3D ToF sensor design and it's application in gesture and object recognition

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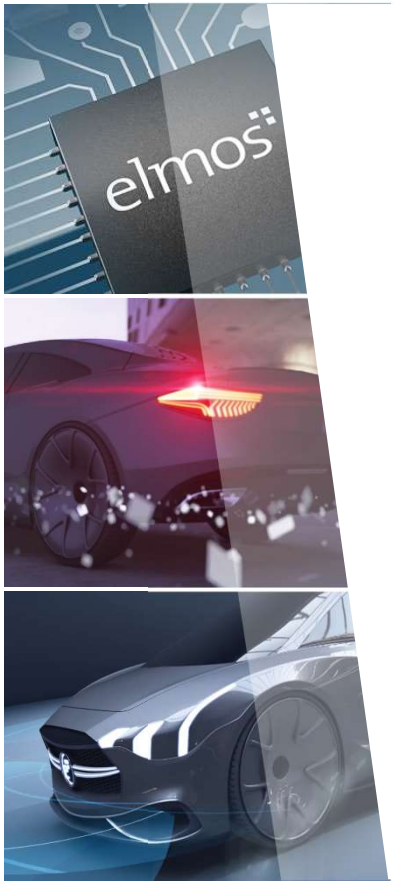
Semiconductor Company driven by System Innovation



WORLDWIDE LEADING PRODUCTS

- Elmos serves the **megatrends** (ADAS, EV…) and **attractive niches** with benchmark innovations
- Leading ICs with **#1 positions** worldwide**:**
  Ultrasonic ranging, climate control, gesture recognition, ambient LED light, soon LED rear light

LONG-TERM EXPERIENCE IN ICs

- **Founded in 1984** in Dortmund (Germany), **IPO 1999**
- Broad expertise in analog mixed-signal integrated circuit design; sales: **~85% automotive**
- Main strength: **Deeply understand our customers application needs** to create system innovation

ENABLING GROWTH

- **Global player for automotive** ASSPs and ASICs
- Specialized **design and application experts**; worldwide sales offices and application support
- **Fablite approach**: Flexible production strategy for wafer processing and test operations

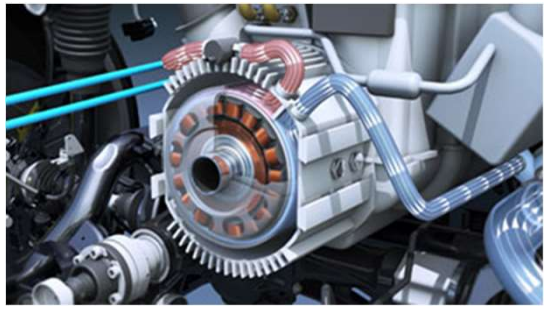
Setting Standards in Innovations

BUSINESS LINE 1

RANGING

SENSOR INTERFACES

OPTICAL



MOTOR CONTROL

LIGHTING

SAFETY, POWER & CUSTOM ICs

BUSINESS LINE 2+3

Product Segment - Optical

TRANSFORMING USER EXPERIENCE

- Intuitive and robust: Pioneering in automotive gesture control with >50 million ICs in the field
  - Proximity and swipes
  - Object detection
  - Touchless door / trunk access
- Reliable and eco-friendly
  - Presence and motion detection
  - Rain and light sensing
  - Smoke detection
- Development of LiDAR key components
  - Highly efficient optical CMOS receivers
  - LiDAR read-out ICs
  - Best of class laser diode driver

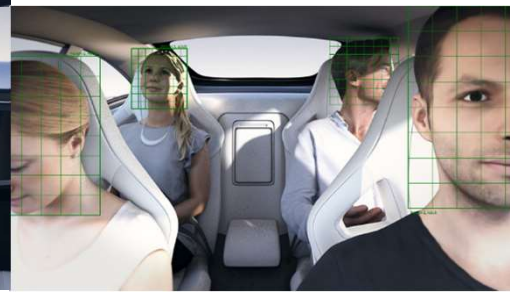
Agenda

- 3D ToF Imager Automotive Applications
  - Interior Applications
  - Exterior Applications
- ToF Measurement Principle
  - Direct and indirect ToF
- Calibration of a 3D ToF Imager
  - From raw data to a real distance value

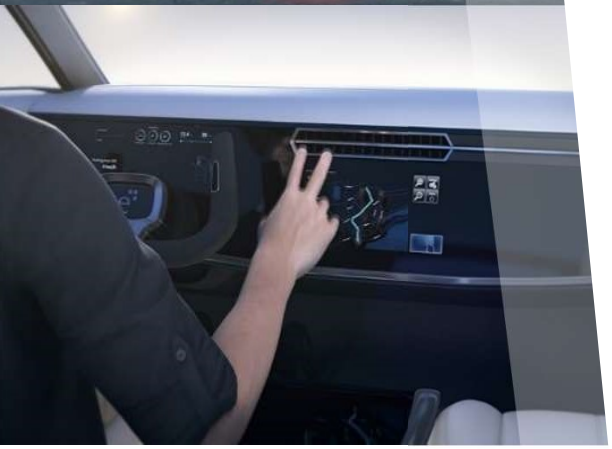
ToF Applications - Overview

Applications for automotive sector

- Interior applications
  - Driver Monitoring
  - People detection
  - HMI/Infotainment
- Exterior applications
  - Automatic Doors
  - Easy Open Liftgate



ToF Applications – Close up



Easy Open Liftgate

State of the art technology: Capacitive sensors

ToF Imager for Easy Open Liftgate:

- Guided Gesture (with personalized light emblem)
- Easy installation
- Robust against humidity, malfunctions

HMI

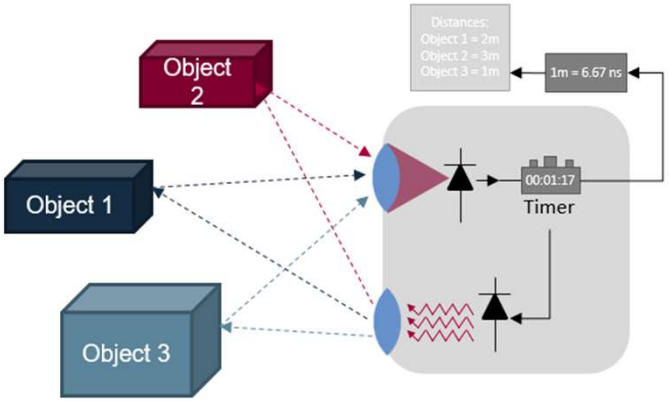
State of the art technology: HR cameras

ToF Imager for HMI:

- Good cost/performance ratio (adequate resolution for finger recognition)
- Robust in all lighting conditions
- Low power consumption

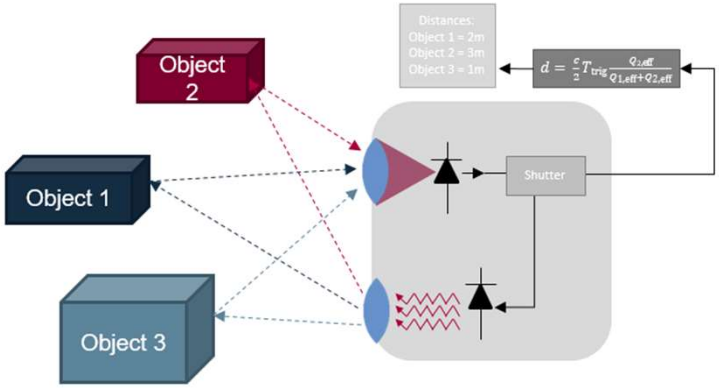
ToF Measurement Principle

Direct Time-of-Flight



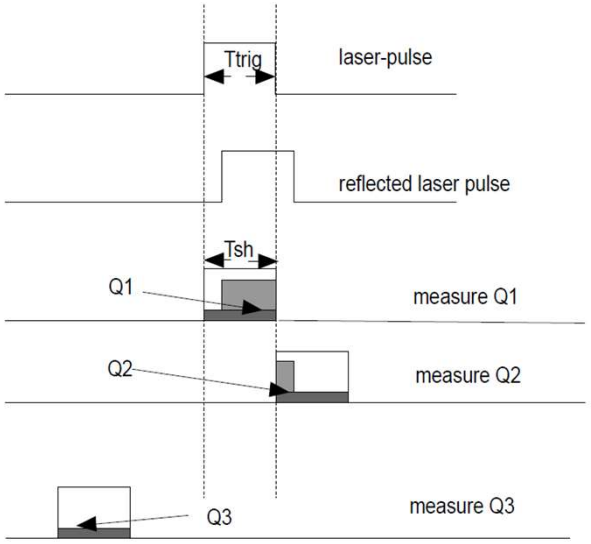
- Run time measurement
- Speed of light makes direct measurement difficult
- Very precise TDCs necessary
- Difficult for high number of pixels

Indirect Time-of-Flight



- Measurement of charge carriers in expected time range
- Continuous wave (cw) or pulsed modulated (pm) method

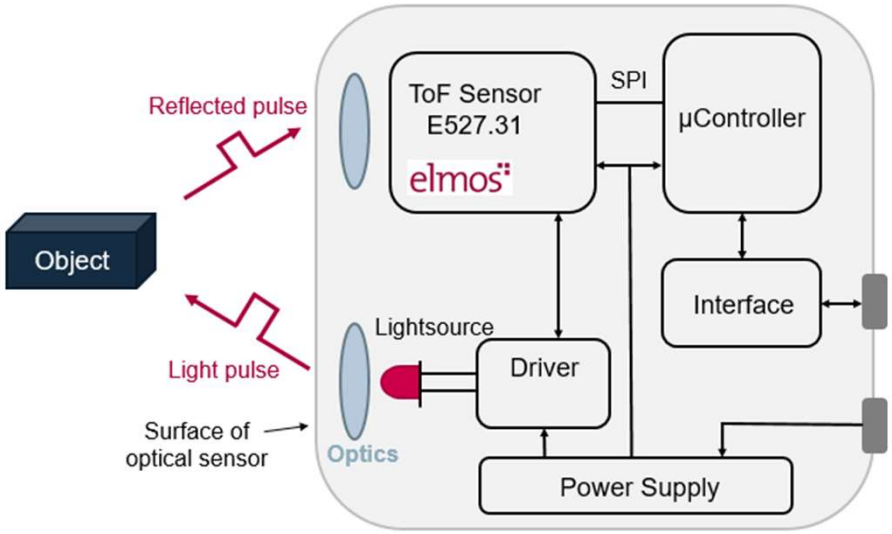
Indirect ToF Measurement



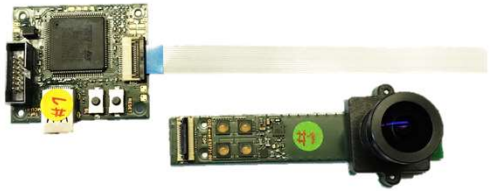
$$d = \frac{c}{2} T_{\text{trig}} \frac{Q_{2,\text{eff}}}{Q_{1,\text{eff}} + Q_{2,\text{eff}}}$$

- Indirect Time-of-Flight
- Distance calculation from the ratio of partial charges
- Q1: starts with light pulse
- Q2: starts with end of light pulse
- Q3: charge due to background light
- Ttrig = light pulse duration
- Sequence is repeated N-times before readout happens

ToF Module



- ToF Sensor
- Lightsource
- Lenses
- µController

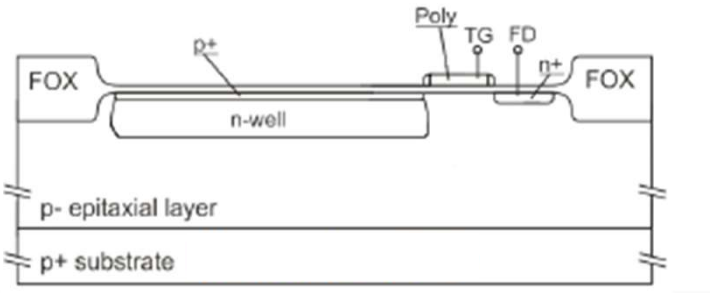


- Multidisciplinary team working is necessary to build a ToF Module!

Photodiode Structure

Standard photodiode structure

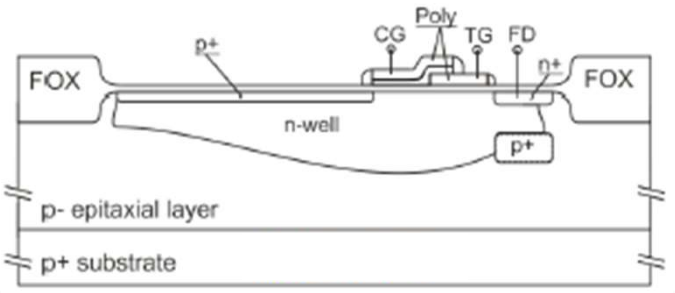
- Potential in the n well is pinned through the two pn junctions at the top and bottom
- No electric field in the well



Standard PPD

Unique lateral drift field photodiode structure

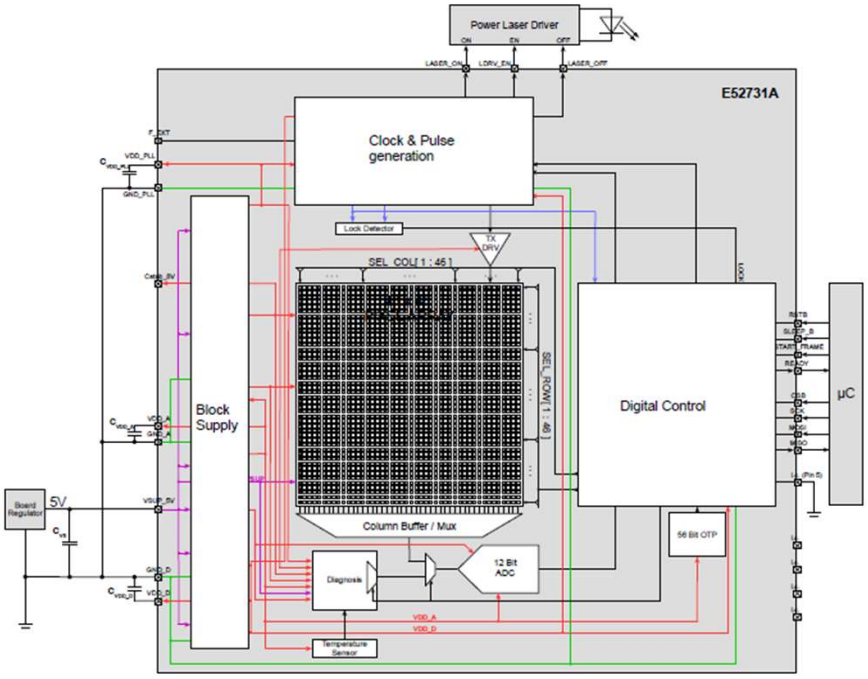
- Dopant gradient in the n-well to generate an e-field
- Additional Collection Gate (CG)
- Electrical field inside the diode



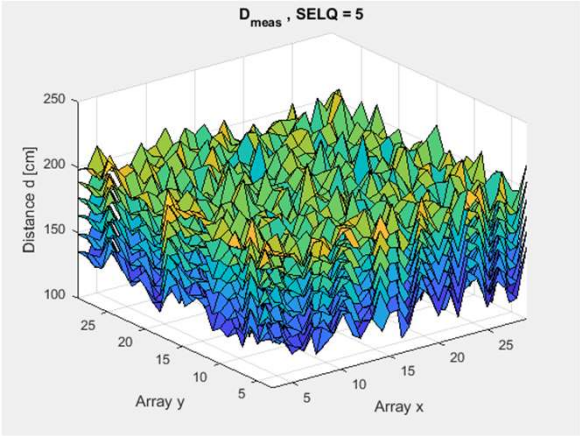
Elmos PD

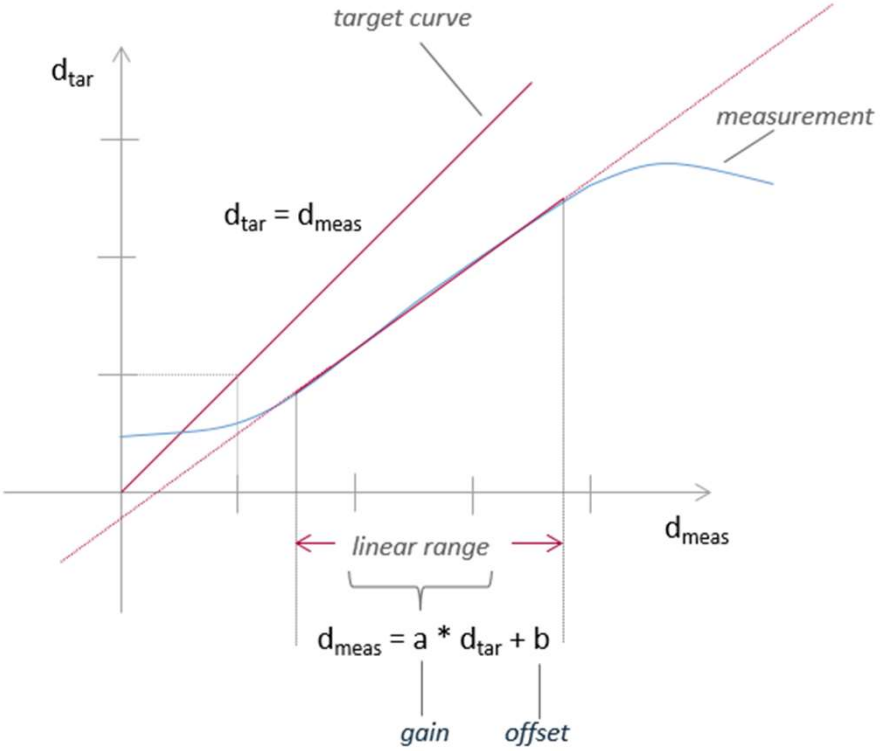
Elmos ToF Sensor – 527.31

- 46 x 46 pixel (32 x 32 pixel used)
- Pixel size: 40 x 40 µm
- Suitable for LEDs and laser light sources (850 - 940 nm)
- Low power always-on-stand-by architecture
- Sleep Current: 14 µA
- Full Operation Mode Current: 2.6 mA
- On board temperature sensor
- Integrated light source control with programmable modulation frequencies
- Programmable Q shutter times



ToF Measurement – Raw Data

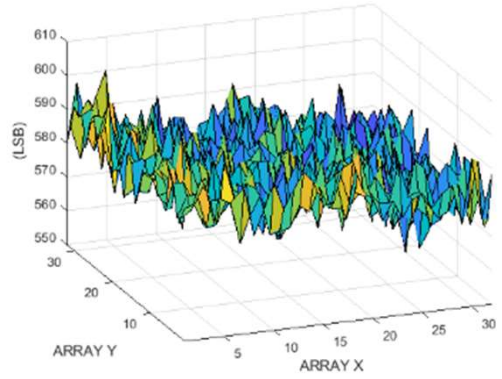


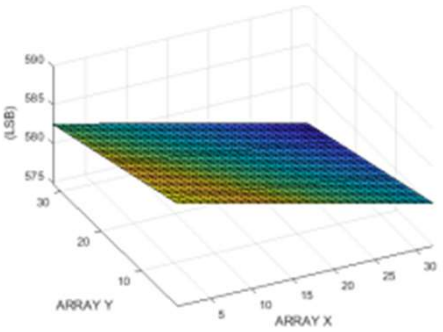


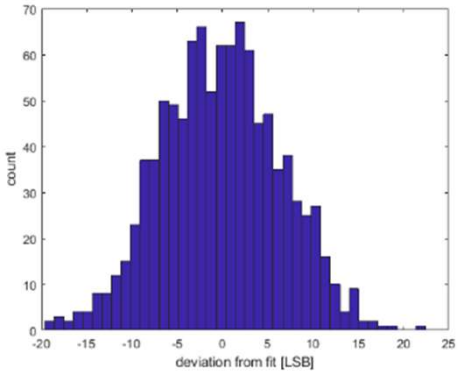
- Raw values show high deviations
- Measured distance deviates from target distance curve

- Calibration of pixel individual gain and offset necessary!

Imager Characterization – Offset





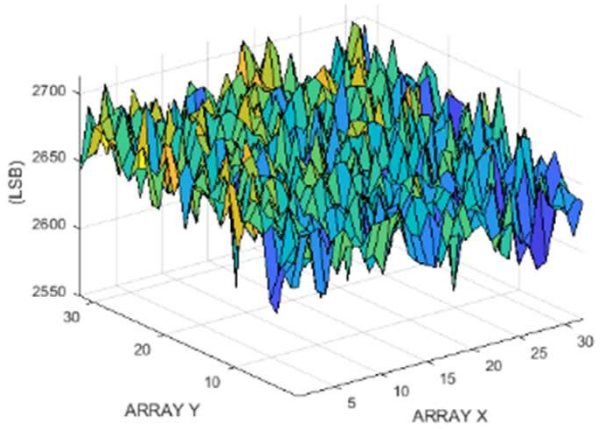


Dark-value without illumination

- Small gradient in x and y direction
- Statistical pixel-to-pixel variation of the dark-value in the range of +/-20 LSB
- Influence of the offset must be eliminated by suitable distance calibration

Imager Characterization – Gain

- Pixel-to-pixel variation under illumination (homogenous, constant (not pulsed) LED-light source, center wavelength=850nm, shutter setting time 31.25ns)
  - Photo response non-uniformity
- Influence of pixel-to-pixel variation must be eliminated by suitable distance calibration



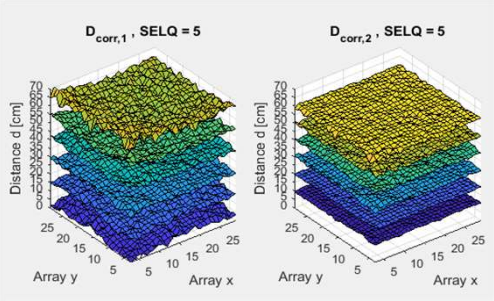
With illumination

Calibration of ToF Sensor

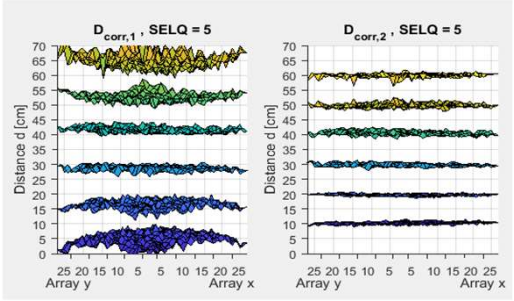
Calibration with 2 coefficients

- Measurement of 6 distances
- Background subtraction
- Mean value of each pixel on each distance
- Build linear equations for measured distance from raw values for one pixel with 1 and 2 coefficients
- Solve linear equation system

Offset correction Offset + Gain correction



Offset correction Offset + Gain correction

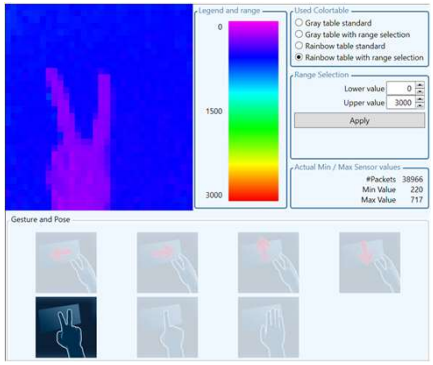


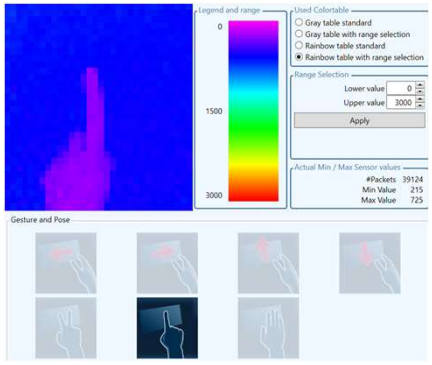
- Gain and offset calibration lead to more precise distance values

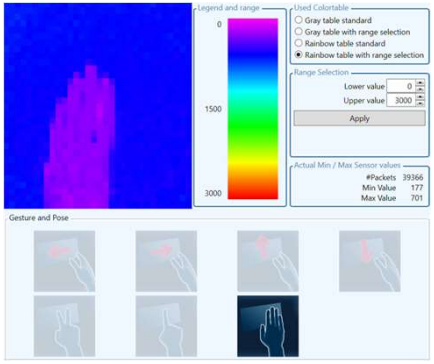
ToF Gesture and Poses Detection

- Finger gesture detection with Elmos ToF Imager
- Distance values are color coded
- Only a small selection of possible gestures is shown (Victory, Forefinger, Palm)

- Intuitive gestures can be used to make the operation of the infotainment system easier and safer while driving







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