S-Fifteen Instruments Pte. Ltd. (Singapore)

EPPS-O

Entangled Photon Pair Source (O-Band)

USER MANUAL
Version 2

Contents

1 Safety 4
1.1 Laser Classification and Safety 4
1.2 Electrical safety 4

2 Description 5
2.1 Introduction 5
2.2 Shipping List 6
2.3 Connectors 8
2.4 Operating Conditions 8

3 Setup and Operation 9
3.1 Before Starting 9
3.2 Power 9
3.3 USB Connection 9
3.4 Fiber Coupling 12
3.5 Operation 13
3.6 First measurements 14

4 Maintenance 16
4.1 Connector Handling 16
4.2 Alignment 16

5 Troubleshooting 19

6 Specifications 21

7 Mechanical Drawing 22

Changelog

October 2023 Revision 2:

- Revised Mechanical Diagram
- Updated Specifications Table.

1 Safety

Please note the following safety considerations.

1.1 Laser Classification and Safety

The EPPS is classified as a Class 1 laser. The internal laser however is rated Class 3B (up to 35 mW at 660 nm). Do not attempt to remove the cover without appropriate laser safety eye protection and proper handling of laser and optical devices.

☞ Warning: Optical alignment and laser operation should only be performed by trained and qualified professionals.

1.2 Electrical safety

As with any electronic devices, the EPPS is susceptible to high voltage discharges. Ensure that the mains powering the power adaptor is protected from surges.

2 Description

The Entangled Photon Pair Source (EPPS-O) is a compact source of O-band polarization-entangled photon pairs based on a linear beam displacement interferometer described in [Fiorentino and Beausoleil, 2008] and [Lohrmann et al., 2020]. It uses a 660 nm narrow linewidth diode to pump a PPKTP crystal in Type-0 configuration to generate photon pairs centered at 1320 nm.

2.1 Introduction

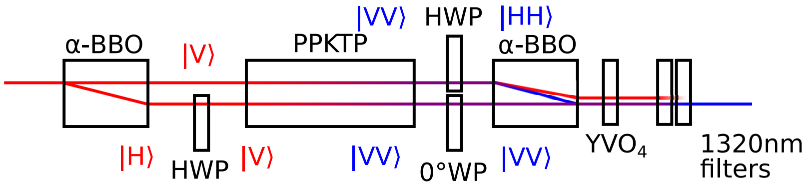

Figure 2.1: Top view of main part of the setup. The first α-BBO splits the pump into two paths which creates vertically polarized photon pairs in the PPKTP. The polarization in one arm is rotated and the two down-converted paths are recombined with the second α-BBO. The YVO$_4$ compensates for phase difference between the two paths and the filters block out the pump.

The main setup of the EPPS source is shown in Figure 2.1. The state that comes out is

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|HH\rangle_{AB} + \mathrm{e}^{i\Delta\varphi}\,|VV\rangle_{AB}\right), \tag{2.1}$$

The alignment of the optical elements are critical to achieve a phase as close to $\Delta\varphi = 0, \pi$ after which they are glued in place. The entangled photon pairs are then separated with a fiber-based wavelength division multiplexer (WDM) into $\lambda_A < 1317.5\,\mathrm{nm}$ and $\lambda_B > 1322.5\,\mathrm{nm}$.

Because the fiber experience birefringence that distorts the polarization, the polarization rotations in the fiber needs to be compensated. This procedure is described in Section 3.6.

2.2 Shipping List

The EPPS is shipped with the following items:

- EPPS source
- 12V DC supply (>3A) with a screw-on connector and C13 socket (mains power cable not included)
- Extra bare screw-on connector for 12V supply
- 2m USB Cable with ferrite beads
- Set of two 10mm PBS holders for alternative polarization compensation (PBS not included)
- Calibration sheet, extra product sticker and warranty.
- This Manual

Figure 2.2: S-Fifteen Instruments' EPPS-O in shipping case with accessories.

2.3 Connectors

The EPPS has the following connections

- 12V DC input Barrel Connector Jack 2.5mm ID, 5.5mm OD(PCL712AS)
- USB 2.0 Type-B socket
- FC/PC connector for signal photons ($\lambda < 1317.5\,\mathrm{nm}$)
- FC/PC connector for idler photons ($\lambda > 1322.5\,\mathrm{nm}$)

☞ Before connecting any fibers to the connectors, check that the fiber connector is clean.

☞ If using a home-made 12V supply, ensure that the polarities connected to the screw-on connector are correct. Refer to Section 3.2.

2.4 Operating Conditions

To achieve the best performance, the EPPS should be operated in a laboratory environment with ambient temperature 20 – 25 °C, stabilised to within $\Delta T < 2\,\mathrm{K}$. When unpacking for the first time, avoid large temperature shocks to the EPPS. Allow the package to achieve room temperature by letting it sit for ~1 hour if there is a large temperature gradient.

The relative humidity in the room should be non-condensating.

3 Setup and Operation

3.1 Before Starting

The EPPS should be placed on a flat stable surface before operation. The EPPS should also be secured to prevent accidental displacement, either by using the M4 screw holes provided along the long edges, or using right-angled clamps. Leave at least 2 – 5 cm on the side of the EPPS with the fiber couplers, to reduce sharp bends on the fiber.

The top cover is secured to the EPPS via six screws along the long edges. These screws should remain accessible in the event the top cover needs to be removed. See Section 7 for the mechanical drawing.

3.2 Power

The EPPS requires a 12V (3A) DC power supply with +ve polarity in the center pin. If using a different supply from the one provided, it should be quiet with a maximum ripple noise of 120 mV at full load.

Connect DC power first before connecting USB cable.

3.3 USB Connection

A USB connection to a PC is needed for switching on and monitoring the EPPS. The EPPS registers itself as a serial device (USB ACM) named “SPDC Driver”. Once connected (with 12 V supplied), the EPPS will list itself as either one of the following devices

- `COM*` in a Windows OS,
- `/dev/ttyACM*` in a Linux/Unix OS,
- `/dev/tty.usbmodem*` in a Mac/BSD OS,

where `*` represents a number assigned by the OS to the device. An additional symbolic link will also be registered in a Linux/Unix environment pointing to the target device, as `/dev/serial/by-id/*SPDCDriver*`.

Any software that can open a serial connection is able to communicate with the EPPS, e.g. `minicom`. The built-in commands are case-insensitive and are listed in Table 3.1. Commands can be terminated either by `\r\n`, `\n`, or `;`.

Table 3.1: List of available commands

Serial Communication Commands	
*IDN?	Returns device identifier.
*RST	Resets device.
PVOLT <value>	When temperature control loops are turned off, sets the voltages for the Laser Peltier element.
HVOLT <value>	When temperature control loops are turned off, sets the voltages for the crystal heater.
HVOLT?	Queries instantaneous crystal heater voltage.
PVOLT?	Queries instantaneous Peltier voltage
HTEMP?	Queries instantaneous temperatures at crystal heater
PTEMP?	Queries instantaneous temperatures at Laser Peltier
LCURRENT <value>	Sets the nominal laser diode current (in mA)
LCURRENT?	Queries the nominal laser diode current (in mA)
ON	Switches laser diode on according to the set current.
OFF	Switches laser diode off.
HSETTEMP <value>	Sets crystal heater temperature target (in Celsius)
HSETTEMP?	Queries crystal heater temperature target (in Celsius)
HRATE <value>	Sets the heater target ramp rate in K/s. For <value>=0, a change of HSETTEMP is instantaneous.
HRATE?	Sets or queries the heater target ramp rate in Kelvin/sec.
HTARGET?	Queries the instantaneous target temperature for the heater control loop, determined by HRATE and HSETTEMP.
HCONSTP <value>	Sets the proportional constant for the crystal heater loop in units of V/K.
HCONSTI <value>	Sets the integral constant for the crystal heater loop in units of V/K/s.
HCONSTD <value>	Sets the differential constant for the crystal heater loop in units of V s/K.
HLOOP <value>	Closes (value!=0) or opens (value=0) the crystal heater control loop.

Serial Communication Commands	
HCONSTP?	Queries the proportional constant for the crystal heater.
HCONSTI?	Queries the integral constant for the crystal heater.
HCONSTD?	Queries the differential constant for the crystal heater.
HLOOP?	Queries the status of the control loop for the crystal heater.
PSETTEMP <value>	Sets the laser Peltier temperature target (in Celsius)
PSETTEMP?	Queries the laser Peltier temperature target (in Celsius)
PCONSTP <value>	Sets the proportional constant for the laser Peltier loop in units of V/K.
PCONSTI <value>	Sets the integral constant for the laser Peltier loop in units of V/K/s.
PCONSTD <value>	Sets the differential constant for the laser Peltier loop in units of V s/K
PLOOP <value>	Closes (value!=0) or opens (value=0) the laser Peltier control loop.
PCONSTP?	Queries the proportional constant for the laser Peltier.
PCONSTI?	Queries the integral constant for the laser Peltier.
PCONSTD?	Queries the differential constant for the laser Peltier.
PLOOP?	Queries the status of the control loop for the laser Peltier.
HLIMIT <value>	Sets the limit for the crystal heater voltage.
HLIMIT?	Queries the limit for the crystal heater voltage.
PLIMIT <value>	Sets the limit for the laser Peltier voltage.
PLIMIT?	Queries the limit for the laser Peltier voltage.
LLIMIT <value>	Sets the limit for the laser diode current.
LLIMIT?	Queries the limit for the laser diode current.
POWER <value>	Sets the power converter enable lines. (value=0) disables all lines. (value=1) enables the peltier and crystal heater converters. (value=2) enables the -5V laser power converter. (value=3) enables both.
POWER?	Queries the power converter enable lines. Value 2 enables the -5V converter, value 1 enables the peltier and heater converters.
SAVE	Saves the current settings into the EEPROM.
HELP	Print this help text.

A Python wrapper library[1] to communicate with the device is also available in S-Fifteen's GitHub repository. The minimal set of commands to initialize the EPPS can be found in Section 3.5.

3.4 Fiber Coupling

The output terminator of the internal wavelength-division multiplexer (WDM) is connected to a pair of FC/PC couplers. Remove the fiber connector dust caps before connection. It is recommended to store them safely, and to cover the couplers when not in use for protection of the internal fiber tips.

☞ Do not use FC/APC (Angled physical contact) fiber connectors as this will damage the surface of the connectors.

Use a SMF-28 fiber for minimal insertion loss. Ensure that the fiber tips are clean and free from debris before connecting to the EPPS. Refer to Section 4.1 for more details on connector handling.

---

[1] `https://github.com/s-fifteen-instruments/pyS15/blob/master/S15lib/instruments/spdc_driver.py`

3.5 Operation

After supplying power to the EPPS, connect the USB cable and check that the USB device registers itself on the PC (see Section 3.3). Using any serial communication software (e.g. putty, minicom, hyperterminal, ArduinoIDE, etc.), send `*IDN?` to verify that device is connected and responding.

Minimal code

The minimum code to switch on the EPPS with the preset PID constants is

```
POWER 3; PLOOP 1; HLOOP 1
SAVE
LCURRENT?
 .000
ON; LCURRENT 70
LCURRENT?
 69.917
```

The heating of the crystal is ramped up to the set temperature once the device is powered on via the `HRATE` command - the ramp and actual temperature can be monitored with `HTARGET?` and `HTEMP?` respectively.

Laser diodes have finite lifetime, especially when operated at the maximum operating current. To extend the operation of the EPPS, we suggest switching off the diode if unused for extended periods of time with

```
OFF; POWER 1
```

Switching on is correspondingly performed with

```
POWER 3; ON
```

For transportation or long term shutdown, the laser peltier and crystal heater should additionally be switched off with

```
OFF; LCURRENT 0
HLOOP 0; HVOLT 0
PLOOP 0; PVOLT 0
POWER 0
SAVE
```

For the equivalent commands in Python, refer to S-Fifteen's GitHub repository[2].

---

[2] Address can be found on page 12.

3.6 First measurements

To perform a first coincidence measurement of photon pairs, the following devices are necessary:

1. Two single photon detectors for the 1320 nm photons,
2. Two sets of SMF-28 fibers to couple the photons from the EPPS to the single photon detectors,
3. A time tagging unit to measure time correlation of detection events between the two detectors.

Coincidence measurement

The simplest measurement is that of coincidence events between the two detectors. When the EPPS has just been switched on, both the crystal and laser temperature need a few minutes to settle to the set values and thus the coincidence rate may vary until the temperature has stabilised.

Verify that the coincidence rate P is close to that specified in the calibration sheet after accounting for detector efficiencies, singles rate and coincidence window via Equation 3.1

$$P = \frac{C - S_{d1} S_{d2} \Delta t}{\eta_{d1} \eta_{d2}}, \tag{3.1}$$

where C is the measured coincidence rate between the two detectors, S_d is the singles rate on each detector, η_d is the corresponding detector efficiency, and Δt is the width of the coincidence window.

Visibility measurement

Measuring visibility for the EPPS is a bit more involved. The following additional devices are necessary:

1. Polarization rotators to compensate for polarization rotations in the fiber, either fiber-based (e.g. fiber polarization controllers, in-line or with paddles) or free space (e.g. Quarter-Half-Quarter waveplates, liquid crystal variable retarders),
2. Two polarization analysers capable of projecting single photons into the Horizontal/Vertical and Diagonal/Anti-diagonal polarization bases (e.g. half waveplate - polarizer pair, rotatable linear polarizers). These analysers should have a good extinction ratio (>200:1) across the span of the output photon wavelengths (1270–1320 nm and 1320–1370 nm)

☞ Before continuing any measurements here, all connected fibers should be firmly secured to prevent additional unwanted polarization rotations after compensation.

The goal is to compensate for polarization rotations in the fiber, such that the output from each port are identical up to a rotation of $n\pi$ phase shift[3] just before the polarization analysers.

For a simple well defined linearly polarized beam, it is sufficient to rotate the polarization analyser and measure the intensity as a function of the polarization angle to do a visibility measurement. This is insufficient for an EPPS since only coincidence measurements are well defined[4], which are obtained by projecting photons from one port to the desired polarization state (e.g. horizontal or diagonal) and sending photons from the other port to the analyser. If these two paths are not compensated[5], the visibility will be low.

Compensation can be performed by sitting at the configuration with maximum/minimum coincidence rates and tuning the polarization rotaters towards increasing visibility. This relies on the existing entanglement of the EPPS output. This needs to be done iteratively in both the HV and DA bases, until convergence to a state where the visibilities in all four (H, V, D, A) projections are similarly high (>96% after correcting for accidentals), i.e. corresponding to Equation 2.1 after compensation.

Alternatively, Section 4.2 details a different compensation method, should convergence to high visibility not occur.

---

[3] For odd n, the notations for Diagonal (+45°) and Anti-diagonal (-45°) are swapped.

[4] Measuring the photon counts vs polarization angle on one arm should give a flat curve.

[5] Theoretically only one path needs to be compensated, but it is often easier to compensate for each path separately.

4 Maintenance

4.1 Connector Handling

Fiber patch cables and the connector tips should be clean before a connection is made. Fiber tips can be cleaned with a standard optical fiber cleaner or if unavailable, lens cleaning paper and solvent. A fiber optical microscope is a convenient tool to verify cleanliness.

4.2 Alignment

The EPPS has been carefully aligned and secured with epoxy to ensure stable performance. There is a possibility of hard knocks causing misalignment in the optical coupling, resulting in lower than expected photon count rates.

☞ Before doing any realignment, confirm that any low count rates are not due to wrong settings, faulty devices, detector saturation, etc. Refer to Table 5.1 for more information.

The simplest and most probable cause of low counts is a misalignment of the coupling mirrors. The top cover of the EPPS needs to be removed to access the adjustment screws of the mirror seen in Figure 4.1. The locking screws need to be released before the mirror can be adjusted, which may induce a slight change in optical coupling.

Do the standard walking the beam procedure for increasing the coincidence signal by alternating between pairs of pitch and yaw screws. We recommend starting with the yaw screw that steers the beam in the horizontal plane. If the coincidence signal is low, try increasing the integration time, or use the photon singles rate for ab-initio alignment (note however that the alignment for maximum singles rate does not necessarily correspond to that for the maximum pair rate nor the pairs to singles ratio).

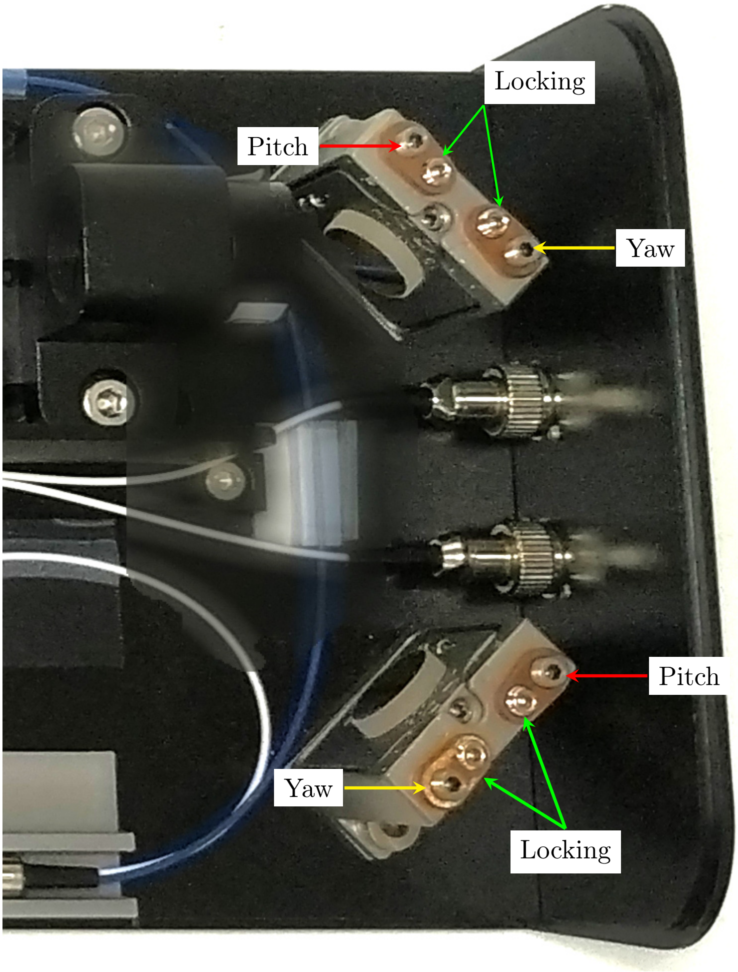

Figure 4.1: Top view of the EPPS coupling mirrors with the top cover removed. The screws accept 1.5mm hex drivers.

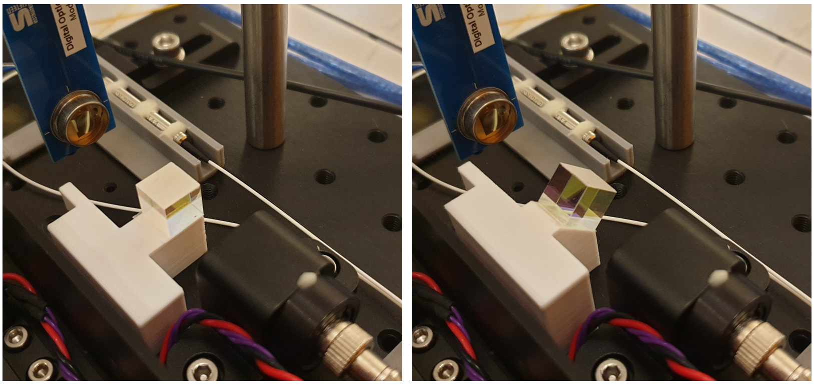

Figure 4.2: Setup for alternative fiber compensation in the EPPS, with light from the fiber coupler incident on polarizing cubes at H/0° (left) and D/45° (right), before detection at the photodetector.

Alternative polarization compensation

If the polarization rotation compensation technique using photon coincidences in Section 3.6 does not converge successfully, an alternative compensation technique using macroscopic light and a normal photodiode can be used, but also requires the removal of the top cover of the EPPS. Additional devices required for this compensation are

1. Broadband 1320 nm light source (∼5–100 nm bandwidth),
2. Photodetector,
3. Polarizers at H/0° and D/45°.

Light can be coupled in the reverse direction from the polarization analyzer into the EPPS with known polarizations of V/90° and A/135°, and the transmission through the polarizers measured with the photodetector as shown in Figure 4.2. Tune the polarization rotaters to minimize light transmission in both bases, i.e. light polarized along V/90° should yield high extinction when projected along H/0° at the polarizer, and similarly for A/135° and D/45°.

Once this is achieved, through optical reversibility, the photon pairs coupled to the fiber will also experience the same optical rotations and thus be compensated for polarization rotations.

Verify that the measured visibility is >98%, otherwise please contact us at `info@s-fifteen.com` for assistance.

5 Troubleshooting

Table 5.1: Common problems and troubleshooting suggestions

Problem	**Possible cause**	**Suggestion**
No serial communication	Wrong device name / permissions	Verify that user has appropriate permissions to access the device[1].
	12 V supply not available	The USB communication chip on the device needs the 12 V to function. Verify that the 12 V supply is switched on.
Temperature does not reach set point	Incorrect `POWER` setting on device	Send `POWER 3` on serial comm.
	Temperature loop not active	Send `HLOOP 1; PLOOP 1` on serial comm.
	Voltage limit reached	Check voltage limit settings, i.e. `HLIMIT` or `PLIMIT`.
No photon signal from EPPS	Laser not switched on	Send `POWER 3; ON` on serial comm.
	Laser current too low	Set laser current above the threshold current.
Low photon pair rate	Crystal temperature not stabilised	Check that crystal temperature is at set temperature with `HTEMP?`.
	Crystal heater control loop is switched off	Check that `HLOOP?` returns 1.
	Detector saturated	Ensure that detector is still not saturated.

---

[1] In Linux, add the user to the `dialout` group. In Windows, check the COM number through device manager–>Ports.

	Pump power is low	Check that the laser current is at the specified set current with `LCURRENT?`.
	Incorrect detector efficiencies used in pair rate calculation	Verify detector efficiencies independently.
	Coincidence window falls outside allowed range in coincidence measurement device	Add appropriate delays to one path to reduce the timing offset between coincidences.
	Coincidence window too narrow	Timing jitters in detector might make the coincidence timing histogram wider than the window. Increase the width of the coincidence detection window.

For further assistance, contact us at `info@s-fifteen.com`

6 Specifications

Table 6.1: Device Specifications

Parameters	Values
Operating wavelength	1320 nm
WDM switch-over wavelength	1320 ± 2.5 nm
Bi-photon bandwidth	50 nm
Photon pair rate[1]	> 500 000 pairs/s (before detection)
Polarization-entanglement visibility	> 96%
Photon-heralding probability[2]	∼25%
Photon Output fibers	SMF-28
Software Control	
Physical port	USB 2.0, Type B
Communication	Serial communication via virtual COM port / USB CDC ACM class
Crystal temperature	Ambient temperature to 70°C
Laser temperature	18–40 °C
Laser current	0–85 mA
Electrical Specifications	
Power Supply	12 V DC, 2.5 mm barrel socket. Supply only, mains cable not included
Maximum power consumption	50 W
Physical dimensions	
Size (L×W×H)	336 mm × 114 mm × 67.5 mm
Weight	3.4 kg
Shipping Weight	6.1 kg

---

[1] Refer to Equation 3.1

[2]

$$\text{Heralding Probability} = \frac{C - S_{d1}S_{d2}\Delta t}{\sqrt{\eta_1\eta_2}\sqrt{S_{d1}S_{d2}}}$$

7 Mechanical Drawing

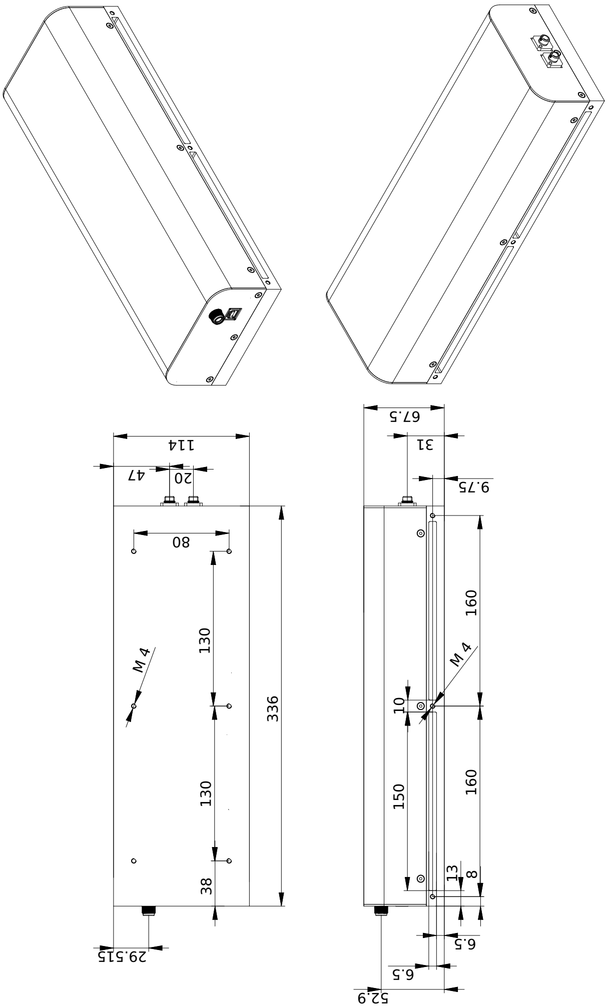

Figure 7.1: Mechanical drawing of the EPPS. All dimensions in millimeters (mm).

Bibliography

[Fiorentino and Beausoleil, 2008] Fiorentino, M. and Beausoleil, R. G. (2008). Compact sources of polarization-entangled photons. *Opt. Express*, 16(24):20149–20156.

[Lohrmann et al., 2020] Lohrmann, A., Perumangatt, C., Villar, A., and Ling, A. (2020). Broadband pumped polarization entangled photon-pair source in a linear beam displacement interferometer. *Applied Physics Letters*, 116(2):021101.