Target Formation Emulator

User Guide

Icon

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**Electrical and Computer Engineering**

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# System Description

The device will be designated as a Target Formation Emulator (TFE). The ASML project scope describes the replication of an event where extreme ultraviolet (EUV) light is generated inside a controlled laboratory environment at the ASML San Diego research center. The event of EUV light creation we are replicating refers to the process of laser-induced vaporization of tin droplets, employed in photolithography. The application of this device will enable the image processing engineers at ASML San Diego to enhance their camera algorithms and routines, eliminating the necessity of operating the laser EUV generation devices within their laboratory.

The TFE is controlled by a Raspberry Pi Model 4B (RPi) and can be accessed remotely with a secure shell (SSH) connection using either a static or dynamic internet protocol (IP). The tin vaporizations are emulated using a Crystalfontz liquid crystal display (LCD) that has been modified to allow transparency while retaining high-contrast pixels at a 4-value greyscale. Pre-generated shadowgraph images from the actual vaporization process are provided and are displayed on the LCD at a maximum refresh rate of 70 Hz. This frequency may be adjusted by RPi firmware through SSH. The LCD is illuminated by two CREE XP-E2 neutral white light emitting diodes (LEDs), referred to as backlight modules (BLMs), which are driven by a pulse width modulated (PWM) signal at a frequency of 1 kHz. Each BLM provides a maximum brightness of 107 lumens at full brightness (100% duty cycle), and each can be adjusted separately with firmware through SSH. The BLMs are arranged at a 90-degree separation from each other behind the center of the LCD. The emulated images with backlighting are viewable through two Allied Vision Technologies GC1290 (“AVT”) industrial cameras, referred to as droplet formation cameras (DFCs), arranged at a 90-degree separation each other from the front of the center of the LCD. The emulation setup is therefore an X-formation between the BLMs and DFCs with the LCD in the center. The TFE is also compatible with the Baumer HXG20NIR (“Baumer”) industrial camera.

The RPi and BLMs are powered by a custom power distribution board (PDB) that steps down a 24VDC input to produce a 5VDC output supplying 4A using a CUI Inc PDQE20-Q24-S5-D switching power supply. The TFE is completely housed in a 20”x16”x8” (LxWxH) modified electrical junction box. The RPi and PDB are secured to one side of the divider located towards the edge of the device which can be pulled up to access the boards and then locked with a pin attached to the outside of the device. The other side of the divider is the X-formation emulation setup. The internal ambient temperature of the emulation setup operates below 50°C and is monitored within a ±2°C accuracy using a DHT-22 temperature and humidity sensor.

The TFE supports a web browser established by an Apache HTTP server to display reported system information including the date, time, RPi CPU temperature, ambient temperature, and humidity of the emulation setup, both BLM PWM values, and the LCD refresh rate. These values are logged every second.

# Hardware

## Safety

This device is powered by a 5-volt, 4-amp power supply. Electrical components within the device carry a risk of electric shock if mishandled. To ensure your safety, please adhere to the following precautions:

1. **Avoid contact with water:** Keep external power supplies and the device away from water or any other liquids to prevent electrical hazards.
2. **Use only the provided power supply:** Use only the supplied power adapter to avoid potential damage to the device or risk of electric shock. Using an incompatible power supply may lead to malfunction or unsafe conditions.
3. **Disconnect power during maintenance:** Before performing any maintenance or connecting/disconnecting wires, ensure the power is disconnected from the electrical outlet.
4. **Inspect cables for damage:** Regularly check the power cables for any signs of wear, fraying, or damage. Power off the device and repair or replace the cables if they appear compromised.

The device is equipped with high-power LEDs that emit intense light (107 lumens). Direct exposure to these bright LEDs can lead to temporary blindness and discomfort. To mitigate the risk of adverse effects, it is imperative to refrain from looking directly into the LEDs, particularly at close range.

The TFE incorporates removable diffuser films positioned behind the LCD (in front of the LEDs). These diffuser films serve to soften the light emitted by the LEDs, enabling safe and up-close viewing during operation. It is recommended to keep the diffuser films in place to enhance user safety and minimize the potential for eye strain.

## Electrical Hardware

### Device Installation

With the TFE enclosure unopened, basic operation of the TFE is possible with the following external power and wiring connections available out of the back panel (shown in Figure 1) of the enclosure:

* Power plug for 120VAC-24VDC adapter
* Power plug for both the DFCs (AVT or Baumer)
* Left DFC ethernet
* Right DFC ethernet
* RPi ethernet

The following are wiring connections available for basic local operation of the TFE:

* USB keyboard (for RPi)
* USB mouse (for RPi)
* RPi HDMI output

The back panel of the TFE includes the following:

* 24VDC power jack
* Power switch
* Right DFC ethernet port
* RPi ethernet port
* Left DFC ethernet port

A close-up of a plug in a cable

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Figure : Back panel of the TFE with the power jack connected, power switched on, and the right DFC ethernet connected. An HDMI, keyboard, and mouse connection are also made internally through the semicircular opening at the bottom of the panel.

To power the system on, the power jack must be connected, and the switch must be pushed on. The system is powered on if a red LED on the switch button is turned on as in Figure 1.

The power jack and ethernet ports may be covered by the attached rubber plugs to protect against dust if unused.

**The TFE enclosure should remain closed unless maintenance, inspection, or configuration is necessary.**

A chain hooked on a clip on the outer side of the device (labeled “Key & Pin”) holds a key and a cylindrical pin as shown below in Figure 2. In the event the TFE needs to be opened, the key may be used to open the lock located on the lid of the device. Once unlocked, the lid may be gently lifted. A top-down view of the opened TFE is shown in Figure 3.

A key chain attached to a lock

Description automatically generated

Figure : Key and pin clip on the left side (facing the rectangular opening) of the TFE.

For convenient inspection of the TFE electronics, the RPi and PCB are secured to a sliding divider that may be pulled up. To pull the divider upwards, it is recommended to grab and pull the rubber lining on the top of the divider. Do not grab and pull the electronics or any of the wiring. To lock the divider in place, the cylindrical pin may be inserted into the circular opening (labeled with an arrow) on the bottom right side (facing the rectangular opening and the electronics) of the divider rail.

Before powering on the device, ensure the power distribution board pins and RPi header pins are connected where desired. The device may be powered with the divider drawn. A basic pin wiring setup for the TFE is provided in the Wiring section.

A machine with wires and cables

Description automatically generated with medium confidence

Figure : Top-down view of the opened TFE. The vertically mounted device electronics on the left are separated from the X-formation emulation setup on the left with the sliding divider.

It should be noted that the Right DFC (“Right Cam” on the back panel) faces the left BLM, and the left DFC (“Left Cam” on the back panel) faces the right BLM.

A picture of the divider pulled up and pinned is shown below in Figure 4.

A key and keychain on a metal box

Description automatically generated

Figure : Divider drawn and pinned in place.

### Wiring

All pins on the power distribution board and RPi are connected with female-to-female jumper wires with a standard 2.54mm pitch.

The pin connections of the PDB are as follows:

* Positive pin and negative pin for the temperature and humidity sensor
* PWM GPIO pin for left BLM
* PWM GPIO pin for right BLM
* Anode pin and cathode pin for left BLM
* Anode pin and cathode pin for right BLM

Power is supplied to the PDB with a 2.50mm ID, 5.50mm OD barrel connector. Output power from the PDB to the RPi is supplied via a USB Type-C power cable.

The pin connections made to the RPi are as follows:

* LCD (via CFA10110 breakout board\*)
  + RPi 3V3 Power (Pin 1) to LCD 3V3
  + RPi GND (Pin 6) to LCD GND
  + RPi GPIO 17 (Pin 11) to LCD RES
  + RPi GPIO 23 (Pin 16) to LCD DC
  + RPi GPIO 27 (Pin 13) to LCD CS
  + RPi GPIO 11 (Pin 23) to LCD D6
  + RPi GPIO 16 (Pin 19) to LCD D7
* BLM
  + RPi GPIO 12 (Pin 32)
  + RPi GPIO 13 (Pin 33)
* Temperature/Humidity Sensor (DHT-22)
  + RPi GPIO 26 (Pin 37)

\*The LCD is connected to the breakout board via a ZIF connector.

A diagram of a circuit board

Description automatically generated

Figure : TFE wiring diagram.

## Mechanical Hardware

### Tripods

To allow for universal camera mounting, standard ¼” screws are used for tripod mounts. The TFE furnishes three CAMVATE ball head tripod mounts: one for the LCD, one for the left DFC, and one for the right DFC. DFCs with the appropriate tripod mounting plates can be simply fastened into the tripod. The ball head allows camera angle adjustments in three dimensions. By loosening the screw at the base of the mount, the camera angle may be adjusted and then locked in place by tightening the screw. The height of the device mounted on the tripod may be increased or decreased slightly by screwing the circular plate on the ¼” screw.

The TFE currently uses ¼”-20 mounting plates (P/N 63-432) for the AVT DFCs. We recommend the [Mounting Adapter Type B (Article no.: 11003060)](https://www.baumer.com/nl/en/product-overview/industrial-cameras-image-processing/accessories-image-processing/mountings/mounting-adapter-type-b-tripod-/p/24144) (tripod) mounting plate for the Baumer HXG20NIR industrial camera. The Type B mounting plate can mate with the CAMVATE tripod mounts already installed in the device.

The LCD is mounted on the tripod with a custom 2-piece 3D-printed clamp mount that mates with the CAMVATE tripod. The LCD is placed between the clamp mount and is secured with two Phillips head screws on the left and right of the mount. The LCD breakout board is secured to a custom 3D-printed block through two mounting holes which fasten to the bottom of the enclosure. The backside of the LCD mount includes eight curved banks which allow BLM light diffusion films to be installed to the user’s liking.

### DFC Lens

**A lens is** **required to view the LCD shadowgrams through the DFCs.**

To support a working distance of 70-80mm, a C-mount type 1/3 lens with a focal length of at least 24mm is recommended. The Arducam lenses (C-mount type 1/3 with adjustable 8-50mm focal length) that are installed on the AVTs are also compatible with the Baumer DFCs.

The Arducam lens can only be adjusted locally:

* To increase the focal length (TELE), loosen the front fastening pin, turn the front part of the lens clockwise (facing the front element), then tighten the fastening pin to lock the position.
* To decrease the focal length (WIDE), loosen the front fastening pin, turn the front part of the lens counterclockwise (facing the front element), then tighten the fastening pin to lock the position.
* To adjust the aperture, loosen the middle fastening pin and turn the middle ring clockwise to open the aperture (low aperture) or clockwise to close the aperture (high aperture).
* To adjust the focus, loosen the back fastening pin and turn the back ring clockwise for up-close objects or counterclockwise for distant objects.

### DHT-22 Mount

The DHT-22 temperature and humidity sensor is fastened to a screw protruding from the bottom of the enclosure located behind the LCD mount. The sensor has a mounting hole through which the screw can be secured with a nut.

### BLM Mount

Each BLM is fastened to an L-shaped bracket using two screws. The height of the bracket may be adjusted by loosening the screws and sliding the BLM to the desired location. The bottom part of the bracket may also be adjusted by loosening the screw and sliding the bracket forward or backward. BLM mount adjustments should be performed when the BLMs are off to avoid eye discomfort and temporary blindness.

# Software

### MAC Address

The MAC address of the RPi placed inside the system is **d8:3a:****dd:27:38:18**. To find the MAC address of the RPi, type “ifconfig” into the RPi terminal.

### For New Raspberry Pis

The RPi itself runs using Raspbian OS. To make sure the TFE system is functioning properly, “Data2.csv” and “main.html” must be created and placed in the correct folder after Apache2 is installed onto the RPi.

1. To create “Data2.csv” type “sudo nano /var/www/html/Data2.csv” into the terminal. This will create Data2.csv and will place it into the Apache2 server folder for the server to access. In the file, type filler words then press Ctrl+X, then hit “Y” and hit enter to save. Then go back into Data2.csv and delete the filler words then press Ctrl+X, then hit “Y” and hit enter to save.
2. To create “main” type “sudo nano /var/www/html/main.html” into the terminal. This will create main.html and will place it into the Apache2 server folder for the server to access. Copy the code from GitHub then press Ctrl+X, then hit “Y” and hit enter to save.

If the RPi is missing the python code to run the system, pull “final.py” from GitHub and install all the supporting libraries mentioned in the code.

NOTE: There is no cutoff point in terms of the data being added to “Data2.csv”. This file will need to be cleared after some time or code will have to be written to edit the length/size of the file.

### Internet access

The Raspberry Pi (RPi) should be connected to ethernet which will give the RPi its IP address and access to the internet. If the IP address is unknown, type “hostname -i” into the terminal to find the IP address.

### Server Test

Apache2 is used as the server to run the webpage. This should be running automatically after the RPi is started up. To verify that the server is running, type the IP address into RPi web browser. If the server is up and running, the Apache2 default screen should be displayed.

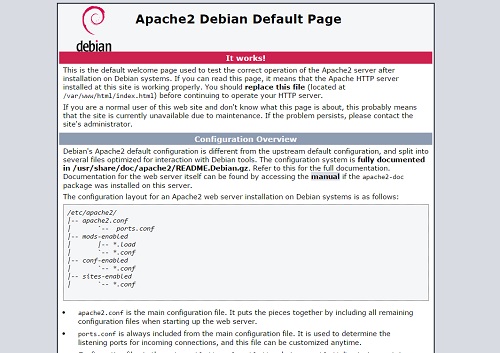


Figure : Apache2 default webpage showing successful connection to the server.

### Accessing the Data Acquisition Webpage

To open the data acquisition webpage, type the RPi’s IP address into the webpage followed by “/main.html”. For example, the complete weblink could be “123.456.78.9/main.html”.

### Debugging

To debug the webpage, use the data log file “Data2.csv” this file will log the TFE system data. The file is sorted by columns using commas. Each data entry line will follow this format “date/time, CPU temperature, right PWM value, left PWM value, LCD frequency, last terminal command”. If the webpage is not responding, right click and select inspect to see the console for the webpage. Any errors for the webpage will be shown there.

### Default Code

In case “final.py” becomes unfixable and fails to run, there is a default python program that can be copied from “Factory\_Default.py”. To fix “final.py” just copy and paste the code from “Factory\_Default.py” and the code will revert the TFE system back to the original working state.

### SSH Access

To access the RPi from a remote device, SSH must be enabled on the RPi. To do this, go into the configuration window and enable SSH. Then go into the remote device terminal and type “*pi*@*ip*”. With this format, pi will be the username of the pi, and ip will be the IP address of the RPi. When prompted to type in a password, enter the password of the RPi login.

To reboot the system and RPi remotely, type “sudo reboot” into the SSH terminal.

### Controlling the System Setup

To change the backlighting and display frequency of the system, the python file will need to be accessed through the terminal. To edit the file, type “sudo nano /home/pi/final.py”. This will allow you to edit the program. To change the duty cycle of the BLMs, edit the values assigned to “dL” (for the left LED) and “dR” (for the right LED). These values will be from 0-100, which relates to the PWM duty cycle percentage. To adjust the frequency of the display, adjust the value assigned to “lcdFreq”. This value has a max of 70, which relates to the frequency of the display in Hertz. Once editing is finished press Ctrl+X, then hit “Y” and hit enter to save.

After editing is finished, it is recommended to reboot the system to apply the changes to the boot program. This will ensure that these new settings will be saved and will load into the system on the off chance the system experiences an unexpected reboot or power loss.

If the reboot is not done, when the program is rerun using “sudo python3 final.py”, two versions of this program will run and the system will fight over which program takes priority, especially the LCD display.

### Warning

For “final.py” to run straight after startup, the file path was added into rc.local found in the /etc/ folder. The only problem with this, is that this program will always be running in the background. Therefore, if changes are made while the RPi is powered, it must be rebooted to ensure only one version of that program is running at a time. If the “final.py” process is running after changes are made, it must be terminated before restarting the program if rebooting is not desired.

If these instructions are not followed it will lead to bugs that will affect the functionality of the system and webpage included.

# Appendix

## GitHub

<https://github.com/Target-Formation-Emulator-Senior-Design>

Includes firmware, software, KiCad schematics for the PDB, 3D printing files for the divider rails mounts and LCD mount, as well as a collection of useful datasheets.

**Note: The pre-generated shadowgraph images are not uploaded to GitHub and must be obtained internally through ASML.**

## Power Distribution Board Schematic

A diagram of a circuit

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Figure : Schematic of the power distribution board as shown in KiCad.

A computer screen shot of a circuit board

Description automatically generated

Figure : Top-down view of the wiring traces in the power distribution printed circuit board as shown in KiCad.

## Parts List

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Electronics | | | | | | |
| Quantity | Ref Des | Description | MFG P/N | Supplier | Cost (Unit) | Ext |
| 1 | N/A | Small Transflective Graphic LCD (128x64) | [CFAG12864T3-NFH](https://www.crystalfontz.com/product/cfag12864t3nfh-sunlight-readable-low-power-lcd) | Crystalfontz | $8.35 | $8.35 |
| 1 | LCD Breakout Board | [CFA10110](https://www.crystalfontz.com/product/cfa10110-lcd-breakout-board) | Crystalfontz | $8.60 | $8.60 |
| 2 | Centaurus High-Power Cree LED Light Module | [J006-CE2840-Q5](https://www.ledsupply.com/cree-leds/centaurus-led-by-luxdrive) | LEDSupply | $3.49 | $6.98 |
| 1 | 24V 4A Power Supply Adapter | [B07DFZ7WYT](https://a.co/d/hEB22qX) | Amazon | $20.69 | $20.69 |
| 1 | Gigastone 64GB Micro SD XC Card | [B089PVGSVH](https://a.co/d/8MDthSU) | Amazon | $12.98 | $12.98 |
| 1 | Raspberry Pi 4 Model B 2019 | [RAS-4-4G](https://a.co/d/2g3wYCV) | Amazon | $65.49 | $65.49 |
| 1 | USB-C Power Cable 22AWG 5V 3A Plug to 2 Pin | [B0BFHXWCS9](https://a.co/d/baAnT9H) | Amazon | $10.80 | $10.80 |
| 1 | Rocker Toggle Switch, 24V/10A | [B07S8TVC5J](https://a.co/d/d9wgG4h) | Amazon | $12.99 | $12.99 |
| 1 | Female to Female Network Bulkhead Coupler | [B0C58V2RLX](https://a.co/d/2Cwq4zz) | Amazon | $26.59 | $26.59 |
| 1 | 5A DC Power Jack Socket Threaded Adapter | [B07QLZ9VWL](https://a.co/d/ajgynS8) | Amazon | $9.99 | $9.99 |
| 1 | U1 | Digital Humidity and Temperature Sensor Module | [DHT22/AM2302](https://a.co/d/6L7DUXH) | Amazon | $11.75 | $11.75 |
| 1 | PS1 | CUI Inc DC DC CONVERTER 5V 20W | [102-6267-ND](https://www.digikey.com/en/products/detail/cui-inc/PDQE20-Q24-S5-D/10230156) | Digikey | $23.89 | $23.89 |
| 1 | F1 | FUSE AUTO 5A 32VAC/VDC BLADE | [F5041-ND](https://www.digikey.com/en/products/detail/littelfuse-inc/0ATO005-V/2519130) | Digikey | $1.14 | $1.14 |
| 1 | F1 | FUSE BLOCK BLADE 500V 50A PCB | [36-3555-2-ND](https://www.digikey.com/en/products/detail/keystone-electronics/3555-2/2137311) | Digikey | $1.94 | $1.94 |
| 1 | J1 | Power Barrel Connector Jack | [2092-KLDX-0202-B-ND](https://www.digikey.com/en/products/detail/kycon-inc/KLDX-0202-B/9990096) | Digikey | $0.76 | $0.76 |
| 2 | R1, R2 | RES 5.6 OHM 5% 2W AXIAL | [BC4812CT-ND](https://www.digikey.com/en/products/detail/vishay-beyschlag-draloric-bc-components/PR02000205608JA100/7350718) | Digikey | $0.24 | $0.48 |
| 2 | Q1, Q2 | TRANS NPN 40V 0.6A SOT23-3 | [MMBT2222ALT1GOSTR-ND](https://www.digikey.com/en/products/detail/onsemi/MMBT2222ALT1G/919593) | Digikey | $0.15 | $0.30 |
| 1 | LDM1 | FIXED IND 2.2UH 5.3A 10 MOHM TH | [RLB0912-2R2ML-ND](https://www.digikey.com/en/products/detail/bourns-inc/RLB0912-2R2ML/2561345) | Digikey | $0.42 | $0.42 |
| 2 | C0, C4 | CAP ALUM 330UF 20% 35V RADIAL | [1189-3752-1-ND](https://www.digikey.com/en/products/detail/rubycon/35ZLH330MEFCT810X12-5/3568153) | Digikey | $0.51 | $1.02 |
| 2 | C1, C2 | CAP 4.7uF/35v ELECT. | [10-ECE-A1VKS4R7ICT-ND](https://www.digikey.com/en/products/detail/panasonic-electronic-components/ECE-A1VKS4R7I/2689189) | Digikey | $0.24 | $0.48 |
| 1 | C3 | CAP 100uF/35v ELECT. | [PCE3951TR-ND](https://www.digikey.com/en/products/detail/panasonic-electronic-components/EEE-1VA101XP/766117) | Digikey | $0.50 | $0.50 |
| 2 | CY1, CY2 | CAP CER 1000PF 760VAC Y5U RADIAL | [BC2974-ND](https://www.digikey.com/en/products/detail/vishay-beyschlag-draloric-bc-components/VY1102M31Y5UC63V0/5320489) | Digikey | $0.35 | $0.70 |
|  |  |  |  |  | Subtotal: | $226.84 |
| Hardware | | | | | | |
| Quantity | Ref Des | Description | MFG P/N | Supplier | Cost (Unit) | Ext |
| 1 | N/A | Standard Grade Polarizing Film with Adhesive | [B07H3R8MB2](https://a.co/d/afEWi90) | Amazon | $11.00 | $11.00 |
| 2 | Arducam 8-50mm C-Mount Zoom Lens | [B08PYMBX9T](https://a.co/d/1lvFDG8) | Amazon | $49.99 | $99.98 |
| 3 | CAMVATE 1/4"-20 Mini Ball Head Mount | [B07MT81D5S](https://a.co/d/9SwjgOT) | Amazon | $8.90 | $26.70 |
| 1 | 5⅝" Black Adjustable L Slot Brace (Pack of 10) | [B0919Y5PWG](https://a.co/d/9cQn1q5) | Amazon | $23.19 | $23.19 |
| 1 | TOOLIOM 20 x 16 x 8'' Steel Enclosure Box | [B0B931MJTY](https://a.co/d/ii6Zzdc) | Amazon | $85.37 | $85.37 |
| 1 | Kemcatui 7 Inch Drawer Slides (Pack of 2) | [B0B2W2NYBX](https://a.co/d/fqOCpd2) | Amazon | $7.99 | $7.99 |
| 1 | 192 PCS Cable Management Kit | [B0B687J37D](https://a.co/d/dRug9a6) | Amazon | $14.99 | $14.99 |
| 1 | 4 Small Extra Tall Round Rubber Feet Bumpers | [B01AU0ISKI](https://www.amazon.com/gp/product/B01AU0ISKI/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1) | Amazon | $7.29 | $7.29 |
| 8 | HEX STANDOFF #4-40 NYLON 5/8" | [36-1902F-ND](https://www.digikey.com/en/products/detail/keystone-electronics/1902F/61870) | Digikey | $0.72 | $5.76 |
| 2 | 1/4"-20 Mounting Plate for Prosilica Cameras | [63-432](https://www.edmundoptics.com/p/frac14-20-mounting-plate-for-prosilica-cameras/18044/) | Edmund Optics | $73.00 | $146.00 |
|  |  |  |  |  | Subtotal: | $428.27 |
|  |  |  |  |  | Grand total: | $655.11 |

Note: The hardware list does not include the various 6-32 and 8-32 screws, nuts, and washers used to assemble the device.