exposure time for the auto-expose algorithm in milliseconds. When swapping optical fibers or blocking the laser, the FZW will typically adjust towards its maximum exposure time, and then it will take some time to adjust back when the light is coupled back in. Reducing the maximum exposure time can improve the device's apparent responsiveness in this situation.

GAIN `CAM,GAIN[,value]`
Set/query the camera analog gain, which is an integer in the range $[8, 126]$. Increasing the gain allows the exposure time to be reduced for the same optical power, enabling an increased measurement rate. The effective increase in measured counts is this value divided by 8.

C.5 Optical switch

OPTSW `OPTSW[,value]`
Query the currently selected optical switch input, or change which is the active input. Many device settings (e.g. exposure time, PID parameters) are stored on a per-input level, allowing them to be separately optimised.

C.6 PID control

ENABLE `PID,ENABLE`
Activate the PID controller, producing the control voltage on the SMA output.

DISABLE `PID,DISABLE`
Deactivate the PID controller, setting the output voltage to 0 V.

STATUS `PID,STATUS`
Returns the current status of the PID controller.

SETPOINT `PID,SET[,value]`
Set/query the PID controller setpoint frequency, ***in THz***.

GAIN `PID,GAIN[,val]`
Set/query the overall gain used for the PID controller in MHz/V.

KP, KI, KD `PID,KP[,val]` or `PID,KI[,val]` or `PID,KD[,val]`
Set/query the PID coefficients K_p, K_i and K_d, which are floating-point values in the range $[-1, 1]$.

OFFSET `PID,OFFSET[,val]`
Set/query the constant DC offset on the analog output, in volts.

MIN `PID,MIN[,val]`
Set/query the minimum output voltage of the PID controller.

MAX `PID,MAX[,val]`
Set/query the maximum output voltage of the PID controller.

VALUE `PID,VALUE`
Returns the current output voltage of the PID controller for monitoring purposes.

D. Communications

The FZW can be connected to a computer by USB or ethernet (TCP/IP) and the software package mogfzw (chapter 3) provides interactive functionality. Device control can also be integrated into existing control software following the protocol below using the commands in Appendix C.

D.1 Protocol

Device communication follows a query/response protocol using CRLF-terminated ASCII strings. Statements are either *commands* or *queries* depending on whether they cause an action to occur. A command will always respond with OK or ERR as appropriate.

It is strongly recommended that all software should wait for this response and check for success before continuing. The python and LabVIEW bindings provided take care of buffering and error checking automatically.

The *MOGLabs Commander* application (mogcmd) is available as part of the mogfzw package and provides a convenient interface for sending commands and receiving responses (Figure D.1).

D.2 TCP/IP

The FZW can be accessed over ethernet via the IPv4 protocol. When ethernet is connected, the FZW 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 (for example, 10.1.1.190:7802), showing the address and port number for communicating with the device.

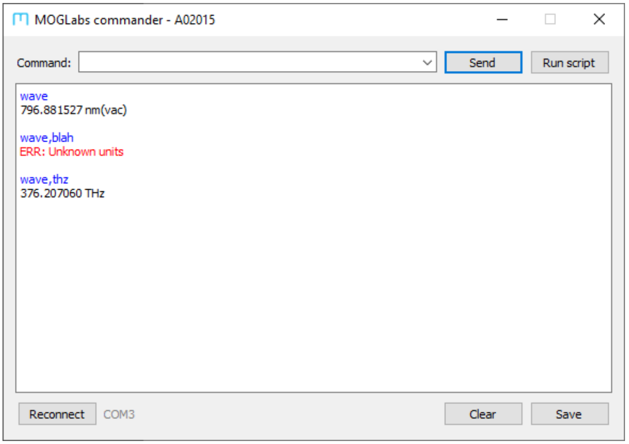


Figure D.1: The `mogcmd` application, showing successful and unsuccessful commands and queries.

D.2.1 Changing IP address

Depending on your network settings you may need to manually set the IP address. This is most easily done via the front-panel interface as detailed below. Once configured, these settings are stored in the non-volatile memory of the unit and will be recalled in future.

1. From the main menu, open Options > Ethernet Settings.
2. Select *Static IP* and use the buttons to set the IP address of the device as required.
3. Select *Gateway* and set the gateway address as required.
4. Select *DHCP* and set to OFF.
5. Select *Restart ethernet* and press the OK button.
6. The new IP address will be displayed in the display footer.

In some situations it may be necessary to power-cycle the device to propagate ethernet changes.

D.3 USB

The FZW can be directly connected to a host computer using a USB cable. The device will appear as a Virtual COM port, which behaves like an RS232 connection. The required STM32 Virtual COM Port Driver (VCP) device driver for the Windows™ operating system is available from the MOGLabs website. After installation, the FZW will appear as a COM port.

To determine the port number of the device, go to Device Manager (Start, then type `Device Manager` into the Search box). You should see a list of devices including `Ports` (Figure D.2).

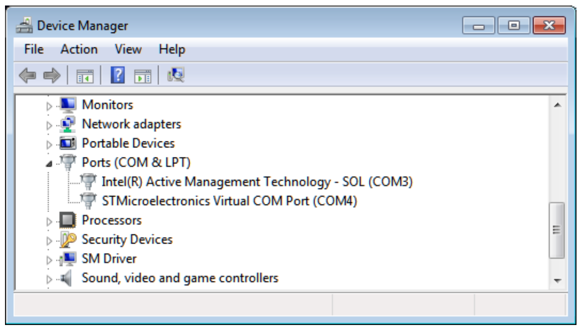


Figure D.2: Screenshot of Device Manager, showing that the FZW can be communicated with using COM4. The port number might change when plugging into a different USB port, or after applying a firmware update.

The device can be identified as a COM port with the following name,

`STMicroelectronics Virtual COM Port (COMxx)`

where `xx` is a number (typically between 4 and 15). In the example above, the device was installed as COM4.

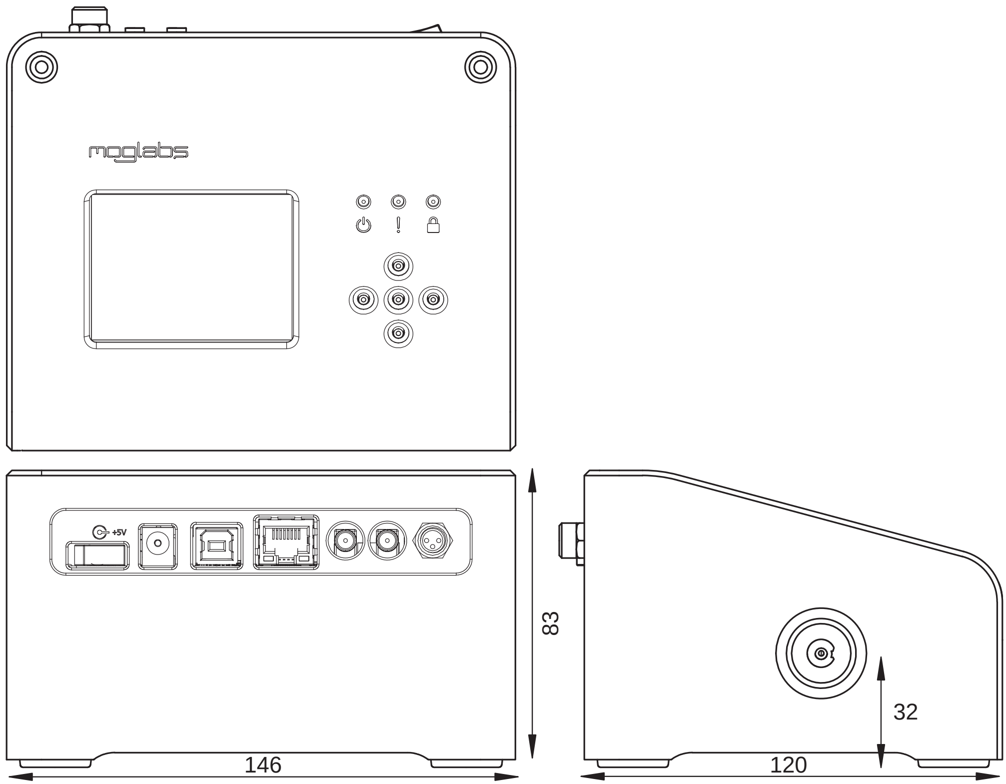
Note that if the port appears in Device Manager with a different name, then the driver was not successfully installed. If this occurs, disconnect the device from the host computer, reinstall the VCP driver (see below), then reconnect the USB cable.

D.3.1 USB driver

If you do not see a virtual COM port under `Ports` in the `Device Manager` then manually install the USB driver, which is available from the MOGLabs website. More detailed instructions are also available on the website.

1. Ensure the wavemeter is **disconnected** from the computer.
2. Run the 32-bit or 64-bit USB driver setup program from the package as appropriate for your computer system (note that all modern computers are 64-bit).
3. Reconnect the wavemeter using the USB cable. The device driver will be activated, which may take up to a minute.
4. The device should be installed as an `Virtual COM Port` as described above.
5. Run the `mogfzw` host application to verify that the detection was successful.

E. Dimensions



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