General Description

TOFcam-611 is an 8 x 8 pixels TOF imager module based on the epc611 chip. It allows basic gesture control and distance measurement in a very cost effective design from a few centimeters up to two meters.

A high dynamic range can be used even with a high measurement rate of up to 80 TOF frames per second (4 x DCS + 1 temperature image).

The TOFcam-611 comes fully calibrated, so the user can simply readout the clean distance data per pixel. The data interface is a standard Rx/Tx UART with 1 MBit/s data rate.

The device is designed at the PCB level which allows to be easily built-in to the user's application housing.

Features

- Up to 3m distance measurement range on white target
- Measurement rate of up to 80 TOF measurements per second
- Customer specific versions and functionality available upon request
- Very light weight
- Low power consumption
- Ambient-light tolerant
- Calibrated and compensated
- Temperature compensated
- High speed serial interface
- FOV of 12° (h, v)

Applications

- Distance measurement from centimeters to a few meters
- Basic gesture control
- People counting
- Proximity sensing
- Background suppression sensing
- Door opener
- Rotating scanners for scenery mapping (SLAM)
- Object classification

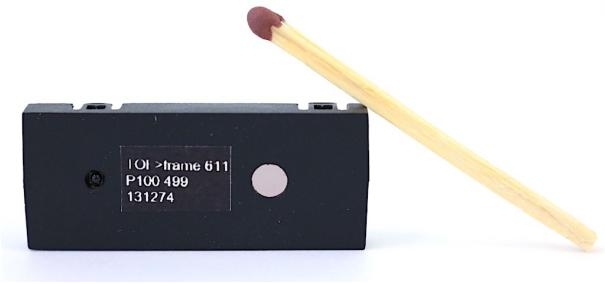

Figure 1: TOFcam-611, front view

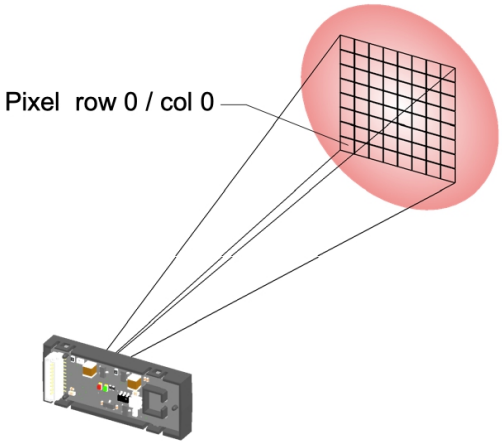

Figure 2: Field of view (12° h/v)

Block Diagram

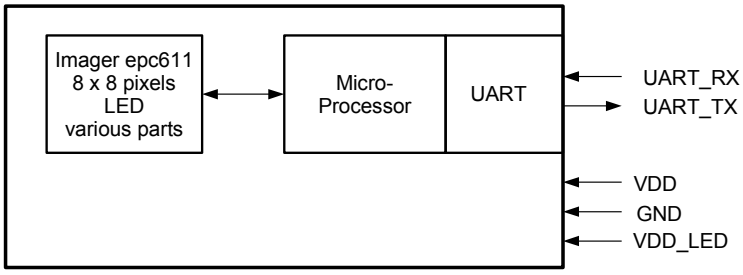

Figure 3: Block diagram

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1. Before you start

1.1. Precaution and Safety

	This product is eye safe according to IEC62471-2013.
	The camera module is an electronic device. Handle it with the necessary ESD precaution.
	Over-voltage: Use only a power supply which correspond to the datasheet of the camera to avoid damage of the device or cause danger for humans.
	Cable-tripping: Place or mount the sensor on solid ground or fix it correctly on a solid support. Place cables carefully. Falling devices can be damaged.
	Take care about the lens surfaces of the camera. Never use any solvents, cleaners or mechanically abrasive towels or high pressure water to clean the sensor.
	Operate the device in compliance with the local EMC regulations.
	This camera is not a safety device. It may not be used in safety applications, explosive atmospheres or in radioactive environment, except the user implements the required safety measures, e.g. by redundancy. However, the sole responsibility for the safety of the application is by the user.
	LIMITED WARRANTY - LOSS OF WARRANTY This camera should only be installed and used by authorized persons. All instructions in this datasheet and in the related documents shall be followed and fully complied with. In addition, the installer and user is required to comply with all local laws and regulations. The installer and user is fully responsible for the safe use and operation of the system. It is the sole responsibility of the installer and the user to ensure that this product is used according to all applicable codes and standards, in order to ensure safe operation of the whole application. Any alteration to the devices by the buyer, installer or user may result in device damage or unsafe operating conditions. ESPROS Photonics AG is not responsible for any liability or warranty claim which results from such manipulation or disregarding of given operating instructions.
epc espros photonics corporation	ESPROS Photonics AG is an ISO 9001: 2015 certified company.
CE RoHS	This product is according to European Union standards and free of hazardous substances.

1.2. Updates

ESPROS Photonics is constantly striving to provide comprehensive and correct product information. Therefore, please check ESPROS' website regularly for updated versions of datasheets and documentations: www.espros.com

	Download the latest Flyer TOFcam-611.
	Download the latest Installation and Operation Manual of the TOFcam-611.
	Download and use the latest TOFCAM611_SW_Package. If there are any questions, please contact your ESPROS sales office or send an email to sales@espros.com.

1.3. Important Notes

Colored marking in text means “under consideration” and refers to not yet applicable or verified information.
Values and/or information are either estimates or show the applicable principle only.

2. Abbreviations

Designator	Description
ACK	Acknowledged
ADC	Analog-to-digital converter
CRC	Cyclic redundancy check (checksum)
DCS	Differential correlation sample
DLL	Delay locked loop, controllable delay line
DRNU	Distance response non-uniformity: Distance error from pixel to pixel with a target at the same distance
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
FOV	Field of view
Frame	One image
GND	Ground terminal, negative supply voltage
GUI	Graphical user interface
ID	Identifier
ISO	International organization for standardization
LED	Light emitting diode used to illuminate the scenery or as indicator
LSB	Least significant bit / byte
LVTTL	Low voltage transistor transistor logic
MSB	Most significant bit / byte
NOP	No operation
RX	Receive terminal, data in
TOF	Time of flight
TX	Transmit terminal, data out
UART	Universal asynchronous receiver transmitter
VDD	Positive supply voltage

Table 1: List of abbreviations used in this document

3. Technical data

T_A = 25°C, VDD = 5V, object reflectivity 90%, unless otherwise stated

Parameter	Description	Conditions	Min.	Typ	Max.	Units	Comments
VDD	Main supply voltage	Ripple [1] < 50 mV_{pp}	4.75	5.0	5.25	V	
VDDLED	LED supply voltage	Ripple [1] < 200 mV_{pp}	4.75	5	5.25	V	
IDD	Main supply current	Acquisition		86		mA	@ VDD 5V
		Power down		17		mA	@ VDD 5V
IDDLED	LED supply current	Acquisition		130		mA	Peak, @ VDDLED 5V
		Power down		9		mA	@ VDDLED 5V
D	Operating range		0.10		3	m	Measured with an object of at least the size of the spot d_{SPOT}, depends on integration time t_{INT} and object reflectivity.
FOVh	Horizontal field of view			12		°	
FOVv	Vertical field of view			12		°	
Acc	Accuracy (mean of 100 samples)			± 4		cm	Amplitude > 500 LSB
D_{NOISE}	Distance noise (1σ value)			2		mm	For amplitudes between 100 ... 1'900 LSB and with Kalman Filter k = 0.01, threshold t =3 00mm
t_{INT}	Integration time selectable		1		1'600	µs	Default 125µs
t_{CYCLE}	Measurement cycle time GET_DISTANCE GET_DISTANCE_AMPLITUDE GET_DCS_DISTANCE_AMPLITUDE			12.35 15.15 20.75		ms ms ms	@t_{INT} = 125µs
t_{PWR_UP}	Power up time until acceptance of commands				200	ms	
t_{WARM_UP}	Warm-up time until output data are in tolerance		Refer to chapter 8.5				
Res	Resolution			0.1		mm/LSB	
	Measurement output for 0.0 … 2.00m		0		20'000	LSB	
V_{APM}	Amplitude		100		1'900	LSB	Amplitude range for accurate results
T_A	Ambient temperature range (operation)		-20		85	°C	
T_{STO}	Storage temperature range		-20		85	°C	
Φ_L	Ambient-light			100		kLux	indirect, on target
RH	Relative humidity		15		90	%	Non condensing
ESD	Electrostatic discharge rating				2	kV	Human body model
	Weight			3.7		g	

Table 2: Technical data

Note:

[1] Min. and Max. voltage values include noise and ripple voltages.

4. Mechanical dimensions

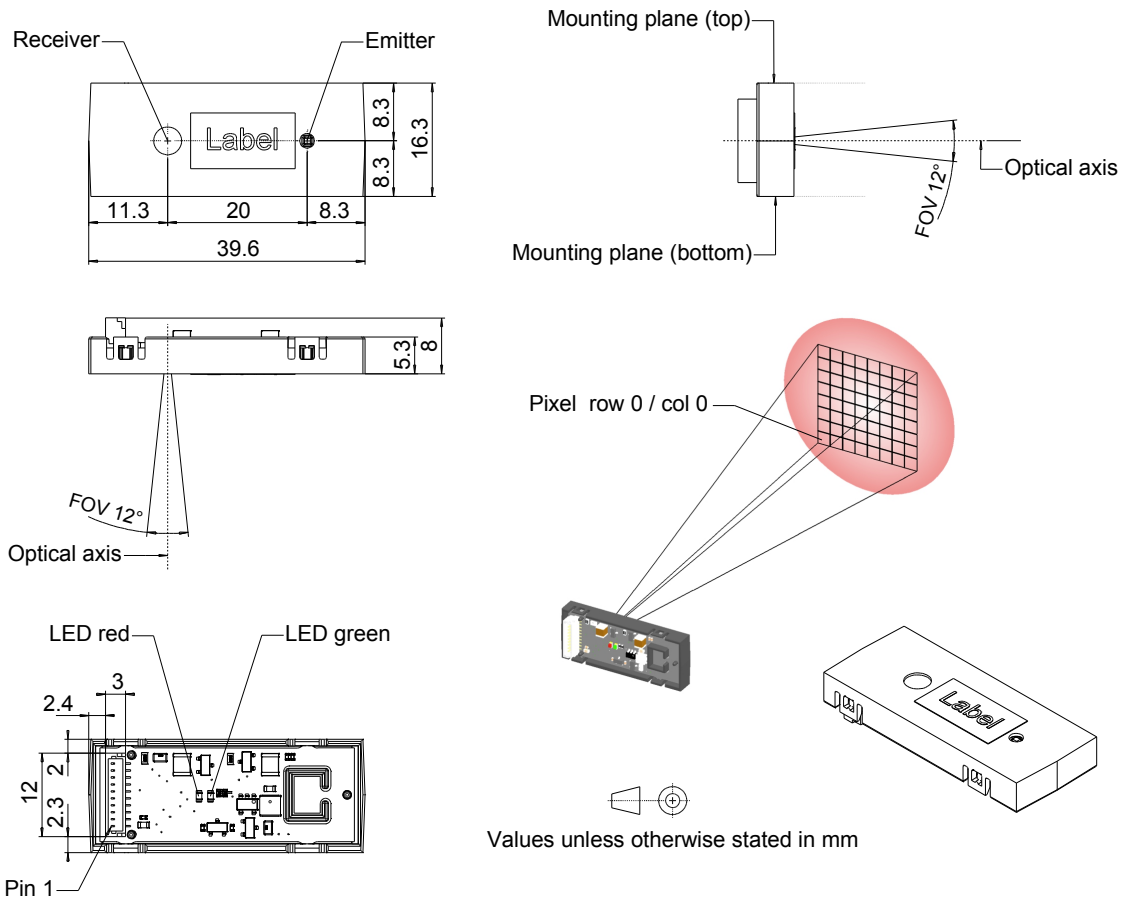

Figure 4: Mechanical dimensions

Notes:

- Zero value is for measured distances at the front of the housing.
- The TOFcam-611 is a very light-sensitive device but its main body is not totally hermetic for stray-light from sides or backside. Therefore for achieving best performance in ambient-light environments, it is suggested to build it into a stray-light dense application housing which is usually anyway the case.

5. Sensor interface

5.1. Connection

Connector type: JST BM10B-SRSS-TB(LF)(SN), 10 pin

Figure 5: Connector

5.2. Pin table

No.	Name	Function	Comments
1	VDD	Main supply voltage	Stable and free of noise. Decouple with min. 10µF low ESR capacitor to GND
2	GND	Ground	
3	PIN3	reserved	Do not connect
4	PIN4		
5	PIN5		
6	UART_TX	Data output Tx	UART interface, LVTTL levels (3.3V)
7	UART_RX	Data input Rx	
8	PIN8	no function	Do not connect
9	GND	Ground	
10	VDDLED	LED supply voltage	Stable and free of noise. Decouple with min. 10µF low ESR capacitor to GND

Table 3: Pin list

5.3. Communication protocol

The communication interface uses 8 bit UART standard on LVTTL levels (3.3V) It operates with following parameters:

Parameter	Value	Unit	Comment
Baud rate	921'600	bit/s	1 bit = 1.085µs
Start bits	1	bit	low active
Data	8	bit	
Stop bits	1	bit	high active
Parity	No		

Table 4: UART configuration

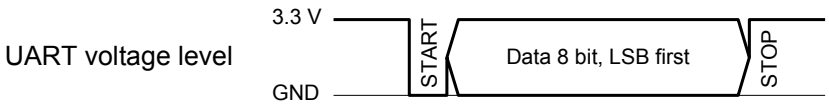

Figure 6: UART frame format

The UART operates in a master-slave mode with the application as the master and the TOFcam-611 as the slave.

A request is initiated with a command of the master by polling. The TOFcam-611 as the slave returns the answer to the request after the internal processing time t_{PROC}.

TOFcam-611 does not accept commands during the processing t_{PROC} and the communication t_{COM_TX}. A next command can be issued earliest after finishing Data Out.

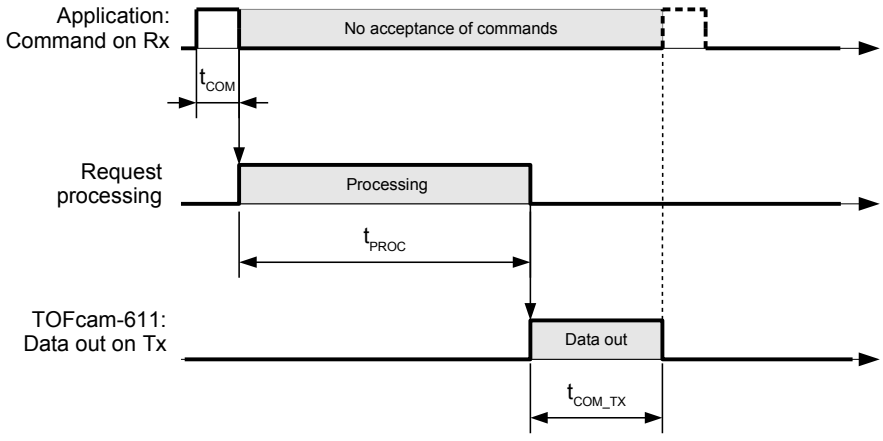

Figure 7: Command and answer sequence

6. System Boot-up

Apply power: VDD and VDDLED. The sequence does not matter. The device notifies the power-up with a short red LED flash and is now in the power down mode. After sending the command for power-up, the green LED turns on and the device is ready.

Error cases:

- Red LED flashing: Firmware not correctly downloaded. Download the firmware anew with the GUI of the epc611 evaluation kit or with the bootloader (refer to chapter 7.19 and 7.26).
- Red LED stays on: Error during boot-up. Switch off/on power again.
- If the error remains, contact your sales responsible.

7. Commands and responses

TOFcam-611 answers to each command with either the required data, acknowledge, not acknowledge or an error. LSByte is transmitted first, MSByte last. Use only commands listed.

7.1. Command format

The command packet has a fixed length of 14 bytes: A start byte (value 0xF5), followed by 1 byte command ID (CMD), 8 bytes of parameters corresponding to the command and 4 closing bytes with a 32 bit CRC.

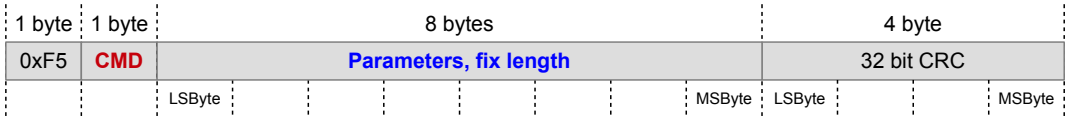

Figure 8: Command format

7.2. Response format

The answer packet has variable length: A start byte (value 0xFA), followed by 1 byte type definition, 2 byte length definition n, n bytes data and 4 closing bytes with a 32 bit CRC.

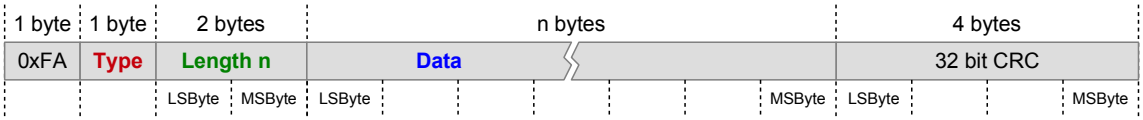

Figure 9: Response format

7.3. CRC calculation

The Cyclic Redundancy Check (CRC) calculation includes all bytes of the packet except the CRC itself. Examples are listed in the command list.

CRC specification:

- Bytewise CRC32
- Init value: 0xFFFFFFFF
- Xor value: 0x00000000
- Polynom: 0x04C11DB7

CRC calculation function:

```
uint32_t CrcCalc::calcCrc32(const uint8_t *data, const uint32_t size)
{
  uint32_t crc = initValue;
  for(uint32_t i = 0; i < size; i++)
  {
    crc = calcCrc32Uint8(crc, data[i]);
  }
  return crc ^ xorValue;
}

uint32_t CrcCalc::calcCrc32Uint8(uint32_t crc, uint8_t data)
{
  int32_t i;
  //This shift is done to make it compatible to the STM32 hardware CRC
  crc = crc ^ (data << 24);
  for (i = 0; i < 8; i++)
  {
    if (crc & 0x80000000)
    {
      crc = (crc << 1) ^ polynom;
    }
    else
```

```
    {
      crc = (crc << 1);
    }
  }
  return (crc);
}
```

7.4. SET_POWER [0x40]

Puts the device in power-up or power-down mode and returns after t_{PROC} acknowledge. Before any acquisition commands, power must be enabled. The green LED indicates power on.

Parameter byte 0: 0x00 disables power, 0x01 enables power
others: 0x00

Command e.g. | 0xF5 | **0x40** | **0x01** 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x9C 0xD7 0xD6 0x91 | (power enable)

Response type 0x00: Acknowledge
Response data 0 bytes
Response time power up t_{PROC} : < 200 ms
Response time power down t_{PROC} : < 30 µs
Response e.g | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.5. SET_INTEGRATION_TIME_DIS [0x00]

Sets the integration time for distance measurements and returns after t_{PROC} acknowledge. The integration time is stored and used as long power is on or until a new time is set. Range: 1 … 1'600 µs. After power-up, default is 125 µs. 0 is not a valid value.

Parameter **byte 1, 2:** Integration time in microseconds, 16 bit unsigned integer
others: 0x00

Command e.g. | 0xF5 | **0x00** | 0x00 **0x1E 0x00** 0x00 0x00 0x00 0x00 0x00 | 0xD9 0x85 0x1A 0x99 | (30µs integration time)

Response type 0x00: Acknowledge
Response data 0 bytes
Response time t_{PROC} : ~ 40 µs
Response e.g | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.6. GET_INTEGRATION_TIME_DIS [0x27]

Returns after t_{PROC} the selected or used integration time for distance measurements.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x27** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0xC4 0x3F 0x68 0x4C |

Response type 0x09: Data
Response data 2 bytes: Integration time in microseconds, 16 bit unsigned integer
Response time ~ 40 µs
Response e.g. | 0xFA | **0x09** | **0x02 0x00** | **0x5E 0x01** | 0x83 0xF9 0x91 0xF0 | (350µs)

7.7. GET_DISTANCE [0x20]

Starts a new distance acquisition and returns after t_{PROC} the result or status.

Parameter no, all bytes 0x00

Command e.g | 0xF5 | **0x20** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x98 0x53 0xE9 0x9B |

Response type 0x03: Data
Response data 64 x 4 bytes: Distance, 0.1mm/LSB or status, 32 bit unsigned integer. Zero according the note of Figure 4.
Readout order: Starts at row 0, pixel 0 … pixel 7 and ends with row 7, pixel 7.
Range: 20 MHz modulation frequency, 0 … 7.5m: 0 … 75'000d
Status: 16'001'000d: Low TOF amplitude
16'002'000d: ADC overflow
16'003'000d: Saturation
16'004'000d: Reserved
16'005'000d: ADC underflow
16'006'000d: High TOF amplitude
Response time Refer to chapter 8.2
Response e.g. | 0xFA | **0x03** | **0x00 0x01** | **0x28 0x0F 0x00 0x00 … (256 bytes total)** | CRC (4 bytes) | (distance 388.0 mm)

7.8. GET_DISTANCE_AMPLITUDE [0x22]

Starts a new distance and TOF amplitude acquisition and returns after t_{PROC} the result or status. The amplitude is a quality indicator for the distance result.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x22** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0xE3 0x1A 0x29 0x7B |

Response type 0x05: Data

Response data 64 x 4 bytes distance followed by 64 x 4 bytes amplitude, total: 2 x 256 bytes = 512 bytes
Readout order each: Starts at row 0, pixel 0 … pixel 7 and ends with row 7, pixel 7.

Distance byte 0..3 each: Distance, 0.1mm/LSB or status, 32 bit unsigned integer. Zero according the note of Figure 4.
Range: 20 MHz modulation frequency, 0 … 7.5m: 0 … 75'000d

Amplitude byte 4..7 each: TOF amplitude or status, 32 bit unsigned integer.
Status: Values < 100 LSB, distance noise is significant; > 1'900 LSB, the distance can contain considerable error.
16'001'000d: Low TOF amplitude
16'002'000d: ADC overflow
16'003'000d: Saturation
16'004'000d: Reserved
16'005'000d: ADC underflow
16'006'000d: High TOF amplitude

Response time Refer to chapter 8.2

Response e.g. | 0xFA | **0x05** | **0x00 0x02** | **0x24 0x0F 0x00 0x00 … 0x63 0x10 0x00 0x00 … (2x 256 bytes total)** | CRC (4 bytes) |
(distance 387.6mm ... amplitude 4'195 LSB)

7.9. GET_DCS [0x25]

Starts a new acquisition and returns after t_{PROC} DCS values only.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x25** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0xBF 0x76 0xA8 0xAC |

Response type 0x07: Data

Response data 64 x 2 bytes DCS0 followed by 64 x 2 bytes DCS1, 64 x 2 bytes DCS2 and 64 x 2 bytes DCS3
Readout order each: Starts at row 0, pixel 0 … pixel 7 and ends with row 7, pixel 7.
byte 0, 1 each: DCSx, 16 bit 2's complement signed integer. Range: -2'048 … +2'047 LSB
0x 07 FF: Saturation
0x 07 FE: ADC overflow
0x F8 00: ADC underflow

Response time Refer to chapter 8.2

Response e.g. | 0xFA | **0x07** | **0x00 0x02** | **0x12 0x00 … 0x12 0x00 … 0x10 0x00 ... 0x12 0x00 … (512 bytes total)**| CRC (4 bytes) |
(DCS0(r0,c0) = 18, DCS0(r0,c1) = 18, DCS0(r0,c2) = 16, DCS0(r0,c3) = 18)

7.10. GET_DCS_DISTANCE_AMPLITUDE [0x23]

Starts a new acquisition and returns after t_{PROC} DCS, distance and amplitude values as a set.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x23** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x85 0xB0 0x29 0x89 |

Response type 0x08: Data

Response data 64 x 2 bytes DCS0 followed by 64 x 2 bytes DCS1, 64 x 2 bytes DCS2, 64 x 2 bytes DCS3,
64 x 4 bytes distance and 64 x 4 bytes amplitude
Readout order each: Starts at row 0, pixel 0 … pixel 7 and ends with row 7, pixel 7.

DCSx byte 0, 1 each: DCSx, 16 bit 2's complement signed integer. Range: -2'048 … +2'047 LSB
0x 07 FF: Saturation
0x 07 FE: ADC overflow
0x F8 00: ADC underflow

Distance byte 0..3 each: Distance, 0.1mm/LSB or status, 32 bit unsigned integer. Zero according the note of Figure 4.
Range: 20 MHz modulation frequency, 0 … 7.5m: 0 … 75'000d

Amplitude byte 0..3 each: TOF amplitude or status, 32 bit unsigned integer.
Status: Values < 100 LSB, distance noise is significant; > 1'900 LSB, the distance can contain considerable error.
16'001'000d: Low TOF amplitude
16'002'000d: ADC overflow
16'003'000d: Saturation
16'004'000d: Reserved
16'005'000d: ADC underflow
16'006'000d: High TOF amplitude

Response time Refer to chapter 8.2

Response e.g. | 0xFA | **0x08** | **0x00 0x04** | **0x26 0x00 … 0x7A 0x00 … 0xEE 0xFF … 0xA5 0xFF … 0x36 0x3d 0x00 0x00 …. 0x6E 0x00 0x00 0x00 … (1'024 bytes total)** | CRC (4 bytes) | (DCS0(r0,c0) = 38, DCS1(r0,c0) = 122, DCS2(r0,c0) = -18, DCS3(r0,c0) = -91, distance = 15'670, amplitude = 110)

7.11. GET_TEMPERATURE [0x4A]

Returns after t_{PROC} the chip temperature during last distance acquisition. Temperature information is useful for error compensation of the measured distance.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x4A** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x18 0x41 0xF5 0xA4 |

Response type 0xFC: Data

Response data 2 bytes: Temperature, 0.01 ºC / LSB, 16 bit 2's complement signed integer.

Response time t_{PROC}: ~ 40 µs

Response e.g. | 0xFA | **0xFC** | **0x02 0x00** | **0x47 0x13** | 0x4F 0xEE 0x12 0x1F | (temperature 49.35°C)

7.12. DRNU_COMPENSATION [0x41]

Enables or disables the Distance Response Non-Uniformity (DRNU) compensation and returns after t_{PROC} acknowledge.

Parameter byte 0: 0x00 = Compensation enabled; 0x01 = Compensation disabled

others: 0x00

Command e.g. | 0xF5 | **0x41** | **0x01** 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0xFA 0x7D 0xD6 0x63 | (disable compensation)

Response type 0x00: Acknowledge

Response data 0 bytes

Response time t_{PROC} : ~ 40 µs

Response e.g. | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.13. GET_FIRMWARE_VERSION [0x49]

Returns after t_{PROC} the firmware version of the TOFcam-611: Version.Subversion (V.s)

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x49** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x05 0xA2 0x35 0xB6 |

Response type 0xFE: Data

Response data 4 bytes

byte 0, 1: Subversion s, 16 bit unsigned integer

byte 2, 3: Version V, 16 bit unsigned integer

Response time t_{PROC}: ~ 40 µs

Response e.g. | 0xFA | **0xFE** | **0x04 0x00** | **0x0E 0x00 0x01 0x00** | 0xDA 0xD7 0x3A 0xFB | (Version 1.14)

7.14. GET_CHIP_INFORMATION [0x48]

Returns after t_{PROC} the epc611 Chip ID and Wafer ID.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x48** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x63 0x08 0x35 0x44 |

Response type 0xFD: Data

Response data 4 bytes

byte 0, 1: Chip ID, 16 bit unsigned integer

byte 2, 3: Wafer ID, 16 bit unsigned integer

Response time t_{PROC}: ~ 40 µs

Response e.g. | 0xFA | **0xFD** | **0x04 0x00** | **0x10 0x04 0x10 0x00** | 0x4F 0x56 0xF8 0x21 | (Chip ID 1040 , Wafer ID 16)

7.15. GET_PROD_DATE [0x50]

Returns after t_{PROC} the production date of the TOFcam-611.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x50** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x8B 0x10 0x32 0xD2 |

Response type 0xF9

Response data 2 bytes

byte 0: Last two digits of the year as unsigned integer e.g. 18

byte 1: Number of the week as integer e.g. 22

Response time ~ 40 µs

Response e.g. | 0xFA | **0xF9** | **0x02 0x00** | **0x12 0x16** | 0x00 0x76 0x04 0xA7 | (year 18, week 22)

7.16. DATA_NACK

System response only: Command not accepted or unknown.

Response type 0x01: Not acknowledged

Response data 0 bytes

Response e.g. | 0xFA | **0x01** | **0x00 0x00** | (**0 bytes**) | 0x35 0x07 0x24 0xE9 |

7.17. DATA_ERROR

System response only: Error occurred during the execution of the command. Response instead of the required data

Response type 0xFF: Error

Response data 2 bytes:

bit 0..14: Error number. Try it again. If the error remains, contact your sales responsible.

bit 15: 0

Response e.g. | 0xFA | **0xFF** | **0x02 0x00** | **0x03 0x00** | 0x94 0xF6 0x35 0x81 | (error No. 3)

7.18. IDENTIFY [0x47]

Returns after t_{PROC} the device identification ID and the mode (normal operation or bootloader e.g. a firmware update was not successful). Is TOFcam-611 in bootloader mode, run a firmware update with the epc611 evaluation kit GUI or with the bootloader (see next). The GUI detects missing firmware and runs update automatically. This command may be used for communication check.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x47** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x0A 0x67 0xF6 0x1D |

Response type 0x02: Data

Response data 4 bytes:

byte 0: Hardware version

byte 1: Device type, TOFcam-611 = 0x01

byte 2: Chip type, epc611 = 0x06

byte 3: 0x00 = normal operation, 0x80 = bootloader

Response time ~ 40 µs

Response e.g. | 0xFA | **0x02** | **0x04 0x00** | **0x00 0x01 0x06 0x00** | 0x8B 0x2D 0x83 0x29 | (HW version 0, TOFcam-611, epc611, normal operation)

| 0xFA | **0x02** | **0x04 0x00** | **0x00 0x01 0x06 0x80** | 0x65 0xCD 0x8F 0x40 | (HW version 0, TOFcam-611, epc611, bootloader)

7.19. JUMP_TO_BOOTLOADER [0x44]

Stops all normal operation activities and changes to bootloader. Now, the bootloader is answering to this and all following commands. Refer also to chapter 7.26.

Parameter no, all bytes 0x00

Command e.g. | 0xF5 | **0x44** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x17 0x84 0x36 0x0F |

Response type 0x00: Acknowledge

Response data 0 bytes

Response time t_{PROC} : < 5ms

Response e.g. | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.20. UPDATE_FIRMWARE [0x45]

Bootloader command only: Copies the firmware into the flash memory of the sensor. It returns acknowledge after t_{PROC}.

Procedure:
1st, write control byte "start" with password and file size; 2nd, write control byte "write" with index and data; 3rd, write control byte "complete".

Parameter 8 bytes: Contents differs and depends on operation step: Refer to Table 5.

Step	Action	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
1st	Start	0x00	Password = 0x654321			Size of the update file			
2nd	Write data	0x01	FirmwareData[index] (3 bytes)			Firmware data (4 bytes)			
3rd	Complete	0x02	All 7 bytes = 0x00						

Table 5: Bootloader data format

Command e.g. | 0xF5 | **0x45** | **0x00 0x21 0x43 0x65 0x10 0x00 0x00 0x00** | 0x29 0x7B 0xFA 0x1C | (start for 16 byte file size)
| 0xF5 | **0x45** | **0x01 0x00 0x00 0x00 0x10 0x4A 0x56 0x50** | 0x10 0x20 0x8A 0xE6 | (write data to index 0)
| 0xF5 | **0x45** | **0x02 0x00 0x00 0x00 0x00 0x00 0x00 0x00** | 0xE5 0x97 0x75 0x4A | (complete)

Response type 0x00: Acknowledge
Response data 0 bytes
Response time t_{PROC} : < 400ms
Response e.g. | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.21. WRITE_CALIBRATION_DATA [0x4B]

Writes the calibration data into the flash memory and returns after t_{PROC} acknowledge. This data are used during DRNU compensation.
Warning: Deletes previous stored calibration.

Procedure:
1st, write control byte "start" with password and file size; 2nd, write control byte "write" with index and data; 3rd, write control byte "complete".

Parameter 8 bytes: Contents differs and depends on operation step: Refer to Table 6.

Step	Action	Byte 0	Byte 1	Byte 2	Byte 5	Byte 4	Byte 5	Byte 6	Byte 7
1st	Start	0x00	Password = 0x654321			Size of the update file			
2nd	Write data	0x01	CalibrationData[index] (3 bytes)			Calibration data (4 bytes)			
3rd	Complete	0x02	All 7 bytes = 0x00						

Table 6: Calibration data download format

Command e.g. | 0xF5 | **0x4b** | **0x00 0x21 0x43 0x65 0x10 0x00 0x00 0x00** | 0x29 0x7B 0xFA 0x1C | (start for 16 byte file size)
| 0xF5 | **0x4b** | **0x01 0x00 0x00 0x00 0x10 0x4A 0x56 0x50** | 0x10 0x20 0x8A 0xE6 | (write data to index 0)
| 0xF5 | **0x4b** | **0x02 0x00 0x00 0x00 0x00 0x00 0x00 0x00** | 0xE5 0x97 0x75 0x4A | (complete)

Response type 0x00: Acknowledge
Response data 0 bytes
Response time t_{PROC} : < 400ms
Response e.g. | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.22. SET_DLL_STEP [0x06]

Sets the number of DLL steps for artificial phase/distance shifting and returns after t_{PROC} acknowledge. 1 step is around 2.15ns / 315mm.

Parameter byte 0: Number of DLL steps
others: 0x00

Command e.g. | 0xF5 | **0x06** | **0x01** 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0xD2 0x7E 0x43 0xD5 | (Number of steps = 1)

Response type 0x00: Acknowledge
Response data 0 bytes
Response time t_{PROC} : ~ 40 µs
Response e.g. | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |

7.23. WRITE_REGISTER [0x4C]

Writes the value into a register of the sensor and returns after t_{PROC} 16 bit SPI response from epc611 chip.

Parameter 3 bytes:
- byte 0: Register address inside the page (0x00 … 0x20)
- byte 1: Page address
- byte 2: Register value
- others: 0x00

Command e.g. | 0xF5 | **0x4C** | **0x01 0x00 0x56** 0x00 0x00 0x00 0x00 0x00 | 0x7D 0xAD 0xE1 0xE6 |
(Write into page 0, register 1 = 0x56)

Response type 0xFB: Data
Response data 2 bytes: 16 bit SPI response from epc611 chip
Response time t_{PROC} : ~ 40 µs
Response e.g. | 0xFA | **0xFB** | **0x02 0x00** | (**2 bytes**) | CRC (4 bytes) |

7.24. READ_REGISTER [0x4D]

Reads the value of the sensor register and returns after t_{PROC} 16 bit SPI response from epc611 chip.

Parameter 2 bytes:
- byte 0: Register address inside the page (0x00 … 0x20)
- byte 1: Page address
- others: 0x00

Command e.g. | 0xF5 | **0x4D** | **0x01 0x00** 0x00 0x00 0x00 0x00 0x00 0x00 | 0x8E 0xF1 0xD5 0x28 | (read page, 0, register 1)

Response type 0xFB: Data
Response data 2 bytes: 16 bit SPI response from epc611 chip
Response time t_{PROC} : ~ 40 µs
Response e.g. | 0xFA | **0xFB** | **0x02 0x00** | **(2 bytes)** | CRC (4 bytes) |

7.25. READ_NOP [0x4E]

Returns after t_{PROC} the value of the last SPI command to the epc611.

Parameter no, all bytes 0x00
Command e.g. | 0xF5 | **0x4E** | 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 | 0x59 0xCE 0xB4 0x61 |

Response type 0xFB : last 16 bit SPI command to the epc611
Response data 2 byte
Response time t_{PROC} : ~ 40 µs
Response e.g. | 0xFA | **0xFB** | **0x02 0x00** | (2 **bytes)** | CRC (4 bytes) |

7.26. Firmware update

Firmware update of the camera in the field is possible. In such a case, ESPROS provides an “update file” on the website www.espros.com as part of the ESPROS TOFcam-611 Evaluation Kit Software package.The upgrade will neither touch nor overwrite the calibration with the bootloader. The bootloader is bounded on 12 kByte Flash Memory for the update file. Calibration data has additionally own 2 kByte.

The command sequence according Table 7 must be executed for uploading the “update file” to the camera.

The following example of an “update file” with 16 bytes is used in the table below (no valid file, demonstrator only)

0x10 0x4A 0x56 0x50 0xFF 0x67 0xA0 0xC0 0x23 0x45 0xAA 0x00 0x34 0x78 0x99 0xBB

Application action	Device reaction	Device answer
Send command “JUMP_TO_BOOTLOADER”: | 0xF5 | **0x44** | **0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00** | 0x17 0x84 0x36 0x0F |	Jump to bootloader	ACK *
1st step, send command “UPDATE_FIRMWARE” with the control byte “0x00”, the password and the size of the update file: | 0xF5 | **0x45** | **0x00 0x21 0x43 0x65 0x10 0x00 0x00 0x00** | 0x29 0x7B 0xFA 0x1C |	Start update: Verify password and store file size	ACK *
2nd step, send the command “UPDATE_FIRMWARE” with the control byte “0x01” , the index and 4 bytes of the “update file”. Repeat this step as often as needed = Update file size / 4, e.g. with given update file above: | 0xF5 | **0x45** | **0x01 0x00 0x00 0x00 0x10 0x4A 0x56 0x50** | 0x10 0x20 0x8A 0xE6 | | 0xF5 | **0x45** | **0x01 0x04 0x00 0x00 0xFF 0x67 0xA0 0xC0** | 0xA1 0x67 0xFB 0xA7 | | 0xF5 | **0x45** | **0x01 0x08 0x00 0x00 0x23 0x45 0xAA 0x00** | 0x7A 0x71 0x34 0xA7 | | 0xF5 | **0x45** | **0x01 0x0C 0x00 0x00 0x34 0x78 0x99 0xBB** | 0x8B 0x89 0xB2 0x8F |	Write update: Store data Store data Store data Store data	 ACK * ACK * ACK * ACK *
3rd step, send command “UPDATE_FIRMWARE” with control byte “0x02”: | 0xF5 | **0x45** | **0x02 0x00 0x00 0x00 0x00 0x00 0x00 0x00** | 0xE5 0x97 0x75 0x4A | Wait until the end of the boot time.	Complete update: Verify data and return to regular operation	ACK *
The device is now ready to operate. Communication may be tested with the command “IDENTIFY”	---	---

Table 7: Update procedure

Notes:

- * ACK: ACKNOWLEDGE: Response e.g.: | 0xFA | **0x00** | **0x00 0x00** | (**0 bytes**) | 0xB2 0xAB 0xFC 0xE8 |
- If an error occurs (e.g. corrupted data, invalid command), the device answers with DATA_NACK = NOT ACKNOWLEDG”. Refer to Chapter 7.16.
- Is the update procedure interrupted, no valid application is in the flash. The device stays in bootloader mode.
- In such cases, the update procedure must be restarted. It can be repeated at any time.

8. Application information

8.1. Integration time setting

The TOFcam-611 does not set / select integration times automatically. This must be done by the application.

An optimum working TOF amplitude is around 1'000 LSB ± 50 LSB; values < 100 LSB, distance noise is significant; > 1'900 LSB, the distance can contain considerable error.

8.2. Timing

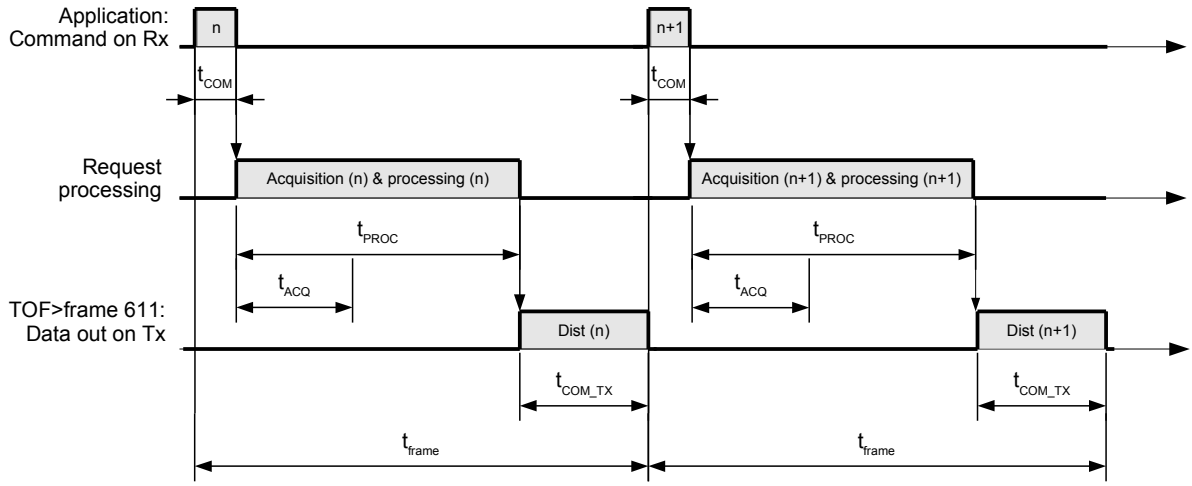

Figure 10: Timing of the complete TOF measurement

The timings for distance, amplitude and DCS acquisition are:

$t_{ACQ} = t_{SHUTTER} + 4 \times t_{INT} + t_{SIGNAL\_PROCESSING} = 4 \times t_{INT} + 850\mu s$

$t_{FRAME} = t_{COM} + t_{PROC} + t_{COM\_TX}$

For GET_DISTANCE: t_{FRAME} = 12.35ms @ t_{INT} = 125µs

For GET_DCS / GET_DISTANCE_AMPLITUDE: t_{FRAME} = 15.15ms @ t_{INT} = 125µs

For GET_DCS_DISTANCE_AMPLITUDE: t_{FRAME} = 20.75ms @ t_{INT} = 125µs

8.3. Operating range (unambiguity distance)

The TOFcam-611 uses the continuous wave TOF phase-shift measurement technique with a modulation frequency of 20MHz. This leads to an unambiguity distance of 7.5m. Highly reflective objects at a distance greater than 7.5m will appear closer due to wrap-around of the modulation period.

Example: With a highly reflective object at a distance of 8.5m, the output of the TOFcam-611displays 1m (8.5m – 7.5m). This is obviously wrong.

8.4. Object reflectivity

The reflectivity of the object can have an impact on the distance accuracy. Such a distance error can be corrected by an additional compensation based on measuring the amplitude.

8.5. Warm-up distance drift

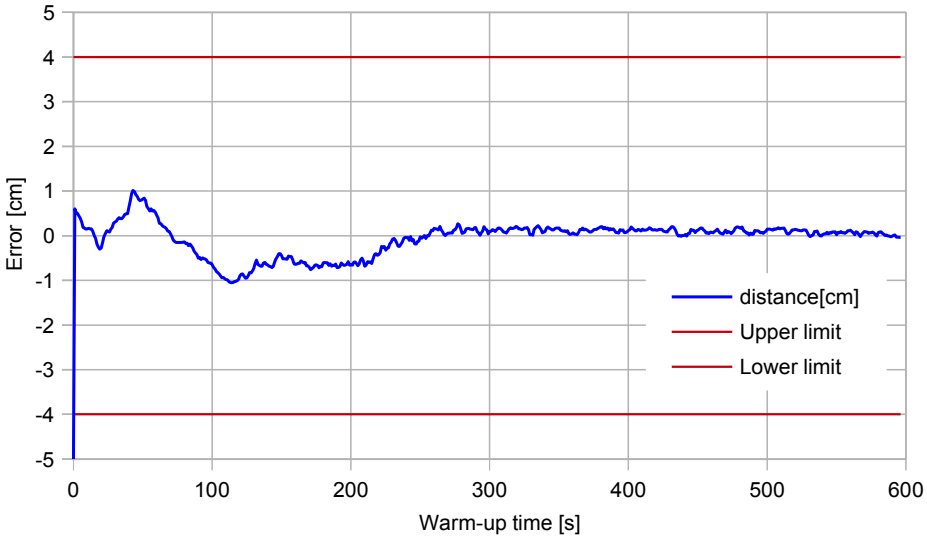

Figure 11: Typical warm-up phase of TOFcam-611

9. Ordering Information

Part Number	Part Name	Comments
P100 499	TOFcam-611	
P100 498	USB-UART Adapter	Refer to epc611 Evaluation Kit
P100 516	Cable 10 Pin F JST 1.0 mm (L=76 mm)	Refer to epc611 Evaluation Kit
P100 487	epc611 Evaluation Kit	

Table 8: Ordering Information

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