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ESPRESSO

Fabry-Pérot Calibrator

Final Design Report

VLT-TRE-ESP-13520-0154, Issue 2

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		All	Updated after manufacturing and in view of Sub-system acceptance
		Performance Analysis	Removed and moved to the test report

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Chapter 1. Introduction

1.1 Scope of the Document

This document describes the Fabry-Pérot Calibrator (FPC) foreseen as a backup for ESPRESSO, in case the Laser Frequency Comb will not be available within the proper specifications in due time. Refer to the LFC procurement strategy document RD-1. The document has been updated after manufacturing of the FPC and for sub-system acceptance.

1.2 Documents

The applicable and reference documents are listed below:

1.2.1 Applicable Documents

AD-1	ESPRESSO Statement of Work	VLT-SOW-ESO-13520-5059	1	01.02.2011
AD-2	ESPRESSO Technical Specifications	VLT-SPE-ESO-13520-4633	3	01.02.2011

1.2.2 Reference Documents

RD-1	Wavelength calibration system based on a laser frequency comb: Status and procurement strategy	VLT-TRE-ESO-13529-5823	2	12.03.2013
RD-2	Fabry-Pérot Calibrator Product Tree	VLT-LIS-ESP-13520-9201	1	04.05.2016
RD-3	ESPRESSO – Paranal Observatory ICD	VLT-ICD-ESO-13529-5412	3	28.11.2014
RD-4	ICD Calibration Unit – Fabry-Pérot	VLT-ICD-ESP-13520-0190	2	12.09.2014
RD-5	Vacuum and Cryogenic PLC Control System	VLT-TRE-ESO-13520-5953	1	08.12.2014
RD-6	Instrument Control Electronics design report	VLT-TRE-ESP-13520-0041	3	25.11.2014
RD-7	Instrument Software Design Description	VLT-TRE-ESP-13520-0101	1.1	19.07.2013

1.3 Acronyms and Abbreviations

1.3.1 Acronyms

AD	Applicable Document
AIV	Assembly, Integration and Verification
CCL	Combined Coudé Laboratory (of the VLT)
CIDL	Configuration Items Data List

CTE	Coefficient of Thermal Expansion
E-ELT	European Extremely Large Telescope
ESO	European Southern Observatory
ESPRESSO	Echelle Spectrograph for Rocky Exoplanets and Stable Spectroscopic Observations
FDR	Final Design Review
FP	Fabry-Pérot (etalon)
FPC	Fabry-Pérot Calibrator
FWHM	Full-Width at Half Maximum
HW	Hardware
ICD	Interface Control Document
ICS	Instrument Control Software
ISO	International Organisation for Standardisation
IP	Instrumental Profile
LDLS	Laser-Driven Light Source
LFC	Laser-Frequency Comb
LRU	Line-Replaceable Unit
MTBF	Mean Time Between Failures
N/A	Not Applicable
PAC	Provisional Acceptance Chile
PAE	Provisional Acceptance Europe
PDR	Preliminary Design Review
PI	Principal Investigator
PLC	Programmable Logic Controller
PM	Project Manager
QA	Quality Assurance
RAMS	Reliability Availability Maintainability Safety
RD	Reference Document
RfW	Request for Waiver
RV	Radial Velocity
SOW	Statement Of Work
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined/To Be Developed
ThAr	Thorium-Argon (lamp)
ULE	Ultra-Low Expansion (material)
UPS	Uninterrupted Power Supply
UT	Unit Telescope (8.2 meter telescope at Paranal)
VLT	Very Large Telescope
VM	Verification Matrix
WBS	Work Breakdown Structure
WP	Work Package

Chapter 2. General Requirements

2.1 General characteristics of the Fabry-Pérot Calibrator

The FPC is designed as a fallback solution in case of an LFC of suitable properties would not be available by the end of the ESPRESSO project or beginning of operations. The purpose of the Fabry-Pérot Calibrator FPC is to provide a large number of ultra-stable lines in the wavelength range of the ESPRESSO spectrograph. The FPC shall ensure 'at least' adequate short-term stability, i.e. better than 10 cm/s during an observing night. Since the FPC system is fully passive, no guarantee can be given a priori that the stability of 10 cm/s is achieved over long term or even years. It will therefore be operated in addition to an absolute reference, so a ThAr lamp or a stabilized laser to which it will be referenced periodically.

We remind here the properties desired for this module:

1. The calibration source must cover the full wavelength domain of the spectrograph.
2. The line position and shape repeatability of all lines must be better than 0.1 m/s over the instrument lifetime.
3. The lines are not resolved by the spectrograph, since otherwise information is lost, respectively we do not take full advantage of the spectral resolution of the instrument. The resolution of the spectrograph is 120'000 in its standard mode, limited by the illuminating fiber size.
4. The line distance is perfectly stable and analytically defined.
5. The line distance must be minimum 2 and maximum 7 FWHMs of the spectrograph IP.
6. The relative intensity of any neighboring lines must be stable at 10% over time.
7. The dynamic range of line intensities over one order must be smaller than a factor 4.

As a first goal, the system shall be made sufficiently stable to be used as a relative reference during an astronomical observing night of typically 12 hours. The module will possibly need to be re-calibrated every night, e.g. with a ThAr lamp or a LFC, for absolute referencing, but will serve as perfect simultaneous reference within the night. The second objective will be to extend the time during which the module remains stable. Ideally, the module will be intrinsically so stable, that re-calibration will not be needed over large time scales (years).

Reflection is obtained by a multi-layer thin film coating of the inner optical surfaces. The following aspect must be considered: *The apparent separation of the two spacers depends on the effective penetration depths of the wave on the reflective surface.*

- Because of the varying real and imaginary part of the refractive index as a function of wavelength, the effective Etalon separation will vary with wavelength. This wavelength dependence must be avoided as far as possible, in particular, a temperature or aging effect must be avoided. If this wavelength dependence cannot be avoided completely, it should be at least very "smooth".
- Thermal effects in the coating will affect the way the etalon behaves: The dielectric stack will have a certain thickness. When the ambient temperature changes, the stack will

expand (CTE of some 10^{-6}) and this will change the effective gap of the etalon. With a gap of 7 mm, for instance, and a dielectric stack of 4 µm thick with a CTE of 7 10^{-6}, the variation of the apparent separation will be about 8 10^{-9} / K. In the same way, the index of refraction will change with temperature and affect the apparent penetration depth of the optical wave in the coating.

- Aging of Zerodur has been studied in metrology labs. Schott data indicates shrinkage of 10^{-7} per year. However, the experience on the HARPS FP shows that the effect of aging is well below the estimated value. In alternative to Zerodur, ULE can be used.

When making trade-off, the following order of priorities shall be considered:

1. Relative wavelength stability over temperature and time (between two neighboring lines)
2. Wavelength stability over temperature and time
3. Equidistance of transmitted wavelengths
4. Uniformity of line intensity and line shape and width

2.2 Dimensioning of the Fabry-Pérot etalon

The primary parameters for which the Fabry-Pérot etalon has to be dimensioned are:

Variables:

- Spectrograph resolution R_S
- Shortest wavelength λ_B
- Longest wavelength λ_R

Requirements for an optimum use of the lines are:

i. The line separation is minimum on the blue side, because of the FP equation. The separation must be chosen such that the lines can be resolved by the spectrograph:
The peak separation at all wavelength must be > 3 FWHM: $\Delta\lambda \geq 3 \cdot \frac{\lambda}{R_S}$ (R1)

ii. The line separation is highest on the red side. At a given Finesse, the FP lines become wider there. It shall be avoided, that the spectrograph resolves the lines:
The FP line must be under-resolved by a factor of 2/3 : $\delta\lambda \leq 2/3 \cdot \frac{\lambda}{R_S}$ (R2)

Let us now first derive the required FP. Given the gap D of the etalon, the resonance of the FP will be achieved whenever $2D = m\lambda$ (1).

Therefore, the separation between the 2 bluest peaks will be, using requirement (R2):

$$\Delta\lambda = \frac{2D}{m-1} - \frac{2D}{m} = \frac{2D}{m(m-1)} \geq 3 \cdot \frac{\lambda}{R_S} \qquad (2)$$

Let's replace m in the last inequality by using equation (1),

$$\frac{2D}{m(m-1)} \cong \frac{2D}{m^2} = \lambda^2/2D \geq 3 \cdot \frac{\lambda}{R_S} \tag{3}$$

and solve for D. In order to be true for all wavelengths, the relation must me satisfied for the shortest wavelength $\lambda = \lambda_B$, such that we get $D = \lambda_B \cdot R_S/6$ (P1)

Now let's derive the required finesse *F* of the etalon: The Finesse is defined as the ratio of the line separation to the FWHM: $F = \Delta\lambda/\delta\lambda$ (4)

We can express again $\Delta\lambda$ as a function of the gap and the FP order

$$\Delta\lambda = 2\mathrm{D}/\mathrm{m}(\mathrm{m}-1) \cong 2\mathrm{D}/\mathrm{m}^2 \tag{5}$$

and introduce equation (5) and requirement (R2) into equation (4)

$$F = \frac{\Delta\lambda}{\delta\lambda} \geq \frac{2D3R_S}{m^2 2\lambda} = \frac{3DR_S}{m^2\lambda} = \frac{3DR_S\lambda^2}{4D^2\lambda} = \frac{3R_S\lambda}{4D} \tag{6}$$

where in the step before the last we used the etalon equation (1). Since this condition must apply at all wavelengths, we have to choose *F* for the longest wavelength and substitute *D* using (P1):

$$F = \frac{3R_S\lambda_R}{4D} = 18 \cdot \frac{\lambda_R}{4\lambda_B} = \frac{9\lambda_R}{2\lambda_B} \tag{P2}$$

Let's now look at the etalon parameters from the instrument figures: R_S = 120'000, $\lambda_B = 380nm$, $\lambda_R = 780nm$ we find

D = 7.6 mm

F = 9.2

Chapter 3. Technical Requirements

3.1 Operational conditions

The FPC will be operated in the CCL at the Paranal Observatory, Chile. It will be located within 2T. The FPC will not be exposed to any motion, gravity, vibrations, etc.

3.1.1 Atmospheric pressure

Atmospheric pressure is 760 mbar in average. Given the high ambient pressure variations the FPC etalon will be operated in vacuum. A pressure value of 0 mBar must be considered for the optical computations.

3.1.2 Temperature

The temperature of the environment is typically of 16 ± 5°C.

3.1.3 Relative humidity

The system is working normally in a controlled environment with relative humidity always lower than 100%. During manufacturing, transportation, installation, and maintenance the humidity can attain peeks close to 100%.

3.2 Performance requirements

3.2.1 Etalon requirements

Operational wavelength range:	380 nm - 780 nm	
Total transmittance at peak:	T > 10% in the wavelength range	
Transmittance uniformity	$T_{max}/T_{min} < 2$	in the wavelength range
Transmittance variations	$dT/d\lambda < 2\%$ per nm	in order not to distort the
	Lines by more than 10 cm/s	

3.2.2 Fabry-Pérot parameters

Effective total Finesse:	$10 < F < 12$	in the wavelength range
Fabry-Pérot spacing:	$D = 7.6$ mm $\pm$ 0.0005 mm	

In order to achieve a total (reflectivity-limited) Finesse of $F = 10$, the various Finesse contributions must be:

Reflectivity Finesse: $F_R \geq \frac{5}{4} \cdot 10 = 12.5$

Aperture Finesse: $F_\theta \geq 2.35 \cdot F = 23.5$

Defect Finesse: $F_D \geq \sqrt{2} \cdot 2.35 \cdot F = 33.2$

Parallelism Finesse: $F_P \geq \sqrt{2} \cdot 2.35 \cdot F = 33.2$

3.2.3 Delivered flux and flux homogeneity

The FPC shall deliver sufficient flux at peak wavelength within the étendue accepted by the spectrograph, such that a global photon-noise precision of better than 5 cm/s is achieved in less than 20 s.

The white-light sources should be selected and/or balanced in a way that the ratio between maximum and minimum counts per extracted pixels measured all over the spectrum must not exceed a factor of 5 (dynamic range).

3.2.4 Wavelengths stability

The Fabry-Pérot transmitted wavelengths must remain stable with time. The Fabry-Pérot shall be placed in vacuum, and the required temperature stability specified. Changes of the transmitted wavelengths must be minimized.

Wavelength repeatability: $d\lambda/dt < 2\ 10^{-10}\ \lambda$ (0.07 m/s) at any wavelength

required: during at least 12 hours

goal: during 10 years

Absolute wavelength: $\lambda - \lambda_0 < 3 \times 10^{-8}\ \lambda$ (10 m/s) at any wavelength

The absolute wavelength of a line is defined on the centroid of the transmitted FP line with respect to the expected wavelength given by the nominal etalon spacing. Wavelength repeatability indicates the stability of the centroid of a line.

The Fabry-Pérot must be optimized for minimum sensitivity of the transmitted wavelengths with regard to temperature variations. If the final design is intrinsically stable it relaxes the contraints on the thermal control stability.

3.2.5 Line shape and line shape stability

The shape of the transmitted FP lines (intensity, symmetry, width) shall be as uniform as possible. The line shape shall be as stable as possible. It is therefore suggested that the etalon finesse is determined by the reflectivity finesse, which is the most insensitive to geometrical aspects. However, in order to make the transmitted lines 'equidistant' to a level described by the 'absolute wavelength' requirement, the phase of the etalon transmittance function, and thus the reflectance of the individual mirrors, shall be kept constant as a function of wavelength, if possible. Since this is very difficult, the plan will be to calibrate the phase variations at the beginning of the lifetime of the FPC.

3.2.6 Vacuum

From the stability requirements we deduce that the air pressure around the FP etalon must be kept stable within 10^{-3} mbar during 12 hours. The requirement shall be therefore formulated as:

$$dp/dt < 2 \times 10^{-3} \text{ mbar per day.}$$

3.2.7 Monitoring

The temperature of the FPC, and in particular the etalon, must be monitored and controlled continuously with a resolution of 0.001 K, a short-term repeatability of 0.002 K over time scales of 1 months and of 0.025 K over five years, and an absolute accuracy of 0.1 K. The monitoring must have a data link to the ESPRESSO control system.

The air pressure around the etalon must be monitored continuously with a resolution and precision of 0.0001 mbar, and an absolute accuracy of 0.001 mbar. The monitoring must have a data link to the ESPRESSO control software.

3.2.8 Summary of performances requirements towards the FPC

In the following Table 1 we summarize the relevant technical requirements towards the FPC.

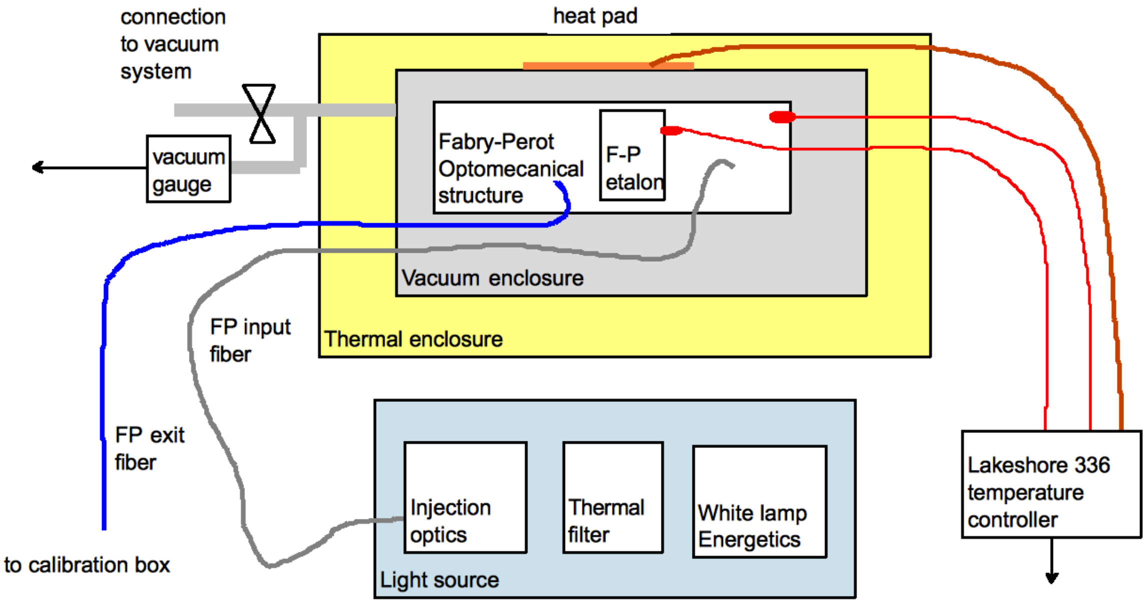
Table 1: Requirements towards the FPC

Item	Requirement	Comment
Wavelength coverage	380 – 780 nm	Wavelength range of ESPRESSO
System transmittance	> 10%	In the wavelength range
Transmittance uniformity	$T_{max}/T_{min} < 2$	In the wavelength range
Transmittance variations	$dT/d\lambda < 2\%$ per nm	
Etalon total Finesse	$10 < F < 12$	In the wavelength range
Etalon spacing	$D = 7.6$ mm ± 0.0005 mm	
Photon noise	< 5 cm/s	Global precision achieved in a single exposure
Flux homogeneity	$F_{max}/F_{min} < 5$	In the wavelength range
Line width	< 2/3 of spectral element	A spectral element is the wavelength divided by the spectral resolution
Line separation	2-7 x spectral element	
Short-term repeatability	$d\lambda/dt < 2\ 10^{-10}\ \lambda$ (0.07 m/s)	Over 12 hours
Long-term repeatability and line-shape stability	$d\lambda/dt < 2\ 10^{-10}\ \lambda$ (0.07 m/s)	Over 20 years (goal)
Local wavelength accuracy	$\lambda - \lambda_0 < 3 \times 10^{-8} \lambda$ (10 m/s)	For any FPC line with respect to theoretical

Chapter 4. Design architecture

The proposed FPC is derived from a new concept that has been successfully evaluated on HARPS and HARPS-N: The stability reference for the radial velocity is essentially a Fabry-Pérot etalon housed in a temperature controlled vacuum enclosure. The etalon is fiber-fed by a bright white lamp. A symmetrical set-up of parabolas couples the input to the exit fibers, with the etalon located in the collimated beam between the two parabolas, making the design achromatic.

Figure 1: Functional diagram of the FPC



4.1 Product Tree of the FPC

The complete product tree, including parts details and manufacturers, is given in the Excel file RD-2. A top-level extract is given in Table 2.

Table 2: Product Tree of the Fabry-Pérot Calibrator

Unit	Assembly	Subassembly	Part
Fabry-Pérot Calibrator			Fabry-Pérot Calibrator
	Cabinet Assembly		Cabinet Assembly
		Electronic Cabinet	Electronic Cabinet
		Isolating Panels	Isolating Panels
	Light Source Assembly		Lights Source Assembly
		ENERGETIQ Laser-Driven Light Source LDLS	ENERGETIQ Laser-Driven Light Source LDLS
		ENERGETIQ Remote Control for LDLS	ENERGETIQ Remote Control for LDLS
		ENERGETIQ Extreme Solar-Resistant fiber	ENERGETIQ Extreme Solar-Resistant fiber
		Filter Box	Filter Box
			Filter Box Holder
			Filter Box Input Collimator
			Filter Box Thermal Filter Holder
			Filter Box Thermal Filter
			Filter Box Output Collimator
			Filter Box Cover
		Fiber Connection Filter-Box to	Fiber Connection Filter-Box to Fabry-Pérot

		Fabry-Pérot	
	Fabry-Pérot Assembly		Fabry-Pérot Assembly
		Vacuum System Assembly	Vacuum System Assembly
			Input Vacuum Flange
			Vacuum Tank Body
			BLANK FLANGE DN40 CF MODIFIED
			Isolating Spacer
			CENTRING RING DN 160 ISO-K
			CLAW CLAMP DN63-250 ISO-K
			CLAMPING RING DN25 ISO-KF
			SEAL & CENTERING RING DN 25 ISO-KF
			CLAMP
			ELECTRICAL FEEDTHROUGH CONNECTOR
			O-RING Ø2 - Øint. 23 HITEC FKM 75.5/VA75F
			BLANK FLANGE DN160 ISO-K ALUMINUM
			T-PIECE STAINLESS STEEL DN 25 ISO-KF
			diaphragm angle valve
			Adapter DN 40 CF/ DN 40 ISO-KF
			Flange with Pipe Thread and FKM Seal DN 25 ISO-KF
			SPACER
			SEAL & CENTERING RING DN40 ISO-KF
			CF Copper Gasket
		FP Mechanics Assembly	FP Mechanics Assembly
			Flange 1
			Flange 2
			Flange 3 (VIS-FP)
			Holders for VIS-FP
			Mask for VIS-FP
			Flange 4
			Flange 5
			Body Spacer 1
			Body Spacer 2
			Body Spacer 3
			Body Spacer 4
			Mirror Pillars
			Mirror Holder
			XY Spider
			XY Ring
			Fixed Spider
			Mirror Mask
			Adjustable Shims
			OWIS FGS 10-17 écrou
			OWIS FGS 10-17 vis
			O-RING Ø3-Øint52 HITEC FKM 75.5/VA75F
			O-RING Ø2-Øint22 HITEC FKM 75.5/VA75F
			Fiber connector adapter SM1-FC
		FP Optics	FP Optics
			FP Input Fiber Feed-Through
			FP Input Fiber
			FP Parabolic Collimator Mirror
			FP Etalon
			FP Parabolic Focussing Mirror
			FP Output Fiber
			FP Output Fiber Feed-Through
	Pressure Control		Pressure Control
			Pressure Gauge
			Pressure Controller (only in lab. configuration)
			Electrical Cable Controller-Gauge (only in lab. Configuration

	Temperature Control		Temperature Control
			LakeShore 336 Temperature Controller
			Si-Diodes Temperature Sensor + Wiring
			Electrical Cable Controller-FP
			Heating Foils + Wiring

4.2 Primary source and spectral flux

For irradiance reasons, spectral flatness and MTBF, we would like to use a innovative source called “laser driven light source” EQ-99FC Plus from the company Energetiq. This source is presently being used in integration on HARPS North with convincing results. The light source possesses a complete remote control system for control via software. However, the lamp will be controlled through PLCs and attached to the ICS. For stability reasons the lamp must be kept continuously ON and the ICS/PLC control to switch the lamp ON/OFF must be disabled. The lifetime of such a lamp is longer than 20’000 hours. A LRU spare shall be procured for immediate exchange in case of failure. For the fibers standard Ceramoptec octagonal fibers with high internal transmittance will be chosen.

Figure 2: EQ99 light source and lamp controller

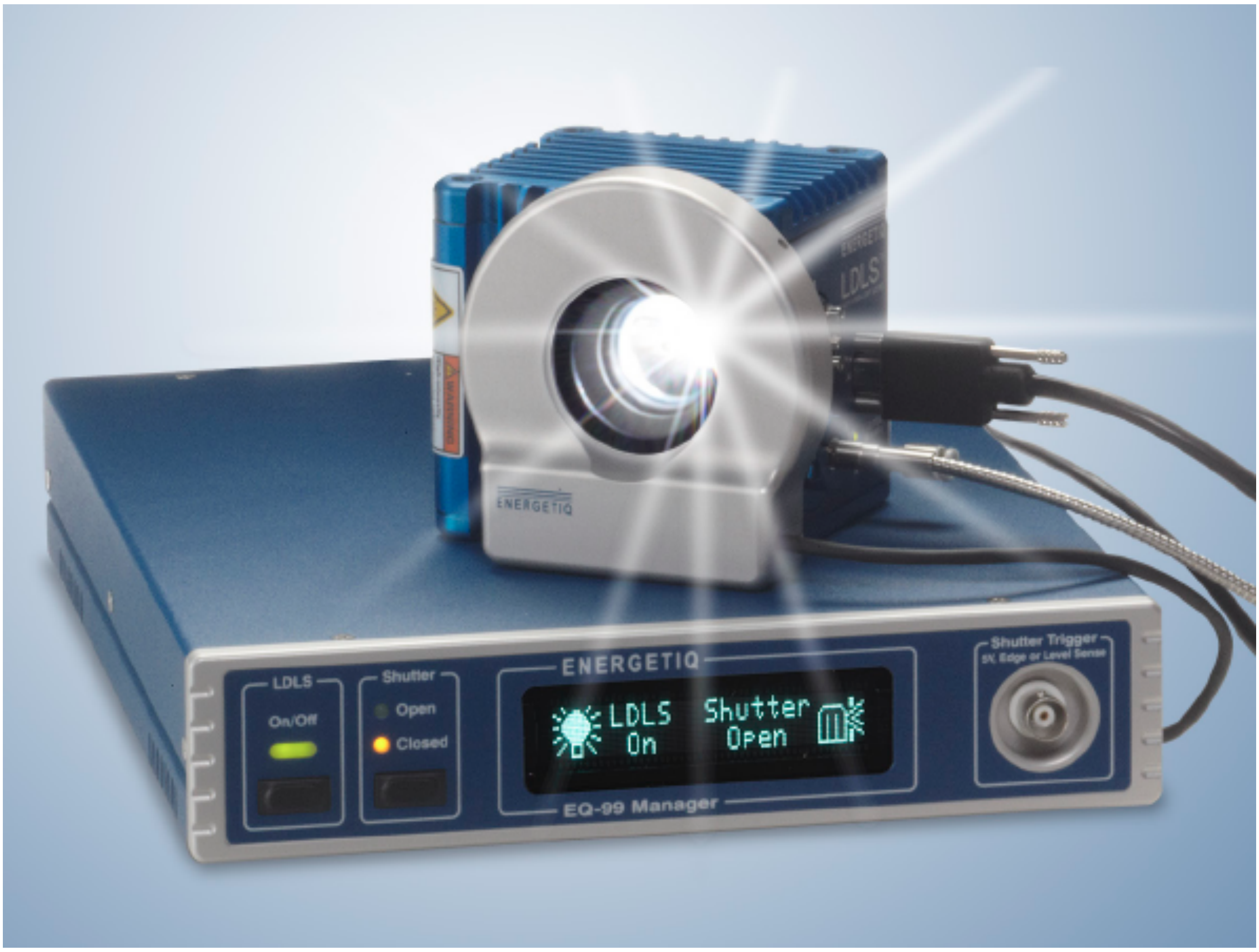


Figure 3: Spectral power distribution of the LDLS source.

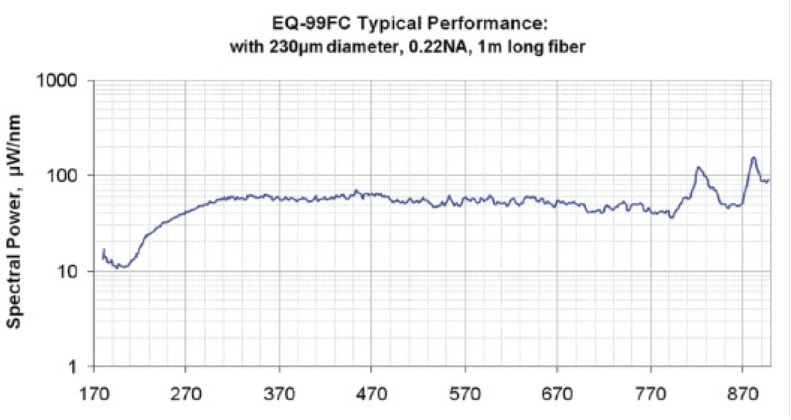
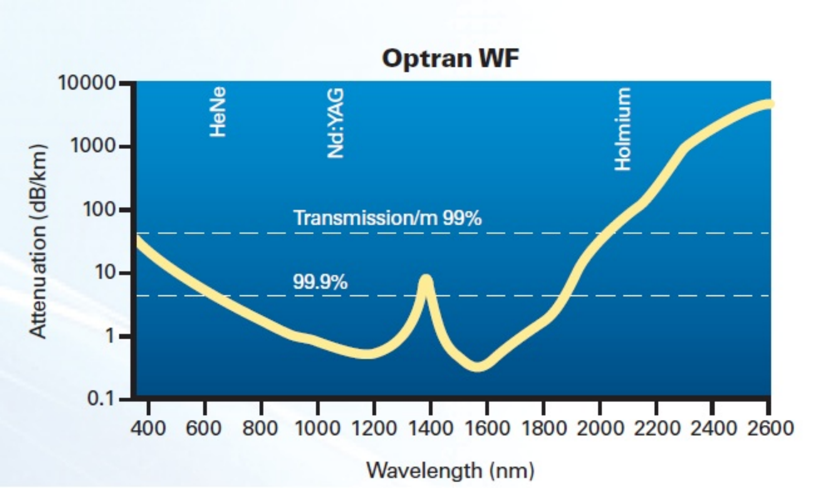
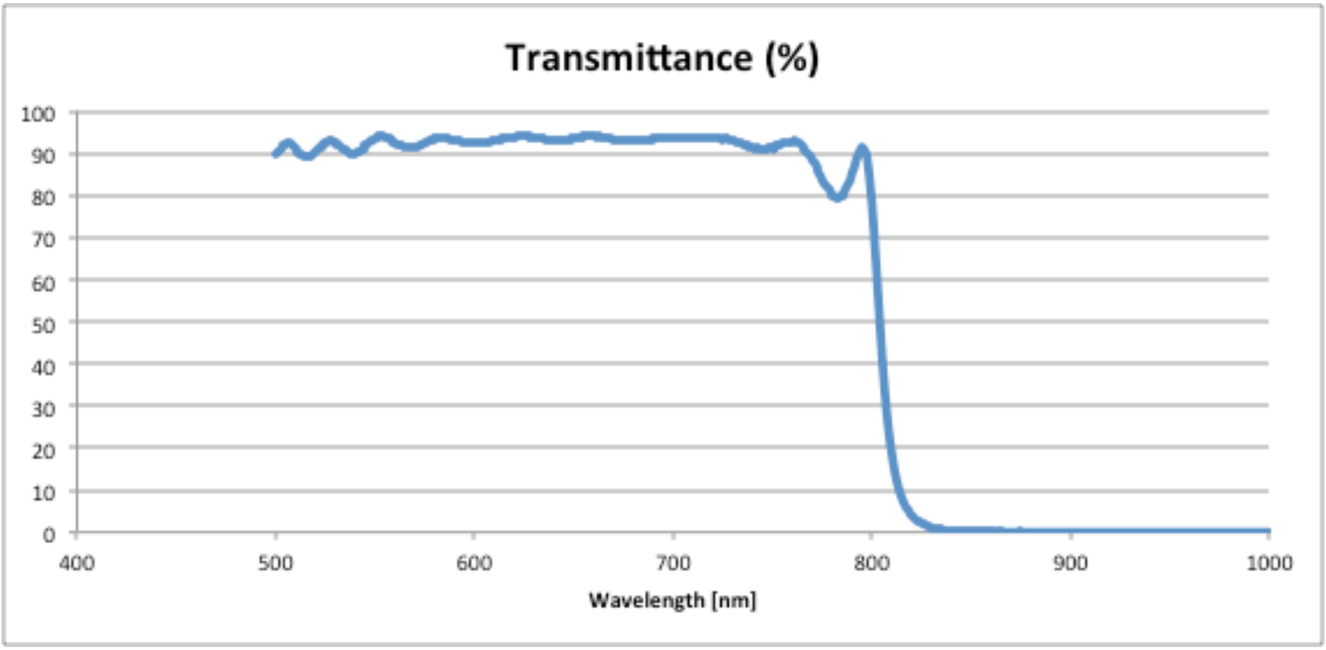


Figure 4: Internal transmission of the FPC fibers



In order to reduce the heat-up of the FP etalon by the source, we will introduce in the laser source a heat-blocking filter by Andover Corp. (Type 800FL07-12.5) with the transmittance curve shown is Figure 5. As a function of the obtained chromatic distribution, a balancing filter will be added. For the moment no choice has been made, since a) a balancing filter may not be necessary, given the high blue flux of the Fabry-Pérot, and b) we prefer in any case to see the resulting chromatic flux distribution. A filter can be inserted easily at anytime an a appropriate location will be reserved for it.

Figure 5: Heat-blocking filter TKG – 5253 transmittance



4.3 Etalon parameters

Given the gap and Finesse requirement, the etalon is designed according to the following parameters:

Gap:	D = 7.6 mm	
Clear diameter:	D = 40 mm (design), focal length of collimator f = 100 mm	
Reflectivity Finesse:	$F_R = 11$	$R(\lambda)$ = const = 75%
Aperture Finesse:	$F_\lambda = 23$	Fiber diameter d < 300 microns @ f_{coll} = 100 mm
Defect Finesse:	$F_D = 33$	Mirror wavefront better than l/50 P-V
Parallelism Finesse:	$F_P = 33$	Departure from parallelism < 10 nm -> $0.25\ 10^{-7}$ rad

The Fabry-Prérot is manufactured by ICOS (UK) in accordance with the drawing of Figure 6. The etalon plates are manufactured in INFRASIL (see transmittance in Figure 7: ESPRESSO etalon's mirror reflectivity

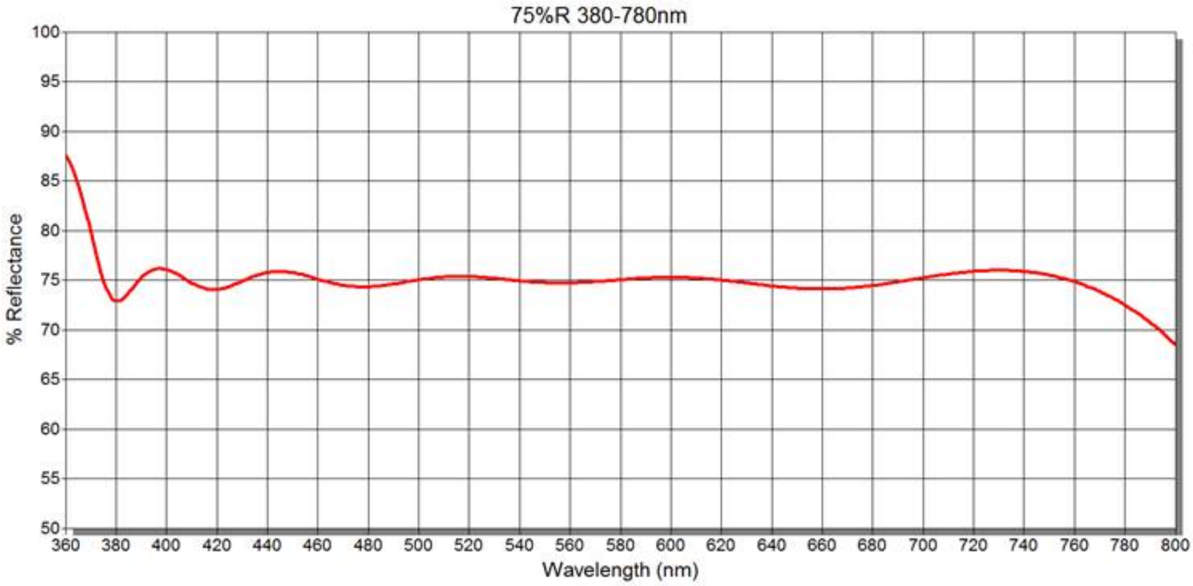


Figure 8). The reflectivity curve is given in Figure 7. The internal fibers being very short, we use Ceramoptec WF fibers. The input fiber has a core diameter of 200 µm and is octagonal for illumination stability reasons, the output fiber core diameter is 600 µm and the fiber is circular.

Figure 6: ICOS 3-D drawing of the Fabry-Pérot. The gaps of the ESPRESSO etalon is of 7.6 mm

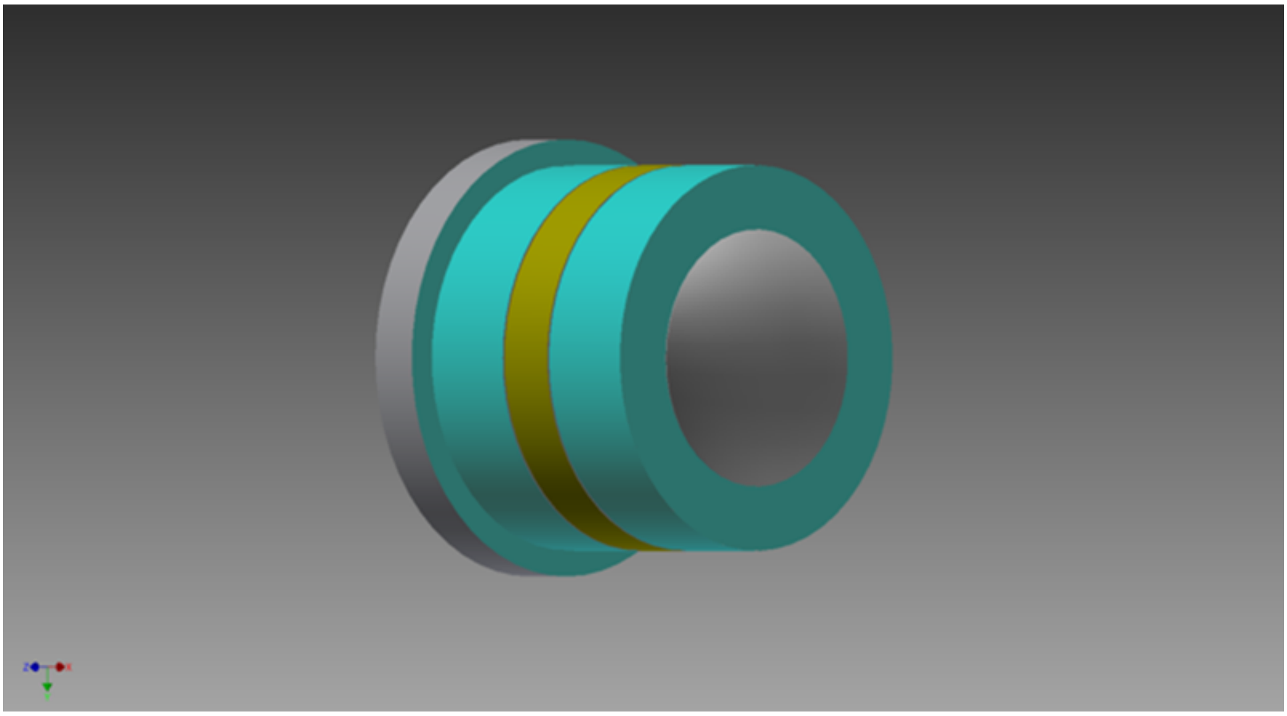


Figure 7: ESPRESSO etalon's mirror reflectivity

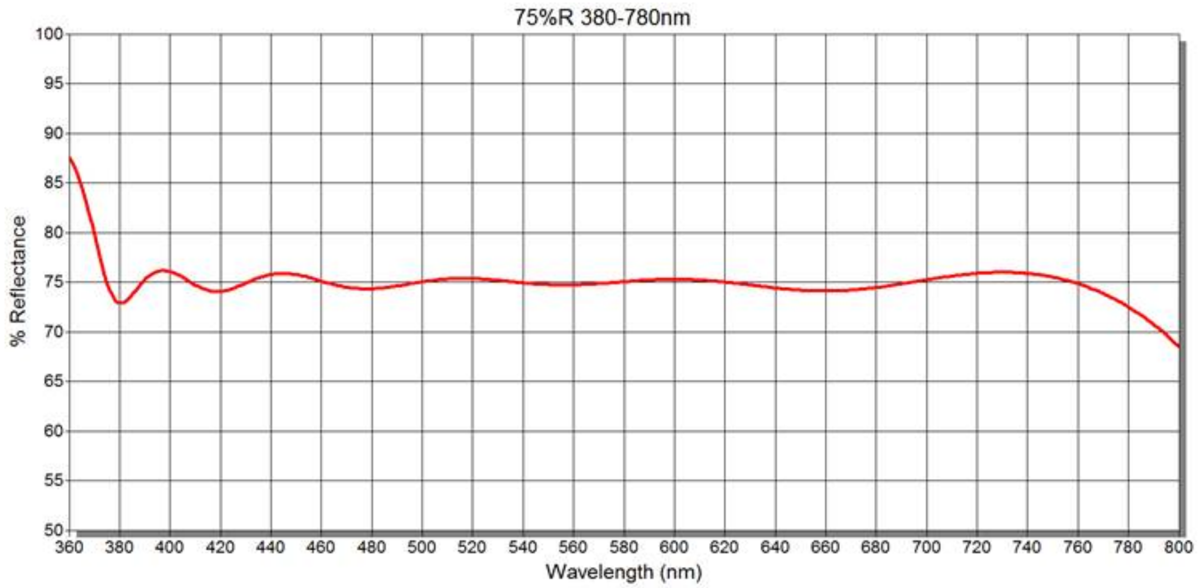
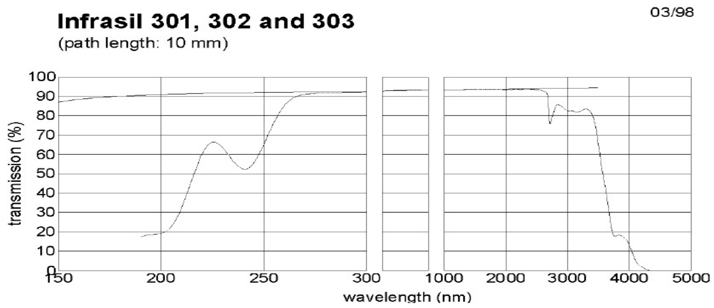


Figure 8: Internal transmission of Infrasil Fused Silica



4.4 Thermal control

From our experience with previous similar systems, the thermal control of the etalon structure to a couple of mK rms should be a straightforward affair. It is based on a Lakeshore 336S temperature controller (Figure 9) using silicon diodes as sensors and four thermal pads as heating elements, which are glued around the vacuum tank of the Fabry-Pérot.

Figure 9: Lakeshore 336S Temperature Controller

4.5 Pressure sensor and controller

The pressure of the FPC and thus around the etalon will be measured by means of an WRG.NW25 gauge from Edwards attached to the vacuum tank (Gauge delivered by ESO, see

Figure 10). Stand-alone controller will be used in the laboratory setup. For operations, however, the pressure is attached directed to PLC on the Vacuum Control cabinet.

Figure 10: Vacuum gauge (left) and its controller for laboratory purposes (right)

4.6 Summary of hardware devices

Table 3: FPC hardware devices

Type	Manufacture	Reference	Interface	Notes
Temperature controller	LAKESHORE	336	Ethernet	
Temperature sensor	LAKESHORE	Si diodes DT-670		Silicon diode
Pressure gauge	Edwards	WRG.NW25		
Lamp controller EQ99 Plus	Energetiq		Will by by-passed by PLC/ICS system	

Chapter 5. Mechanical design

5.1 Overview

The vacuum tank is a simple cylinder of electro-polished aluminum with 2 aluminum covers. It contains the actual FPC and its etalon, which is sketched in the following. Figure 11 shows the mechanical assembly while Figure 12 gives the optical layout.

While the first model of the FPC had a structure made of optically contacted Zerodur cylinders, a sensitivity analysis demonstrated later that this was not necessary. The mechanical structure of the second model (HARPS North) is more classical and a less expensive assembly of aluminum elements holding the mirrors, the etalon and the fiber connectors.

Figure 11: Mechanically assembly of the FPC

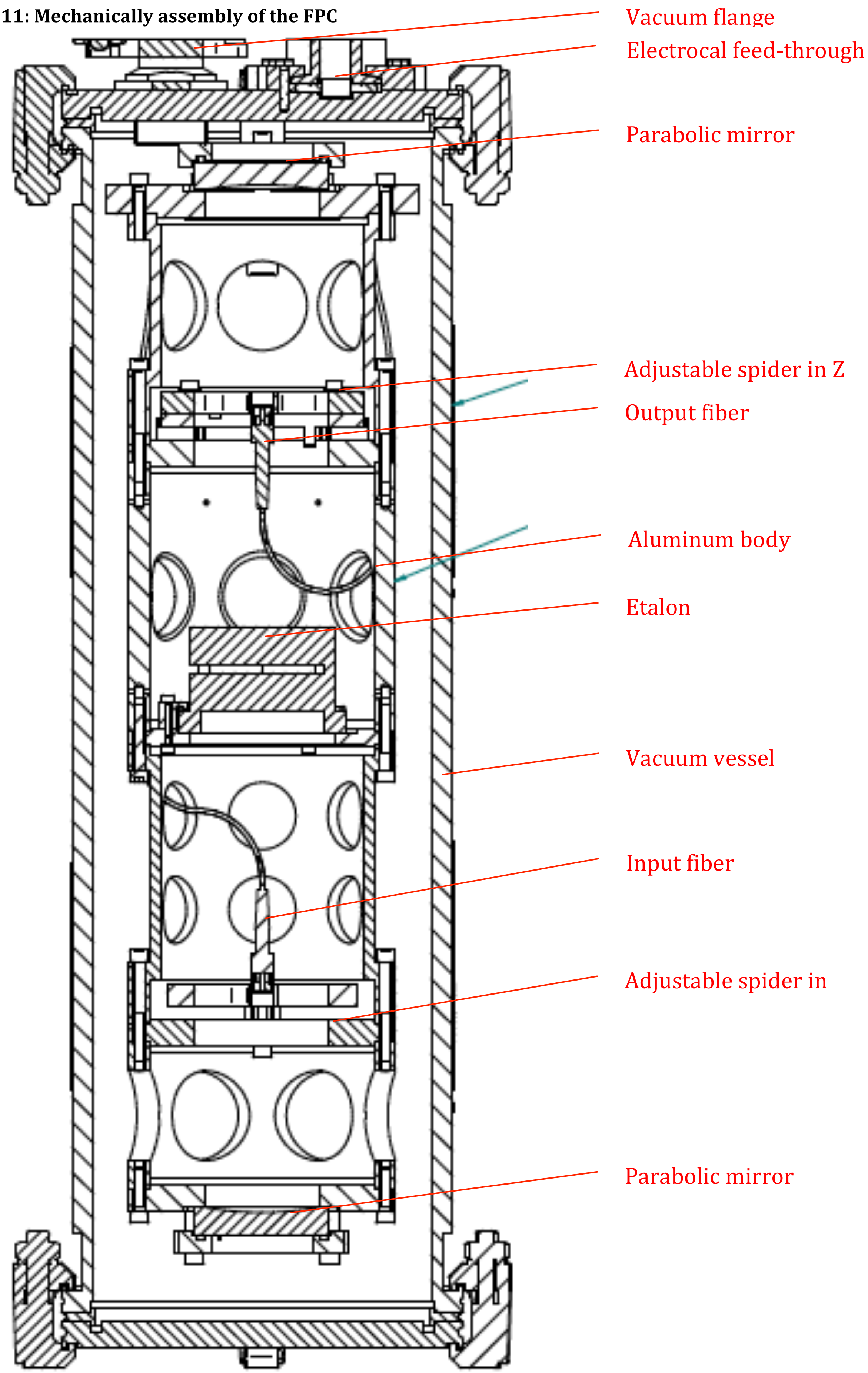
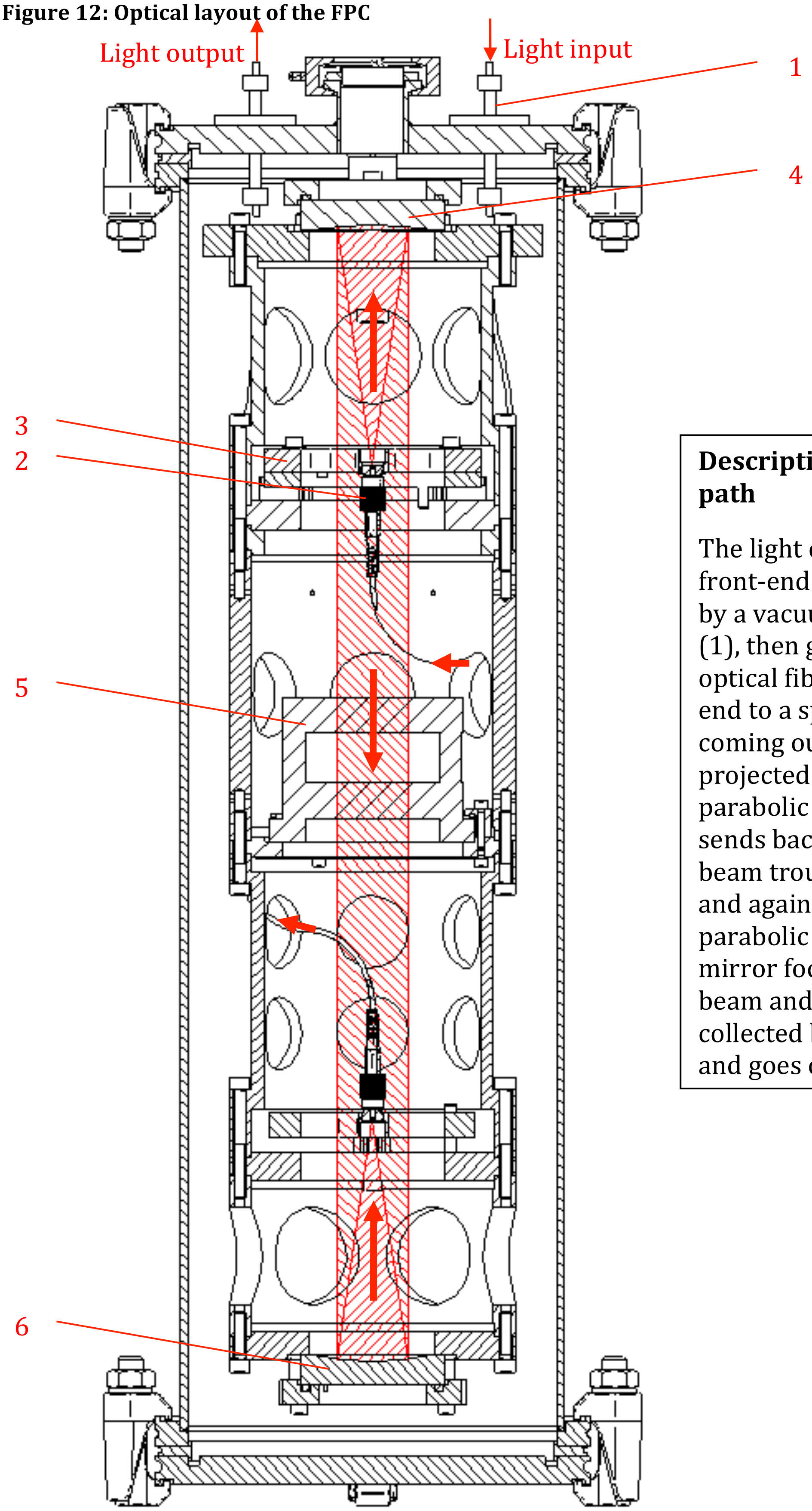


Figure 12: Optical layout of the FPC



Description of the light path

The light coming from the front-end enters the system by a vacuum feed-through (1), then goes through an optical fiber (2), fixed at one end to a spider (3). The light coming out of the fiber is projected against a parabolic mirror (4) which sends back the collimated beam trough the etalon (5) and against the second parabolic mirror (6). This mirror focuses again the beam and the light is finally collected by the output fiber and goes out trough the

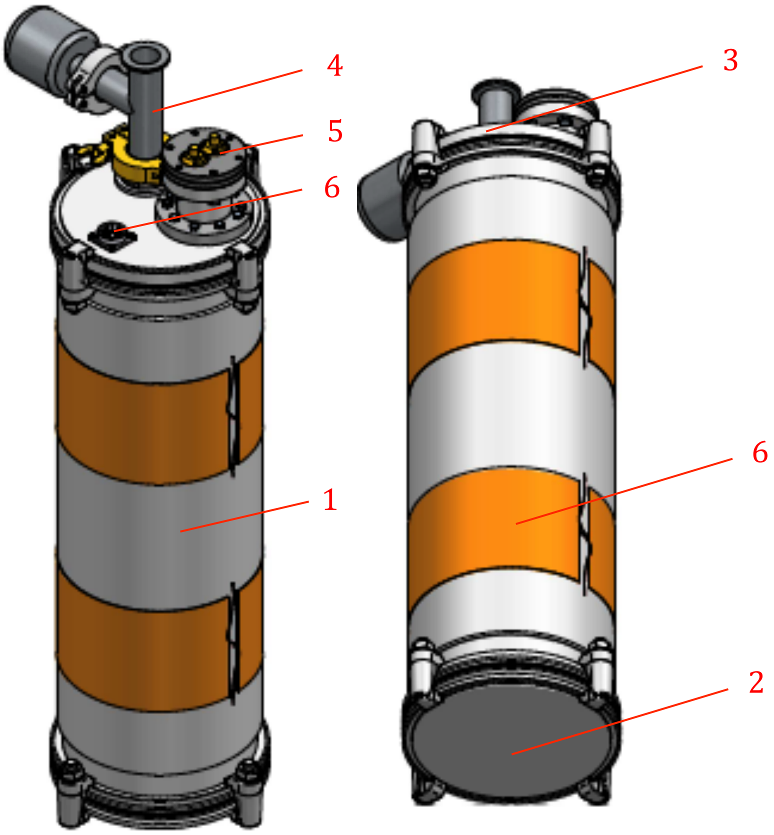
5.2 The vacuum tank

The vacuum vessel is a hermetic chamber in which the pressure can be evacuated to 1E-4 mbar and the temperature is controlled. It is made out of Aluminum and is composed by 3 parts:

a) A centre body (1): it is a tube with 2 welded flanges at each end.
b) A blind flange (2) on the bottom side.
c) A modified blind flange (3) with a pumping flange (4) on the upper side, an optical feed-through (5) and 1 electrical feed-through (6).

2 viton o-rings insure the airtightness and 2 times four clamps maintain all parts together. 4 heater pads for temperature control surround the central body.

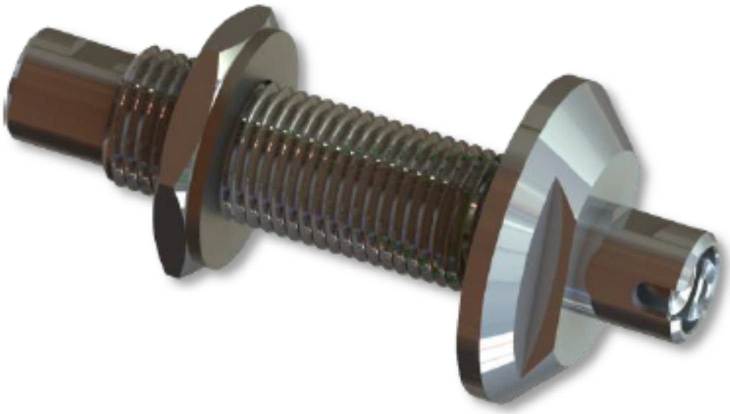
Figure 13: Ouside view of the FPC's vacuum vessel



5.3 Optical feed-through

The optical feed-through is composed of two off-the-shelf fiber feed-though of the type K-TRAV-FC-M10 manufactured by SEDI-ATI (Figure 14). They are equipped with standard 200 µm and 600 µm core diameter step-index fiber for the input and the output feed, respectively. Both end are equipped with femal FC connectors. The feed-throughs are mounted on a standard KF-40 blind flange on which two holes have been drilled.

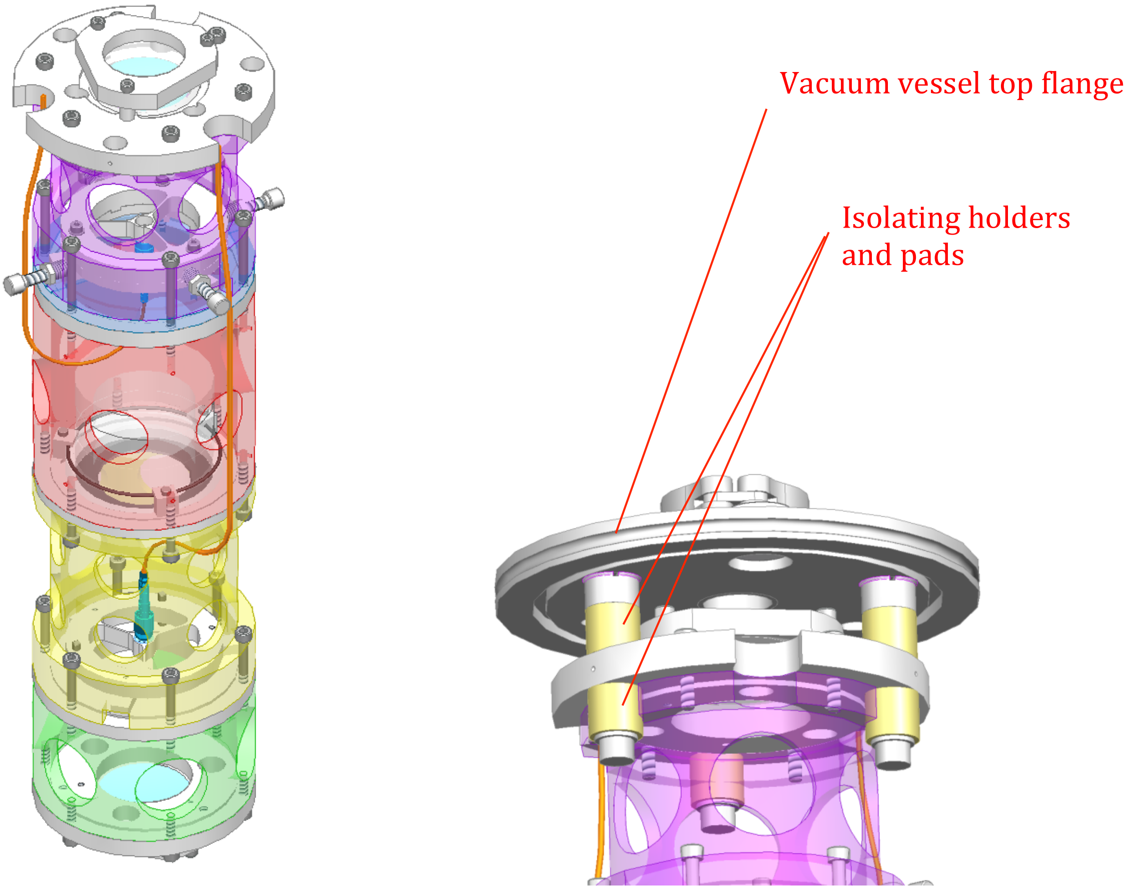
Figure 14: Fiber-optical vacuum feed-though by SEDI-ATI



5.4 Fabry-Pérot assembly

The FPC mechanical assembly (Figure 15) is a stand-alone system placed in the vacuum vessel and fixed to the top flange in 3 points (see Figure 15, right hand). Insulating pads avoid direct metal-metal contact between the flange and the mechanical assembly and provide by this mean thermal insulation from the outside.

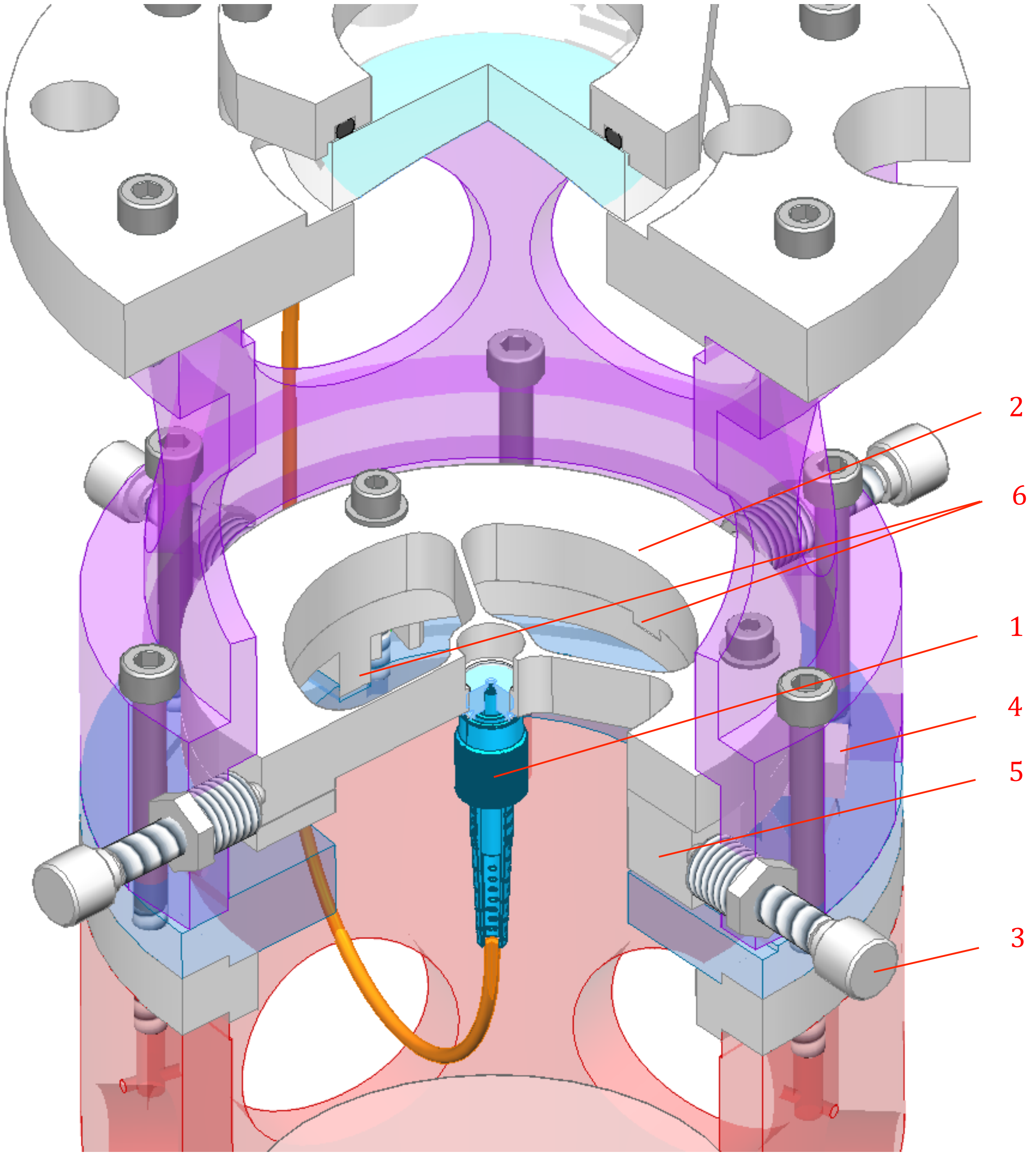
Figure 15: General view of the FPC opto-mechanical assembly (left) and details of the fixation (right)



5.5 The input fiber-holder and spider

Details of the input fiber system are shown in Figure 16. The light is injected through the input (upper) optical fiber connector (1). A spider (2) is used for the final optical alignment. In fact, focus and alignment must be ensured within a couple of tens of microns in order to preserve spectral finesse. The system is therefore adjustable in all directions (X,Y and Z, focus): 4 pushing screws (3) for X,Y direction and 3 spacers (4) to shim for the vertical direction. The 4 screws are removed after adjustment. To insure an accurate displacement in X and Y direction, an intermediate ring (5) is placed between the supporting flange and the spider. In this intermediate ring are machined grooves (6) in the 2 directions.

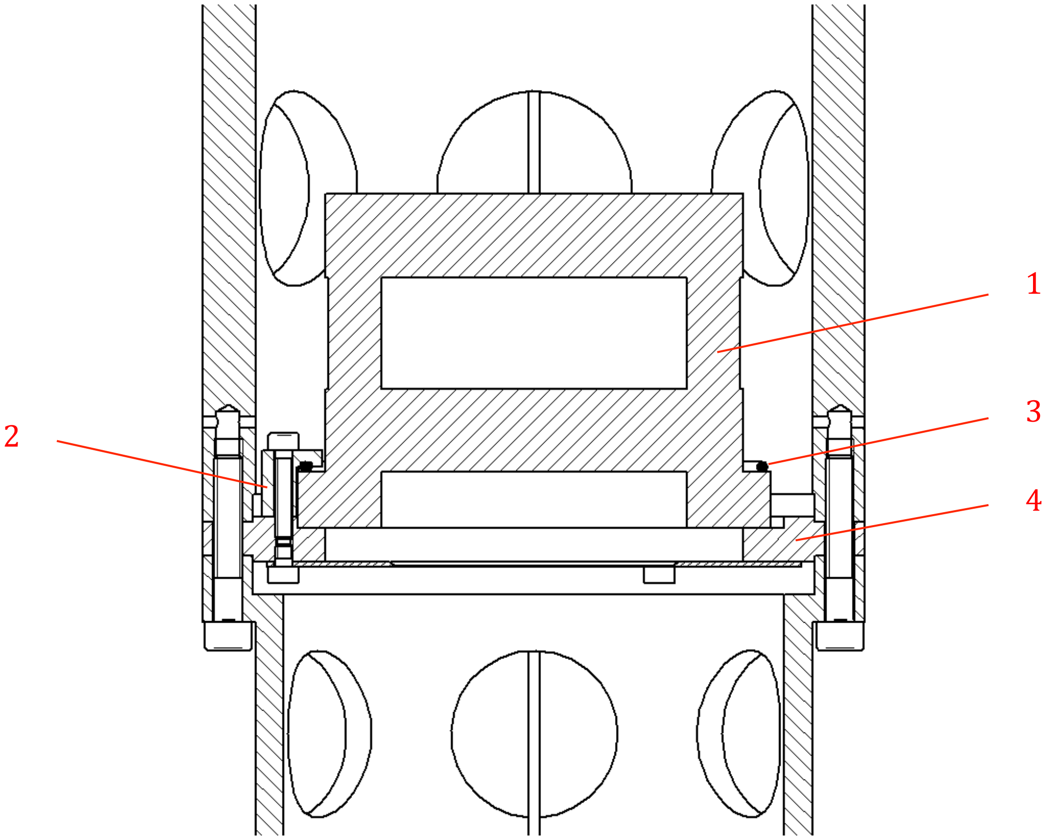
Figure 16: Section view of the upper spider and fiber support



5.6 The etalon mounting

The etalon (1) is the main optical part. Its base is an optically-contacted glass flange by which it is fixed it to the metallic base plate. 3 brackets (2) and a Viton® O-ring (3), used as a spring, maintain the etalon in position on the base plate (4). See Figure 17 for details.

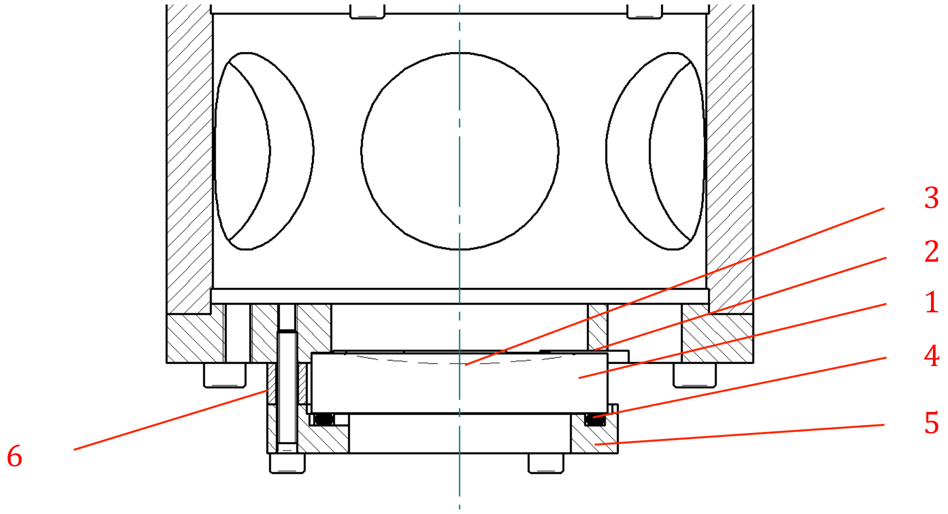
Figure 17: Section view of the etalon and its support



5.7 The parabolic mirror mounting

Two parabolic mirrors (1) are mounted on each end of the FPC mechanically assembly (Figure 18). The first one collimates the beam coming from the input fiber and reflects it back through the etalon. The second one collects the light coming from the etalon and focuses it onto the output fiber. These mirrors have a reference surface (2) on the same side as the parabola (3). A Viton® O-ring (4) compressed by an aluminum ring (5) maintains the mirror in position. 3 spacers (6) define the mechanical distance between the base plate and the aluminum ring, such to avoid stresses on the mirror.

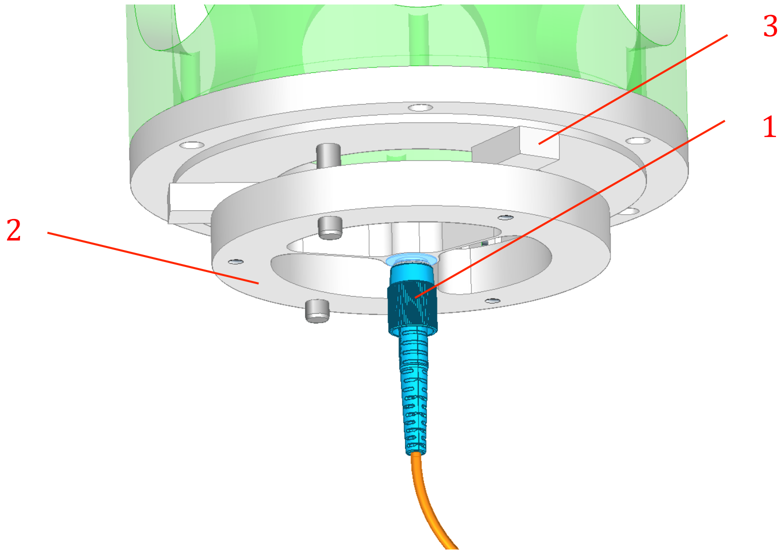
Figure 18: Section view of the parabolic mirror and its support



5.8 The output fiber-holder and spider

Figure 19 shows the support for the output (lower) optical fiber connector (1). This spider (2) is adjustable only in vertical direction (Z, focus) by shimming spacers (3). The mechanical precision of the mechanical assembly and the size of the output fiber (600 µm) are such that no optical X,Y-alignment is necessary in principle. Nevertheless, and if necessery, the output parabolic mirror can be slightly shifted in X,Y direction to maximize the coupling efficiency.

Figure 19: View of the lower (output) spider and fiber support



Chapter 6. Interfaces

6.1 Mechanical interface

The FPC system will be housed by a dedicated cabinet (Figure 20). The implantation and location of the cabinet inside the Combined-Coudé Laboratory at Paranal is defined and described in RD-3 (see also Figure 21).

The Fabry-Pérot can be attached to the pumping system of the vacuum system for initial pumping and possible periodic pumping. However, given the fact that the pressure increase is sufficiently small to avoid nightly drifts larger than the maximum required 10 cm/s, and, because long-term drifts will be calibrated with an external absolute calibration reference, no regular pumping is required and the FPC will be disconnected from the pumping system during regular operations.

Figure 20: FPCS cabinet

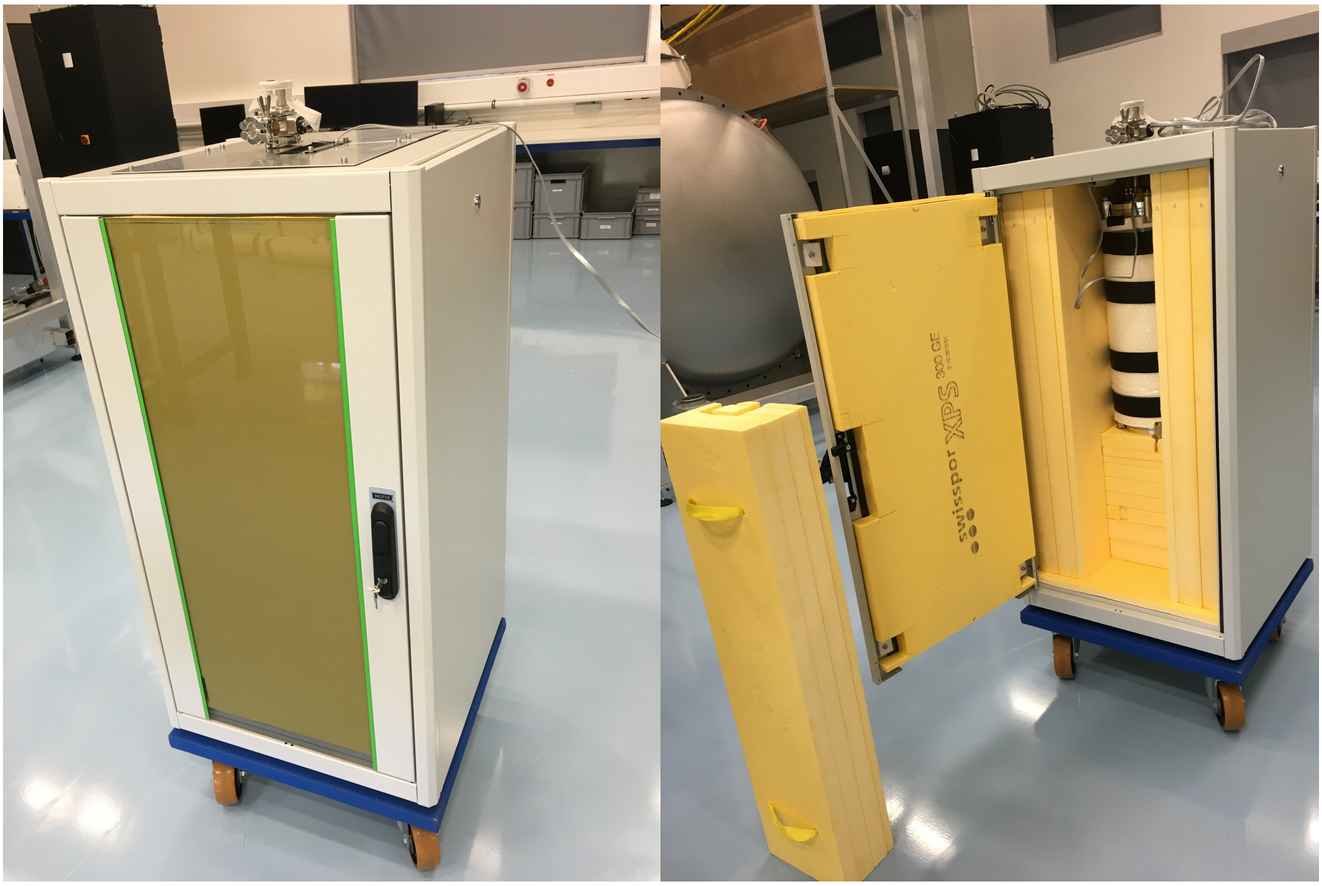
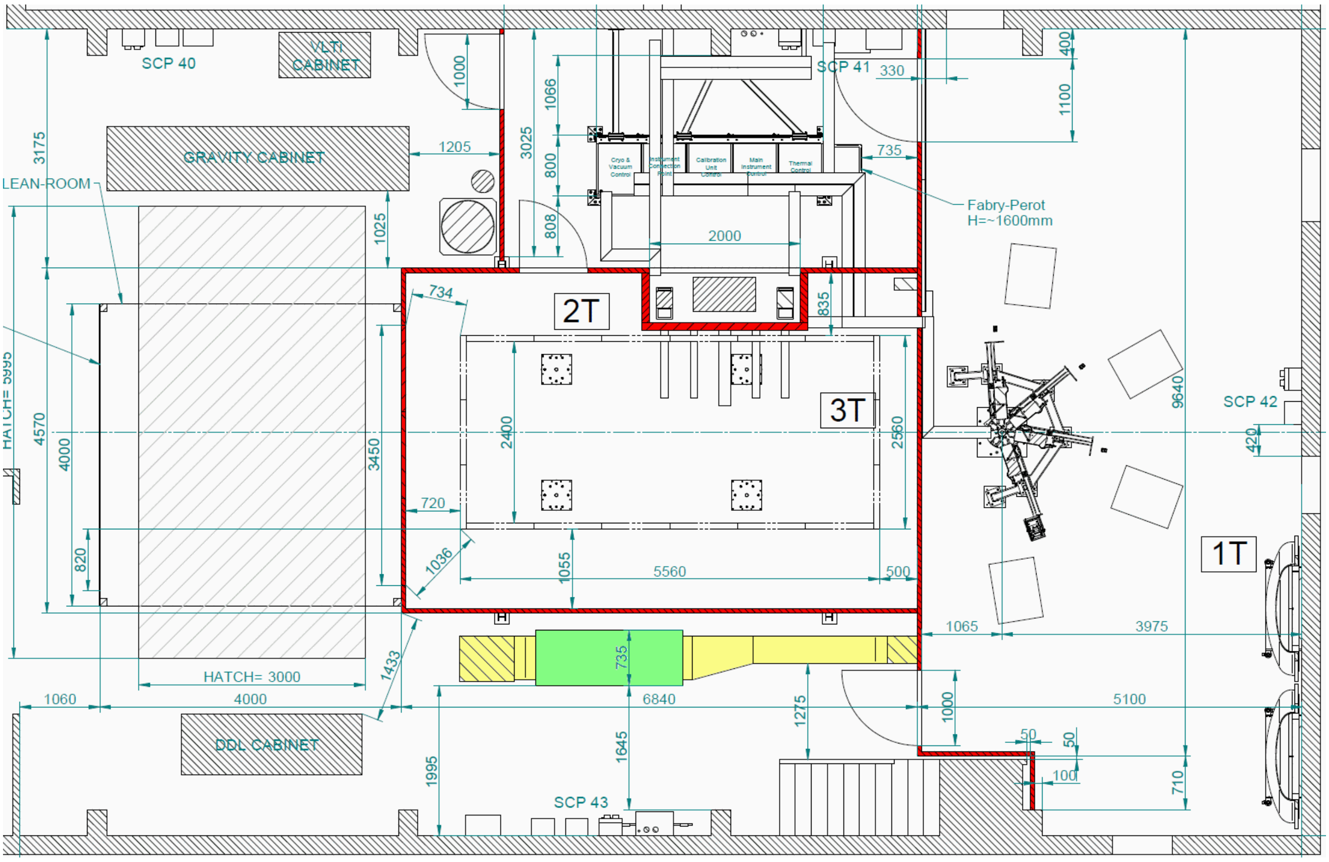


Figure 21: Configuration of ESPRESSO and location of the FPC inside VLT's Combined Coudé Laboratory



The primary light source (LDLS) and its control electronics will be packaged in a 3U 19" crate within the 'Thermal Control' cabinet (Figure 21). In the same cabinet another 3U 19" crate will be allocated to the Lakeshore 336S temperature controller.

6.2 Optical interface

The FPC will have only one optical interface to the calibration unit. It will provide a female FC connector holding a 600 μm fiber. A Y-fiber will connect the FPC with the Calibration Unit providing two FC-connectorized fibers of 300 μm core diameter each. The interface is defined and described in RD-4.

6.3 Hardware interfaces

The FPC is a stand-alone and passive unit. No remote power control is required since it will be continuously operated. The unit (LDLS, T-control and pressure gauge) can be turned ON and turned OFF manually, whenever necessary. The LDLS and the Lakeshore T-controllers are installed in the 'Thermal Control' cabinet. Standard 230V50Hz UPS power lines must be delivered by the cabinet. Both devices are connected to the Ethernet switch. Details are given in RD-6. The pressure gauge of the FPC is connected directly to a PLC on the cryo- and vacuum-control cabinet. The detailed system is described in RD-5.

6.4 Control system software interface

In principle, no active control is required by the FPC. All devices, the T-controller, the pressure sensor and the LDLS light source can be operated as stand-alone. Nevertheless, the FPC will be connected 'passively' to the ICS for monitoring:

- The Lakeshore temperature controller is read for the monitoring of the two temperature sensors of the FPC.
- The Edwards pressure gauge, and thus the pressure of the FPC, will be read directly through a PLC installed on the Cryo- and Vacuum-Control cabinet.
- The status of the LDLS will be read by the ICS.

All active commands must be disabled in the ICS! The hardware devices will be configured such to start-up automatically after re-start or power up. Details of the intergration of the monitoring of the FPC hardware devices into the ICS is detailed in RD-7.

Chapter 7. Appendix

7.1 Data sheets

In the following we will present the data sheets of:

- Energetiq EQ99 Plus lamp controller
- Lakeshore 336 Temperature Controller
- Edwards WRG.NW25 Pressure Gauge

LDLS™
EQ-99 Manager
Smart Controller for Laser-Driven Light Sources

The EQ-99 Manager offers enhanced control of the EQ-99 series Laser-Driven Light Source (LDLS), adding valuable functionality to the brightest, longest lasting, broadband light source available today.

USB Computer Interface

The EQ-99 Manager connects to a computer with a simple USB interface, allowing easy control and monitoring of the Laser-Driven Light Source.

LDLS Status Monitoring

Monitor the status of the LDLS, including bulb operation hours, through the USB interface or on the high visibility front-panel display.

Advanced Shutter Control

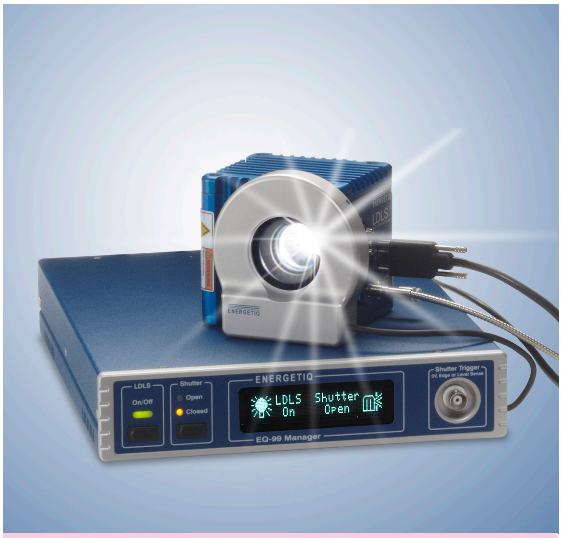
The EQ-99 Manager includes advanced shutter control with a variety of control modes and programmable shutter speed. The optional EQ-99 Shutter can be mounted to the window of the EQ-99 or directly to an optical bench.

Universal Power Supply

The EQ-99 Manager houses a universal power supply for worldwide operation without a separate power adapter.

Compatible with the Latest EQ-99 Products

The EQ-99 Manager is a smart controller designed to be used with the latest EQ-99, EQ-99FC and EQ-99CAL Laser-Driven Light Source products.



Energetiq's Laser-Driven Light Sources

The groundbreaking Laser-Driven Light Source (LDLS) is the brightest, longest lasting, broadband light source available today, making it ideal for researchers working in demanding imaging and analytical spectroscopy applications. Energetiq's patented laser-driven technology enables extreme high brightness over a broad spectral range — from 170nm through visible into the near infrared.

- Broadband light source covers the entire spectral range, eliminating the need for multiple lamps
- Extremely high brightness across the complete spectrum
- Patented laser-driven bulb technology for ultra-long lamp life
- Excellent spatial and power stability enhances repeatability
- Electrodeless operation reduces consumable costs and minimizes calibration

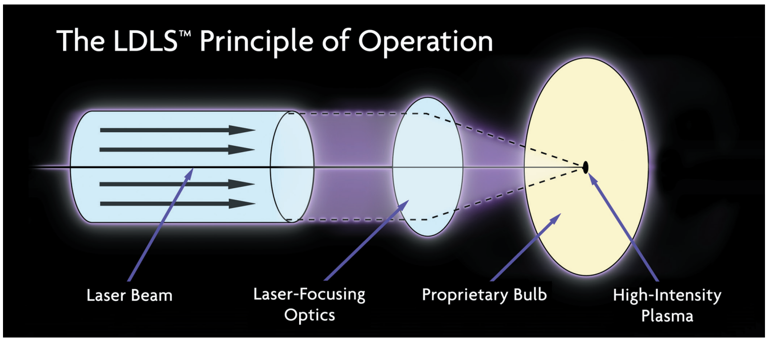
ENERGETIQ

Specifications

Physical Specifications	**Dimensions (H x W x D)**	**Weight**
• Controller	47 x 215 x 280mm (1.8 x 8.5 x 11 in.)	1.6 kg (3.4 lbs)
Utility Requirements		
• Electrical	100-240v, 50/60Hz, 2.5A	
• Compliance	CE Mark	
Shutter Performance		
• 100ms minimum exposure time, 2Hz maximum cycle rate.		

Energetiq's Laser-Driven Light Source Patented Technology

Winner of the prestigious R&D 100 Award for technological significance and the Prism Award for Photonics Innovation, Energetiq's Laser-Driven Light Source is developed with revolutionary technology that offers unprecedented brightness and long life across the complete spectrum, from 170-2100nm.



Energetiq's innovative LDLS technology uses a CW laser to directly heat a Xenon plasma to the high temperatures necessary for efficient deep ultraviolet production. In traditional approaches, brightness, UV power, and lamp life are limited by the use of electrodes to couple power to the plasma. In contrast, LDLS technology creates small, high brightness plasma without electrodes, allowing efficient collection of light, a broad spectral range from the deepest UV through visible and beyond, and long lamp life.

About Energetiq

Energetiq Technology, Inc. is a developer and manufacturer of advanced light sources that enable the analysis and manufacture nano-scale structures and products. The Energetiq team combines its deep understanding of the high power plasma physics needed for high-brightness light generation with its long experience in building rugged industrial and scientific products. The result is that users can expect the highest levels of performance combined with the highest reliability.

Energetiq Technology, Inc.
7 Constitution Way
Woburn, MA 01801
Phone: +1 781-939-0763
Fax: + 1 781-939-0769
info@energetiq.com
www.energetiq.com

Specifications are subject to change without notice.
EQ99 Manager—1/13

Model 336
Temperature Controller

Lake Shore
CRYOTRONICS

Model 336 Temperature Controller

- Operates down to 300 mK with appropriate NTC RTD sensors
- Four sensor inputs and four independent control outputs
- Two PID control loops: 100 W and 50 W into a 50 Ω or 25 Ω load
- Autotuning automatically calculates PID parameters
- Automatically switch sensor inputs using zones to allow continuous measurement and control from 300 mK to 1 505 K
- Custom display setup allows you to label each sensor input
- Ethernet, USB, and IEEE-488 interfaces
- Supports diode, RTD, and thermocouple temperature sensors
- Sensor excitation current reversal eliminates thermal EMF errors for resistance sensors
- ±10 V analog voltage outputs, alarms, and relays
- CE certification
- Full 3 year standard warranty

Introduction

The first of a new generation of innovative temperature measurement and control solutions by Lake Shore, the Model 336 temperature controller comes standard equipped with many advanced features promised to deliver the functionality and reliable service you've come to expect from the world leader in cryogenic thermometry. The Model 336 is the only temperature controller available with four sensor inputs, four control outputs and 150 W of low noise heater power. Two independent heater outputs providing 100 W and 50 W can be associated with any of the four sensor inputs and programmed for closed loop temperature control in proportional-integral-derivative (PID) mode. The improved autotuning feature of the Model 336 can be used to automatically collect PID parameters, so you spend less time tuning your controller and more time conducting experiments.

The Model 336 supports the industry's most advanced line of cryogenic temperature sensors as manufactured by Lake Shore, including diodes, resistance temperature detectors (RTDs), and thermocouples. The controller's zone tuning feature allows you to measure and control temperatures seamlessly from 300 mK to over 1,500 K by automatically switching temperature sensor inputs when your temperature range goes beyond the usable range of a given sensor. You'll never again have to be concerned with temperature sensor over or under errors and measurement continuity issues. Alarms, relays, and ±10 V analog voltage outputs are available to help automate secondary control functions.

Another innovative first from Lake Shore, the ability to custom label sensor inputs eliminates the guesswork in remembering or determining the location to which a sensor input is associated. As we strive to maintain increasingly demanding workloads, ease of use and the ability to stay connected from anywhere in the world are critical attributes. With standard Ethernet, USB, and IEEE-488 interfaces and an intuitive menu structure and logic, the Model 336 was designed with efficiency, reliable connectivity, and ease of use in mind. While you may need to leave your lab, Ethernet ensures you'll always be connected to your experiments. The new intuitive front panel layout and keypad logic, bright graphic display, and LED indicators enhance the user friendly front panel interface of the Model 336.

In many applications, the unparalleled feature set of the Model 336 allows you to replace several instruments with one, saving time, money, and valuable laboratory space. Delivering more feedback, tighter control, and faster cycle times, the Model 336 keeps up with increasingly complex temperature measurement and control applications. It is the ideal solution for general purpose to advanced laboratory applications. Put the Model 336 temperature controller to use in your lab and let it take control of your measurement environment.

Sensor inputs

The Model 336 offers four standard sensor inputs that are compatible with diode and RTD temperature sensors. The field installable Model 3060 thermocouple input option provides support for up to two thermocouple inputs by adding thermocouple functionality to inputs C and D.

Sensor inputs feature a high-resolution 24-bit analog-to-digital converter; each input has its own current source, providing fast settling times. All four sensor inputs are optically isolated from other circuits to reduce noise and to provide repeatable sensor measurements. Current reversal eliminates thermal electromotive force (EMF) errors in resistance sensors. Nine excitation currents facilitate temperature measurement and control down to 300 mK using appropriate negative temperature coefficient (NTC) RTDs. Autorange mode automatically scales excitation current in NTC RTDs to reduce self heating at low temperatures as sensor resistance changes by many orders of magnitude. Temperatures down to 1.4 K can be measured and controlled using silicon or GaAlAs diodes. Software selects the appropriate excitation current and signal gain levels when the sensor type is entered via the instrument front panel. The unique zone setting feature automatically switches sensor inputs, enabling you to measure temperatures from 300 mK to over 1 500 K without interrupting your experiment.

The Model 336 includes standard temperature sensor response curves for silicon diodes, platinum RTDs, ruthenium oxide RTDs, and thermocouples. Non-volatile memory can also store up to 39 200-point CalCurves for Lake Shore calibrated temperature sensors or user curves. A built-in SoftCal algorithm can be used to generate curves for silicon diodes and platinum RTDs that can be stored as user curves. Temperature sensor calibration data can be easily uploaded and manipulated using the Lake Shore curve handler software.

Temperature control

Providing a total of 150 W of heater power, the Model 336 is the most powerful temperature controller available. Delivering very clean heater power, it precisely controls temperature throughout the full scale temperature range for excellent measurement reliability, efficiency, and throughput. Two independent PID control outputs supplying 100 W and 50 W of heater power can be associated with any of the four standard sensor inputs. Precise control output is calculated based on your temperature setpoint and feedback from the control sensor. Wide tuning parameters accommodate most cryogenic cooling systems and many high-temperature ovens commonly used in laboratories. PID values can be manually set for fine control, or the improved autotuning feature can automate the tuning process. Autotune collects PID parameters and provides information to help build zone tables. The setpoint ramp feature provides smooth, continuous setpoint changes and predictable setpoint approaches without the worry of overshoot or excessive settling times. When combined with the zone setting feature, which enables automatic switching of sensor inputs and scales current excitation through ten different preloaded temperature zones, the Model 336 provides continuous measurement and control from 300 mK to 1505 K.

Control outputs 1 and 2 are variable DC current sources referenced to chassis ground. Output 1 can provide 100 W of continuous power to a 25 Ω load or 50 W to a 50 Ω or 25 Ω load. Output 2 provides 50 W to 25 Ω or 50 Ω heater loads. Outputs 3 and 4 are variable DC voltage source outputs providing two ±10 V analog outputs. When not in use to extend the temperature controller heater power, these outputs can function as manually controlled voltage sources.

Temperature limit settings for inputs are provided as a safeguard against system damage. Each input is assigned a temperature limit, and if any input exceeds that limit, all control channels are automatically disabled.

Interface

The Model 336 is standard equipped with Ethernet, universal serial bus (USB) and parallel (IEEE-488) interfaces. In addition to gathering data, nearly every function of the instrument can be controlled through a computer interface. You can download the Lake Shore curve handler software to your computer to easily enter and manipulate sensor calibration curves for storage in the instruments non-volatile memory.

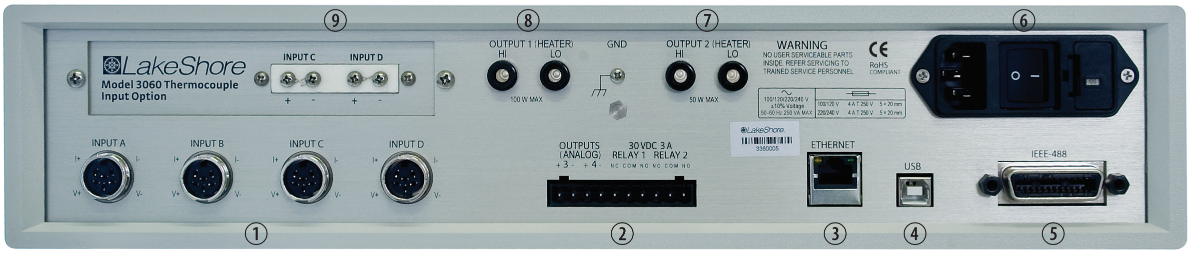
Ethernet provides the ability to access and monitor instrument activities via the internet from anywhere in the world. The USB interface emulates an RS-232C serial port at a fixed 57,600 baud rate, but with the physical connections of a USB. It also allows you to download firmware upgrades, ensuring the most current firmware version is loaded into your instrument without having to physically change anything.

Each sensor input has a high and low alarm that offer latching and non-latching operation. The two relays can be used in conjunction with the alarms to alert you of a fault condition and perform simple on/off control. Relays can be assigned to any alarm or operated manually.

The ±10 V analog voltage outputs on outputs 3 and 4 can be configured to send a voltage proportional to temperature to a strip chart recorder or data acquisition system. You may select the scale and data sent to the output, including temperature or sensor units.

① Sensor input connectors
② Terminal block (analog outputs and relays)
③ Ethernet interface
④ USB interface
⑤ IEEE-488 interface
⑥ Line input assembly
⑦ Output 2 heater
⑧ Output 1 heater
⑨ Thermocouple option inputs

Model 336 rear panel connections



Configurable display

The Model 336 offers a bright, graphic liquid crystal display with an LED backlight that simultaneously displays up to eight readings. You can show all four loops, or If you need to monitor one input, you can display just that one in greater detail. Or you can custom configure each display location to suit your experiment. Data from any input can be assigned to any of the locations, and your choice of temperature or sensor units can be displayed. For added convenience, you can also custom label each sensor input, eliminating the guesswork in remembering or determining the location to which a sensor input is associated.

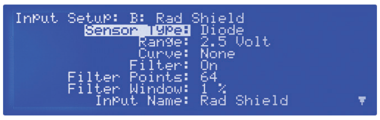
```
A: Sample Space        B: Rad Shield
      5.2014 K              27.8645 K
SP1:  5.2000 K    37%  SP2:  0.0000 K    0%
C: Magnet              D: Waste Stage
      4.6103 K              35.6387 K
SP4:  0.0000 K     0%  SP3:  0.0000 K    0%
```

Four input/output display with labels
Standard display option featuring all four inputs and associated outputs.

```
A: Sample Space         B: Rad Shield
     5.2014 K              27.8645 K

L1 A: Sample Space     P    50.0
Setp  273.000 K        I    20.0        MOut
Heat    0.00% of Low   D     0.0        0.00%
```

Two input/output display with labels
Reading locations can be user configured to meet application needs. Here, the input name is shown above each measurement reading along with the designated input letter.



```
Input Setup: B: Rad Shield
           Sensor Type: Diode
                Range: 2.5 Volt
                Curve: None
               Filter: On
        Filter Points: 64
        Filter Window: 1 %
           Input Name: Rad Shield
```

Intuitive menu structure
Logical navigation allows you to spend more time on research and less time on setup.

Model 3060 thermocouple input option

The field installable Model 3060 thermocouple input option adds thermocouple functionality to inputs C and D. While the option can be easily removed, this is not necessary as the standard inputs remain fully functional when they are not being used to measure thermocouple temperature sensors. Calibration for the option is stored on the card so it can be installed in the field and used with multiple Model 336 temperature controllers without recalibration.

Sensor selection

Sensor temperature range (sensors sold separately)

		Model	Useful range	Magnetic field use
Diodes	Silicon diode	DT-670-SD	1.4 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon diode	DT-670E-BR	30 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon diode	DT-414	1.4 K to 375 K	T ≥ 60 K & B ≤ 3 T
	Silicon diode	DT-421	1.4 K to 325 K	T ≥ 60 K & B ≤ 3 T
	Silicon diode	DT-470-SD	1.4 K to 500 K	T ≥ 60 K & B ≤ 3 T
	Silicon diode	DT-471-SD	10 K to 500 K	T ≥ 60 K & B ≤ 3 T
	GaAlAs diode	TG-120-P	1.4 K to 325 K	T > 4.2 K & B ≤ 5 T
	GaAlAs diode	TG-120-PL	1.4 K to 325 K	T > 4.2 K & B ≤ 5 T
	GaAlAs diode	TG-120-SD	1.4 K to 500 K	T > 4.2 K & B ≤ 5 T
Positive temperature coefficient RTDs	100 Ω platinum	PT-102/3	14 K to 873 K	T > 40 K & B ≤ 2.5 T
	100 Ω platinum	PT-111	14 K to 673 K	T > 40 K & B ≤ 2.5 T
	Rhodium-iron	RF-800-4	1.4 K to 500 K	T > 77 K & B ≤ 8 T
	Rhodium-iron	RF-100T/U	1.4 K to 325 K	T > 77 K & B ≤ 8 T
Negative temperature coefficient RTDs	Cernox™	CX-1010	0.3 K to 325 K[1]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1030-HT	0.3 K to 420 K[1, 3]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1050-HT	1.4 K to 420 K[1]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1070-HT	4 K to 420 K[1]	T > 2 K & B ≤ 19 T
	Cernox™	CX-1080-HT	20 K to 420 K[1]	T > 2 K & B ≤ 19 T
	Germanium	GR-300-AA	0.35 K to 100 K[3]	Not recommended
	Germanium	GR-1400-AA	1.8 K to 100 K[3]	Not recommended
	Carbon-glass	CGR-1-500	1.4 K to 325 K	T > 2 K & B ≤ 19 T
	Carbon-glass	CGR-1-1000	1.7 K to 325 K[2]	T > 2 K & B ≤ 19 T
	Carbon-glass	CGR-1-2000	2 K to 325 K[2]	T > 2 K & B ≤ 19 T
	Rox™	RX-102	0.3 K to 40 K[3]	T > 2 K & B ≤ 10 T
	Rox™	RX-103	1.4 K to 40 K	T > 2 K & B ≤ 10 T
	Rox™	RX-202	0.3 K to 40 K[3]	T > 2 K & B ≤ 10 T
Thermocouples *Option—3060*	Type K	9006-006	3.2 K to 1505 K	Not recommended
	Type E	9006-004	3.2 K to 934 K	Not recommended
	Chromel-AuFe 0.07%	9006-002	1.2 K to 610 K	Not recommended

[1] Non-HT version maximum temperature: 325 K
[2] Low temperature limited by input resistance range
[3] Low temperature specified with self-heating error: ≤ 5 mK

Silicon diodes are the best choice for general cryogenic use from 1.4 K to above room temperature. Silicon diodes are economical to use because they follow a standard curve and are interchangeable in many applications. They are not suitable for use in ionizing radiation or magnetic fields.

Cernox™ thin-film RTDs offer high sensitivity and low magnetic field-induced errors over the 0.3 K to 420 K temperature range. Cernox sensors require calibration.

Platinum RTDs offer high uniform sensitivity from 30 K to over 800 K. With excellent reproducibility, they are useful as thermometry standards. They follow a standard curve above 70 K and are interchangeable in many applications.

Typical sensor performance

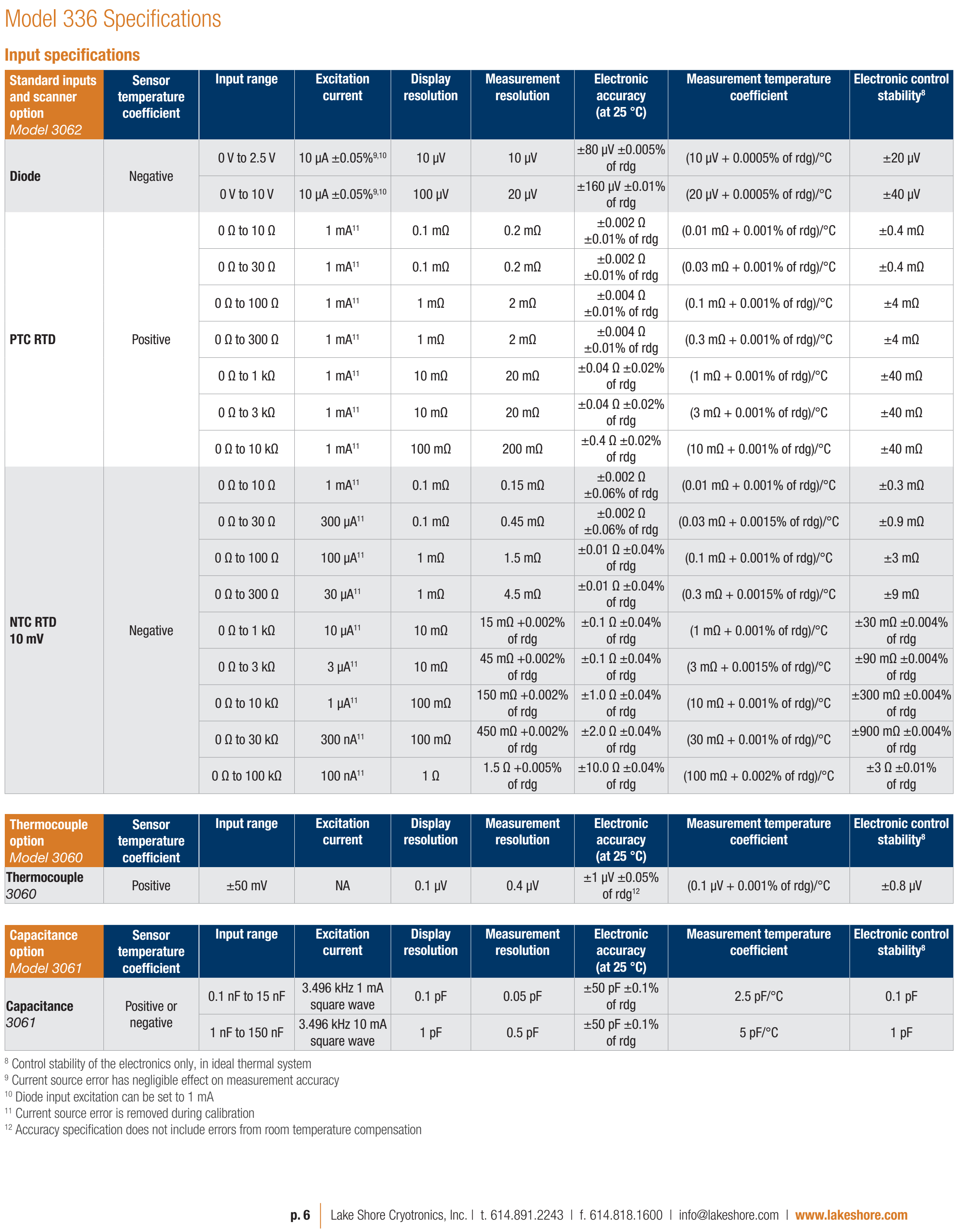
	Example Lake Shore sensor	Temperature	Nominal resistance/ voltage	Typical sensor sensitivity[4]	Measurement resolution: temperature equivalents	Electronic accuracy: temperature equivalents	Temperature accuracy including electronic accuracy, Calcurve™, and calibrated sensor	Electronic control stability[5]: temperature equivalents
Silicon diode	DT-670-CO-13 with 1.4H calibration	1.4 K	1.664 V	-12.49 mV/K	0.8 mK	±13 mK	±25 mK	±1.6 mK
		77 K	1.028 V	-1.73 mV/K	5.8 mK	±76 mK	±98 mK	±11.6 mK
		300 K	0.5596 V	-2.3 mV/K	4.3 mK	±47 mK	±79 mK	±8.7 mK
		500 K	0.0907 V	-2.12 mV/K	4.7 mK	±40 mK	±90 mK	±9.4 mK
Silicon diode	DT-470-SD-13 with 1.4H calibration	1.4 K	1.6981 V	-13.1 mV/K	0.8 mK	±13 mK	±25 mK	±1.6 mK
		77 K	1.0203 V	-1.92 mV/K	5.2 mK	±68 mK	±90 mK	±10.4 mK
		300 K	0.5189 V	-2.4 mV/K	4.2 mK	±44 mK	±76 mK	±8.4 mK
		475 K	0.0906 V	-2.22 mV/K	4.5 mK	±38 mK	±88 mK	±9 mK
GaAIAs diode	TG-120-SD with 1.4H calibration	1.4 K	5.391 V	-97.5 mV/K	0.2 mK	±8.8 mK	±21 mK	±0.4 mK
		77 K	1.422 V	-1.24 mV/K	16 mK	±373 mK	±395 mK	±32 mK
		300 K	0.8978 V	-2.85 mV/K	7 mK	±144 mK	±176 mK	±14 mK
		475 K	0.3778 V	-3.15 mV/K	6.4 mK	±114 mK	±164 mK	±12.6 mK
100 Ω platinum RTD 500 Ω full scale	PT-103 with 14J calibration	30 K	3.660 Ω	0.191 Ω/K	1.1 mK	±13 mK	±23 mK	±2.2 mK
		77 K	20.38 Ω	0.423 Ω/K	0.5 mK	±10 mK	±22 mK	±1.0 mK
		300 K	110.35 Ω	0.387 Ω/K	5.2 mK	±39 mK	±62 mK	±10.4 mK
		500 K	185.668 Ω	0.378 Ω/K	5.3 mK	±60 mK	±106 mK	±10.6 mK
Cernox™	CX-1010-SD with 0.3L calibration	0.3 K	2322.4 Ω	-10785 Ω/K	8.5 µK	±0.1 mK	±3.6 mK	±17 µK
		0.5 K	1248.2 Ω	-2665.2 Ω/K	26 µK	±0.2 mK	±4.7 mK	±52 µK
		4.2 K	277.32 Ω	-32.209 Ω/K	140 µK	±3.8 mK	±8.8 mK	±280 µK
		300 K	30.392 Ω	-0.0654 Ω/K	23 mK	±339 mK	±414 mK	±46 mK
Cernox™	CX-1050-SD-HT[6] with 1.4M calibration	1.4 K	26566 Ω	-48449 Ω/K	20 µK	±0.3 mK	±5.3 mK	±40 µK
		4.2 K	3507.2 Ω	-1120.8 Ω/K	196 µK	±2.1 mK	±7.1 mK	±392 µK
		77 K	205.67 Ω	-2.4116 Ω/K	1.9 mK	±38 mK	±54 mK	±3.8 mK
		420 K	45.03 Ω	-0.0829 Ω/K	18 mK	±338 mK	±403 mK	±36 mK
Germanium	GR-300-AA with 0.3D calibration	0.35 K	18225 Ω	-193453 Ω/K	4 µK	±48 µK	±4.2 mK	±8 µK
		1.4 K	449 Ω	-581 Ω/K	41 µK	±481 µK	±4.7 mK	±82 µK
		4.2 K	94 Ω	-26.6 Ω/K	56 µK	±1.8 mK	±6.8 mK	±112 µK
		100 K	2.7 Ω	-0.024 Ω/K	6.3 mK	±152 mK	±175 mK	±12.6 mK
Germanium	GR-1400-AA with 1.4D calibration	1.8 K	15288 Ω	-26868 Ω/K	28 µK	±302 µK	±4.5 mK	±56 µK
		4.2 K	1689 Ω	-862 Ω/K	91 µK	±900 µK	±5.1 mK	±182 µK
		10 K	253 Ω	-62.0 Ω/K	73 µK	±1.8 mK	±6.8 mK	±146 µK
		100 K	2.8 Ω	-0.021 Ω/K	7.1 mK	±177 mK	±200 mK	±14.2 mK
Carbon-glass	CGR-1-500 with 1.4L calibration	1.4 K	103900 Ω	-520000 Ω/K	13 µK	±0.1 mK	±4.1 mK	±26 µK
		4.2 K	584.6 Ω	-422.3 Ω/K	63 µK	±0.8 mK	±4.8 mK	±126 µK
		77 K	14.33 Ω	-0.098 Ω/K	4.6 mK	±108 mK	±133 mK	±9.2 mK
		300 K	8.55 Ω	-0.0094 Ω/K	16 mK	±760 mK	±865 mK	±32 mK
Rox™	RX-102A-AA with 0.3B calibration	0.5 K	3701 Ω	-5478 Ω/K	41 µK	±0.5 mK	±5 mK	±82 µK
		1.4 K	2005 Ω	-667 Ω/K	128 µK	±1.4 mK	±6.4 mK	±256 µK
		4.2 K	1370 Ω	-80.3 Ω/K	902 µK	±8 mK	±24 mK	±1.8 mK
		40 K	1049 Ω	-1.06 Ω/K	62 mK	±500 mK	±537 mK	±124 mK
Thermocouple 50 mV *Option—3060*	Type K	75 K	-5862.9 µV	15.6 µV/K	26 mK	±0.25 K[7]	Calibration not available from Lake Shore	±52 mK
		300 K	1075.3 µV	40.6 µV/K	10 mK	±0.038 K[7]		±19.6 mK
		600 K	13325 µV	41.7 µV/K	10 mK	±0.184 K[7]		±20 mK
		1505 K	49998.3 µV	36.0 µV/K	11 mK	±0.73 K[7]		±22 mK
Capacitance *Option—3061*	CS-501	4.2 K	6.0 nF	27 pF/K	1.9 mK	NA	Calibration not available from Lake Shore	±3.8 mK
		77 K	9.1 nF	52 pF/K	1.0 mK			±2.0 mK
		200 K	19.2 nF	174 pF/K	2.9 mK			±5.8 mK

[4] Typical sensor sensitivities were taken from representative calibrations for the sensor listed

[5] Control stability of the electronics only, in an ideal thermal system

[6] Non-HT version maximum temperature: 325 K

[7] Accuracy specification does not include errors from room temperature compensation



Model 336 Specifications

Input specifications

Standard inputs and scanner option *Model 3062*	**Sensor temperature coefficient**	**Input range**	**Excitation current**	**Display resolution**	**Measurement resolution**	**Electronic accuracy (at 25 °C)**	**Measurement temperature coefficient**	**Electronic control stability[8]**
Diode	Negative	0 V to 2.5 V	10 µA ±0.05%[9,10]	10 µV	10 µV	±80 µV ±0.005% of rdg	(10 µV + 0.0005% of rdg)/°C	±20 µV
		0 V to 10 V	10 µA ±0.05%[9,10]	100 µV	20 µV	±160 µV ±0.01% of rdg	(20 µV + 0.0005% of rdg)/°C	±40 µV
PTC RTD	Positive	0 Ω to 10 Ω	1 mA[11]	0.1 mΩ	0.2 mΩ	±0.002 Ω ±0.01% of rdg	(0.01 mΩ + 0.001% of rdg)/°C	±0.4 mΩ
		0 Ω to 30 Ω	1 mA[11]	0.1 mΩ	0.2 mΩ	±0.002 Ω ±0.01% of rdg	(0.03 mΩ + 0.001% of rdg)/°C	±0.4 mΩ
		0 Ω to 100 Ω	1 mA[11]	1 mΩ	2 mΩ	±0.004 Ω ±0.01% of rdg	(0.1 mΩ + 0.001% of rdg)/°C	±4 mΩ
		0 Ω to 300 Ω	1 mA[11]	1 mΩ	2 mΩ	±0.004 Ω ±0.01% of rdg	(0.3 mΩ + 0.001% of rdg)/°C	±4 mΩ
		0 Ω to 1 kΩ	1 mA[11]	10 mΩ	20 mΩ	±0.04 Ω ±0.02% of rdg	(1 mΩ + 0.001% of rdg)/°C	±40 mΩ
		0 Ω to 3 kΩ	1 mA[11]	10 mΩ	20 mΩ	±0.04 Ω ±0.02% of rdg	(3 mΩ + 0.001% of rdg)/°C	±40 mΩ
		0 Ω to 10 kΩ	1 mA[11]	100 mΩ	200 mΩ	±0.4 Ω ±0.02% of rdg	(10 mΩ + 0.001% of rdg)/°C	±40 mΩ
NTC RTD 10 mV	Negative	0 Ω to 10 Ω	1 mA[11]	0.1 mΩ	0.15 mΩ	±0.002 Ω ±0.06% of rdg	(0.01 mΩ + 0.001% of rdg)/°C	±0.3 mΩ
		0 Ω to 30 Ω	300 µA[11]	0.1 mΩ	0.45 mΩ	±0.002 Ω ±0.06% of rdg	(0.03 mΩ + 0.0015% of rdg)/°C	±0.9 mΩ
		0 Ω to 100 Ω	100 µA[11]	1 mΩ	1.5 mΩ	±0.01 Ω ±0.04% of rdg	(0.1 mΩ + 0.001% of rdg)/°C	±3 mΩ
		0 Ω to 300 Ω	30 µA[11]	1 mΩ	4.5 mΩ	±0.01 Ω ±0.04% of rdg	(0.3 mΩ + 0.0015% of rdg)/°C	±9 mΩ
		0 Ω to 1 kΩ	10 µA[11]	10 mΩ	15 mΩ +0.002% of rdg	±0.1 Ω ±0.04% of rdg	(1 mΩ + 0.001% of rdg)/°C	±30 mΩ ±0.004% of rdg
		0 Ω to 3 kΩ	3 µA[11]	10 mΩ	45 mΩ +0.002% of rdg	±0.1 Ω ±0.04% of rdg	(3 mΩ + 0.0015% of rdg)/°C	±90 mΩ ±0.004% of rdg
		0 Ω to 10 kΩ	1 µA[11]	100 mΩ	150 mΩ +0.002% of rdg	±1.0 Ω ±0.04% of rdg	(10 mΩ + 0.001% of rdg)/°C	±300 mΩ ±0.004% of rdg
		0 Ω to 30 kΩ	300 nA[11]	100 mΩ	450 mΩ +0.002% of rdg	±2.0 Ω ±0.04% of rdg	(30 mΩ + 0.001% of rdg)/°C	±900 mΩ ±0.004% of rdg
		0 Ω to 100 kΩ	100 nA[11]	1 Ω	1.5 Ω +0.005% of rdg	±10.0 Ω ±0.04% of rdg	(100 mΩ + 0.002% of rdg)/°C	±3 Ω ±0.01% of rdg

Thermocouple option *Model 3060*	**Sensor temperature coefficient**	**Input range**	**Excitation current**	**Display resolution**	**Measurement resolution**	**Electronic accuracy (at 25 °C)**	**Measurement temperature coefficient**	**Electronic control stability[8]**
Thermocouple *3060*	Positive	±50 mV	NA	0.1 µV	0.4 µV	±1 µV ±0.05% of rdg[12]	(0.1 µV + 0.001% of rdg)/°C	±0.8 µV

Capacitance option *Model 3061*	**Sensor temperature coefficient**	**Input range**	**Excitation current**	**Display resolution**	**Measurement resolution**	**Electronic accuracy (at 25 °C)**	**Measurement temperature coefficient**	**Electronic control stability[8]**
Capacitance *3061*	Positive or negative	0.1 nF to 15 nF	3.496 kHz 1 mA square wave	0.1 pF	0.05 pF	±50 pF ±0.1% of rdg	2.5 pF/°C	0.1 pF
		1 nF to 150 nF	3.496 kHz 10 mA square wave	1 pF	0.5 pF	±50 pF ±0.1% of rdg	5 pF/°C	1 pF

[8] Control stability of the electronics only, in ideal thermal system

[9] Current source error has negligible effect on measurement accuracy

[10] Diode input excitation can be set to 1 mA

[11] Current source error is removed during calibration

[12] Accuracy specification does not include errors from room temperature compensation

Sensor input configuration

	Diode/RTD	Thermocouple
Measurement type	4-lead differential	2-lead differential, room temperature compensated
Excitation	Constant current with current reversal for RTDs	NA
Supported sensors	**Diodes:** Silicon, GaAlAs **RTDs:** 100 Ω Platinum, 1000 Ω Platinum, Germanium, Carbon-Glass, Cernox™, and Rox™	Most thermocouple types
Standard curves	DT-470, DT-670, DT-500-D, DT-500-E1, PT-100, PT-1000, RX-102A, RX-202A	Type E, Type K, Type T, AuFe 0.07% vs. Cr, AuFe 0.03% vs. Cr
Input connector	6-pin DIN	Screw terminals in a ceramic isothermal block

Thermometry

Number of inputs 4 (8 with scanner option)

Input configuration Inputs can be configured from the front panel to accept any of the supported input types. Thermocouple and capacitance inputs require an optional input card that can be installed in the field.

Supported option cards Thermocouple (3060), capacitance (3061), or scanner (3062)

Option slots 1

Isolation Sensor inputs optically isolated from other circuits but not each other

A/D resolution 24-bit

Input accuracy Sensor dependent, refer to Input Specifications table

Measurement resolution Sensor dependent, refer to Input Specifications table

Maximum update rate 10 rdg/s on each input, 5 rdg/s when configured as 100 kΩ NTC RTD with reversal on, 2 rdg/s on each scanned input (scanner option only)

Autorange Automatically selects appropriate NTC RTD or PTC RTD range

User curves Room for 39 200-point CalCurves™ or user curves

SoftCal™ Improves accuracy of DT-470 diode to ±0.25 K from 30 K to 375 K; improves accuracy of platinum RTDs to ±0.25 K from 70 K to 325 K; stored as user curves

Math Maximum and minimum

Filter Averages 2 to 64 input readings

Control

Control outputs 4

Heater outputs (Outputs 1 & 2)

Control type Closed loop digital PID with manual heater output or open loop

Update rate 10/s

Tuning Autotune (one loop at a time), PID, PID zones

Control stability Sensor dependent, see Input Specifications table

PID control settings

Proportional (gain) 0 to 1000 with 0.1 setting resolution
Integral (reset) 1 to 1000 (1000/s) with 0.1 setting resolution
Derivative (rate) 1 to 200% with 1% resolution
Manual output 0 to 100% with 0.01% setting resolution

Zone control 10 temperature zones with P, I, D, manual heater out, heater range, control channel, ramp rate

Setpoint ramping 0.1 K/min to 100 K/min

Output 1

	25 Ω setting	50 Ω setting
Type	Variable DC current source	
D/A resolution	16-bit	
Max power	100 W	50 W
Max current	2 A	1 A
Voltage compliance	50 V	50 V
Heater load for max power	25 Ω	50 Ω
Heater load range	10 Ω to 100 Ω	
Ranges	3 (decade steps in power)	
Heater noise	0.12 µA RMS (dominated by line frequency and its harmonics)	
Grounding	Output referenced to chassis ground	
Heater connector	Dual banana	
Safety limits	Curve temperature, power up heater off, short circuit protection	

Output 2

	25 Ω setting	50 Ω setting
Type	Variable DC current source	
D/A resolution	16-bit	
Max power	50 W	50 W
Max current	1.41 A	1 A
Voltage compliance	35.4 V	50 V
Heater load for max power	25 Ω	50 Ω
Heater load range	10 Ω to 100 Ω	
Ranges	3 (decade steps in power)	
Heater noise	0.12 µA RMS (dominated by line frequency and its harmonics)	
Grounding	Output referenced to chassis ground	
Heater connector	Dual banana	
Safety limits	Curve temperature, power up heater off, short circuit protection	

Unpowered analog outputs (Outputs 3 & 4)

Control type Closed loop PID, PID zones, warm up heater mode, manual output, or monitor output

Tuning Autotune (one loop at a time), PID, PID zones

Control stability Sensor dependent, see Input Specifications table

PID control settings

Proportional (gain) 0 to 1000 with 0.1 setting resolution
Integral (reset) 1 to 1000 (1000/s) with 0.1 setting resolution
Derivative (rate) 1 to 200% with 1% resolution
Manual output 0 to 100% with 0.01% setting resolution

Zone control 10 temperature zones with P, I, D, manual heater out, heater range, control channel, ramp rate

Setpoint ramping 0.1 K/min to 100 K/min

Warm up heater mode settings

Warm up percentage 0 to 100% with 1% resolution
Warm up mode Continuous control or auto-off

Monitor output settings

Scale User selected
Data source Temperature or sensor units
Settings Input, source, top of scale, bottom of scale, or manual

Type Variable DC voltage source

Update rate 10/s

Range ±10 V

Resolution 16-bit, 0.3 mV

Accuracy ±2.5 mV

Noise 0.3 mV RMS

Minimum load resistance 1 kΩ (short-circuit protected)

Connector Detachable terminal block

Front panel

Display 8-line by 40-character (240 × 64 pixel) graphic LCD display module with LED backlight

Number of reading displays 1 to 8

Display units K, °C, V, mV, Ω

Reading source Temperature, sensor units, max, and min

Display update rate 2 rdg/s

Temperature display resolution 0.0001° from 0° to 99.9999°, 0.001° from 100° to 999.999°, 0.01° above 1000°

Sensor units display resolution Sensor dependent, to 6 digits

Other displays Input name, setpoint, heater range, heater output, and PID

Setpoint setting resolution Same as display resolution (actual resolution is sensor dependent)

Heater output display Numeric display in percent of full scale for power or current

Heater output resolution 0.01%

Display annunciators Control input, alarm, tuning

LED annunciators Remote, Ethernet status, alarm, control outputs

Keypad 27-key silicone elastomer keypad

Front panel features Front panel curve entry, display contrast control, and keypad lock-out

Interface

IEEE-488.2

Capabilities	SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT0, C0, E1
Reading rate	To 10 rdg/s on each input
Software support	LabVIEW™ driver (see www.lakeshore.com)

USB

Function	Emulates a standard RS-232 serial port
Baud rate	57,600
Connector	B-type USB connector
Reading rate	To 10 rdg/s on each input
Software support	LabVIEW™ driver (see www.lakeshore.com)

Ethernet

Function	TCP/IP, web interface, curve handler, configuration backup, chart recorder
Connector	RJ-45
Reading rate	To 10 rdg/s on each input
Software support	LabVIEW™ driver (see www.lakeshore.com)

Alarms

Number	4, high and low for each input
Data source	Temperature or sensor units
Settings	Source, high setpoint, low setpoint, deadband, latching or non-latching, audible on/off, and visible on/off
Actuators	Display annunciator, beeper, and relays

Relays

Number	2
Contacts	Normally open (NO), normally closed (NC), and common (C)
Contact rating	30 VDC at 3 A
Operation	Activate relays on high, low, or both alarms for any input, or manual mode
Connector	Detachable terminal block

General

Ambient temperature 15 °C to 35 °C at rated accuracy; 5 °C to 40 °C at reduced accuracy

Power requirement 100, 120, 220, 240 VAC, ±10%, 50 or 60 Hz, 250 VA

Size 435 mm W × 89 mm H × 368 mm D (17 in × 3.5 in × 14.5 in), full rack

Weight 7.6 kg (16.8 lb)

Approval CE mark, RoHS

Ordering information

Part number	Description
336	4 diode/RTD inputs and 4 control outputs, including one dual banana jack heater input connector (106-009), four 6-pin DIN plug sensor input mating connectors (G-106-233), one 10-pin terminal block (G-106-750), a calibration certificate and a user's manual
336-3060	Model 336 with a 3060 option card installed
336-3061	Model 336 with a 3061 option card installed
336-3062	Model 336 with a 3062 option card installed
3060	2-thermocouple input option, uninstalled
3061	Capacitance input option for 350/336, uninstalled
3062	4-channel scanner option for diodes and RTD sensors for 350/336, uninstalled

Please indicate your power/cord configuration:

1 100 V—U.S. cord (NEMA 5-15)
2 120 V—U.S. cord (NEMA 5-15)
3 220 V—Euro cord (CEE 7/7)
4 240 V—Euro cord (CEE 7/7)
5 240 V—U.K. cord (BS 1363)
6 240 V—Swiss cord (SEV 1011)
7 220 V—China cord (GB 1002)

Accessories

6201	1 m (3.3 ft long) IEEE-488 (GPIB) computer interface cable assembly
8001-336	CalCurve™, factory installed—the breakpoint table from a calibrated sensor stored in the instrument (extra charge for additional sensor curves)
CAL-336-CERT	Instrument recalibration with certificate
CAL-336-DATA	Instrument recalibration with certificate and data

All specifications are subject to change without notice

EDWARDS

PRODUCT CATALOGUE

2014

WWW.EDWARDSVACUUM.COM

WRG Active Wide Range Gauge

The Wide Range Gauge (WRG) family offers the capability of single port pressure measurement in the range atmosphere to 10^{-9} mbar with a linear output. Its a compact solution, halving the space and connectivity hardware requirement, which can be all important in many applications. The WRG has many novel features, including a new patented striker, pushbutton calibration and set point controls and comprehensive diagnostics. The WRG is a cost-effective vacuum management solution when used either with a Edwards controller or directly integrated into the system controls.

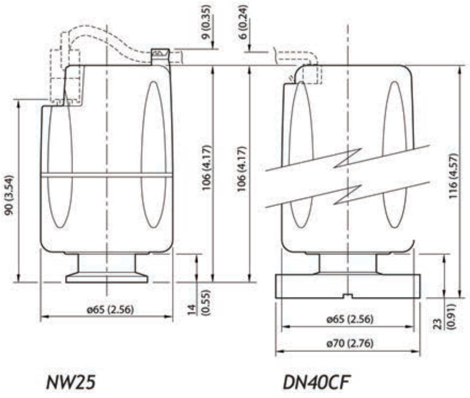
Features & Benefits

- Microprocessor signal processing gives seamless transition between Pirani and magnetron outputs as well as linear output (log pressure scale)
- D-type version including cable strain relief and enhanced ingress protection - IP44
- Low magnetic field version (SL) available for sensitive applications e.g. mass spectrometry and electron microscopy
- Easily programmed set point covering entire measuring range
- Magnetron uses an advanced patented technique for highly reliable striking, even at high vacuum or in relatively contaminated conditions

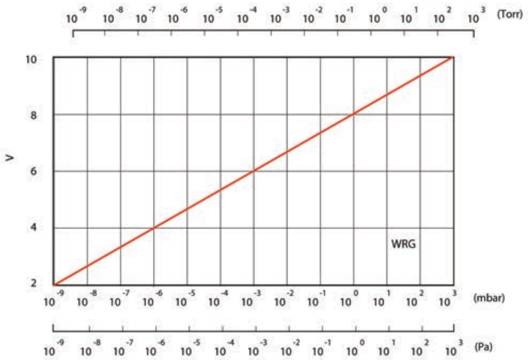
Applications

- Any vacuum system where there is a need to measure pressure over a wide range. The WRG with an AGD represents a very simple and cost effective means of achieving this.
- The linear output and equation make WRG's an attractive option for industrial OEM's where the gauge may be directly integrated into the process controller.
- The WRG is suitable for a wide range of HV and UHV applications, however if your process will spend a significant amount of time between $5x10^{-4}$ and $5x10^{-3}$ mbar then Edwards recommend using independent APG100 Pirani and AIM Penning gauges, as this will improve gauge reliability for your application.

Dimensions



Performance Curves



Technical Data

Pressure range	Atmosphere to 10^{-9} mbar/Torr
Accuracy *	Typically ±15% <100 mbar and ±30%<10^{-3} mbar
Maximum over pressure	6 bar absolute (87 psia)
Power supply	+14.5 to +36 V d.c.
Power consumption	2 W maximum
Output signal	1.8 to 10.2 V d.c.
Adjustments	Atmosphere and setpoint
Set point	Open collector transistor
Maximum voltage	40 V d.c.
Current	100 mA maximum
Temperature range	
Operating	+5 to +60 °C
Storage	0 to +70 °C
Materials exposed to vacuum (Both NW and CF versions)	Stainless steel (AISI 304, 316, 321, 347), Fluoroelastomer, soda lime glass, Tungsten, trace of Nickel and Nickel Iron
Internal volume	26 cm^3
Weight	0.8 kg
External interface connector	8-way FCC68 / RJ45 Socket
Interface cables	Use range of active gauge cables
Standards	
Electromagnetic compatibility	EN 61326 Industrial Location, Class B emissions
Enclosure rating	IP40

Pin allocation **

1. Power supply positive
2. Power supply common
3. Gauge output
4. Gauge identification
5. Signal common
6. Set-point output
7. Atmosphere calibration
8. Not connected

* Accuracy is reduced at the limits of the measuring range.
** Not shown on diagram

Ordering Information

Product Description	Order No.
WRG-S-NW25	D14701000
WRG-S-DN40CF	D14703000
WRG-S-NW25, Certificated	D1470100C
WRG-S-DN40CF, Certificated	D1470300C
WRG-D-NW25	D14702000
WRG-SL-NW25	D14711000
WRG-SL-NW25, Certificated	D1471100C

Accessories & Spares	Order No.
0.5M Active Gauge Cable	D40001005
100M Active Gauge Cable Assembly	D40001999
10M Active Gauge Cable	D40001100
15M Active Gauge Cable	D40001150
1M Active Gauge Cable	D40001010
25M Active Gauge Cable	D40001250
3M Active Gauge Cable	D40001030
50M Active Gauge Cable	D40001500
5M Active Gauge Cable	D40001050
NW25 Centering Ring 3D Baffle Viton	D02110000
Spares Kit WRG Electrode Assy	D14701802
Spares Kit WRG Full Body Tube	D14701804
Spares Kit WRG Pirani Tube	D14701803
Surge Protector Box	D40006000
WRG Body Tube Assy DN40CF	D14703801
WRG Body Tube Assy NW25	D14701801
WRG D Adapter Cable 9-Way D/Fcc68	D40003100
WRG-D Elect & Mag Housing NW25	D14702800
WRG-S Elect & Mag Housing NW25	D14701800
WRG-SL Elect & Mag Housing NW25	D14711800

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