General Description

The epc600 chip is a general purpose, monolithic, fully integrated photoelectric CMOS device for optical distance measurement and object detection. Its working principle is based on the three-dimensional (3D) time-of-flight (TOF) measurement.

The system-on-chip (SOC) contains:

- A full data acquisition path with the driver for the LED, the photoreceiver, the signal conditioning, the A/D converter and the signal processing.
- An on-chip controller managing the data acquisition and the data communication.
- A 2-wire interface for the command and data communication.
- A supply-voltage power management unit.

Together with a tiny microprocessor and few external components, a fully functional TOF range-finder can be built.

The working principle is based on the elapsed time-of-flight (TOF) of a photon (modulated light) emitted by the transmitter (LED) and reflected back by the object to the photosensitive receiver.

The very high photosensitivity allows operating ranges up to several meters and an accuracy down to a centimeter depending on the lens and the illumination power.

Features

- Complete data acquisition system for distance measurement or object detection on chip. Allows for minimum part count designs.
- On-chip high power LED driver.
- Easy to use operation in combination with a tiny microprocessor.
- Absolute distance measurement with digital data output.
- Integrated signal-processing.
- High sensitivity and resolution for measured distances up to 15m.
- Response time of less than 1ms possible.
- Digital data output with 12 bit distance data.
- Excellent ambient-light suppression up to >100kLux.
- Integrated ambient-light meter (“Luxmeter”) e.g. for brightness control or dimmer functions.
- Voltage supply with low power consumption.
- Easy to use 2-wire interface with simple command set.
- Fully SMD-compatible flip-chip CSP24 package with very small footprint.

Possible Applications

- Light barrier with powerful ambient-light suppression
- People and object counting sensor
- Door opening and safety sensor
- Limit and proximity switch
- Machine control and safety sensor
- Water tap and toilet flushing sensor
- Single spot parking sensor
- Distance measurement gauge

Functional Block Diagram

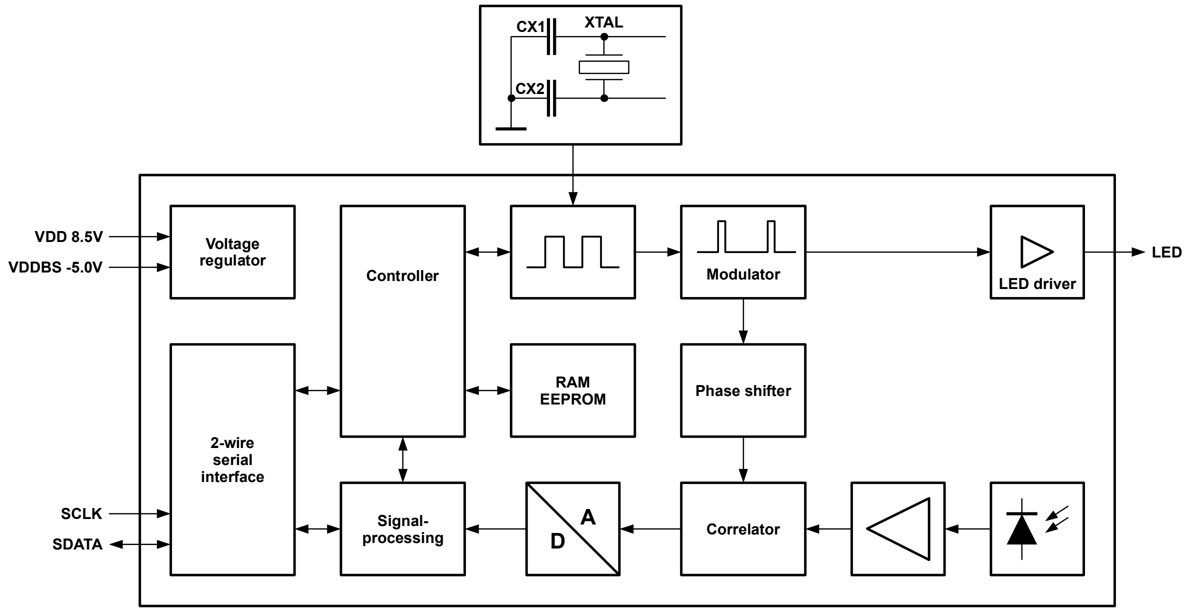


Figure 1: epc600 on-chip data acquisition system for range-finders

Table of Contents

Absolute Maximum Ratings (Note 1, 2)

Supply Voltage V_{DD}	-0.5V to +9.5V
Voltage to any pin except V_{DD} according voltage class V_{SC} (Note 3)	-0.3V to V_{SC}+0.3V
Storage temperature (T_A)	-65°C to +150°C
Soldering Lead Temperature (T_L), 4 sec	+260°C

Operating Ratings

Operating temperature (T_A)	-20°C to +65°C
Humidity, non-condensing	5% to 95%

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating conditions indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see Electrical Characteristics.

Note 2: This is a highly sensitive CMOS mixed signal device with an ESD rating of JEDEC HBM class 2 (2kV to < 4kV) except for the pins VDD, VDDIO and SCLK with an ESD rating of JEDEC HBM class 1B (0.5kV to < 1kV). Handling and assembly of this device should only be done at ESD protected workstations.

Note 3: For voltage classes V_{SC} refer to Figure 4 and Table 4.

Electrical Characteristics

Operational Ratings - unless otherwise specified.

Symbol	Parameter	Conditions / Comments	V_{SC}	Min.	Typ.	Max.	Unit
V_{DD}	Supply voltage at VDD		8.5V	+8.0	+8.5	+9.0	V
$V_{DD\text{-}PP}$	Ripple on V_{DD}	peak-to-peak	8.5V			100	mV
$I_{DD\text{-}Average}$	Supply current	DC average , excl. LED driver current	8.5V			20	mA
$I_{DD\text{-}Peak}$	Supply current	peak, excl. LED driver current	8.5V			30	mA
V_{DDBS}	Bias voltage	no drift allowed	-5.0V	-4.9	-5.0	-5.1	V
$V_{DDBS\text{-}PP}$	Ripple on V_{DDBS}	peak-to-peak	-5.0V			50	mV
I_{DDBS}	Bias current		-5.0V			1.0	mA
V_{LED}	Voltage at LED	maximum	+5.0V			5.0	V
$I_{LED\text{-}ON}$	Sink current at LED	open drain driver	+5.0V			180	mA
$V_{LED\text{-}ON}$	Forward voltage at LED	@ $I_{LED\text{-}ON}$ = 180mA	+5.0V		200		mV
$V_{Digital\text{-}OH}$	Output high voltage	at SDATA	+5.0V	4.5		5.2	V
$V_{Digital\text{-}OL}$	Output low voltage	at SDATA	+5.0V	0		0.5	V
$I_{Digital\text{-}OH}$	Output current	at SDATA, DC, average	+5.0V			0.1	mA
$I_{Digital\text{-}OL}$	Output current	at SDATADC, sink current	+5.0V			8.0	mA
$C_{Digital\text{-}Out}$	Load capacitance		+5.0V			30	pF
$V_{Digital\text{-}IH}$	Input high voltage	at SDATA and SCLK	+5.0V	4.0		5.0	V
$V_{Digital\text{-}IL}$	Input low voltage	at SDATA and SCLK	+5.0V	0		1.0	V
$I_{Digital\text{-}In}$	Input leakage current	except VDDT, DC	+5.0V			1.0	µA
$I_{Digital\text{-}In}$	Input current	at VDDT; DC	+5.0V		42		µA
R_{DOWN}	Termination resistor	at VDDT; pull-down resistor	+5.0V		120		kΩ
$C_{Digital\text{-}In}$	Input capacitance		+5.0V			3	pF

Table 1: Electrical characteristics

Timing and optical Characteristics

Operational Ratings - unless otherwise specified.

Symbol	Parameter	Conditions / Comments	Min.	Typ.	Max.	Unit
t_{ON}	Power-up rise time	at VDD	1		10	ms
t_{INIT}	Start-up time				100	ms
t_{OFF}	Power drop-down time	at VDD	1		10	ms
f_{XTAL}	Center frequency	of the crystal oscillator (or ceramic resonator)		4		MHz
Δf_{XTAL}	Frequency deviation	of the oscillator, any deviation is added as a linear distance error			±100	ppm
$\Delta\varphi_{XTAL}$	Phase jitter	of the oscillator, peak-to-peak, cycle to cycle			50	ps
f_{SCLK}	Clock frequency	of SCLK, 2-wire interface			10	MHz
t_{SCLK}	Cycle time	of SCLK2, 2-wire interface, SCLK = $1/f_{SCLK}$	100			ns
t_H / t_L	HIGH / LOW period	of SCLK2, 2-wire interface, refer to Table 8	50ns		1.0ms	ns
f_{MOD}	LED modulation frequency at pin LED	see Figure 14, standard products fixed 10MHz, (customer specific factory setting possible: 1.25 - 10MHz)		10		MHz
$t_{LED\text{-}rise/fall}$	Required rise/fall time of the illumination LED	@ 50 ohm load Remark: Use high speed LEDs with short switching times e.g. Osram SFH4059, Vishay VSMB2000, Stanley DNK5306, etc.			12	ns
A_{SENSOR}	Photosensitive area	of the sensor		320x320		µm
S_{AC}	AC sensitivity (conversion rate)	for distance measurement (modulated light), refer to Table 3 and Figure 14. @ λ = 850±50nm, Integration time = 103 µsec. Note: The chip does internal an averaging over the sensitive area, refer to chapter 1.3.4.		31		$\frac{nW/cm^2}{LSB}$
S_{DC}	DC sensitivity (conversion rate)	for ambient-light measurement (unmodulated light), refer to Table 3 and Figure 14 @ λ = 850±50nm, Integration time = 103 µsec. Note: The chip does internal an averaging over the sensitive area, refer to chapter 1.3.4.		12.3		$\frac{nW/cm^2}{LSB}$
A_{AC}	Received modulated light amplitude	dynamic range for distance measurement	50		1'000	LSB
A_{DC}	Ambient-light amplitude	dynamic range for ambient-light measurement	50		1'000	LSB
E_{Sup}	Ambient-light suppression	@ λ = 850±50nm, Integration time = 103 µsec, total power on sensor area	40 4			W/m^2 µW/Sensor
λ_{max}	Peak wavelength	maximum sensitivity, see Figure 2		850		nm
λ	Wavelength range	operating range	550		1'000	nm
$\varphi_{50\%}$	Half angle	see Figure 3		±60		deg

Table 2: Timing and optical characteristics

Symbol	Parameter	Conditions / Comments	Min.	Typ.	Max.	Unit
t_{INT}	Integration time	refer to Figure 14, programmable in 16 binary steps	1.60		52'600	µs
t_{MEAS}	Measurement time	refer to Figure 14	0.8	1.2	212	ms
DR	Dynamic range	fixed integration time using integration times 1.6µs, 13.2µs, 205µs using the full range of integration times	32	80	110	dB dB dB
D_{UA}	Operating range	unambiguity range, @10MHz LED modulation frequency			15.0	m
ΔD_{RES}	Distance resolution	@10MHz LED modulation frequency, ≙ 1 LSB	0.5			cm
ΔD	Distance noise	single shot, 1σ value, ratio ambient-light : modulated light < 60dB ratio ambient-light : modulated light < 70dB for amplitude values inside AC dynamic range		2.5 12.0		mm mm
D_{OFFSET}	Distance offset	compensation to be done by the external micro-processor				
ΔD_{DRIFT}	Distance drift	@ temperature range from -20°C to +65°C; compensation to be done by the external micro-processor				

Table 2 cont.: Timing and optical characteristics

Other Parameters

Operational Ratings and λ = 850±50nm, AOI = 0°, LED modulation frequency = 10MHz - unless otherwise specified.

Sensitivity: epc600	**with bandpass filter**			**without filter**
@ integration time 103µs	**640nm ± 27.5nm**	**860nm ± 32.5nm**	**940nm ± 30nm**	**sunlight equivalent**
max. AC amplitude (1'000 LSB)	407 nW/mm²	310 nW/mm²	407 nW/mm²	
min. ambient-light suppression E_{Sup}	53 W/m²			70 klx
		40 W/m²		69 klx
			53 W/m²	192 klx

Table 3: Sensitivity and ambient-light suppression vs. wavelength

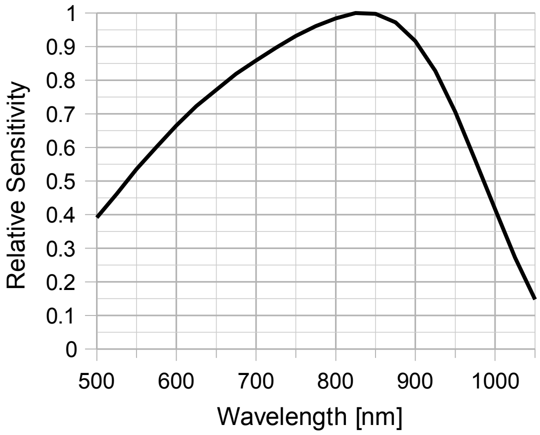


Figure 2: Relative spectral sensitivity (S_λ) sensitivity S_{AC} vs. wavelength

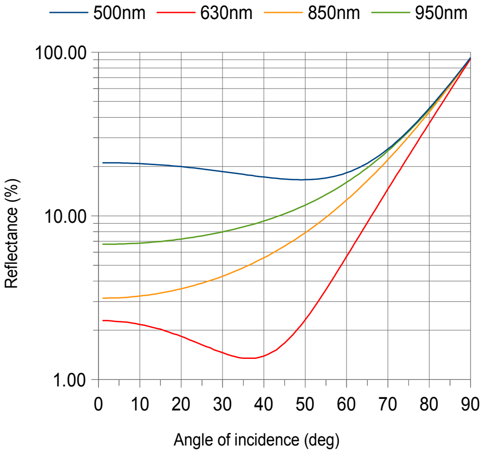


Figure 3: Reflectance vs. illumination angle (AOI)

Pin Configuration

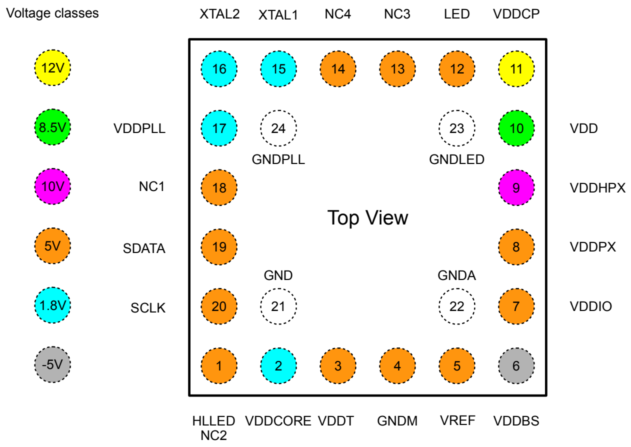


Figure 4: Pin configuration

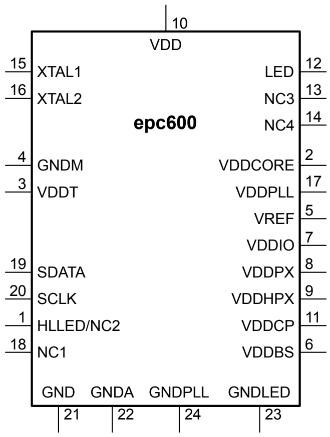


Figure 5: Schematic symbol

Pin Name	Pin No.	Type	V_{SC}	Description
SDATA	19	DOUT DIN	+5.0V	Serial data, bidirectional data transmission of the 2-wire interface
SCLK	20	DIN	+5.0V	Serial clock input SCLK of the 2-wire interface
LED	12	AOUT	+5.0V	LED driver output, high current, open drain, square-wave signal
XTAL1	15	AIN	+1.8V	Oscillator input, use only with crystal (or ceramic) oscillator
XTAL2	16	AOUT	+1.8V	Oscillator output, use only with crystal (or ceramic) oscillator
VDD	10	SUPPLY	+8.5V	Power supply +8.5V
VDDCORE	2	SUPPLY	+1.8V	Decoupling of internal digital core supply +1.8V
VDDPLL	17	SUPPLY	+1.8V	Decoupling of internal PLL supply +1.8V
VREF	5	SUPPLY	+5.0V	Attention: Do not connect this pin
VDDIO	7	SUPPLY	+5.0V	Decoupling of the internal internal I/O supply +5.0V
VDDPX	8	SUPPLY	+5.0V	Decoupling of the internal pixel reference voltage +5.0V
VDDHPX	9	SUPPLY	+10V	Decoupling of the internal pixel reference voltage +10V
VDDCP	11	SUPPLY	+12V	Filter capacitor pin for the charge pump circuit +12V
VDDBS	6	SUPPLY	-5.0V	Power supply: Bias voltage -5.0V
VDDT	3	DIN	+5.0V	With pull-down resistor 120kOhm; connect to +5.0V.
GND	21	SUPPLY	---	Ground for digital circuitry +1.8V
GNDA	22	SUPPLY	---	Ground for analog circuitry, charge pumps and +5.0V I/O circuit
GNDPLL	24	SUPPLY	---	Ground for PLL
GNDLED	23	SUPPLY	---	Ground for LED driver
GNDM	4	DIN	+5.0V	Connect to GND
NC1	18		+5.0V	Attention: Do not connect this pin
HLLED/NC2	1		+5.0V	Connect this pin with a 1kOhm resistor to GND
NC3	13		+5.0V	Attention: Do not connect this pin
NC4	14		+5.0V	Connect this pin with zero ohm resistor to GND

Table 4: Pin function descriptions

Abbreviations to Table 4:

V_{SC}	Supply class for matching components and I/O voltage levels
DOUT	Digital output
DIN	Digital input
AOUT	Analog output
AIN	Analog input

Layout information

CSP-24 Package (all measures in mm,)

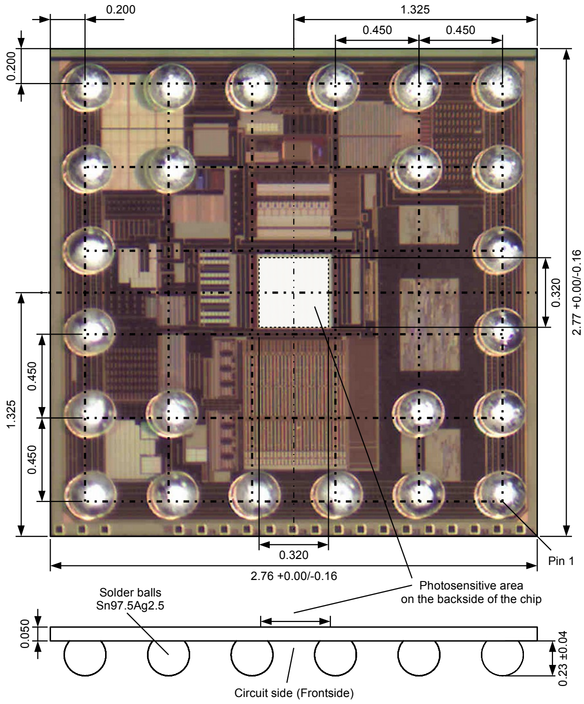


Figure 6: Mechanical dimensions

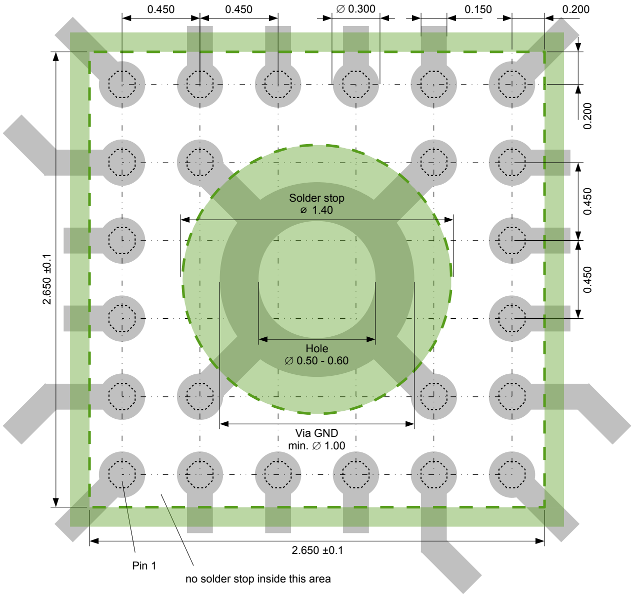


Figure 7: Layout recommendation

Recommendations for a strong ground connection and for reliable soldering of solder balls:

- Use a pad layout similar to Figure 7. Notice, all tracks should go underneath the solder mask areas.
- To keep the noise floor low in the sensitive receiver path of the chip, a low ohmic and low inductive connection to the supply ground is needed. Figure 7 suggests a recommended grounding of the chip (if a ground plane is not feasible):
  Feed all grounds into a central via-hole with a drill diameter 0.5 - 0.60mm.
- No additional connects to any pins inside of the opening of the solder mask.
- The open via underneath the chip must be covered with a solder-stop lid, to prevent ascending solder during the soldering process.
- Refer also to our application note AN04 and AN08 Assembly of Wafer Level Chip Scale (WL-CSP) Packages.

Design precautions

The sensitivity of the sensor area is very high in order to achieve a long operational range of the range-finder. Thus, the epc600 device is very sensitive to EMI. Special care should be taken to keep the chip away from the IR LED signal tracks and other sources which may induce unwanted signals.

ESD protection

Highly sensitive CMOS mixed signal devices are sensible to electrostatic discharge (ESD). Figure 8 shows the principle how each pin of the chip is protected against ESD over-voltages by the corresponding safety elements.

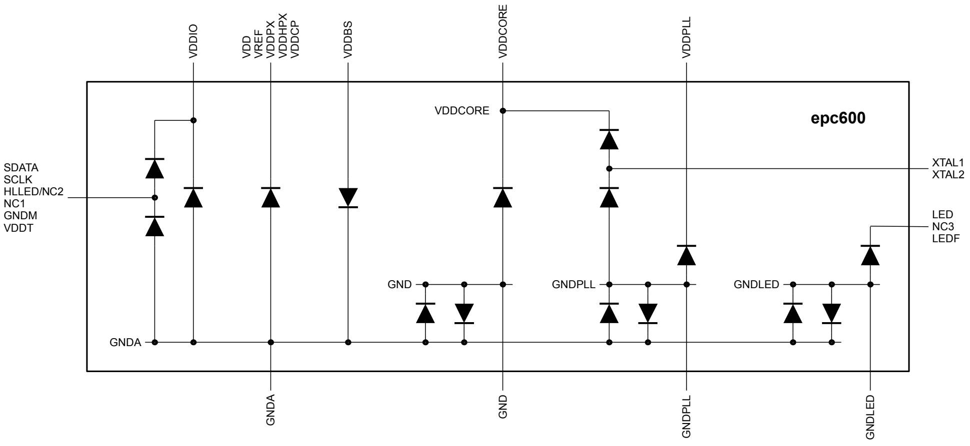


Figure 8: ESD protection of the pins

Reflow Solder Profile

For infrared or conventional soldering, the solder profile has to follow the recommendations of IPC/JEDEC J-STD020C (revision C and later) for lead-free assembly. The peak soldering temperature (T_L) should not exceed +260°C for a maximum of 4 sec.

Packaging Information (all measures in mm)

Tape & Reel Information

The devices are packaged into embossed tapes for automatic placement systems. The tape is wound on 178mm (7inch) or 330mm (13inch) reels and individually packaged for shipment. General tape-and-reel specification data are available in a separate datasheet and indicate the tape size for various package types. Further tape-and-reel specifications can be found in the Electronic Industries Association EIA-Standard 481-1, 481-2, 481-3.

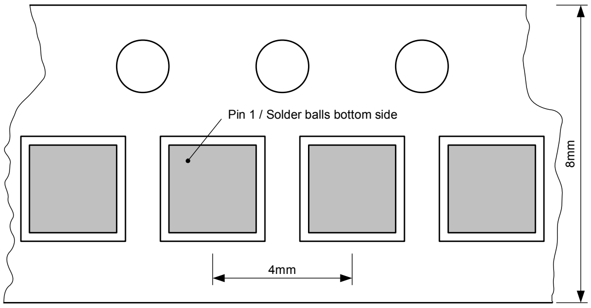


Figure 9: Tape dimensions

epc does not guarantee that there are no empty cavities in the tape. Thus, the pick-and-place machine should check the presence of a chip during picking.

Ordering information

Part number	Part name	Package	RoHS compliance	Packaging method
P100 037	epc600-CSP24	CSP24	Yes	Reel

Table 5: Ordering information

Functional Description

This manual is arranged in the following sections:

- Operation
  This general description of the operation and the functionalities is targeted at the user and application level.
- Hardware Design
  All information regarding hardware design aspects are covered here.
- Instruction Set
  Contains a detailed description of the data communication and the command set.
- Optical Design Considerations
  The chapter where the user finds some design guidelines for developing appropriate optics and illumination for the device.

1. Operation

1.1. Introduction

The epc600 chip is based on the 3D-TOF principle. Modulated light is sent out by a transmitter. This light is then reflected by the object to be detected and the returning light is sampled by a photosensitive sensor. The receiver compares the phase difference between the emitted and the received light and computes the time difference of the "time-of-flight". This value multiplied by the speed of light (ca. 300'000km/sec) and divided by 2 corresponds directly to the distance.

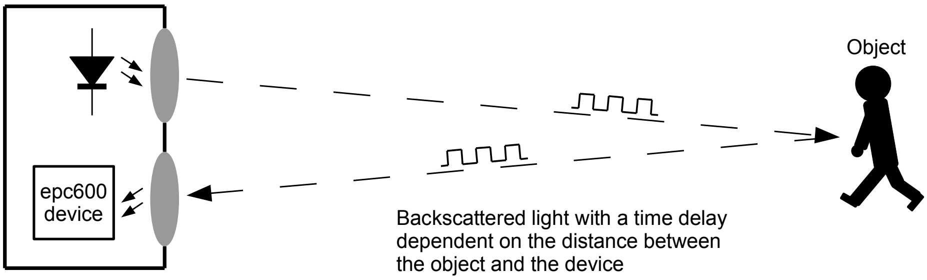


Figure 10: The time-of-flight principle

1.2. General overview

The epc600 chip is designed to enable simple and cost effective system designs. Together with a tiny microprocessor and few external components, a very low cost but fully functional TOF sensor system can be built (refer to Figure 11).

The epc600 system-on-chip contains:

- A full data acquisition path with a power driver for the LED, the photo-receiver, the signal conditioning, the A/D converter and the signal processing.
- An on-chip controller managing the data acquisition and the data communication.
- A 2-wire serial interface for the command and data communication.
- A supply-voltage power management unit.

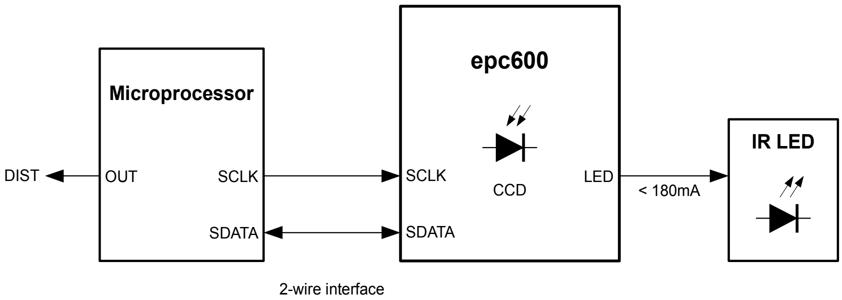


Figure 11: Basic application

The measurement functionality supports distance and ambient-light measurement with variable integration times and on-chip temperature measurement for drift compensation.

The sensitivity of the system can be adjusted on the fly to the object reflectivity, the object distance and the ambient-light conditions by means of integration time. The longer the integration time, the higher the sensitivity.
In cases where the illumination power of the built-in driver is not sufficient, the epc600 chip can also be used with an external LED driver. This allows longer operational ranges or faster measurements, resulting in a faster response time and a reduced ambient-light sensitivity.

1.3. Operational mode

This chapter lists the available features for the epc600-device.

The range-finder works in combination with a tiny microprocessor. It operates according to a single shot principle. A command sent by the microprocessor sets the user parameters in the chip and stimulates either a distance or ambient-light measurement. The device executes the requested task standalone and sends back the answer (data) according to Figure 12.

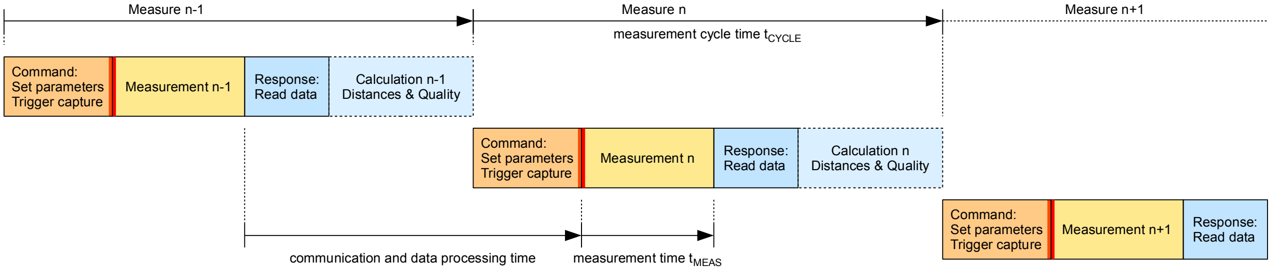


Figure 12: Basic measurement cycle e.g. distance (or ambient-light)

The microprocessor controls the parameter settings for the measurement and the start. It computes from the read-out data the final distance. This also includes applying the necessary correction algorithms based on quality, ambient-light and temperature data and to adapt the epc600 settings to the useful operational range and present scenery conditions.

The epc600 chip supports range finding as a single spot distance measurement, ambient-light measurement (similar to an optical power-meter or “Luxmeter”) and temperature metering.

1.3.1. Distance measurement

The distance measurement is done by single shots following the protocol in Figure 13, first section.

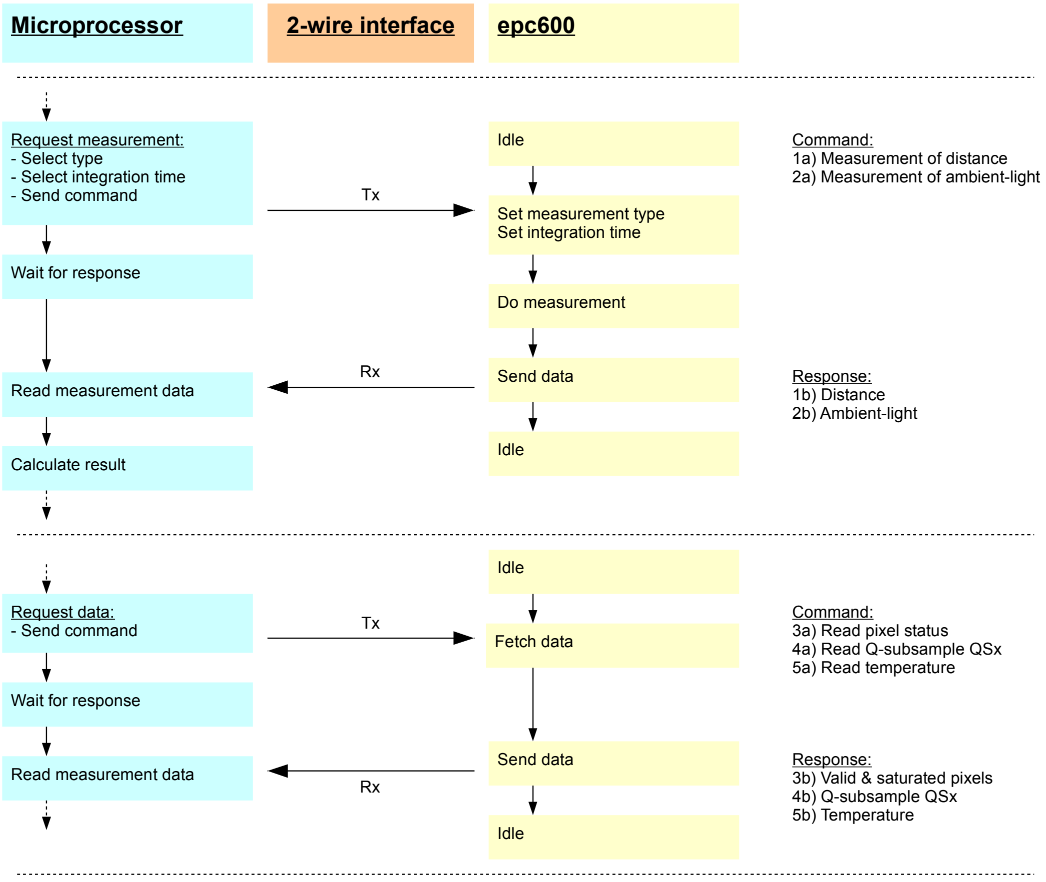


Figure 13: 2-wire communication sequences:
measurement (above) and data reading (below)

A command, including the measurement type and integration time, sent by the microprocessor to the 2-wire interface, sets the epc600-chip configuration and triggers the measurement. The device operates standalone to perform the distance measurement. When it is finished, the chip responds by sending the results: the distance value. It is without any calibration, correction or offset compensation. Based on this data, the microprocessor computes the final measurement result in regards to the necessary correction factors e.g. quality, offset, ambient-light and temperature drift. The actual result must be read first before starting the next capture cycle. The detailed method of communication and the instruction set are described in chapter 3.: Instruction Set. For more details refer also the the epc600 Handbook.

The epc600 range-finder uses the time-of-flight principle. It is implemented with a repeating, continuous-mode modulation signal during the measurement phase (refer to Figure 14). Consequently, only signals returning within the maximum time slots can be detected unambiguously. This corresponds for the epc600 to a maximum operating range of 15m. Strongly reflected signals outside of this range may therefore interfere with the measurement.

1.3.2. System sensitivity, integration time and operating range

The operational range of the complete system is limited by the sensitivity of the receiver as well as by the illumination power emitted by the modulating light source (e.g. LED).

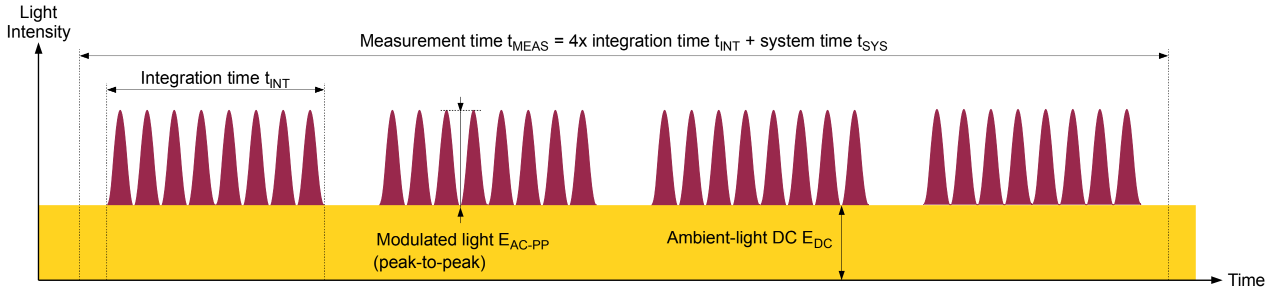


Figure 14: The light detected by the receiver

The system sensitivity consists of two factors: The hardware sensitivity S_{AC} of the photo-sensor (refer to chapter: Timing and optical Characteristics) and the integration time t_{INT} (exposure time).

The measurement evaluation is done by computing the distance out of 4 samples received in one measurement cycle t_{MEAS}. A sample is the collected power of the receiving light signal during the integration time (refer to E_{AC} in Figure 14). This means the system's sensitivity relates to the integration time: The longer the integration time, the more sensitive the measurement.

The measured irradiance E_{AC} (uncalibrated) at the sensor surface can be calculate out of the AC sensitivity S_{AC}, the used integration time t_{INT-AC}, the reference integration time $t_{INT-REF-AC}$ and the amplitude A_{AC} of the received modulated signal (refer to chapter 1.3.4.Quality of the measurement result) in the following way:

$$E_{AC} = S_{AC} \cdot \frac{t_{INT\text{-}REF\text{-}AC}}{t_{INT\text{-}AC}} \cdot A_{AC} \qquad \text{e.g.} \quad E_{AC} = 31\,\frac{\text{nW/cm}^2}{\text{LSB}} \cdot \frac{103\,\mu\text{s}}{205\,\mu\text{s}} \cdot 1'000\ \text{LSB} = 16\,\mu\text{W/cm}^2$$

Illumination power, remission of the object (reflectivity), sensitivity of the sensor together with the integration time are limiting the distance operational range. For more detailed information, refer to epc's application note: AN02 Reflected power calculation.

It will probably not be possible to cover the full operational range within one integration time step due to the dynamic range of the receiver's electronics. The possibilities to extend the operating range or to influence the response time are:

- to adapt the integration time correspondingly to the necessary sensitivity as demonstrated in Figure 15.
- or alternatively: use an additional, external LED driver to adjust the illumination to the needed system sensitivity level (refer to chapter 1.3.9.: Extended operating range).

The easiest way is to adapt the integration time to the current illumination situation (e.g. in Figure 15). With the command formats, which allow adjusting of the integration time, it is easy to do. It is simple to change the integration time on the fly: a capture is initiated by a command sent to the chip.

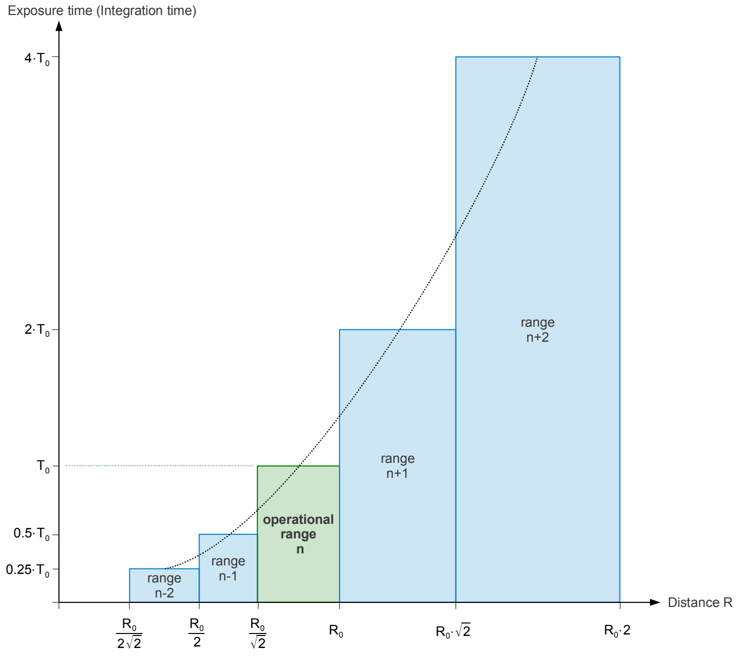


Figure 15: Example of operating ranges as a function of distance and exposure time based on doubling the light power to the sensor per range

1.3.3. Ambient-light suppression

An important function of the range-finder is the ability to separate the self-emitted and reflected modulated light E_{AC} from the ambient light E_{DC} (refer to Figure 14). The built-in ambient-light suppression E_{Sup} removes the DC or low frequent signal distortions, caused by foreign light sources e.g. sunlight, daylight, room illumination, etc., from the measuring signal. The user has not to take care of this, it is done by the chip automatically. To see the capability of this function, refer to Table 3 for example values as a function of the wavelength and compared to sunlight.

Similar to the system's sensitivity of the modulated light, is the ambient-light suppression a function of the integration time. The longer the integration time, the more the measurement becomes sensitive to the ambient-light.

Notes:

- The ambient-light suppression of the chip must not be confused with the ambient-light measurement command. It is a fixed built-in functionality, which is removing the DC light component from the AC measurement signal only.
- A DC or AC photo-signal can be generated by ambient-light (e.g. sunlight) or by cross-talk from the IR-LEDs. If this signal is above the stated maximum value, then the sensor or the input electronics are saturated. This blocks the detection of the AC modulation signal.

1.3.4. Quality of the measurement result

The epc600 provides information on the quality and the validity of the received optical signal. This reflects the confidence level of the measurement result. The better the received signal, the better and more precise the distance measurement will be.

The primary quality indicator for the measured distance data is the **amplitude value of the received modulated light A_{AC}**.
After each measurement this needs to be calculated from the Q-subsamples QSx delivered by the chip(r efer to chapter 3.2.4. Response: Q-subsample QSx). This amplitude value is the **feedback parameter that is used to set the integration time for the next measurement**.

$$A_{AC} = \frac{1}{4} \cdot \sqrt{\frac{(QS0+QS2)^2}{4} + \frac{(QS1+QS3)^2}{4}}$$

Quality indicator: **Weak illumination: e.g. A_{AC} < 50 LSB**
Status & reason: The signal has a reduced accuracy, because it is above, but close to the noise level.
Action: Increase integration time for the next measurement

Quality indicator: **Sufficient illumination: e.g. 50 LSB < A_{AC} < 100 LSB**
Status & reason: The signal quality and the accuracy is sufficient and not close to any limits. Noise level may be increased.
Action: No action necessary. See note below

Quality indicator: **Excellent illumination: e.g. 100 LSB < A_{AC} < 1'000 LSB**
Status & reason: The signal quality and the accuracy is excellent and not close to any limits.
Action: No action necessary. See note below

Quality indicator: **Too bright illumination: e.g. 1'000 LSB < A_{AC}**
Status & reason: The signal is close to or above the limit of too much light (maximum signal limit).
Action: Decrease integration time for the next measurement. See note below

Note:
Generally, the higher the received signal, the better and more precise the distance measurement will be. However, it is good practice to control the integration time such that an amplitude value between 100 ... 200 LSB is achieved. Higher values will only slow down the acquisition rate due to longer integration times, but are not significantly improving signal to noise ratio.

The quality indicator for the ambient-light measurement is the **ambient-light amplitude A_{DC}**.
The rules to apply are the same as for the modulated light amplitude.

The quality indicator for the distance noise is the ratio AMR of ambient-light to the modulated light. This value may be calculated and used additionally to the above amplitude value if the respective application is subject to intense ambient light.

Quality indicator: **Ratio AMR of ambient-light to modulated light**

$$AMR[dB] = 20 \cdot \log\left(\frac{E_{DC}}{E_{AC}}\right) \qquad \text{e.g.} \qquad AMR[dB] = 20 \cdot \log\left(\frac{792\mu\,W/cm^2}{16\mu\,W/cm^2}\right) = 34dB$$

Refer for E_{DC} to chapter 1.3.5. Ambient-light measurement (optical power-meter) and for E_{AC} to chapter 1.3.1. Distance measurement.
Status & reason: This ratio is one of the influencing factors on the distance noise (refer to Table 2, section Distance noise)

Action:	< 60 dB: excellent	No action necessary.
	< 70 dB: sufficient	Is a lower noise level needed, do the next measurement with a longer integration time or an increased illumination power.
	> 70 dB: weak	Do the next measurement with a longer integration time or an increased illumination power.

There are also validity indicators delivered by the chip after a measurement. These will help to detect saturated pixels as a result of too much illumination or too long integration time.

Validity indicator: **MIN_VALID_PIX** (refer to chapter 3.2.3.Response: Valid & saturated pixels)
Meaning: The chip internally detects saturation of pixels and internal signal electronics and flags them non-valid. Since there are four samples for one measurement, a different number of saturated pixels may internally be detected for each of the samples. However, the chip output number is the valid pixel count from the sample with the least valid pixels.

The subsequent distance calculation routine uses only this subset of valid pixels. Therefore, the higher the MIN_VALID_PIX value, the higher the accuracy and reliability of the distance data will be.
How to use: A low MIN_VALID_PIX value most likely indicates a global saturation of the pixel field resulting from a too long integration time and/or a too bright illumination. Such a state will also display in the amplitude value (see above).
However, there may be situations where the global illumination is appropriate but there are individual pixels driven into saturation. This can occur if very bright (high-reflecting) areas are within the scene and blind individual pixels(e.g. a painted machine part with a small, chrome-polished area). In such a situation, the MIN_VALID_PIX count may help to differentiate if the shot is still containing enough valid pixels for a reliable distance calculation.
What values are acceptable has to be established within the context of the respective application. As a safe value we recommend to use only measurements with a value of MIN_VALID_PIX>60.

Validity indicator: **MAX_SAT_PIX** (refer to chapter 3.2.3.Response: Valid & saturated pixels)
Meaning: The MAX_SAT_PIX is a complementary value to the above MIN_VALID_PIX value. But it counts only the saturated pixels (not the subsequent signal electronics). The lower the MAX_SAT_PIX value, the higher the accuracy and reliability of the distance data will be.
How to use: Like above.
As a safe value we recommend to use only measurements with a value of MIN_SAT_PIX<5.

Remember, the epc600 chip is using a sensor array with 64 pixels and the single distance output is an average of these pixels. The two parameters above indicate how many of these pixels are actually used for this average calculation. Refer to the epc600 Handbook for more details on the averaging algorithm.

Table 6 shows a quality decision matrix as a summary of the validity and quality parameters for the distance measurement.

Step	Sensor status	Saturated pixels MAX_SAT_PIX	Valid pixels MIN_VALID_PIX	Modulated light amplitude A_{AC}	Ambient to modulated light AMR	Action
1	Saturation or bright object within scene	> max. limit (e.g. 5)				Repeat measurement with decreased integration time and/or illumination
2	Saturation or bright object within scene	< max. limit	< min. limit (e.g. 60)			Repeat measurement with decreased integration time and/or illumination
3	Over-exposure or bright object within scene	< max. limit	> min. limit	> 1'000 LSB		Repeat measurement with decreased integration time or illumination
4	No object detected	< max. limit	> min. limit	< 50 LSB		Repeat measurement with increased integration time or illumination
5	Too much ambient-light	< max. limit	> min. limit	50 LSB … 1'000 LSB	> 60 db (or > 70 dB)	Repeat measurement with increased integration time or illumination
6	Object detected	< max. limit	> min. limit	Excellent: 100 … 1'000 LSB Sufficient 50 … 100 LSB	< 60 db (or < 70 dB)	No action necessary

Note: min. and max limits are customer defined acceptable values depending on the application

Table 6: Quality decision matrix

1.3.5. Ambient-light measurement (optical power-meter)

Instead of reading distance data, the epc600 chip can measure the ambient-light level (Refer to 3.2.1.: Command: Commands & Integration times and 3.2.5.: Response: Ambient-light level). Functions of this feature are:

- Use to compensate deviations in the distance measurement caused by the presence of ambient-light.
- Monitor the ambient-light level during the distance measurement to prevent faulty conditions.
- Use the ecp600 as an optical power-meter (“Luxmeter”) e.g. for brightness control.
- or in combination e.g. where the presence or absence of an object in the environmental illumination needs to be controlled.

The measured irradiance E_{DC} (uncalibrated) of the received ambient-light at the sensor surface can be calculate out of the DC sensitivity S_{DC}, the used integration time $t_{INT\text{-}DC}$, the reference integration time $t_{INT\text{-}REF\text{-}DC}$ and the amplitude A_{DC} of the received modulated signal (refer to chapter 3.2.5.: Response: Ambient-light level) in the following way:

$$E_{DC} = S_{DC} \cdot \frac{t_{INT\text{-}REF\text{-}DC}}{t_{INT\text{-}DC}} \cdot A_{DC} \qquad \text{e.g.} \quad E_{DC} = 12.3 \frac{\mathrm{nW/cm^2}}{\mathrm{LSB}} \cdot \frac{103\,\mu\mathrm{s}}{1.6\,\mu\mathrm{s}} \cdot 1'000\ \mathrm{LSB} = 792\,\mu\mathrm{W/cm^2}$$

Notes:

- The quality indicator for the ambient-light measurement is the ambient-light amplitude A_{DC}. The rules to apply are the same as for the modulated light amplitude.
- The ambient-light measurement is a metering functionality only, which can be used for distance correction or ambient-light reading. It is completely independent of the chip internal ambient-light suppression function that eliminates DC light components from the measurement signal (refer to chapter 1.3.3.: Ambient-light suppression).

1.3.6. Temperature metering

An on-chip temperature sensor provides uncalibrated temperature readings. The data access follows the protocol in Figure 13, second section.

- This allows compensation of signal drifts caused by changing thermal conditions in the light source and the sensor.
- If the user does his own calibration (e.g. °C or F), he can use it as a temperature sensor too.

1.3.7. Measurement sequence

A basic possible measurement flow is given in Figure 16:

- Execute a distance measurement and check the validity and quality of the signals. If action is needed, act accordingly.
- If the camera operates in an ambient-light changing condition, occasionally read the ambient-light for quality check and compensation.
- In thermally changing conditions, occasionally read the temperature for compensation.
- Calculate, based on the correction data, the final distance value – or whatever is needed.

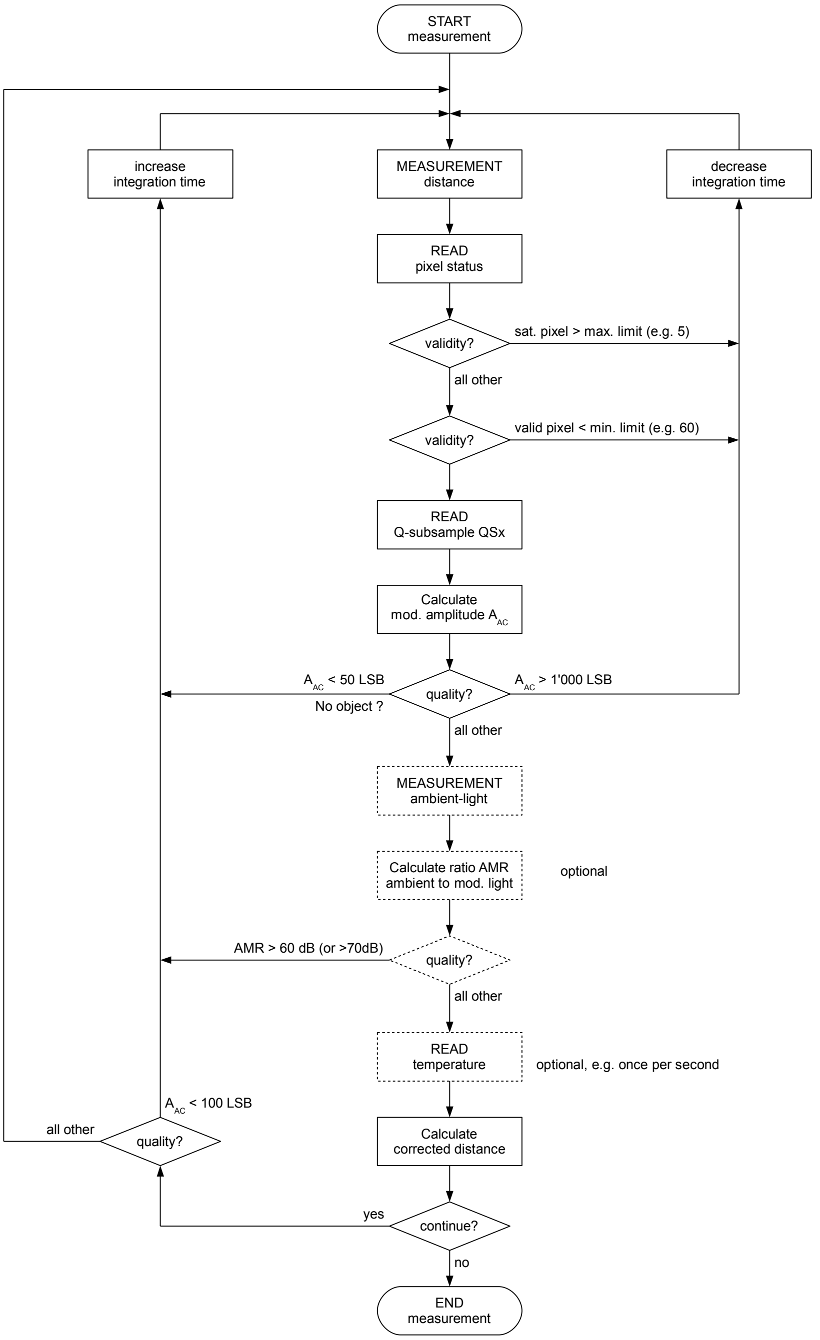


Figure 16: Principle measurement flow

This flow is not only for detecting objects: It is also possible to observe and track the object (once captured).

1.3.8. Calibration and compensations

Due to the fact that the range-finder chip does not know its surrounding environment and the phase-shifts caused by the electronic implementation and also due to manufacturing tolerances, a calibration of the sensor is necessary.

Whereas a simple light barrier doesn't need the same accuracy as a range-finder, the compensation and the required calibration is dependent on the application.

Influencing variables for various attributes are:

- Distance: Offset, Slope scaling, Linearity, Reflectivity, Quality, Ambient-light, Integration time, Temperature.
- Reflectivity of the object: Quality, Ambient-light.
- Ambient-light: Offset, Slope scaling, Linearity, Integration time, Temperature.
- Temperature: Offset, Slope scaling, Linearity.

These compensations are necessary for the microprocessor to correct the raw distance data in the final measurement.

1.3.9. Extended operating range

The epc600 is a range-finder designed as a system-on-chip for minimum part count circuits. Therefore, a LED driver is integrated on-chip.

In cases where the illumination, achieved with the built-in driver, is not sufficient to detect near and far objects in the expected operational range or in the necessary response time, the epc600 chip can be used with a more powerful external LED driver (refer to chapter 2.5. External LED driver).

1.3.10. Multi range-finder application

Light barriers are not always operating in a single sensor application. In some applications, more than one sensor is deployed to partially or entirely cover the same observation field. The epc600 range-finder uses signal-processing based on the sinusoidal modulation theory of the time-of-flight principle.The LEDs are modulated with 10MHz square-wave and a duty cycle of 1:1. There is no coding in the modulation signal to make each device unique. To date, in multi range-finder applications, cross-talk between the signals of closely placed individual sensors can occur.

The single shot principle of the epc600 chip allows an easy synchronization of multiple sensors by a fixed time synchronization between range-finder devices (sequencing of sensors).

2. Hardware Design

2.1. What performance can be achieved?

A typical example of an application is a very small, single spot distance gauge (refer to Figure 17).

Figure 17: Low power, high performance distance gauge.
Size: 32 x 22 x 25 mm

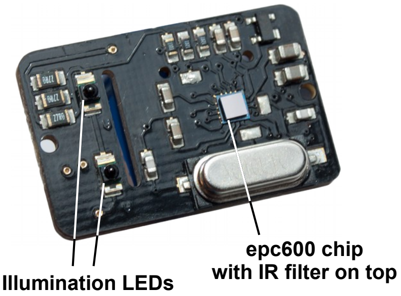


Figure 18: Chip on PCB board

In this example, a range of up to 4m can be expected on white targets when using: two SFH4059 LEDs directly driven by the LED pin with a collimator lens of 17mm focal length, a receiver lens of approx. 15x15mm with a focal length of 17 mm and an integration time t_{int} of 410µs.

The response time in this application is: $t_{RESPONSE} = 2 \cdot (4 \cdot t_{INT} + 0.798ms) + 0.1ms = 4.976ms$
(refer also to chapter: Response time).

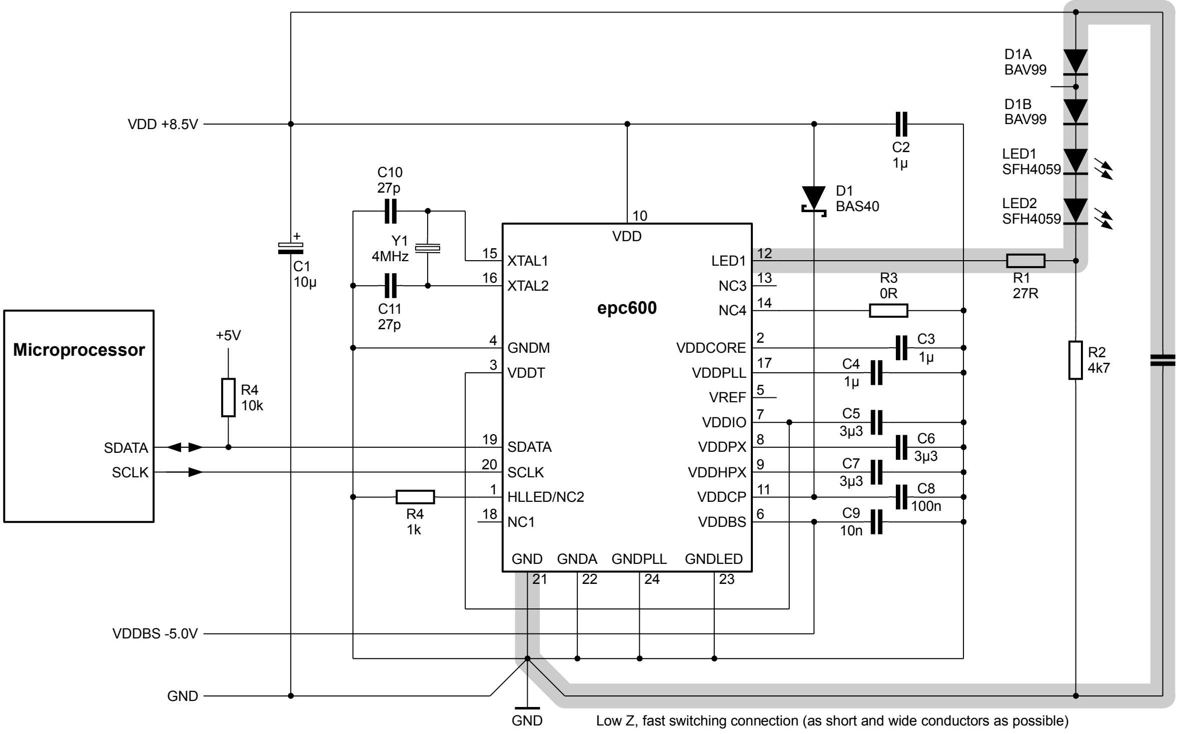


Figure 19: Minimum part count application

2.2. General Hardware Configuration

The general hardware configuration section covers all design aspects for an epc600 circuit.

2.3. Power Supply, Clock generation

The external voltage supplies are +8.5V DC as a main supply and -5.0V DC as a bias voltage. Both supplies need to be stable, well regulated and with a low level of noise and ripple voltage (because the epc600 chip is a sensitive, highly amplifying device).

All other necessary voltages are generated on-chip. The internally generated voltage levels V_{SC} (see Table 4) have to be taken into consideration in order to choose the right components for the design.

All necessary power supply decouplings and the supply of the external reference clock have to be designed according to Figure 20 and Table 7. Capacitors C3 – C9 are used for decoupling of the internally generated voltages.

The Schottky diode D1 is vital to ensure a correct power-up of the device.

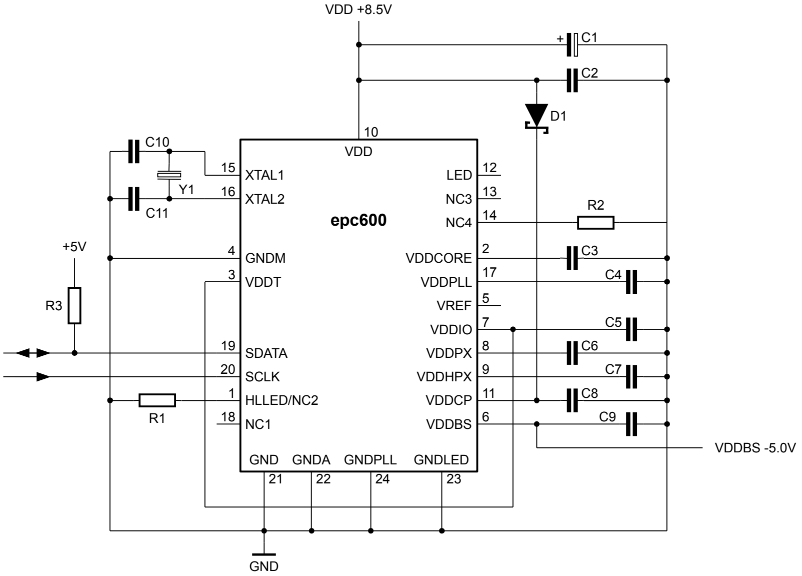


Figure 20: Main power supply decoupling and clock supply

Part No.	Pin	Pin No.	Component value				
			Min.	Nom.	Max.	V_{SC}	Type
C1	VDD	10		10µF		+8.5V	
C2	VDD	10		1µF		+8.5V	Ceramic X7R
C3	VDDCORE	2	1µF	1µF	3.3µF	+1.8V	Ceramic X7R
C4	VDDPLL	17	1µF	1µF	3.3µF	+1.8V	Ceramic X7R
C5	VDDIO	7	3.3µF	3.3µF	10µF	+5.0V	Ceramic X7R
C6	VDDPX	8	3.3µF	3.3µF	10µF	+5.0V	Ceramic X7R
C7	VDDPXH	9	3.3µF	3.3µF	6.8µF	+10V	Ceramic X7R
C8	VDDCP	11	10nF	100nF	100nF	+12V	Ceramic X7R
C9	VDDBS	6	10nF	10nF	20nF	-5.0V	Ceramic X7R
C10	XTAL1	15		27pF		+1.8V	Ceramic NP0
C11	XTAL2	16		27pF		+1.8V	Ceramic NP0
Y1	XTAL1 & XTAL2	15 & 16		4 MHz			Crystal-oscillator
D1	VDD & VDDCP	10 & 11					Schottky diode
R1	HLLED	1		1kOhm		+5.0V	Resistor
R2	NC4	14		zero Ohm		+5.0V	Resistor
R3	SDATA	19	see chapter 2-wire serial interface			+5.0V	Resistor

Leave open the pins NC1, NC3 and VREF. They do not require any termination.

Table 7: Component values

2.4. On-chip LED driver

A feature for the minimum part count system is the on-chip LED driver. Figure 21, Figure 22 & Figure 23 show examples for possible circuits. The design has to take in consideration that these LEDs are switched very fast (e.g. 10MHz square-wave) and with high power (<180mA). Suggested are high speed LEDs with short switching times e.g. Osram SFH4059, Vishay VSMB2000, Stanley DNK5306. The layout needs to be well decoupled and with low Z conductors.

Notes:

- Take care that the voltage at pin LED do not exceed the specified operational range of maximum +5V.
- The signal processing of the epc600 chip is based on a sine-wave modulated light-signal. All descriptions in this manual are related to this. However, to simplify the LED driver circuit as well to reduce the power-losses of the LED, the chip uses a square-wave modulated signal for the LED. This change together with all the other non-linear influences on the signal path leads to only a small error, which can easily be corrected in the measurement data (refer to chapter 1.3.8. Calibration and compensations).

LEDs with a +5V supply

If a +5V supply is available, the LEDs can simply be supplied by this as shown in Figure 21. Resistor R1 limits the LED current <180mA.

For the LED power dissipation calculation, refer to chapter 3.3.6.: Cycle times & response time.

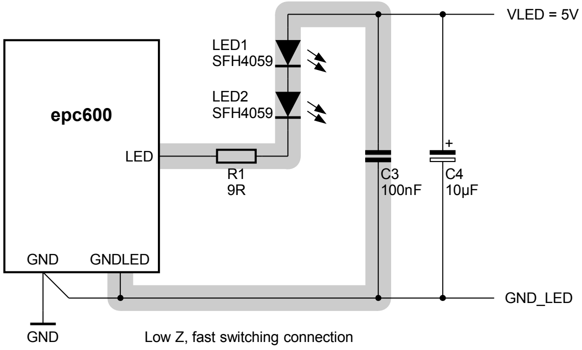


Figure 21: Short range application
with +5Vdecoupled LED supply

Short range application design (LED supply from +8.5V)

The circuit in Figure 22 drives two power IR LEDs. The output LED is driven by an open drain switching transistor. The illumination intensity of the LEDs is defined by the current flowing through the resistor R1. For the output LED = on, the current of the resistor R1 is <180mA. In order to have safe voltage operating conditions for the output LED (max. +5V), there is a minimum current of <1mA flowing through the LED diodes and the D1 diodes in the off-state. This also gives the advantage of the enhanced switching performance for the LEDs. This off-current is set by the resistor R2. C3 and C4 are the charge capacitors to supply the LEDs. In order to support the required fast switching, C3 shall be of a ceramic type. The decoupling of the supply of the epc600 chip is done by C1 and C2 (ceramic type). The resistor R3 decouples the LED feeding circuit from the ep600 supply. The voltage drop of the diodes D1A and D1B adjust the voltage supply level to the LED supply level. The advantage of this concept is that it gives a good decoupling between the epc600- and the LED-supply.

For the LED power dissipation calculation, refer to chapter 3.3.6.: Cycle times & response time.

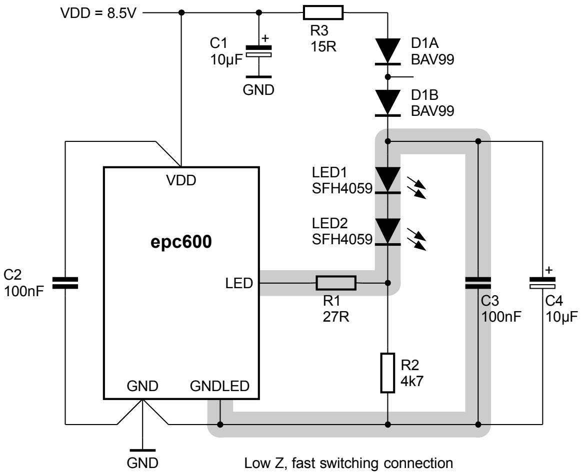


Figure 22: Short range application
with a decoupled LED supply

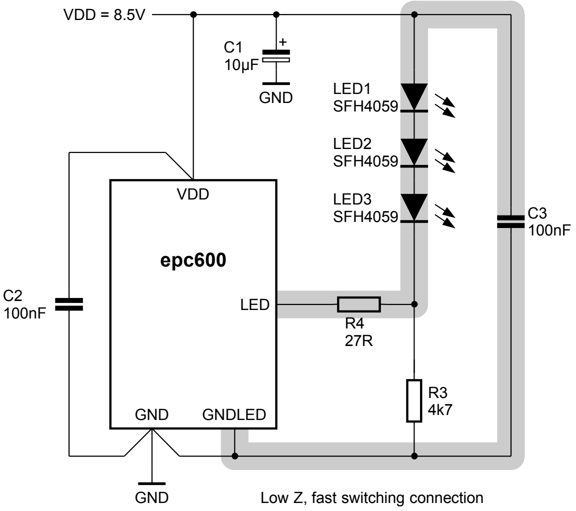


Figure 23: Mid range application
with a minimum part count circuit

Mid range application design (LED supply from +8.5V)

The circuit of Figure 23 is a minimum part count design for a more powerful illumination (3 LEDs are equal to 50% more illumination energy).

The design considerations are exactly the same as before. The difference is the additional third LED3, which replaces the diodes D1A and D1B, in order to have more powerful illumination. As it is used as a minimum part count design, the decoupling between the LED supply circuit and the epc600 supply is not of the same quality as in the short range example before. Therefore, the layout design regarding the noise and ripple voltage has to be done very carefully.

2.5. External LED driver

For a more powerful, sensitive or fast system application with an epc600 chip, the use of an external LED driver is an option. The design has to take into consideration that the LEDs are modulated at high frequencies (e.g. 10MHz) and with high power. So far, the layout needs to be well decoupled and with low Z conductors. The schematic has to follow the correct signal inversions as given in Figure 24. This is important in order to have the correct phase for the modulation.

Note: Take care that the voltage at pin LED do not exceed the specified operational range of maximum +5V.

epc600's pin LED is driven by an open drain switching transistor. The pull-up termination resistor R1 tied to the V_LOGIC supply (+5V) guarantees safe voltage operating conditions for the output LED. The modulation signal of output LED feeds a fast inverting digital buffer IC1. It drives the fast switching transistor T1. T1 switches the current through LED1-LEDn on/off in order to modulate the light. Output LED = low corresponds to light = on.

As opposed to the on-chip driver, such a design can have additional light levels as the circuit in Figure 24 shows. An I/O port of the microprocessor switches the intensity to the LOW or HIGH level. IC1 and IC2 are the necessary selecting logics to drive the transistors T1 and T2. The illumination (current through LED1-LEDn) is controlled by R2 and R3 for the high and the low illumination level.

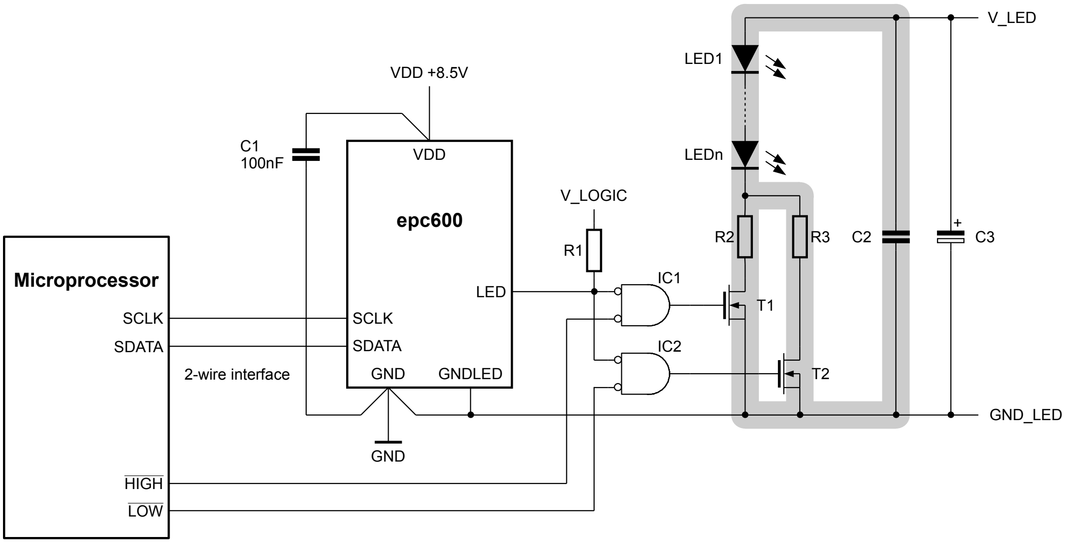


Figure 24: Long range or fast response application (principal schematic)

Advantages of this circuit are: the free design of the illumination power (number of LEDs), the additional selectable light levels for extending the operational range, the independent voltage supply for the LEDs and the strong decoupling of the epc600 supply and LED circuitry.

3. Instruction Set

The 2-wire serial interface allows the user to communicate with the epc600 chip. The graph of the principle communication flow is in Figure 13.

Starting a measurement, reading the result and setting the correct user parameters for operation are the main functions. All configurations are set at run-time, are loaded immediately and are not stored in the chip.

3.1. 2-wire serial interface

The interface is for single slave use. It is targeted to operate up to a 10MHz clock frequency. Only 2 wires, one bidirectional data transmission SDATA and a clock line SCLK, are needed (refer to Figure 25). This allows the use of a tiny microprocessor as a controller for the chip. Based on a handshake protocol the chip is either receiving or transmitting data during active clock cycles.

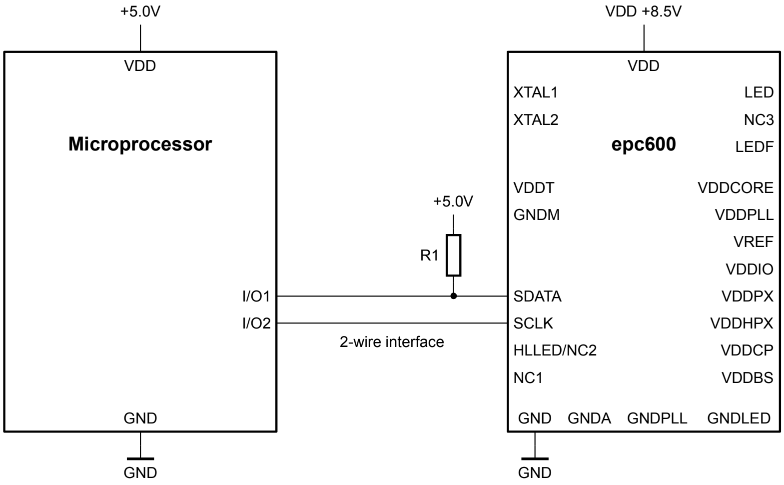


Figure 25: 2-wire interface wiring (Note: For details to R1 see section SDATA line)

3.1.1. SCLK line

SCLK is the serial clock signal. It is unidirectional and always driven by the microprocessor. It is switched between LOW and HIGH state.

The maximum 'HIGH' pulse length is not defined. The maximum 'LOW' pulse length must be < 1ms.

ERROR handling: A 'LOW' pulse > 1ms will reset the epc600 chip.

3.1.2. SDATA line

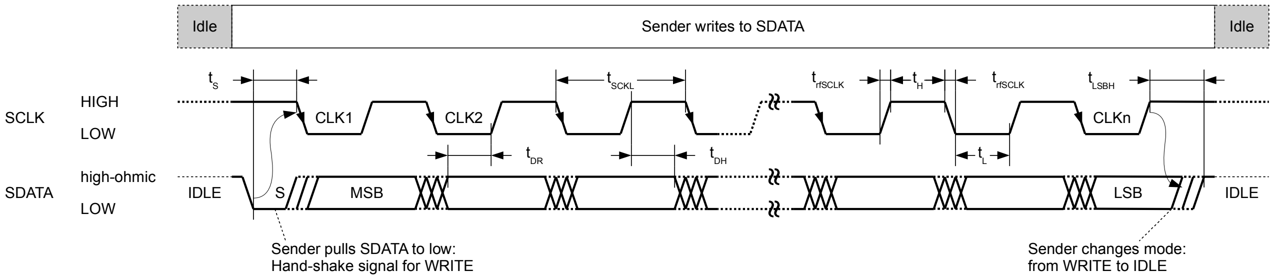
SDATA is the serial data line. It is used in a bidirectional way. It is switched between LOW and high-ohmic state.
Depending on the communication direction, it is either driven to LOW by the microprocessor or the epc600 chip (refer to Figure 25). A “wired-OR” compatible I/O circuitry on either side is used to handle unexpected error situations. It avoids permanent damage of each party in case they drive opposite logic values.

The microprocessor can achieve the Wired-OR connection by using programmable open-drain I/O pads, or writing a permanent logic LOW to the output and switching the line between the high-ohmic and transparent modes. A pull-up resistor R1 to +5.0V will terminate the line to logic HIGH during the high-ohmic state. If the rise time of the SDATA line is not fast enough, the user may either enable an embedded pull-up resistor in the microprocessor or add on each side of the line, close to the pins, external resistors in parallel.

ERROR handling: If the epc600 device detects a communication error, it will pull the SDATA line permanently to LOW until the interface will be reset.

The general waveform definition and timing are listed in Figure 26 and Table 8.

In the idle state, the SCLK and SDATA lines are in the high state (outputs are in tristate mode terminated with a pull-up resistor). The transmission is always initiated with a start bit on the SDATA line: SDATA = low. This forces the microprocessor to clock the SCLK line with the necessary number of cycles for sending or reading the data. The falling edge of the clock puts the data to the SDATA line. At the time of the rising edge, the data is valid and readable. After the last rising clock edge the sender unlocks the SDATA line and both lines remain in the high state.



Sender pulls SDATA to low:
Hand-shake signal for WRITE

Sender changes mode:
from WRITE to IDLE

Figure 26: General waveforms for 2-wire transmission (telegram)

Symbol	Parameter	Min.	Typ.	Max.	Unit
SCLK	2-wire serial clock				
SDATA	Serial data, bidirectional transmission				
t_{SCLK}	Cycle time of SCLK	100			ns
t_H	High period of SCLK	50			ns
t_L	Low period of SCLK (refer to ERROR handling)	50ns		1.0ms	
t_{rfSCLK}	Rise or fall time of SCLK (20% - 80% of signal amplitude)			10	ns
t_S	First negative SCLK edge after negative edge of SDATA	100			ns
t_{DR}	Data ready before positive SCLK edge	50			ns
t_{DH}	Data hold after positive SCLK edge	0			ns
t_{LSBH}	Data hold after positive SCLK edge of last bit transmitted (LSB)	0			ns

Table 8: General timing 2-wire transmission

3.2. Commands & responses

The epc600 device works on a task principle: The chip is in a idle state and performs a single measurement or a read-out on command only (refer to Figure 13).

The microprocessor sends a command to the chip. It is processed immediately. The tasks are: Execute a measurement or read data. When the processing of the instruction is finished, then the chip sends back the answer to the controller by default. Refer to Figure 12 and Figure 13.

The command format always has 8 bits, including 4 bits for command itself (C0-C3) and 4 bits to set the integration length (I0-I3). Bit 7 (MSB) is transmitted first, bit 0 (LSB) last.

The response format is always 16 bits. Bit 15 (MSB) is transmitted first, bit 0 (LSB) last.

3.2.1. Command: Commands & Integration times

Name:	**Command & Integration time**							
Bit	7	6	5	4	3	2	1	0
	C3	C2	C1	C0	I3	I2	I1	I0
Description	CMD [3:0]				INT [3:0]			

CMD: Command to start the measurement with a defined integration time or to read data.

Description	CMD	INT	epc600 response	Waiting time
Read Q-subsample QS0	0001	0000	Q-subsample QS0	t_{ACC} = 3µs
Read Q-subsample QS1	0010	0000	Q-subsample QS1	t_{ACC} = 3µs
Read Q-subsample QS2	0011	0000	Q-subsample QS2	t_{ACC} = 3µs
Read Q-subsample QS3	0100	0000	Q-subsample QS3	t_{ACC} = 3µs
Read temperature	0101	0000	Temperature	t_{ACC} = 3µs
Read pixel status	0110	0100	Valid & saturated pixels	t_{ACC} = 3µs
Measurement of distance Note: Modulated light is emitted	1000	see INT	Distance	t_{MEAS}
Measurement of ambient-light level Note: No light is emitted	1101	see INT	Ambient-light level	t_{MEAS}
Don't use	Others			

INT: Sets the integration time for the measurement. The measurement time is t_{MEAS} = 4x integration time + 770µs.
Note: A doubling of the integration time is equal to a doubling of the illumination in the scenery.
The integration times below in the table are for a LED modulation frequency of 10MHz.

Time	INT
1.60 µs	0000
3.20 µs	0001
6.40 µs	0010
12.8 µs	0011

Time	INT
25.6 µs	0100
51.2 µs	0101
103 µs	0110
205 µs	0111

Time	INT
408 µs	1000
818 µs	1001
1.64 ms	1010
3.28 ms	1011

Time	INT
6.56 ms	1100
13.2 ms	1101
26.3 ms	1110
52.6 ms	1111

3.2.2. Response: Distance

Name:	**Distance**															
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Q3	Q2	Q1	Q0	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Description	Don't care				DIST [11:0]											

DIST: Distance value
Data format: unsigned 12 bit integer; Unit: LSB

For 10MHz LED modulation frequency the following values and formulas apply:
1 LSB = 0.5 cm. Minimum DIST = 0d ≙ 0m. Maximum DIST = 3'000d ≙ 15m.

The basic calculation formula is

$$D\,[\text{cm}] = \text{DIST} \cdot \frac{1'500\ \text{cm}}{3'000\,\text{LSB}} + D_{\text{OFFSET}}$$

D	Distance in centimeters
D_{OFFSET}	Offset compensation, needs to be evaluated by a calibration of the sensor. Refer also to chapter Calibration and compensations.

Note:
The epc600 chip is using a sensor array with 64 pixels. The distance value output is an average calculation. Refer also to the epc600 Handbook for more details.

3.2.3. Response: Valid & saturated pixels

Name:	**Valid & saturated pixels**															
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Q0	D6	D5	D4	D3	D2	D1	D0	Q0	D6	D5	D4	D3	D2	D1	D0
Description	0	MAX_SAT_PIX [6:0]							0	MIN_VALID_PIX [6:0]						

MIN_VALID_PIX: During the measurement, one of the 4 samples has used only this number of valid pixels per sample for the averaging. The remaining pixels were detected as non-valid. A pixel is valid if the measurement value is: not in the pixel saturation and below the input electronics saturation. Refer to chapter 1.3.4.: Quality of the measurement result.
Data format: unsigned 7 bit integer; Output range: 0d ... 64d.

Note: Distance values are valid as long as MIN_VALID_PIX >0 (minimum condition).

MAX_SAT_PIX : During the measurement, one of the 4 samples has skipped / not used this number of saturated pixels during averaging. A pixel is marked as saturated if the sensor has detected a pixel signal value that exceeds the linear range of the pixel. Refer to chapter 1.3.4.: Quality of the measurement result.
Data format: unsigned 7 bit integer; Output range: 0d … 64d

3.2.4. Response: Q-subsample QSx

Name:	Q-subsample QSx															
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Q1	Q0	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Description	0	0	QSx [13:0]													

QSx: Q-subsample x of the last measurement.
Data format: signed 14 bit integer (two's complement); Unit: LSB

For the calculation of the signal quality refer to chapter 1.3.4.: Quality of the measurement result.

3.2.5. Response: Ambient-light level

Name:	**Ambient-light level**															
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Q1	Q0	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Description	0	0	AMBIENT [13:0]													

AMBIENT: Ambient-light

Data format:	signed 14 bit integer (two's complement); Units: LSB; A/D conversion value.
Output range:	Refer to Table 2: DC sensitivity and DC dynamic range Note: Small negative numbers can occur due to noise.

The basic calculation formula for the amplitude A_{DC} is $A_{DC}\ [\mathrm{LSB}] = \frac{\mathrm{AMBIENT}}{4}$

Note:
The epc600 chip is using a sensor array with 64 pixels. The ambient-light value output is an average calculation. Refer also to the epc600 Handbook for more details.

3.2.6. Response: Temperature

Name:	**Temperature**															
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	Q3	Q2	Q1	Q0	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Description	0	0	0	0	TEMP [11:0]											

TEMP: Temperature value
Data format: unsigned 12 bit integer; Units: LSB; A/D conversion value

3.3. Communication tasks

3.3.1. Measurement sequence (Distance or ambient-light)

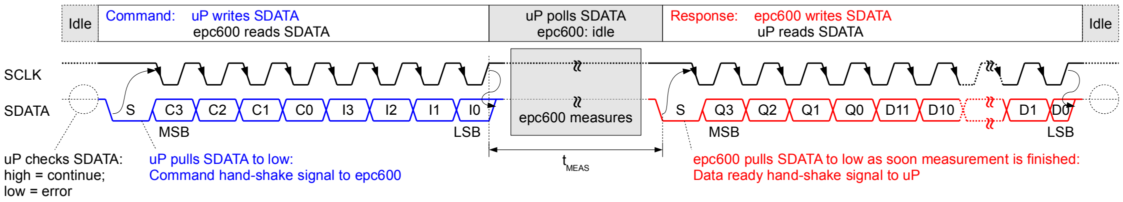


Figure 27: Measurement sequence

- ■ Before and after, the microprocessor performs an access to the epc600, the SDATA line should be checked for an error according to Figure 27. If SDATA is LOW, this indicates an ERROR in communication.
- ■ The microprocessor initiates the communication with a start bit on the SDATA line followed by actively clocking the line SCLK and the command transmission.
- ■ After completion of the command, the epc600 chip starts the measurement. Meanwhile, the microprocessor waits for a response.
- ■ The epc600 chip sets the start bit on SDATA when the measurement is executed and the data are ready (t_{MEAS}, refer to Table 9).
- ■ Now the microprocessor can read out the data by active clocking.

Symbol	Parameter	Min.	Typ.	Max.	Unit
t_{MEAS}	Measurement duration. Depends on the selected integration time	0.8		212	ms
t_{ACC}	Propagation delay of the epc600 after command transmission			3.0	µs
t_{RST}	Reset signal to the epc600. The time SCLK must be pulled low.	1.0			ms
t_{REC}	Recovery time after reset of epc600			4.0	ms

Table 9: Timing of the measurement, read and reset sequence

3.3.2. Read sequence (Valid & saturated pixels, Q-subsample QSx, Temperature)

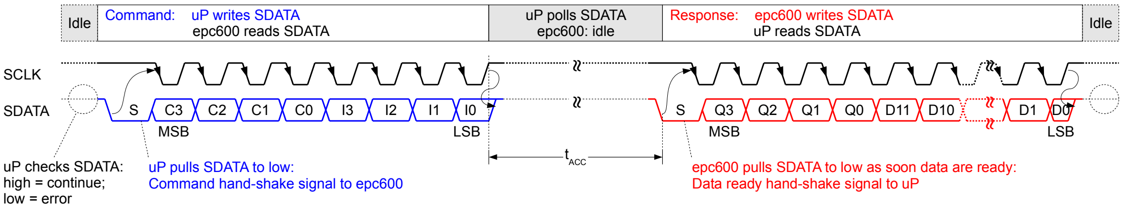


Figure 28: Read sequence

The sequence is identical to the above except for the waiting time t_{ACC} of the response of the chip (refer to Table 9).

- ■ Before and after, the microprocessor performs an access to the epc600, the SDATA line should be checked for an error according to Figure 28. If SDATA is LOW ,this indicates an ERROR in communication.
- ■ The microprocessor initiates the communication with a start bit on the SDATA line followed by actively clocking the line SCLK and the command transmission.
- ■ After completion of the command, the epc600 chip fetches the data. Meanwhile, the microprocessor waits for a response.
- ■ The epc600 chip sets the start bit on SDATA when the data are ready (t_{ACC}).
- ■ Now the microprocessor can read out the data by active clocking.

3.3.3. Error detection by the microprocessor

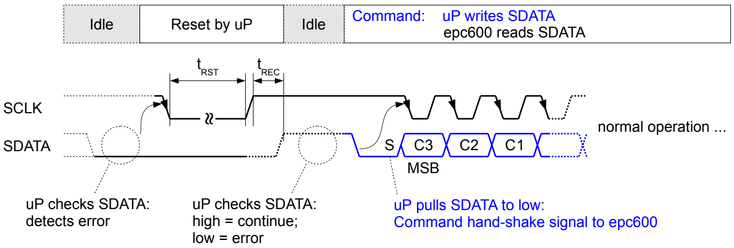


Figure 29: Error detection by the uP and the reset sequence

Before the microprocessor tries to set a start bit, it first checks the SDATA line according to Figure 29. SDATA = LOW indicates an ERROR. This means that the epc600 chip signals an error status or the interface is faulty.

At the end of the transmission, the microprocessor can check, if the communication was successful: Reads the microprocessor data from SDATA, the line must go to HIGH (IDLE) after the positive edge of the last clock cycle (refer to Figure 27 and Figure 28). Is this not the case, the epc600 chip signals an error status or the interface is faulty. Do not use the received data, because it is uncertain, if the last transmission was successful.

Use the reset sequence for the recovery.

3.3.4. Reset and recovery sequence sequence

Whenever necessary, the microprocessor can reset the epc600 chip. The reasons for the reset are either due to an error detection during the transmission or in order to resynchronizing the interface. The epc600 interprets a LOW signal > 1ms on the SCLK line as a reset command for the chip (Figure 29). After reset, the communication has to restart.

NOTE: After reset sequence, the microprocessor must wait pre-defined amount of time t_{REC} before starting with measurements (Table 9).

3.3.5. Error detection by the epc600 chip

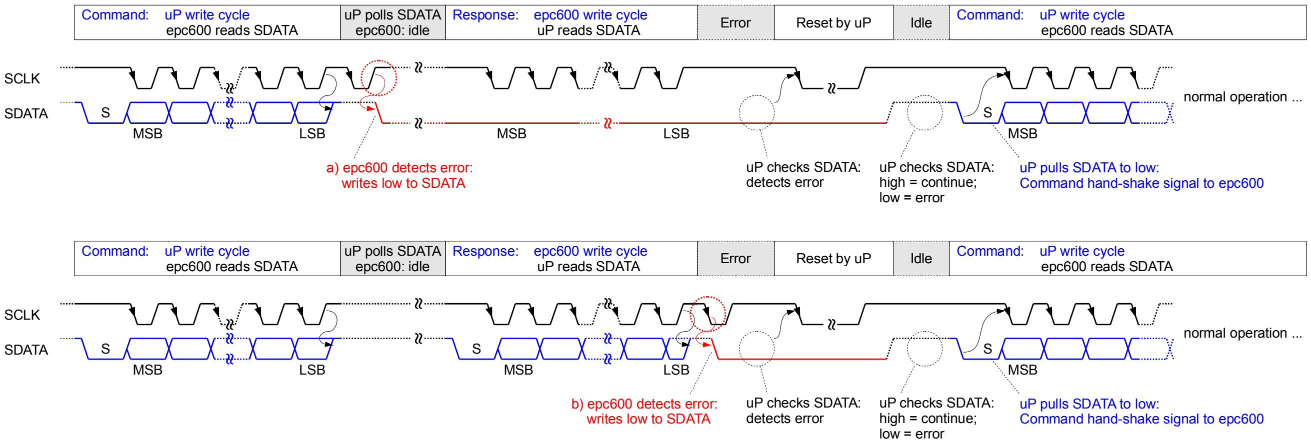


Figure 30: Error detection by epc600

The epc600 chip detects if there are more falling clock edges than necessary for the transmission (see Figure 30). If it happens, the communication is erroneous and the device puts the interface in an ERROR condition by pulling down SDATA = 0. To leave this state, the microprocessor has to reset the epc600 chip.

3.3.6. Cycle times & response time

For a common understanding, we distinguish between the cycle and the response times.

The following examples use:

- 10MHz modulation frequency at the LED pin.
- An integration time of 103µs.
- A 2-wire serial clock SCLK of 1MHz.

Integration time

The integration time t_{INT} is the timeframe in which the light is sampled by the sensor (refer to chapter 3.2.1.: Command: Commands & Integration times). It is equal the exposure time (where a shutter is open for passing the light to the sensor).

Measurement time

The time the epc600 device needs to execute a measurement from the point of receiving the command until it responds.

$$t_{MEAS} = 4 \cdot t_{INT} + 770\,\mu s \qquad \text{e.g.} \quad t_{meas} = 4 \cdot 103\,\mu s + 770\,\mu s = 1'182\,\mu s$$

Communication time

It is the period from the end of the measurement until the next start in a continuous mode manner (refer to Figure 12). It is the real communication time used by the 2-wire interface and all the additional time the microprocessor needs to send the next command to the chip.

Example:	Command write:	1 check bit + 1 start bit + 8 command bits
	Read response:	1 check bit + 1 start bit + 16 data bits
	2-wire serial clock SCKL:	1MHz
	Communication time t_{COM}	e.g. $t_{com} = 10 \cdot 1\,\mu s + 18 \cdot 1\,\mu s = 28\,\mu s$

Data processing time

It is the period $t_{PROCESS}$ needed by the microprocessor for the final result: “calculation distance & quality” (refer to Figure 12)

Measurement cycle time

The measurement cycle time t_{CYCLE} includes the duration to execute a complete measurement cycle until the next cycle propagation is possible (refer to Figure 12).

$$t_{CYCLE} = t_{MEAS} + t_{COM} + t_{PROCESS} \qquad \text{e.g.} \quad t_{CYCLE} = 1'182\,\mu s + 28\,\mu s + 100\,\mu s = 1'310\,\mu s$$

Response time

The response time denotes the necessary time interval to change the distance output DIST of the microprocessor from one state to the other (refer to Figure 11). The maximum response time $t_{RESPONSE}$ of the range-finder system is given by

$$t_{RESPONSE} = 2 \cdot t_{CYCLE} \qquad \text{e.g.} \quad t_{RESPONSE} = 2 \cdot 1'310\,\mu s = 2'620\,\mu s$$

LED on-time and LED duty cycle

For the power dissipation estimation of the emitter LED (at pin LED), the LED on-time and the duty cycle are of importance. The following time periods have to be taken into consideration:

- t_{INT} : during the integration period, the LED outputs are active for 50% of the time.
- t_{MEAS} : there are 4 integration periods t_{INT} per measurement cycle t_{MEAS}.
- t_{COM} : during the communication time the LED outputs are not active.

The formula for the LED on-time is:

$$t_{LED-ON} = 4 \cdot \frac{t_{INT}}{2} + 15\,\mu s \qquad \text{e.g.} \quad t_{LED-ON} = 4 \cdot \frac{103\,\mu s}{2} + 15\,\mu s = 221\,\mu s$$

The LED duty cycle DC_{LED-ON} for LED on-time versus the cycle time is

$$DC_{LED-ON} = \frac{t_{LED-ON}}{t_{CYCLE}} \qquad \text{e.g.} \quad DC_{LED-ON} = \frac{221\,\mu s}{1'310\,\mu s} = 17\%$$

4. Optical Design Considerations

This section summarizes some parameters that are of importance when designing the optical system of a TOF sensor.

Photosensitive area

The photosensitive area is the optical area which has to be well (full) covered by the receiver optics. This is the relevant surface for calculating the light sensitivity of the chip. It is also the relevant area for object detection without any gaps. For more details refer to chapter 1.3.4.: Quality of the measurement result.

Note:
Measurement values are reliable only if the object covers the entire photosensitive area. Measurement values are average values over the sensor array's 64 pixels. Refer to the epc600 Handbook.

Signal sensitivity

The signal sensitivity is defined by the minimum and maximum detectable AC modulation signal (reflected light). It is defined by the light power (Watt/m^2) in relation to:

- the photo-sensitive area of the sensor.
- the operating integration time t_{INT} .
- the operating wavelength λ.
- the angle of incidence (or reflectance of the sensor surface). Refer to Figure 3.

It is independent of
- the modulation frequency

Ambient-light suppression

The ability to suppress DC or low-frequency modulation parts of the received light signal. It is defined by the light power (Watt/m^2) in relation to:

- the photo-sensitive area of the sensor.
- the operating integration time t_{INT}.
- the operating wavelength λ.
- the angle of interest (or reflectance of the sensor surface). Refer to Figure 3.

Refer also to chapter 1.3.3.: Ambient-light suppression.

Operating range

The maximum non-ambiguity distance is < 15m for a modulation frequency of 10MHz @ the pin LED. It is given by the modulation frequency and the speed of light.

The operating range (dynamic range) of the epc600 receiver for a certain illumination level is given by the photosensor and its electronics:
- the AC signal sensitivity for the modulated light.
- the capability of the ambient-light suppression.
- the level of illumination.

Depending on the optical design, these ranges do not match. The optical engineer has to plan the optical design and the light power in a way that matches the application best.

For more detailed information refer to epc's application note AN02 - Reflected power calculation.

IMPORTANT NOTICE

Information furnished by ESPROS Photonics AG (epc) is believed to be accurate and reliable. However, no responsibility is assumed for its use.

ESPROS Photonics AG and its subsidiaries (epc) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is the latest and is complete. All products are sold subject to epc's terms and conditions of sale supplied at the time of order acknowledgment.

epc warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with epc's standard warranty. Testing and other quality control techniques are used to the extent epc deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

epc assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using epc components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

epc does not warrant or represent that any license, either express or implied, is granted under any epc patent right, copyright, mask work right, or other epc intellectual property right relating to any combination, machine, or process in which epc products or services are used. Information published by epc regarding third-party products or services does not constitute a license from epc to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from epc under the patents or other intellectual property of epc.

Resale of epc products or services with statements different from or beyond the parameters stated by epc for that product or service voids all express and any implied warranties for the associated epc product or service. epc is not responsible or liable for any such statements.

epc products are not authorized for use in safety-critical applications (such as life support) where a failure of the epc product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of epc products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by epc. Further, Buyers must fully indemnify epc and its representatives against any damages arising out of the use of epc products in such safety-critical applications.

epc products are neither designed nor intended for use in military/aerospace applications or environments unless the epc products are specifically designated by epc as military-grade or "enhanced plastic." Only products designated by epc as military-grade meet military specifications. Buyers acknowledge and agree that any such use of epc products which epc has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

epc products are neither designed nor intended for use in automotive applications or environments unless the specific epc products are designated by epc as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, epc will not be responsible for any failure to meet such requirements.