Limitation of Liability

MOG Laboratories Pty Ltd (MOGLabs) does not assume any liability arising out of the use of the information contained within this manual. This document may contain or reference information and products protected by copyrights or patents and does not convey any license under the patent rights of MOGLabs, nor the rights of others. MOGLabs will not be liable for any defect in hardware or software or loss or inadequacy of data of any kind, or for any direct, indirect, incidental, or consequential damages in connections with or arising out of the performance or use of any of its products. The foregoing limitation of liability shall be equally applicable to any service provided by MOGLabs.

Copyright

Copyright © MOG Laboratories Pty Ltd (MOGLabs) 2017 – 2019. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of MOGLabs.

Contact

For further information, please contact:

MOG Laboratories P/L
49 University St
Carlton VIC 3053
AUSTRALIA
+61 3 9939 0677
info@moglabs.com

MOGLabs USA LLC
419 14th St
Huntingdon PA 16652
USA
+1 814 251 4363
www.moglabs.com
Contents

1 Introduction ........................................... 1
   1.1 How it works ........................................ 1
   1.2 Features ............................................ 2
   1.3 Getting started ...................................... 3

2 Connections and controls ................................. 5
   2.1 Front panel interface ............................... 5
   2.2 Rear panel controls and connections .............. 8

3 User interface ........................................ 9
   3.1 On-board UI ........................................ 9
   3.2 Web UI ............................................. 10
   3.3 Software UI ......................................... 11

4 Operation ........................................... 15
   4.1 Fringe identification and optimisation ............ 15
   4.2 Measurement averaging ............................. 18
   4.3 PID control ......................................... 19
   4.4 Calibration adjustment ............................ 20

A Specifications ....................................... 23

B Firmware updates ..................................... 25

C Command language .................................... 27
   C.1 General functions ................................. 27
   C.2 Display settings .................................. 28
   C.3 Measurement settings ............................. 28
   C.4 Camera settings .................................. 29
   C.5 PID control ........................................ 30
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.](image)

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.
1.3 Getting started

The FZW is powered from a single +5 V supply, either 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.

A device driver is required to control the FZW through the USB serial port interface. This driver is the same as used by other MOGLabs products, and is available as part of the host software, which can be downloaded from the MOGLabs website. No driver is required for Ethernet control, but if the local network does not support DHCP then the network configuration must be entered manually using the menu system (§2.1.1).

The FZW wavemeter accepts light through an FC/PC fibre input port on the side of the device. Free-space beams cannot be used, and other types of fibre connectors (such as FC/APC) cannot be used reliably. In labs where FC/APC is preferred, a fibre that is connectorised with FC/APC on the input and FC/PC on the output should be used.

Single-mode fibres are strongly preferred, although small-core multimode fibres (up to 62.5 µm) can be used at the expense of reduced accuracy.\(^1\) Typically the FZW only needs a few microwatts to operate, so high coupling efficiency is not required.

Both on-board display and host software provide an indicator showing the saturation, which is a measure of the amount of light reaching the detector (Figure 1.2). The auto-exposure algorithm will quickly tune 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, where the laser output power tends to fluctuate rapidly and confuse the auto-expose algorithm.

\(^1\)Absolute accuracy specifications are only valid when using single-mode fibres.
Chapter 1. Introduction

Figure 1.2: Both the built-in wavemeter display (left) and host software (right) provide saturation indicators that measure the optical power reaching the detector.

Once coupled, the fringes should be inspected for correct structure to ensure the measurement is reliable. As explained in §4.1, the fringes should have high contrast and there should be no secondary peaks present.

The FZW can be affected by changes in environmental conditions, so 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 the formation of thermal gradients. Typically the FZW will reach thermal equilibrium within 10 minutes of being turned on.
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.](image)

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.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Colour</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWR</td>
<td>Off</td>
<td>Unit is powered off</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>Normal operation</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>Firmware update mode</td>
</tr>
<tr>
<td>ERR</td>
<td>Off</td>
<td>No measurement in progress</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>Normal operation</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>Measurement error</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>Critical device error</td>
</tr>
<tr>
<td>LOCK</td>
<td>Off</td>
<td>PID/analog output disabled</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>PID locked</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>PID engaged but not locked</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>PID output saturated</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>Analog output error</td>
</tr>
</tbody>
</table>

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.

![Settings Menu](image)

![Device Options](image)

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

Within the menu system, the up and down buttons control the selected item. Pressing OK on a selected item activates it to allow 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 a 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.

![Ethernet Settings](image)

**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

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

**Power switch**  Switches the unit on/off.

**DC supply**  A 2.1mm centre-positive barrel-jack connector for supplying +5V to 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 device connector for supplying power and/or enabling computer control through the serial interface. 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 and control, 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 §4.3). 12-bit resolution with ±2.5 V output range.
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.

![Fizeau Wavemeter Display](image)

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).
Chapter 3. User interface

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.
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.](image-url)
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).
4.1 Fringe identification and optimisation

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 (\(\sim 20\) GHz uncertainty). In some applications this estimate may be sufficient, but smaller core fibres are strongly recommended.

### 4.2 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

![Allan Deviation Graph](image)

**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.
causes drift on longer timescales is small fluctuations in the device
temperature (at the 0.05°C level) that cannot be corrected by the
temperature-compensation algorithm.

The internal averaging can be configured using the MEAS,AVERAGE
command. Setting the value to zero disables the internal averaging,
causing the instantaneous measurement values to be displayed.

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.

### 4.3 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 pro-
portional, 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. The range of the analog
output is $\pm 2.5$ V, with an offset voltage $V_0$ that may be useful for
interacting with some laser controllers.

```markdown
# 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
```
Chapter 4. Operation

Listing 4.1: Example script to configure the PID controller

| PID,KI,0.1                  |
| PID,KD,0.001               |
| # set the PID to average over 100ms |
| PID,AVERAGE,100            |
| # set the offset voltage to 1V |
| PID,OFFSET,1.0             |
| # activate the PID         |
| PID,ENABLE                 |

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.

4.4 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 least the precision required from calibration. Then access the recalibration function.
4.4 Calibration adjustment

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.

through the “Device” menu of the host software (Figure 4.6) and enter the 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.
A. Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
</tr>
<tr>
<td>Measurement range</td>
<td>400 – 1100 nm</td>
</tr>
<tr>
<td>Absolute accuracy&lt;sup&gt;1&lt;/sup&gt;</td>
<td>600 MHz</td>
</tr>
<tr>
<td>Measurement precision</td>
<td>10 MHz (full-speed), 1 MHz (100-sample average)</td>
</tr>
<tr>
<td>Minimum optical power&lt;sup&gt;2&lt;/sup&gt;</td>
<td>500 µW (300 meas/s), 10 µW (100 meas/s), 100 nW (10 meas/s)</td>
</tr>
<tr>
<td>Maximum optical power</td>
<td>10 mW</td>
</tr>
<tr>
<td>Measurement rate</td>
<td>Up to 350 meas/s</td>
</tr>
<tr>
<td>Number of etalons</td>
<td>4</td>
</tr>
<tr>
<td>Smallest etalon FSR</td>
<td>7.5 GHz</td>
</tr>
</tbody>
</table>

| **Electronics**             |                                                    |
| Power supply                | +5V (via USB or DC barrel jack)                    |
| Power usage                 | < 3 W                                              |
| Display                     | Integrated colour LCD screen                       |
| PID feedback                | 12-bit DAC output, ±2.5 V range                   |
| Exposure time               | 100 µs to 1 s                                      |

<sup>1</sup>Absolute accuracy as measured in a temperature-stabilised laboratory environment using a spectrally-narrow laser coupled into single-mode fibre.

<sup>2</sup>Stated optical powers are indicative for 780 nm light; actual optical power limits scales with detector responsivity (Figure A.1).
Appendix A. Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interface</strong></td>
<td></td>
</tr>
<tr>
<td>Ethernet</td>
<td>10/100 RJ45</td>
</tr>
<tr>
<td>USB</td>
<td>USB2.0 device with USB-B plug</td>
</tr>
<tr>
<td>Optical input</td>
<td>FC/PC-connectorised fibre</td>
</tr>
<tr>
<td>Control software</td>
<td>Integrated on-device menu system</td>
</tr>
<tr>
<td></td>
<td>Windows™ software suite</td>
</tr>
<tr>
<td>Language bindings</td>
<td>Examples provided for python, MATLAB, LabVIEW</td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>W×H×D = 146×120×81 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1.5 kg</td>
</tr>
</tbody>
</table>

*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.
Appendix B. Firmware updates

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.

**RATE**  
`MEAS,RATE`  
Returns the current rate at which wavelength measurements are being calculated, in measurements per second.
**C.4 Camera settings**

**AVERAGE** MEAS,AVERAGE[,val]
Specify the wavelength measurement to average over val milliseconds for improved measurement precision. 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.

**EXP** 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”.

**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.
C.5 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.

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