

Focus Tunable Lenses

Within milliseconds, the focal length of our electrical lenses is tuned by applying a control current. The unique principle enables the design of faster and more compact optical systems without complex mechanics. We are a leading supplier of focus tunable lenses for diverse applications. Whether electrically or mechanically actuated, the advantages of tunable lenses over traditional optics are striking. Our lenses can be tailored to your specific demands in terms of size, tuning range, transmission range or speed. Tell us your requirements and we will be happy to assess the feasibility.

- Compact design
- Less mechanics
- Fast response
- Low power
- Less tolerance sensitivity

Our electrical lenses are current controlled. There are several options for current drivers ranging from regular lab power supplies to tiny VCM (voice-coil mirror) driver ICs. We offers a high-precision USB driver with a resolution of 0.1mA, which includes read-out of integrated temperature sensors over I2C.

The following table summarizes the main specifications of our most popular focus tunable lenses:

Part number	STOT-EL-3-10	STOT-EL-10-30 Series	STOT-EL-10-30-C Series	STOT-STOT-EL-10-42-OF	STOT-STOT-EL-16-40-TC Series	STOT-ML-20-37 Series
Picture						
Product description	Fast electrically tunable lens	Fast electrically tunable lens	Fast electrically tunable lens	Fast electrically tunable lens	Fast electrically tunable lens	Manually tunable lens
Size (ØxH)	10x4.0mm	30x9.7mm	30x20.7mm	42x36mm	40x11.9mm	37x8mm
Clear aperture	3mm	10mm	10mm	10mm	16mm	20mm
Lens Type	Plano convex to plano concave	Plano convex	Plano convex (offset lens optional)	Plano convex + plano concave offset lens	Plano convex to plano concave	Plano convex to plano concave
Focal length range	+50 to +120mm	+20 to +140mm	-600 to +170 mm	-500 to +500 mm	-500 to +333 mm	-40 to +40mm
Refractive Index	1.300	1.300 or 1.559	1.300	1.300	1.300	1.300 or 1.559

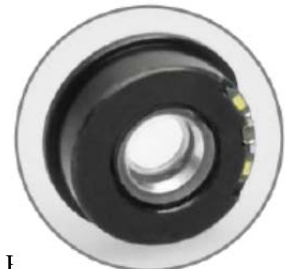
1. Fast electrically tunable lens STOT-EL-3-10

The compact STOT-EL-3-10 lens was 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 very 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 STOT-EL-3-10 focus tunable lens is extremely reliable and robust, well suited even for applications in harsh environments over large temperature ranges. We offer three different types of housings of the STOT-EL-10-30. The compact 30x10.7 mm housing, a 30x20 mm housing with C-mount threads and the Industrial C-mount housing (Ci) with Hirose connector. For each housing there are different options to adapt the lens to your needs:

- Diverse cover glass coatings
- Optional offset lenses
- Optical power range

Applications

STOT-EL-3-10 is the ideal choice for:



- Imaging up to 1/1.8” sensors
- Biometric systems
- Optical coherence tomography (OCT)
- Laser illumination

Mechanical specifications

- Clear aperture: 3.0 mm
- Outer diameter: 10 mm (11mm on flange)
- Height: 4 +0/-0.2 mm
- Weight: 1.25 g
- Lifecycles (10-90% sinusoidal): >1'000'000'000 CL

Electrical specifications

- Control current (typical): -120 to +120 mA
- Operating voltage: -1...1 V
- Coil resistance at 30°C: 7.1 Ohm
- Power consumption (full tuning range): 0 to 100 mW ($P = R_{Coil} \times i^2$)
- Power consumption (+/- 5 dpt tuning range): 0 to 15 mW
- Settling time: 2/4 ms (Low pass filtered / normal step signal)

Optical specifications STOT-EL-3-10-XXX-26D

- Focal tuning range (@20°C): -77 to +77 mm
- Focal power range (@20°C): -13 to +13 dpt
- Wavelength range: 420 to 1600 nm
- Wavefront error @525nm (vertical/horizontal): <0.2/<0.2 λRMS (Tighter spec available upon request (e.g. 0.07 λRMS))
- Refractive index nD (589.3nm): 1.300
- Abbe number Vd: 100
- Optical damage threshold: >1 kW/cm²
- Operating temperature: -20 to +65 °C
- Storage temperature: -50 to +85 °C

Overview of standard products

Standard products	Tuning range	Flex cable	Cover glass	Container- and/or cover glass coating	Wavefront error
EL-3-10-VIS-26D-FPC	-13 to +13 dpt	Yes	Yes	420 – 900 nm	<0.2/<0.2 λ
EL-3-10-NIR-26D-FPC	-13 to +13 dpt	Yes	Yes	850 – 1600 nm	<0.2/<0.2 λ
EL-3-10-VIS-26D-OEM	-13 to +13 dpt	No	No	420 – 900 nm	<0.2/<0.2 λ
EL-3-10-NIR-26D-OEM	-13 to +13 dpt	No	No	850 – 1600 nm	<0.2/<0.2 λ
EL-3-10-VIS-26D-OEM-CG	-13 to +13 dpt	No	Yes	420 – 900 nm	<0.2/<0.2 λ

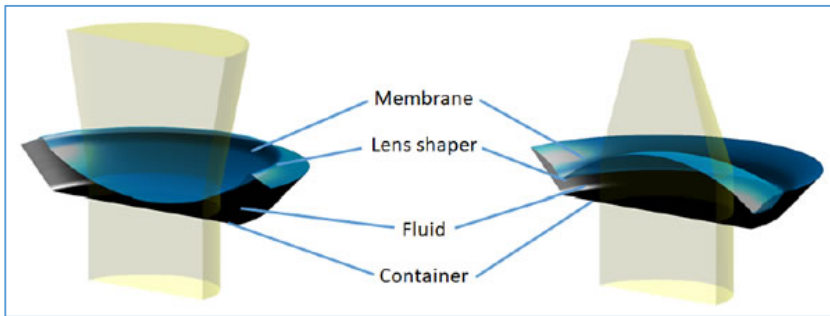
Remark: (1) 420-900 nm T>94%; (2) 850-1600 nm T>94%

Driver

The compact STOT-EL-3-10 lens can be driven with our STOT-EL-E-4 lens driver by simply connecting the flex cable of the lens to the Molex connector on the lens driver. In our software interface, the current to the lens can be adjusted to drive the lens. It's important to note that +/-120 mA are required to tune across the whole optical power range. As the lens driver can output more current, it has to be connected to the PC without the lens connected first. Then, in the “Hardware Configurations” tab, the software limit has to be set to +/-120mA. Afterwards the lens driver can be disconnected, the lens connected to the lens driver and the lens driver connected back to the PC. The current will now only be adjustable from +/-120mA, hence an overdriving of the lens can be prevented.

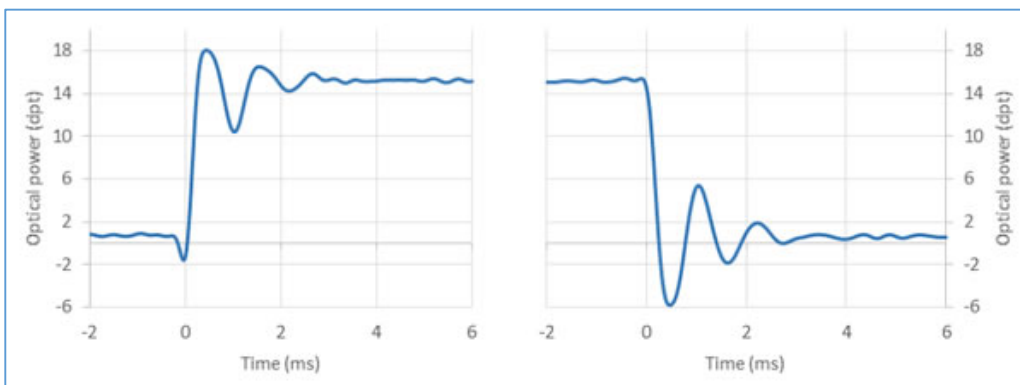
Working principle

The working principle of the STOT-EL-3-10 is based on our 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. 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 optical power of the lens is controlled.



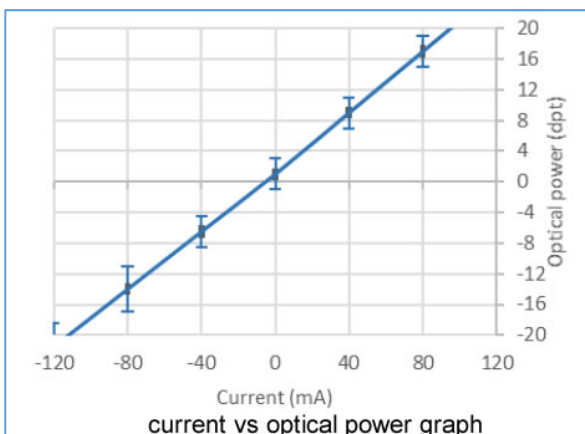
Response time

The rise time when applying a current step is <1 ms and it takes only about 4 ms until the lens has fully settled. The graphs of the step response measurements below show the optical response of the STOT-EL-3-10 lens. Low pass filtering of the drive signal to the lens allows to damp the oscillations seen in the step response graphs below and as a result drive a controlled 80% step in <2ms.



Optical power versus current

The optical power of the STOT-EL-3-10 increases with positive current and decreases with negative current as shown as follows. The specified optical power range is from +13 to -13 diopters.



2. Fast Electrically Tunable Lens STOT-EL-10-30 Series

The curvature of this shape changing polymer lens is adjusted by applying current. The focal length is accordingly tuned to a desired value within milliseconds. We offer three different types of housings of the STOT-EL-10-30. The compact 30x10.7 mm housing, a 30x20 mm housing with C-mount threads and the Industrial C-mount housing (Ci) with Hirose connector. For each housing there are different options to adapt the lens to your needs:

- Diverse cover glass coatings
- Optional offset lenses
- Optical power range

The table below summarizes the possible options for the three different housings.

Option	STOT-EL-10-30-TC	STOT-EL-10-30-C	STOT-EL-10-30-Ci
Cover glass coating	VIS(1), NIR(2)	VIS, NIR, 1064nm(3)	VIS, NIR, 1064nm
Optional offset lens	No	Yes	Yes

(1) 400-700 nm broad band; (2) 700-1100 nm infra-red broad band; (3) narrow band 1064 nm

The following table outlines the specifications of our standard electrically tunable lens STOT-EL-10-30. Cover glass coatings and tuning range can be adapted on demand.

Mechanical Specifications

Part number	STOT-EL-10-30-TC	STOT-EL-10-30-C	STOT-EL-10-30-Ci
Clear aperture	10mm	10mm	10mm
External diameter	30mm	30mm	Oval shape 48x30.5mm
Thickness	10.7mm	24.6mm	24.6mm
Weight	22.9g	34.0g	46.0g
Connector length	100	100	10001mm
Lifecycles (10-90% sinusoidal)	>1'000'000'000	>1'000'000'000	>1'000'000'000

Electrical specifications

Part number	STOT-EL-10-30-TC	STOT-EL-10-30-C STOT-EL-10-30-Ci
Absolute maximum voltage (coil)	5V	5V
Absolute maximum voltage (temp. sensor)	4.3V	4.3V
I2C supply voltage	3.3 (nominal), 3.6 (maximum)	3.3 (nominal), 3.6 (maximum)
Nominal control current with Lens Driver 4	0 to 250mA	0 to 250mA
Absolute max. control current	0 to 400mA	0 to 400mA
Power consumption	0 to 0.9 (nominal), 0 to 2.0 (absolute max.)	0 to 0.9 (nominal), 0 to 2.0 (absolute max.)
Temperature sensor & memory	Yes (STTS2004)	Yes (SE97B or equivalent STTS2004)
Response time (10%-90% step)	<2.5	
Settling time (typical at 30°C)	15 (rectangular step), 6 (controlled step)	15 (rectangular step), 6 (controlled step)

Optical Specifications

Focal tuning range @ 30°C2	+50 to +120mm	+100 to +200 mm
Dispersion (at 20°C) 486 nm	1.302	1.302
589 nm	1.300	1.300
656 nm	1.299	1.299
800 nm	1.298	1.298
1065 nm	1.297	1.297
1550 nm	1.296	1.296
Abbe number V	100	
Wavefront error (@530 nm, 0 mA)	<0.25 / <0.6λ RMS	<0.15 / <0.25λ RMS

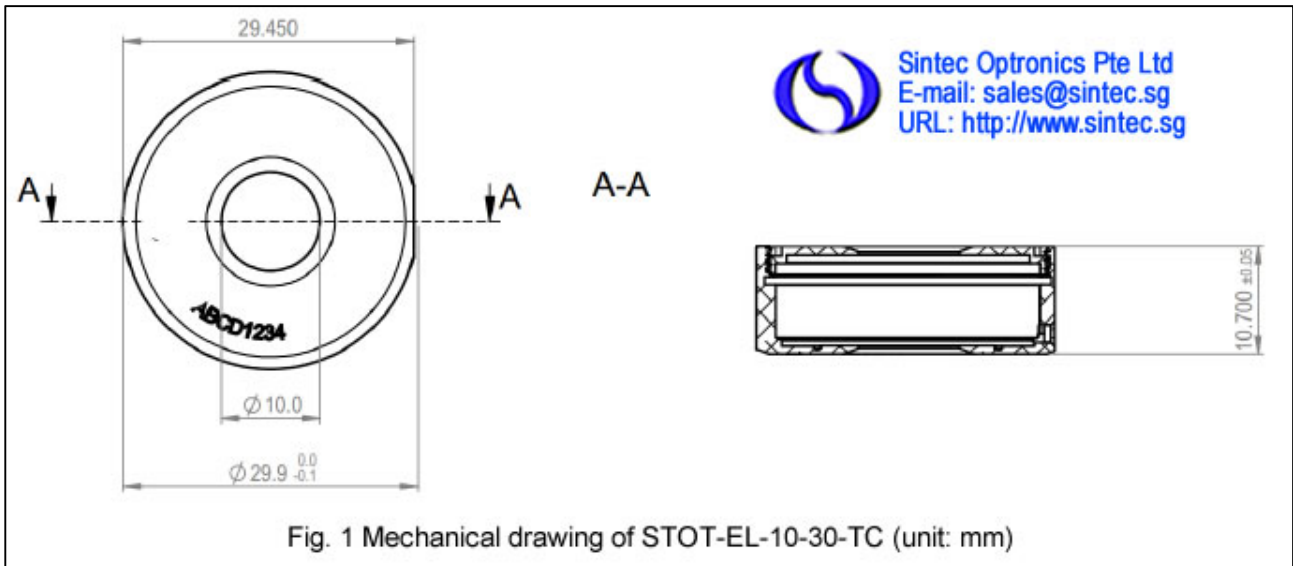
Optical axis vertical / horizontal		
Lens type	plano-convex	plano-convex
Optical retardance @590nm	6.4 nm	6.4 nm
Optical damage threshold @ 1064 nm	10 kW/cm ²	10 kW/cm ²
Polarisation	Perserving	Perserving

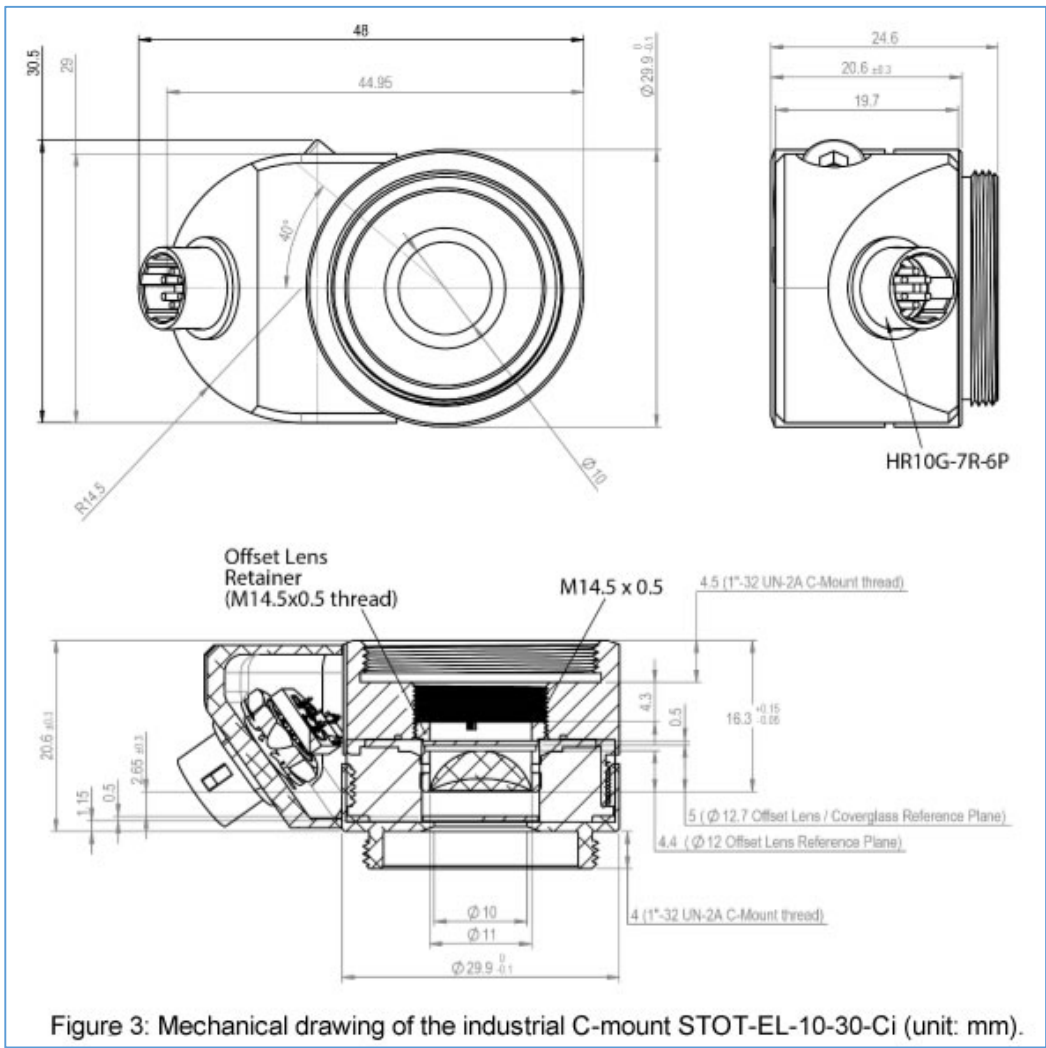
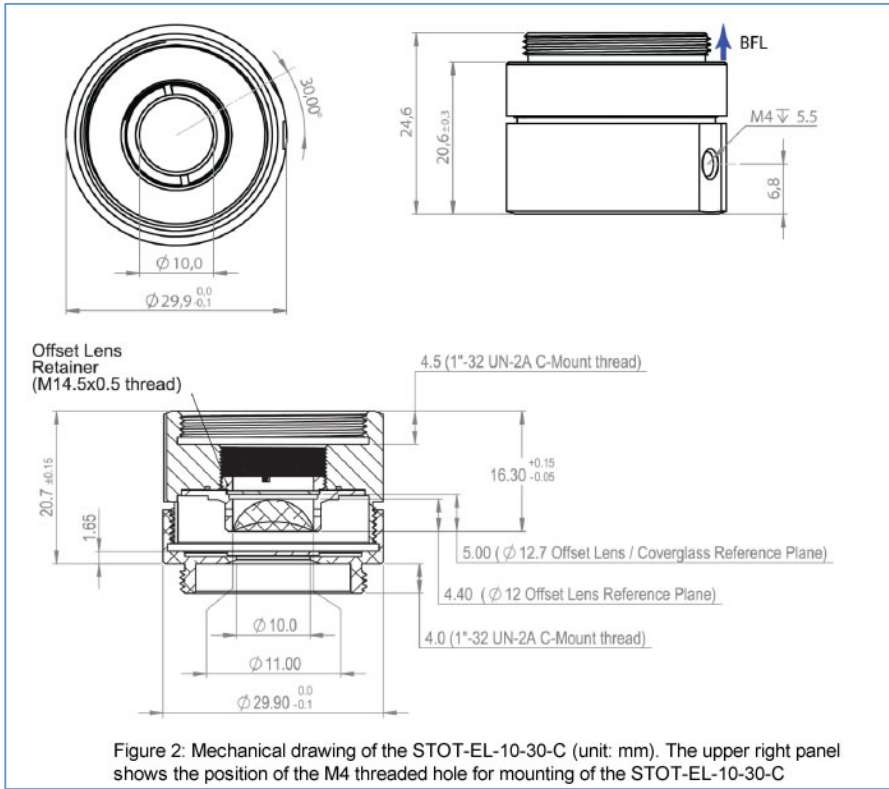
Overview of available standard products

	Turning range	Refractive index	Cover glass coating	RMS wavefront error	Integrated offset lens	Temp. sensor
STOT-EL-10-30-TC-VIR-12D	+8.3 to +20dpt	1.30	400 – 1100nm	<0.25/<0.60	No	Yes
STOT-EL-10-30-TC-NIR-12D	+8.3 to +20dpt	1.30	700 – 1100nm	<0.25/<0.60	No	Yes
STOT-EL-10-30-C-VIS-LD	+5 to +10dpt	1.30	400 – 700nm	<0.15/<0.25	No	Yes
STOT-EL-10-30-C-NIR-LD	+5 to +10dpt	1.30	700 – 1100nm	<0.15/<0.25	No	Yes
STOT-EL-10-30-C-VIS-LD-MV	-1.5 to +3.5dpt	1.30	400 – 700nm	<0.15/<0.25	Yes (-150 mm)	Yes
STOT-EL-10-30-C-NIR-LD-MV	-1.5 to +3.5dpt	1.30	700 – 1100nm	<0.15/<0.25	Yes (-150 mm)	Yes
STOT-EL-10-30-Ci-VIS-LD	+5 to +10dpt	1.30	400 – 700nm	<0.15/<0.25	No	Yes
STOT-EL-10-30-Ci-NIR-LD	+5 to +10dpt	1.30	700 – 1100nm	<0.15/<0.25	No	Yes
STOT-EL-10-30-Ci-VIS-LD-MV	-1.5 to +3.5dpt	1.30	400 – 700nm	<0.15/<0.25	Yes (-150 mm)	Yes
STOT-EL-10-30-Ci-NIR-LD-MV	-1.5 to +3.5dpt	1.30	700 – 1100nm	<0.15/<0.25	Yes (-150 mm)	Yes

Housings

The STOT-EL-10-30-TC is preferably mounted in a 30 mm ring holder. The relevant mechanical drawings are depicted below in Figure 1. Figure 2 shows the drawings of the C-mount housing. This housing has threads on either side and exhibits an M4 threaded hole in the housing for mounting on optical posts. Figure 3 shows the drawings of the industrial C-mount STOT-EL-10-30-Ci. This housing has an oval shape and no M4 threaded hole, however C-mount threads on either side like the C-mount housing. Apart from the housing and connector, the performance of the STOT-EL-10-30-C and STOT-EL-10-30-Ci are identical.



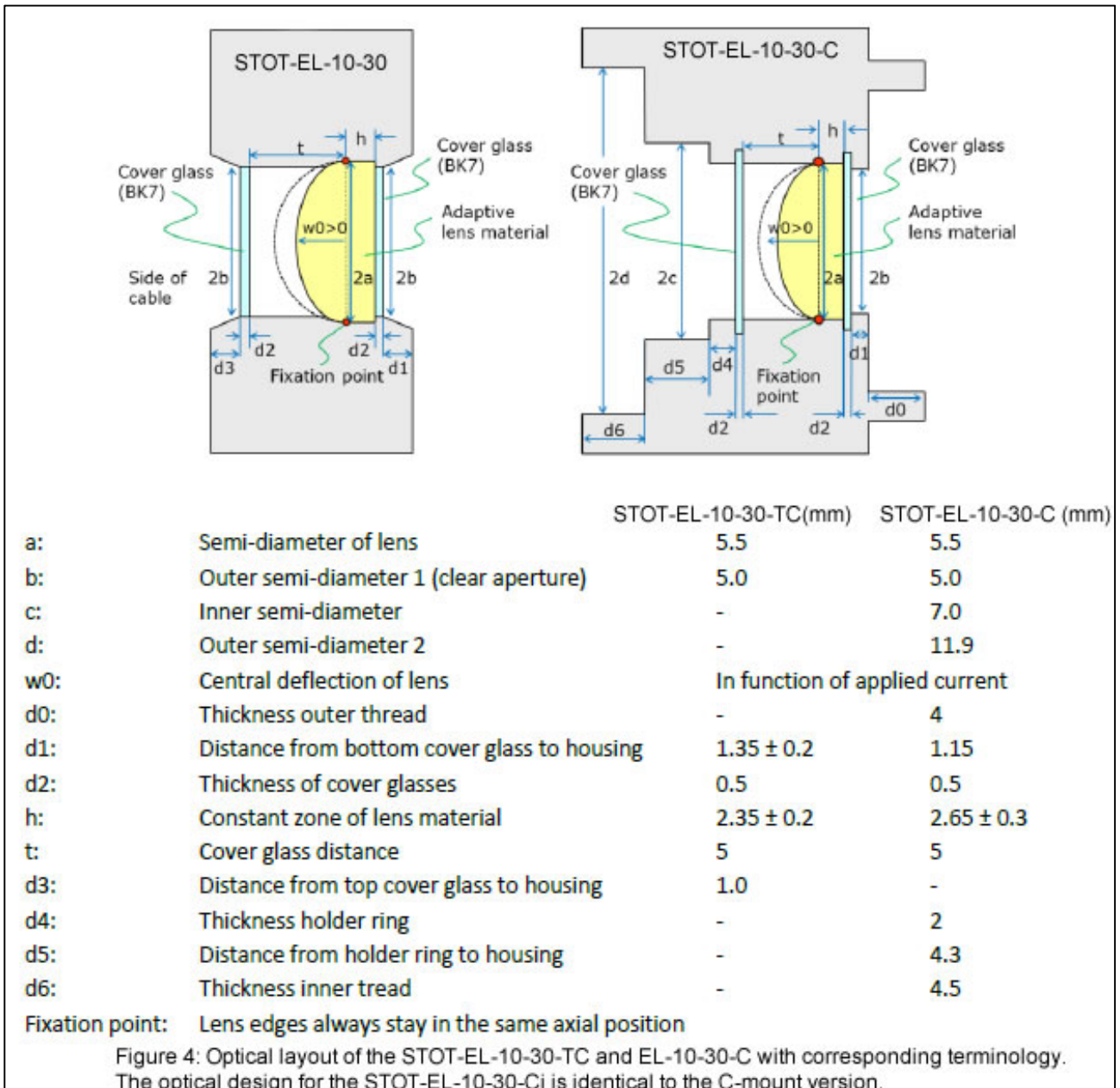


Electrical connection

The industrial design STOT-EL-10-30-Ci comes with a 6-pin Hirose connector. A 1m long cable to connect the STOT-EL-10-30-Ci to the STOT-EL-E-4i driver is available (P/N CAB-6-100). The STOT-EL-10-30-TC and STOT-EL-10-30-C has a 10 cm long FPC connection, which is compatible with Molex 0.5mm pitch 6 way FPC backflip connector (P/N 503480-0600). All STOT-EL-10-30 lenses feature an SE97B temperature sensor with 256 bytes of memory. The I2C addresses of the temperature sensor and the EEPROM are 0x18 and 0x50, respectively.

Optical layout

Figure 4 contains the information needed to model the STOT-EL-10-30 lenses for simulation.



Using offset lenses

In the STOT-EL-10-30-C and -Ci the protective cover glass can be replaced by an offset lens of 12 or 12.7-mm diameter. This allows shifting the focal length range to any desired value. For example, adding an offset lens with $f = -150$ mm to the STOT-EL-10-30-C-VIS-LD will yield a focal length range of about -666 mm to infinity to +286 mm ($1/f_{res} = 1/f_{EL-10-30} + 1/f_{offset}$). The design of the STOT-EL-10-30-C is

optimized for good alignment of the tunable lens and the offset lens. The maximal thickness of the offset lens may be 4.7 mm.

Working principle

The STOT-EL-10-30 is a shape-changing lens, as illustrated in Figure 5. It consists of a container, which is filled with an optical fluid and sealed off with an elastic polymer membrane. The deflection of the lens is proportional to the pressure in the fluid. The STOT-EL-10-30 has an electromagnetic actuator that is used to exert pressure on the container. Hence, the focal distance of the lens is controlled by the current flowing through the coil of the actuator.

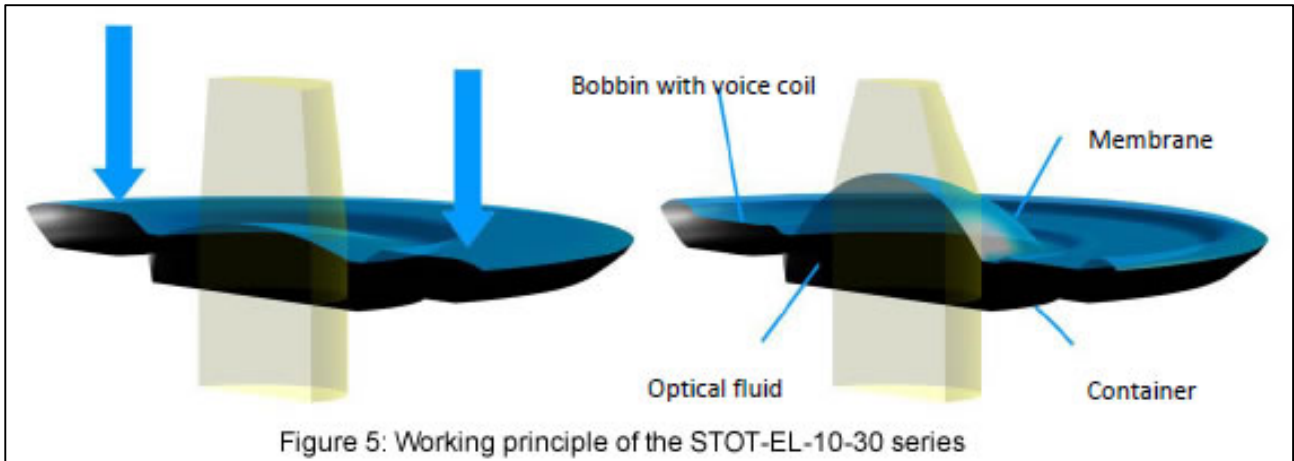


Figure 5: Working principle of the STOT-EL-10-30 series

Focal length versus current

The optical power of the STOT-EL-10-30 increases with current, shown in Figure 6. The starting point at zero current is set during production and can be varied from lens to lens, whereas the maximal value is 500 mm. The slope of the optical power is influenced by the mechanical properties of the membrane, which can also be varied on request to achieve different ranges. In open loop systems, a calibration of the lens with look-up tables is recommended. The focal length also depends on temperature, see paragraph temperature effects.

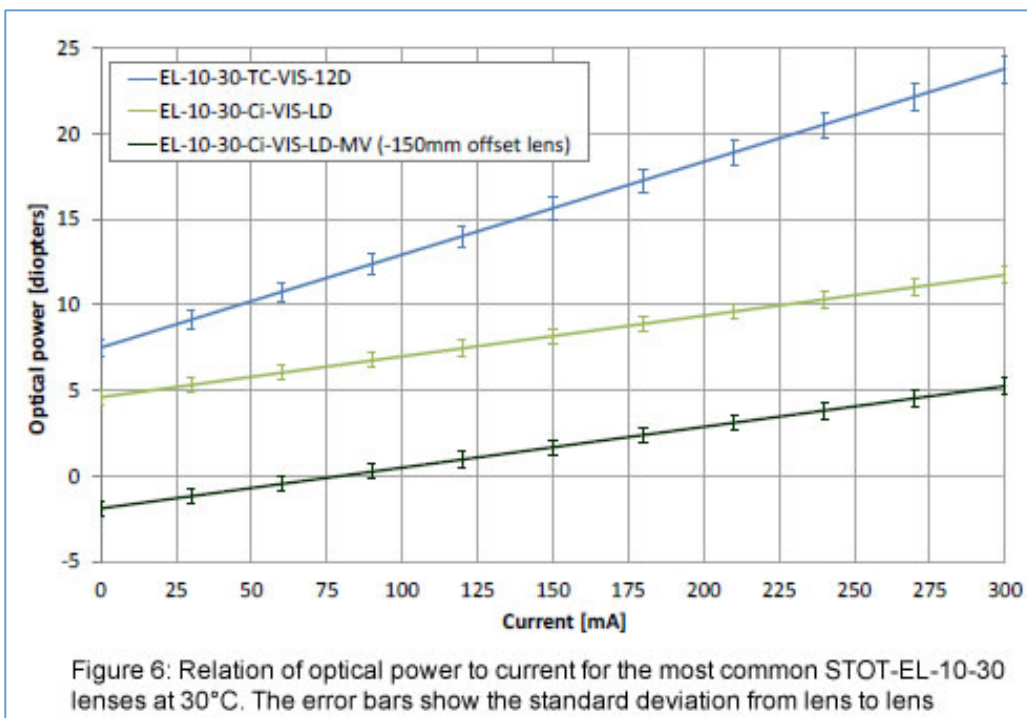
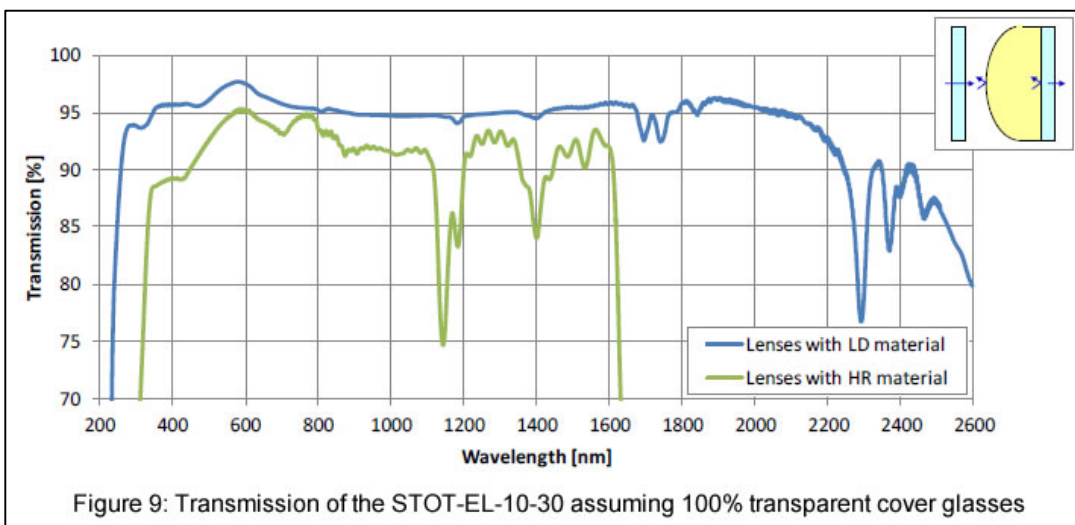
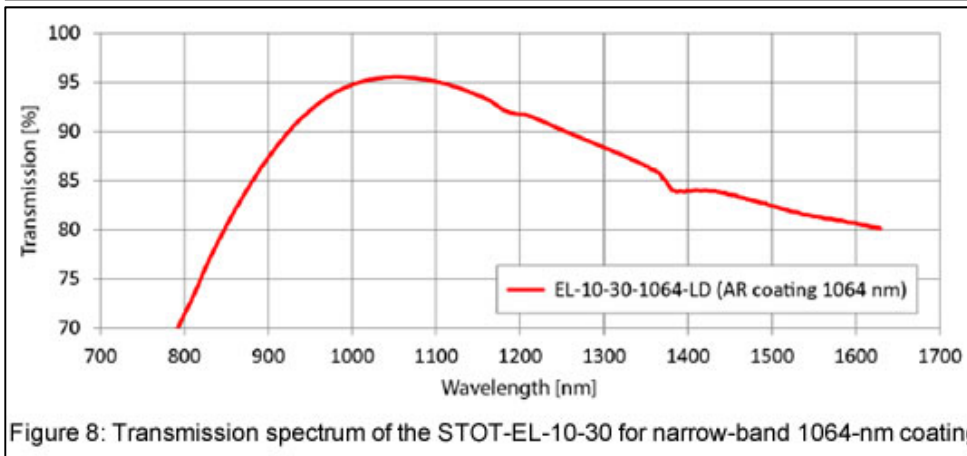
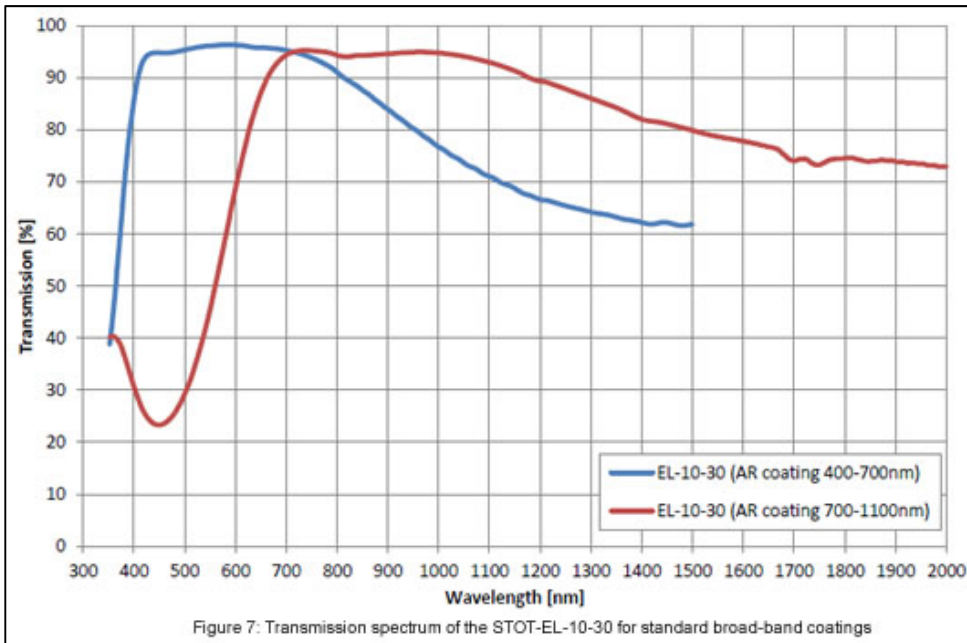


Figure 6: Relation of optical power to current for the most common STOT-EL-10-30 lenses at 30°C. The error bars show the standard deviation from lens to lens

Transmission range

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 7 and Figure 8 show the transmission spectrum for our two standard broad-band coatings (visible and near infrared) as well as a custom narrow-band coatings:



Laser damage measurements

The CW damage threshold of the lens material is 10 kW/cm² for a wavelength of 1064 nm. Further damage measurements with pulsed lasers have been performed with the following results:

- 1064 nm, 125 ns-pulsed at 50 kHz, damage at 2.6J/cm²
- 1064 nm, 10 ps-pulsed at 50 kHz, damage at 2.05J/cm²
- 532 nm, 1 ns-pulsed at 300 kHz, damage at 0.11J/cm²

For 1064 nm, long term measurements over 2000h show no degradation or change in the optical characteristic of the lens. The parameters of this measurement were: 100 ns-pulsed at 100 kHz and 40mJ/cm² fluence. For 532 nm, measurements over 60h show no degradation or change in the optical characteristic of the lens. The parameters of this measurement were: 10 ns-pulsed at 30 kHz and 1.4mJ/cm² fluence. While no heating up of the lens is observed with the pulsed lasers, a 200 W CW laser does heat up the lens, resulting in a focus drift, which stabilizes after about 10 seconds. To avoid heating of the lens due to reflections hitting absorbing surfaces, it is advised to calculate such reflections and preferably not use more than 8 mm of the clear lens aperture.

Temperature effects

Heating up of the lens has two consequences: First, the refractive index of the optical fluid decreases. Second, the fluid expands in volume. While the first effect would decrease the optical power, the second effect increases it. With the STOT-EL-10-30 design, the second effect prevails. The optical power increases by approximately 0.7 diopters per 10°C temperature increase.

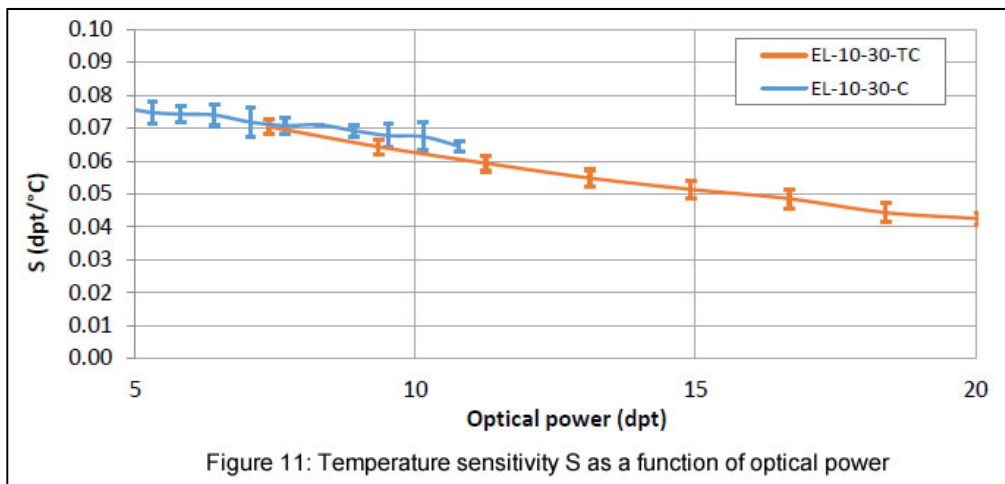


Figure 11: Temperature sensitivity S as a function of optical power

This temperature effect is systematic and reproducible. This means the focal length can be controlled if the temperature is known. All STOT-EL-10-30 lenses have a built-in temperature sensor (SE97B). Heating up of the lens occurs at room temperature if driven at high currents or due to absorption of high power laser light. In such cases the lens is preferably mounted using heat-conducting metal clamps. For custom designs it is possible to balance the two temperature effects such that the focus shift becomes minimal at a certain focal length.

Resolution and reproducibility

The step size of the focal power is limited by the resolution of the DAC of the current driver. For high precision applications a driver with 12 bits is recommended. As the relation between current and focal power is linear, the smallest step of e.g. the STOT-EL-10-30-C-VIS-LD about 0.0018 Dpt.

Unlike piezo systems, the STOT-EL-10-30 exhibits no hysteresis. The current through the coil induces a force, which is directly transferred onto the elastic membrane. There is no friction in the system. This means that at a constant temperature jumping between alternate current levels will always yield the same focal length. The effect of changes in temperature are described above. Our Lens Driver 4 offers a focal power mode, which makes use of calibration data stored in the lens (EEPROM of the SE97B). The absolute reproducibility achieved over an operating temperature range of 10 to 50°C amounts to typically 0.1 diopters. More details on the focal power mode are provided in the Lens Driver manual.

Resistance and Inductance of the driving coil

In principle, the STOT-EL-10-30 can be driven using a DC voltage (e.g. even a simple battery) or a current source. However, the focal length of the lens depends on the current flowing through the coil and the resistance of the coil changes with temperature (12.5 Ohm at 25°C) with a linear rate of 3.93%/°C. That is why, for highest stability, it is recommended to use a current source. Note that this temperature effect is visible within seconds and has nothing to do with the expansion of the optical fluid described above, which is on the order of minutes. For AC operation, the inductance of the coil, which depends on frequency, is an important parameter.

Frequency(Hz)	Coil Inductance (mH)
10000	0.76
1000	1.1
100	1.14
10	1.15

Recommended drivers and power supplies

We provide its own high-precision USB drivers with a resolution of 0.1 mA. It includes the I2C readout of the temperature sensor, which can be used for temperature compensation.

The lens can also be driven using pulse width modulation (PWM) with a frequency between 20 kHz and 50 kHz. Another very useful component is the ADN8810 programmable precision current source of Analog Devices, which features 12 bits of resolution and can be controlled with an SPI interface.

Exchanging the offset lens of the STOT-EL-10-30-C Series

The STOT-EL-10-30-C is shipped with a planar cover glass or with an integrated offset lens (MV version), which is held in place by a retainer ring. The cover glass or offset lens can easily be exchanged by hand following the procedure outlined below. Please note that this is preferably done in a clean room or under a flow hood to avoid dust entering the tunable lens.

1. Loosen the retainer ring carefully with a small screw driver
2. After about 5 rotations turn the lens with the ring pointing down so no dust can get into the lens
3. Take out the cover glass / offset lens with the retainer ring. Prepare the new cover glass or lens.
4. Turn the lens again, but be careful, that no dust gets inside. Carefully drop the new cover glass or lens (planar side should usually look down towards the lens) inside using tweezers.
5. Put the retainer ring in by hand
6. Tighten the retainer ring with a screw driver. Be careful not to scratch the glass.

IMPORTANT: At the end, do not exert much torque (<1 Nm) as this might damage the tunable lens.



Ordering information for custom versions of the STOT-EL-10-30

For custom versions, please use the following concept for part numbers:

STOT-EL-10-30-H-AR-MAT-RANGE

- **H** = TC: Compact housing with FPC connector; C: C-mount housing with FPC connector; Ci: Industrial C-mount housing with Hirose connector
- **AR** = VIS: visible broad-band anti-reflection coating (400 – 700 nm); NIR: near broad-band infrared anti-reflection coating (700 – 1100 nm); 1064: narrow-band anti-reflection coating at 1064 nm; NOC: No coating
- **MAT** = LD: low dispersion lens material (nD = 1.300, V = 100, standard); HR: high refraction lens material (nD = 1.559, V = 32, available as customization)
- **RANGE** = 12D: Focus tuning range from 8 to 20 diopters (standard for all STOT-EL-10-30-TC lenses); MV: Machine vision option: Includes -150 mm focal length offset lens to achieve a total focal tuning range of -666 mm (-1.5 dpt) to infinity to +286 mm (3.5 dpt). Note: standard STOT-EL-10-30-C and -Ci lenses without the MV option range from 5 to 10 diopters.

Example: STOT-EL-10-30-C-NOC-LD refers to a custom electrical tunable lens of 10 mm aperture and 30 mm outer diameter (C-mount housing) with uncoated cover glasses, low dispersion lens material and a focal tuning range from +5 to +10 dpt.

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.

2.1 Fast electrically tunable lens STOT-EL-10-30-TC

Design faster and more compact optical systems without complex mechanics using the electrically focus tunable lens STOT-EL-10-30-TC. By applying a current, the focal length of the 10 mm aperture lens can be tuned to a specific value in milliseconds. Thanks to an integrated temperature sensor and characterization data, the lens can be driven to precise focal powers using our lens driver 4. The STOT-EL-10-30-TC is available with two broadband coating options, VIS for 400-700nm and NIR for 700-1100nm.



The following table summarizes the main specifications of the compact STOT-EL-10-30-TC:

Standard products	Tuning range	Refractive index	Cover glass coating	Wavefront error*
-------------------	--------------	------------------	---------------------	------------------

STOT-EL-10-30-TC-VIS-12D	+120 to +50 mm +8.3 to +20 dpt	1.30	400 - 700nm	<0.25 / <0.60 λ
STOT-EL-10-30-TC-NIR-12D	+120 to +50 mm +8.3 to +20 dpt	1.30	700 - 1100nm	<0.25 / <0.60 λ

* Wavefront error provided in λ RMS @525nm with optical axis vertical / horizontal

Applications

- Microscopy
- Atom trapping
- Optical coherence tomography (OCT)
- Laser shows

2.2 Fast electrically tunable lens STOT-EL-10-30-C

Design faster and more compact optical systems without complex mechanics using the electrically focus tunable lens STOT-EL-10-30-C. By applying a current of 0 to 300mA, the focal length of the 10 mm aperture lens can be tuned to a specific value within milliseconds. The STOT-EL-10-30-C also features threads on either side for easy mounting as well as the possibility to replace the cover glass with a fixed focus offset lens, allowing for free adjustment of the focal length range according to the requirements of your application.



STOT-EL-10-30-C
(OEM version)



STOT-EL-10-30-Ci
(industrial version)

The STOT-EL-10-30-C has two main optical configurations:

1. The basic configuration has planar cover glasses and a focal tuning range of 200mm down to 100mm, making this the best choice for macro imaging.
2. The "MV" configuration is optimized for the machine vision market. It contains a negative offset lens so that the overall focal tuning range goes from slightly negative down to 286mm, making this the ideal choice for combinations with infinity corrected fixed-focus lenses.

The following table summarizes the main specifications of the STOT-EL-10-30-C series:

Standard products*	Tuning range with Lens Driver 4 (0 - 250mA)	Integrated offset lens	Cover glass coating	Wavefront error**
STOT-EL-10-30-C-VIS-LD	200 to 100 mm 5 to 10 dpt	No	400 - 700nm	<0.15 / <0.25 λ
STOT-EL-10-30-C-NIR-LD	200 to 100 mm 5 to 10 dpt	No	700 - 1100nm	<0.15 / <0.25 λ
STOT-EL-10-30-C-VIS-LD-MV	-667 to +286mm -1.5 to +3.5 dpt	Yes (-150mm)	400 - 700nm	<0.15 / <0.25 λ
STOT-EL-10-30-C-NIR-LD-MV	-667 to +286 mm -1.5 to +3.5 dpt	Yes (-150mm)	700 - 1100nm	<0.15 / <0.25 λ

* All the above models are available with a 6-pin FPC connector (OEM version) or with a 6-pin Hirose connector (industrial version)

** Wavefront error provided in λ RMS @525nm with optical axis vertical / horizontal

Since 2014 all lenses offer "Focal Power Mode", which makes use of calibration data saved directly on the lens, allowing for open loop control including temperature compensation at a repeatability of typically +/-0.1 diopters.

Applications

- Machine vision
- Microscopy
- Biometric systems
- Optical coherence tomography

3. Fast Electrically Tunable Lens STOT-EL-10-42-OF

The working principle of STOT-EL-10-42-OF lens with integrated optical feedback is based on the well-established shape-changing flexible lens. The curvature of the lens is adjusted by applying an electrical current. The focal length is accordingly tuned to a desired value within milliseconds. The STOT-EL-10-42-OF has an integrated optical feedback, measuring the optical power of the lens in real-time. Optimal control is guaranteed using the STOT-EL-E-OF-A analog driver board or STOT-DSD digital driver board developed. This makes STOT-EL-10-42-OF suitable for laser marking and engraving applications.

Applications

- Laser marking
- Micromachining
- OCT
- 3D printing
- Laser projection templating



Main specifications

Product	STOT-EL-10-42-OF-1064	STOT-EL-10-42-OF-1064-S (SCAPS)
Clear aperture	10mm	10mm
Focal length	-500 to ∞ to +500 mm	-555 to ∞ to +555 mm
Optical power: tuning range	-2.0 to 0 to +2.0 dpt	-1.8 to 0 to +1.8 dpt
Optical power: pointing stability (+/- STD)	< +/- 0.002 dpt	< +/- 0.002 dpt
Optical power: repeatability (+/- STD)	< +/- 0.010 dpt	< +/- 0.010 dpt
Optical power: long term stab. 8h (+/- STD)	< +/- 0.0201 dpt	< +/- 0.0201 dpt
Lateral spot shift over full tuning range	< 45 μ Rad λ μ Rad	< 45 μ Rad λ μ Rad
Lateral long term drift at fixed focal length	< 5 μ Rad μ Rad	< 5 μ Rad μ Rad
Wavefront error	< 0.25 @ 525 nm RMS	< 0.25 @ 525 nm RMS
Transmission	> 95% @ 1064 nm	> 95% @ 1064 nm
Long term radiation damage @ 1064 nm: 40 mJ/cm ² at 20 kHz	No effect after 2000 h	No effect after 2000 h
Damage threshold ² @ 1064 nm: 125 ns-pulsed at 50 kHz 10 ps-pulsed at 50 kHz	2.6 J/cm ² 2.05 J/cm ²	2.6 J/cm ² 2.05 J/cm ²
Response time Controlled with EL-E-OF-A analog board	80% step: 12 20% step: 6ms	80% step: 12 20% step: 6ms
Response time Controlled with STOT-DSD digital board		80% step: 8ms 20% step: 4.5 ms
Tracking delay Controlled with STOT-DSD digital board		< 2 ms
Focal length resolution	Continuous (depends on control electronics)	Continuous (depends on control electronics)
Lifecycles (10%-90% sinusoidal)	> 1'000'000'000	> 1'000'000'000
Weight	90 g	90 g
Heater set temperature	47 °C	47 °C
Operating temperature	10 to 40 °C	10 to 40 °C
Storage Temperature	-20 to 80 °C	-20 to 80 °C

Parameters in combination with f = 160 mm f-theta lens³

Max z-tuning range in a marking system	100mm	90mm
Repeatability (10%-90% step)	< 250 μ m	
Long term drift over 8h	< 500 μ m	

Electrical specifications

Max lens power consumption	1.5 W
Max lens current	385 mA
Max heater power consumption	12 W
Heater resistance @ 25°C	25 +/- 10% Ohm
Voltage Vcc	3.3 V
LED forward voltage	1.5 V

1 Mainly due to residual temperature effects

2 Characterization done by Inspire AG and IWF/ETH Zurich

3 See laser processing application note for details

Housing

The STOT-EL-10-42-OF comes with a black metallic housing. The rectangular shaped part of the housing at the side includes the electrical connections. Four M3 thread holes located at the front surface of the housing are designated for mounting. A typical assembly is shown in section Alignment and mounting. The $\varnothing 40.0$ mm and $\varnothing 25.5$ mm diameter flank is tightly tolerated (ISO tolerance g6) and suitable as an alignment feature. The included Teflon washer provides thermal isolation and has to be placed between the STOT-EL-10-42-OF and an external holder.

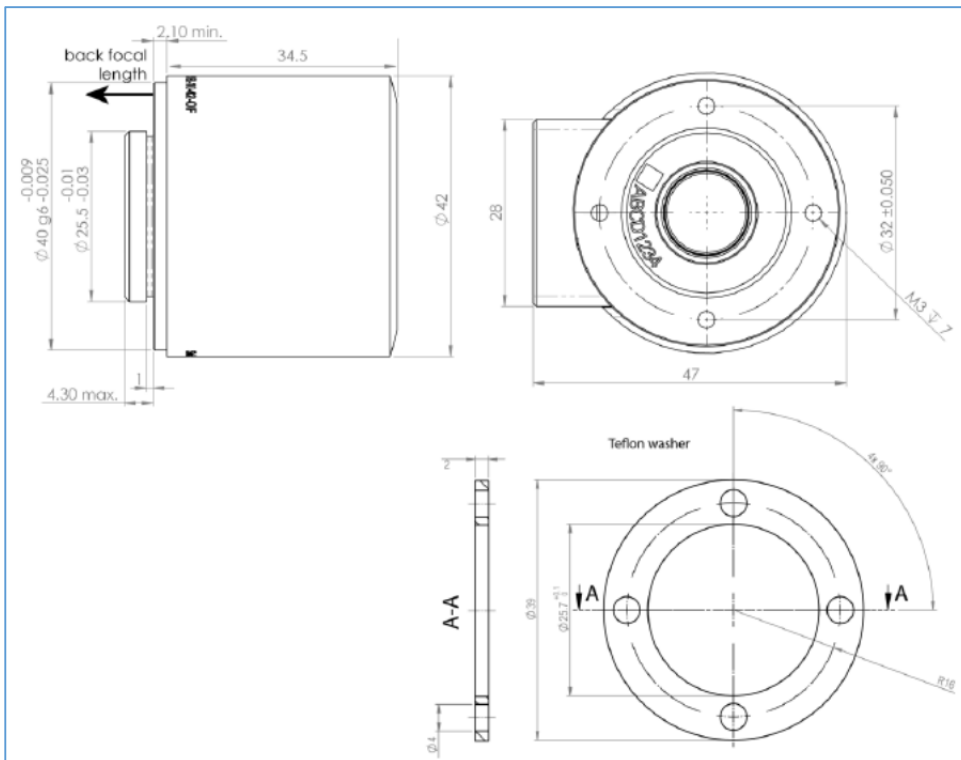


Figure 1: Mechanical drawing of the STOT-EL-10-42-OF (unit: mm). Four M3 thread holes are available for mounting. The Teflon washer has a thickness of 2mm and its flatness is tolerated within +/- 0.05 mm.

Electrical connection

The electrical connection of the STOT-EL-10-42-OF consists of two female 1.5 mm AMP Mini CT connectors with 6 and 8 pins (see e.g. www.te.com, No. 292207-6 and 292207-8). The detailed pin-out is summarized in the table below.

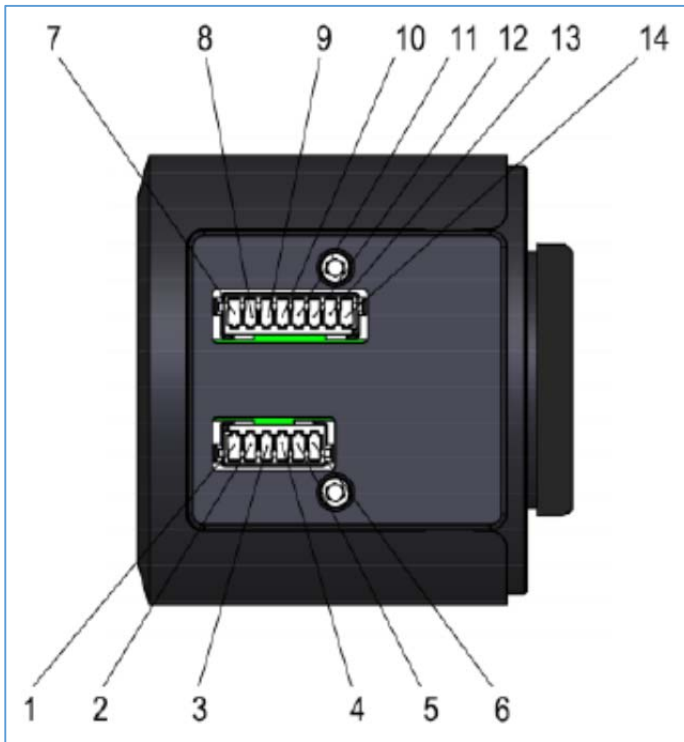


Figure 2: Electrical connections of STOT-EL-10-42-OF. Both connectors are of type 1.5 mm AMP Mini CT.

Position	Function	Value	Position	Function	Value
1	GND	-	8	Control current -	-
2	Heater in	Max. 12W	9	GND	-
3	Heater out	-	10	LED + Anode	30mA @1.5V
4	I ² C SDA	Digital signal	11	LED – Cathode	-
5	I ² C SCL	Digital signal	12	Photodiode Common Cathode GND	-
6	Vcc	3.3V	13	Photodiode Anode back	Typ. 100 μ A

Optical power (focal length) versus current

The optical power of the STOT-EL-10-42-OF increases with increased current, shown in Figure 3. The working principle is based on our well-established technology of electrically tunable lenses. The core that forms the lens contains an optical fluid, which is sealed off with an elastic polymer membrane. An electromagnetic actuator is used to exert pressure on the container and therefore changes the curvature of the membrane such that the focal length is adjusted. By applying the electrical current to the coil of the actuator, the optical power of the lens is controlled.

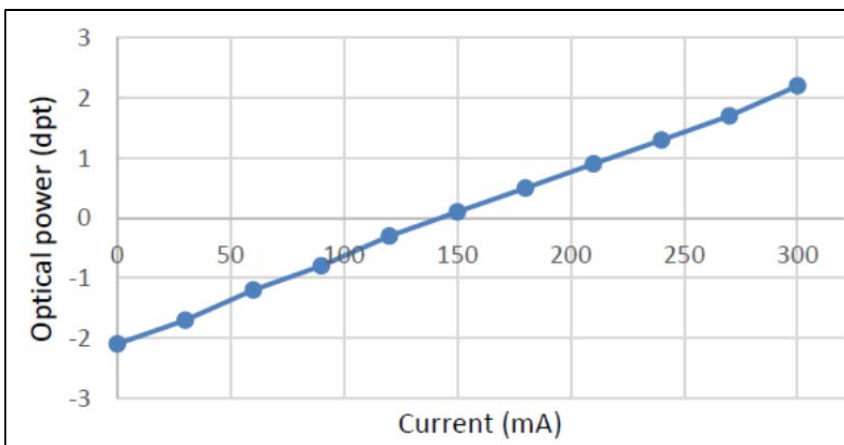


Figure 3: Typical data shows the linear relation between optical power (in diopters) and electrical current.

Optical feedback signal

Optical feedback is used to stabilize the focus of the lens in real time. The way to establish optical feedback is to detect light passing through the lens, emitted from a built-in LED. There are two photodiodes installed inside the lens which are used to measure the LED light. The typical photodiode signals are as shown in Figure 4. The slopes of the two curves are different, and both photo currents strongly depend on the optical power of the lens. With subsequent electronics these currents are converted into voltages through transimpedance amplifiers. The normalized signal $(V1-V2)/(V1+V2)$ of the two voltages V1 and V2 is then calculated in order to perform the optical feedback control for the lens. Note that the normalized signal is independent of intensity fluctuations of the LED.

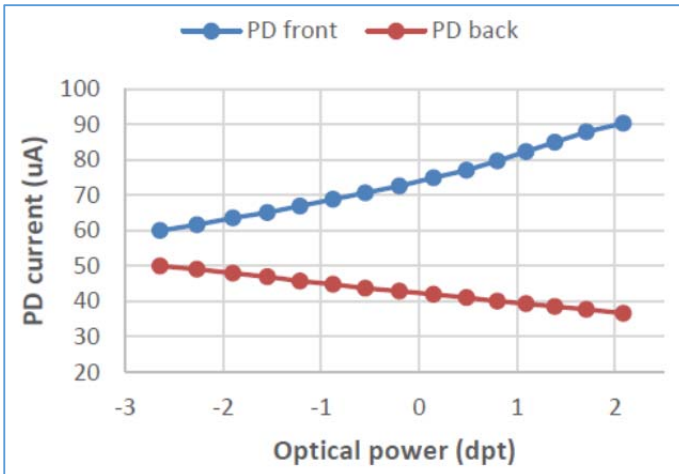
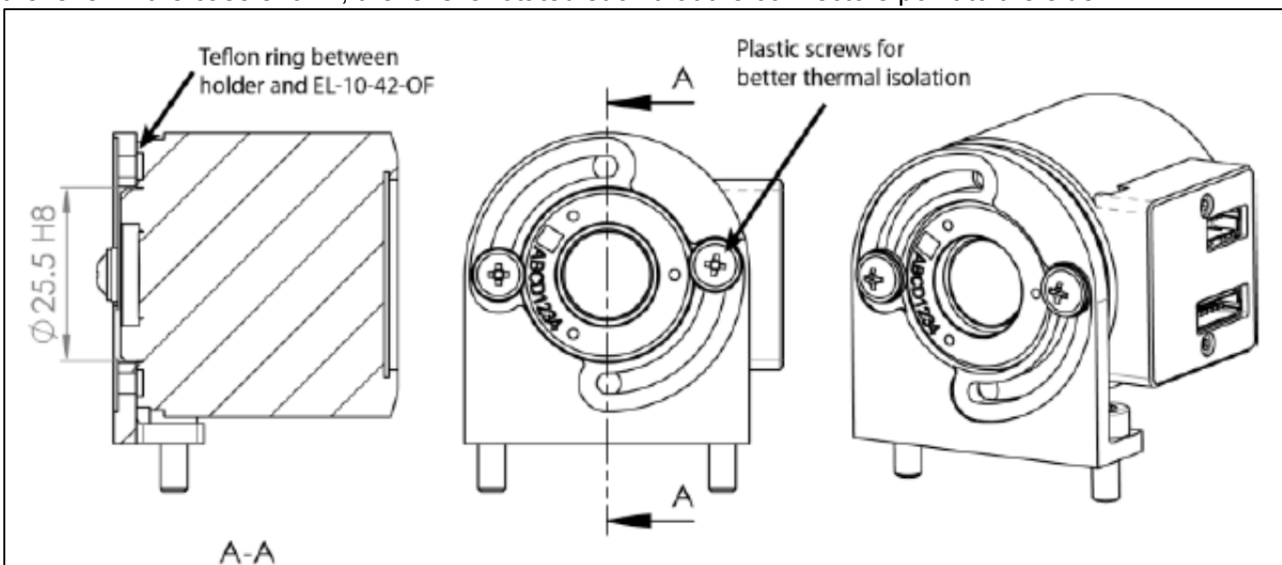


Figure 4: Output current from two photodiodes versus optical power of the lens.

Alignment and mounting

An important aspect when mounting the STOT-EL-10-42-OF is to ensure proper alignment with respect to the optical axis. The figure below shows an implementation of a holder plate. For detailed dimensions in your design, we can provide a CAD file of the holder. We propose a scheme that utilizes the part of the smaller diameter of the lens which is specified with low tolerance (ISO g6). The through hole of the holder plate has the corresponding DIN tolerance H8. The lens is screwed from the front onto the holder plate. This guarantees best alignment with respect to the optical axis. The elongated holes give the rotational freedom to align the connectors, since the relative position of the connectors and the screw holes vary from lens to lens. For best thermal isolation, a Teflon washer (included in the package) has to be placed between the lens and the holder. Also, it is recommended to use plastic screws to fix the lens. In the case shown, the lens is rotated such that the connectors point to the side.



Bode diagram

In order to characterize the dynamics of the STOT-EL-10-42-OF itself, which behaves similar to a mass-spring system, it is common to measure the Bode diagram. It contains both the magnitude of the frequency response and the phase shift. The result is shown in Figure 5 which is applicable as a generic model for the STOT-EL-10-42-OF. Lens to lens variations are negligible. The first resonance peak is at 200 Hz and in the same region the phase shift reaches -90° and continues to lower values. The diagram gives an indication of the physical limit of the lens' maximum control speed, which will be around 100 Hz (half of the resonance frequency).

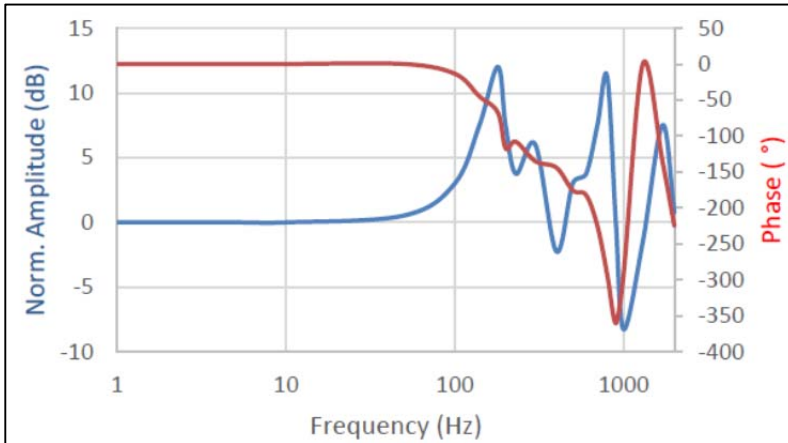


Figure 5: Bode diagram of the STOT-EL-10-42-OF. The amplitude is normalized to the DC limit (constant current) and shows a resonance at 200 Hz (blue curve). The phase shift is shown in red.

Temperature stabilization

In order to have the highest focus stability, STOT-EL-10-42-OF lens is operated at a fixed temperature of 47°C . This can be achieved using the controller boards we provide. The set temperature is controlled using a PI controller for the heater element. When the lens is initialized, it requires a certain amount of time until the set temperature is reached. In Figure 6, two extreme conditions (environmental temperature of 10°C and 40°C) are demonstrated. It can be seen that the system takes approximately 4 and 6 minutes respectively to get the temperature stable. After a short time, indicated by the red and blue arrows, the lens is set to maximum current (300 mA) in order to see the effect of additional heat input. Even for the 40°C environmental temperature only a small increase of about 2°C is visible, which is the desirable result.

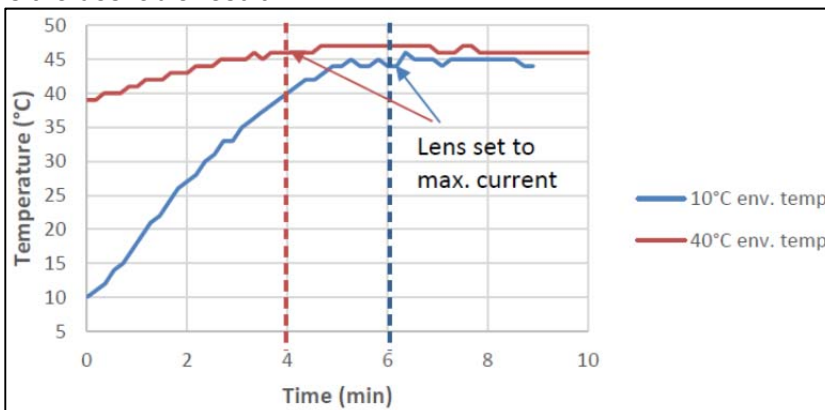


Figure 6: Initial heating phase for two extreme environmental temperatures 10°C and 40°C . It takes approximately 4 and 6 minutes (dashed vertical lines) until the set temperature is reached.

4. Fast electrically tunable lens STOT-EL-16-40-TC

With a clear aperture of 16 mm we presents the world's largest electrically focus tunable lens. Its design has been optimized in many ways:

- The 60% larger aperture than its predecessor, the STOT-STOT-EL-10-30, allows for 2.5x more light throughput
- The tunable lens can be shaped from a flat zero-state into a plano-concave or plano-convex lens, resulting in a focal tuning range of up to -10 to $+10$ diopters (at -250 to $+250\text{mA}$)

- The design was optimized to minimize thermal drift effects to as little as 0.02 dpt/°C and with the built in temperature sensor, an overall reproducibility of typically +/- 0.05 diopters is achievable
- Response & settling times are 5 & 25ms, respectively, which is still magnitudes faster than most mechanical alternatives
- Integration of the lens shaper inside the container allows for the highest possible positioning accuracy of the tunable lens

The STOT-EL-16-40-TC is available in its compact form for OEM integration but also with multiple thread adapters and a robust Hirose connector for industrial use, where the tunable lens can be easily combined with off-the-shelf imaging lenses.



STOT-EL-16-40-TC
(OEM version)



STOT-EL-16-40-TC with thread adapters
(industrial version)

The following table summarizes the main specifications of the STOT-EL-16-40-TC series:

Standard products*	Tuning range	Wavefront error**	Top thread	Bottom thread
STOT-EL-16-40-TC-VIS-5D	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	None	None
STOT-EL-16-40-TC-VIS-20D	-100 to 100 mm -10 to 10 dpt	<0.50 / <2.5 λ	None	None
STOT-EL-16-40-TC-VIS-5D-M25.5	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	M25.5x0.5 male	M40.5x0.5 female
STOT-EL-16-40-TC-VIS-5D-M27	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	M27x0.5 male	M40.5x0.5 female
STOT-EL-16-40-TC-VIS-5D-M30.5	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	M30.5x0.5 male	M40.5x0.5 female
STOT-EL-16-40-TC-VIS-5D-C	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	C-mount male	C-mount female
STOT-EL-16-40-TC-VIS-5D-M42	-500 to 333 mm -2 to 3 dpt	<0.25 / <0.5 λ	M42x1 male	M42x1 female

* All models are available with a 6-pin FPC connector. The models with thread adapters come with a 6-pin Hirose connector

** Wavefront error provided in λ RMS @525nm with optical axis vertical / horizontal

Applications

Applications for Our STOT-EL-16-40-TC are among others:

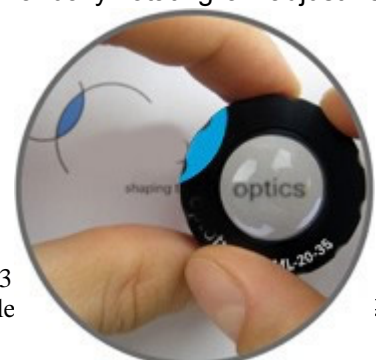
- Machine vision
- Microscopy
- True 3D in augmented and virtual reality
- Refraction correction in ophthalmic devices

5. Manually Tunable Lens STOT-ML-20-37

The STOT-ML-20-37 adapts itself to your specific requirements. By manually rotating an adjustment ring, the lens changes its shape from convex to flat or to concave. This unique feature allows you to choose and finely tune the focal length of the lens within -40 to +40 mm range.

Our manually focus tunable lens is the ideal choice for applications in:

- LED illumination
- Optics R&D (e.g. beam expander)



- Education
- Ophtalmology
- System prototyping

Mechanical specifications

- Optical aperture: 120mm
- External diameter: 37mm (39 including gears)
- Thickness: 13.2 mm
- Weight: 13.7g (without adapter) / 25.2 (with adapter)
- Max torque: 80 mNm (at gear teeth)
- Full tuning angle: 337°

Optical specifications

Lens type: from plano-convex to plano-concave
 Optical power tuning range (BFL): -18 to +18 Dpt
 Focal tuning range (BFL): -55 to infinity to +55 mm
 Focus resolution: Depends on motorization
 Optical liquid (Refractive index) @20°C: 1.38
 Optical liquid (Abbe number): V 65
 Transmission spectrum: See Figure 2
 Wavefront error (@525 nm, 5mm CA): 0.95λ RMS (across tuning range); 0.19λ RMS (at 0 dpt)
 Polarization preserving

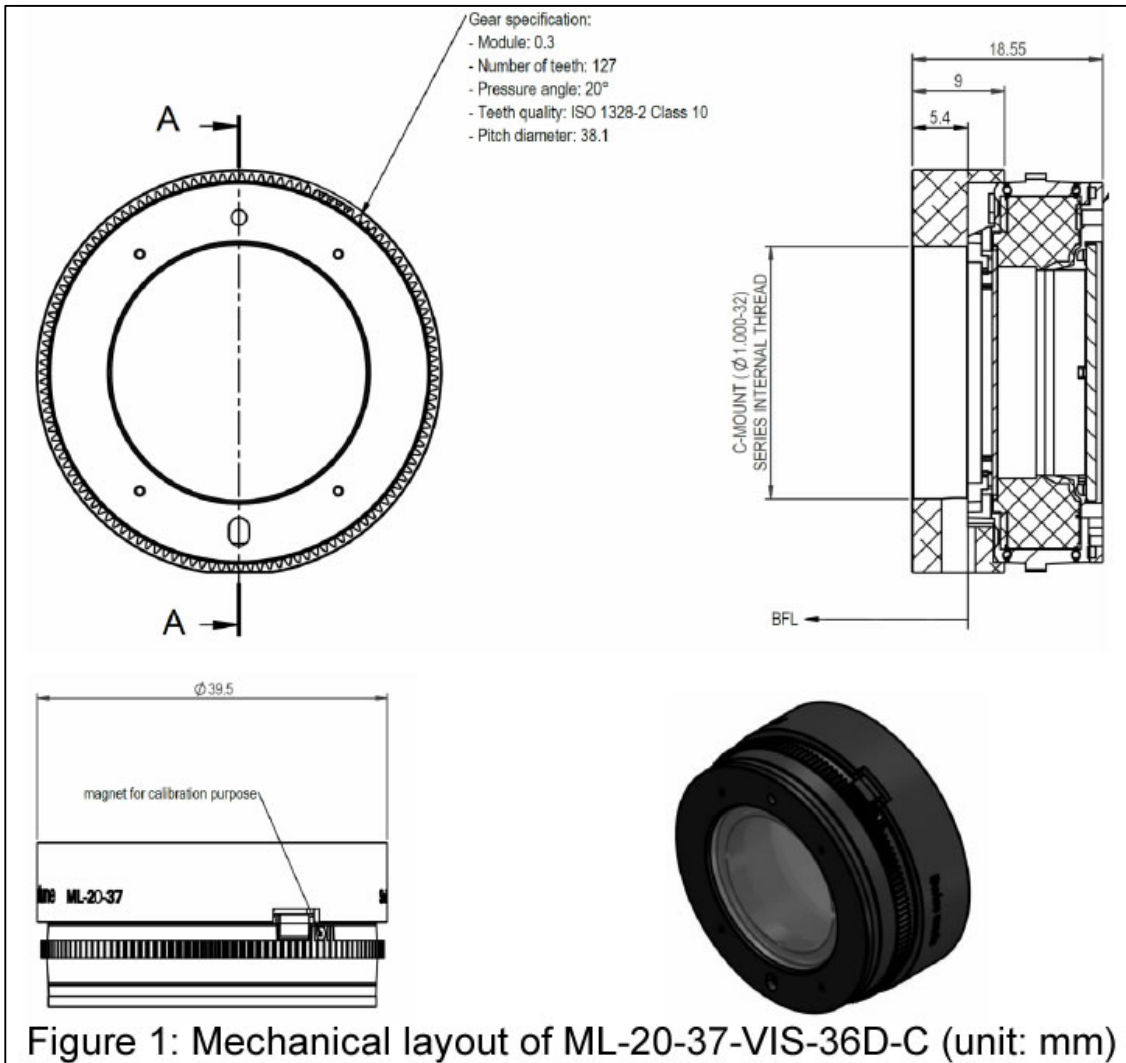
Environmental specifications

Operating temperature: 10 to 40 °C
 Storage temperature: -20 to +75 °C
 Humidity: 30-50% R.H. (non-condensing)
 Lifetime (#random cycles): 5 mio #

Standard product number	Turning range	AR coating	C-mount adapter
STOT-ML-20-37-VIS-36D	-18 to +18dpt	400-700nm	no
STOT-ML-20-37-VIS-36D-C	-18 to +18dpt	400-700nm	yes

Mechanical mounting

Figure 1 shows the dimensions of the STOT-ML-20-37 lens. The back-focal range is measured from the mating surface of the housing of the OEM lens. This surface lies 5.4 mm behind the outermost surface of the C-mount adapter. The ring is used to set the focal range to the desired value.

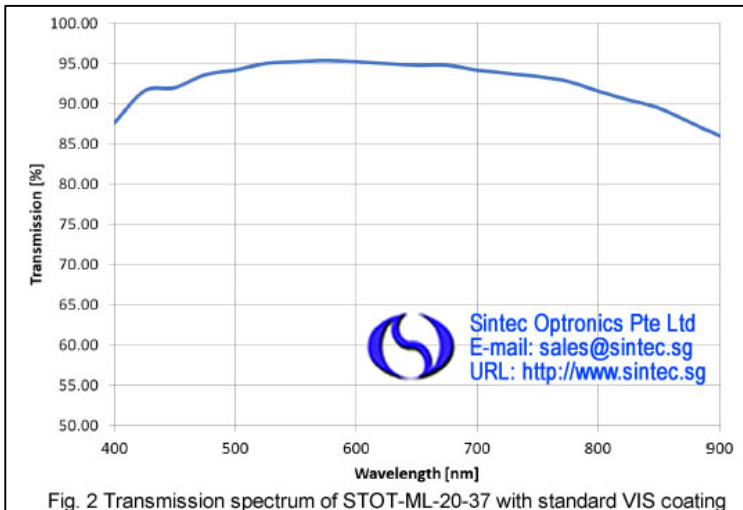


Motorization

The STOT-ML-20-37 can be motorized using either a direct drive or a worm gear. The magnet can be used for calibration purposes.

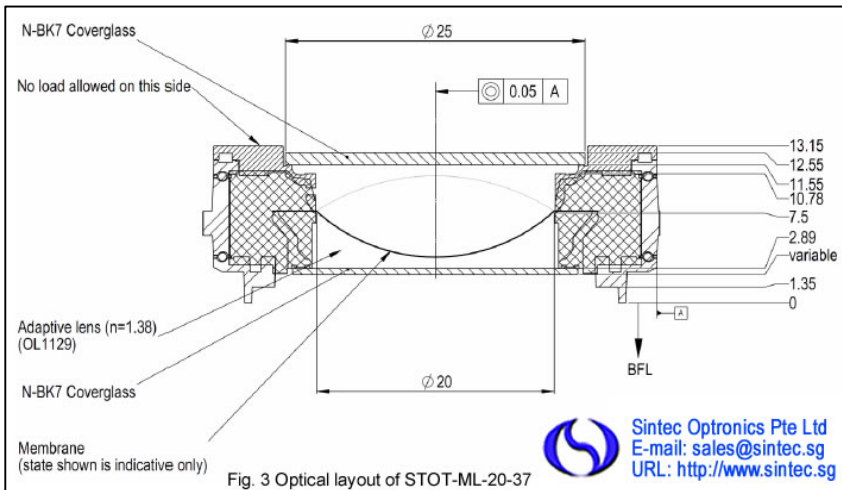
Transmission

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 2 shows the transmission spectrum for the standard broad-band VIS coating.



Optical layout

Figure 3 contains the information needed to model the STOT-ML-20-37 lens for simulation. A precise ZEMAX model can be given upon request. As the cover glass is moved up and down, the membrane deflection changes continuously.



Mounting possibilities

As depicted there exists different mechanical mounting possibilities of the C-mount version. For mounting recommendations of the version without C-mount adapter, please contact us.



Figure 4: Mounting possibilities for the STOT-ML-20-37-C.

(a) STOT-ML-20-37-VIS-LD-C shown with a standard 1/2" optical post mount with M4 screw.

(b) STOT-ML-20-37-VIS-LD-C mounted to a 30 mm to 60 mm Cage Plate Adapter (LCP02/M) with the help of a C-mount to SM1 adapter ring (SM1A39)

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.

6. Electrical lens driver 4

The Lens Driver 4 offers a simple yet precise way to control our electrically tunable lenses, in particular the EL-6-18 and STOT-STOT-EL-10-30 series. Communication with the driver follows an open simple serial protocol, which can be implemented in any programming language on Windows or Linux (C#, Labview and Python source code available). The driver comes with free software and can be used as a standalone solution or integrated into OEM designs. As a compact USB-powered current source, it also serves for driving LEDs or laser diodes.



Lens Driver 4 (OEM version)



Lens Driver 4i (industrial version)

Main features:

- Current control from -290 to +290 mA in 0.07mA steps
- Drive frequencies from 0.2 to 2000 Hz (rectangular, triangular or sinusoidal)
- I2C sensor read-out e.g. for temperature compensation ("Focal Power Mode")
- USB powered (5V)
- Driver software for Windows 7, 8 & 10
- Available with plastic, steel or without housing

This constant current source is suitable for:

- Electrically tunable lenses
- LEDs
- Laser diodes

Industrial Lens Controller TR-CL180 by Gardasoft

Designed for industrial use, this Lens Controller by Gardasoft is the ideal solution for machine vision customers. GigE Vision, RS232 and analog interfaces as well as numerous SDKs allow for easy integration. The trigger input and fast response time of the controller make it also interesting for Z-stacking in microscopy and life science applications.

Main features:

- Current control from -400 to +400 mA in 0.1mA steps at 0.5mA accuracy
- GigE Vision, RS232 & front panel interfaces
- 0-10V analog input (12-bit)
- I2C sensor read-out for temperature compensation ("Focal Power Mode")
- Power supply: 24V
- SDKs: C++, C#, VB, Labview, Cognex VisionPro, Teledyne Dalsa Sherlock, Stemmer Imaging CVB



STOT-EL-E-OF-A Lens Driver for STOT-STOT-EL-10-42-OF with Analog Interface (0-5V)

The STOT-EL-E-OF-A enables the control of the STOT-EL-10-42-OF lens module via an analog voltage signal. Several digital signals are available for status verification. The electronics essentially provides an analog-to-digital stage to read the control and set voltage signal, digital processing with an implemented PID-loop and current sources to drive the lens and the heater unit. The board is optimized for OEM-integration in laser marking systems and therefore comes without housing.



Main features:

- Analog control voltage from 0 to 5 V (ADC resolution 16 bit)
- Sampling rate 1.1 kHz
- Lens driving current ranging from 0 to 300 m
- Integrated optical feedback (OF) control
- JTAG or USB interface for firmware update

SCAPS DSD Lens Driver for STOT-STOT-EL-10-42-OF with Digital Interface (XY2-100)

STOT-DSD is an FPGA-based digital controller which is used for the control of the STOT-STOT-EL-10-42-OF lens module. The board is composed of two layers for which the top one is Digital Servo Interface (DSI-1-O16) and the bottom one is Digital Servo Controller (DSC-1). The board is particularly designed and optimized for OEM-integration in 3D laser marking systems.



Main features:

- Pulse-width modulation (PWM) based lens control
- Automatic tuning for the lens
- Tracking delay of <1ms
- Heater control unit
- XY2-100 and bi-directional XY-SCAPS interface
- Marking speed up to 8000 mm/s for a 45-degree hatching job