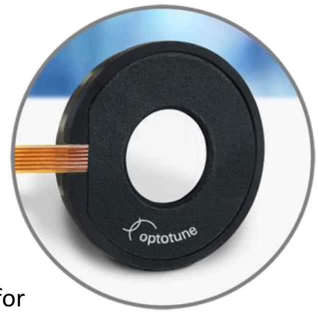


Electrically tunable lens EL-12-30-TC

The compact EL-12-30-TC lens is designed for OEM integration into optical systems for various applications. The working principle is based on the well-established shape-changing lens technology. The curvature of the lens is adjusted by applying an electrical current. Thereby, the focal length is tuned to a desired value within a few milliseconds. The lens architecture is “push pull” which means that the lens curvature is deflected from concave to convex. With actuators based on proven voice-coil technology, the EL-12-30-TC focus tunable lens is extremely reliable and robust, well suited even for applications in harsh environments over large temperature ranges.

Lens specifications

Clear aperture	11.6	mm
Focal power range: (25°C, ±250 mA)	-6 to +10	dpt
Focal power @ 0 mA (25°C, typical)	-1 to +2	dpt
Transmission range	VIS: 450 to 1050	nm
Wavefront error @ 0 dpt (Optical axis vertical / horizontal)	0.15 / 0.23	λ RMS @ 532 nm
Lens type	plano-concave to plano-convex	
Refractive index / Abbe number	$n_D = 1.45$ / $\nu = 55$	
Response time (typ. at 25°C, 0 to ±250 mA step)	3	ms
Settling time (typ. at 25°C, 0 to ±250 mA step, ±0.1 dpt)	10 (with signal conditioning) 20 (rectangular step)	ms
Lifecycles (-200mA to + 200mA, sinusoidal, 20Hz)	> 1’000’000’000	
Operating temperature	-20 to 65	°C
Storage temperature	-40 to 85	°C
Weight	10.5	g

Electrical specifications

Nominal control current	-250 to 250	mA
Absolute max. control current	-300 to 300	mA
Motor coil resistance @ 25°C	15	Ω
Power consumption for 5 dpt range (±60mA)	55	mW
Max power consumption (@ 250 mA)	940	mW
Memory	ON Semiconductor: CAT24C64C4CTR (or similar)	
Temperature sensor	Maxim Integrated: MAX31875R2TZS+T (or similar)	
Absolute maximum voltage (coil)	6	V
Absolute maximum voltage (memory & sensor)	4	V

Overview of available standard products

Standard Product [1]	Tuning Range	Top Thread	Bottom Thread	Controller
EL-12-30-TC-VIS-16D	-6 to 10 dpt	None	None	-
EL-12-30-TC-VIS-16D-C	-6 to 10 dpt	C-mount male	C-mount female	-
EL-12-30-TC-VIS-16D-C-E				ECC-1C in Hirose adapter

1 All models are available with NIR coating or custom coating upon request

Liquid lens working principle

The working principle of the EL-12-30-TC is based on Optotune's well-established technology of shape-changing polymer lenses. The core that forms the lens contains an optical fluid, which is sealed off with an elastic polymer membrane as shown in Figure 1. An electromagnetic actuator is used to exert pressure on the container and therefore changes the curvature of the lens. By changing the electrical current flowing through the coil of the actuator, the focal power of the lens is controlled.

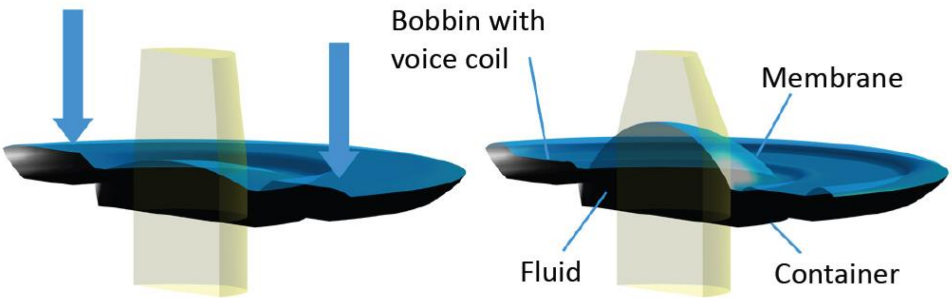


Figure 1: Working principle of the sealed lens container filled with an optical fluid and embedded in an EL-12-30-TC housing.

Mechanical Layout

The EL-12-30-TC comes with a steel top return structure and an LCP base. The electrical connection and communication with the controller is established via an FFC cable at the side. The relevant mechanical drawings are depicted in Figure 2.

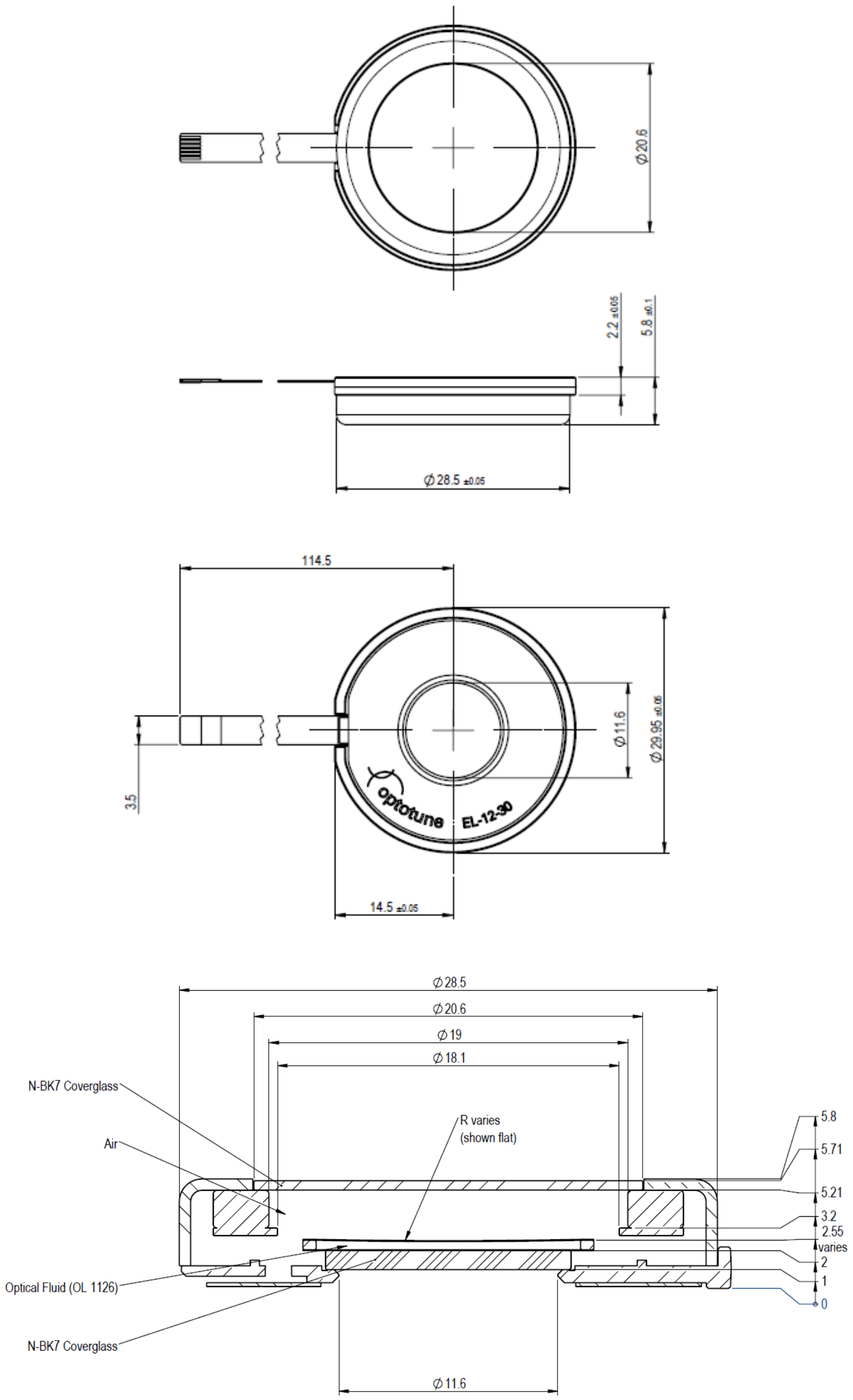


Figure 2: Mechanical drawing of the EL-12-30 in its most simple version, the EL-12-30-TC-VIS-16D without any thread adapters attached (unit: mm)

For easier integration in an optical system the EL-12-30 alternatively comes in a M40.5x0.5 tube offering C-mount top and bottom adapters, see Figure 3. The adapter is rotatable and lockable with one setscrew. The extension on the side of the thread adapter provides a 6-pin Hirose connector (HR10G-7R-6P), making it suitable for harsh environmental conditions.

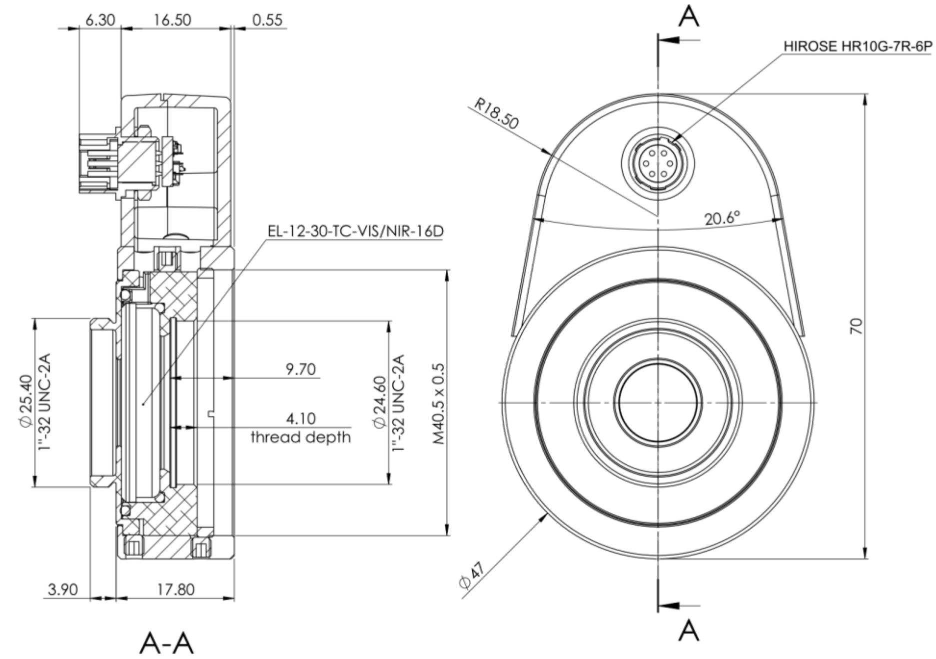
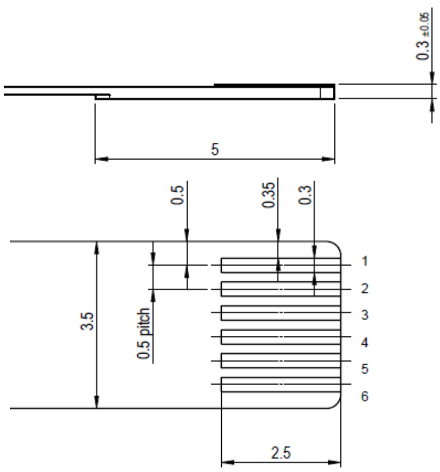


Figure 3: Mechanical drawing of the EL-12-30-TC-VIS/NIR-16D-C

Electrical connection

The electrical connection of the EL-12-30-TC without adapters consists of a FPC flex cable with 6 pins suitable for Molex connector no. 503480-0600 or equivalent. Two pins are for the coil of the lens, the other four pins are for the I²C connection to the temperature sensor and EEPROM.



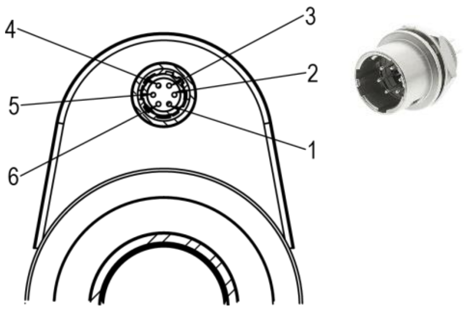
Pin out: EL-12-30-TC		
Position	Function	Value
1	GND	-
2	Max. control current -	-300 to 300 mA
3	Max. control current +	-300 to 300 mA
4	I²C SDA	Digital signal
5	I²C SCL	Digital signal
6	Vcc	3.3 V

Figure 4: Electrical flex connections of the EL-12-30-TC

Component:	Temperature Sensor	EERPROM
I^{2}C Address	Maxim Integrated: MAX31875R2TZS+T	ON Semiconductor: CAT24C64C4CTR
BIN	0b 1001 010x	0b 1010 000x
HEX	W: 0x94; R: 0x95	W: 0xA0; R: 0xA1
DEC	W: 148; R: 149	W: 160; R: 161

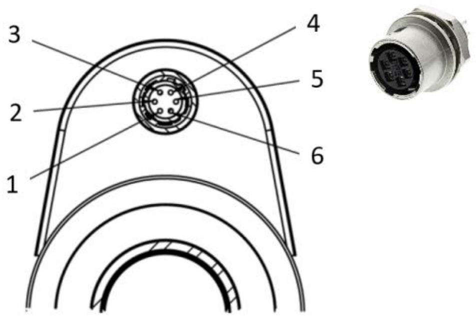
Figure 5: Electrical components and addresses

The industrial version of the EL-12-30-TC provides connection through 6-pin Hirose connectors, whereas the type of connector indicates whether a controller is embedded in the Hirose adapter or not, as shown in the figures below:



Pin out Hirose connector HR10G-7R-6PB(73)		
Position	**Function**	**Sensor pins**
1	Max. control current +	-
2	Max. control current -	-
3	GND	1-4
4	Vcc	8
5	I^{2}C SCL	6
6	I^{2}C SDA	5

Figure 6: Electrical connections of lens models without embedded controller featuring (male) Hirose connector.



Pin out Hirose connector HR10G-7R-6SB(73)		
Position	**Function**	**Value**
1	GPIO Trigger	-
2	Analog In	0-10V
3	UART Tx / I^{2}C SCL	TTL
4	UART Rx / I^{2}C SDA	TTL
5	GND	-
6	Vcc	5-24V

Figure 7: Electrical connections of lens models with embedded controller ECC-1C featuring (female) Hirose connector.

Focal power versus current

The focal power of the EL-12-30-TC increases with positive and decreases with negative current as shown in Figure 8. When driving the lens up to absolute maximum control current, the tuning range increases further but significant heat generation must be considered.

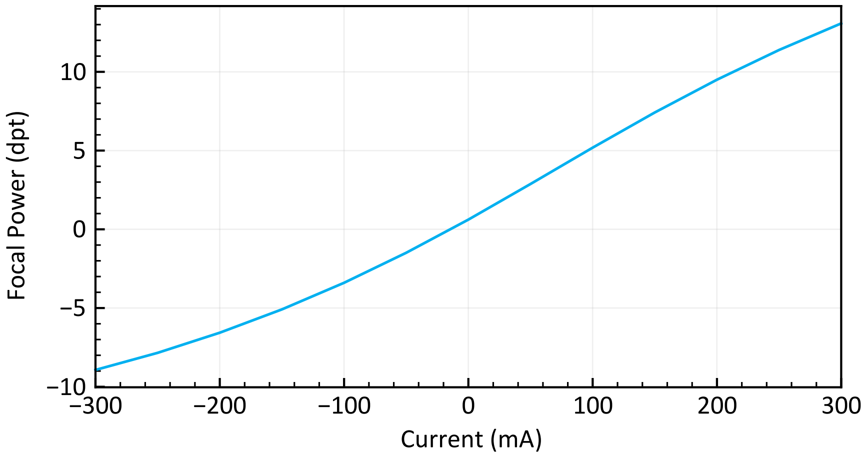


Figure 8: Typical data showing the relation between focal power (in diopters) and electrical current.

Transmission

Both the optical fluid and the membrane material are highly transparent in the range of 400 to 2500 nm. As the membrane is elastic it cannot be coated using standard processes, hence a reflection of 3 – 4% is to be expected. Cover glasses can be coated as desired. Figure 9 shows the transmission spectrum for the standard broad-band coating.

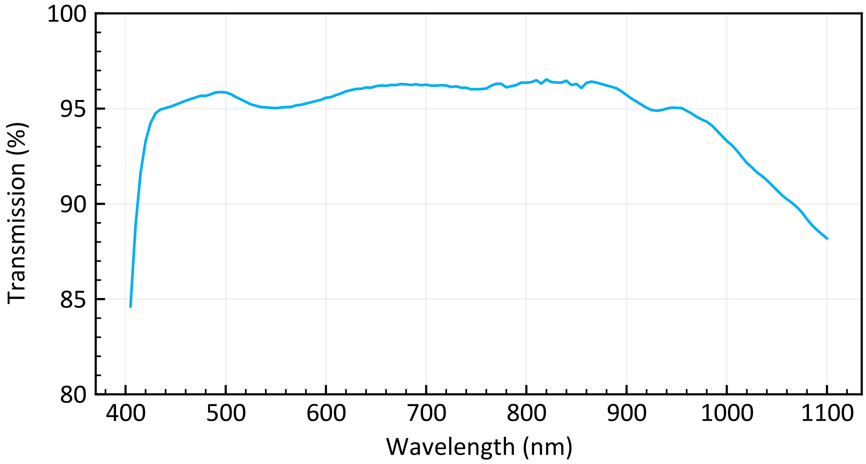


Figure 9: Transmission spectrum of standard EL-12-30-TC.

Wavefront quality

Figure 10 shows the typical wavefront error as a function of focal power. The wavefront quality varies from lens to lens can be specified differently upon request. Best wavefront performance is typically achieved between 0 and 5 diopters. When using the lens standing upright (optical axis horizontal) a Y-coma term must be added resulting in a wavefront error in the order of 0.2-0.25 λ RMS. The gravity induced Y-coma term depends on the clear aperture of the lens, the density of the liquid, the mechanical properties of the membrane and can be optimized upon request.

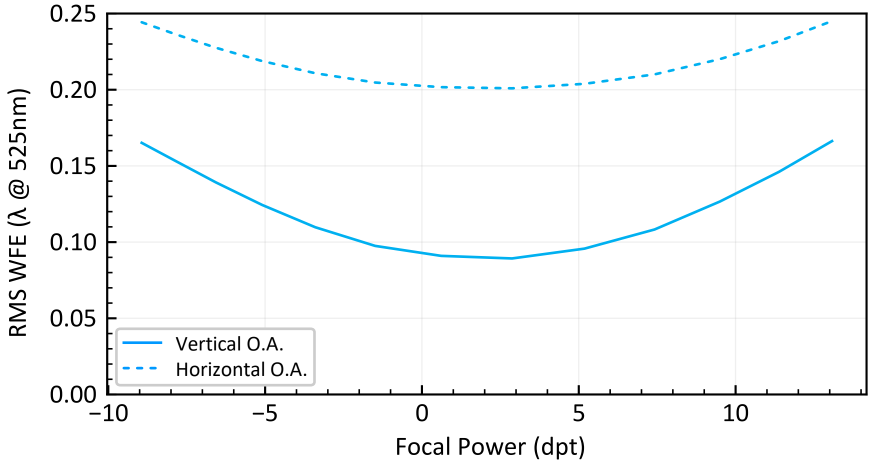


Figure 10: Typical wavefront error of the EL-12-30-TC vs focal power with optical axis vertical and horizontal (@525nm, measured over 80% of the clear aperture).

Response time

The EL-12-30-TC exhibits a very fast response time of about 3 ms and a settling time of about 20 ms based on a rectangular step. Optotune controllers can provide appropriate signal conditioning which is able to halve the settling time, as shown in Figure 11. For more information, please contact.

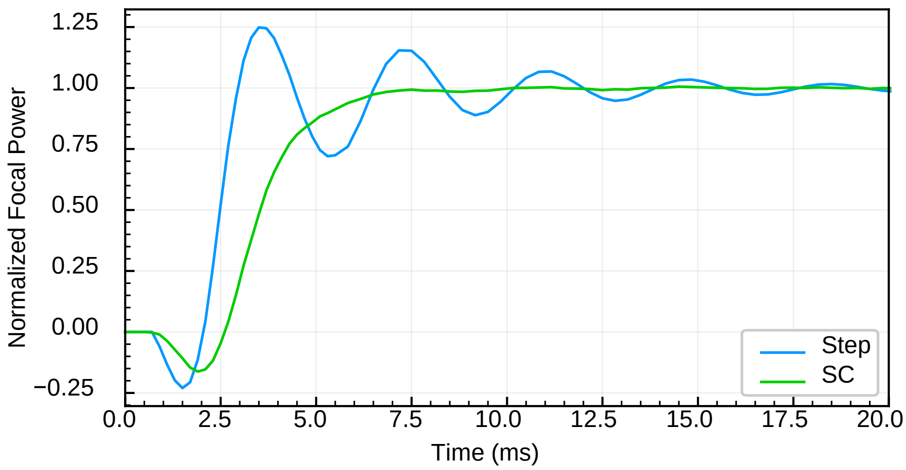


Figure 11: The settling time can be improved with signal conditioning (SC)

Figure 12 shows the focal power response for several current steps measured at room temperature.

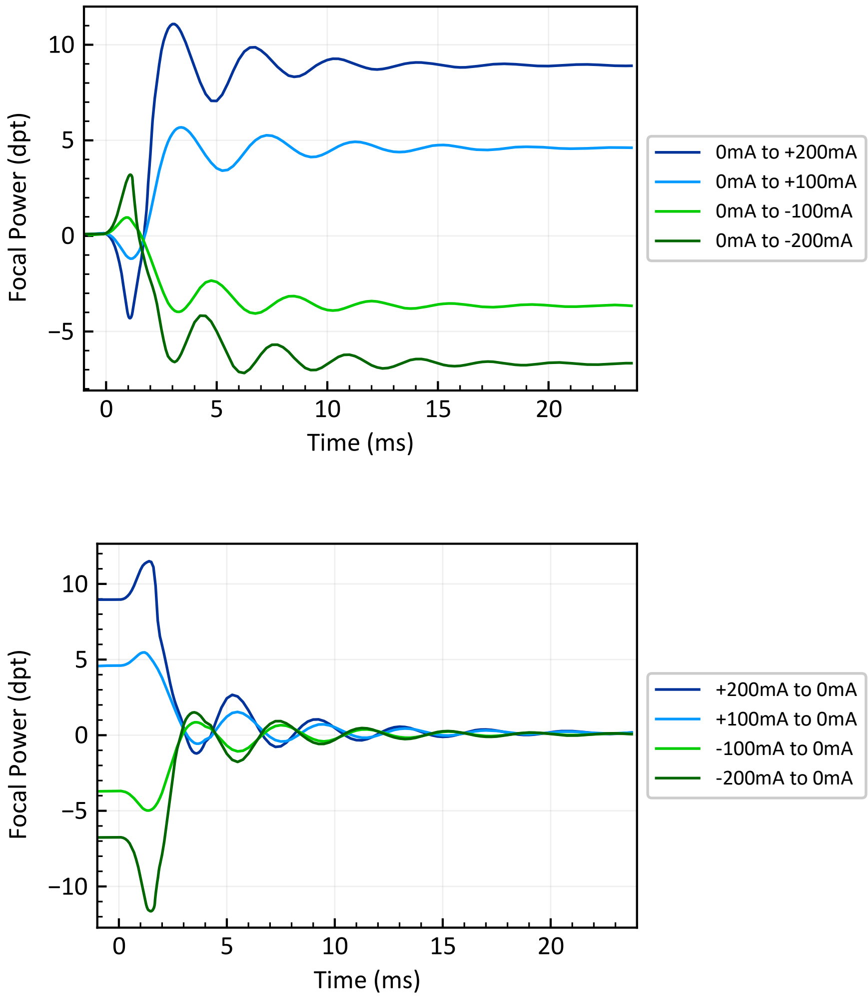


Figure 12: Typical focal power response of the EL-12-30-TC for several current steps. The upper plot shows a series of steps from low to high current and the lower plot for steps from high to low current.

The frequency response over a broad range is presented in Figure 13, showing a resonance peak at around 275 Hz. Due to the excitation of higher order modes, and the associated increase in wavefront error, the lens can generally not be used for imaging applications around the resonant frequency. When applying a current step, it is recommended to damp frequencies above 150 Hz range by using a low pass filter. This avoids excitation oscillations as seen in Figure 12.

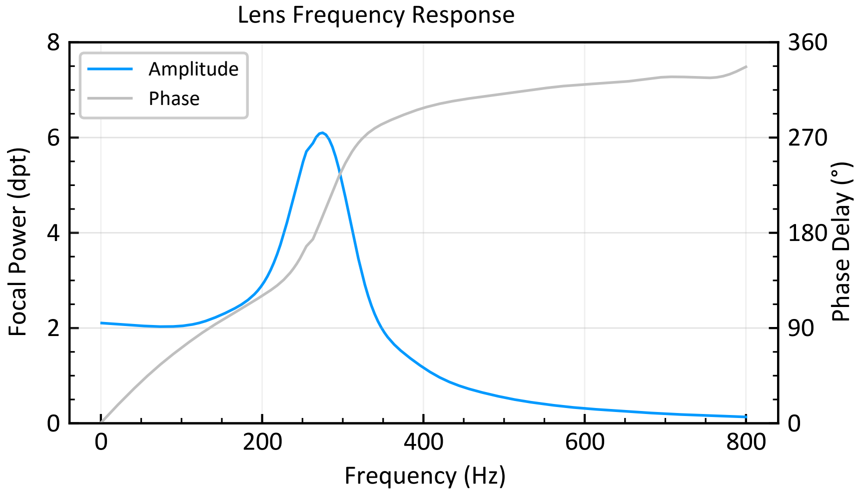


Figure 13 :Typical frequency response and phase delay of the EL-12-30-TC. The driving amplitude is -50 to 50 mA

Temperature effects

Residual temperature effects influence the long-term drift of focal power stated in the specification table. These temperature effects are quantified by the temperature sensitivity S (dpt/°C), giving the change in focal power per degree Celsius. As shown in Figure 14, there is an almost linear dependence of S with focal power. Generally, temperature effects can be minimized when the EL-12-30-TC is thermally connected to a heat sink (large mass with high thermal conductivity).

Best thermal performance is achieved when operating the EL-12-30-TC in the range of 0 to 5 diopters.

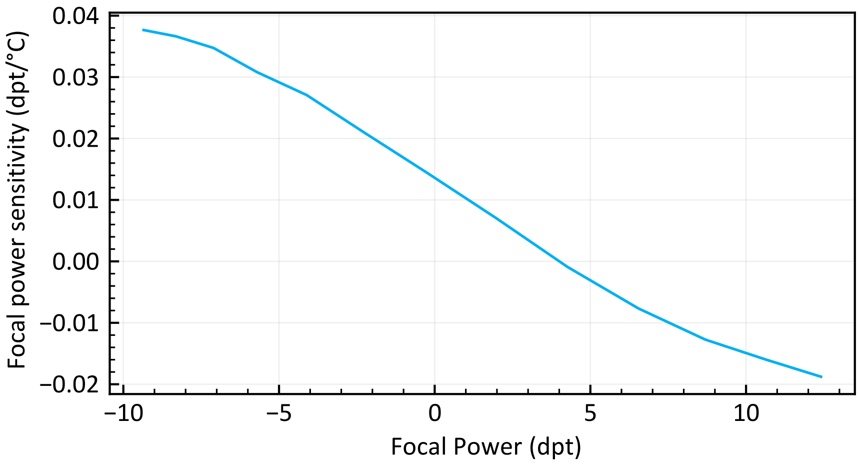


Figure 14: Temperature sensitivity as a function of focal power.

As the viscosity of the lens' liquid changes with temperature, the response varies as shown in Figure 12. Note that at very low operating temperatures it is possible to apply up to 300mA of current to the EL-12-30 to heat up the lens by about 10-20°C.

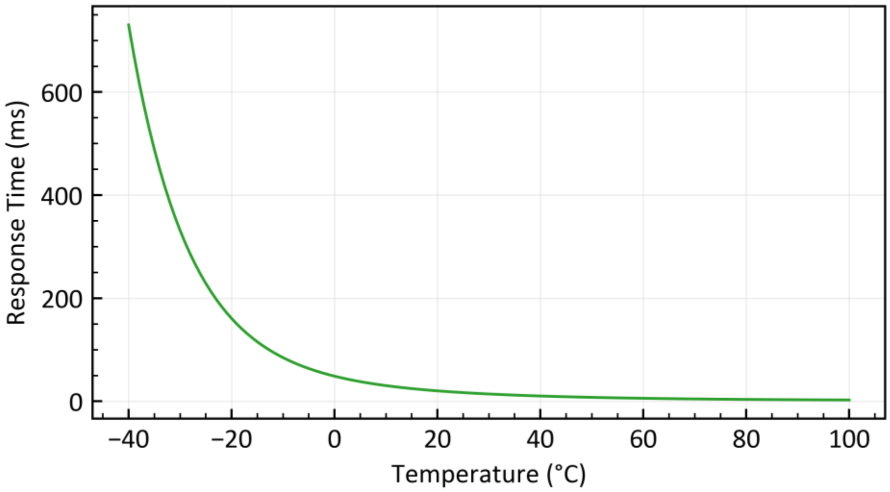
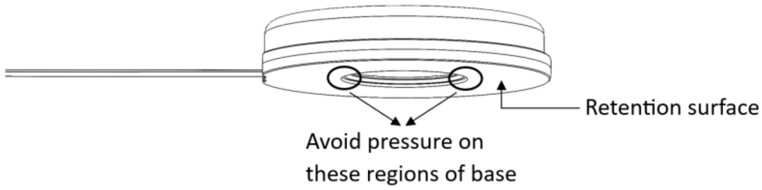


Figure 15: Response time in function of lens temperature.

Mounting possibilities for EL-12-30-TC

To mount EL-12-30-TC, it can be clamped on the flange. The LCP base is designed for retention of the lens in the direction of the optical axis.



EL-12-30-TC is designed for OEM integration and the following components from Thorlabs, Edmund Optics, and Qioptiq can be used for mounting.

G024503000 LINOS- Qioptiq	G061042000 LINOS- Qioptiq	LMR30/M Thorlabs	KM200V/M Thorlabs	SM30L03 Thorlabs	NT64-564 Edmund Optics	NT03-676 Edmund Optics

A C-mount version of EL-12-30-TC is also available upon request.

Optical layout

Zemax simulations to model the EL-12-30 lens series within an optical design are available at this link.

Autofluorescence, birefringence & polarization effects

The EL-12-30-TC is neither auto-fluorescent, birefringent or in any other way polarization dependent.

Safety and compliance

The product fulfills the RoHS and REACH compliance standards. The customer is solely responsible to comply with all relevant safety regulations for integration and operation.

Lifetime and reliability

The EL-12-30 has passed the environmental and accelerated aging tests as outlined in Table 1. When applicable we have aligned our tests with those defined by ISO 9022: Optics and photonics – Environmental test methods.

Test	ISO	Status
Mechanical cycling 200 million full range cycles (-200mA to +200mA, sinusoidal, 20Hz)	-	Pass, continued test ongoing
Mechanical Shock 500g 1ms, 3 shocks along each axis	9022-30-08-1	Pass
High Temperature Storage 85±2 °C, rel. hum. <40%, 2h	9022-11-08-1	Pass
Low Temperature Storage -35±2 °C, 16h	9022-10-07-1	Pass
Damp Heat 55±2 °C, rel. hum. 90% to 95%, 16h	9022-12-07-1	Pass
Temperature Shock -40 to 55 °C, 2.5h/cycle, <20s transition time, 5 cycles	9022-15-03-1	Pass

Table 1: Reliability and lifetime testing of the EL-12-30-TC