

Electrically tunable large aperture lens

EL-16-40-TC (5D)

By applying an electric current to this shape changing polymer lens, its optical power is controlled within milliseconds over a diopter range of -2 dpt to +3 dpt. A major hallmark of this shape changing lens is the clear aperture of 16 mm. In order to achieve good repeatability and focus stability, Optotune integrated a temperature sensor allowing for in-situ compensation of temperature effects. The lenses are therefore ideally suited for a large variety of applications where imaging and a large beam diameter is of importance.



Main specifications

| | | |
|---|--|-------|
| Clear aperture | 16 | mm |
| Optical power: tuning range @ 30°C with Optotune's Lens Driver 4 | -2 to +3 | dpt |
| Repeatability in focal power mode | +/- 0.05 (small steps) +/- 0.1 (large steps) | dpt |
| Wavefront error (@525 nm, 0 mA) Optical axis vertical / horizontal | ~ 0.25 / ~0.5 | λ RMS |
| Lens type | plano-concave to plano-convex | |
| Refractive index & Abbe number | nD=1.300, V=100 | |
| Cover glass coating | 420 to 1500 ¹ | nm |
| Optical retardance @590nm | 6.1 | nm |
| Response time (typical at 30°C, 0 to +/- 250mA step) | 5 | ms |
| Settling time (typical at 30°C, 0 to +/- 250mA step) | 25 | ms |
| Lifecycles (10%-90% sinusoidal) ² | >1'000'000'000 | |
| Operating temperature ³ | -20 to 65 | °C |
| Storage temperature | -40 to 85 | °C |
| Weight | 40 | g |
| Temperature sensor & memory | STTS2004 (STMicroelectronics) | |

Electrical specifications

| | | |
|--|--|----|
| Nominal control current with Lens Driver 4 | -250 to 250 | mA |
| Absolute max. control current | -500 to 500 | mA |
| Power consumption | 0 to 0.7 (nominal), 0 to 2.8 (absolute max.) | W |
| Motor coil resistance @ 30°C | 11 | Ω |
| Absolute maximum voltage (coil) | 5 | V |
| Absolute maximum voltage (temp. sensor) | 4.3 | V |

Overview of available standard products

| Standard Product ⁴ | Main application | Tuning range | Top thread | Bottom thread |
|----------------------------------|-----------------------------------|----------------|----------------|------------------|
| EL-16-40-TC-VIS-5D | OEMs, imaging, microscopy | -2 to +3 dpt | None | None |
| EL-16-40-TC-VIS-20D ⁵ | OEMs, ophthalmology, microscopy | -10 to +10 dpt | None | None |
| EL-16-40-TC-VIS-5D-M25.5 | Imaging (on filter thread) | -2 to +3 dpt | M25.5x0.5 male | M40.5x0.5 female |
| EL-16-40-TC-VIS-5D-M26 | Imaging (above Mitutoyo lenses) | -2 to +3 dpt | M26x0.706 male | M26x0.706 female |
| EL-16-40-TC-VIS-5D-M27 | Imaging (on filter thread) | -2 to +3 dpt | M27x0.5 male | M40.5x0.5 female |
| EL-16-40-TC-VIS-5D-M30.5 | Imaging (on filter thread) | -2 to +3 dpt | M30.5x0.5 male | M40.5x0.5 female |
| EL-16-40-TC-VIS-5D-C | Imaging (between lens and camera) | -2 to +3 dpt | C-mount male | C-mount female |

¹ Standard VIS & NIR coatings available. Further coating options available upon request.

² Lifecycle tests are ongoing. Very similar results as for the EL-10-30 series are expected, since the core technology is the same

³ Guaranteed tuning range is reduced over operating temperature range by approximately 0.025 dpt/°C

⁴ All standard products in this list are also available with NIR coated cover glasses (850-1500nm). The transmission curve is illustrated on page 5.

⁵ Specific datasheet available

| | | | | |
|------------------------|-----------------------------------|--------------|------------|--------------|
| EL-16-40-TC-VIS-5D-M42 | Imaging (between lens and camera) | -2 to +3 dpt | M42x1 male | M42x1 female |
|------------------------|-----------------------------------|--------------|------------|--------------|

Housing and adapter combinations

The EL-16-40-TC comes with a black metallic housing. The electrical connection and computer communication is established via a FFC cable at the side. In addition, customers can attach their own FFC cable via the ZIF-FFC-slide connector at the side of the housing. The relevant mechanical drawings are depicted in Figure 1.

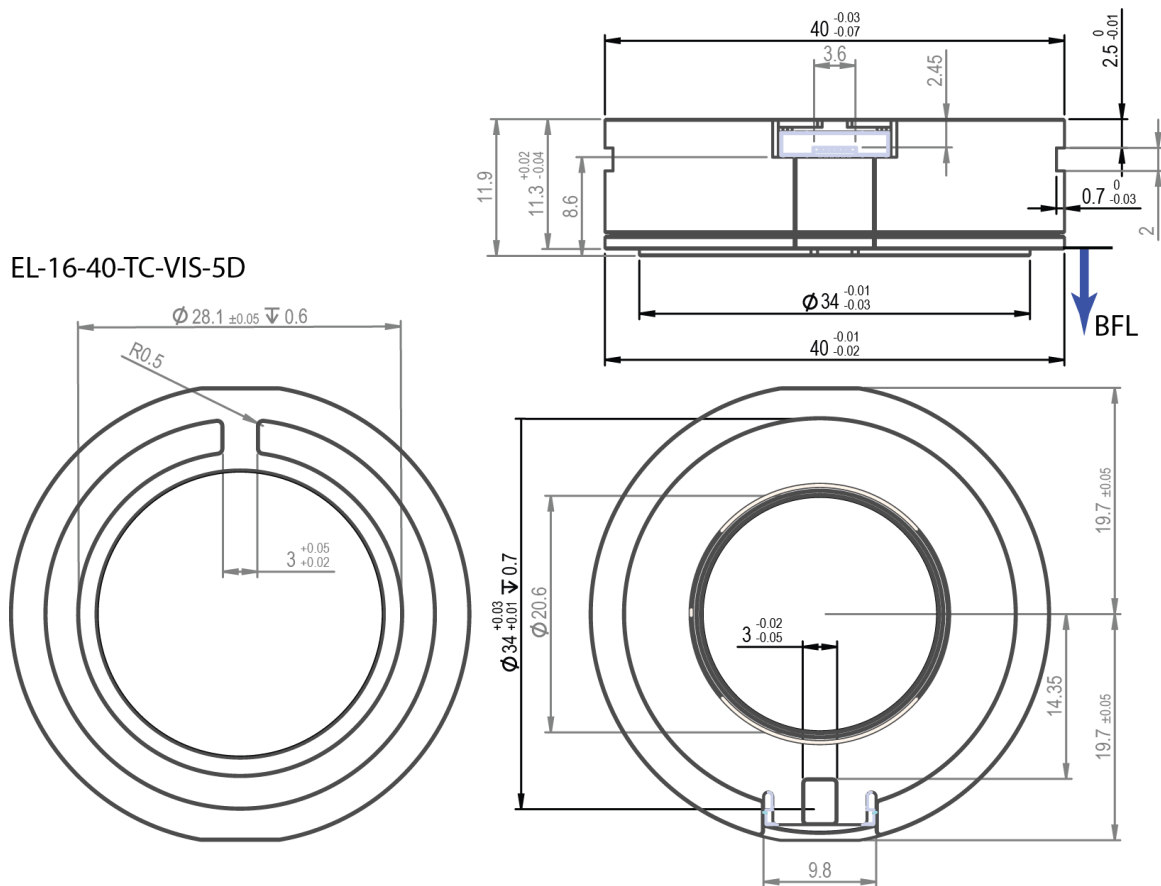


Figure 1: Mechanical drawing of the EL-16-40-TC in its most simple version, the EL-16-40-TC-VIS-5D without any thread adapters attached (unit: mm).

In order to allow for maximum flexibility for the integration in an optical system, several adapter configurations are available, as seen in the overview of the standard product range. The EL-16-40-TC-VIS-5D-M42 is shown in the upper part of Figure 2. Here, the adapters provide a M42 male and female thread combination suitable for most M42-mount lenses and cameras. The top male thread is rotatable, can be extended along the z-axis by 3mm and is held in place with three setscrews (requiring 1.5mm Allen keys).

All other combinations –M25.5, –M26, –M27, –M30.5 and –C are realized by mounting the EL-16-40-TC in an M40.5x0.5 tube and offering different top and bottom adapters, which are also rotatable and lockable with one setscrew. As an example, the EL-16-40-TC-VIS-5D-C is shown in the lower part of Figure 2.

All adapter configurations come with an extension at the side, providing a 6-pin Hirose connector (HR10G-7R-6P), making it suitable for rough environmental conditions. This can be seen on the right part of Figure 2.

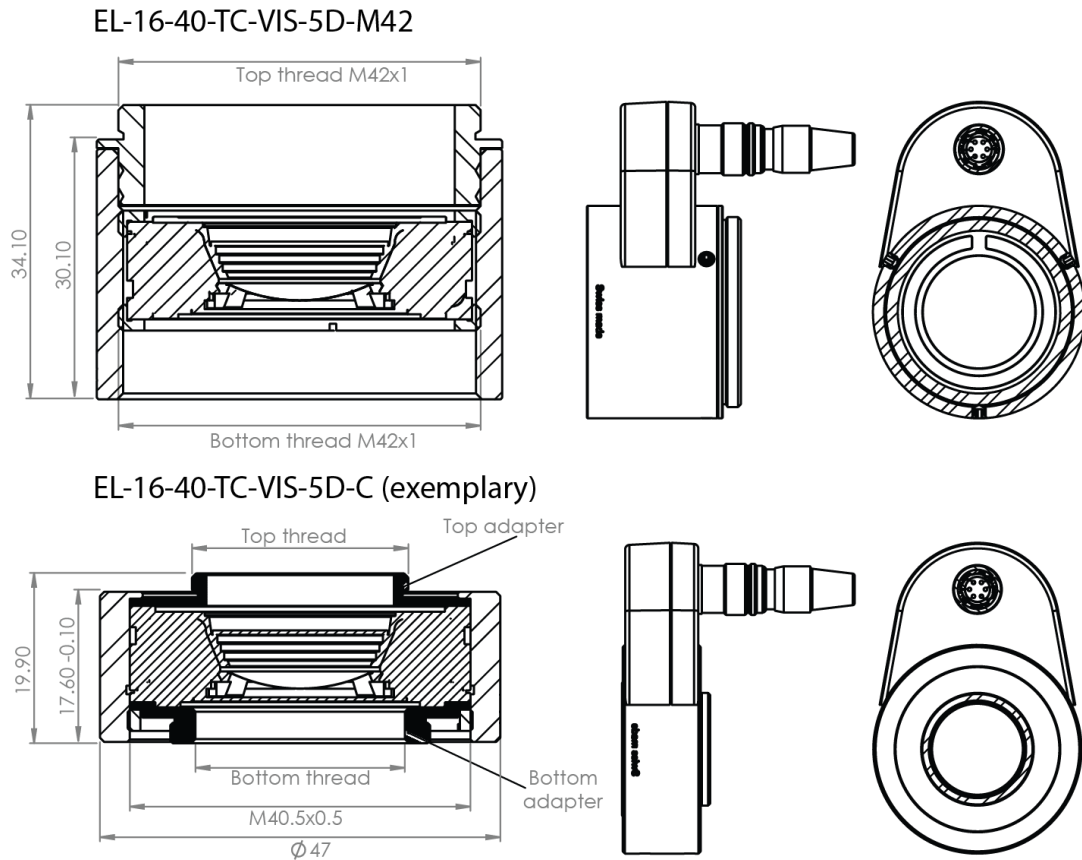
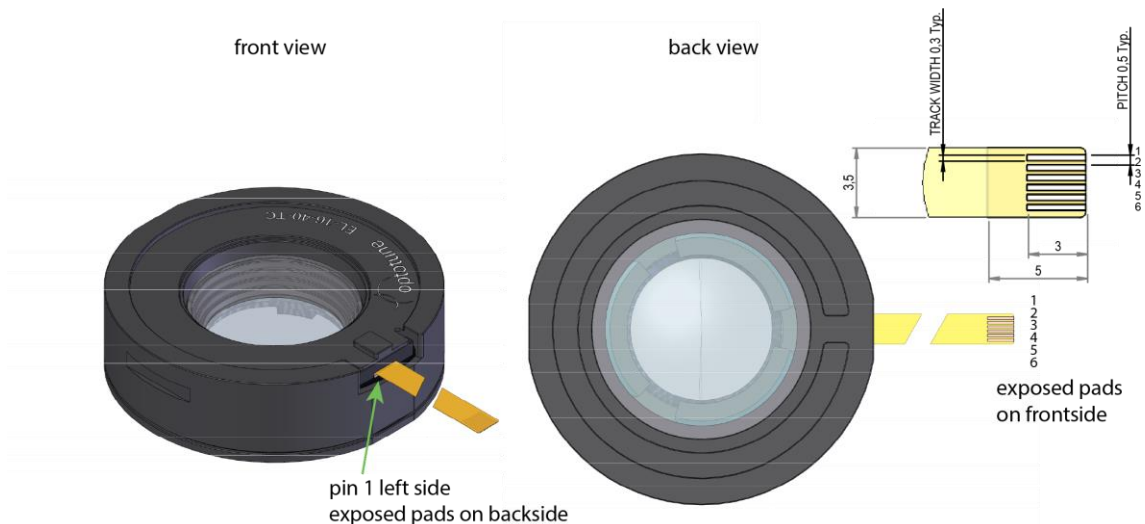


Figure 2: Mechanical drawing of EL-16-40-TC-VIS-5D-M42 and EL-16-40-TC-VIS-5D-C, whereas the latter example also represents the combinations –M25.5, –M26, –M27, –M30.5 (unit: mm).

Attention: The distance from flange to bottom cover glass of the EL-16-40-TC-VIS-5D-C is 4.8mm. Please make sure not to screw in any C-mount lenses with protruding optics as they may scratch or even crack the glass.

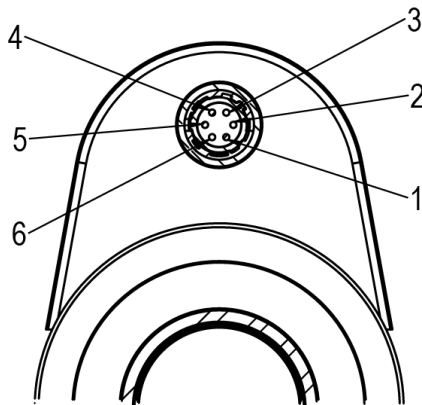
Electrical connection

The electrical connection of the basic version of the EL-16-40-TC without adapters consists of a FPC flex cable with 6 pins suitable for Molex connector no. 503480-0600. Two pins are for the coil of the lens, the other four pins are for the I2C connection to the temperature sensor and EEPROM. The I2C addresses are 0x18 and 0x50, respectively.



| Pinning flex connector | | |
|------------------------|------------------------|----------------|
| Position | Function | Value |
| 1 | Gnd | - |
| 2 | Max. control current - | -500..500 mA |
| 3 | Max. control current + | -500..500 mA |
| 4 | I ² C SDA | Digital signal |
| 5 | I ² C SCL | Digital signal |
| 6 | Vcc | 3.3V |

Figure 3: Electrical flex connections of the EL-16-40-TC basic version without adapters.



| Pinning Hirose connector HR10G-7R-6PB(73) | | |
|---|------------------------|-------------|
| Position | Function | Sensor pins |
| 1 | Max. control current + | - |
| 2 | Max. control current - | - |
| 3 | Gnd | 1-4 |
| 4 | Power | 8 |
| 5 | I ² C SCL | 6 |
| 6 | I ² C SDA | 5 |

Figure 4: Electrical connections of the Hirose connector. The pinout is the same for all adapter versions.

Working principle

The working principle of the EL-16-40-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 5. 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.

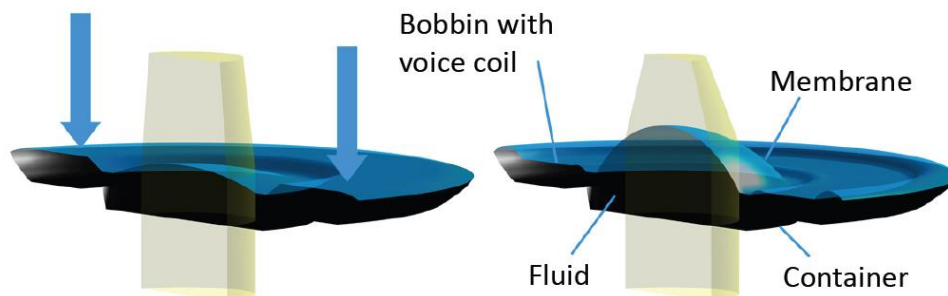


Figure 5: Working principle of the sealed lens container filled with an optical fluid and embedded in an EL-16-40-TC housing.

Optical power versus current

The optical power of the EL-16-40-TC increases with positive current and decreases with negative current as shown in Figure 6. When using Optotune's Lens Driver 4, the optical power range of the EL-16-40-TC is -2 to +3 diopters for the nominal control current -250 to +250 mA. When driving the lens up to absolute maximum control current, the tuning range increases further (see Figure 6) but significant heat generation has to be considered.

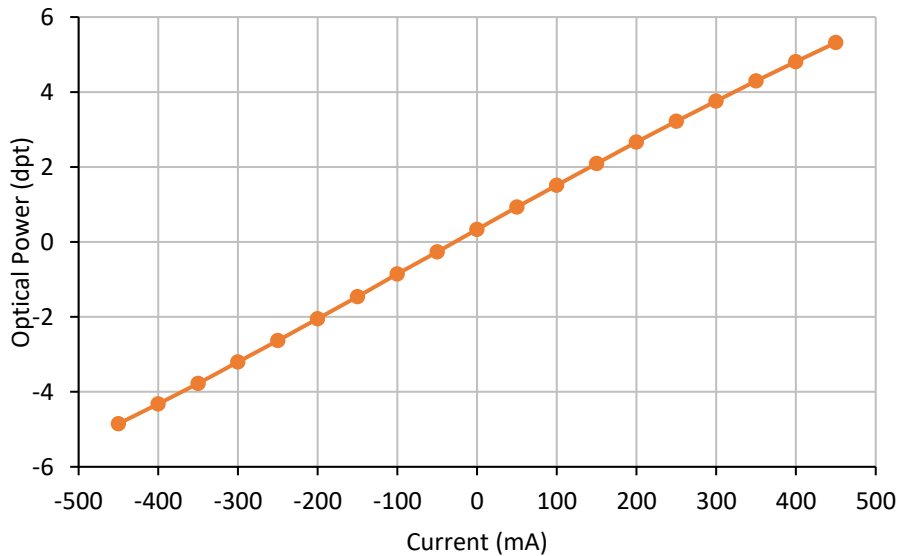


Figure 6: Typical data showing the relation between optical power (in diopters) and electrical current.

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 shows the transmission spectrum for the standard broad-band coatings.

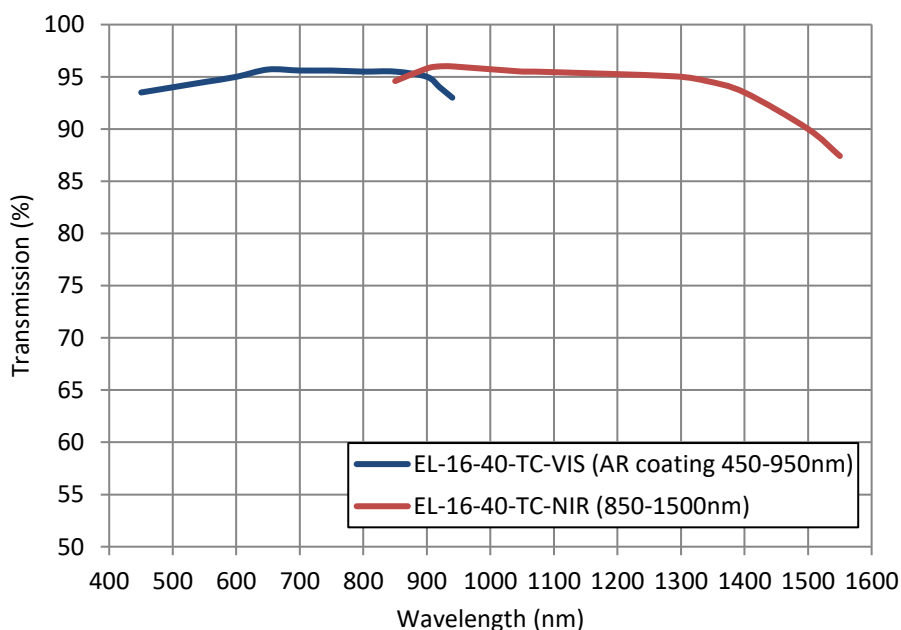


Figure 7: Transmission spectra of EL-16-40-TC standard VIS & NIR coating.

Wavefront quality

In principle, Optotune's focus tunable lenses exhibit a spherical lens shape. As the membranes used are elastic, the lens shape is influenced by gravity. Results are summarized in Figure 8. With the lens lying horizontally (optical axis vertical), the RMS wavefront error of the EL-16-40-TC is 0.25λ (measured at 525 nm). With the lens standing upright (optical axis horizontal) a Y-coma term must be added resulting in a wavefront error in the order of 0.5λ (measured at 525 nm). The gravity induced Y-coma term depends on the size of the lens, the density of the liquid and the mechanical properties of the membrane. If the orientation of the lens does not change during use, the Y-coma can be compensated by using a wave plate.

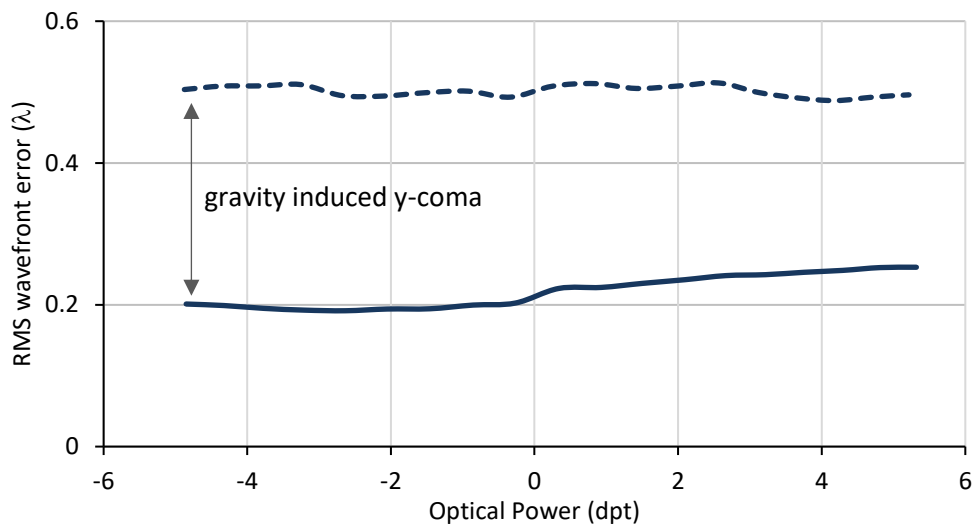
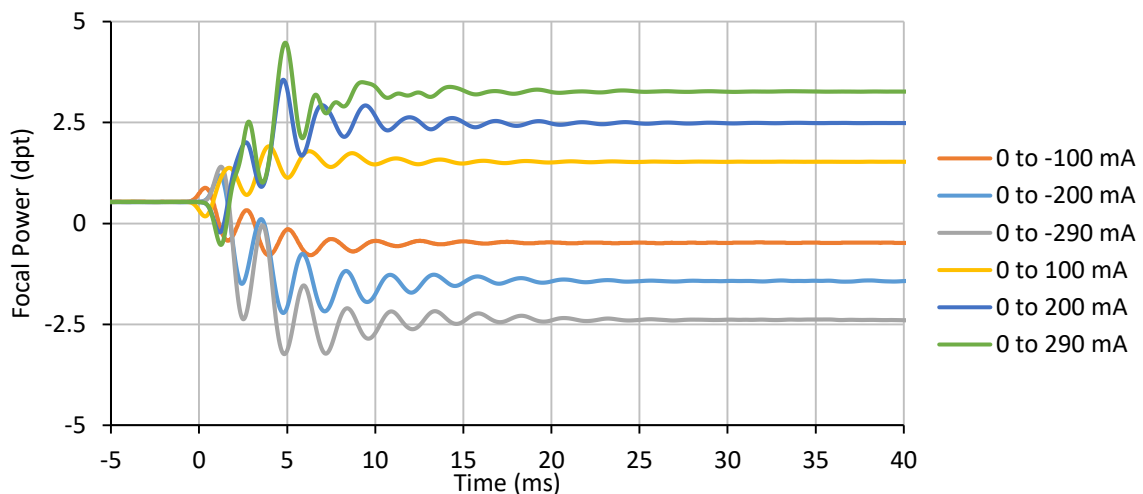


Figure 8: Typical wavefront measurement of the EL-16-40-TC at 525 nm, defocus, tilt & sphere excluded.

Response time

The rise time when applying a current step is about 5 ms. However, it takes about 25 ms until the higher order oscillations of the lens have fully settled. Figure 9 shows the optical response for several current steps measured using a photodiode after a pinhole at room temperature. The settling time can be reduced by typically up to 50% by applying a low-pass filtered step signal as opposed to a rectangular step.



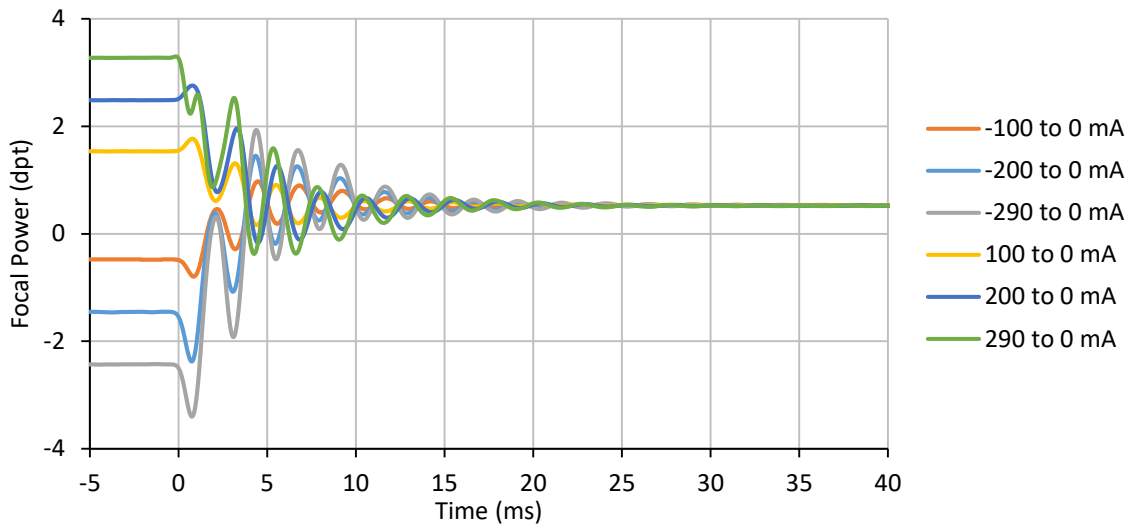


Figure 9: Typical optical response of the EL-16-40-TC-VIS-5D for several current steps. The upper plot shows a series of steps from low to high current and the lower plot for steps from high to low current.

The frequency response over a broad range is presented in Figure 10, showing a resonance peak at 400 Hz. Note that this resonance is from a higher order mode, which can generally not be used for imaging over the entire clear aperture. When applying a current step, it is recommended to damp frequencies above 200 Hz range by using a low pass filter. This avoids excitation oscillations as seen in Figure 9.

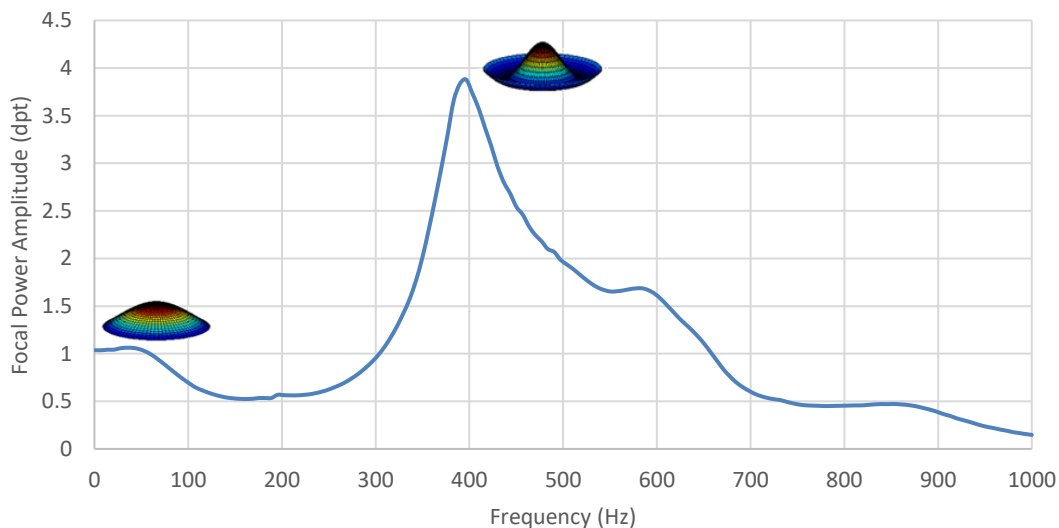


Figure 10: Typical frequency response of the EL-16-40-TC. The driving amplitude is -50 to 50 mA.

Temperature effects

Residual temperature effects influence the long-term drift of optical power stated in the specification table. These temperature effects are quantified by the temperature sensitivity S (dpt/°C), giving the change in optical power per degree Celsius. As shown in Figure 11, there is an almost linear dependence of S with optical power. Generally, temperature effects can be minimized when the EL-16-40-TC is thermally connected to a heat sink. The mounting itself can be used as a heat sink. Large mass and high thermal conductivity of the material dissipates the heat more efficiently. Optotune's Lens Driver 4 and Gardasoft's TR-CL180 both offer automatic thermal compensation to achieve a repeatability of typically ± 0.05 dpt for small and ± 0.1 dpt for large focus steps.

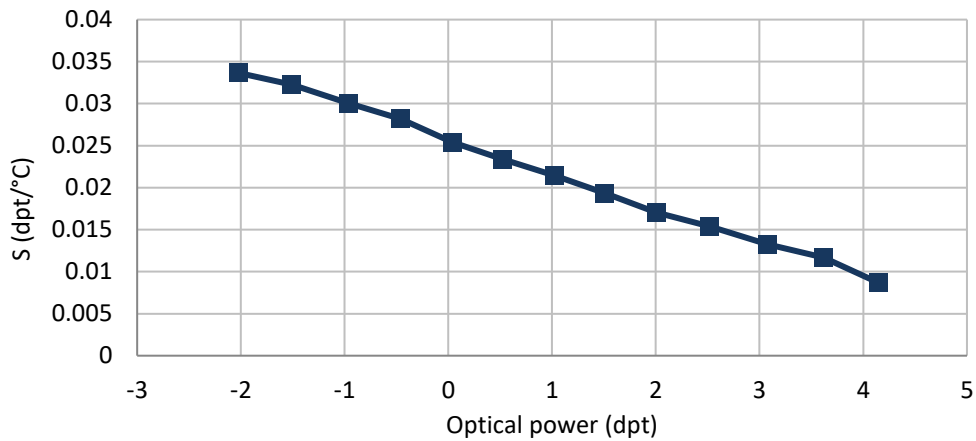
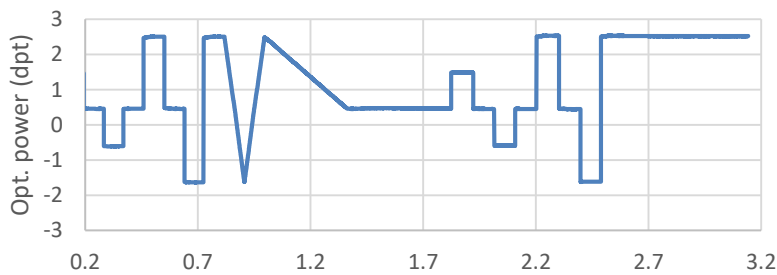


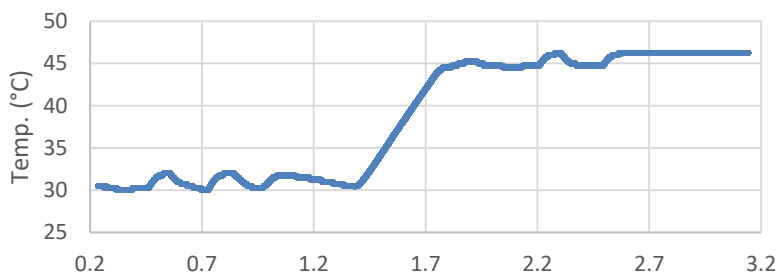
Figure 11: Temperature sensitivity S as a function of optical power.

Repeatability measurement

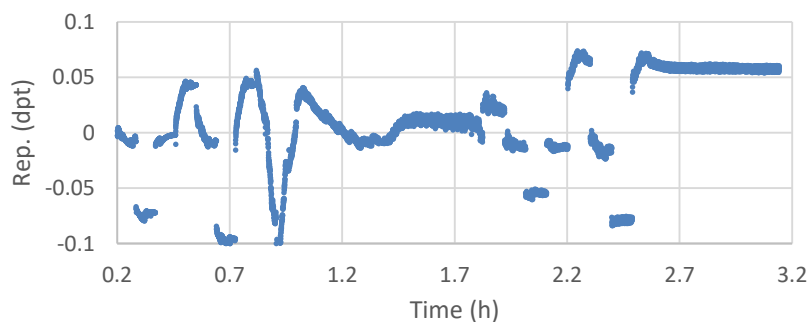
In order to verify the repeatability under demanding conditions we perform a long term measurement using Optotune's Lens Driver 4. During the measurement which lasts for about 3 hours, we change the optical power of the lens and environmental temperature significantly.



The optical power is varied in different patterns, e.g. large and small steps, fast and slow ramps. The x-axis represents the time in hours, as for the other plots.



After about 1.5 hours, the temperature is increased by 15°C to 45°C.



The error of optical power represents the repeatability and is the difference between measured and set focal power. The repeatability remains within +/- 0.1 dpt.

Figure 12: Repeatability measurement over a time span of about 3 hours. Optical power and environmental temperature are varied over a broad range while the error between measured and set optical power remains small.

We measure the actual optical power on the Shack Hartmann sensor in parallel. To infer the repeatability, we calculate the difference between actual (measured) and set optical power. The resulting errors remain within +/- 0.1 dpt.

Resistance and Inductance of the driving coil

In principle, the EL-16-40-TC 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 | 1.67 |
| 1000 | 1.86 |
| 100 | 1.90 |
| 10 | 1.92 |

Optical layout

Zemax simulations to model the EL-16-40 lens series within an optical design are available upon request.

Autofluorescence

The EL-16-40 is not auto fluorescent and can be used for fluorescence microscopy.

Ordering information for EL-16-40-TC

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

EL-16-40-TC-VIS-DPT-THR

DPT = 5D: 5 diopter range
20D: 20 diopter range

THR = C: C-mount thread
M25.5: M25.5x0.5 thread
M26: M26x0.706 thread
M27: M27x0.5 thread
M30.5: M30.5x0.5 thread
M42: M42x1 thread

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.

For more information on optical, mechanical and electrical parameters, please contact sales@optotune.com.

Packaging

The EL-16-40 industrial version is available in single units packaged in a box. The EL-16-40 OEM version is available in single units packaged in a membrane box or in trays of 25 units each.

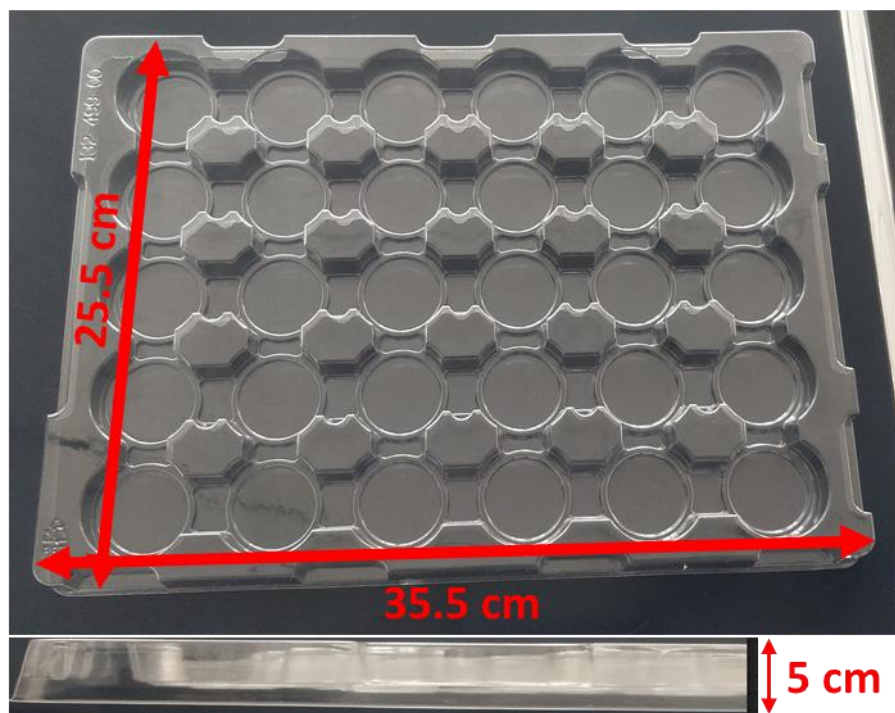


Figure 13: Sizes of the 25 units tray for the OEM version.