

General Description

The DME 660 is a standalone 3D-TOF Distance Measurement Camera with a resolution of 320x240 pixel (QVGA). It is a highly integrated camera system with a wide field of view (FOV). The operating range is up to 10m on white objects. The camera system is a combination of a epc660 sensor board including a lens system, an LED illumination board and a BeagleBone Black host controller board. Even for mobile devices, only a few additional components are needed to integrate this 3D camera, e.g. a housing.

The host controller operates the epc660 in all available operation modes and reads the distance values over the TCMI communication. The controller reads the imager data, applies calibration and compensation algorithms and delivers the results to an external computer via its integrated API. It is also possible to operate the DME 660 as a standalone sensor system. In this case, application software can be downloaded and run on the BeagleBone Black board also by using the full software framework like the operating system and the 3D-TOF API.

39 full frame TOF images are delivered by the epc660 camera chip in maximal configuration. By using the advanced operation modes, this can be boosted up to more than 1'000 TOF images per second! The high degree of integration lays base for straight-forward system integration with minimal part count. The extremely high sensitivity of the optical front end allows to operate with a low power illumination subsystem which reduces the power consumption of the overall system significantly.

The camera comes with a fully documented SDK based on open-source SW and HW.

Features

- 320 x 240 pixel (QVGA)
- Wide field of view H108° x V77°
- Up to 10m distance measurement range on white targets
- Low power consumption
- Robust and stable
- High speed USB or ETHERNET interface
- Linux server with 3D-TOF API

Applications

- People detection and counting
- Parcel size measurement
- Machine safety
- Object recognition
- Automatic door safety
- Humanoid robotics
- Helicopter near terrain flight assistance
- Man-Machine interface
- Gesture control
- Body size measurement
- General volumetric mapping



Figure 1: DME 660

1. Precaution and safety



Eye safety: Do not look directly into the camera under operation. Depending on the mode of operation, the camera device emits highly concentrated non-visible infrared light. It can be hazardous to the human eye. The use of these devices has to follow the safety precautions given in IEC 60825-1 and IEC62471.



The DME 660 is a bare electronic device without a housing around. Therefore, handle it with the necessary ESD precaution.



Over-voltage: Use only power supplies which corresponds to the datasheet DME 660 to avoid damage of the DME 660 or cause danger for humans.



Cable-tripping: Place the DME 660 with a tripod on a flat solid ground or fix it correctly on a solid support. Place cables carefully. Falling devices can be damaged or harm persons.



This camera comes with its own calibrated firmware. For proper operation of the camera, upload the correct firmware with the evaluation kit to the camera according the instructions given in the quick guide. Do this when you are changing the camera module.



This camera comes with high quality lens. Do not touch, twist or turn it. Otherwise loss of performance occurs.



EMC compatibility: The DME 660 is designed on module level. It is not an EMC certified device. It is users responsibility to operate it in compliance with the EMC regulations.



The DME 660 is designed on module level. It is NOT a CE, UL, CSA certified device. It is the users responsibility to operate it in compliance with the relevant regulations.



The DME 660 and its software may only be used in accordance of the datasheet DME 660



This devices may not be used in safety applications, explosive atmospheres or in radioactive environment.



Limited warranty - Loss of warranty

The DME 660 should only be installed and used by authorized people. 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. Should any of these instructions not be carefully followed, seriously injury may occur. 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 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.

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



Download the actual Datasheet epc660: www.espros.com → Downloads → Datasheets → Chips.



Download the actual Datasheet DME 660: www.espros.com → Downloads → Datasheets → Camera_and_Modules.



Download the current GUI software (client) and the current BeagleBoneBlack software (server).
Questions: Send an email with your request to your local sales office or to info@espros.com.



Update the DME 660 (BeagleBone board): Go to the folder "ESPROS_TOF-imager_Evaluation_Kit_Software_vX.X.X". Read the Readme-file and follow the instructions accordingly.

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2. The DME 660 distance measurement engine

2.1. System overview

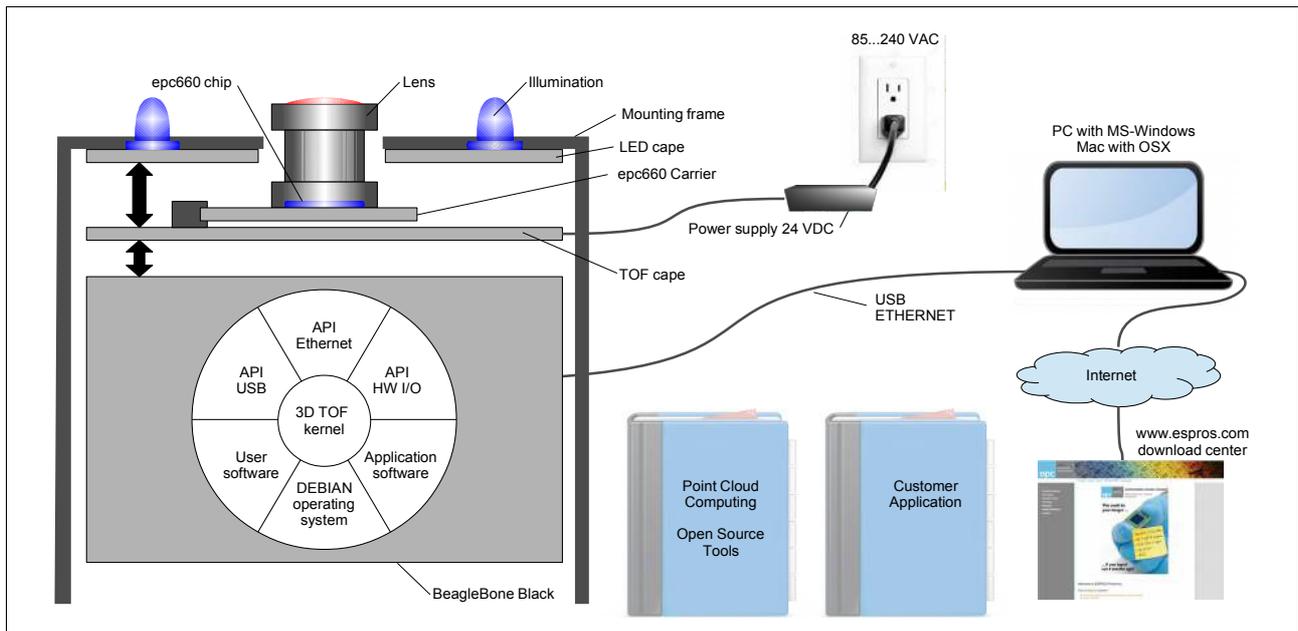


Figure 2: System overview

The DME 660 is a general purpose camera module based on the epc660 chip:

- The camera is based on a BeagleBone Black (BBB) Linux computer board.
- The TOF cape board communicates with the BBB and carries the epc660 CC Chip Carrier board with the epc660 camera chip and the lens with the lens holder. It carries also the single wire power supply for the whole camera system.
- The camera's active illumination is done by 8 power LEDs on the LED cape which is driven by the TOF cape. The LED cape's metal frame offers two camera mount 1/4" - 20UNC.
- The application software runs on the DEBIAN GNU/Linux operating system. The 3D-TOF kernel manages the camera including correction algorithms. Data for further processing e.g. cloud computing is available on APIs (application programming interface) for USB, Ethernet interfaces or hardware I/O. It opens the world for point cloud computing, using open source tools or creating own customer applications.

2.2. Scope of delivery

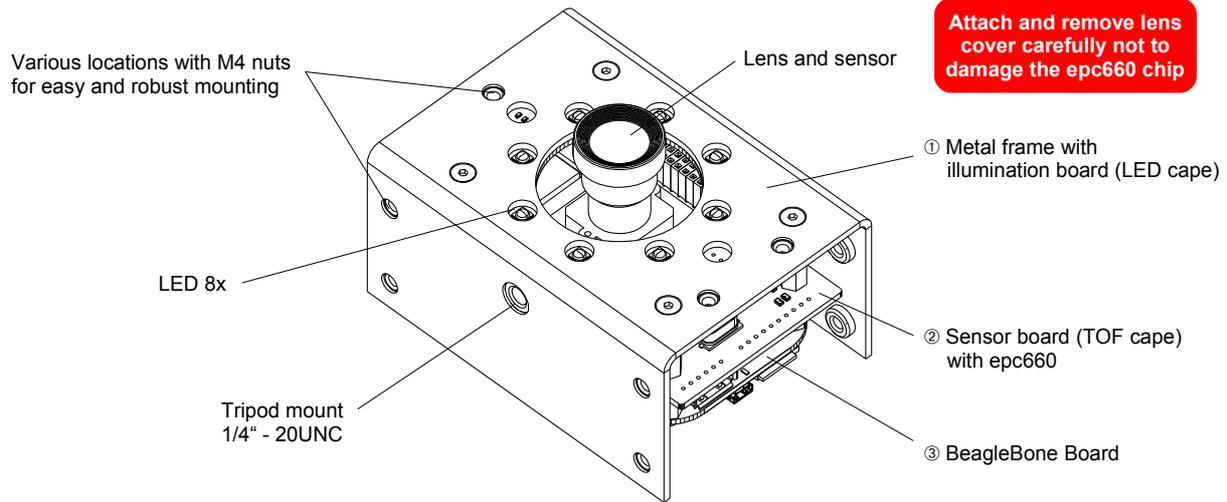


Figure 3: DME 660 overview

2.2.1. Bill of material

No.	Designation	Remarks
①	Metal frame with camera/tripod mount 1/4" - 20UNC	Use only the 1/4" - 20UNC or the M4 tread inserts for mounting the camera
	LED cape: Illumination board	on metal frame
②	TOF cape: Sensor board	on LED cape
	epc660-CSP68 chip (P/N P100 183) assembled on CC Chip Carrier (P/N P100 244)	on TOF cape
	Lens Holder, M12-Mount with 860nm Filter (P/N P100 410)	on epc660 CC chip carrier board, includes optical bandpass filter 860nm
	Lens for DME 660 (P/N P100 506): - FOV: H108°, V77° - Lens with non-linear distortion - EFL 3.7mm (center) - F1.3 - 1/2" - M12mount	on lens holder, including lens cover other lens types upon request
③	BeagleBone Black board	Host controller

2.2.2. Documentation

Designation	Remarks
Datasheet DME 660	available at www.espros.com → Downloads
Datasheet epc660	available at www.espros.com → Downloads
Application and configuration software	use the epc660 Evaluation Kit for accessing licensed corresponding tools and software development kit (SDK).

Table 1: Bill of material of the delivery

3. Ordering information

Part Number	Part Name	Remark	RoHS compliance
P100 518	DME 660-108°/10m/bp860nm	completely assembled, tested and calibrated	Yes

Accessories:

Part Number	Part Name	Remark	RoHS compliance
P100 244	epc660 CC Chip Carrier	epc660 on CC chip carrier without optical filter	Yes
P100 506	Lens FOV 149°, 1/2", M12	Lens for DME 660: - FOV: H50°, V19° - Lens with non-linear distortion - EFL 3.7mm (center) - F1.3 - 1/2" - M12mount	
P100 410	Lens Holder, M12-Mount with 860nm Filter	includes optical bandpass filter 860nm	
	Optical bandpass filter	included in lens holder	

Table 2: Ordering Information

3.1. Notes for various DME 660 versions:

- The supplied DME version can be identified by reading the extension -XXX of the part name on the packaging labels or delivery papers: DME 660-XXX.
- This Datasheet is valid for DME 660 version -004 or later.
- Use the appropriate older version of the datasheet for former DME versions.

Support and technical contact: info@espros.com

4. Technical data

4.1. Recommended operating conditions

($T_A = 25^\circ\text{C}$, $V_{\text{SUPPLY}} = 24\text{V}$, object reflectivity 90%, unless otherwise stated)

Parameter	Description	Min.	Typ.	Max.	Units	Comments
V_{SUPPLY}	Supply voltage	21.6	24	26.4	VDC	
V_{PP}	Ripple on the supply voltage V_{SUPPLY}			0.25	V_{PP}	Peak value must not below min. and not above max. supply voltage
I_{SUPPLY}	Supply current	Idle	0.10		A	after power up
		Grayscale imaging	0.10			100 fps
		3D-TOF imaging	0.25			25 fps, $t_{\text{INT}} = 1 \text{ ms}$
	Image resolution	320 x 240			Pixel	
FOV	Field of view	H108 x V77			°	with lens P/N 100 506
λ	Operating wavelength	850			nm	
$f_{\text{LED_INT}}$	Internal modulation frequency	0.675, 1.25, 2.5, 5, 10, 20			MHz	Software controllable
$f_{\text{LED_EXT}}$	External modulation input	1		80	MHz	
d	Operating range	0.00		10.0	m	Measured with an object that has a size at least the size of the pixel (d_{PIXEL}). It is depending on the integration time t_{INT} and the object reflectivity.
Out	Distance output word	12			Bit	
Res	Resolution		0.5		cm/LSB	at 10 MHz modulation frequency
	Measurement output	0		2'000	LSB	at 10 MHz modulation frequency, refers to 0.0 ... 10.0 m, measurement results depending on object reflectivity
d_{CAL}	Calibration distance		0.8		m	Output @ 0.8m = 900 LSB
V_{APM}	Amplitude	50		2'000	LSB	useful amplitude range
Φ_L	Ambient light suppression	0		130'000	Lux	indirect, depending on integration time and object distance, ABS on
	Data interface	USB 2.0 full speed or Ethernet				
T_A	Ambient temperature range (operation)	0		60	°C	

Table 3: Operating conditions

4.2. Optical power data

Parameter	Description	Min.	Typ.	Max.	Units	Comments
$E_{\text{e_PEAK}}$	Peak illumination irradiance			372	W/m^2	in 200mm distance to the front surface of the DME 660
$E_{\text{e_AVG}}$	Average illumination irradiance		108		W/m^2	in 200mm distance to the front surface of the DME 660

Table 4: Optical power data

The analysis of the photo-biological hazards show that the DME 660 emits radiation levels below the safety limits described in EN 62471. The calculated exposure level is below the limit for any exposure time at a distance of 200 mm or more. Therefore, the DME 660 can be assumed to be safe to the eye and skin in terms of the standard and would belong to the open group (RG0).

Refer also to the report 'DME_660_Photobiological_Safety_Analysis.pdf' which can be downloaded from the ESPROS website.

4.3. Distance measurement timing

Figure 4 shows the general timing diagram. For a full range measurement cycle, four differential correlation samples (DCS_n in Figure 4) have to be acquired. After each DCS acquisition, the image containing the DCS per pixel, has to be read out from the epc660 imager (Data readout in Figure 4). Once four DCS are acquired, the distance is calculated on the BeagleBone Black board and an image containing a point cloud is ready to be through the API.

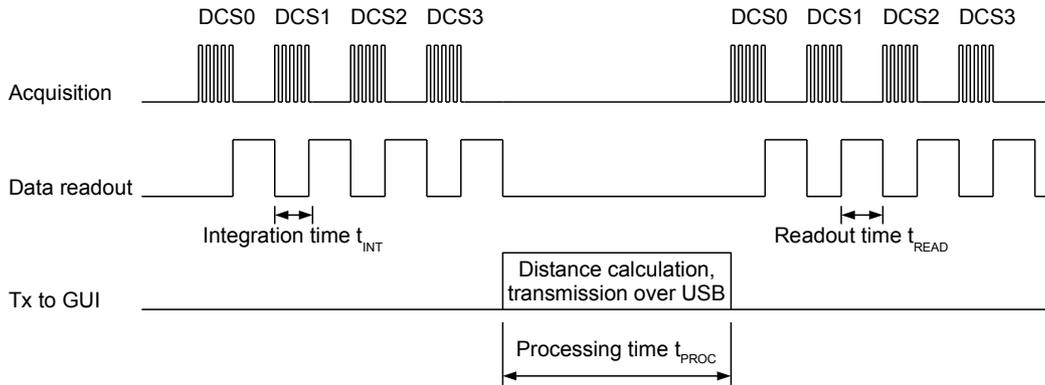


Figure 4: DME 660 measurement timing: 3D TOF with 4 DCS frames (standard API)

Parameter	Description	Min.	Typ.	Max.	Units	Comments
t_{INT}	Integration time selectable	0.1		4,000	μ s	
t_{READ}	Full frame image readout time (1 DCS)		6.3		ms	with 24MHz TCMI data rate
t_{CYCLE}	Total distance measurement cycle time (all compensations and filters disabled)		144		ms	$t_{INT} = 1.0$ ms, refer to Figure 4
T_{PWR_UP}	Power up time		20		s	Refer to chapter 5.2

Table 5: Typical distance measurement timing parameters

There are various options to increase the frame rate:

Parameter	Description	Acquisition time reduction	Comments
No π -delay matching	DCS0 and DCS1 acquisition only	reduces the frame cycle by $2 * t_{INT}$ plus $2 * t_{READ}$	In-pixel non-linearities and asymmetries reduce the distance measurement quality
Dual MGX	Acquires the odd DCS' in the odd rows and simultaneously the even DCS' in the even row	reduces the frame cycle by $2 * t_{INT}$ plus $2 * t_{READ}$	Pixel tolerances in the even and odd rows reduce the distance measurement quality
No π -delay matching and Dual MGX	Acquires DCS0 in the even rows and simultaneously DCS1 in the odd row	reduces the frame cycle by $4 * t_{INT}$ plus $4 * t_{READ}$	see above
ROI	A reduced ROI reduces t_{READ} and the distance calculation time because less data need to be processed	depending on ROI settings	reduced FOV
Row reduction	It is possible to skip rows at readout	depending on Row Reduction settings: - Full = full frame - Half = every second row is skipped - Quarter: 3 out of 4 rows are skipped - One-Eight: 7 out of 8 rows are skipped	

Table 6: Frame rate tuning options

Additional options are to modify the calculation software in the API and utilizing the 3D graphics accelerator and the NEON floating-point accelerator of the BeagleBone Black processor.

4.4. Absolute maximum ratings

Parameter	Conditions
ESD rating	Not classified. Handle it with the necessary ESD precaution.
Storage temperature range (T _s)	-40°C to +85°C
Relative humidity	15 ... 95%, non-condensing

Table 7: Absolute maximum ratings

5. Interfaces

5.1. Connectors

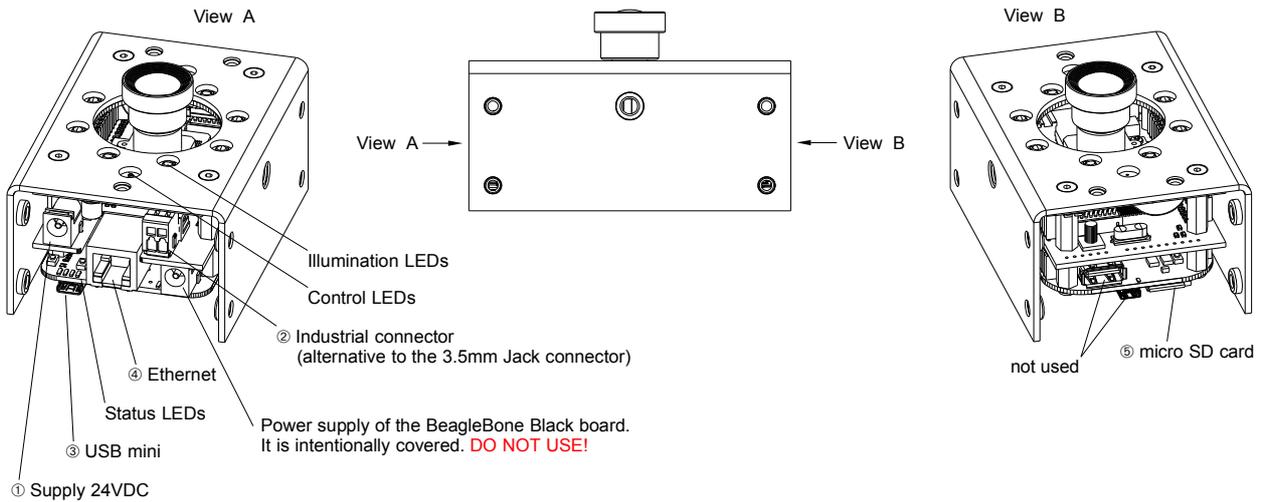


Figure 5: Connectors, status and control LEDs

No.	Connector	Plug	Remarks
①	Supply 24VDC / 2.5A	Power jack 5.0/2.1mm	for supply from power adapter 24VDC / 2.5A
②	Industrial supply	Power jack WAGO 3.5mm	for supply by industrial connection 24VDC / 2.5A
③	USB micro	Micro USB-B	 NEVER CONNECT THE USB CABLE AS LONG POWER IS NOT TURNED ON COMPUTER AND/OR THE CAMERA CAN BE DAMAGED! 
④	ETHERNET	RJ45	
⑤	Micro SD card		

Table 8: Connector list



Figure 6: View to the connector side (USB and ETHERNET not connected)

5.2. Indicators and reset button

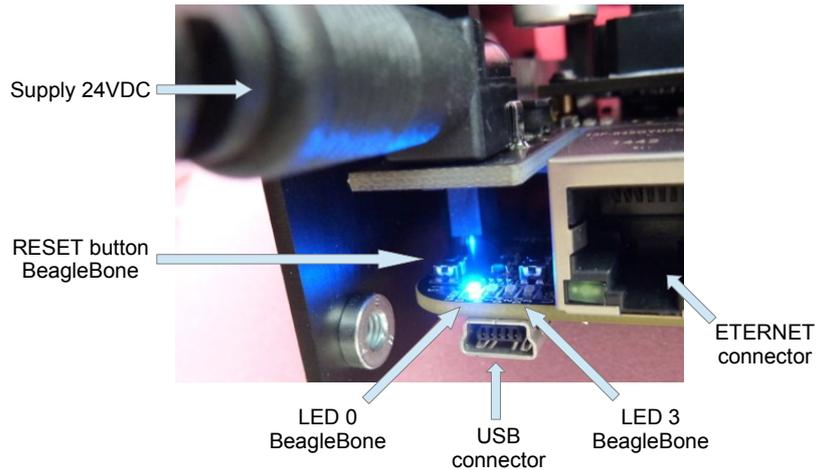


Figure 7: Status LEDs and RESET button

5.2.1. Status LEDs

Status	LED 0	LED 1	LED 2	LED 3	Remarks
Start-up DME 660 or BeagleBone: The blue status LEDs start flashing	☒	☒	☒	☒	After power up or RESET. Startup procedure of the board operating system. For details refer to the BeagleBone manual
After around 20s: Boot epc660 chip					
Trying to boot the epc660 chip	☒	☒	☒	■	Wait until LED 0 only (most left) is flashing only. LEDs 1 to 3 shall be off.
READY for handling requests	☒	□	□	□	Server successfully started on DME 660. Start communicating with the BeagleBone Black server by using either Ethernet or USB.
Regular operation:					
BUSY: Handles request of single command or video	☒	□	□	■	
READY again	☒	□	□	□	
Error message:					
Caught signal (Error), application closed	☒	■	■	■	Error detected by API. Reset the BeagleBone.

Table 9: Blue status LEDs on BeagleBone, refer to Figure 7

Notes:

- LED off
- ☒ LED flashing
- LED on

5.2.2. Monitoring LEDs

Red control LEDs on LED Cape, visible from the frontside; refer to Figure 5:

- D12: On if the LED cape is powered e.g. 3D TOF modes. **Safety advise: Be careful, IR LEDs are active during exposure.**
Off during modes having not an active illumination e.g. greyscale mode without active illumination.
- D13: On during integration period (exposure) independent of selected mode.

5.2.3. Reset button on BeagleBone

Resets the DME 660. Instead of the this button, the terminal command, as described in the "Readme" of the GUI source, can be used.

5.2.4. Reset button on TOF cape

Do not use. Reset the epc660 chip only. Lost of the synchronization with the BeagleBone board.

6. Mechanical properties

6.1. Part list

No.	Part name	Qty.
1	BeagleBone Black Rev. C	1
2	Illumination board: LED cape	1
3	Distance sleeve M3/18mm, hole/hole, PA	4
4	Distance sleeve M3/12mm, bolt/hole, PA	4
5	Screw - cylinder head, cross recess, M3x6	4
6	Metal frame	1
7	Nut self-clinching	2
8	Sunk screw, M3x8	4
9	Lens FOV 149°, 1/2", M12	1
10	Connection Cable	1
11	Lens Holder, M12-Mount with 860nm Filter	1
12	Sensor board: TOF Cape	1
13	Screw - cross recessed, M1.6x3	2
14	Mounting pillar	2
15	Screw - cross recessed, M2x5	2
16	Female header Dip, 2.54, 180°	1
17	epc660 CC Chip Carrier	1
18	5.0/2.1mm DC Power Jack 24VDC / 2.5A	1
19	Industrial supply female plug	1
20	Industrial supply male connector	1
21	Micro SDHC card 16GB, programmed	1

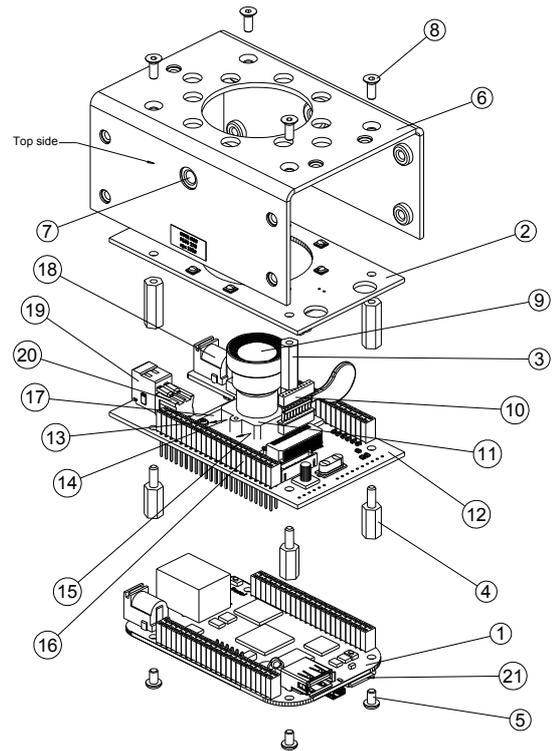


Figure 8: Part list and exploded view

6.2. Mechanical and optical properties

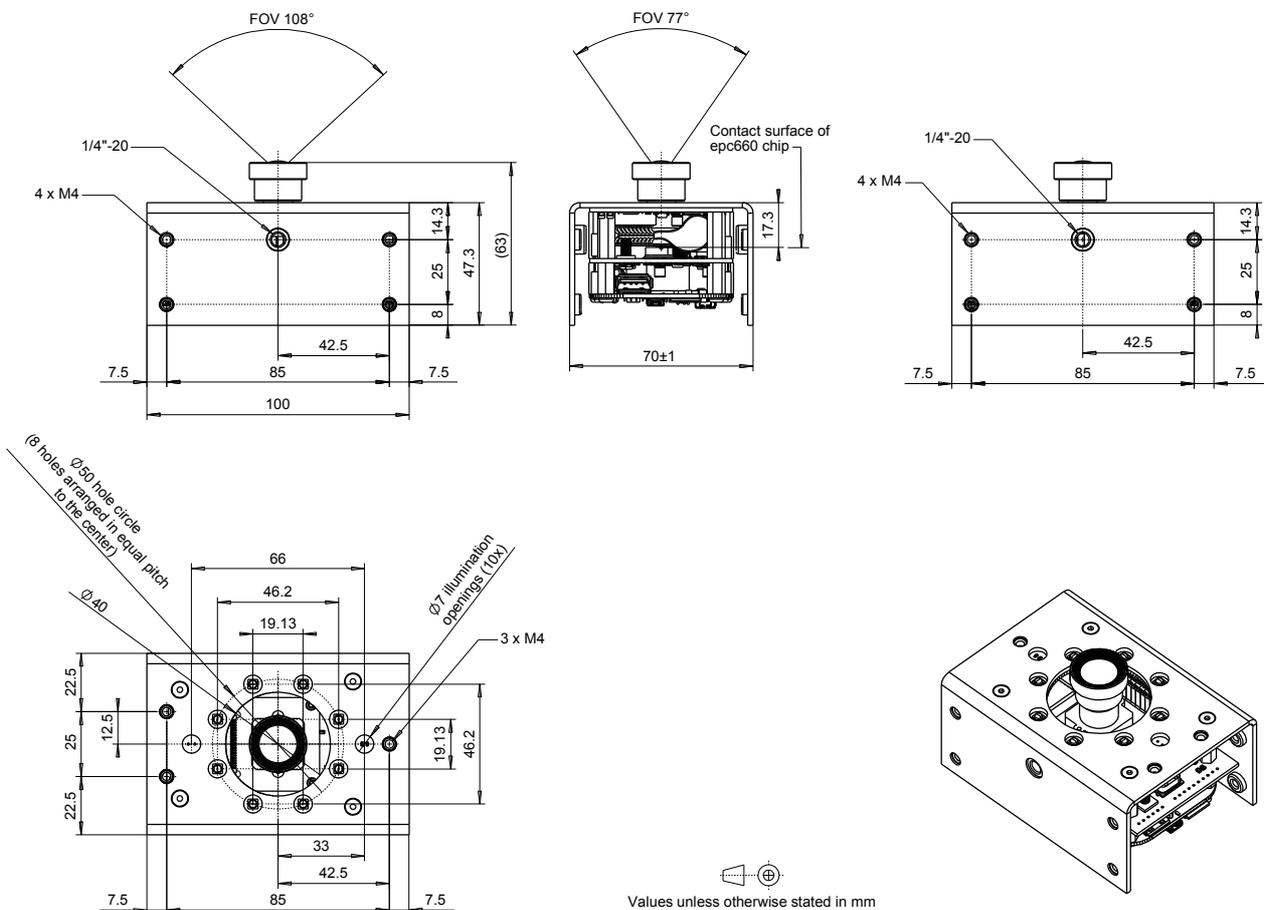


Figure 9: Reference dimensions of the optical axis and illumination

7.2. PCB layout

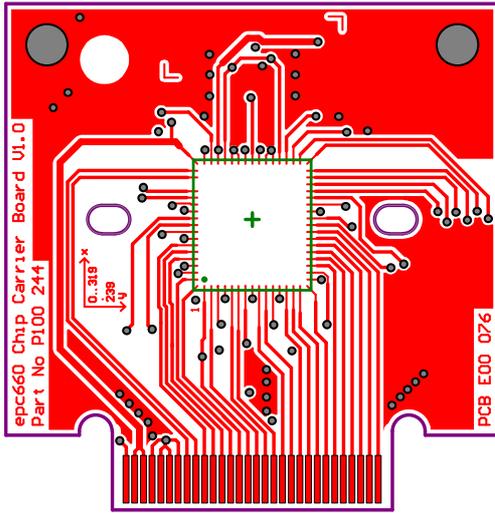


Figure 12: PCB layout top

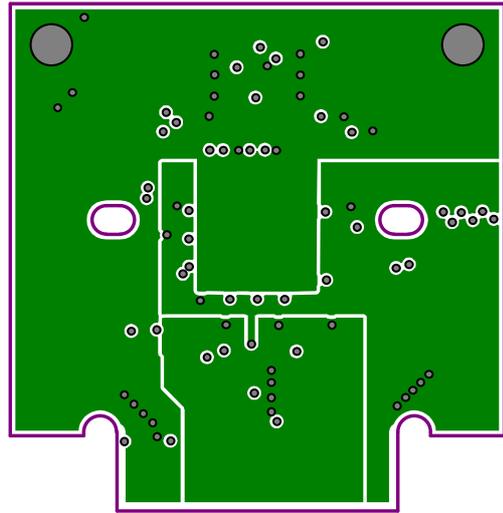


Figure 13: PCB layout top-middle

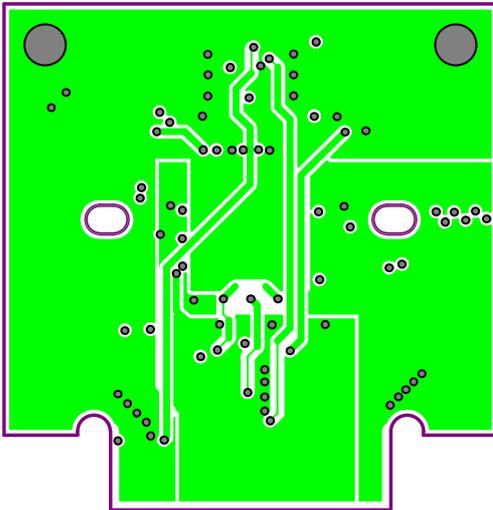


Figure 14: PCB layout bottom-middle

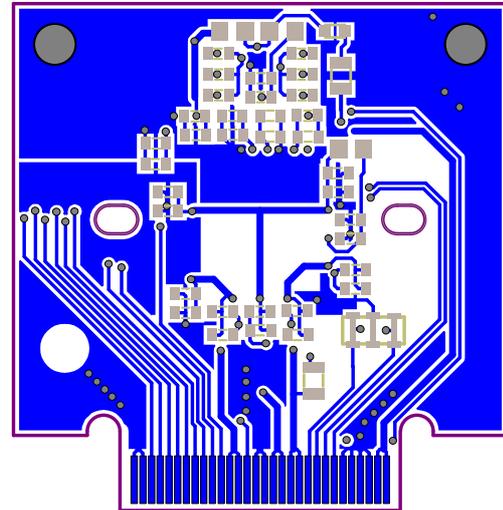


Figure 15: PCB layout bottom

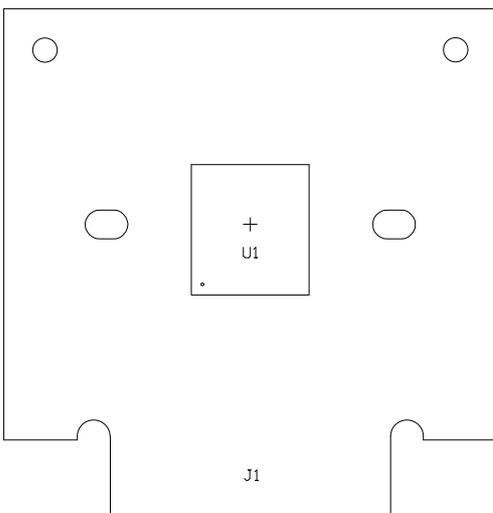


Figure 16: PCB assembly top

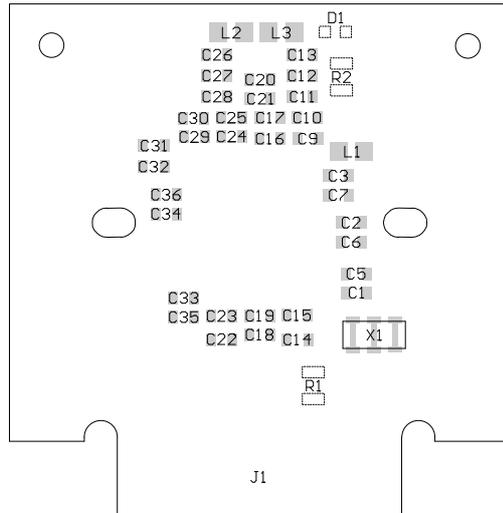


Figure 17: PCB assembly bottom

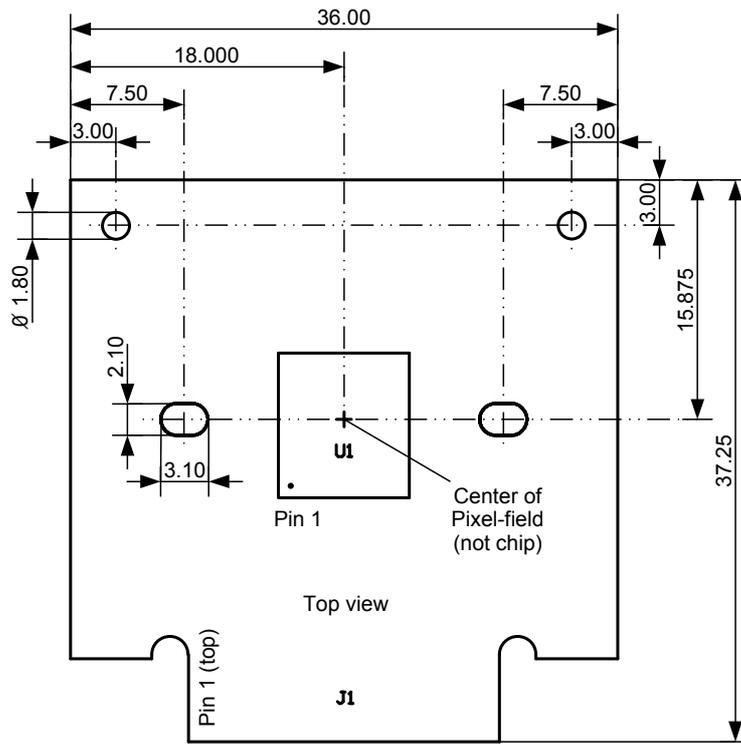


Figure 18: Mechanical dimensions PCB

7.3. Pin table

60	59	TMS
VSS	58	TCK
TESTAI_VFSDG	56	TDI
VFSAB	54	TDO
TESTAOHB	52	DATA11
TESTAOHA	50	DATA10
TESTAIHB	48	DATA9
TESTAIHA	46	DATA8
VSEAL	44	DATA7
SCL	42	DATA6
SDA	40	DATA5
	38	DATA4
VBS	36	DATA3
VDDPXH	34	DATA2
	32	DATA1
VSSIO	30	DATA0_FS
VDD	28	XSYNC SAT
	26	MODCLK
VDDIO	24	DCLK
	22	HSYNC
XTALOUT	20	VSYNC
XTALIN	18	TESTAIO2
SHUTTER	16	TESTAIO1
RESET	14	
	12	
	10	
	8	VDDA
VSSA	6	
	4	LED
VSSLED	2	LEDFB

Figure 19: Pin table

Important note:

Use for connector J1 Pin 1 marking of schematic, PCB and assembly drawing. Pin 1 marking on connector housing J1 can deviate.

8. TOF Cape

8.1. Schematics

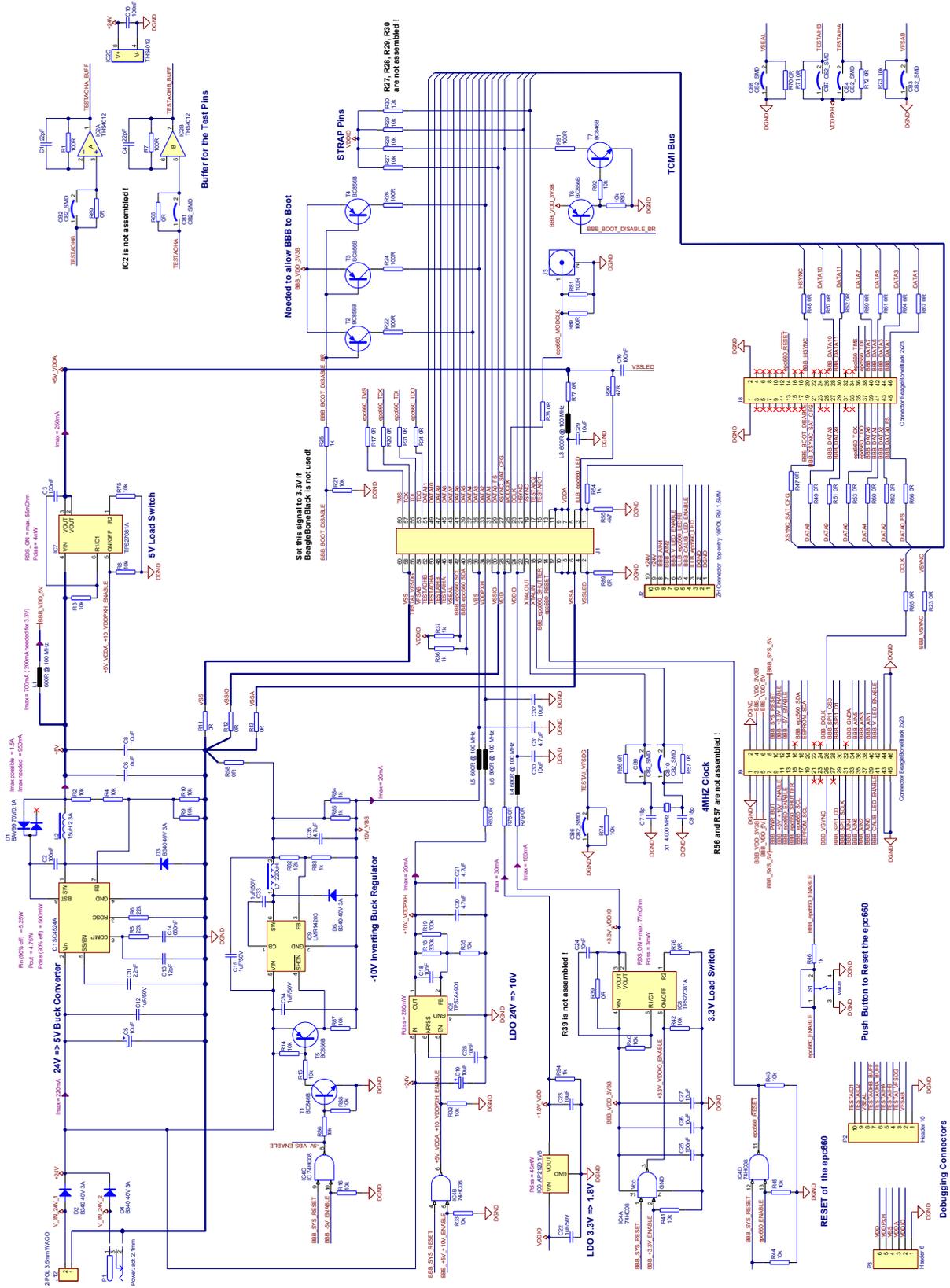


Figure 20: Schematic

Important note:
Use for connector J1 Pin 1 marking of schematic, PCB and assembly drawing. Pin 1 marking on connector housing J1 can deviate.

8.2. PCB assembly

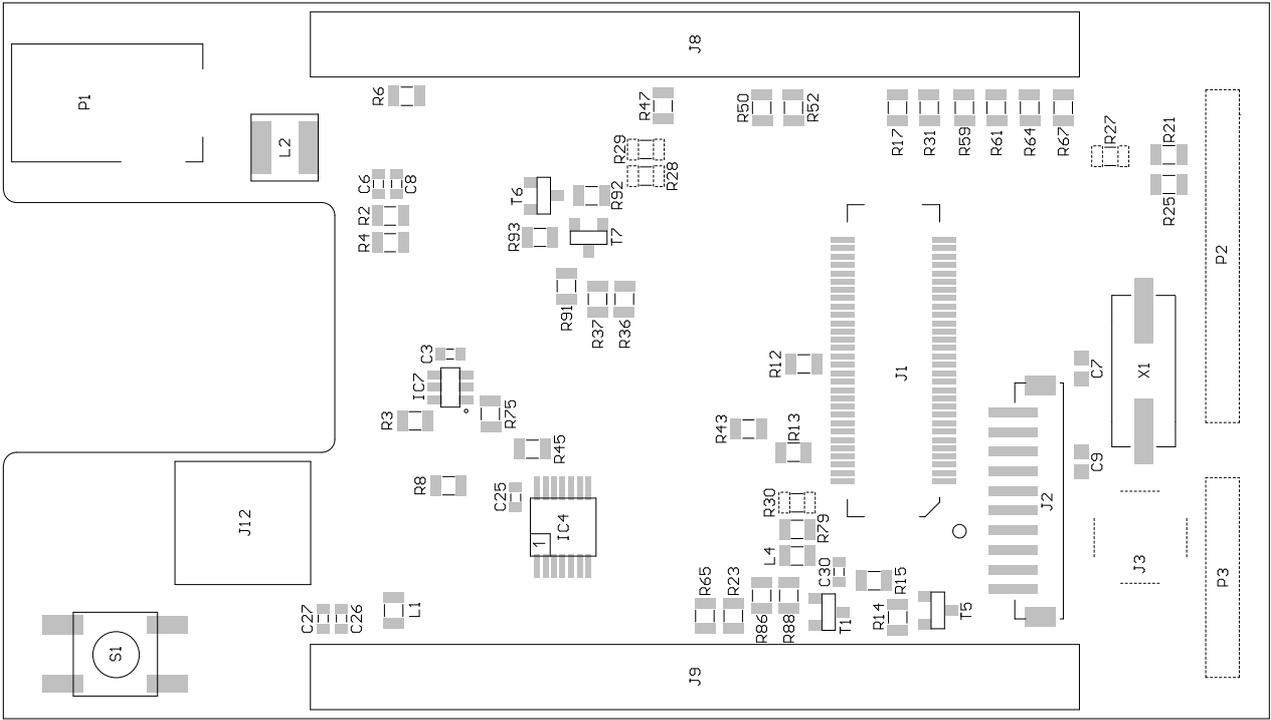


Figure 21: PCB assembly top

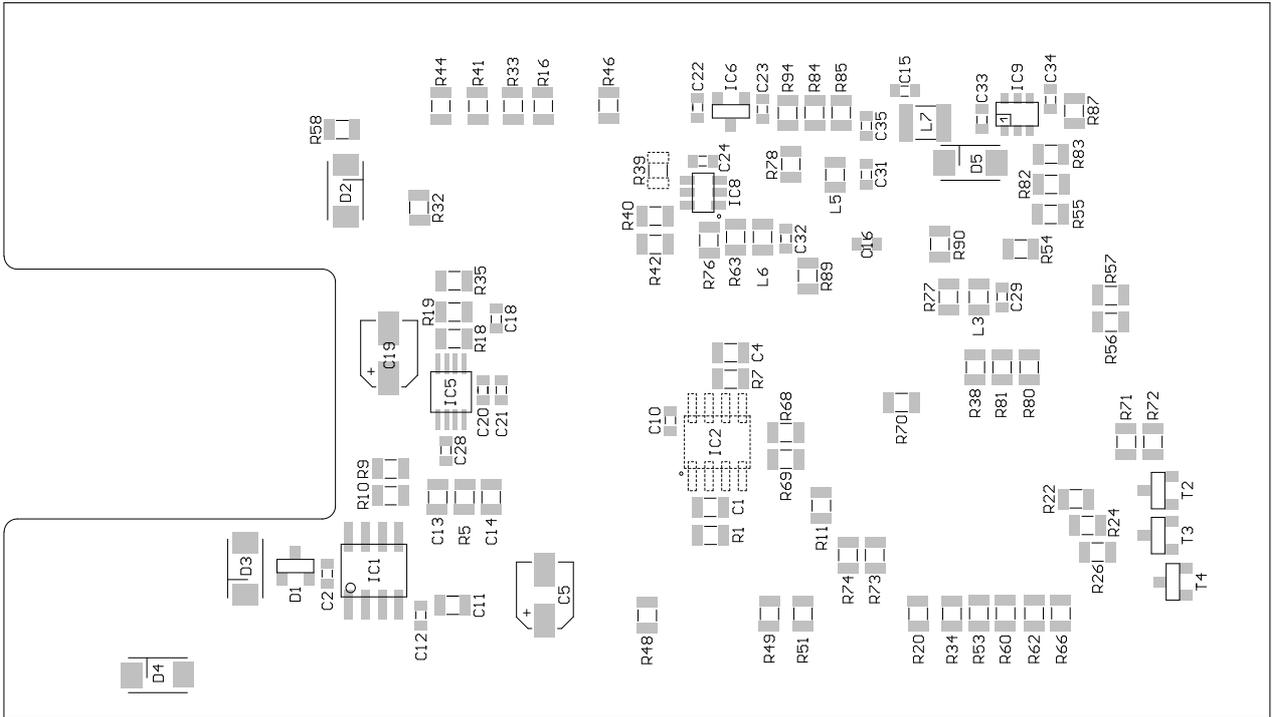


Figure 22: PCB assembly bottom

8.3. Pin table J8 & J9

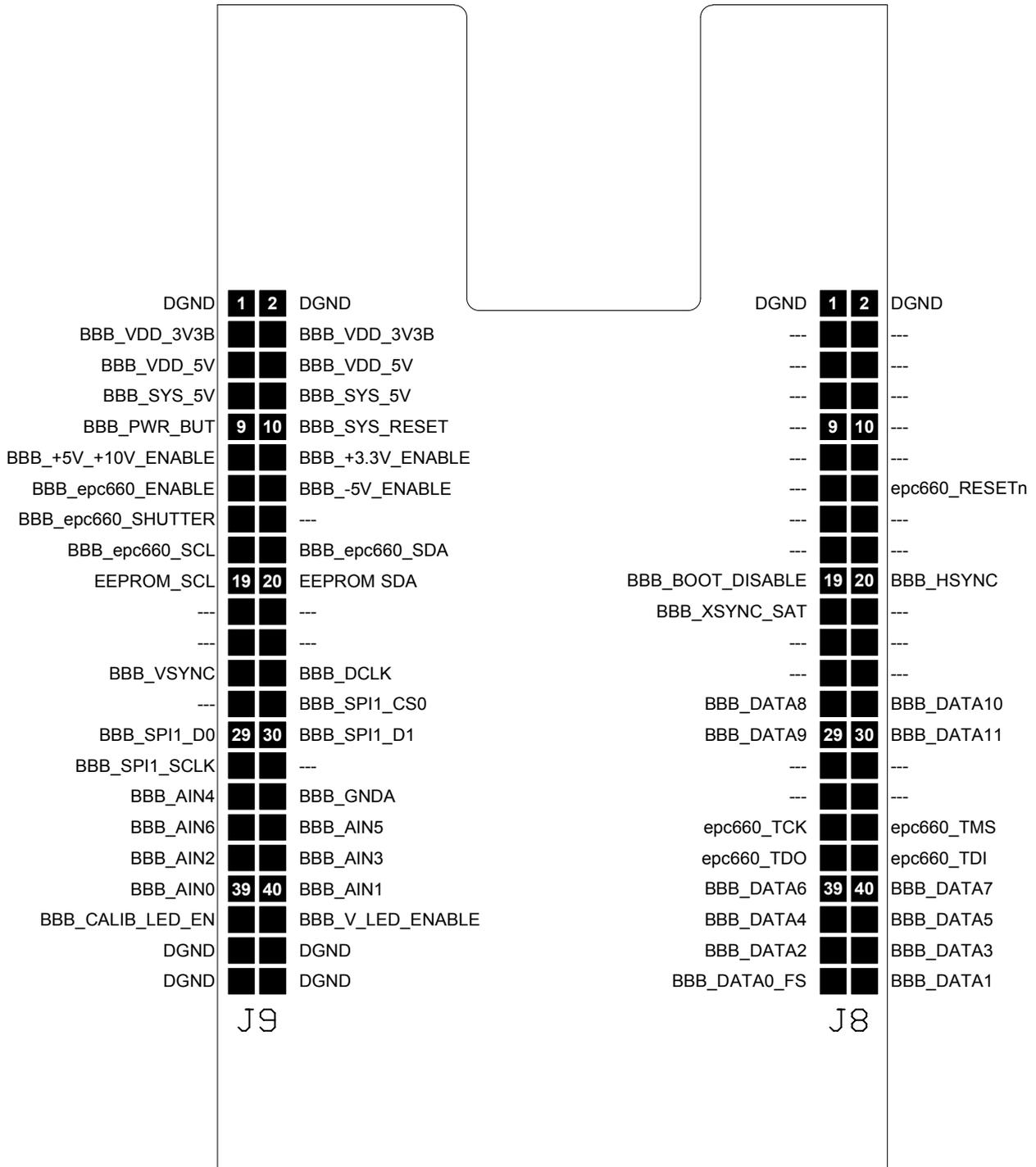


Figure 23: Pin table J8 & J9

9. LED Cape

9.1. Schematics

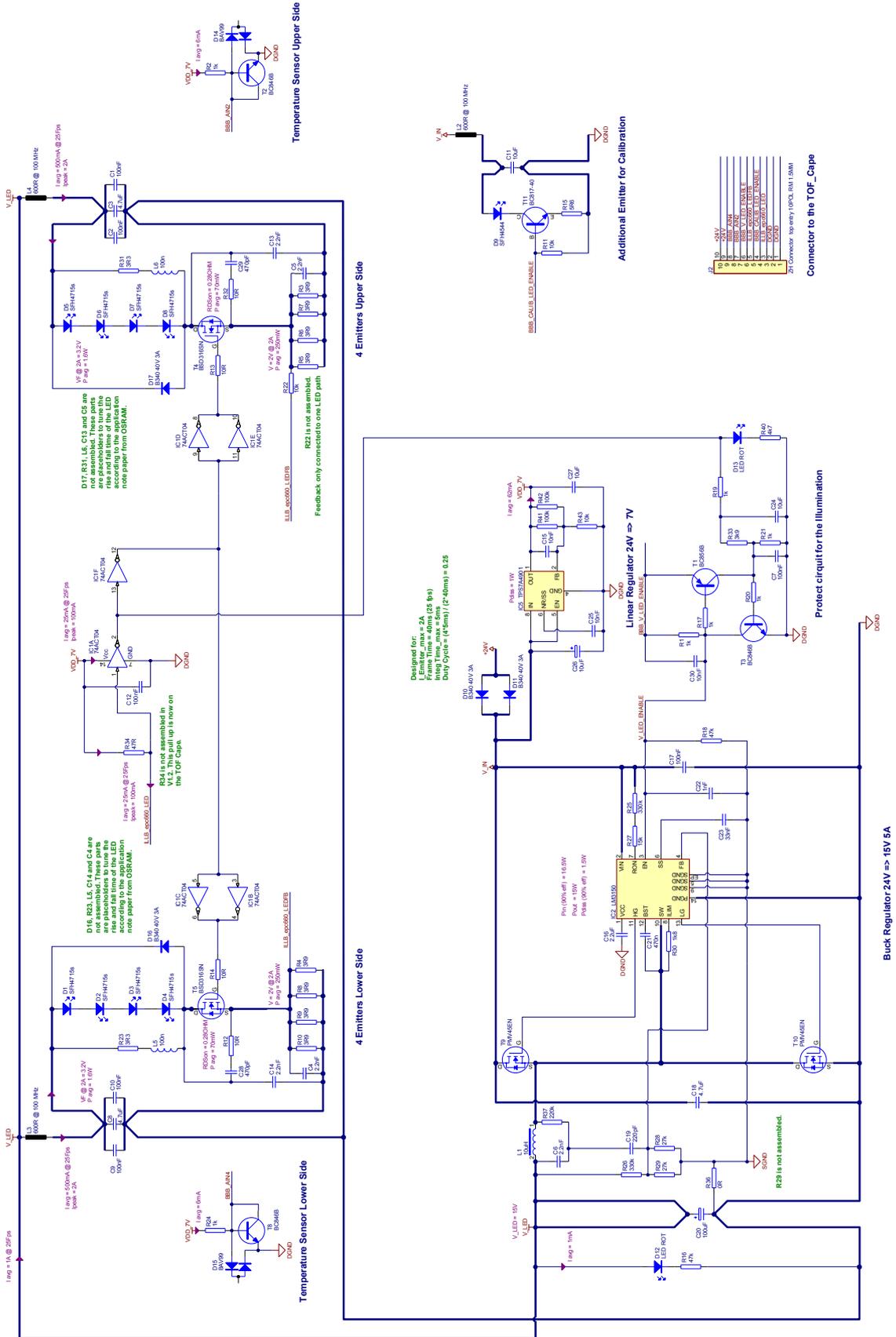


Figure 24: Schematics

9.2. PCB assembly

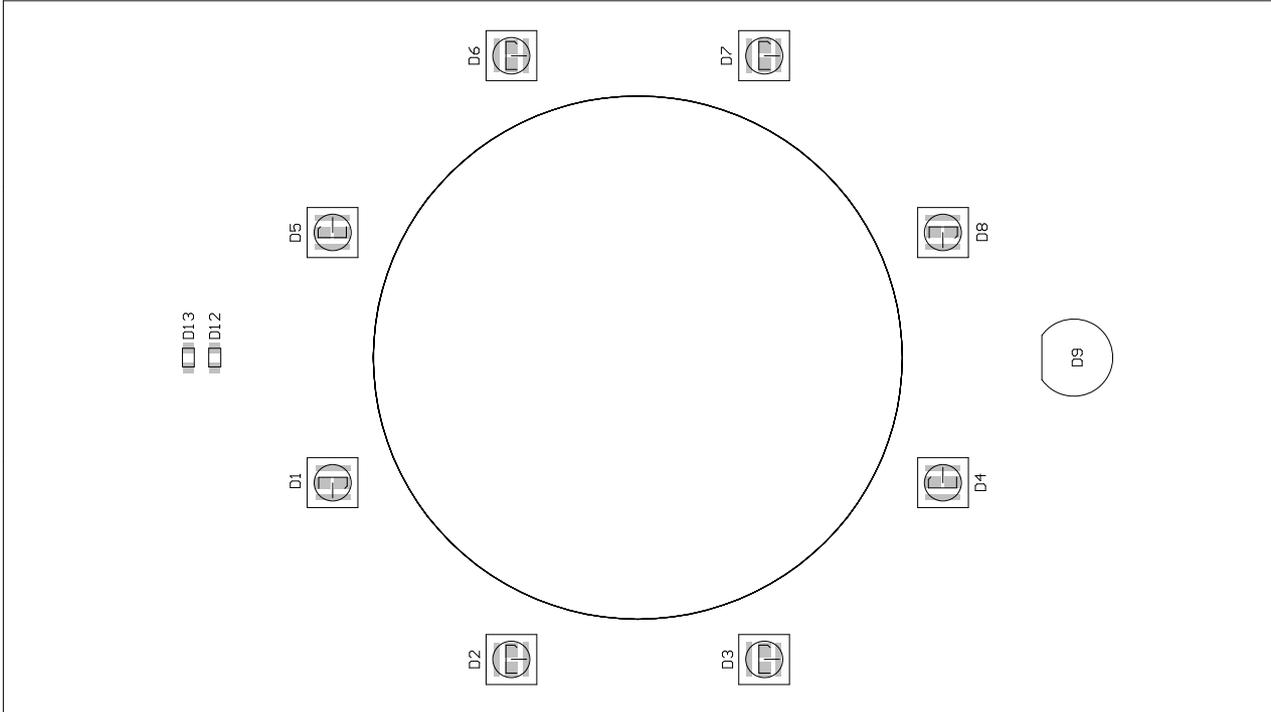


Figure 25: PCB assembly top

- D1..D8: Illumination LEDs
- D12, D13: Monitoring LEDs (red), refer to chapter 5.2.2, Monitoring LEDs

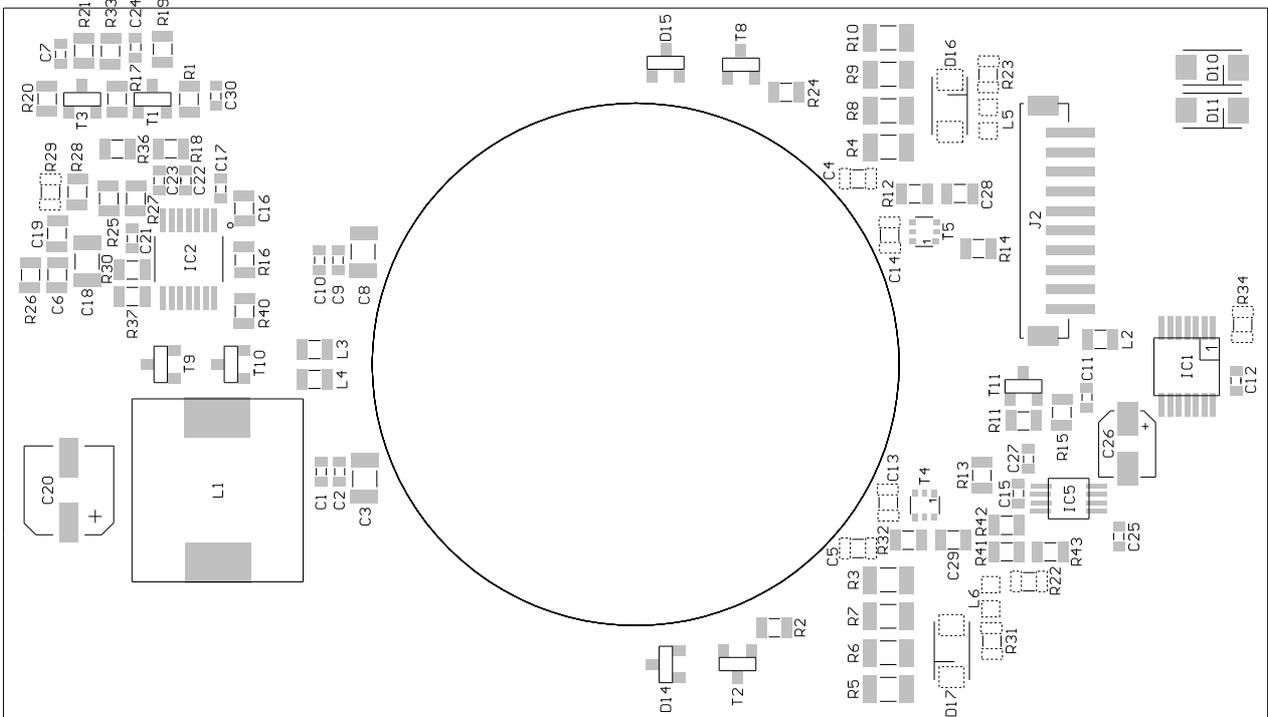


Figure 26: PCB assembly bottom

10. BeagleBone Black board

10.1. System Overview

- Processor: AM335x 1GHz ARM® Cortex-A8
- 512MB DDR3 RAM, 4GB 8-bit eMMC on-board flash storage
- 3D graphics accelerator, NEON floating-point accelerator, 2x PRU 32-bit micro controllers
- USB client for power & communications, USB host, Ethernet
- Software Compatibility: Debian, Android, Ubuntu, much more
- Open-source tools:
 - Point Cloud Library (PCL); www.pointcloud.org
 - OpenCV; www.opencv.org

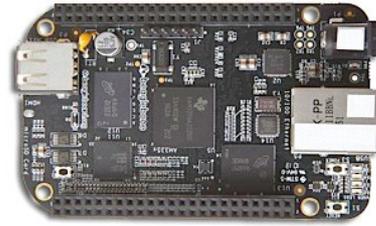


Figure 27: The BeagleBone Black board

10.2. Modification on BeagleBone board

The BeagleBone board is modified the following way for working properly in combination with the DME TOF cape.

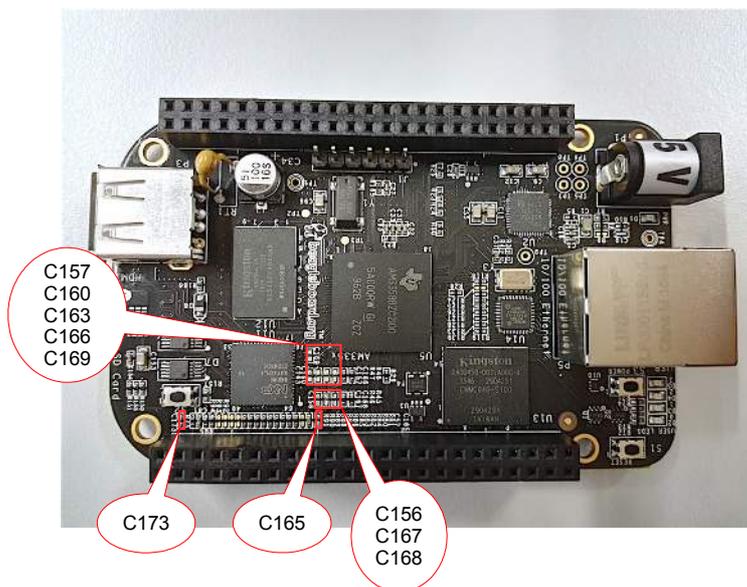


Figure 28: Marked capacitors are removed/disassembled from the Beagle Bone board top side

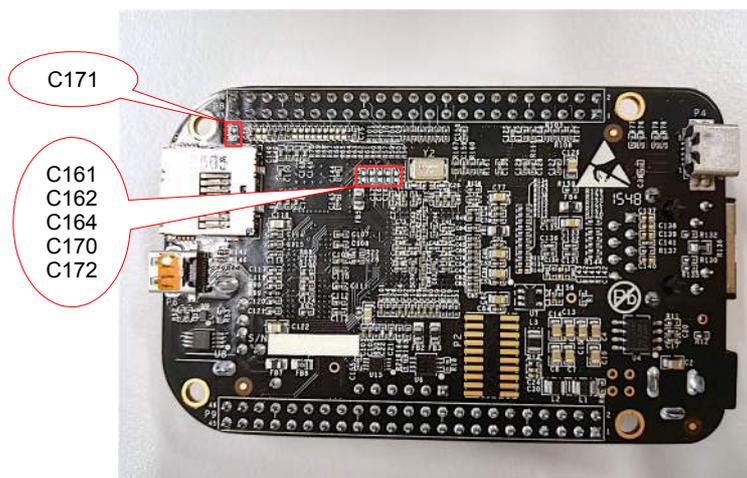


Figure 29: Marked capacitors are removed/disassembled from the Beagle Bone board bottom side

10.3. Documentation

Technical description of the BeagleBone Black board can be downloaded from www.beagleboard.org.

- BeagleBone Hardware Specs and Material, BeagleBone Black wiki
- BeagleBone Black System Reference Manual, BeagleBoard.org, 2014
- BeagleBone Black, Document No. 450-5500-001 (Schematics), BeagleBoard.org, 2014

11. Installation and setup

11.1. Mechanical fixation

The DME 660 has various mounting options provided by the metal frame:

- On each long side
 - one tripod mount 1/4" - 20UNC, refer to Figure 3
 - four nut M4
- On top side: three nut M4

Use the options only to attach the DME 660 to a housing, a tripod or something else. Never use the threaded pillars or attach something directly to one of the PCB. You may damage the PCB.

11.2. Setup of the DME 660

The DME 660 can be operated by using the GUI software provided with the epc660 Evaluation kit. The setup described by the QUICK START GUIDE.

11.3. Software tools

ESPROS Photonics supports the user's development and application by having available various support tools e.g. software development kit (SDK), updates and emulation program downloads for the epc660 chip, application interfaces (API), etc. They are available by contacting ESPROS by email at info@espros.com. The same way, the user can update the DME 660 (BeagleBone board) by using this service.

11.4. Exchange of epc660 CC Chip Carrier



Make sure, all assembly procedures are executed on an ESD-compatible workstation.

- Power off the DME 660 and remove cables
- Remove the BeagleBone board
- Remove the TOF cape
- Remove the locking screws from the epc660 CC Chip Carrier
-  Softly remove the epc660 CC Chip Carrier. The epc660 chip can be destroyed when excessive force is applied.
- Remove lens holder
- Attach the lens holder to the new epc660 CC Chip Carrier
-  Softly insert the new epc660 CC Chip Carrier
- Insert the locking screws for the epc660 CC Chip Carrier
- Install the TOF cape
- Install the BeagleBone board
-  First power on the DME 660
- Connect the USB cable
- Download and install the latest server software according the Readme.txt
- Start the epc660 Evaluation Kit GUI and run a black & white video (start)
- Unlock the fixation of the lens
- Adjust lens focus
- Lock the fixation of the lens
- Calibrate the DME 660 with this new chip carrier

12. epc660 Evaluation Kit

There is an evaluation kit available which supports the development of own applications on the DME 660 in terms of the evaluation of the optical performance parameters.

12.1. Scope of delivery



Figure 30: epc660 Evaluation Kit overview

No	Pieces	Designation	Remarks
①	1	Toolbox	
②	1	DME 660-108°/10m	P/N P100 518; with quick release fastener of the tripod
③	1	Power Supply 24V/2.5A	
④	1	Power cord 2 pole EU version and US adapter	Power plug EU Europlug (CEE7/16, 2 pole) Power plug US Type A (NEMA 1-15, 2 pole)
⑤	1	Cable - USB 2.0, A plug - mini-B plug	Length 2m
⑥	1	Plastic bag with Industrial Supply Connector and the toolbox key	The connector can also be inserted in the DME 660
⑦	1	Camera Tripod	
⑧	1	Toolbox belt	
⑨	1	epc660 Evalkit Quick Start Guide	also available at www.espros.com/Downloads
		Datasheet DME 660	available at www.espros.com/Downloads
		Datasheet epc660	available at www.espros.com/Downloads
		Application and configuration software, SDK	Use the epc660 Evaluation Kit for accessing licensed corresponding tools and software development kit (SDK).

Table 10: Bill of material of the delivery

12.2. Ordering information

Part Number	Part Name	Remarks
P100 280	epc660 Evaluation Kit EU & US	Power plug EU Europlug (CEE7/16, 2 pole) & US adapter

Table 11: Ordering Information epc660 Evaluation Kit



Figure 31: DME 660 on tripod



Figure 32: epc660 Evaluation Kit



Figure 33: DME 660 tripod mounting



Figure 34: DME 660 with quick release fastener of the tripod



Figure 35: GUI - b&w picture

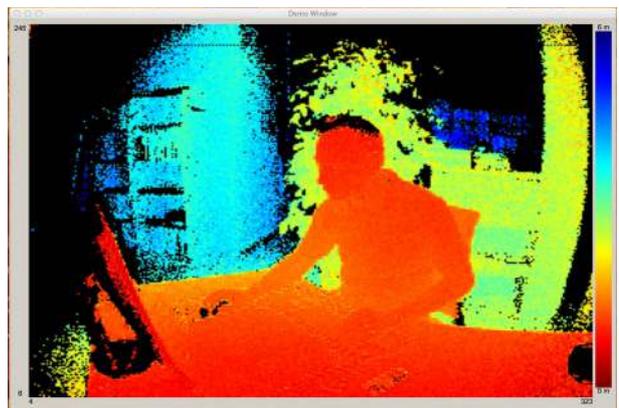


Figure 36: GUI - 3D TOF picture

13. Maintenance and disposal

13.1. Maintenance

The components of the device do not need regular maintenance. A functional check is recommended each time the device is taken into operation:

- Check the mounting position and the detection area of the sensor with respect to the operational conditions. Also check that there is no hazardous situation.
- From time to time, clean the lens with a soft towel and with a little soapy water to remove dust or dirt.

13.2. Disposal

Disposal should be done using the most up-to-date recycling technologies for electronic components according to the local regulations and laws. The design and manufacture of the kit's components are done in compliance with the RoHS legal regulations. Traces of dangerous materials may be found in the electronic components, but not in harmful quantities.

14. Addendum

14.1. Related documents

- Datasheet epc660, ESPROS Photonics Corp.
- BeagleBone Hardware Specs and Material, BeagleBone Black wiki
- BeagleBone Black System Reference Manual, BeagleBoard.org
- BeagleBone Black, Document No. 450-5500-001 (Schematics), BeagleBoard.org

14.2. Links

www.espros.com

www.beagleboard.org

www.pointcloud.org - Point Cloud Library (PCL)

www.pdal.io - Point Data Abstraction Library (PDAL)

www.opencv.org - OpenCV (OpenSource Computer Vision)

14.3. Licenses

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- **Qwt-6.1**: <http://qwt.sourceforge.net/qwtlicense.html>
Copyright (C) 1997 Josef Wilgen & Copyright (C) 2002 Uwe Rathmann under **Qwt License, Version 1.0**
- **QwtPlot3D**: <http://qwtplot3d.sourceforge.net/web/navigation/license.txt>
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