



Sun Simulator 2 project documentation

ISIS-SUNSIM

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Change Log

Version	Date	Affects	Description
1.0	2022-02-15	All	First Version – action plan created
2.0	2022-06-01	All	Full documentation

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Acronyms

Name	Description
3U	3 Unit (Unit is a CubeSat measuring system, 1U being 10cm x 10cm x 10cm)
ADC	Analogue to Digital Converter
AM0	Air mass 0 (Solar radiation in space near Earth)
DAC	Digital to Analogue Converter
ELM	ElectroLuminescence Method
FR-4	Flame Retardant – 4 (PCB material, made out of woven fiberglass and epoxy resin)
GND	(Electrical) Ground
GPIO	General-Purpose Input/Output
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
IR	Infra-Red
ISPA	ISISPACE Solar Panel Array
IV	Current Voltage
LDU	LED Driver Unit
LED	Light Emitting Diode
LPU	LED Plate Unit
MB	Motherboard
MCPCB	Metal Core PCB
MCU	Micro Controller Unit
PC	Personal Computer
PCB	Printed Circuit Board
PDAU	Power/Data Adapter Unit
PSU	Power Supply Unit
PTC	Positive Temperature Coefficient
PWM	Pulse-Width Modulation
SPI	Serial Peripheral Interface
SS	Sun Simulator
UART	Universal asynchronous receiver-transmitter
USB	Universal Serial Bus

1 About the project

The project sun simulator, next generation sun simulator or sun simulator 2 is about designing and manufacturing the improved sun simulator for ISISPACE Solar Panel Array (ISPA) testing activity. Within this document the new, currently under development sun simulator for this project will be referred as "sun simulator". The already present and functioning sun simulator will be referred as "old sun simulator".

Old sun simulator is a device that can generate light sufficient for solar panel evaluation. The solar cells used for the solar panels requiring the test have a very wide spectrum where they function. A special array of LEDs with 3 different types of LEDs is used to create the sufficient spectrum of light necessary to test the solar panels. The light output of the old sun simulator can be controlled by rotary knobs. It was calibrated once using special calibration solar cells with known characteristics.

There are number of issues with the old sun simulator. The most major one is the size. It is too small for proper testing of bigger solar panels (3U (3 Unit, or 300x100mm) and bigger). The spectrum of the old sun simulator is almost sufficient, but the IR light is slightly too weak, the effect is small, but undesired. The test that is performed with old sun simulator is not absolute measurement of the performance. This means that each test may give different values, but relative to each other they will stay the same. For example, an IV curve (Current Voltage curve) test. This is a test where the relation between current and voltage is measured and plotted. Two tests of the same panel can give different results, but the overall shape of IV curve will stay the same. The issue is with the uniformity of light and with the size, but also calibration plays a role.

Those problems can be fixed with the next generation sun simulator. The sun simulator will be bigger, modular and more automated. This brings a number of challenges that need to be solved. A bigger sun simulator means more power consumption. The estimate is that the sun simulator will now use approximately 1kW to 1,5kW. For comparison the old sun simulator requires approximately 280W. This also brings a lot of thermal management into the project. To ensure better reusability of the sun simulator, it will have self-calibration/adjustment capabilities. All test should be automated as much as possible. A PC interface is planned as well. The test that that are performed on the solar panel, other than the IV curve one are the diode test and the ELM (Electroluminescence Method). The diode test focuses on testing if bypass diodes (will bypass the current if a cell is shaded or damaged) and blocking diode (blocks current from back powering the solar panel). For this the forward voltage is measured and evaluated. The ELM test is a test where a solar cell is powered. This will make the cell glow and reveal its internal structure. To achieve that, roughly 10mA is passed through the cell. A picture then is taken to save the results.

1.1 Requirements

The following lists will list the requirements for the Sun Simulator.

The functional requirements that are necessary to make product function:

1. Light output has to be at least 1366W/m^2 with the ability to change light output per wavelength.
2. Uniform/repeating pattern for light sources
3. The minimum size of the light source is 40cm x 50cm
4. Output spectrum should contain light in wavelength from 400nm to 1400nm
5. Sun simulator shall be automated as much as possible
 - a. IV curve test shall be automated
 - b. Telemetry test shall be automated
6. Basic front panel control
7. Automation of IV and telemetry test through PC software.
8. Sensors to measure sun simulator light output and temperature and react to it accordingly

The following list will include some things that should be added, but in case there is a good reason, can be neglected (nice to have):

1. Easy way to add extra functionality to the sun simulator (for example: expansion cards)
2. Build in hardware to perform all ISPA tests with the use of the sun simulator
 - a. Small current source suitable for doing the electroluminescence method test
 - b. Way of replacing electronic load (used for IV curve test) with a build in version in the sun simulator.

2 Action plan

The plan will be as following. Currently there are some old designs for the sun simulator lamp unit that would require updating. They are made in EAGLE software and now Altium software is used for all designs. After they are upgraded, they need to be checked and evaluated. Some changes may be required. Some components are not yet agreed on (like LEDs) and need to be chosen. This is a multi-PCB modular design, so a great care shall be taken to ensure that everything fits perfectly.

After the lamp units are fully updated and ready to be produced, they will be ordered and produced. This will be the proto version of the new lamp unit and need to be evaluated. Basic functionality, like dimming will be checked, thermal properties will be also evaluated.

After lamp unit properties are well understood, the design process for the motherboard starts. This is the brain of the device. The responsibilities of the motherboard will be following:

1. Power management
 - a. Ensuring that all subsystems will receive their power and monitor the performance.
2. Data acquisition from the sensors of the sun simulator and the solar panel.
3. Front panel management.
 - a. It will be responsible for the front panel control response
4. Control of all of its subsystems, motherboard will
 - a. send commands to the LED drivers to control light output
 - b. check telemetry of its sensors to evaluate light output or thermal conditions and take proper action, if needed
 - c. be able to talk to the PC, or other device made here for in the future
 - d. be controlled by a front panel menu, or PC

After the mother board is ready, it will be ordered and produced. The motherboard will use a microcontroller and it has to be programmed. For the initial test a very basic software will be written to test all functionality of the sun simulator. After all parameters are known the actual software has to be written. The software will manage almost all of the motherboard functionalities that were previously stated.

Also, software for the PC will be written. This software shall be used to talk with the sun simulator and control all of its functions. It shall have at very least a basic user interface and ability to save user settings. All test done using the software shall be saved in at very least simple test rapport, for example txt or csv file. IV measurement shall be an image of the plot.

The software shall be tested to ensure its quality. After software works as intended it will conclude the project. The documentation, if not finished at the time, shall be finished. See Table 2-1 for the initial planning.

Table 2-1 Current planning of the sun simulator project

Week	2022																
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Updating the proposal document/ preparation																	
Finilizing design (lamp module)																	
Ordering and receving the PCBs and components (proto)																	
Assembly of the proto PCBs																	
Testing of the proro																	
Designing the motherboard and the PSU decision																	
Full sun sim order																	
Assembly of full sun sim																	
Testing and programming																	
Documentation																	

While working on the project, it was clear half way through that considering the complexity of this project and current component shortage, only the designs will be finished and prototype tested.

3 Initial research

In this paragraph the basic requirements will be evaluated.

3.1 The Solar Panels and cells

This chapter focuses on solar panels and cells that are tested using the sun simulator.

3.1.1 Reason behind special space solar cells

The solar panels used in space flight are made from solar cells that are more efficient than most typical solar cells. Those cells are much more expensive than regular cells in power to price ratio, but power to weight ratio is better.

There are couple reasons why slightly more efficient, but much more expensive cells are used in space flight:

1. Lower weight. Space craft should be as light as possible as the heavier the space craft, the less efficient the fuel will be at changing its velocity, less efficient panels mean you need more, thus heavier.
2. Lower volume. Space craft have to fit inside the fairing or a deployer. More efficient solar panels means that they can be smaller and still achieve the same result, thus saving on volume of the spacecraft.
3. Simplicity. To fit bigger solar panels inside the fairing or a deployer, panels are usually stowed. The bigger the panel, more complex the deployment mechanism may become.

With all those things combined, the slightly more efficient, but much more costly space solar cells are a better and cheaper alternative than the commercial cells.

3.1.2 The difference between the space and commercial solar cells

The main difference between the commercial and space solar cells is that space solar cells are using multiple photovoltaic layers, instead of just one. In a solar cell the photovoltaic layer can be made out of different materials. Depending on the material the spectrum on which the layer is sensitive will be different. A single layered solar cell works well only on a specific spectrum of light, other wavelengths are wasted.

The idea behind the multi-layered solar cells is to have multiple layers of photovoltaic that are made from different materials. First layer will be transparent to wavelength of the following layers. As each layer is made from different material, each layer works on different spectrum of light. This way a wider spectrum of light can be converted to electricity and thus higher efficiency can be achieved. This is the key difference and what makes the space solar cells more efficient. The 3 layers are the following:

1. GaInP - Indium gallium phosphide, sensitive to visible light (~400nm to 700nm)
2. GaAs - Gallium arsenide, sensitive to IR light around 700nm to 900nm
3. Ge on Ge - Germanium on Germanium, sensitive to IR light from 900nm to 1800nm

A script was made to plot the data for this document, it can be found in Attachment 12.

In Figure 3-1 spectral response of a GaInP, GaAs and Ge on Ge layered solar cell is shown.[2]

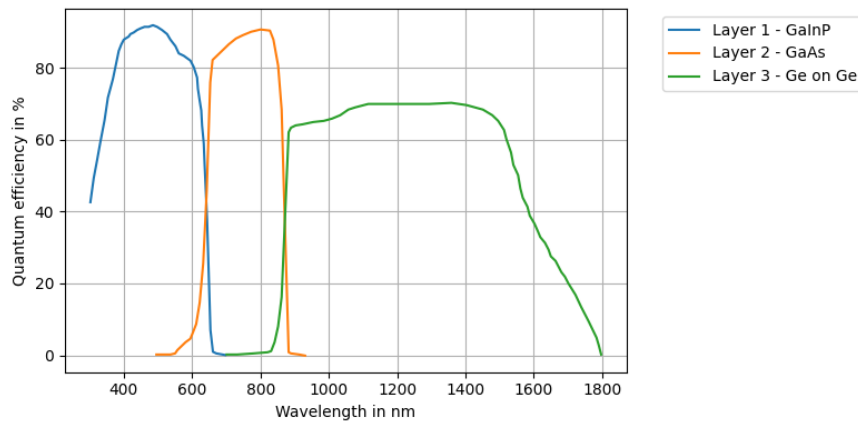


Figure 3-1 Triple junction solar cell spectral response [2]

3.2 The solar light

To be able to create a solar light simulator, the power and spectrum of the light generated by the sun has to be known. This data can be found in the file provided by The National Renewable Energy Laboratory which is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy LLC [1]. From the data the ratio of light for each solar cells layer can be determined. The total solar output equals to roughly 1366 W/m^2 . The light that is interesting for solar testing has wavelength from 280nm to 1800nm. The sun simulator will not generate a uniform spectrum, but peaks in spectrum required for each layer of a solar cell. From experience with the old sun simulator, the light generated within the rated spectral range of a cell, as long as it has the total power of sunlight within this range, will work as if it was under proper sun light. Thus, for solar panel testing it is the total power received that is important, not how it is distributed.

Using this knowledge, the data from the previously mentioned file [1] can be used to extract information about the radiant flux required for each layer. The obtained data can be seen in Table 3-1.

Table 3-1 Radiant flux ratio and power for spectral ranges required for solar cell testing

Radiant flux (W) for spectral ranges of the solar output				
Ranges	280nm to 700nm	700nm to 900nm	900nm to 1800nm	280nm to 1800nm
Ratio	0,55	0,17	0,28	1
Radiant flux (W/m ²)	736,4	228,5	371,3	1336,2
Radiant flux (W/100cm ²)	7,4	2,3	3,7	13,4

For a 10x10cm board the light output has to be at least 13,4W.

This is very simplified way of looking at the situation. It does provide basic idea of how much power is necessary, but ignores the fact that depending on the wavelength, the efficiency of the cell is different.

To obtain a better value for required radiant flux, the function representing the solar output and function representing the layer specific efficiency can be multiplied. This will result in a new function that represents the "felt" radiant flux on the solar cell. By taking an integral of this function the total power absorbed by the solar cell can be found.

Solar radiation in W: $f(\lambda)$

Cell efficiency: $g(\lambda)$

Absorbed solar power in W: $h(\lambda) = f(\lambda) \cdot g(\lambda)$

Total absorbed solar power in W: $\int h(\lambda) d\lambda$

The same operation can be done for function representing the LED light output. By multiplying the function representing the radiant flux and function representing the solar cell layer specific efficiency, the "felt" radiant flux can be calculated by taking the integral of the new function. The power felt from the LEDs shall be equal or higher to the power felt by the sun light.

Led radiation in W: $i(\lambda)$

Cell efficiency: $g(\lambda)$

Absorbed led power W: $j(\lambda) = i(\lambda) \cdot g(\lambda)$

Total absorbed power: $\int j(\lambda) d\lambda$

The previously used data of the solar radiation can be used as function $f(\lambda)$. Cell efficiency data from chapter 3.1.2 can be used as function $g(\lambda)$. As the data is not of the same format as the step sizes are different, data interpolation will be required. The cell spectral response/efficiency is interpolated to match the solar radiation output data. Then the required calculation can be done using a python script. For each layer the data is computed and results are shown in Table 3-2.

Table 3-2 Radiant flux requirement for each layer of solar cell calculated using the formula

Radiant flux (W) required for each layer of the solar cell			
Layer	GaInP layer	GaAs layer	Ge on Ge layer
Required radiant flux (W/100cm²): $\int h(\lambda) d\lambda$	5.23	2.62	2.59

The data can also be plotted using the same script, the data is visualised in Figure 3-2, Figure 3-3 and Figure 3-4. The script to plot this data was made specifically for this project and can be found in attachment 13. What the plots show is basically what part of the solar radiation is felt by the layer of the cell itself. The data in Table 3-2 is the area of the orange plots.

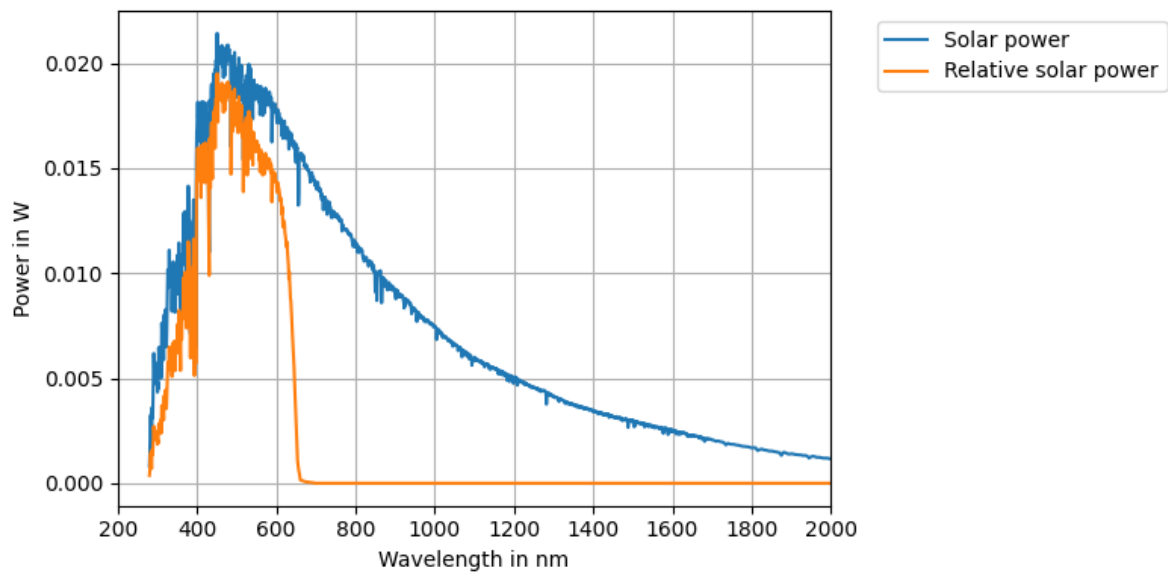


Figure 3-2 Power felt on GaInP layer

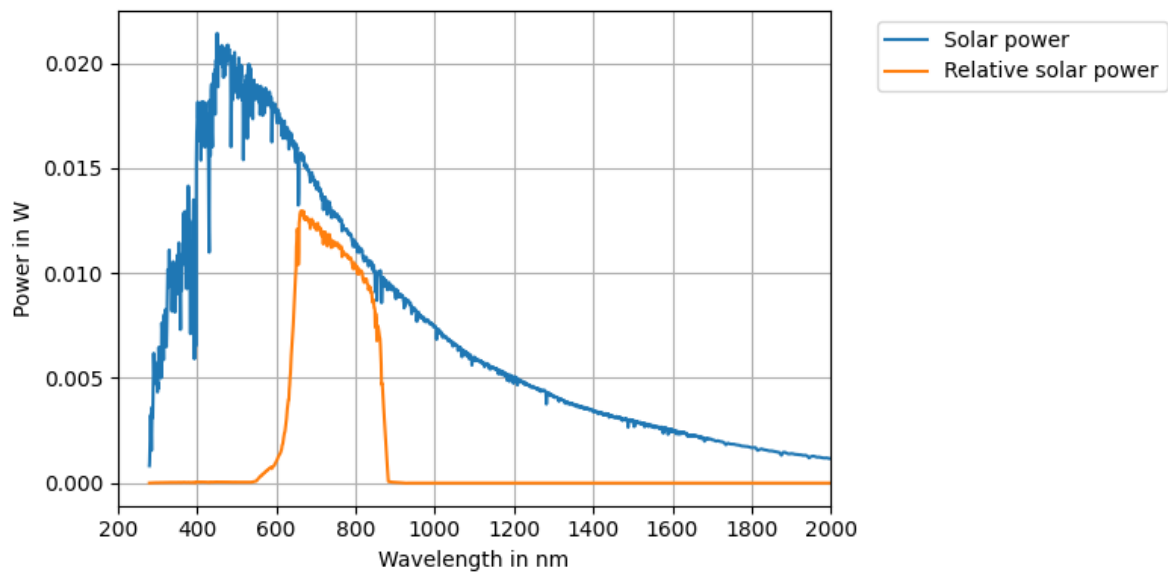
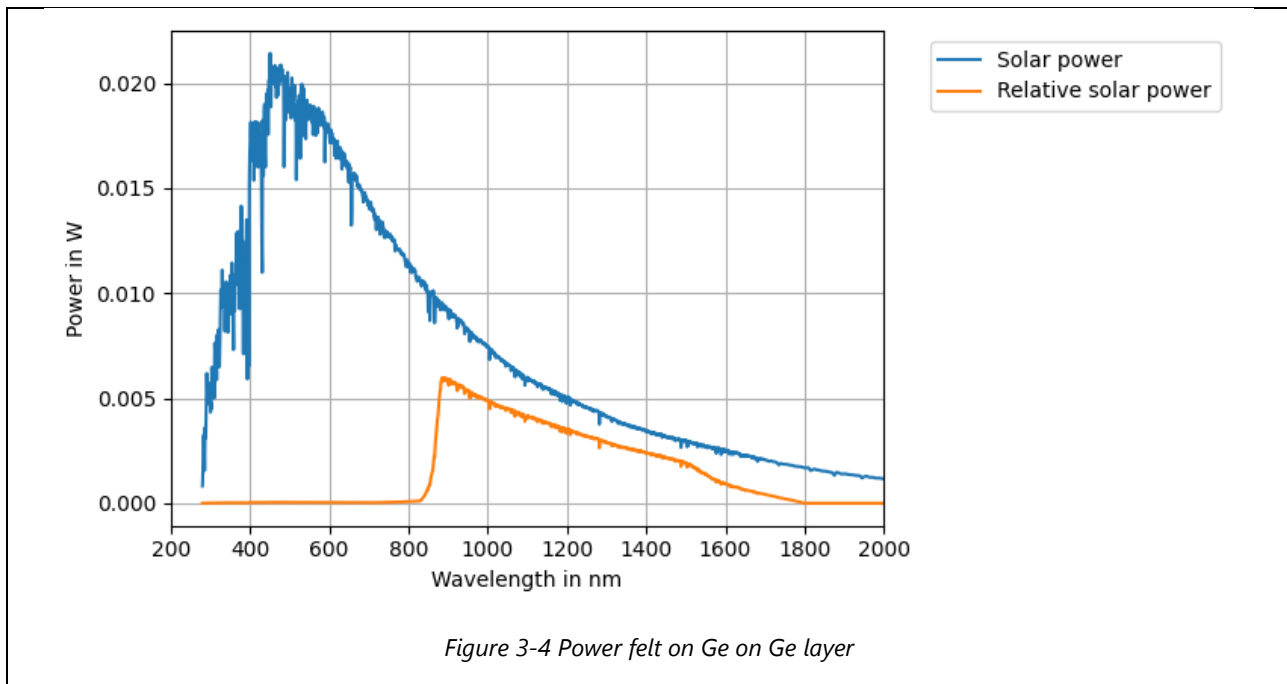


Figure 3-3 Power felt on GaAs layer



This is much more accurate representation of what the solar panel absorbs from the sun light. This can be used to determine the correct LEDs.

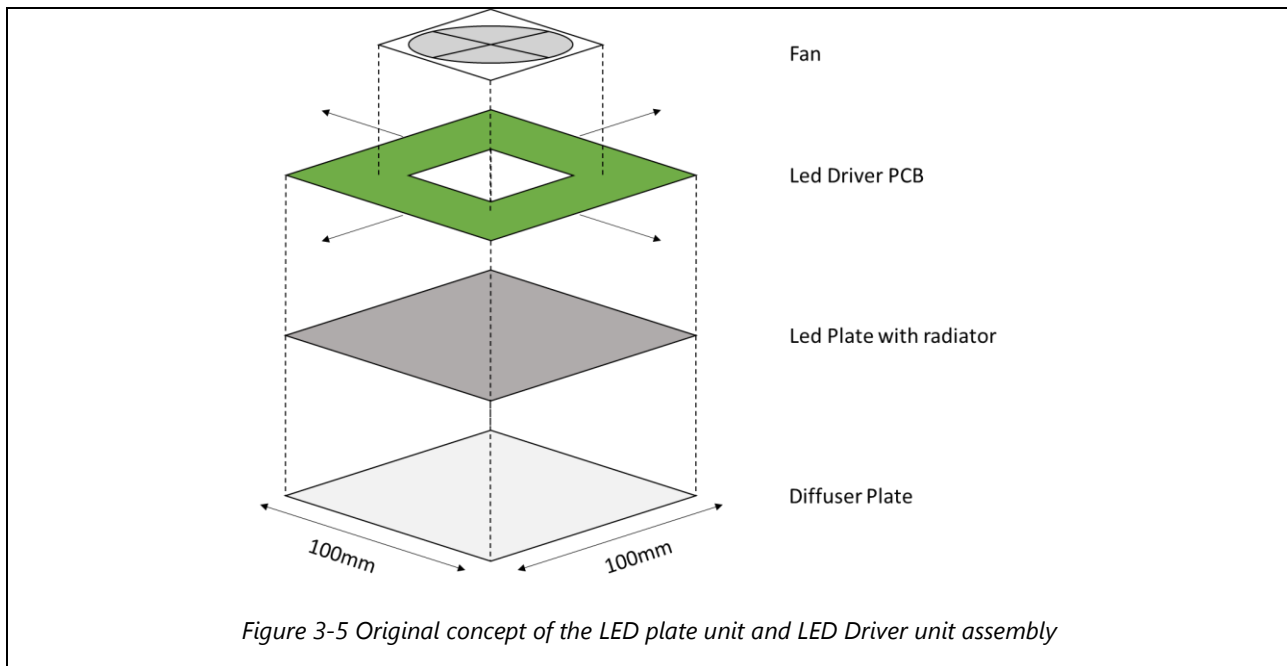
3.3 Old design

The design of the lamp unit was already started, but not finished. It was also old and outdated. The lamp unit was designed in EAGLE. It is desired however, to convert the designs to Altium. Altium is a professional designer tool for PCB design. It can do a lot more than EAGLE. For example, it will create a 3D model of the PCB in real-time while designing. This can be easily converted to a step file which is very useful for enclosure design.

The current design consisted of 3 separate PCBs:

1. LED plate
2. LED driver
3. Power/Data adapter

The idea of this design is to connect the LED plate PCB to the LED driver PCB so they create a single unit, see Figure 3-5 for details. The original EAGLE designs can be found in the attachments. In Attachments 1, 2 the led plate designs are located. In attachment 3 and 4 the led driver unit designs are located. In attachment 5 and 6 the Power/data adapter unit designs are located.



The components used had to be reevaluated as the design was old and some components were not active anymore.

The most important part of the Sun Simulator is the part that generates light. In this design LEDs are used to generate light. LEDs have their own advantages and disadvantages. Primary driving factor to use LEDs is their high efficiency and simplicity. The disadvantage for this particular project is the spectrum generated by the LED. LEDs have very narrow spectrum band. For example, the visible light LED only really produces just the visible light and no IR light. This is usually a good thing when a regular lamp is desired, as this is much more efficient, but in a case of the sun simulator, IR light is also required. There are IR LEDs available, the most commonly used ones are in the TV remotes. In case of the sun simulator, high power LEDs are required. IR LEDs have in general very narrow spectral output. In case of the sun simulator, what really is desired is to see if each layer of the solar cell works. This means that the spectral output of given LED has to be within the boundaries of the spectral response of the given cell layer. Technically 3 different LED are needed for the 3 layers of the cells that are used in the ISISPACE Solar Panel Array (ISPA). From the experience from the old sun simulator, it is known that the last layer does not quite receive enough IR radiation. The new design has space for 4 different types LEDs. As solar cells have 3 layers, the fourth LED type/string is meant to ensure correct radiation intensity on the solar cell.

The LED plate has in total 36 LEDs on it, divided between 4 strings. One LED string has thus 9 LEDs in total.

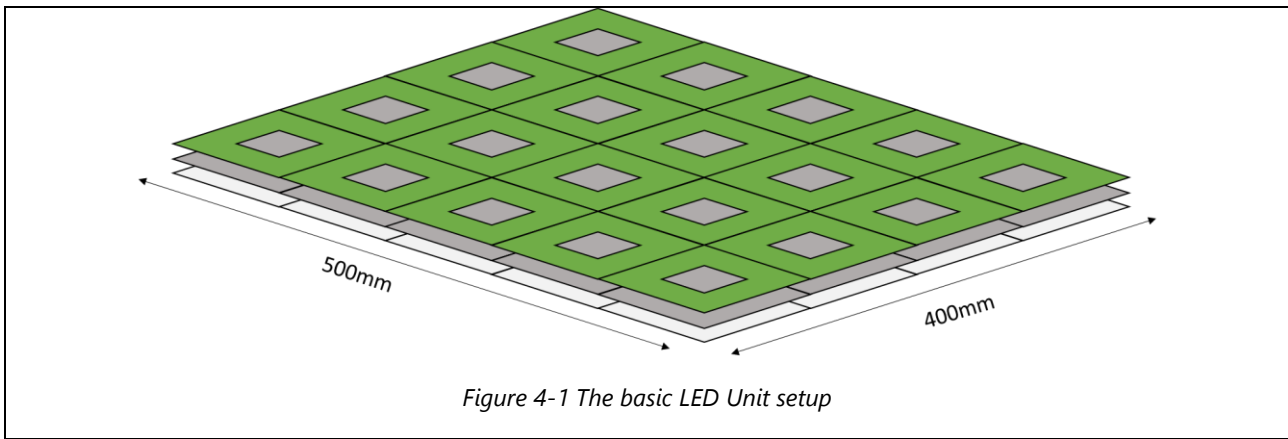
4 Lamp unit design

This section will cover the lamp unit design process.

4.1 Basic design overview

The lamp unit is made out of 3 PCB components. The sun simulator LED plate unit (SS-LPU) and the sun simulator LED driver unit (SS-LDU) and the sun simulator power/data adapter unit (SS-PDAU). The SS-LPU and SS-LDU are connected together to form a single unit, those then can be connected in an array. Multiple arrays of the LED units can be connected in a matrix using a single array of SS-PDAU. Each SS-PDAU can have a single array of LED units attached and two other SS-PDAUs on the side. The original EAGLE designs can be seen in the attachments 1, 2, 3, 4, 5 and 6.

The basic idea is following. The LED units will be connected together as shown in Figure 4-1.



4.2 The Design

The design was upgraded to Altium. Altium had an export function which allows to export EAGLE designs to Altium, however, the schematics needs to be transformed to an Altium like format manually. Technically the exported data works out of the box, but is almost impossible to maintain, so the manual conversion is mandatory. The actions that were performed are the following:

- Created a new library and converted/created all components in Altium library.
- Replaced all old components with the Altium components.
- Reworked the layout of the documents to match the company standards.
- Ensured all components had they proper 3D model (step file).
- All settings and rules were setup

The finished design could be rendered as a 3D image. Those renders are visible in Figure 4-3, Figure 4-4, Figure 4-5 for LED Plate Unit, LED Driver Unit and Power/Data Adapter Unit. In those renders some of the design choices are very well visible. The LED Plate Unit uses the IMS pooling of the PCB. Those metal core PCBs could only be made one layered at the time of the initial design. Later different manufacturer was found that can make 2 layered MCPCBs (Metal Core PCB), but as the design was created with one layer limitation for such PCBs, this was not required. The MCPCB is required when components generate a lot of heat and it has to be efficiently radiated into the environment. Thermal properties of normal PCB made out of FR-4 are very bad. The metal core ensures low thermal resistance and components can be cooled much more efficiently.

As there is only one layer, when LEDs are on one side, it is impossible to put the connector on the other side. To solve this issue the required headers used for the connection will be placed at the top layer, but upside-down through a hole in the PCB, see Figure 4-3. This way the connection to the LED driver unit can be done. Those two boards together will form a LED unit. LED units can be connected together using a card edge. The

card edge connector that is used to do that is a 10-pin connector, 009159010061916, see Figure 4-2 for a picture from the datasheet.

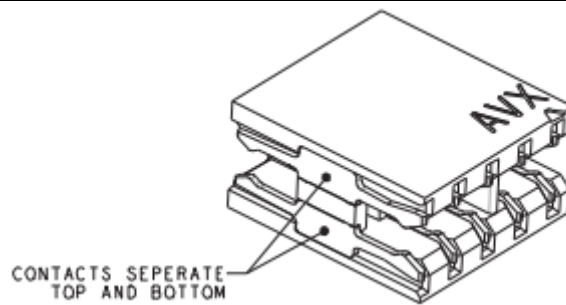


Figure 4-2 10 pin card edge connectors [3]

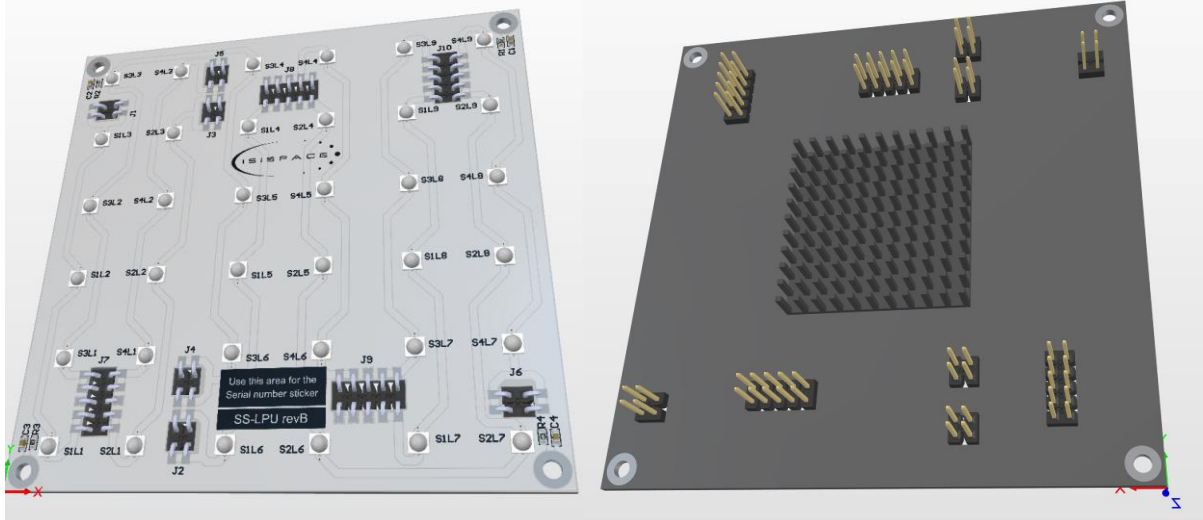


Figure 4-3 LED Plate Unit (LPU) PCB 3D render

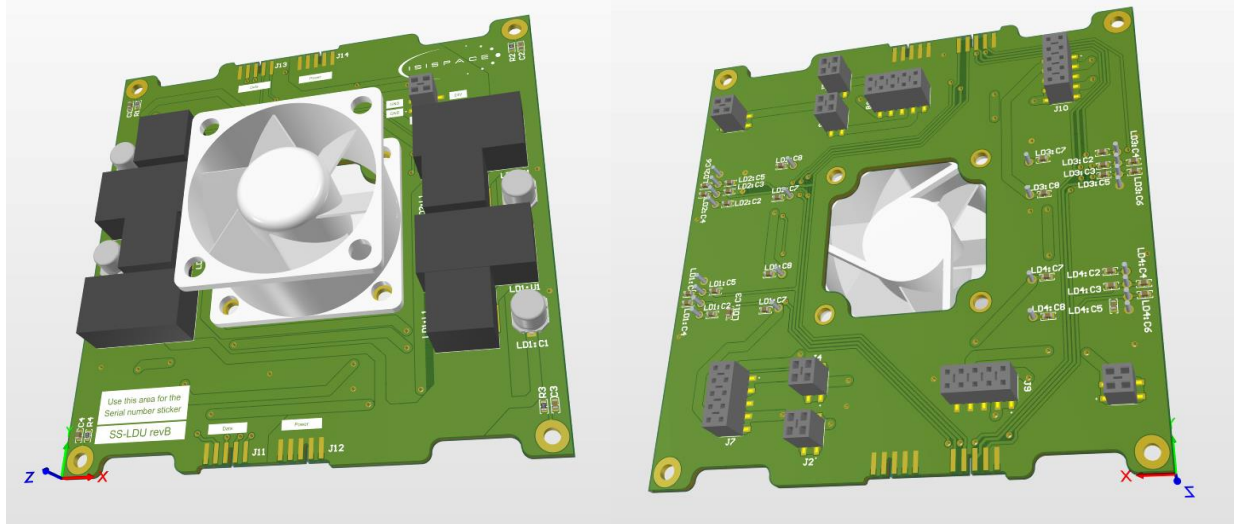


Figure 4-4 LED Driver Unit (LDU) PCB 3D render

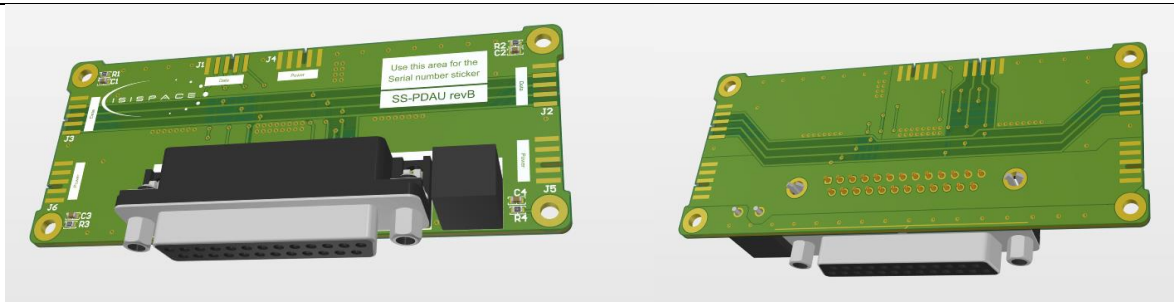


Figure 4-5 Power/Data Adapter Unit (PDAU) PCB 3D render

4.3 The LEDs

The sun simulator has to produce light suitable for solar panel testing. The solar panels, as explained in 3.1, have three layers which have different spectral response. To ensure that the solar panel is correctly generating electricity, every layer has to be lit with the spectrum of light that the layer is sensitive to. As LEDs have very narrow spectral output, each layer will require its own type of LED.

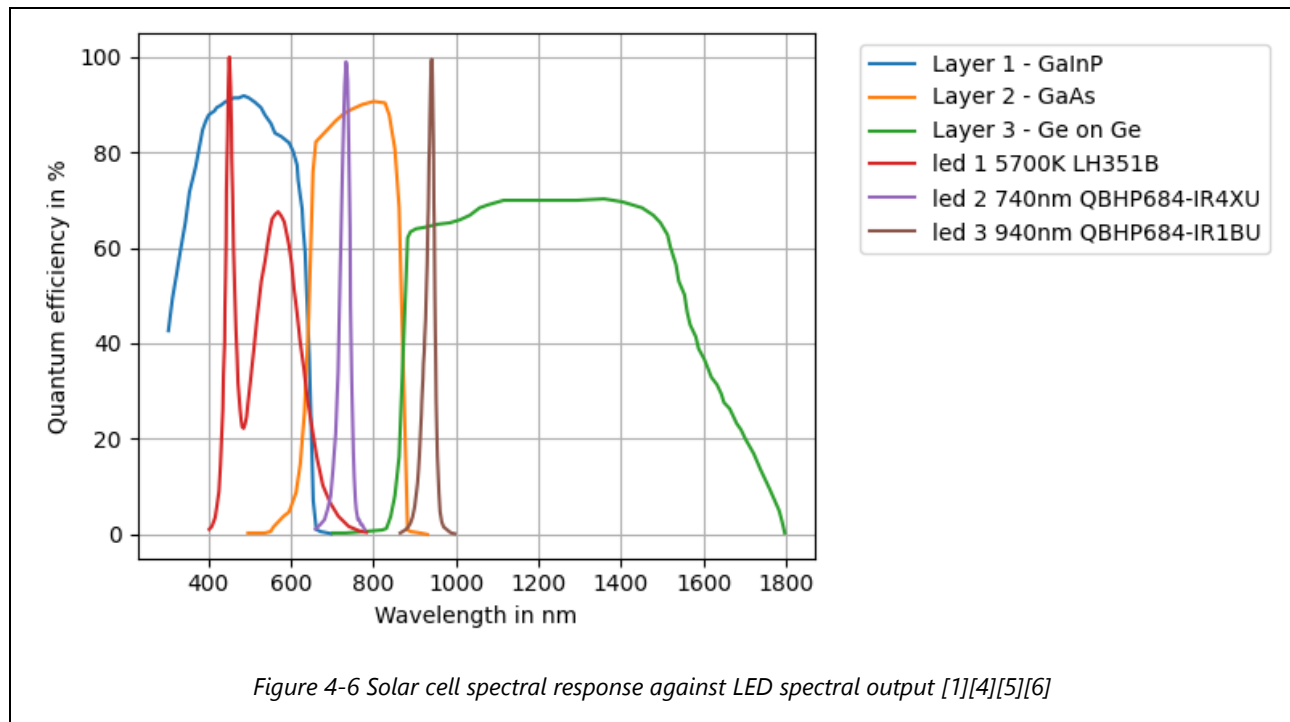
The spectral response of the cells was shown in Figure 3-1. With the old sun simulator, it was proven that a single type of LED for each layer works very well. The LEDs were reconsidered again for this project. But some LEDs stayed the same, as they got selected again when LEDs got chosen again.

4.3.1 Chosen LEDs

The chosen LEDs are the following:

- SPHWH2L3D30CD4QTP3 – a visible light LED
- QBHP684-IR4BU – IR LED at 740nm (same as in old sun simulator)
- QBHP684-IR1BU – IR LED at 940nm (same as in old sun simulator)

Those LEDs were chosen because of their spectrum, power output and view angle (120°). The design had space for 4 different LED types. The initial idea was to improve the IR performance of the sun simulator by using extra type of IR LED. A LED that generates light in longer wavelengths would be desired. At this spectral output LEDs are slowly getting more and more expensive and at around 1000nm the price per unit starts to go up very quickly. A very good candidate for the fourth LED was LZ1-10R802-0000. This LED could generate light at peak wavelength of around 1050nm. The price per unit was more than 10 times the price of other LEDs at around 30 euro per LED. It was more of a nice to have than a requirement, so the same 940nm LED (QBHP684-IR1BU) was chosen for the fourth string as well. The layer's efficiency zones and LED spectral output is shown in Figure 4-6.



The data of those LEDs can now be further checked to ensure that they indeed are sufficient. For this the formula and script from paragraph 3.2 is used. In Table 4-1 the required radiant flux and the LED generated radiant flux is shown. The radiant flux that is generated by LEDs and absorbed by the cells shall be higher than required radiant flux in the area of a single LPU. This is indeed the case with the given LEDs. Layer 3 has 2 LED

strings dedicated for it as it was known to be underpowered in the old sun simulator. In the data it can be clearly seen that just one string would not be enough, but two are.

Table 4-1 Radiant flux requirement for each layer of solar cell calculated using the formula

Radiant flux (W) required for each layer of the solar cell and generated by the LED			
Layer	GaInP layer	GaAs layer	Ge on Ge layer
Required radiant flux (W/100cm²): $\int h(\lambda)d\lambda$	5.23	2.62	2.59
Total radiant flux of 9 LEDs (W): $9 \int i(\lambda)d\lambda$	8.37	3.78	3.47
Absorbed radiant flux of 9 LEDs (W): $9 \int j(\lambda)d\lambda$	6.55	3.32	2.23* *(two strings used for total of 4.46W)

Same data is also plotted in Figure 4-7, Figure 4-8, Figure 4-9. Solar power, the relative or felt solar power by the layer, power of 9 LEDs and the light of the LED felt by the layer is plotted there.

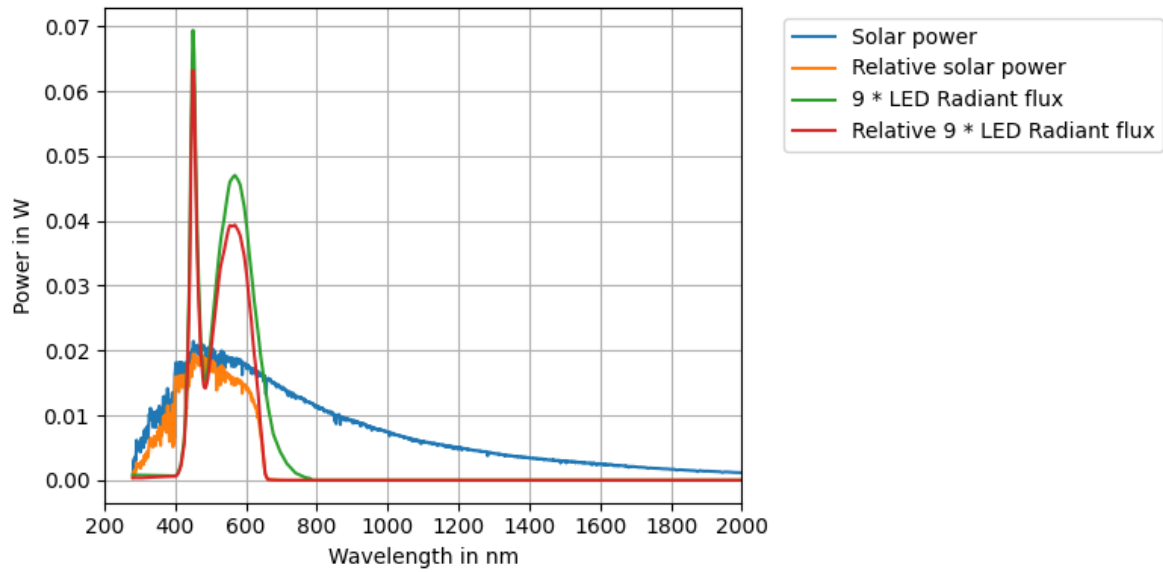


Figure 4-7 Solar power, relative felt solar power, LED radiant flux and relative felt LED radiant flux plotted against each other for GaInP layer

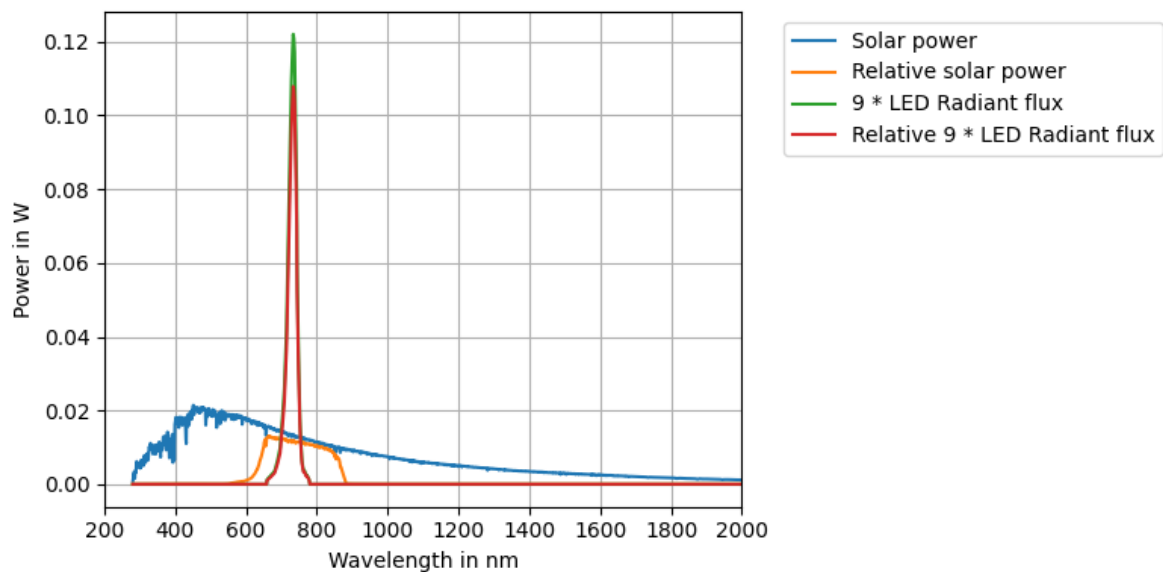


Figure 4-8 Solar power, relative felt solar power, LED radiant flux and relative felt LED radiant flux plotted against each other for GaAs layer

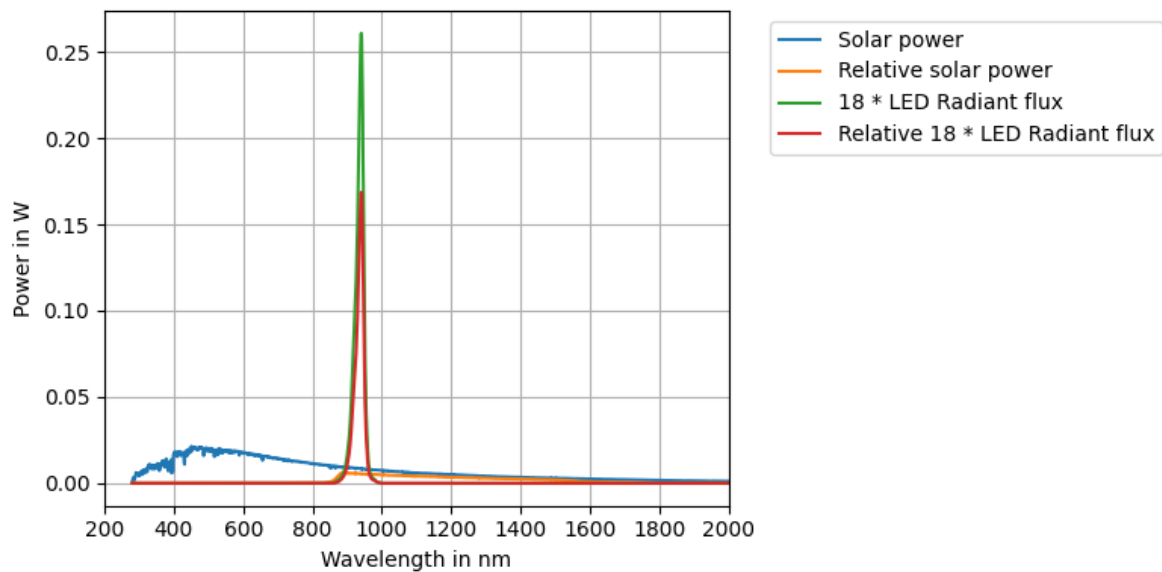


Figure 4-9 Solar power, relative felt solar power, LED radiant flux and relative felt LED radiant flux plotted against each other for Ge on Ge layer

4.3.2 Other LEDs

More LEDs were considered, in this section some of them details will be discussed.

SFH 4725S – this LED would be a good addition to the long wavelength LEDs at 950nm, but the only issue was the viewing angle of 90°.

SFH 4737 – This LED was very promising, as it could generate light at a wide spectrum at IR frequencies, but the output at those frequencies was very low. This LED generates mostly visible light. This could work as a replacement for visible light LED while generating a little bit of IR light at wide spectrum. The main issue is that this LED is much weaker than most visible light LED s. Also, this LED has different solder pad than most high-power LEDs, keeping the standard solder pad makes the design compatible with most other high-power LEDs. Viewing angle is 130° which would work as it is very close to 120°. All things considered, this LED would not work very well.

Many other LEDs were considered, but in general they were quickly eliminated as had too many undesired parameters, like viewing angle or output power.

4.4 The prototype design

In Figure 4-10 and Figure 4-11 a render of the prototype is shown. For the prototype a matrix of 2x2 LED panels shall be built. This will enable the test possibility for all essential components of the design.

The boards shall be tested as single units initially, but this does not allow to test the system as a whole. When in the matrix formation, also the interconnections can be tested and whole system can be evaluated.

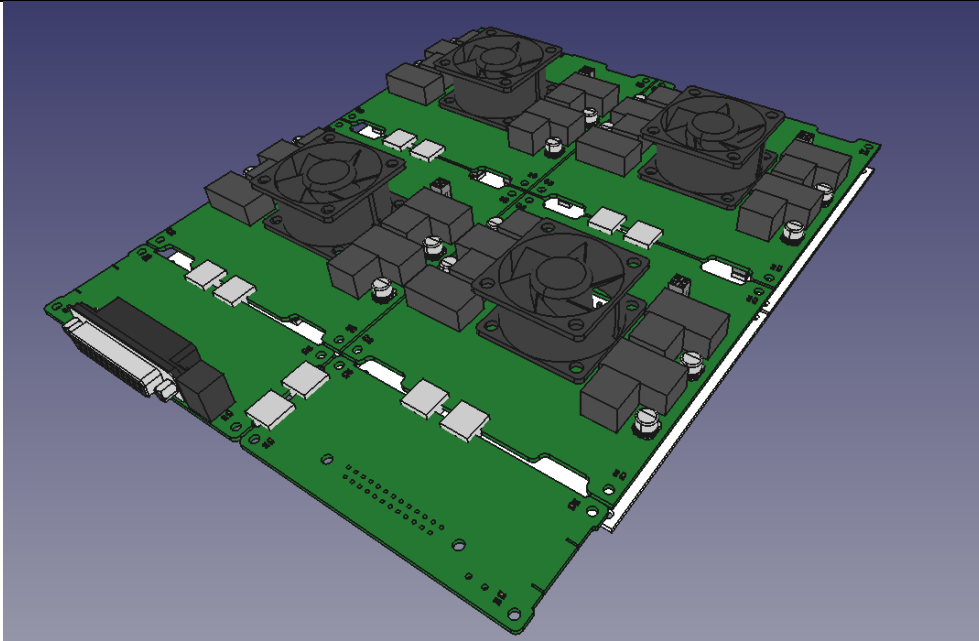


Figure 4-10 The top view of the prototype of the lamp unit

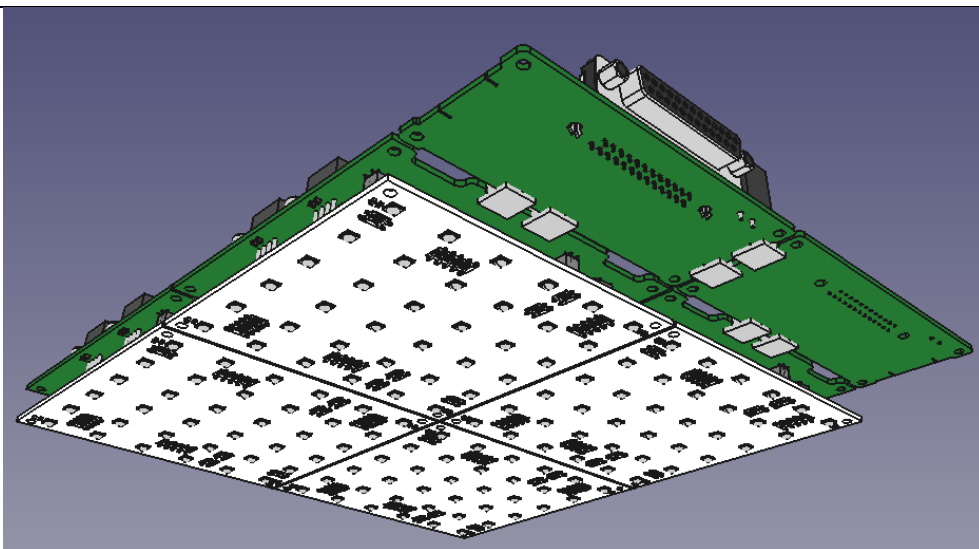


Figure 4-11 The bottom view of the prototype of the lamp unit

4.5 Prototype and test of the lamp unit

On this chapter the prototype lamp unit is tested and evaluated.

4.5.1 The LED plate assembly

The lamp unit was assembled. The prototype can be seen in Figure 4-12 and Figure 4-13. In the picture a

reworked version is seen, that will be further explained in paragraph 4.5.2.2.

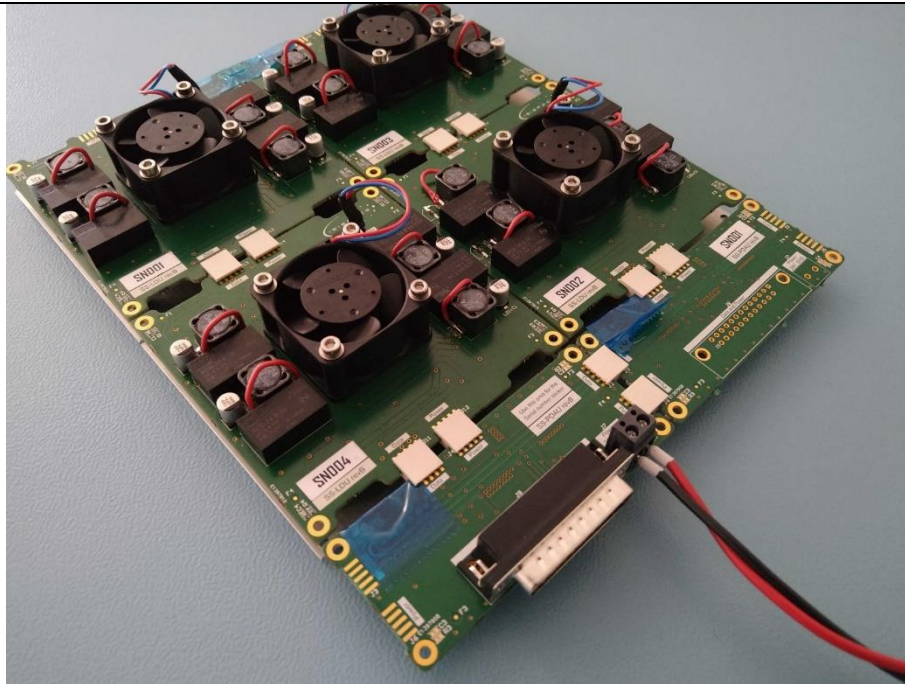


Figure 4-12 Prototype top

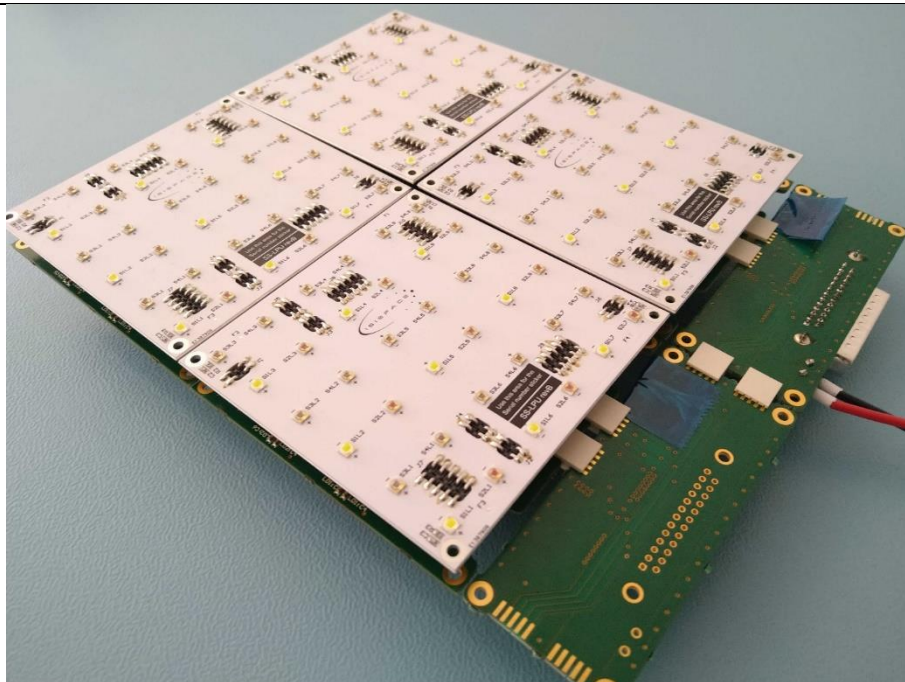


Figure 4-13 Prototype bottom

4.5.2 Initial test

The boards were assembled to form a single unit. The LPU (LED Plate Unit) was connected with the LDU (LED Driver Unit) using the terminals present on the board. The PDAU (Power and Data Adapter Unit) was connected to the LDU. It was discovered that the 24V and GND pins of the PDAU and 24V and GND pins of the LDU were

swapped relative to each other. A work around for this issue was to connect 24V to the GND pin and GND to the 24V pin. To not cause a short the data connector should not have been connected as it also had GND pins which would be connected to 24V on the PDAU and GND on the LDU with this work around.

With the polarisation issue been noted, the next test was to power up the setup and document its behaviour. After turning it on the LEDs did light up, but there was a high pitch noise coming out of the board and white LEDs weren't fully lit. Initially the noise was thought to have been an effect of the LED driver's disability to feed the white LEDs. It appeared that the total voltage that will be present on the visible light LEDs at full power (1,2A) would be higher that the input voltage.

From the datasheet [4] the forward voltage and forward current relation can be found on page 16. As the LEDs are supplied 1,2A at most, this means a forward voltage of approximately 3,1V. As there are 9 LEDs in the string, this would mean the following is true:

$$\text{Required input viltage} = 3,1V \cdot 9 = 27,9V$$

The supply voltage is set to 24V which is below the 27,9V that was calculated. This seems like an obvious parameter to check. The main issue why this could have occurred is the supply chain issue and constant need to change the LED. Therefor those parameters of the new LED have been missed. After all issues have been addressed a test was performed using the 2x2 matrix. The full power mode was tested for approximately 30 minutes. The PWM and Analogue control was also tested and it performed as expected. The test can be seen in Figure 4-14.

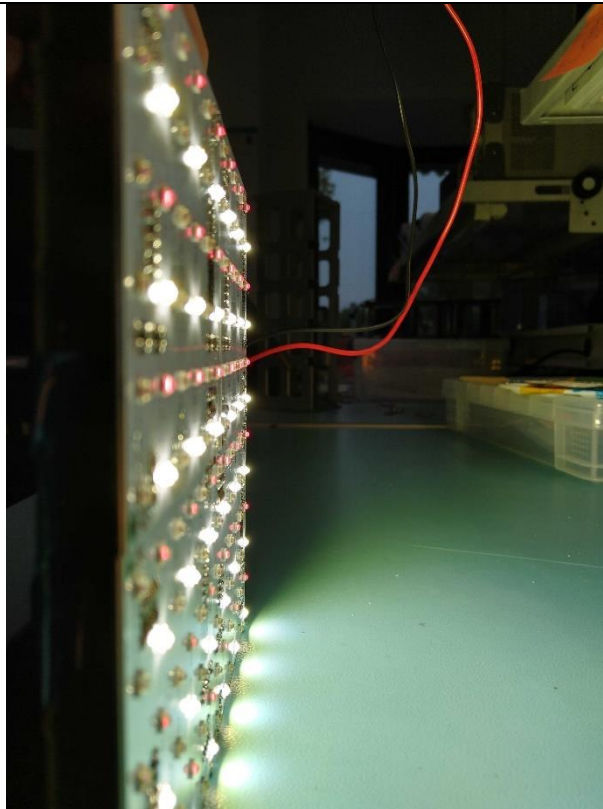


Figure 4-14 Full power test. Notice the camera adjustment. Background room looks dark while being properly illuminated and in day time.

4.5.2.1 LED power fix option

This issue of LED not been able to be powered at maximum power can be solved by decreasing the maximum allowed current and slightly increasing the voltage. Of all the components on the LDU the fan can handle the

lowest maximum voltage at 28V. The decrease of maximum current would mean that the maximum radiant flux would be also lower. To ensure that the radiant flux in W/m^2 is still correct, a recalculation will be required. The power of the LED can be checked on multiple current sources. The LED driver that is used is the RCD-24 series. The current LED driver for white LEDs is the 1,2A version. The other available versions are 1,0A and 0,7A or lower. The values for 1,0A and 0,7A will be checked. The required effective radial power is 5,22W. In Table 4-2 the data is shown.

Table 4-2 Power output for 9 LEDs of SPHWH2L3D30CD4QTP3 type for different current sources.

Current on the string	LED forward voltage at given current	Total voltage required	Effective radiant flux (power felt by GaInP layer)
1,2A	3,10V	27,90V	6,55W
1,0A	3,01V	27,27V	5,33W
0,7A	2,95V	26,55V	3,64W

From the data in Table 4-2 it is very clear that input voltage will need to be increased. The lower current source of 1,0A could be used to keep voltage a little bit lower than the input voltage.

Another idea is to replace some of the LEDs on the string 4 with visible light LEDs. This would make string 4 a more general LED string. A ratio between the two LEDs can be decided by calculating all possible combinations and choosing the combination giving the most flexibility. In Table 4-3 power output of LEDs is given for a certain number of LEDs. As some of the IR LEDs in string 4 are replaced by visible light LEDs the power output of each type of LED is reevaluated. More visible LEDs mean less IR LEDs. The best LED combo is marked in green. LED type 1 is the visible light LED. Type two the IR LED (700nm to 900nm). Type 3 is the IR LED (900nm to 1800nm). The type 1 and 3 will be reevaluated.

Table 4-3 LEDs relative power for numbers from 9 to 18. Current source of 0,7A

	LED Type 1	LED Type 2	LED Type 3
Relative Radiant Flux (W) (0,7A)	0,40	0,37	0,25
Number of LED	Total light power (W/100cm ²)		
9	3,64	3,32	2,23
10	4,04	3,69	2,48
11	4,44	4,06	2,73
12	4,85	4,43	2,98
13	5,25	4,80	3,22
14	5,66	5,17	3,47
15	6,06	5,54	3,72
16	6,46	5,91	3,97
17	6,87	6,28	4,22
18	7,27	6,65	4,46

Using 5 extra visible light LEDs would be sufficient at 0,7A. The minimum required radiant flux of the LPU for

the GaInP layer (layer 1, visible light) is 5,23W. For the Ge on Ge layer (layer 3, for ~1000nm light) minimum required radiant flux of the LPU is 2,59. The input voltage is required to be increased, however now it will not be at the edge of functionality. At 0,7A the forward voltage of the visible light LED would be 2,95V. For one string of 9 LEDs, it would translate to 26,55V. Considering the efficiency of the LED drivers is 96% at full load, it would mean that minimum voltage required is 27,66V.

$$\text{Minimum required voltage} = \text{maximum led string voltage} \cdot \frac{1}{\text{led driver efficiency}} = 26,55 \cdot \frac{1}{0,96} = 27,66V$$

Best option will be to let the system work at 28V. This way all electronics can be supplied with the power they require.

4.5.2.2 Oscillation of the filter circuit

The LED Plate Unit worked; however, it made a noise while working. After investigation and advice from the RF&E members the general notion was, do not make filters unless it is known what it is needed to filter. To not waste too much time on this issue, the coils were shorted and the noise on the signal was gone. As a general practice, do not use filters for unspecified signals.

5 Motherboard design and PSU

The motherboard will control the entire sun simulator. The tasks of the motherboard are the following:

- Host a user interface
- Control the sun simulator light output per LED type
- Measure the voltage and current on the solar panel
- Read the telemetry from the solar panel
- Perform an IV curve test
- Semi-automate the bypass/blocking diode test
- Semi-automate the ELM (ElectroLuminescence Method) test

For the control of the device a microcontroller is required. Considering the ongoing chip crisis, the stock of the company was searched for the components. ATMEGA1280 is a very good choice considering its large number of ports, PWM capabilities and 16 ADC inputs. It was also in companies' stock and unused for any other projects.

Telemetry test can be performed automatically. Data shall be directly read from the solar panel and processed by the motherboard.

To generate an IV curve, a controllable current source could be used. An operational amplifier circuit can be used for this task. This way a specific current can be drawn from the solar panel. By measuring both the current and voltage for many different current settings, an IV curve can be assembled.

To test the bypass/blocking diode, a simple resistor and diode under test voltage divider can be used. With resistor of value 4,7kΩ would let roughly 1mA for wide range of diodes. The voltage on the diode can be then measured using the probes. Data can be then acquired by the motherboard and processed.

For ELM test a current source can be used as well. In this case the current will be supplied from the motherboard. User will be able to use the red probe and connect it to the end of the string. This has to be done using a probe, as sending a current in reverse through a solar panel is impossible using the build in connector. The blocking diode on the solar panel does not allow that as its function is to block such currents. User will still be responsible for the picture of the cells.

5.1 The PSU

As this design is modular, the maximum power output should have power rating as high as possible for flexibility in the future.

For this project the RSP-3000 was the perfect power supply. It can supply up to 3kW of power. This power supply is modular and 3 of those can be connected in parallel. Then those power supplies can be connected to 3 phase net and a total of 9kW of power can be supplied. The sun simulator will be designed with upgradability from 1 to 3 PSUs in mind.

The output voltage can be tweaked between 20V and 28V. That makes it good as it was established with the previous test that higher voltage was required.

5.2 Motherboard design

In this chapter each design sheet will be explained. Whenever there is a reference to 24V net, it is the name of the net that was supposed to be powered by 24V, but now it was increased to 28V. The name remained 24V and will be referred as such in this paragraph.

5.2.1 Global design overview

Everything in the design is controlled from the MCU, which is controlled by the user through the build in user interface or PC connected through USB. The global overview is shown in Figure 5-1. For better visibility of the

sheets, refer to attachment 10.

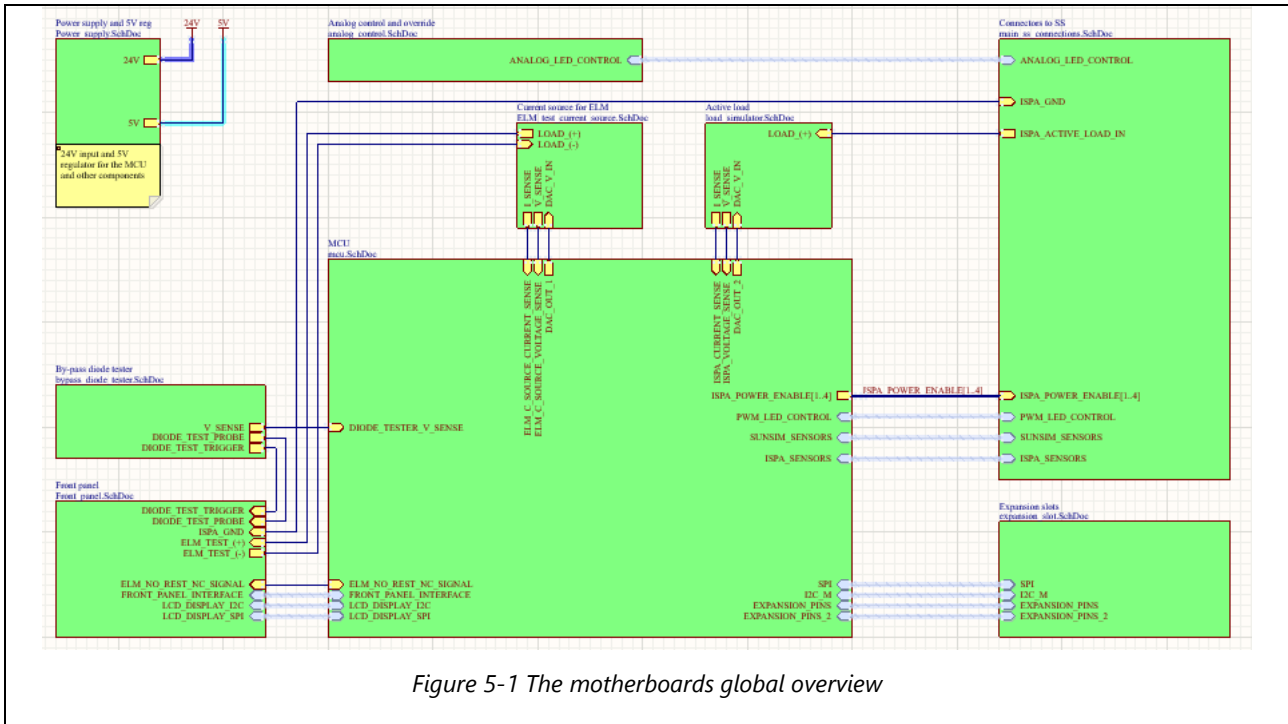


Figure 5-1 The motherboards global overview

5.2.2 Bypass and blocking diode tester

The bypass diode tester is very simple. The diode is connected in series with a 4,7kΩ resistor. This works well for wide range of forward voltages of the diodes.

If for a moment the voltage on the diode is ignored, the maximum current through the circuit can be determined.

$$I = \frac{V}{R} = \frac{5}{4700} = 0,00106A \text{ or } 1,06mA$$

When shorted, the circuit will conduct approximately 1mA. Now the behaviour with the diode will be evaluated. The current can be calculated by evaluating the voltage on the resistor first and calculating the current as before. For external bypass or blocking diode with forward voltage of roughly 0,3V in all of our tests. According to datasheet the value should be below 0,7V and the 0,3V for 1mA can be seen in the second graphs on page 6 of the PDS5100H datasheet[7]:

$$I = \frac{V_R}{R} = \frac{V - V_{th}}{R} = \frac{5 - 0,3}{4700} = \frac{4,7}{4700} = 1mA$$

$$I = \frac{V_R}{R} = \frac{V - V_{th}}{R} = \frac{5 - 0,7}{4700} = \frac{4,3}{4700} = 0,91mA$$

For the 1,2V forward voltage expected on the integrated bypass diode according to all our tests. According to the datasheet, maximum expected value is 2,5V at 620mA[8]:

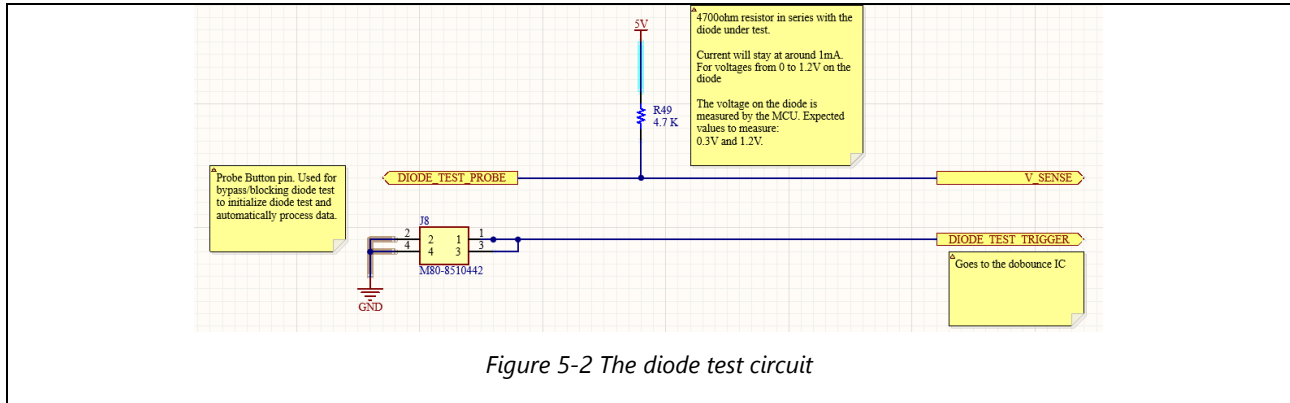
$$I = \frac{V_R}{R} = \frac{V - V_{th}}{R} = \frac{5 - 1,2}{4700} = \frac{3,8}{4700} = 0,81mA$$

$$I = \frac{V_R}{R} = \frac{V - V_{th}}{R} = \frac{5 - 1,2}{4700} = \frac{2,5}{4700} = 0,53mA$$

The 2,5V forward voltage will not happen as the current for it is too high. Our tests always used the multimeter with diode mode, with by itself is just a small 1mA current source. As for most of our diodes the current would

be around 1mA this is a valid and simple solution.

This was also tested in real experiment and result were identical to a multimeter measurement. This verified that this simple method can indeed be used. This simple circuit can be seen in Figure 5-2.



5.2.3 Active load

An active load uses an operational amplifier with conjunction of an MOSFET. Op-amp will try to keep the voltage on the negative input port same as the voltage on the positive port. This means that by setting the voltage on the positive port, op-amp will try to adjust its output so the voltage on the negative port stays the same. As a result, by having a known resistor, by forcing certain voltage on it, the current will also be known. This way the current on the output circuit can be forced.

The MOSFET will dissipate the most of the energy. This will require the MOSFET to be cooled down by a large heatsink. For the resistor, a small value should be used so high currents can be passed easily. For the resistor a value of 100mΩ was chosen. From these all-other values can be calculated. For example, if the voltage on the resistor is set to 1V, the current will be then U/R thus $1/0,1$ thus 10A. Varying the voltage on the resistor gives a linear control over the current. To gain full control of the current spectrum, the 5V output of a DAC is passed through a voltage divider to decrease the maximum voltage to 1V. That DAC is controlled by the MCU, this is further shown in paragraph 5.2.5.

The circuit of the active load is shown with all the components mentioned before in Figure 5-3. The current of the solar panel relative to voltage output from the MCU is plotted in Figure 5-4.

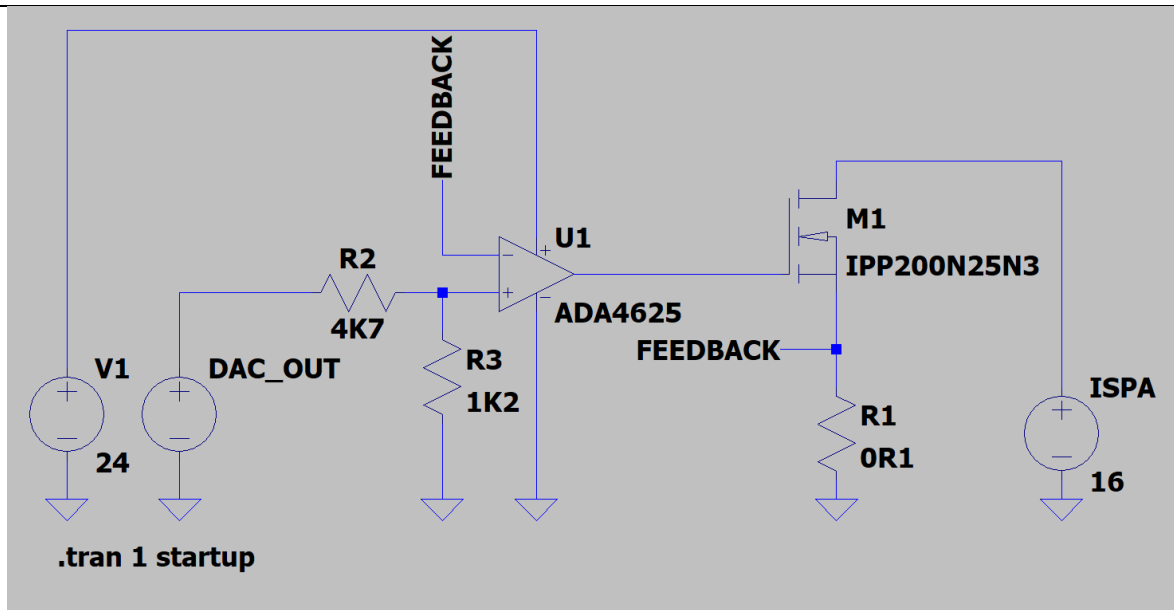
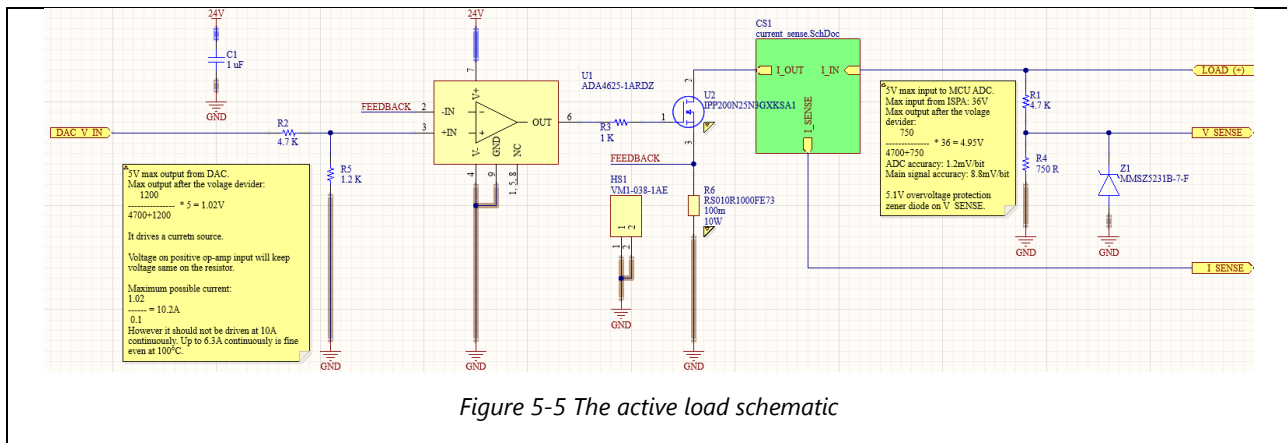


Figure 5-3 Active load simulation



Figure 5-4 Active load Current trough ISPA circuit relative to DAC output

The circuit used can be seen in Figure 5-5. This is the actual circuit used on the motherboard. Functionally it is the same as the circuit seen in Figure 5-3.



5.2.4 Current sense

The current sense uses the INA2XX-Q1 family ICs. This current sense IC can amplify the voltage on the shunt resistor to meaningful voltage for use with the microcontroller. This is a signal that can be read by a Microcontroller ADC port, which is a 10-bit 5V input. In general, the values have the following relation:

$$INA_{V_{OUT}} = Gain * V_{Shunt_{MAX}}$$

$$V_{Shunt_{MAX}} = R_{Shunt} * I_{MAX}$$

For the Active load the INA210-Q1 is used with a shunt resistor of $1\text{m}\Omega$. As maximum designed current for the Sun simulators active load circuit is 10A .

Those values can be put into the formula:

$$V_{Shunt_{MAX}} = R_{Shunt} * I_{MAX} = 0,001 * 10 = 0,01V$$

$$INA_{V_{OUT}} = 200 * 0,01V = 2V$$

For the ELM test current of 0,1A at most is expected and shunt resistor of 10mΩ. For greater amplification, the INA212-Q1 is used here. This can also be checked:

$$V_{Shunt_{MAX}} = R_{Shunt} * I_{MAX} = 0,01 * 0,1 = 0,001V$$

$$INA_{V_{OUT}} = 1000 * 0,001V = 1V$$

Again, the voltage is amplified to meaningful values that can be read by the MCU. In case current are higher than expected they can still be read by the MCU using its ADC port, as it can read signals to up to 5V. As it is implemented as a single sheet, using Altium variation feature, the specific component can be adjusted easily for each circuit in the schematics. The general circuit can be seen in Figure 5-6. This circuit is used in many products around the company and the resistor and capacitor values were predefined by existing designs.

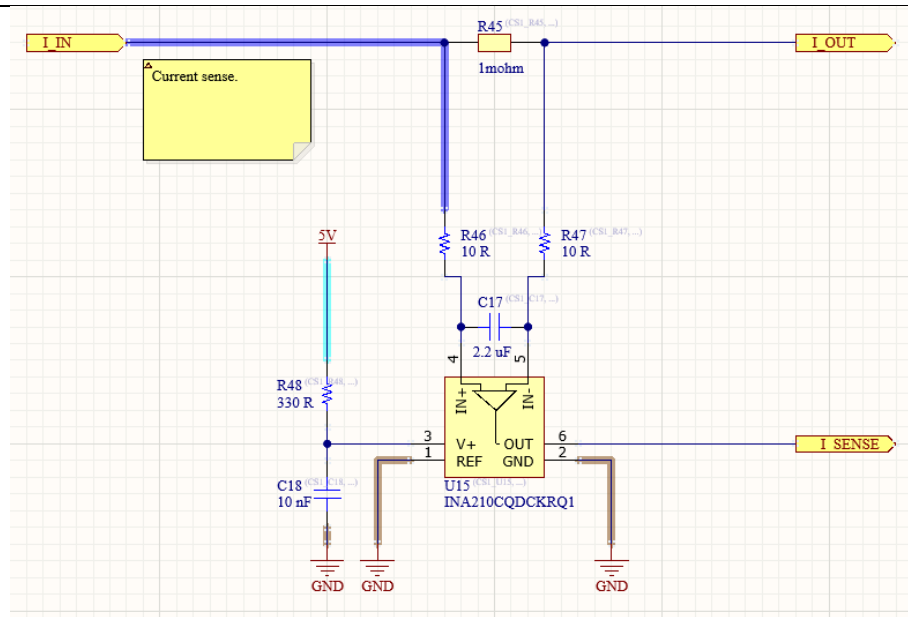


Figure 5-6 Current sense circuit

5.2.5 Microcontroller

The microcontroller is the brain of the device. The microcontroller used is the ATMEGA1280. This is very versatile microcontroller unit (MCU) and has a lot of GPIOs. It is Arduino compatible making it easy to develop software for. Currently it is quite hard to find any microcontrollers on the market because of the chip shortage. This one is in our local company stock and not used in any of our products. With all of its parameters considered, this is a good choice from the project and logistic point of view.

An alternative could be the MSP430. This MCU is also in our local stock and in high quantities. The reason to not use it is that it is critical for most of our products and if we can afford not to use it, then better to preserve them. This MCU is also way overpowered for what is required, what by itself is not a bad thing, but all things considered it is better not to use it.

The MCU has an analogue multiplexer IC for the sensor data input and a DAC IC for the active load and ELM current source.

The multiplexer used is DG408LEDQ-GE3. It is an 8-channel multiplexer. 8 Sensor were connected here. Sensor on the multiplexer are the general temperature and light sensor of the system. Solar panel related sensors are connected directly to the MCU ADC for speed and accuracy reasons.

The DAC used is DAC122S085C1MM. It is SPI controlled 2-channel, 12-bit DAC. There are 2 circuits that require the analogue signal. This DAC is therefore fitting. The 12-bits also add a lot of extra accuracy.

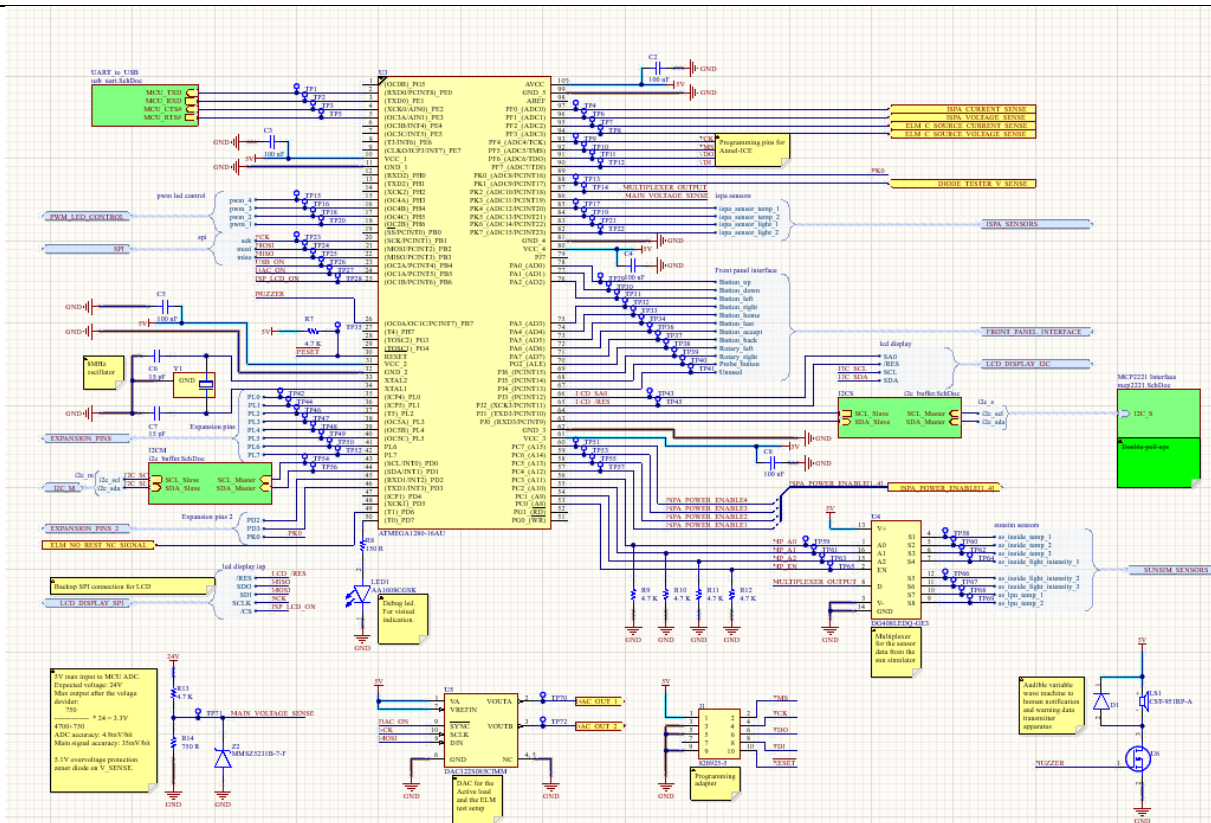


Figure 5-7 The MCU sheet. For details, refer the attachment.

5.2.6 I2C buffer

The I2C buffer utilizes the PCA9517ADP,118 IC. The main function of it is to stabilize I2C communication lines between master and slaves. The design for it is simple and is used around every product at the company. This designed was copied from existing designs as it is proven to work and is standard to use in any product at the company. The circuit can be seen Figure 5-8.

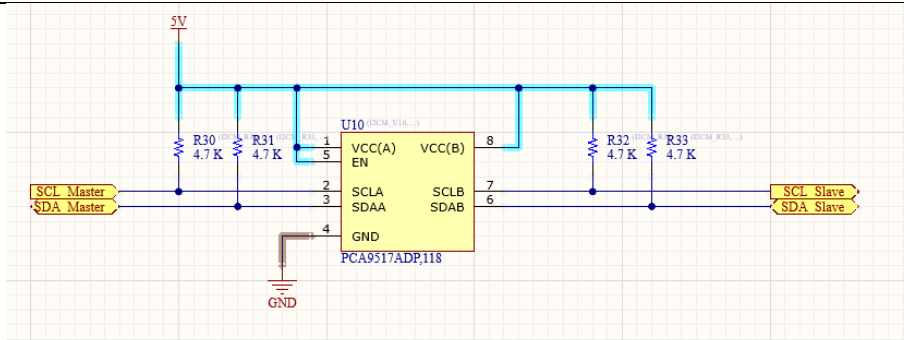


Figure 5-8 I2C buffer circuit

5.2.7 USB/UART converter

The USB/UART connection is meant for the MCU to PC communication. The main design is copied from the datasheet as it is already pre-defined how to use it for USB/UART communication. The full description can be found in the datasheet at page 27. [9] The circuit used is shown in Figure 5-9.

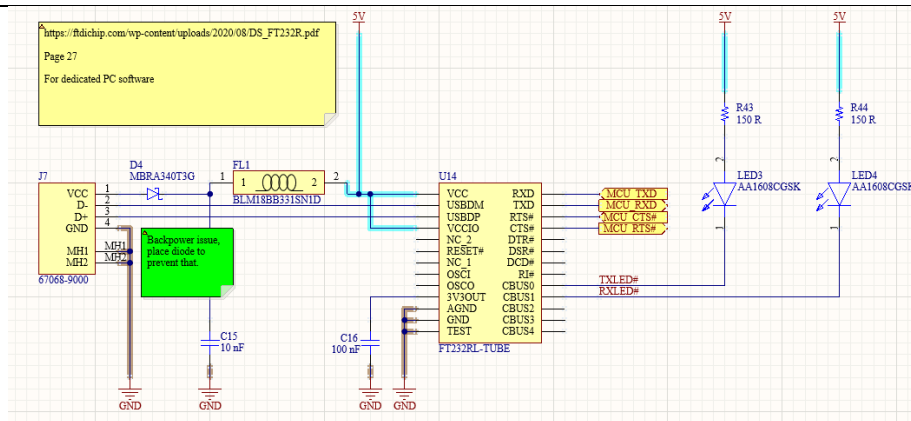


Figure 5-9 The UART to USB interface - FTDI

5.2.8 On board MCP2221 circuit for I2C communication

The MCP2221 circuit is literal copy of the circuit used on the ADM00559 board used around the company for USB to I2C communication. This type of communication is used with the subsystem interface develop at the company for all of the products and also test equipment. To make it easier to use, the circuit will be built into the sun simulator. The circuit is based on design published by microchip [10]. The circuit build for this is shown in Figure 5-10.

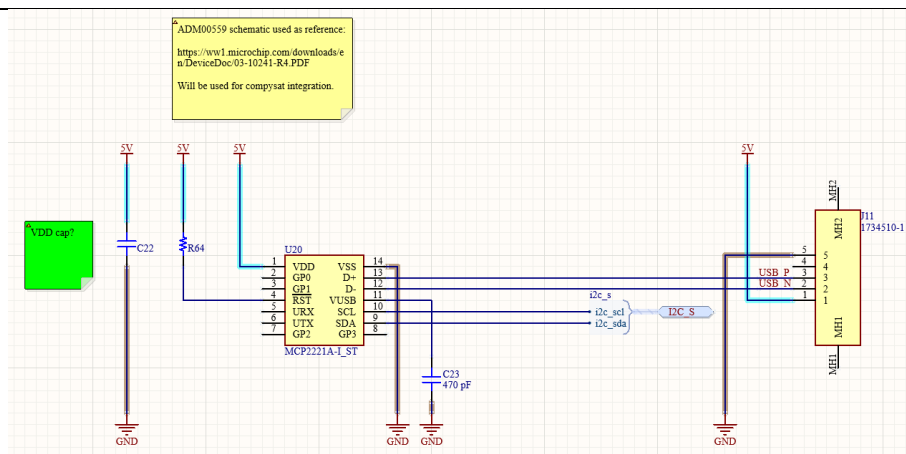


Figure 5-10 MCP2221 interface

5.2.9 Power supply

The power supply circuit consists of a block terminal where the 24V line and GND of the main power supply (RSP-3000) is connected. 24V is also connected to a 5V regulator. The output of the 5V regulator is also protected by a diode to prevent back powering from the USB connection. The circuit can be seen in Figure 5-11.

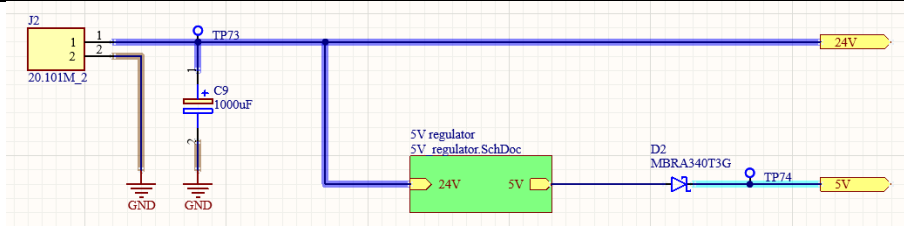


Figure 5-11 Power supply circuit

5.2.10 5V regulator

5V regulator consist of IFX27001TFV50ATMA1 IC. According to datasheet the regulator can supply up to 1A. The 5V line will only be used for low power components. The total absolute maximum expected current is in Table 5-1. The absolute maximum current on 5V line is thus 255mA. The circuit is shown in Figure 5-12.

Table 5-1 Currents per component on 5V line

Expected currents in mA			
Component	Max current in mA	number of components	Total current (mA)
INA210	5	2	10
MCU	0,5	1	0,5
DG408LEDQ-GE3	30	1	30
DAC122S085C1MM	20	1	20
PCA9517ADP,118	5	2	10
FTDI	15	1	15
MCP2221A-I_ST	13	1	13
MC14490DWG	10	2	20
NHD-0420CW-AY3	135	1	135
LMP7702MA_NOPB	1,5	1	1,5
Total current in mA			255

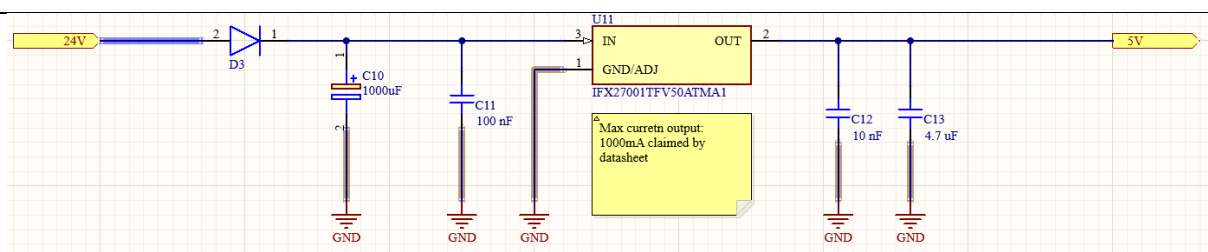
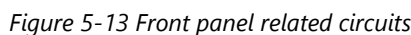


Figure 5-12 5V regulator

5.2.11 Front panel circuit

Front panel sheet consists of the front panel buttons connection, debouncer circuit and connection that further

Further there are resistors for screen mode. By default, the I2C mode is used, but ability to switch to SPI mode is implemented, in case it is required. The entire circuit can be seen in Figure 5-13, for detailed version, refer to attachment 10.



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The capacitor can be calculated in the following manner for 5V V_{DD} :

$$\frac{1,5}{C_{ext}(in \mu F)} = f \rightarrow \frac{1,5}{f} = C_{est}(in \mu F) = \frac{1,5}{1000} = 0,0015\mu F = 1,5nF$$

The value of 1,5nF is therefore used. To ensure proper power down behaviour, extra clamping diodes are used at the oscillator pins. Those are placed according to the datasheet specifications. The whole circuit is shown in Figure 5-14.

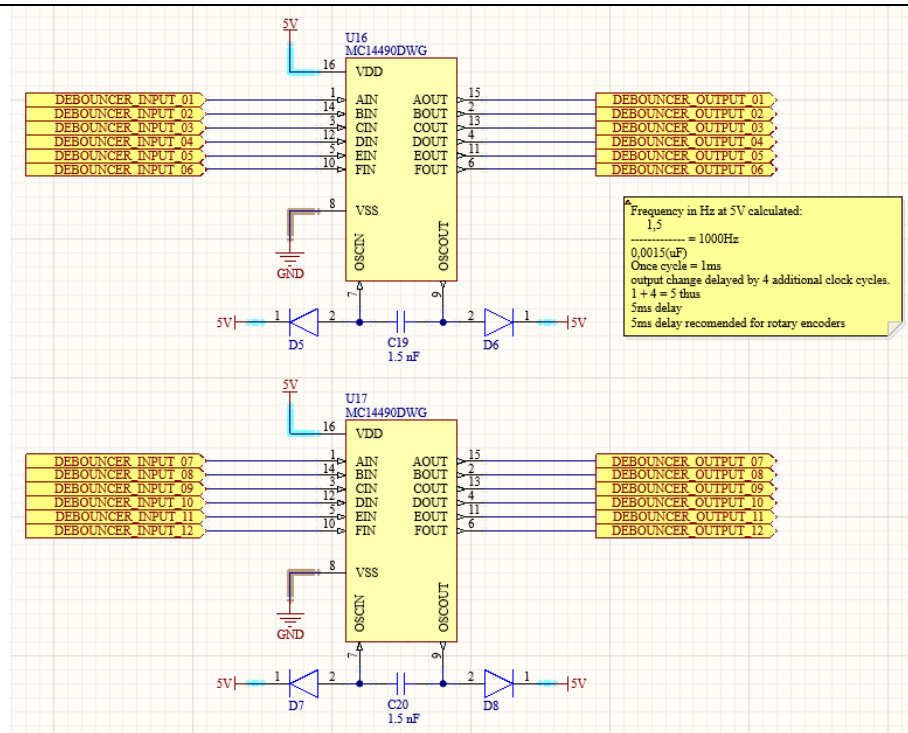


Figure 5-14 Debouncer circuit

5.2.13 Front panel interface

The front panel interface consists of the screen, buttons and the rotary encoder. Components on this sheet will be placed on the part after the flex part of the PCB. The bend part of the PCB will be connected to the front panel. This is further explained in paragraph 5.3. The circuit for it is shown in Figure 5-15. The screen used is a character display 4x20 characters in size.

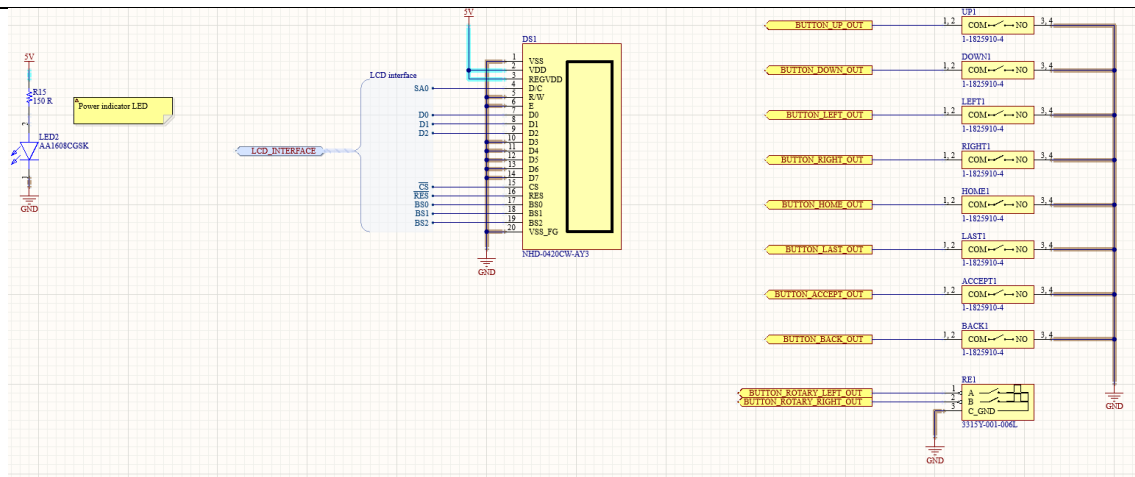


Figure 5-15 Front panel interface

5.2.14 Main sun simulator connection

This part connects all required nets from the motherboard to the lamp unit. The 24V line is connected through a separate connector. This is to ensure that the high currents that the lamp unit will require do not go through the entire motherboard and are separated from the main circuit.

The main connector also has connections for the PWM and analogue control. There are also connections for the sensors and the ISPA power lines.

Further there is a circuit for the temperature and light sensor data processing. Those are explained in paragraph 5.2.15. The circuit is shown in Figure 5-16. Refer the attachment 10 in for detailed view.

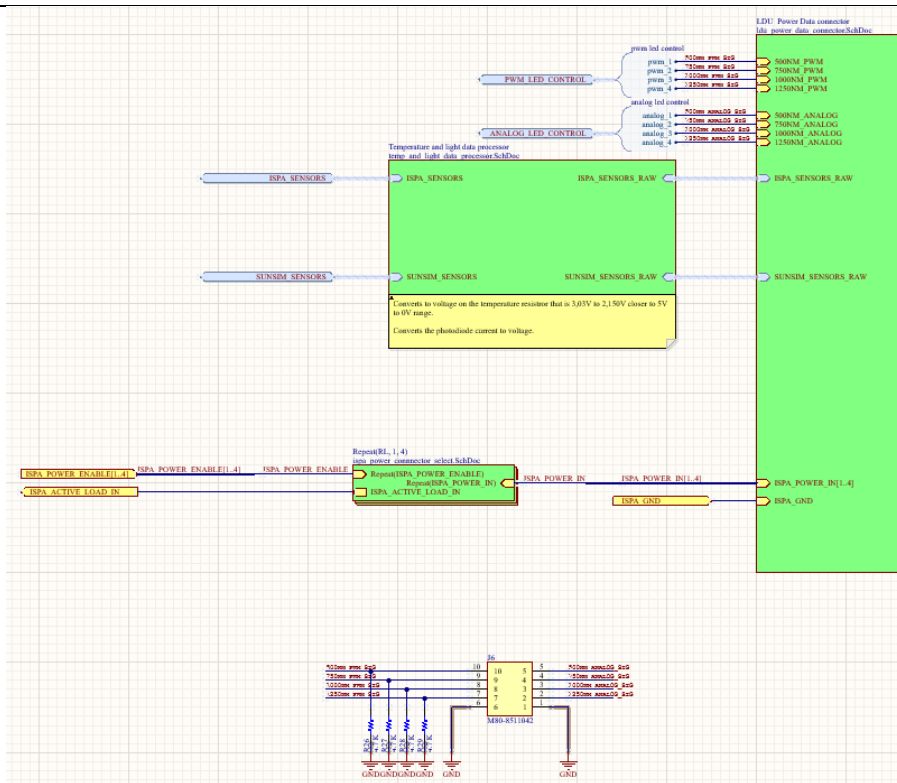


Figure 5-16 The main lamp connection circuit

5.2.15 Temperature and light sensor data processor

The temperature and light sensor are present in this sheet. There is technically existing design within the company, but apparently it is too complicated and a lot of risks are involved. It utilizes multichannel PTC temperature sensor IC, but is complicated to use and is not really necessary. It was advised to not use it for this project.

The temperature is measured by a PTC. As it is a resistor, the easiest way to measure the change in resistance is by use of a voltage divider. The basic idea is that the voltage from the voltage divider is converted to a value between 0 and 5V. This is to ensure full ADC usage and to increase the accuracy. The PTC used on the ISPA is PTS120601B1K00P100. Its nominal value is 1kΩ and ranges from roughly 780Ω to 1,4kΩ for temperatures from -55°C to 100°C. A resistor in between those values would give the highest voltage difference between the 2 maximus considered here, like 1,2kΩ. The circuit used can be seen in Figure 5-17.

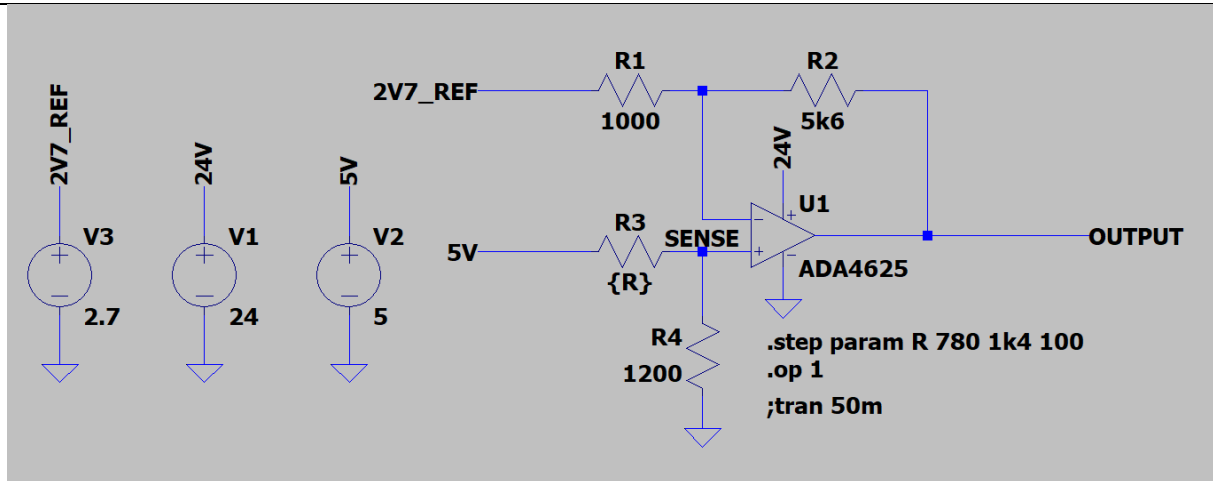


Figure 5-17 Temperature signal processing circuit

The voltage divider is made thus out the PTC and a 1,2kΩ resistor. Now the maximum and minimum voltage at the sense signal on the 1,2kΩ can be calculated:

$$V_{SENSE} = \frac{1200}{R_{PTC} + 1200} * V_{DD} \rightarrow V_{SENSE_{MAX}} = \frac{1200}{780 + 1200} * 5 = 3,03V \text{ \& } V_{SENSE_{MIN}} = \frac{1200}{1400 + 1200} * 5 = 2,31V$$

To normalize the value a differential amplifier can be used. The measured voltage needs to be lowered and then amplified.

The general formula for differential amplifier is:

$$V_{OUT} = V_1 * \left(\frac{R_2}{R_1 + R_2} \right) * \left(1 + \frac{R_4}{R_3} \right) - V_2 * \frac{R_4}{R_3}$$

The R1, R2 and V1 is already determined. R3, R4 and V2 still needs to be determined. In general, the voltage of roughly 2,3V needs to be removed and gain of roughly 5 is required. By applying those values to R3, R4 and V2, a value close to the desired, but with offset.

$$V_{OUT}(V_1, R_1, R_2, V_2, R_3, R_4) \rightarrow$$

$$\text{Max output: } V_{OUT}(V_1 = 5, R_1 = 780, R_2 = 1200, V_2 = 2,3, R_3 = 1000, R_4 = 5000) = 6,68V$$

$$\text{Min output: } V_{OUT}(V_1 = 5, R_1 = 1400, R_2 = 1200, V_2 = 2,3, R_3 = 1000, R_4 = 5000) = 2,35V$$

$$\text{Difference} = V_{OUT_{MAX}} - V_{OUT_{MIN}} = 6,68 - 2,35 = 4,33V$$

The difference is already close to 5, but the offset is too big. The reference voltage V2 can be changed to higher value so the output range is moved to lower values. As we have gain of 5, the increase should be 5 times lower.

$$V2_{NEW} = V2_{OLD} + \frac{V_{OUT_{MIN}}}{5} = 2,3 + \frac{2,35}{5} = 2,77V$$

This value is right on edge, so rounding up to 2,8V would result in negative output voltage which can't be used. The value will be rounded down to 2,7V. As we rounded down and have a lot of room to tweak the signal as difference is below 5V, the gain can be increased slightly to tweak the circuit further. A value of 5,6kΩ worked well.

$$V_{OUT}(V_1, R_1, R_2, V_2, R_3, R_4) \rightarrow$$

$$\text{Max output: } V_{OUT}(V_1 = 5, R_1 = 780, R_2 = 1200, V_2 = 2,7, R_3 = 1000, R_4 = 5600) = 4,88V$$

$$\text{Min output: } V_{OUT}(V_1 = 5, R_1 = 1400, R_2 = 1200, V_2 = 2,7, R_3 = 1000, R_4 = 5600) = 0,11V$$

$$Difference = V_{OUT_{MAX}} - V_{OUT_{MIN}} = 4,88 - 0,11 = 4,77V$$

Now the output of the temperature sensor is converted to a wider range that fits neatly within the 5V constraint. The good thing about this approach is that the output is linear transformation of the input value. This makes the math required to calculate the temperature much easier.

Circuit using those values is simulated in Figure 5-17 and Figure 5-18. In Figure 5-18 the output voltage over the changing resistor R3 is plotted. In the simulation R3 is the PTC.



Figure 5-18 Temperature signal processing circuit; output voltage relative to sense signal over R3 resistance change.

With this the design for the temperature circuit is fully functional. The output is connected to the ADC of the MCU.

Next is the photodiode. For this already functional circuit existed. This circuit was copied into the sun simulator design as it is known to work well. In short what it does, it converts the current source that the photodiode is, into a voltage source. This way the MCU can properly read the data. The circuit sheet is shown in Figure 5-19. Temperature processing circuit is shown in Figure 5-20 and light sensor data processing circuit is shown in Figure 5-21.

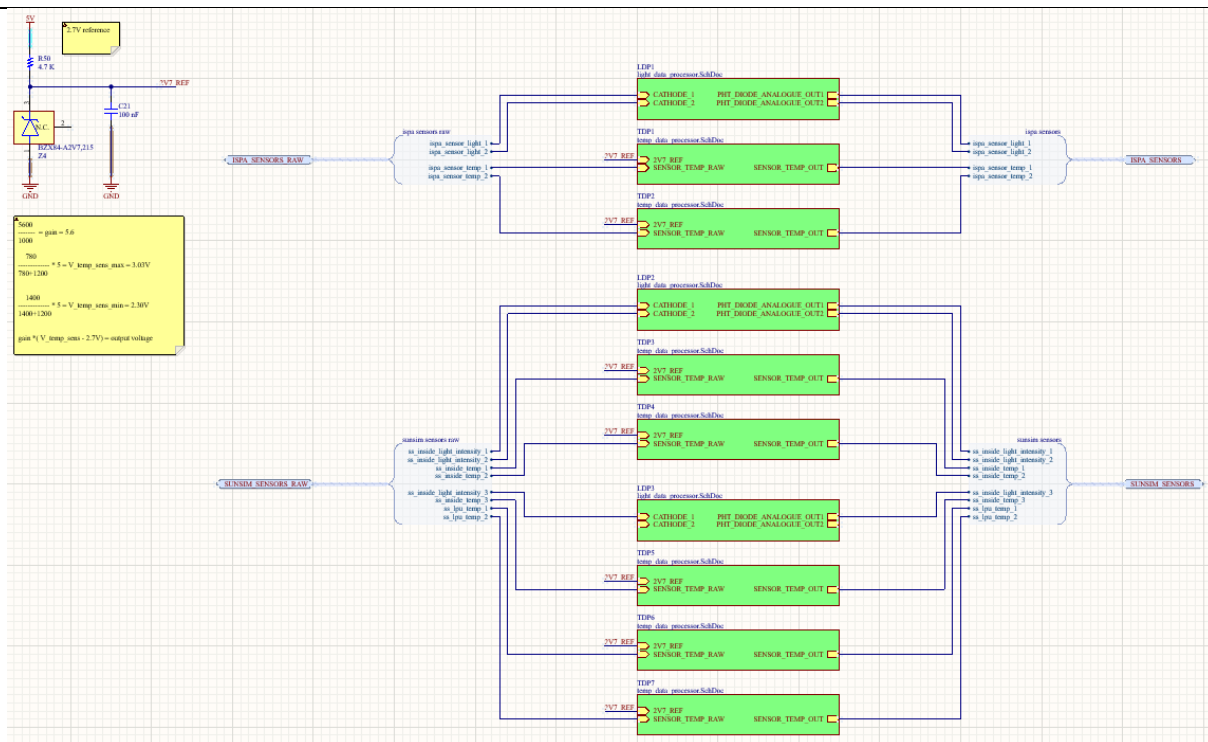


Figure 5-19 Sensor data processing

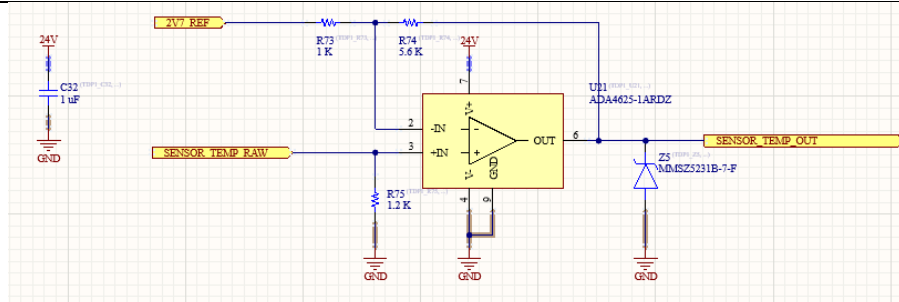


Figure 5-20 Temperature data processing circuit

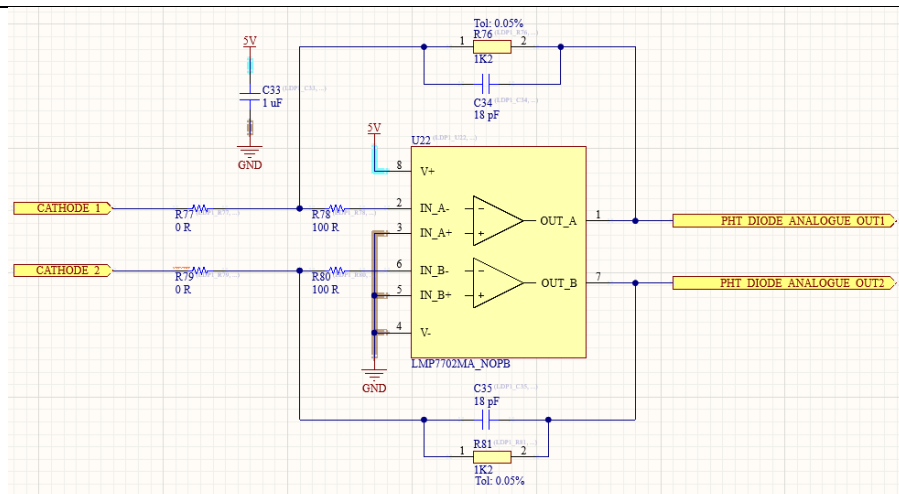
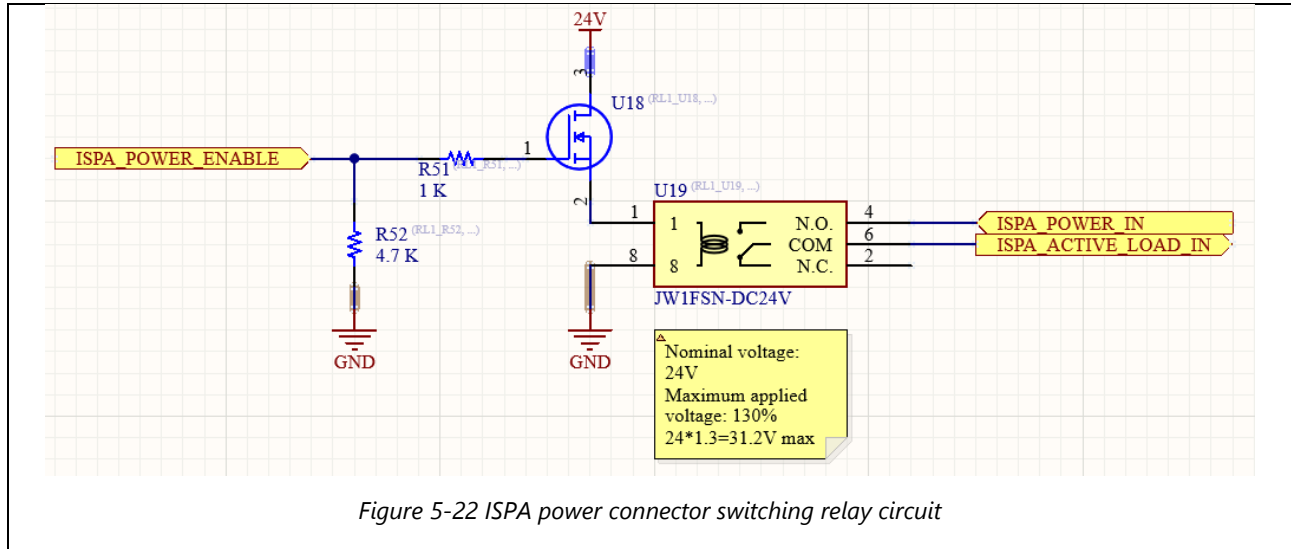


Figure 5-21 Light sensor data processing circuit.

5.2.16 ISPA power connector switching circuit

This simple circuit is a relay setup where the MCU can switch a power line of the ISPA on and off. MCU can switch on a MOSFET which can power a relay. The relay switches the ISPA power line on and off. The connection is connected to the active load input. This can be seen Figure 5-22.



5.2.17 LDU power and data connector

This is where the power and data to the lamp unit is coming from. A D-Sub harness will connect the sun simulator mother board with the lamp unit. A second power terminal block is placed here to limit the current through the mother board and making this line separate from the rest of the mother board. The PWM, analogue signal, The ISPA power and data connection and sun simulator telemetry is also connected via the master connector. The slave connector only supplies the power and PWM/analogue control to the lamp unit.

5.2.18 ELM test current source

The ELM (Electroluminescence Method) test makes the solar panels cell glow by letting a small current flow through them. With the new sun simulator, the idea will be to test multiple cells in a string, or multiple strings at the same time. Having control over the current will make it possible to test any number of strings and adjust the current if required for further investigation of the cells.

The necessary current is approximately 10mA. With more strings, this number can be multiplied by the number of strings.

For the current source a LT3092 is used. It is a simple to use current source with maximum output of 200mA. It can be used as fixed or programable current source. By applying certain voltage on the set pin, the output current can be set. The proposed circuit by the datasheet was used. The requirement is to be able to set a current across the cells to 10mA. Maximum number of strings for ISPA design at the time of writing this, is 4. With output of 100mA 10 strings could be tested, which is more than enough.

The circuit is very simple, output of the DAC goes to a voltage divider to change range from 0V to 5V to range from 0V to 1V. This range can control the output current from 0A to 100mA.

In Figure 5-23 and Figure 5-24 the circuit and simulation of it can be seen. R10 simulates the cell, value of the resistor does not matter as long as the desired current can flow through it with the given voltage source. The differential amplifier senses the voltage between the pins and the output is then down scaled through a voltage divider. The signal can be there read by MCU on an ADC GPIO.

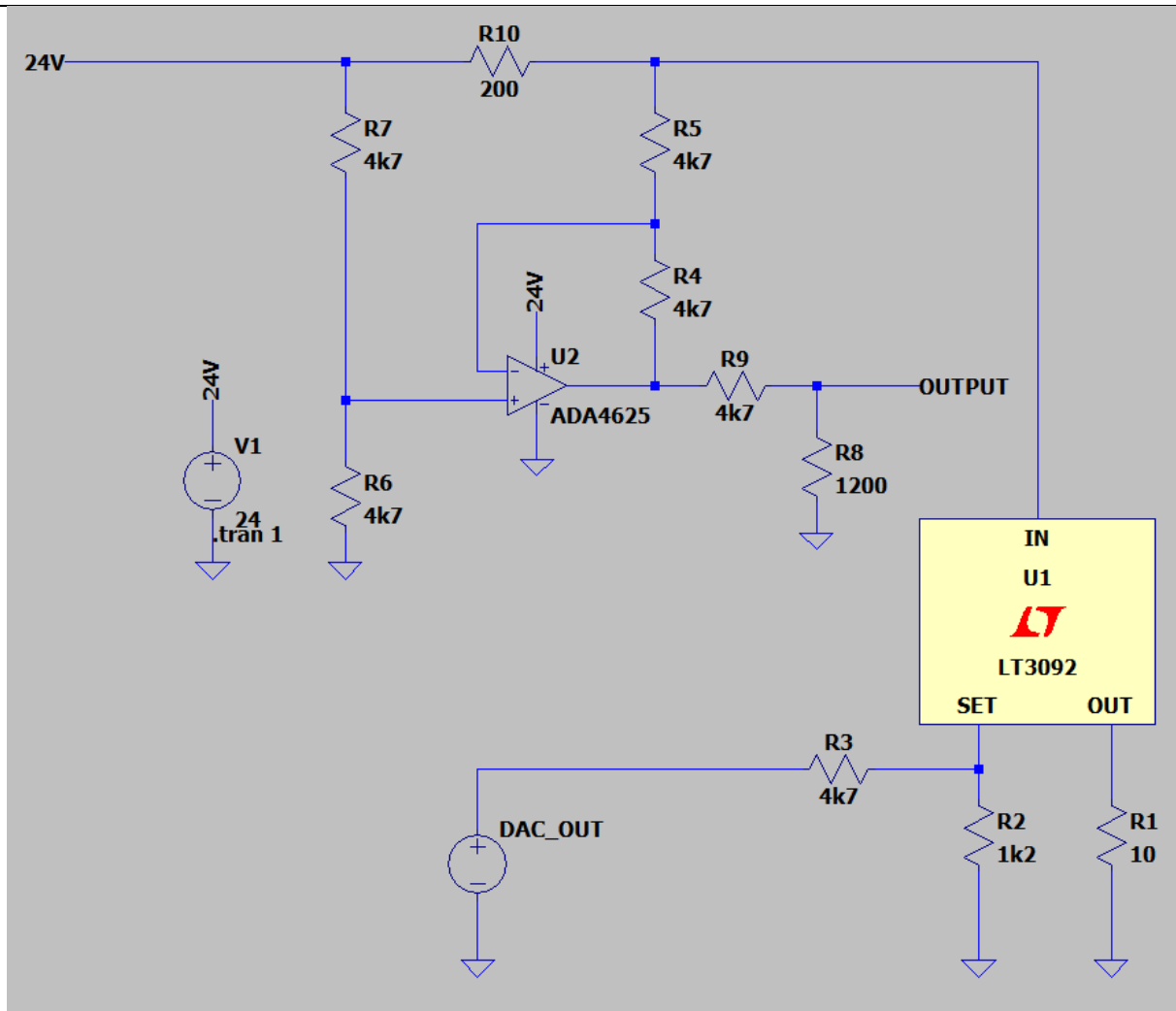


Figure 5-23 ELM test current source

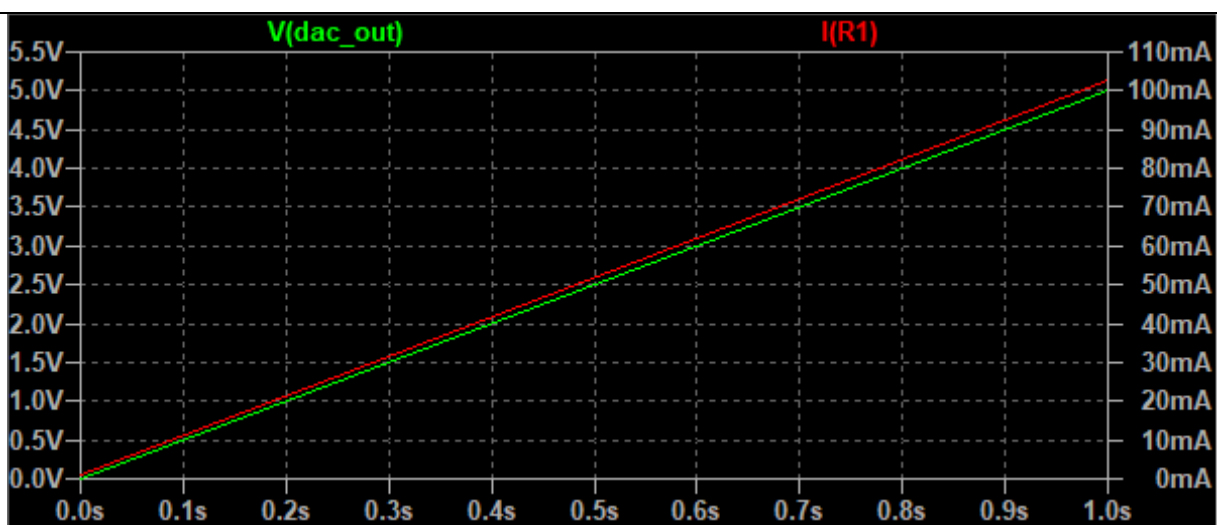


Figure 5-24 ELM test current source DAC voltage relative to current through ISPA cells

As seen in Figure 5-24, The conversion is completely linear, making the math required much easier. The circuit sheet is shown in Figure 5-23.

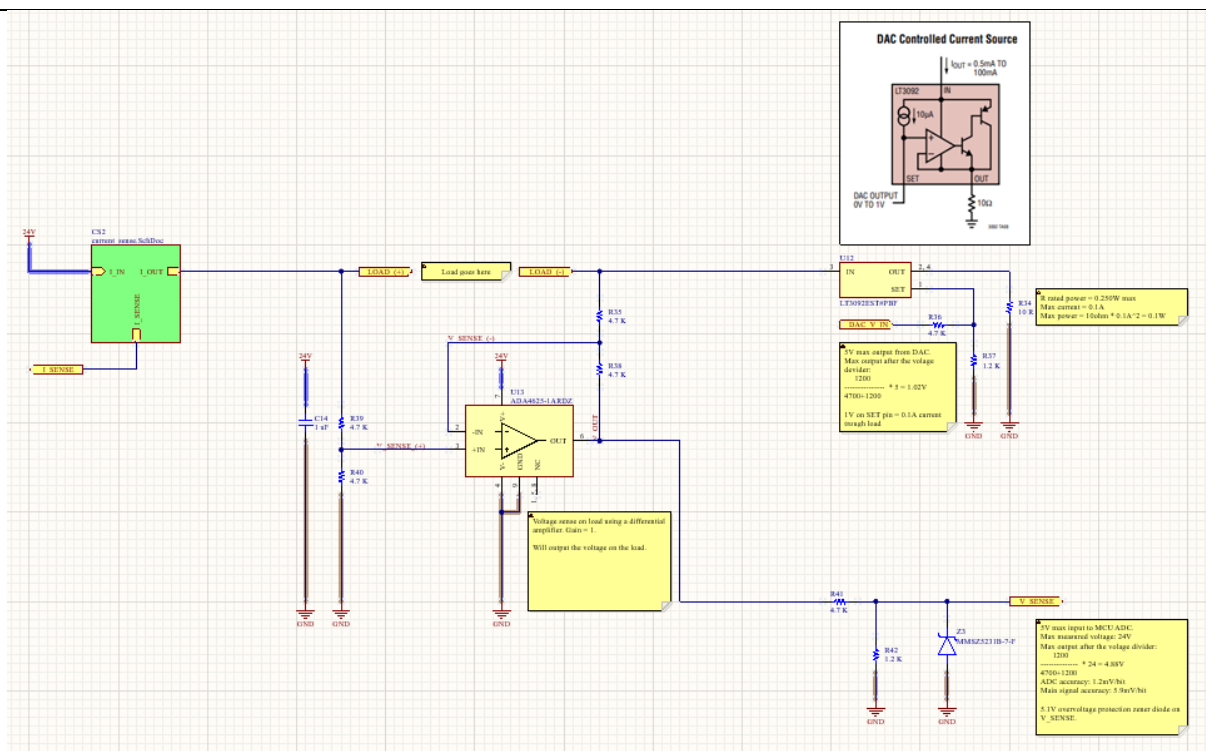


Figure 5-25 ELM test current source

5.2.19 Analogue control terminal

This sheet contains connection for the analogue control, it by itself is not used, but can be implemented in the future, if so desired.

5.2.20 Expansion slots

Some of the unused GPIOs of the MCU were connected here, as well as the communication channels like I2C and SPI. This port is meant for further modularity of the design.

5.3 PCB and enclosure design

To create the PCB design, it has to be designed to be within an enclosure. Therefore, an enclosure has to be designed first.

Enclosure was designed in "Front Panel Designer" by Schaeffer. This company can create front panels according to the design made in their software.

The enclosure designed process was following. Initially an entry design was made to have a base to work from. Then the basic PCB layout was created. While working on the design of the PCB, the front panel design and PCB layout were tweaked constantly to ensure best results in correct design. In Figure 5-26 the basic shape of the enclosure can be seen. This image was made out of step files of each frame part. As those do not hold any texture data, some details are not visible.

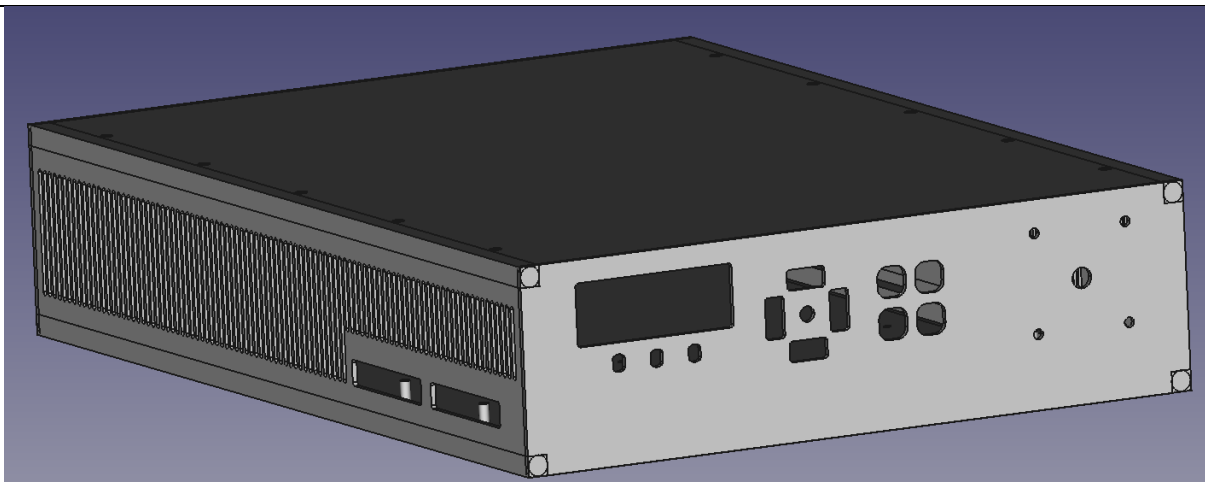


Figure 5-26 Enclosure design

In Figure 5-27 the front panel with all the details can be seen. This is where the front panel part of the PCB will be mounted.

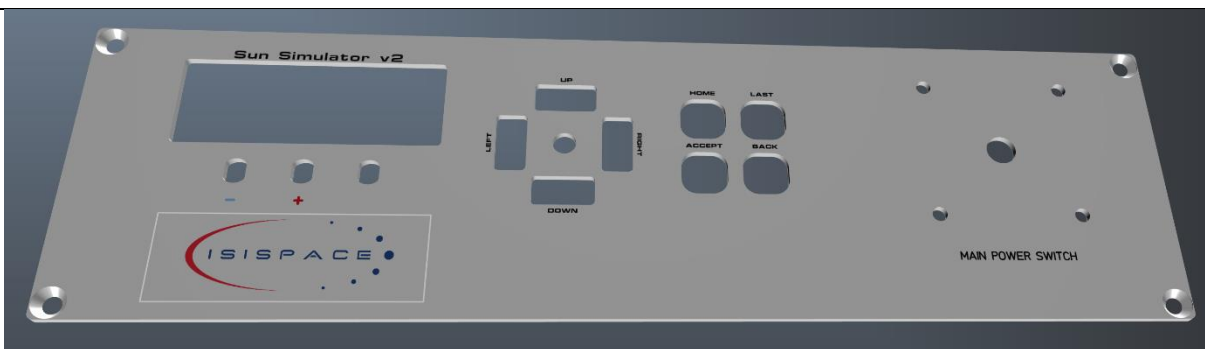


Figure 5-27 Front panel design as seen in "Front Panel Designer". The front panel of the motherboard will be mounted here.

The motherboard itself will be mounted on the bottom plate, see Figure 5-28. It will be mounted on the 16mm standoffs as seen in Figure 5-28.

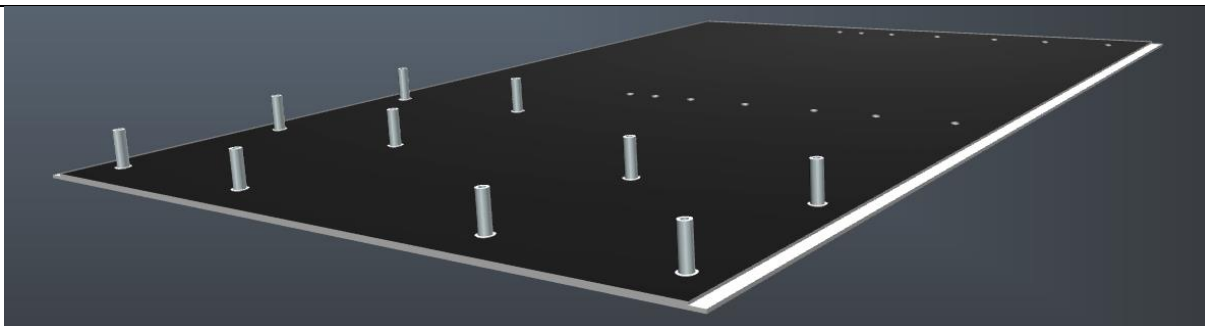


Figure 5-28 Bottom plate design. The motherboard will be mounted here.

The basic layout of the motherboard can be seen in Figure 5-29.

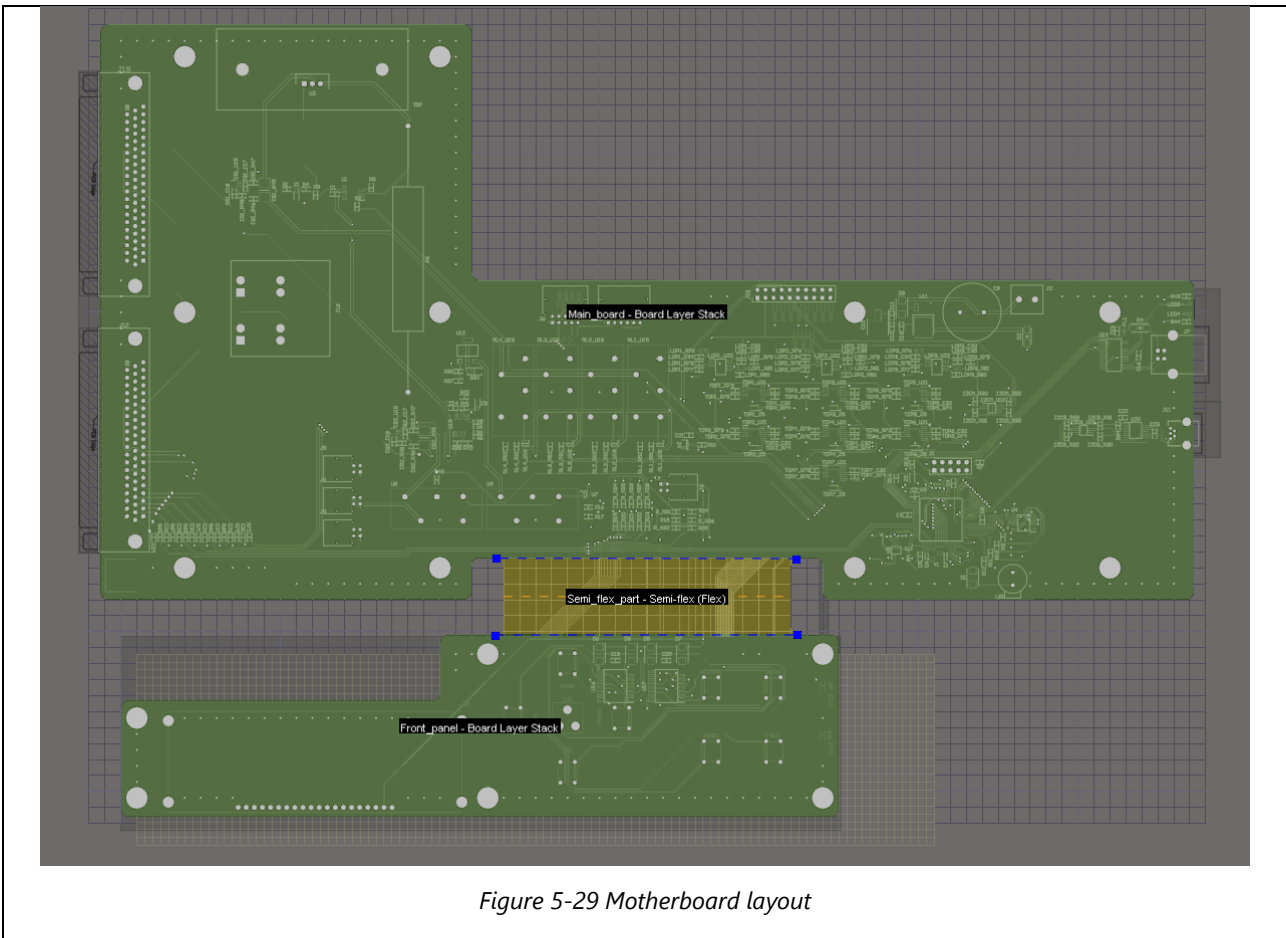


Figure 5-29 Motherboard layout

The upper part of the PCB is the main part. This is where all of the critical components will be placed. The bottom part is the front panel part. This will house the buttons and display. In the middle there is a flex part. This will be bend by 90° and connected to the front panel. This can be seen in Figure 5-30 and Figure 5-31.

The length of the flex part is 24mm with a bend radius of 15mm. This is done according to the manufacturers (Eurocircuits) formula for semi flex length. The formula is as follows:

$$(2 * \pi * \text{bend radius}) * \left(\frac{\text{bend angle}}{360} \right) = \text{semiflex length}$$

In case of this PCB thus:

$$(2 * \pi * 15) * \left(\frac{90}{360} \right) = 23,6mm$$

Therefore, the length of 24mm is a good choice. In practice the number will align by itself if entire semi-flex length is used to bend the PCB the desired number of degrees.

The PCB can be put inside the enclosure and rendered in it. This is shown in Figure 5-30, Figure 5-31 (enclosure set to be mostly transparent for visibility reasons).



Figure 5-30 The motherboard inside the enclosure. Front view.



Figure 5-31 The motherboard inside the enclosure. Back view

5.4 The motherboard layout

The layout of the motherboard can be seen in Figure 5-32. The design can be seen in more details in the attachment 10. The board consists of four layers. The 2 inner layers are used by the entire board. Those are the two layer that also are present on the flex part and connect the two parts of the board. The outer layers are only used on the rigid part of the PCB and are the only layers where components can be soldered.

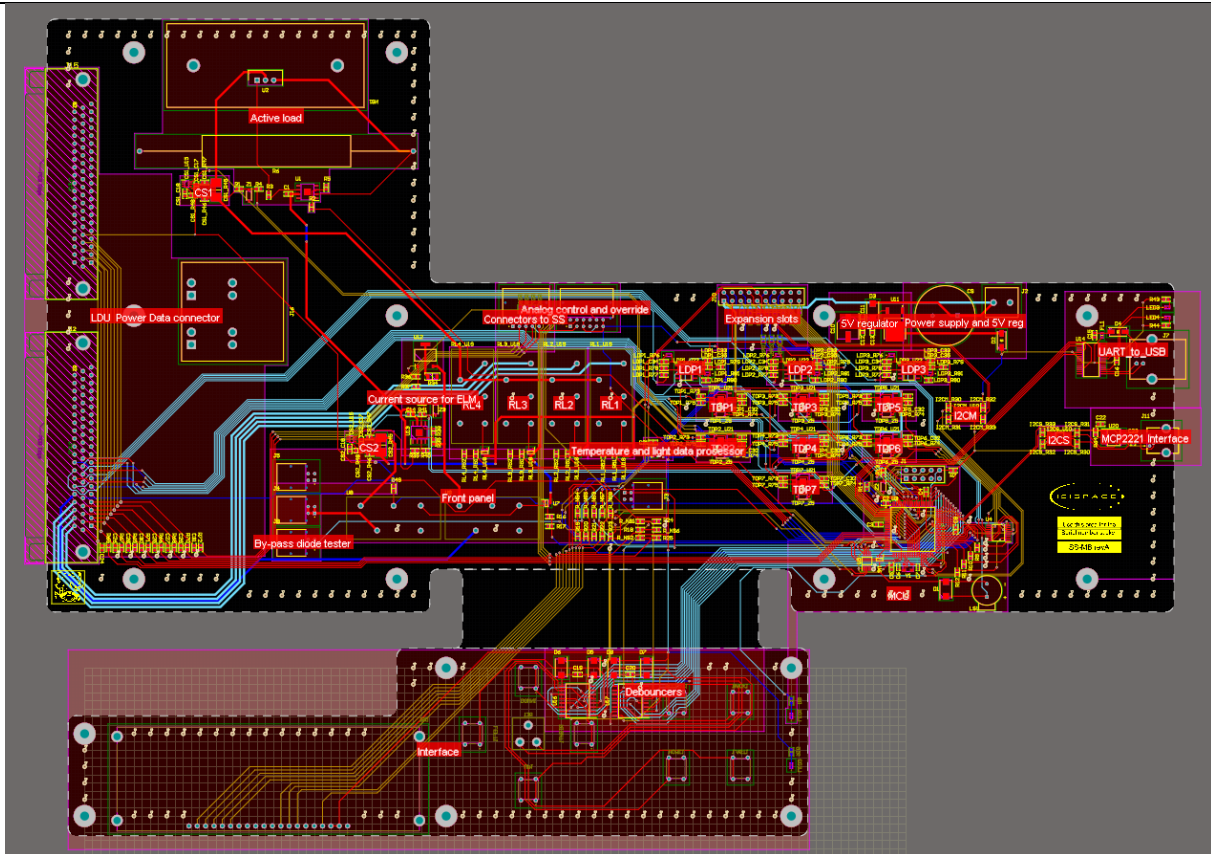


Figure 5-32 The mother board PCB layout

5.5 Final product

The final product is composed of 4 PCBs and enclosure. In Figure 5-34 the main control circuit can be seen. This contains the enclosure, motherboard and the power supply. There was no step file available for the on/off switch, so it is not present in the render. The switch used is 3LD2103-0TK53, see Figure 5-33. This is a 9,5kW switch. It will be usable for upgraded 9kW version of sun simulator. In general, the upgrade to 9kW version is very easy. The only activity that has to be done is to add remaining 2 power supplies and the 3-phase connector. The enclosure needs slight changes for it, but because it would be much bigger and have housing for the 3-phase connector. As it is not required right now, it was chosen to make the smaller enclosure. The designs of the enclosure are seen in attachment 11. The on/off switch is located at the right part of the front panel.

The buttons and the rotary knob will be 3D printed later when the PCB is manufactured.



Figure 5-33 3LD2103-0TK53 - 9,5kW switch

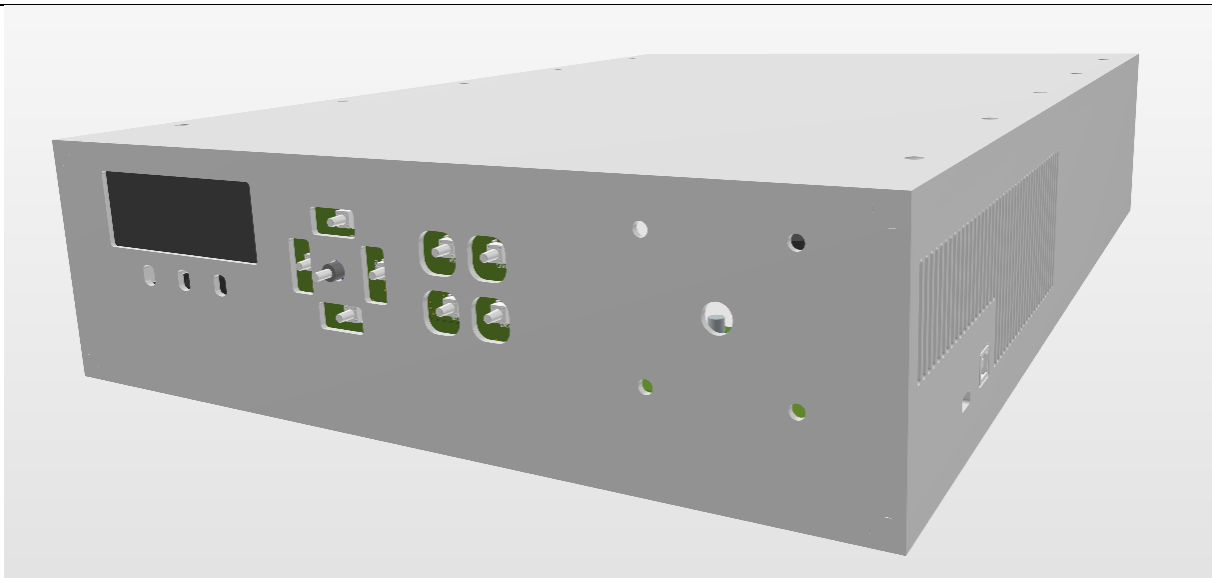


Figure 5-34 Final assembly, basic render of the enclosure with the PCB

The design of the other PCBs has changed as well. The LPU now has a build in temperature sensor. The LEDs combination is changed as well, as discussed in paragraph 4.5.2.1. The new render is shown in Figure 5-35. For the details, refer to attachment 7.

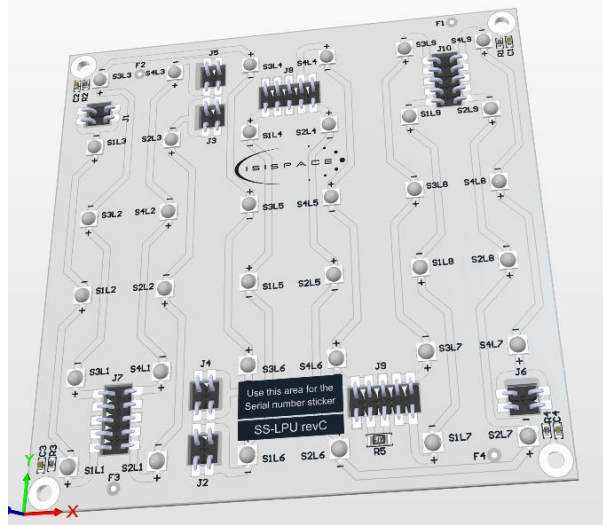


Figure 5-35 Final LPU design

On the LDU the connectors have been changed and the filter removed. The connector for the temperature sensor has been added and the existing fan connector is replaced with an M80 connector for more secure connection. The design did not change much other than that. The board can be seen in Figure 5-36. For details, refer to attachment 8.

The temperature sensor connection will be connected to the PDAU.

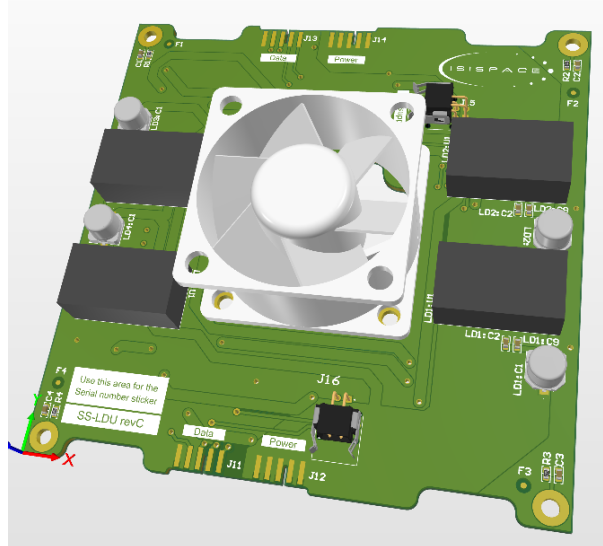


Figure 5-36 Final LDU design

The PDAU got the most significant upgrade. The D-Sub connector was replaced with a 62-pin version and a many new features were added. In the new PDAU not only power and light intensity data is transferred over the D-Sub, but also the sun simulator sensor data and ISPA power and data. That ensures that only one long harness is required for connection of the Motherboard unit and on the lamp unit level all the connection can be distributed locally. The PDAU now has a terminal block for all the sensor on the top side. For detailed view, see Figure 5-37. On the bottom side picolock connectors for the ISPA power and data can be found. There are 4 connectors for the power and 2 for data. See Figure 5-38 for detailed view. For full details, see attachment 9.

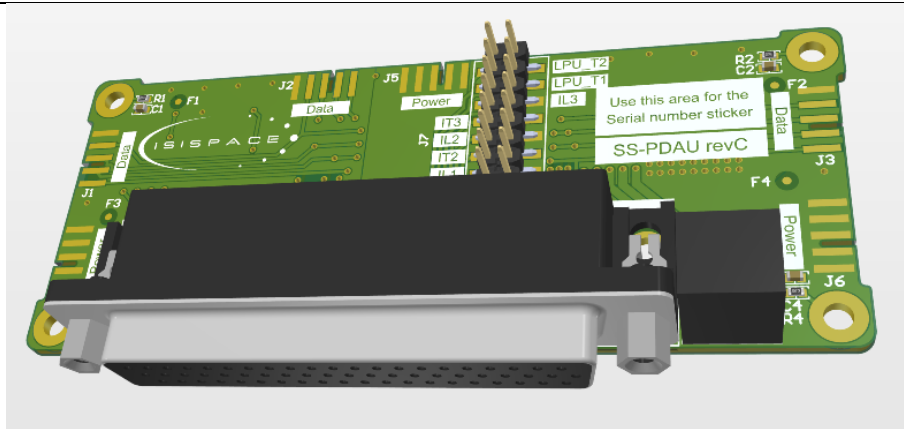


Figure 5-37 Final PDAU design - Top

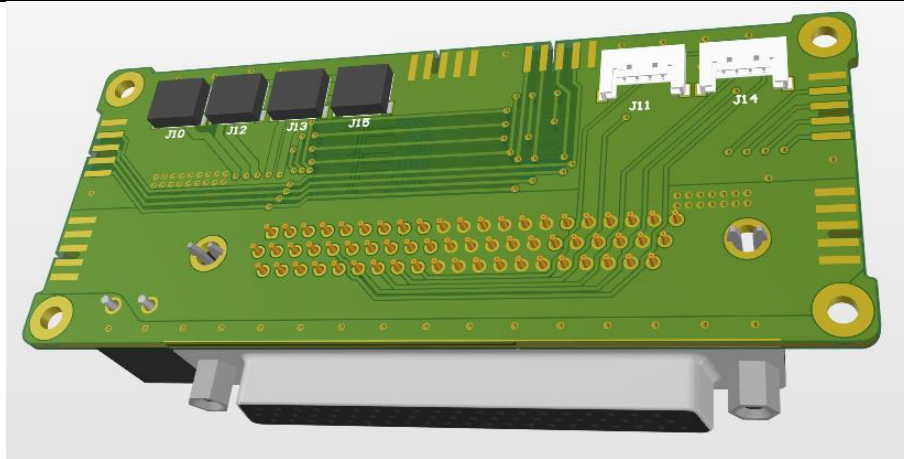


Figure 5-38 Final PDAU design - Bottom

5.5.1 Mechanical frame for the lamp unit

The mechanical team was working with me to design a frame for the lamp unit. The result is an enclosed frame with an interface to put in the solar panels in for testing. There is an idea of testing multiple solar panels one by one in the future, and this frame will support that. It will require a small add-on to the sun simulator, but it was designed for this, as it is modular sun simulator. The frame design can be found in Figure 5-39.

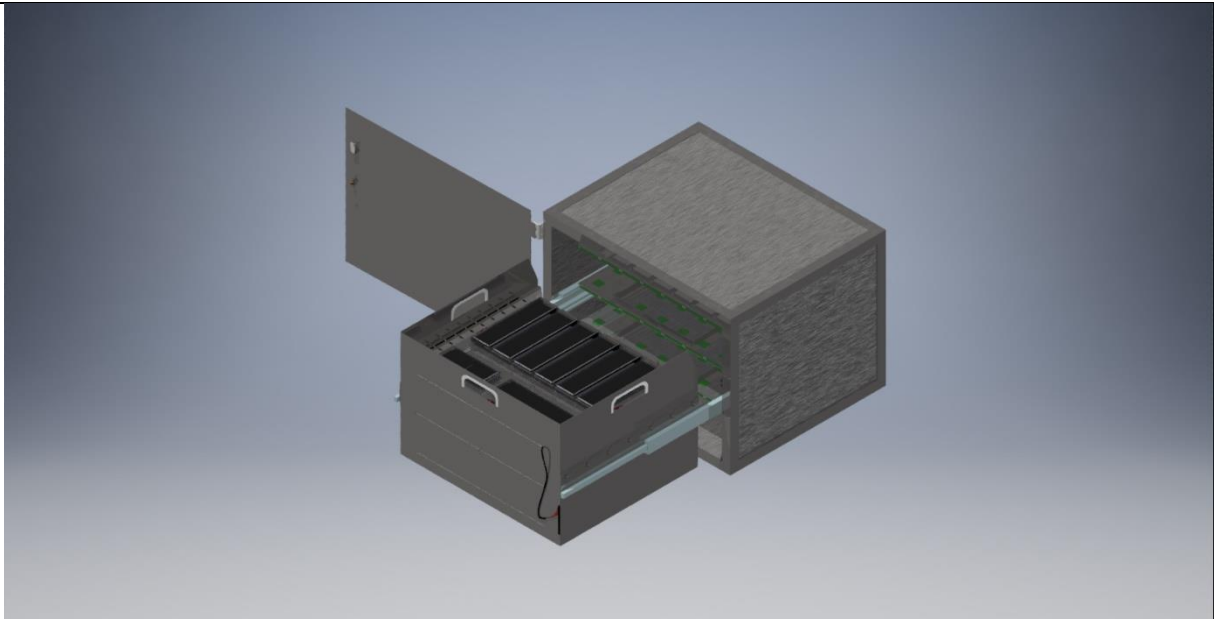


Figure 5-39 The frame

6 Testing, software and recommendation

Because of major delays in component shipment, component availability and scale of the project, the full-scale test could not be performed yet. The design process is done and all that is left is:

- Order the new PCBs
- Order the enclosure
- Assemble the harnesses.
- Create the software for the motherboard
- Final tests and calibration

After that, the Sun simulator will be ready.

6.1 Motherboard test software

The initial motherboard software shall be very simple and basic, it will not use the full potential of the sun simulator right away. Initially it will be used to test all the components of the sun simulator. Over time it will be improved upon and expanded.

6.2 Motherboard basic test

The motherboard can be simply tested by applying the 28V to the power terminals and connecting a lamp unit composed of a single LPU/LDU combo. With this basic functionality can be tested.

6.3 Sun Simulator full test

After basic functionality is established, a full setup should be built. The chosen power supply shall be used and a full 20 LPU/LDU combo assembled. Entire ISPA test shall be performed and the performance of the sun simulator can be determined.

6.4 Sun simulator and PC software development

This is a feature that will take more time to create, but the current design was meant to be easily upgradable. This functionality is meant to be added over time, without any need to change the hardware itself.

6.5 Finalisation

The final step to be performed is full calibration of the system. For light calibration a solar cell kit can be used. It consists of 4 solar cells with known parameters at AM0 (Air Mass 0) spectrum (solar light in space near Earth). When the light output is adjusted to proper values, the sensors of the sun simulator can be calibrated. For this a range of outputs can be read for each type of LED. A value for each LED at each power level can be determined. Using the calibration cells, the expected sensor value for proper light output can be determined. Those values are saved and can be used to readjust the sun simulator in the future.

After that is taken care of, a full solar panel test can be performed, making the sun simulator fully functional for its task.

7 Conclusion

7.1 The sun simulator

The sun simulator is a device that can generate a light with same spectrum as the sun. Generating exactly the same spectrum as sun is rather difficult and such device would be very expensive. For solar testing, so long the cell receives the correct amount of power in light, it can still be tested.

The solar cells used for space have 3 layers with every single layer sensitive to different spectrum of light. The goal is to supply enough light power to each layer of the solar cell. The cheapest and most efficient means of producing the light are LEDs. LEDs have one common property, and that is the very narrow output light spectrum. All that is required is to create enough light in the spectrum that given layer can convert to electric energy.

Use of LEDs has the benefit of higher efficiency. At 50x40cm the sun simulator will require a little bit over 1kW. In the future the plan is to increase the size. If not for the efficiency of the LEDs, it would be very hard to power the sun simulator. The design is fully modular so it is easy to make the sun simulator bigger.

The prototype shown that this design works well and can indeed be used. The prototype also shown some issues with the design and those were quickly fixed.

The main focus after that was the motherboard for the control unit. This PCB is responsible for the control of the sun simulator and perform the automated test. The motherboard will do following actions:

- Supply the sun simulator with power.
- Send PWM signal to control light output
- Read sensor data from the sun simulator
- Receive power from the solar panel and perform the IV curve test.
- Receive sensor data from the solar panel
- Perform by-pass/blocking diode test (user required)
- Supply current for ELM test (user required)

7.2 Reflection

This project plan was in some cases a bit too optimistic and with the current chip crisis it made everything a lot harder. Designing was hard as each time a component is needed, it took a lot of time to find one that is available on the market. In some cases, some components disappeared from the market while working on the sun simulator. The design of the motherboard was bigger than initially envisioned. Thus took a lot more time. In general, the project is finished, just needs to be ordered and final tests needs to be performed.

This project was great learning experience. The PCB design software Altium was used here. This was new and a lot needed to be learned to use it. The general design process performed was a great learning experience as well. This project has great effect on the design capabilities and efficiency of the design process performed. Also, this project is of big value for the company, with makes it even more rewarding.

8 Nederlands samenvatting (Dutch summary)

De "sun simulator" project, of zonnlicht simulator is een project waar een apparaat werd gemaakt om zonnepanelen te testen. De zonnepanelen die getest moeten worden zijn speciale hele efficiënte zonnepanelen. Deze zonnepanelen zijn gemaakt uit 3 lagen. Elke laag is gevoelig voor andere spectrum van licht. Zolang de zonnepanel cel genoeg licht ontvangt in zijn werk spectrum, zonnepaneel zal normaal functioneren. Uit ervaring zolang de lichtsterkte correct is, het exacte spectrum maakt niet zo veel uit.

Voor deze zonnlicht simulator worden 3 types LEDs gebruikt om licht te genereren. Elke LED was gekozen voor de specifieke laag van de zonnecellen. De LEDs zijn geplaatst op een PCB met afmetingen van 10cm x 10cm. Deze PCB heet LPU ("LED Plate Unit").

De LPU wordt met de driver PCB verbonden, de LDU (LED Driver Unit). Meerdere LDU boorden kunnen met elkaar verbonden worden met een "card-edge" connector. Op die manier strings van de LDU boorden kunnen gemaakt worden.

Die strings kunnen verbonden worden met de PDAU boor (Power/Data Adapter Unit). Deze boord koppelt alle LDU boorden tot een matrix. De initiële matrix voor dit project is een 5 x 4 matrix van de LDU/LPU boorden. Hiervoor zijn 5 PDAU boorden nodig, elke verbonden met een string. Een van de PDAU boorden zal een D-Sub connector hebben die met de moederboord is verbonden.

Het moederbord zal de stroom en aansturing voor de zonnlicht simulator zorgen. Het moederbord zal ook een verbinding voor de zonnepanelen en sensoren zorgen. Die zullen ook via de D-Sub kabel verbonden worden. Op de PDAU zijn de verbindingen voor de sensoren en de zonnepanelen.

Het moederboord design was gemaakt met een behuizing design tegelijk tijd. De behuizing heeft ruimte voor de moederboord en het PSU. Alle front paneel knoppen en display zitten direct op het boord. Het moederbord maak gebruik van semi-flex technologie. Dat betekend dat boord gebogen kan worden tot een statische positie. Dankzij dat er hoeven geen extra kabels gemaakt worden, die veel tijd, documentatie en dus ook veel geld kosten.

Het compleet product is gemaakt uit een matrix van LDU en LPU boorden, PDAU boorden die de matrix volledig verbonden maken en een moederbord. Moederbord zit in een behuizing met een PSU (of drie PSUs voor 9kW versie).

9 Sources

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10 Attachment

Included with this document:

1. Attachment_1_led_plate_revA.pdf
2. Attachment_2_led_plate_revA.png
3. Attachment_3_led_plate_driver_revA.pdf
4. Attachment_4_led_plate_driver_revA.png
5. Attachment_5_pdau_revA.pdf
6. Attachment_6_pdau_revA.png
7. Attachment_7_Job_LPU_RevC.PDF
8. Attachment_8_Job_LDU_RevC.PDF
9. Attachment_9_Job_PDAU_RevC.PDF
10. Attachment_10_Job_MB_RevA.PDF
11. Attachment_11_enclosure_design.pdf
12. Attachment_12_plotter.py
13. Attachment_13_light_source_to_cell_spectrum_relative_power_absortion_converter.py