

## Electrically tunable lens EL-16-40-TC (20D version)



By applying an electric current to this shape changing polymer lens, its optical power is controlled within milliseconds over an optical power range of -10 dpt to +10 dpt. A major hallmark of this shape changing lens is the clear aperture of 16 mm. 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.

### Lens specifications

|   |                                  |                |
|---|----------------------------------|----------------|
| Clear aperture  | 16                               | mm             |
| Focal power range:<br>(30°C, ±250 mA)                           | -10 to +10                       | dpt            |
| Repeatability in focal power mode                               | ~ 0.1                            | dpt            |
| Wavefront error @ 0 dpt<br>(Optical axis vertical / horizontal) | <0.5 / <2.5(due to gravity coma) | λ RMS @ 532 nm |
| Lens type   | plano-concave to plano-convex    |                |
| Refractive index / Abbe number                                  | n <sub>D</sub> = 1.30 / v = 100  |                |
| Response time<br>(typ. at 30°C, 0 to ±250 mA step)              | 7                                | ms             |
| Settling time<br>(typ. at 30°C, 0 to ±250 mA step)              | 40                               | ms             |
| Lifecycles (10% - 90% sinusoidal)                               | > 1'000'000'000                  |                |
| Operating temperature   | -20 to 65                        | °C             |
| Storage temperature   | -40 to 85                        | °C             |
| Weight  | 40                               | g              |

### Electrical specifications

|  |                               |    |
|--|-------------------------------|----|
| Nominal control current                    | -250 to 250                   | mA |
| Absolute max. control current              | -500 to 500                   | mA |
| Motor coil resistance @ 25°C               | 12                            | Ω  |
| Power consumption (nominal 0 - 250 mA)     | 0 - 0.7                       | W  |
| Max power consumption (@ 500 mA)           | 3.0                           | W  |
| Temperature sensor                         | STTS2004 (STMicroelectronics) |    |
| Absolute maximum voltage (coil)            | 10                            | V  |
| Absolute maximum voltage (memory & sensor) | 4.3                           | V  |

### Overview of available standard products

| Standard Product                  | Wavefront error (@525 nm, 0 mA) |  | Bottom Thread | Top thread     |
|-----------------------------------|---------------------------------|--|---------------|----------------|
|                                   | vertical optical axis           |  |               |                |
| EL-16-40-TC-VIS-20D (standard)    | <0.5 λ RMS                      |  | None          | None           |
| EL-16-40-TC-VIS-20D-C (standard)  | <0.5 λ RMS                      |  | C-mount male  | C-mount female |
| EL-16-40-TC-VIS-20D-1 (class 1)   | <0.25 λ RMS                     |  | None          | None           |
| EL-16-40-TC-VIS-20D-1-C (class 1) | <0.25 λ RMS                     |  | C-mount male  | C-mount female |

The standard EL-16-40-TC-VIS-20D is targeted to ophthalmic applications, where a larger wavefront error can be tolerated since the human eye only uses a sub-pupil of the lens. For imaging applications and microscopy, we recommend the class 1 model with better wavefront quality.

### Housing and adapter combination

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.

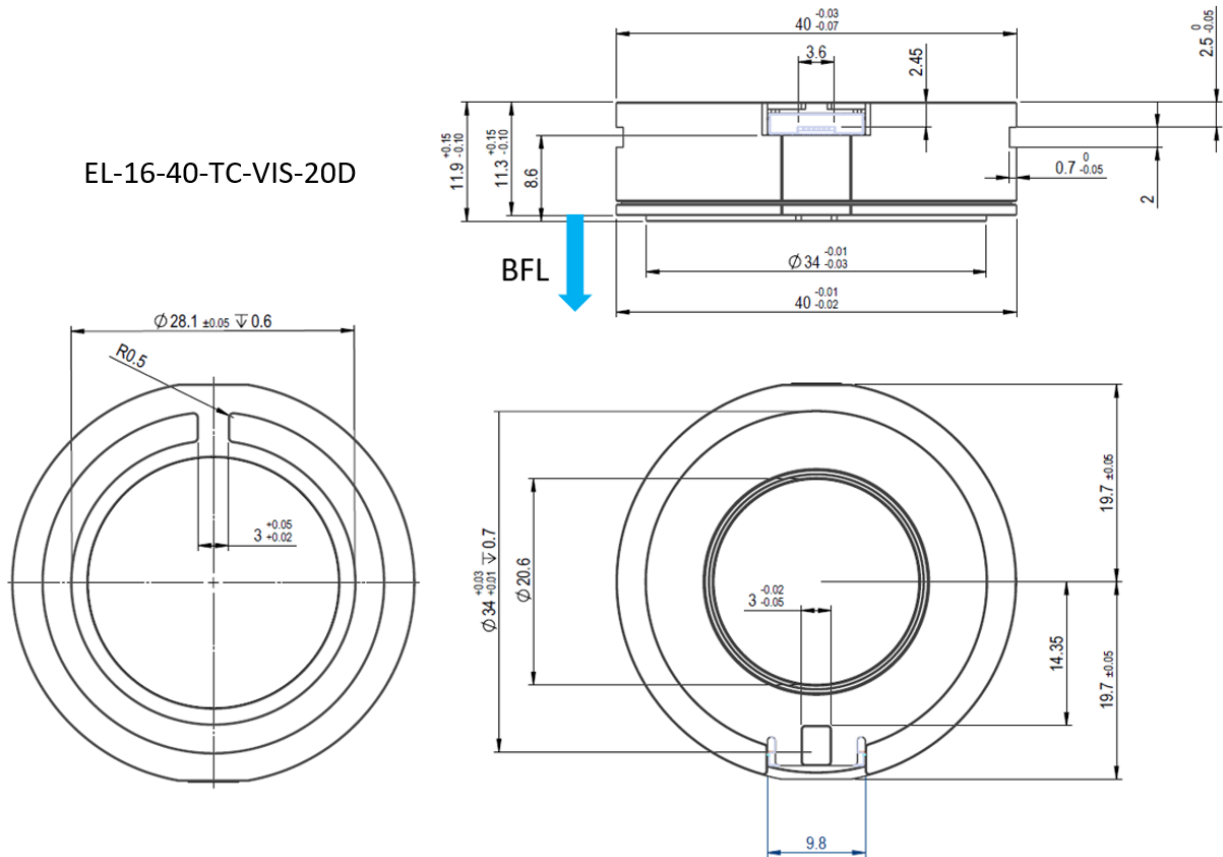


Figure 1: Mechanical drawing of the EL-16-40-TC in its most simple version, the EL-16-40-TC-VIS-20D without any thread adapters attached (unit: mm).

A C-mount adapter configuration is realized by mounting the EL-16-40-TC in an M40.5x0.5 tube, which is rotatable and lockable with one setscrew. The EL-16-40-TC-VIS-20D-C is shown in Figure 2. The adapter configuration comes with an extension at the side, providing a 6-pin Hirose connector (HR10G-7R-6P), making it suitable for tough environmental conditions. This can be seen on the right part of Figure 2.

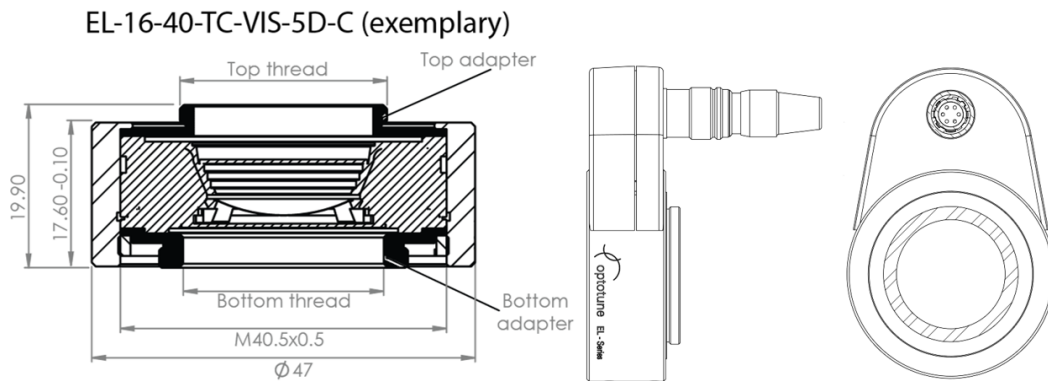
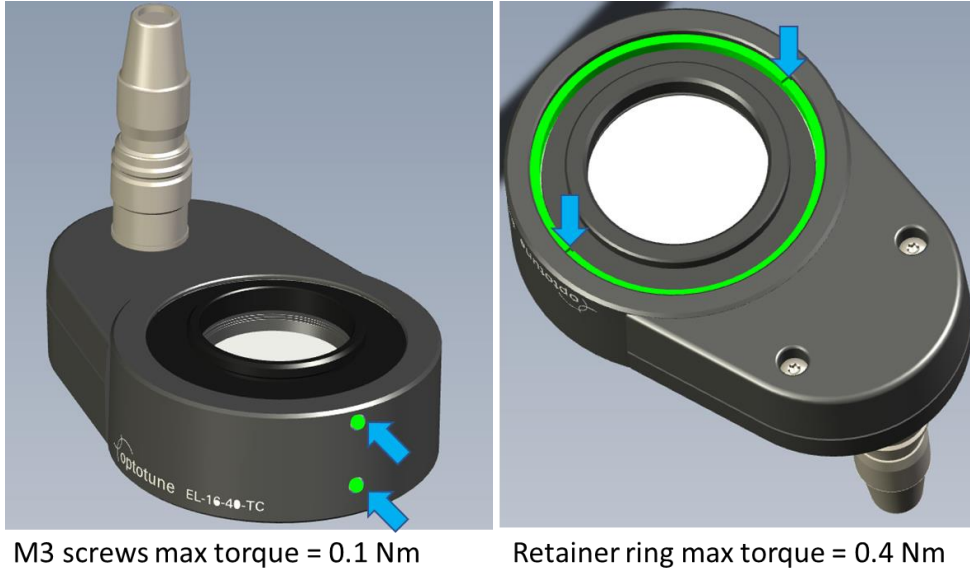


Figure 2: Mechanical layout of EL-16-40-TC-20D-C configuration (unit: mm).

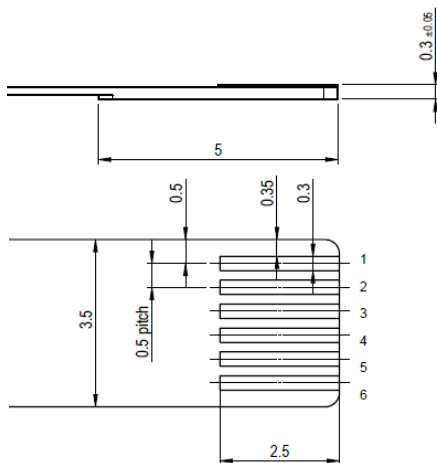
The design features two M3 screws on the side, which are used to lock the position of the thread adapters. The upper M3 screw can be loosened to freely rotate the Hirose connector against the top thread if needed. The lower M3 screw holds in place the bottom thread. Each M3 screw can be tightened with a maximum torque of 0.1 Nm. It is recommended to first loosen both M3 screws, tighten the retainer ring, then tighten the M3 screws.



**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 EL-16-40-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 I<sup>2</sup>C connection to the temperature sensor and EEPROM. The I<sup>2</sup>C addresses are 0x18 and 0x50, respectively.



| Pin out: EL-16-40-TC |                        |                |
|----------------------|------------------------|----------------|
| Position             | Function               | Value          |
| 1                    | GND                    | -              |
| 2                    | Max. control current - | -500 to 500 mA |
| 3                    | Max. control current + | -500 to 500 mA |
| 4                    | I <sup>2</sup> C SDA   | Digital signal |
| 5                    | I <sup>2</sup> C SCL   | Digital signal |
| 6                    | Vcc                    | 3.3 V          |

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



Figure 4: Electrical connections of lens models without embedded controller featuring (male) Hirose connector.



Figure 5: Electrical connections of lens models with embedded controller ECC-1C featuring (female) Hirose connector.

## 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 6. 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.

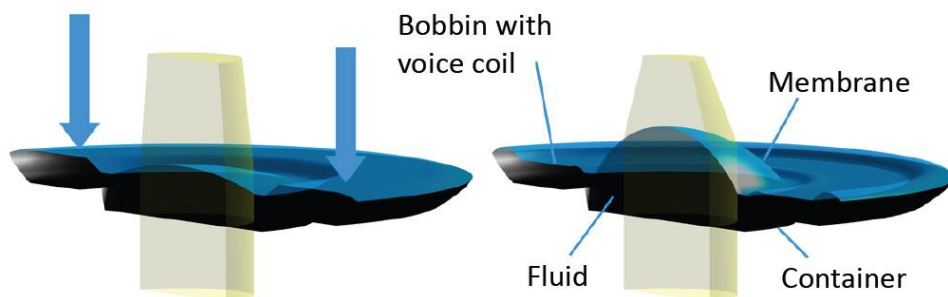


Figure 6: Working principle of the sealed lens container filled with an optical fluid and embedded in an EL-16-40-TC housing.

## Optical power versus current

The optical power of the EL-16-40-TC increases with positive and decreases with negative current as shown in Figure 7. When using Optotune's Lens Driver 4, the optical power range of the EL-16-40-TC is at least -10 to +10 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 must be considered.

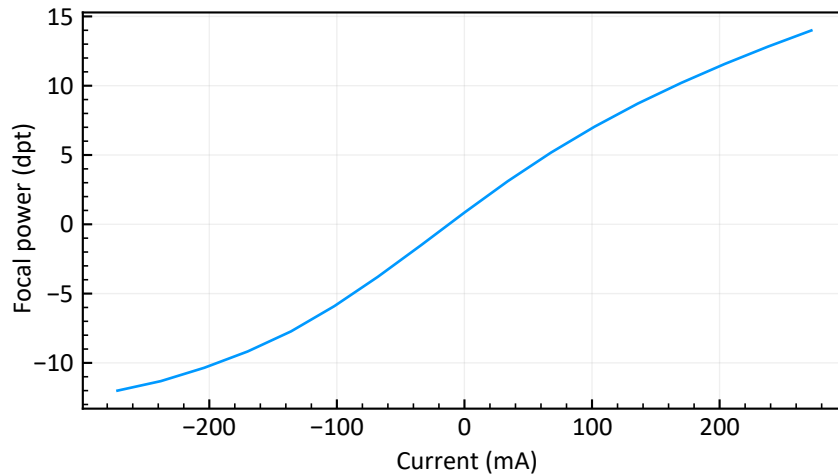


Figure 7: Typical data showing the relation between optical power (in diopters) and electrical current.

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

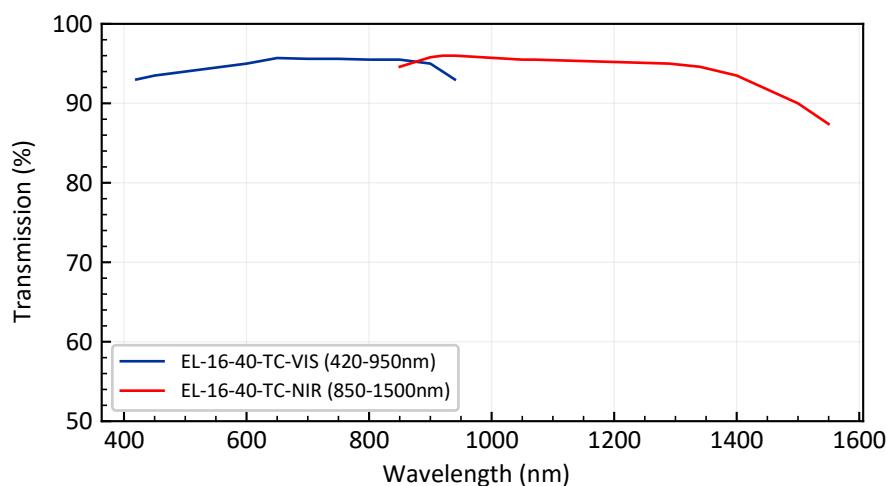


Figure 8: Transmission spectra of EL-16-40-TC standard VIS & NIR coating.

## 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. With the lens' optical axis vertical, the RMS wavefront error of the EL-16-40-TC is  $0.5 \lambda$  (measured at 525 nm). With the optical axis horizontal a coma term must be added resulting in a wavefront error in the order of  $2.5 \lambda$  (measured at 525 nm). For imaging applications it is therefore highly recommended to work with vertical optical axis. Alternatively, if the orientation of the lens does not change during use, the Y-coma can be compensated to a certain extent by using a wave plate.

## 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. 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-passed filtered step signal as opposed to a rectangular step.

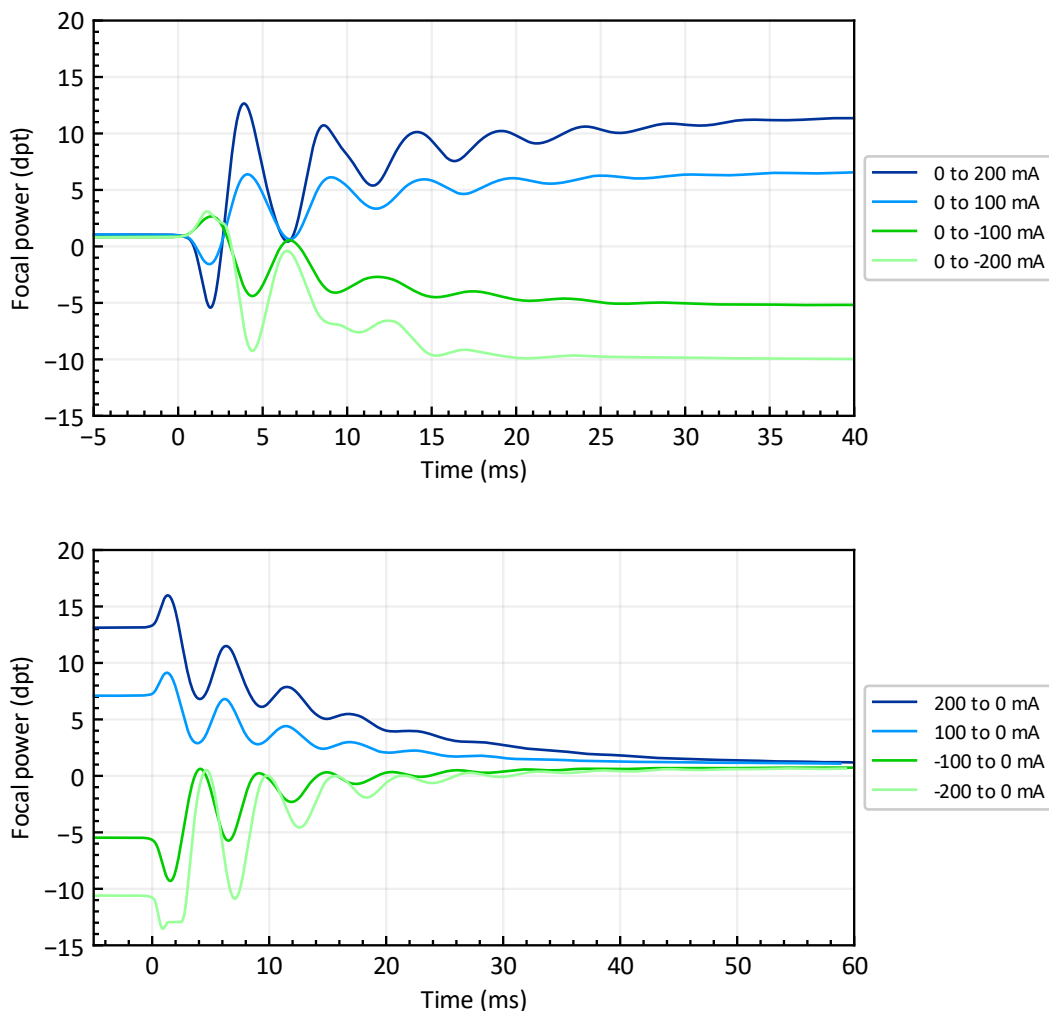


Figure 9: Typical optical response of the EL-16-40-TC-VIS-20D for several current steps. The upper plot shows a series of steps from low to high current and the lower plot for steps from high to low current.

The frequency response over a broad range is presented in Figure 10, showing a resonance peak at 200 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 100 Hz by using a low pass filter. This avoids excitation oscillations as seen in Figure 9.

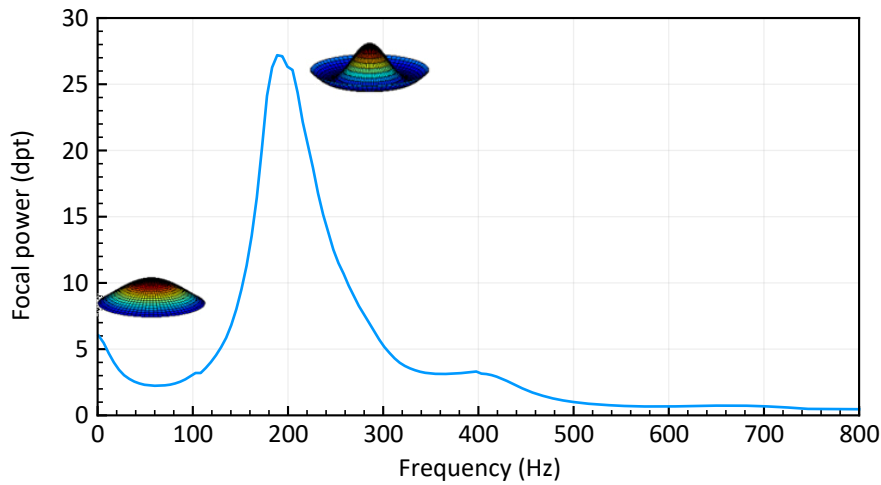


Figure 10: Typical frequency response of the EL-16-40-TC. The driving amplitude is -50 to 50 mA.

### 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  $\pm 0.05$  dpt for small and  $\pm 0.1$  dpt for large focus steps.

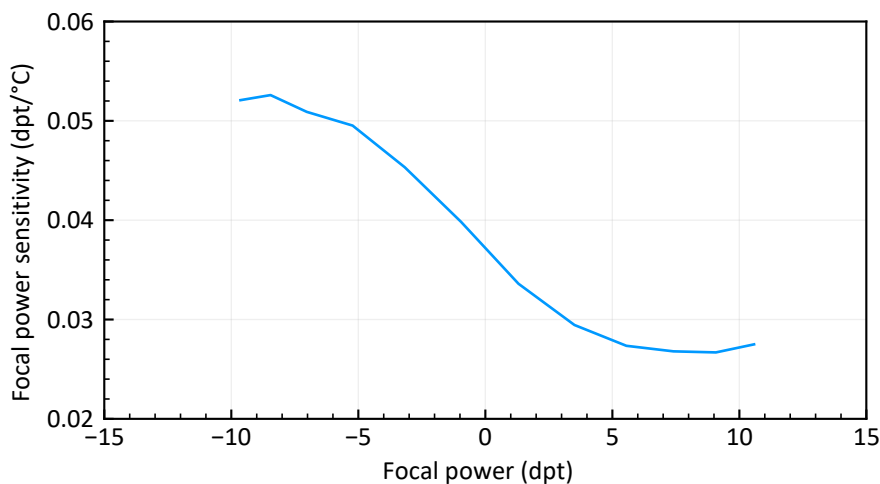


Figure 11: Focal power sensitivity as function of the focal power.

## Optical layout

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

## Autofluorescence, birefringence & polarization effects

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

## Ordering information for EL-16-40-TC

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

**EL-16-40-TC-AR-DPT-CL-THR-CTRL**

|        |  |
|--------|--|
| AR =   | VIS: 420 – 950nm<br>NIR: 850 – 1500nm  |
| DPT =  | 5D: 5 diopter range<br>20D: 20 diopter range   |
| CL =   | 1: class 1 specification for wavefront error   |
| THR =  | C: C-mount thread<br>M25.5: M25.5x0.5 thread<br>M26: M26x0.706 thread<br>M27: M27x0.5 thread<br>M30.5: M30.5x0.5 thread<br>M42: M42x1 thread |
| CTRL = | E: Includes embedded lens controller ECC-1C  |

## 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](mailto:sales@optotune.com)