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Test Devices and Testing Procedure Development for New Electronics' Product

Master's thesis

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TALLINNA TEHNIKAÜLIKOOL
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Uue elektroonikatoote testseadmete ja testimisprotseduuride väljatöötamine

Magistritöö

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Tallinn 2022

Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

The aim of this thesis was to analyse the need for a testing solution for a small-to-medium size electronics products' manufacturing firm. Based on analysing different test types for different manufacturing steps (PCB, PCBA & final assembly) most suitable ones were determined for applying.

Based on the selection of test types and design requirements for products two test devices were designed: one for a simple voltage regulator module and the second one for a LED based lamp controller PCBA.

The first test device is for a simple voltage regulator module, that has the functionality to control DUT's input voltage, enable signal, output load, measure its output voltage and apply a predetermined algorithm to evaluate the compliance and stability to test criteria. A test passed DUT is indicated by a green light and a test failed by a red light indicator.

The second test device is for a PCBA that is used as a controller for a LED light system. As it has already passed electrical and structural tests, it's only reasonable to apply a functional test before final assembly. It's a dedicated test fixture with a custom-designed test probe interposer board and other requisite test equipment (test controller, PSU, data acquisition, other subassemblies etc.) to emulate as similar as possible use case for the DUT.

Future reiterations are described after the designs, and it is the combination of thoughts during the design process, ideas & suggestions from others and physical construction sidenotes.

This thesis is written in English and is 42 pages long, including 4 chapters, 16 figures and 13 tables.

Annotatsioon

Lõputöö eesmärgiks oli analüüsida testimislahenduse vajadust väikese ja/või keskmise suurusega elektroonikatooteid tootvale ettevõttele. Analüüsides erinevaid testimistüüpe erinevate tootmisetappide jaoks (PCB, PCBA ja lõplik kokkupanek) leiti kasutamiseks sobivaimad.

Lähtudes testimistüüpide valikust ja toodete konstruktsiooninõuetest, projekteeriti kaks katseseadet: üks lihtsa pingeregulaatori mooduli jaoks ja teine LED-põhise lambikontrolleri PCBA jaoks.

Esimene testseade on pingeregulaatori moodul, mis võimaldab juhtida DUT-i sisendpinget, sisse-välja lülitamise signaali, väljundkoormust, mõõta väljundpinget ja rakendada etteantud algoritmi, et hinnata vastavust ja stabiilsust testimiskriteeriumidele. Läbitud testist annab märku roheline tuli ja ebaõnnestunud juhul punane tuli.

Teine testseade on PCBA jaoks, mida kasutatakse LED-valgustussüsteemi kontrollerina. Kuna see on juba läbinud elektrilised- ja konstruktsioonitestid, on enne lõplikku kokkupanemist mõistlik teostada funktsionaalne test. See spetsiaalne testimisseade koosneb disainitud testnõelte vaheplaadist ja muudest vajalikest testseadmetest (testikontroller, toiteallikas, andmehõive, muud alamkoostud jne), et jäljendada DUT-i võimalikult sarnaseid kasutusjuhtumeid.

Edasisi iteratsioone kirjeldatakse pärast disainitud lahendusi ja see on projekteerimisprotsessi käigus tekkinud mõtete, teiste ideede ja ettepanekute kogum ning mehaanilise konstruktsiooni kõrvalmärkused.

See lõputöö on kirjutatud inglise keeles ja on 42 lehekülge pikk, sisaldab 4 peatükki, 16 joonist ja 13 tabelit.

List of abbreviations and terms

DC	Direct Current
DCDC	Direct Current to Direct Current converter
DFT	Design For Test
DMM	Digital Multimeter
FFC	Flexible Flat Cable
GPIO	General-Purpose Input/Output
IC	Integrated Circuit
ICT	In-circuit Testing
IoT	Internet of Things
IPC	Industry association for electronics
ISO	International Organization for Standardization
LED	Light Emitting Diode
NO	Normally Open contact
PCBA	Printed Circuit Board Assembly
PD	Power Delivery
PDN	Power Delivery Network
PSU	Power Supply Unit
QA	Quality Assurance
QC	Quality Control
RBGW	Red Green Blue White (colour LED)
SoC	System On Chip
SoM	System On Module
SPST	Single Pole Single Throw
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver-Transmitter
USB	Universal Serial Bus
WiFi	Wireless Network Protocol

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1 Introduction

The target for this master thesis is to document the design and development of two test devices for a small (currently) sized company's requirements. The topic was chosen because there was a new line of products being developed and due to global semiconductor and other electronics components' shortage new and of unknown reliability suppliers had to be evaluated for further cooperation.

Testing itself (or checking for intended outcome in general) is a fundamental part of any manufacturing process and must be carried through to ensure only the products that fulfil the designed parameters from original design specification are allowed to pass quality control. This kind of a "PASS/FAIL" test benefits the customer, but even more these tests are useful (essentially necessary) for the manufacturing business to reduce wasted resource, scrap created during production and increase yield for given input materials. A simple "1-10-100" rule can be applied for when the fault is found in relation to money: 1$ when found before production; 10$ when found during production; 100$ when found after production [4].

This thesis will focus on establishing the "PASS/FAIL" criteria through numerically measurable qualities, while using solutions that would be generally expandable and not from highly specific components (and tools).

Two test devices will be developed, their function and design choices described in more depth: tester for a simple voltage regulator and a functional tester for a controller board for a LED based lighting system.

2 Testing PCBA's

Production of electronics is a complicated process that involves many steps of which all are controlled by standards. One of these standard-developing organisations is IPC which is the most widely accepted in the electronics industry.

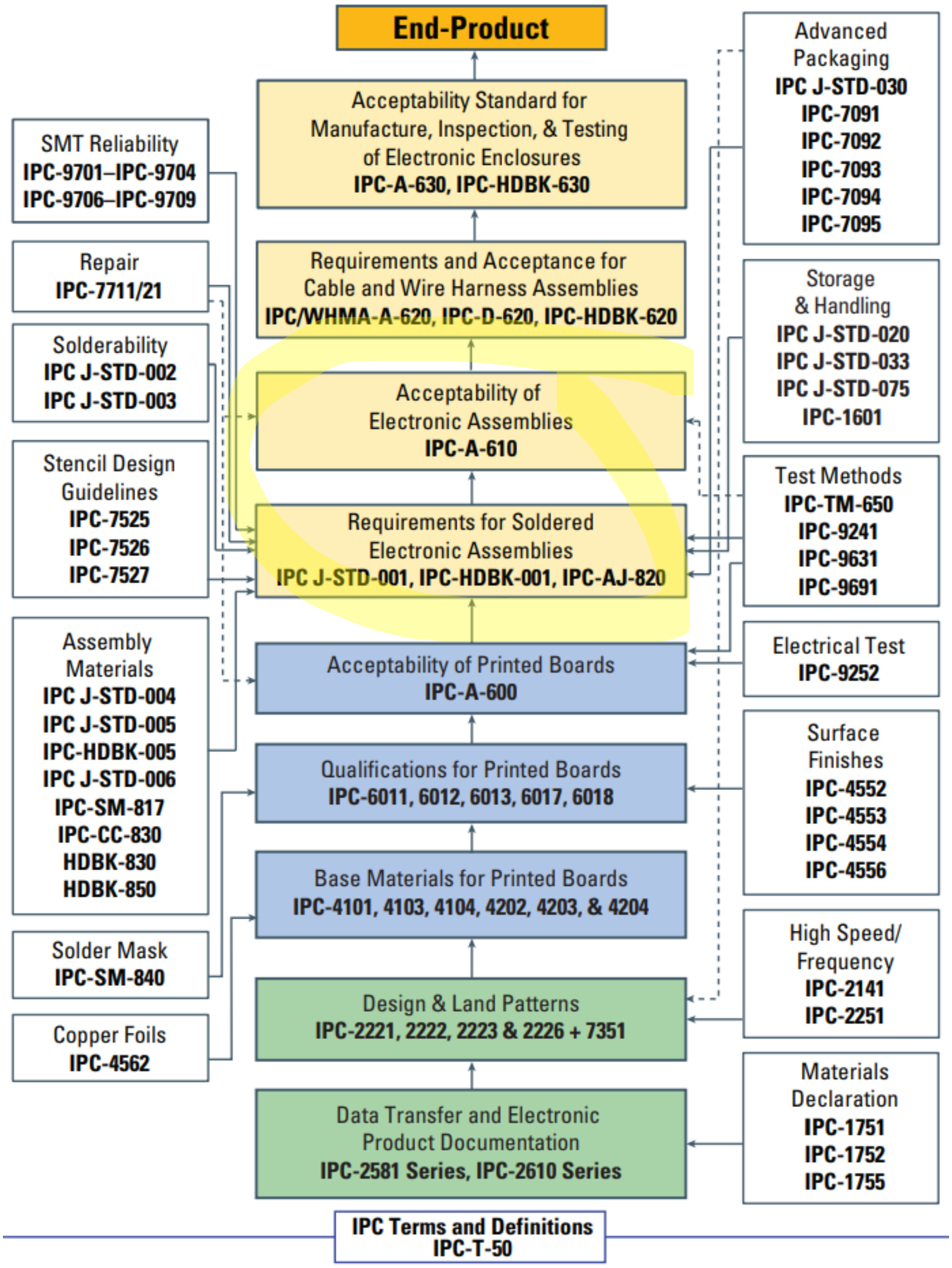

Figure 1. IPC Standard tree [16].

When considering the manufacturing processes that are covered by different standards, then it is clear, that testing is only a small portion of a much larger system. See “Test Methods & Electrical Test” from IPC standard’s tree in Figure 1. for comparison. Of these IPC standards most are manufacturing acceptability related and only a fraction is related to testing and even less to electrical testing. These standards can be taken as informative guide for this development.

Testing electronic sub- and final assemblies is a necessity to assure reliability for any manufacturing process. Thoroughness (deepness) of a test determines how many faults are identified and how much time is spent per unit-assembly. Total amount of testing time is determined by the combination/variation of all possible inputs. When considering the system as a state machine, the idea of 100% testing increases required time by a factorial amount per input [1].

As manufacturing time is an expensive resource then considering “optimizing out”[1] some steps is a worthy option to consider. Such “opportunities” can be used to skip out “not absolutely mandatory steps” of testing not necessary to guarantee a bare minimum of QC. As an example, omitting an optical test after both component placement and reflow is technically possible as faults occurring before the power up test will be uncovered nonetheless, but at a higher cost (ref. 1-10-100 rule from introduction) [4]. This methodology is only reasonable if corresponding risks are known and acknowledged for.

To narrow down on all different types of tests (exhaustive, extremes, etc) only testing electronic functionality is considered in this thesis. Functional testing complements testing of aspects that are the subcontractor’s responsibility. Functional testing is usually done on sub- and final assembly levels i.e. modular level, where each part has a distinctive function and well specified criteria to perform in a system. Such subassemblies can be voltage regulators (module), display & keyboard units (user interface), LED strips, controller boards and so on.

Different methodologies have different levels of automation and throughput (PCB/h), but a fully manual (operator does measurements by hand) variant should always be

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[1] Quotation marks used to show terminology for questionable practices

excluded under normal conditions due to excessive time consumption, unprecise results and for non-reproducibility reasons.

Functional testing of a small to medium size PCB's with limited requirements to throughput is usually done in a dedicated semiautomatic test-fixture, where the operator only places the UUT (Unit Under Test) in the fixture, connects some (or all) cables and initiates the fully automatic test sequence.

A fully automatic testing solution would have the advantage of high throughput "24/7" due to being an autonomous system by itself. Though highly efficient, it is not cost effective to implement it until production volumes are fairly large or product variety is considerable and/or changing often [1].

2.1 Test types

Test devices themselves can broadly be divided into two distinguishable groups based on their access methods to the PCB under test and/or reconfigurability for different products [1]. These are specific testing (machines) and universal testing (machines), which as the name implies have use cases to one and only one DUT or for all shapes and sizes of DUTs (mechanical limitations not discussed).

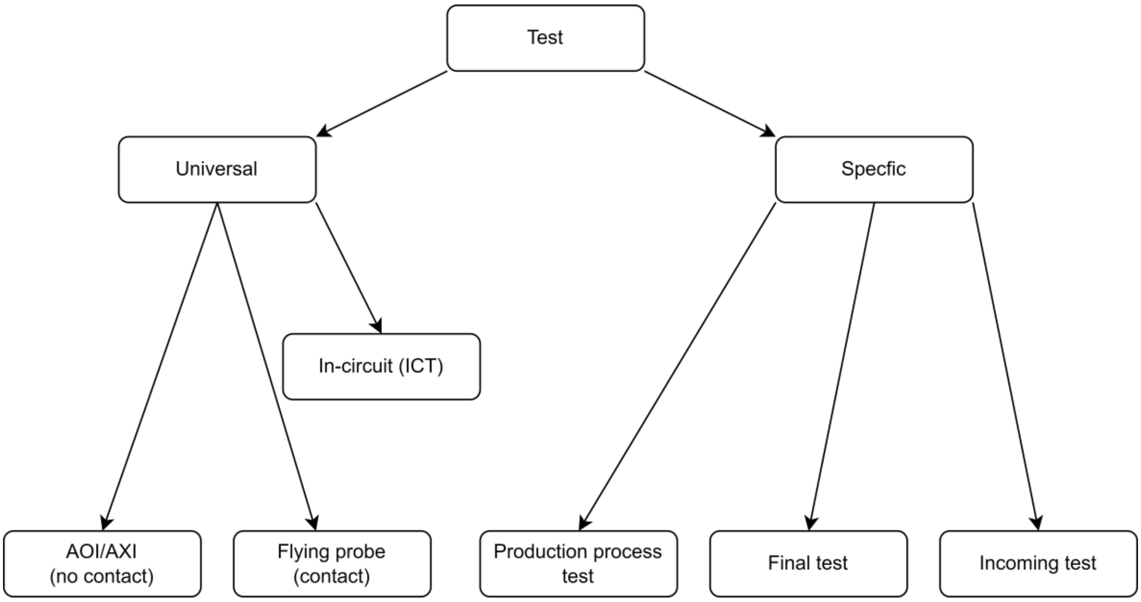

Figure 2. Test types' tree.

The difference is expressed mainly by the form of “how” electrical contact is created between the test device and DUT, where the specific style usually has a matching set of test probes (fixture is often referred to as a “bed-of-nails”) that make electrical contact with the PCB when placed on the work surface and appropriate pressure is applied. The other style, universal testing (machines) has no initial electrical contact with the DUT, but rather have a mechanical system to move a retractable arm assembly to an exact pre-programmed location and push down on the PCB with a sharp needle-like probe to create contact.

Test time difference between universal and specific test types is also notable, as the first one, though being more flexible is slower (cycle time), while the opposite applies for specific test (fixtures).

Another universal style testing is done using solely optical systems (optical inspection) but these have a slightly different purpose for testing (or testing stage). The purpose here is to do a structural test, meaning examine the board before any electrical testing is allowed or possible (safe).

In the next chapters, different types of tests are described and their suitability is evaluated for implementation in small to medium size manufacturing that relies on sub-contractors for electronic sub-assemblies (PCB’s, component assembly and reflow soldering).

2.2 ICT

In-circuit testing is used to measure each component on a populated PCB, e.g. after pick-and-place operation and reflow process. During ICT electrical components can be probed for different parameters, these can be yes/no type: component shorted/open; or a more continuous measurement such as resistance, capacitance, inductance or other factors to confirm if the PCB was correctly manufactured [6]. ICT can either be carried out as a specific test style or universal style, the latter is often preferred as developing a dedicated test fixture and its control systems is highly resource consuming and modern PCBs are often too complex to allow good accessibility to all components at once [2].

A more universal, flying probe test can reach all and any points with a sharp and directionally pointed test pin, usually spring loaded to apply pressure to testpoints or component terminations. Great flexibility and reconfigurability are the main benefits compared to specific testing. All probe movements and operations are fully automatic and can be updated via programming changes.

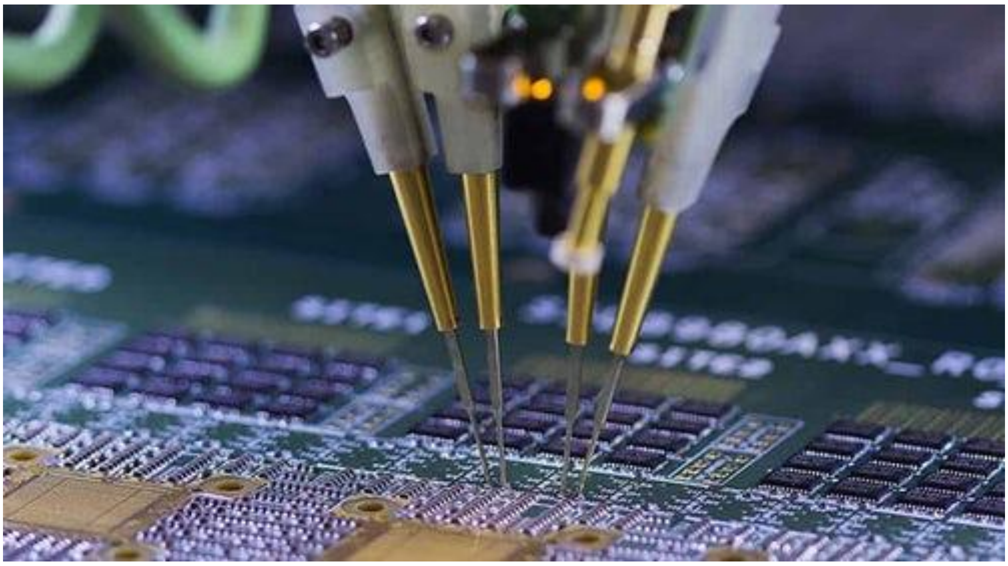

Figure 3. In-circuit test using "flying probes" [17].

While ICT does not test functionality of the PCB, an assumption can already be made based on that the board was correctly assembled and that it is now safe(r) to power it on for functional testing. Though when connectors are used, additional unknown is created due to contacts on those cannot be tested as the surface is not suitable for a probe (usually vertical pin style), which results in possible differences regarding continuity.

This style of testing would be feasible for a high scale of production testing and accordingly needs a high initial investment and experienced engineers to set up the testing procedure from CAD data and capable operators to handle on-site operation.

2.1 AOI

Optical inspection is a type of structural testing where there is no physical contact between DUT and test device. Optical inspection relies on high resolution cameras, either still frames or video. The PCB is lit by several light sources from multiple angles in order to reduce shadows and create a highly detailed image of the board [7]. Then the image is digitally processed and compared to a reference PCB image. AOI can detect incorrect placement of components, missing components, dimensional defects or soldering irregularities [6].

Figure 4. AOI inspection [18].

The advantage here is that AOI can be implemented inline, typically after pick and place/reflow step. It is a well-known and widely used system, but the main drawback is that its visibility is only limited to the surface of the PCB [6].

As this testing method is used mainly before and after PCB component assembly, it is the subcontractor QC’s obligation to ensure their process is correct and pursuant to production documentation. Therefore it is not sensible to retest ready-made PCBA’s as they arrive for final assembly. Retesting can increase statistical probability of less rejects, but is not cost-effective, meaning according to a production process’s risk matrix to reach a higher level (NASA level) of “nines” (99.99…%) in return of exponential investment of time and money.

2.2 Functional test

For testing an electronics assembly functionality some sort of predetermined stimulus must be applied and results measured, which then can be quantitatively compared to design specified parameters. Usually, a test interface such as a test connector, an edge connector or testpoint probes is/are attached to replicate the PCBs use case environment behaviourally (in the final product). For example if the DUT must interface an external device with protocol ‘x’ then it must be given the according input signals [6].

Functional testers are more difficult to standardize than structural testers because each device needs a specific input stimulus and output measurement instruments setup, therefore adding to the overall cost as well. Another variable that adds to the overall expense in functional testing is test depth and test coverage, proportionally relating to time consumed per single DUT.

The superior advantage of functional testing is uncovering (ideally) all functional defects on a board before the final assembly and burn-in test. During functional testing programming and calibrating of the DUT is done, when required, but this can alternatively be done during the final “into-the-box” test.

As this test type needs physical contact to DUT, reliability of test device side connectors must be accounted for as those wear out over time while DUT is new every time, orderly replacement after manufacturer specified contact count is recommended to exclude test errors. If in doubt a “golden DUT” can be used to check quickly on which side the error is introduced [9], [19].

This test has the highest probability of finding faults on a PCBA as a “PASS” here means that all other (earlier prod. tests) are passed and the product is ready to be assembled.

This test type is most suitable for testing already assembled PCBA’s in their intermediary production step to check if they are acceptable for final assembly or need to be rejected by QC. The expected functionality of these assemblies is well defined and can be checked against given parameters (functionality).

2.3 Incoming test

Electronics designs are commonly assembled from both for-purpose designs and from “shelf products”. Those outsourced components/modules may have been tested by manufacturers by 1%, 50%, 100% or any number of random samples from production. 100% testing is normally only done by military- or aerospace industries and that adds complexity to the manufacturer and thus to the final cost for the customer.

If the quality control does not need to account for highest quality products, but for components of questionable origin and manufacturing process then 100% incoming test is reasonable, as discovering faults later in production is exponentially more expensive.

In general, 100% incoming test is reasonable only temporarily for evaluating a new supplier and/or dealing with unbeknown quality issues. A rational solution would be to switch suppliers if a product is needed for a longer time as the price per product might be more affordable than 100% incoming inspection cost.

2.4 Final test

Quality control in the form of a final test is the most important part of a manufacturing process not to reject as many faulty units, but to assure that the customer is getting what they have ordered. This is crucial and after this the product is considered to be in full working order and up to specification. Final test may be done by a person to check features like a customer would use them.

Final assembly process may introduce new faults into functional components that have been tested separately earlier. Faults that occur the most are usually of mechanical origin: damaged component due to negligence, connector/cable misplaced/missing, wrongly placed screws etc.

2.4.1 Burn-in test

Part of the final test can be a burn-in test, where the DUT is loaded with its maximum allowed capacity (or even higher) for a specified test time, usually an extended time. Its purpose is to test the devices’ limits and introduce mechanical wear-and-tear on it (by thermal cycling). This type of test is useful, because most failures occur either at the beginning or the end of a device’s lifetime.

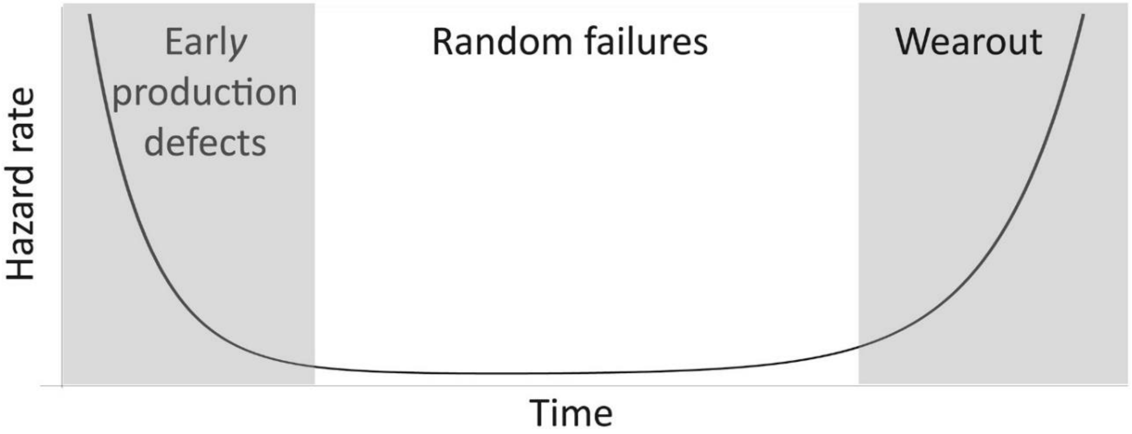

Figure 5. Product failure probability vs time [20].

The product failure rate distribution density figure describes three parts of a product’s life cycle:

1. Burn-in phase, where components with pre-occuring faults fail quickly and the overall reject-rate is rapidly decreasing;
2. The middle and longest part of a product’s life is its normal operation time, when uncorrelated random faults may occur, this rate of failure can be considered almost constant;
3. The last part is end-of-life, where physical degradation, wearout and aging relating issues lead to higher failure rate [20].

The only part of this lifecycle that can be controlled after production is the first, burn-in phase where accelerated aging takes place to move from the quickly decreasing failure rate to a more constant low plateau.

This test will not disclose any direct information (data logging form) about what has failed during the test, but rather leaves that for rejects troubleshooting.

3 Devices under test

This thesis will focus on two printed circuit board assemblies (PCBA) that are similar in their manufacturing process, yet quite different from quality assurance (QA) viewpoint. The first one is a ready-made single purpose voltage regulator module while the second one is a purpose designed controller board for a LED based spotlight.

Both PCB’s have gone through circuit board manufacturing, component assembly, presumably electrical continuity & shorts test (PCB only) and optical inspection before/after reflow soldering (PCBA). There is no financial benefit to retest this locally, again using AOI, ICT or mix of others to prevent overtesting.

To rephrase: the main driver here is the test purpose – excluding non-functioning products. AOI, ICT etc. provide feedback about the manufacturing process, optimising this is the supplier’s responsibility. Therefore, further processes will focus on functional testing as the next logical step.

3.1 Voltage regulator

The first and simpler of the two DUT’s is a “no-name” voltage regulator module that can be modelled as a black box device. It has a total of four outside connections of which three are for power and one for logic control. The module has a standard pinout spacing of 2.54 mm (0.1″) with an empty connector for solder-in pin header. As this module can be purchased from multiple manufacturers and may even have production variations from the same vendor, it is mandatory to test these based on operational parameters.

Faulty non-functioning or malfunctioning devices may cause extensive damage to the assembled product and cause increased scrap as some subassemblies are rather expensive and troublesome to repair. This aspect justifies 100% incoming test as a mitigating solution for that issue.

Table 1. Technical specifications of voltage regulator module.

Input voltage	DC 4.5-24V
Output voltage	DC 0.8-17V
Output current	0-2A (with cooling max. 3A)
Mechanical size	20 (L) · 11 (W) · 5 (H) mm
Quiescent current	~1mA (1)
Switching frequency	500kHz
Output ripple	~20mV (1, 2, 3)

[1] input voltage dependent

[2] 20MHz bandwidth limited

[3] stable operation conditions

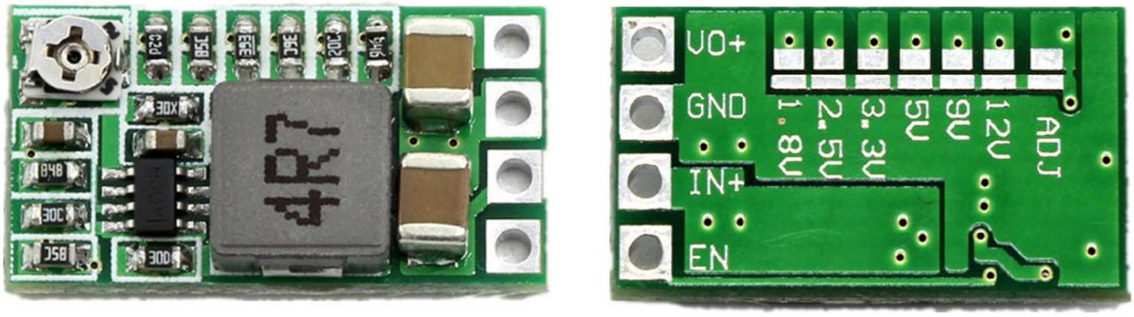

Figure 6. Front and back view of voltage regulator module.

The module has a potentiometer on the top side to either fine adjust the voltage using that or a set of jumper links on the bottom side to make solder connections and select from a list of predefined logic-level or other commonly used voltages such as 3.3V, 5V, 12V etc.

Table 2. Voltage regulator module pinout.

#	NAME	USAGE
1	VO+	Output positive voltage connection
2	GND	Common ground connection and reference for module
3	IN+	Input positive supply for regulator, must be higher than output voltage
4	EN	TTL logic level control to switch on/off the module

3.2 Controller PCB

The second DUT is the main controller board for a LED spotlight that is highly integrated to handle all main tasks needed for the system, such as input protection, LED driving power section, user communication and external devices.

The controller PCBA utilizes digital control to achieve colour mixing with discrete red, green, blue and white (RGBW) LEDs on a separate board, while a SoM handles user interactions through WiFi and on-board tactile buttons. In addition to populated component footprints, testpoints have been added to the board that do not have any restraints to their access. Specific functionality for each testpoint (signal) will be discussed subsequently.

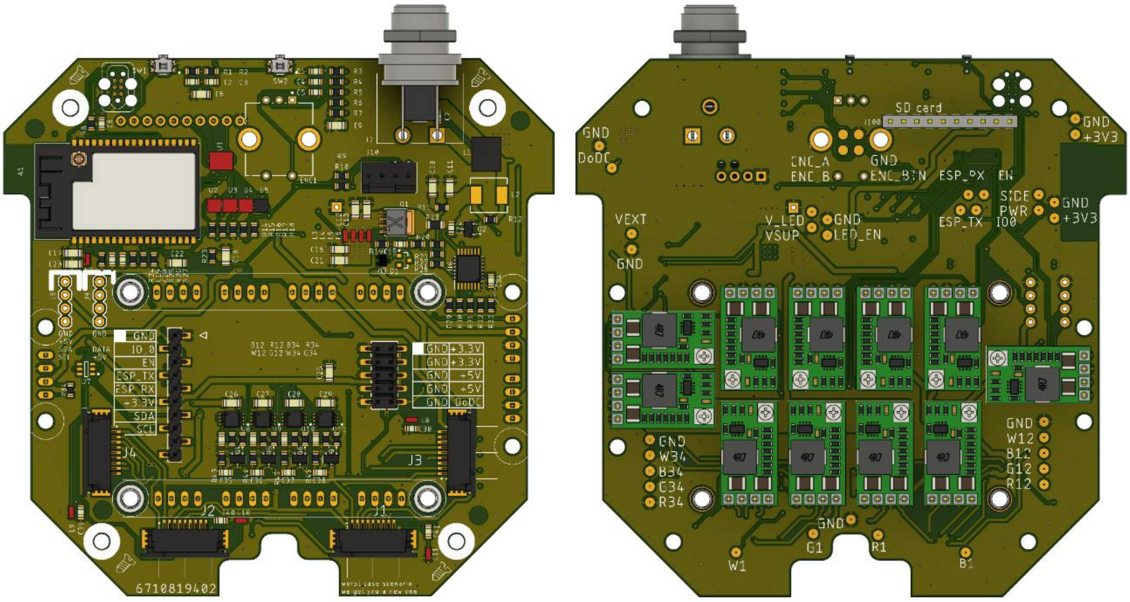

Figure 7. 3D-render of “Apollo 1” controller board revision 2.

The controller PCB has been designed with testability in mind for manufacturing processes, therefore all necessary testpoints are reachable even in fully assembled form to check designed functionality before final assembly.

Table 3. Technical specifications of controller board.

Input voltage	18-24V
Input current	0-6A
Total wattage	120W

# of LED output channels	4
LED regulator voltages	~10-15V
LED current per colour	2.5A
# of different testpoints/signals	20
General logic ref. voltage	+3.3V
Mechanical size	86 (L) · 103 (H) · 6 (H) mm (1)

[1] SMD assembly only

All voltage readings must be taken as differential pairs, meaning both low and high signal (low being usually GND) are measured from a reference physically near to the signal and transmitted as a twisted pair to the DMM to reduce noise and interference captured from nearby sources. Signals can use the same reference testpoint if they have a similar function/voltage level and/or are close to each other, though only a single measurement can be done at once.

Voltages and input-outputs are respectively labelled as ‘V’ and “IO” in the following table describing all possible testsignals, measurement negative (or zero) potential not marked.

Table 4. Testpoints and their responding signal functions.

#	Name	Signal description	Voltage/logic signal	Is tested by measurement
1	GND	Reference point for all measurements		Pair #1 L
2	DODC	Unfiltered DC input	V	Pair #1 H
3	GND			Pair #2 L
4	VEXT	Filtered DC input, before main protection subcircuit	V	Pair #2 H
5	GND			Pair #3, 4, 5, 6 L
6	R34	Supply voltage for red subpixels 3&4	V	Pair #3 H
7	G34	Supply voltage for green subpixels 3&4	V	Pair #4 H
8	B34	Supply voltage for blue subpixels 3&4	V	Pair #5 H

9	R34	Supply voltage for white subpixels 3&4	V	Pair #6 H
10	GND			Pair #7, 8, 9, 10 L
11	R12	Supply voltage for red subpixels 1&2	V	Pair #7 H
12	G12	Supply voltage for green subpixels 1&2	V	Pair #8 H
13	B12	Supply voltage for blue subpixels 1&2	V	Pair #9 H
14	W12	Supply voltage for white subpixels 1&2	V	Pair # 10 H
15	GND			Pair # 11, 12, 13, 14 L
16	R1	Shunt switch for all red subpixels	V	Pair #11 H
17	G1	Shunt switch for all green subpixels	V	Pair #12 H
18	B1	Shunt switch for all blue subpixels	V	Pair #13 H
19	W1	Shunt switch for all white subpixels	V	Pair #14 H
20	GND			Pair #15 L
21	+3.3V	Logic supply voltage	V	Pair #15 H
22	GND			
23	ENC_A	Rotary encoder phase A	IO	Tested manually by rotating
24	ENC_B	Rotary encoder phase B	IO	Tested manually by rotating
25	ENC_BTN	Rotary encoder pushbutton	IO	Tested manually by pressing
26	GND			Pair #16, 17, 18 L
27	V_LED	Filtered LED regulator supply voltage	V	Pair #16 H
28	VSUP	Protected DC input	V	Pair #17 H
29	LED_EN	LED regulator enable	IO	Pair #18H
30	GND			
31	+3.3V_FILT	Filtered logic supply voltage		

32	SIDE_BTN	Button #1	IO	Tested manually by pushbutton press
33	PWR_BTN	Button #2	IO	Tested manually by pushbutton press
34	ESP_TX	SoM UART data transmit	IO	Tested through data interface
35	ESP_RX	SoM UART data receive	IO	Tested through data interface
36	IO0	SoM boot option select	IO	Tested through data interface
37	EN	SoM reset	IO	Tested through data interface

Testing should be done either by measuring voltages and comparing if those are in range to given design values determined from the golden sample or analytically. Voltages can be measured while the system is either in an unloaded or loaded state. There is no statistical advantage to prefer either of those states as long as all measurements are taken in the same way, but measuring the loaded system gives an additional view on stability.

Table 5. Voltage regulator output design values by colour.

Colour	Voltage
Red	10.77V
Green	14.96V
Blue	14.76V
White	14.51V

Other voltages on the controller board are common rail voltages such as 3.3V, 5V and 12V. These do not require separate testing during the main functionality test as they are set by the voltage regulator modules before assembly (and tested during that process). Also, the main circuitry will not function without these present so a deduction can be made from missing functionality (for example no +3.3V means no response from the programming interface).

Testing SoC IO pins can be done using a simple digital output “LOW/HIGH” toggling methodology, where a pin is written ‘0’ then measured, written ‘1’ and measured again. This shows that the output port is working correctly and if connected to the measurement point indirectly through other circuitry then that other circuitry is also functional.

As concluded previously one or multiple separate signals can be combined and evaluated by testing one function as those can be viewed as a series sequence. If one step in the sequence does not work then the whole system cannot operate as intended. It might seem progressive to combine as many measurements under a single result, but a strong drawback of such an action is missing data (information) for troubleshooting and repairs if deemed necessary.

But on the other hand testing everything might also not be that useful. A concept for product development states that a minimum viable product is something that if below that functionality is not worth designing. This idea can be expanded to testing and each product should have a list of functions that must be tested for a test device being viable, other features can be added later for additional functionality. For this controller PCBA those minimum viable functions tested should be those that the end-user wants and uses.

4 Designed test devices

After the design specifications for the product have been determined, product development has completed its (first) iteration and user functionality described, it’s necessary to assure that production output is same as expected by the three stages described.

When describing a test device’s architecture in general, it consists of a test connector, a power supply and a central controller as a minimum. Other additions are more specific to the DUT and exact functionality in need of testing.

The following subchapters will describe how the specifications (presented with the test parameters for better comparison) were used to create the test devices for their specific applications in the most suitable way of using resources (time, money, knowledge).

4.1 Voltage regulator module test device

The voltage regulator will be tested on a “PASS/FAIL” based procedure to identify which modules are acceptable for further processes and which can be disregarded as substandard products. It’s important to check if the voltage regulator module is operational and stable on different input & output conditions by assumed original and genuine component datasheet[1].

Visual inspection can be applied to identify the main DCDC converter IC used on these modules, though few samples from a single production batch is enough to determine component used and consistency of those. It can be said, based on previous analysis, that either genuine, equivalent (but not a direct substitution) and conditionally unsuitable parts have been used by different suppliers. Replacement IC’s have been either lower power variants or with unknown part numbers that were unstable at higher input voltages.

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[1] https://www.monolithicpower.com/en/documentview/productdocument/index/version/2/document_type/Datasheet/lang/en/sku/MP2315/document_id/513/

4.1.1 Test device’s electronics

A minimalistic test device is engineered to meet specified testing requirements and to be scalable while being cost effective at the same time. As this is a simple test device it contains only the basic system components described at the beginning of this chapter.

Table 6. Test device's list of materials.

#	Item	Purpose
1.	USB C PD charger/power supply	Main power supply
2.	USB C PD output module ZY12PDN	USB PD protocol negotiation device
3.	12V 20W GU5 halogen bulb	25W more ideal, but not available
4.	USB C <-> USB C cable	For power PD module, 5-20V
5.	USB A <-> USB C cable	For controller power, 5V
6.	M5Stack ATOM Matrix ESP32 based development board SKU C008-B	Main controller
7.	Connector cable SKU A034	Connection cable between controller and relay board
8.	Relay board, 4 channel SKU U097	SPST-NO type
9.	BP1000 EM03 M 4pcs	Testprobe tip
10.	RCP065U CR03 4pcs	Testprobe receptacle
11.	Proto board, about 200x200mm	For mechanical support

[1] depends on PSU output ports

After all (or most) necessary components are chosen a functional diagram should be sketched to evaluate if all parts fit and are suitable for the task. A first-hand drawn mock-up (to emphasize its conceptualistic origin) can be seen in Appendix 2. A finalised drawing with better connectivity information is presented on Figure 8. Using a drafting software package is a good choice for this task as it allows quicker reiteration during the design phase and a professional CAD system might require too many technical details for such a simple test device.

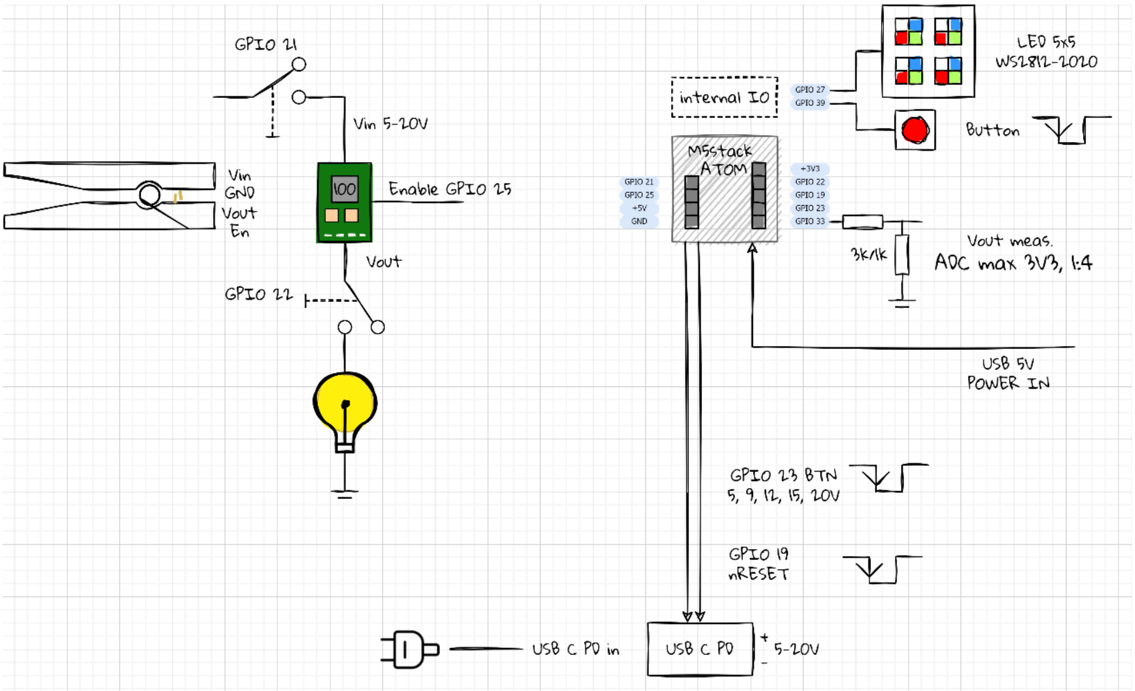

Figure 8. Voltage regulator tester functional diagram.

As the description requires to step through multiple voltages, but does not directly state it has to be a continuous sweep that only adjustable power supplies are capable of, a USB type C PD charger was chosen (to replace an expensive adjustable PSU to reduce overall cost and complexity). USB PD is a rather new technology introduced to the market, but has gained popularity among consumers, making it an easily replaceable design unit. The standard specifies multiple voltages that are available after negotiations with the charger controller itself. Available voltages are 5V, 9V, 12V, 15V and 20V with currents up to 5A [21].

Switching between different voltages is done through a USB PD (ZY12PDN) output module which is connected to the main controller through “reset” and “func” buttons. The “func” signal increments the PSU’s output voltage by every falling-edge cycle in the following order (from USB-C PD logic): 5V->9V->12V->15V->20V. The other signal “reset” is necessary for resetting the module and returning output voltage to 5V. The module also uses a USB type C connector for both power input and data transmission port for voltage negotiation. The output voltage is comfortably brought out to either solderable pads or screw terminals.

The output load for the DUT is chosen to be a 12V 20W incandescent lamp that has a steady-state current of about 2A which is a thermal limit for an uncooled voltage regulator module. While the light bulb is cold it exhibits itself as a lower resistance load and enables to quickly draw a full specified load of about 3A in range of default-set voltage for a short time. This enables to apply a quick pulse for testing, but not to overheat and trigger thermal protection for the module. Another useful feature of using an incandescent lightbulb as a load is its high resistance to heat caused damages when compared to for example high wattage resistors which need special considerations for mounting.

One of the major tasks of any test device design is choosing its system controller. Several different options are available with different parameters, ranging from low power & small size to high power & complex solutions.

The next table will assess each possible master device from a selection of commonly available and used options according to given criteria necessary for successfully complying with the test device's design specifications on a scale of one to three (1 – bad choice, 2 – okay choice, 3 – good choice) based on suitability. If the criteria can only be evaluated as a boolean, then a value of either zero or three (0 – not available, 3 – available) is used.

Table 7. Comparison of system controllers.

Criteria	**Raspberry Pi**	**M5stack**	**Windows based PC**	**Arduino**	**Fully custom design**
Hardware interfacing	3	3	1	3	3
Development cost	2	2	1	3	1
Price	2	2	1	3	1
WiFi	3	3	3	0	3
Button	2	3	1	2	3
Screen/visual	2	2	3	2	3
Ecosystem support	3	3	2	3	1
Physical size	2	3	1	3	3
SUM:	19	**21**	13	19	18

WiFi is specified because further requirements for the next iteration are likely to require an Internet connection for product serial number-based binning or similar unique id-based logging.

Based on the analysis in Table 7, the most suitable central controller is a M5stack based solution. It is the best for quick development as it has a full ecosystem of interconnectable modules with different functionality. It is also open source and marketed towards “industry IoT”.

It is more that reasonable to utilize an existing range of products from the same manufacturer, so the relay board and connection cable between it and the main controller are from the same line-up of products and thus streamline the development process and decrease development time.

Pin count and functionality on M5stack controller (ESP32 based SoC with WiFi) is also suitable for interfacing with a simple test device with limited functionality. 7 pins are available with analog and digital capabilities, refer to pinout diagram in Figure 9.

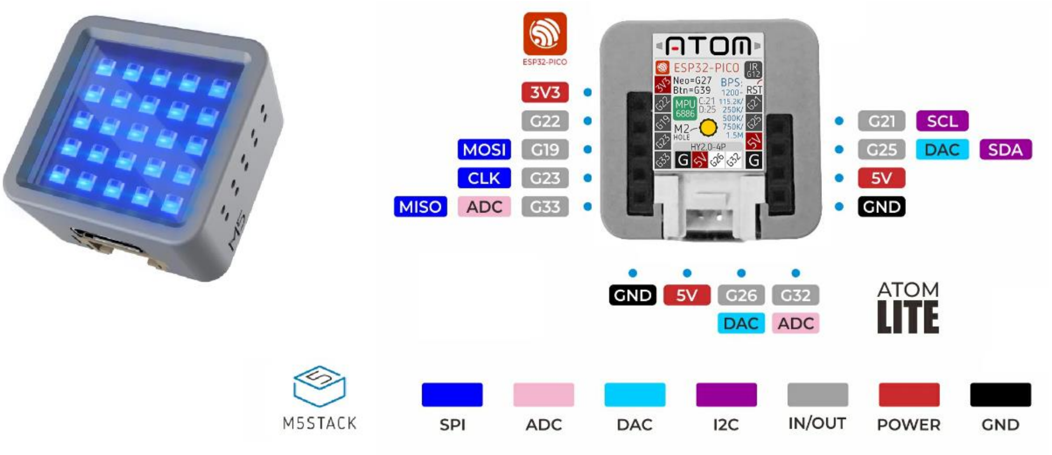

Figure 9. M5stack Atom Matrix front (left), functional pinout (right) [22].

4.1.2 Mechanical aspect

Suitable holding clamp for the device is needed, which would be both mechanically stable and easy to use at the same time to reduce cycle time as the regulator is a commodity item that needs “relatively” high volume of testing. This clothespin-like fixture was designed by the industrial design section of the team and implemented to use the same items that are part of other test devices such as testprobes. See Figure 10 for the test fixture, notice the voltage regulator module (DUT) between its “jaws”.

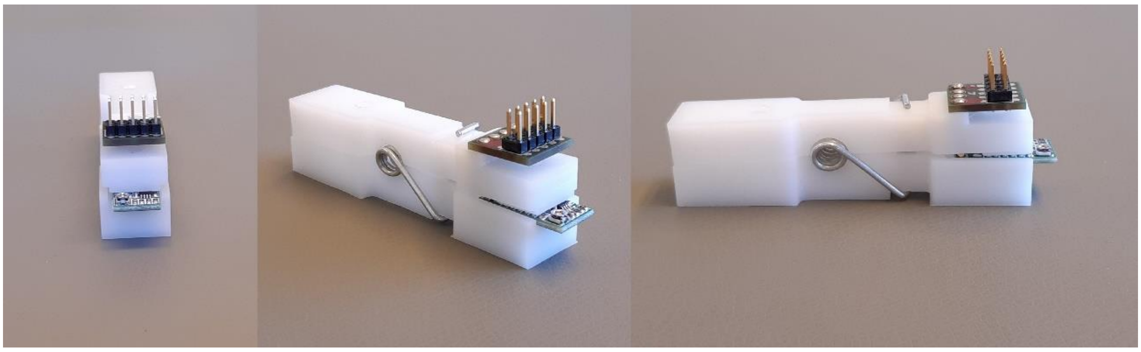

Figure 10. Voltage regulator's test fixture, 3-side view.

Mechanical test is a by-product of this basic incoming test, as it also “checks” if something falls off during handling.

4.1.3 Testing procedure

The testing procedure is designed to be a compromise between test depth and testing time, slightly favouring test time (such subtests e.g. full load testing can use up considerate amount of time) as the voltage regulator module itself is relatively low priced and has mostly good availability for purchasing.

Though visual verification for each individual module is a good way of evaluating them before power-up, it is not an absolutely mandatory step because functional test should cover any functional discrepancies and covers AOI, involving parameters described previously.

Acceptable test parameter ranges are compiled from statistical analysis (calibration data feedback from previous production sets) rather than mathematical one based on component tolerances and combination of worst-case uncertainty of those. The ranges are determined from already verified modules that have passed initial testing and extended usage in designed products.

The voltage regulator module is tested by placing it into the test fixture, applying different input voltages, toggling the enable pin and applying a “dynamic” load to the module under test. Parameters are verified by electrical measurements in each step and comparing those with given ranges of parameters.

Testing procedure algorithm is described in detail in the following Table 8, where module inputs, outputs and test stimulus conditions are presented.

Table 8. Voltage regulator module test procedure.

Step#	Module input	Procedure notes	Expected output
0.	No module	Reset system state, USB PD, relays open state, load off	-
1.	Input disconnected, EN = 0	Insert module into clamp	0V
2.	Input connected 5V, EN = 0	Connect USB VBUS +5V relay	0V
3.	Input connected 5V, EN = 1	Delay of 100ms before next step	4.5±0.5V
4.	Input connected 5V, EN = 1	Connect load through relay, delay of 100ms before measurement	4.5±0.5V
5.	Input voltage 9V, EN = 1	Increase USB PD voltage by one step, delay of 100ms before measurement	8.5±0.5V
6.	Input voltage 12V, EN = 1	Increase USB PD voltage by one step, delay of 100ms before measurement	11.5±0.5V
7.	Input voltage 15V, EN = 1	Increase USB PD voltage by one step, delay of 100ms before measurement	12±1.0V
8.	Input voltage 20V, EN = 1	Increase USB PD voltage by one step, delay of 100ms before measurement	12±1.0V
9.	Input voltage 20V, EN = 1	Repeat voltage measurements 10x, delay of 100ms before measurement, find min-max difference, pass if $\Delta V \leq 50mV$	12±1.0V
10.	Input voltage 20V, EN = 0	End of measurements, all off, Show red/green light	0V
11.	No module	Remove module from clamp	-

The power and load connections must be electrically disconnected during initial module placement to prevent high current and possible arcing between terminals which degrades both module’s and test probes’ connectors. The problem is worse for test probes as those will be subjected to wear and tear during every test, while for the module it’s only once (assuming no retests). Cycle time can be optimised by balancing between soft start and replacing the test probes more frequently. Cost effectiveness is difficult to estimate theoretically, but a rough estimation of potential test time reduction is by ¼ to ⅓.

Output regulation comes on after the input voltage is greater than the set output voltage by feedback resistor network due to it being a step-down topology regulator.

A simpler procedure, that optimises out all not absolutely mandatory steps can be implemented by just connecting both input 19V and load to the module and checking if output is stable in the range of 11-13V (set by the on board potentiometer in that random range). This means if test cycle time is critical only steps 8-10 from Table 8 are executed, reducing cycle time to <5sec.

4.2 Lamp controller test device

The controller PCBA is a top-hierarchy assembly of the whole lamp (product) and functional testing must go through its designed functionality for the user.

Testing will go through initial safe power up to not to cause any more damage if the DUT is faulty in a significant way, after that basic operation is checked e.g. the main SoM is working and can communicate with other subparts and sensors on the board, finally the power sections of the DUT are tested that provide the main functionality of the product.

The following subchapters will describe different aspects of the test device, such as chosen system components, specifically designed parts, purchase parts, testing procedure, expected results etc.

4.2.1 Test device’s electronics

Based on testing specifications and a conceptual drawing a list of the test device’s components was compiled in Table 9, mostly determined by their purpose in the overall system. Mechanical part of the design is only described on the single part level, explained later.

Table 9. List of materials for controller PCB test fixture.

#	Item	Purpose
1.	Generic Windows PC (laptop)	Main system controller PC
2.	Manson HCS-3402 USB	DUT adjustable power supply
3.	Picotest M3500A	System multimeter 6½ digit resolution
4.	Picotest M3500-opt09	20 input relay expansion card for multimeter
5.	TagConnect TC-2030	Testconnector for programming
6.	ESP-PROG	USB to 4-pin serial converter
7.	Generic barcode scanner	For reading DUT unique serial code sticker
8.	Test fixture PCB subassembly	Interposer board for 6710819402 assembly
9.	BP1000 EM03 M 37pcs	Testprobe tip
10.	RCP065U CR03 37pcs	Testprobe receptacle
11.	Wires, cables, crimps	For interconnects
12.	Mechanical test fixture	Box with handle and mechanical structures

[1] depends on PSU output ports

Overall cost of the test fixture with necessary equipment is estimated to be about 1500-2000€, without considering development and design time, which would probably add an equivalent amount.

4.2.2 Test connectors

There are special connectors developed to be used for testing purposes and not by the end user. These usually have a smallish footprint on the PCB and sometimes don’t require a receptable at all. The electrical purpose of these connectors is to pass power and signal to UUT for production testing/programming purposes. These can include known pinout and standard purpose ones such as front plate or backplane connectors for power (IEC) or ethernet (RJ-45). Dedicated test protocols such as JTAG use their own connectors to which the end-user has no use (or access) for, but are not used here as there is no specific need for JTAG and using this would increase development costs and time with little gain that could be otherwise realized with linear programming.

Figure 11. Tag-connect 6-pin testconnector [14].

4.2.3 Testpoints

Testpoints (or testpads) are unmasked areas on PCBs that enable electrical connection by contact. Meaning no soldering or permanent attachment has to be made. These points can be either unused (at that manufacturing step) footprints, pads, holes, vias or purpose placed testpads that are exactly matched to testprobe size.

Testpoints #34-37 described in Table 4 are doubled as regular SMD testpoints on the PCB and also with a special test connector footprint (TagConnect TC-2030) to provide both automatic (test fixture) access and manual repair/troubleshooting access.

4.2.4 Test probes and receptacles

Testneedles/probes/pins (also called pogo-pins) are a special type of spring-loaded single pin “connector” with a sharp and/or task-specifically designed tip to make electrical contact with PCB’s unisolated contact surface or directly to a component on board. These “testpads” can either be standard copper pads, vias, plated through holes, terminals, posts, leads or (BGA) solder balls. The pad type used on the PCB determines the kind of tip on testprobe that is needed to make a reliable and repeatable contact.

Test probes consist of plunger, spring and barrel of which the tip shape determines how contact is made with DUT. Different shapes have different applications: sharp tips are best for making direct contact to a flat pad, serrated/star shapes and flat tips are the least intrusive to the PCB, a chisel tip is a combination of both as it is suitable for flat pads and plated through holes.

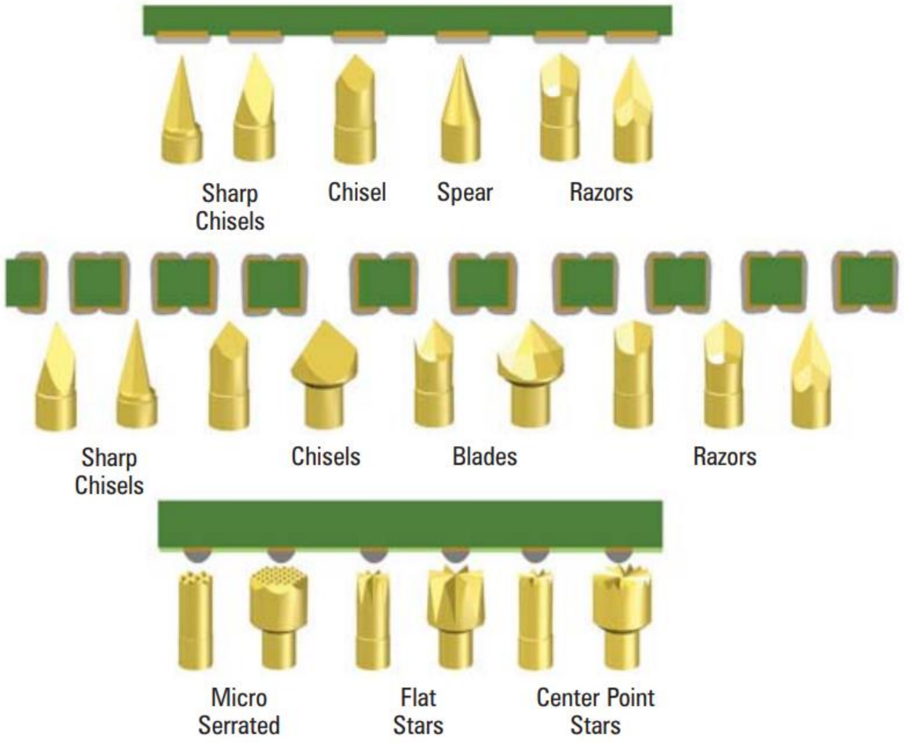

Figure 12. Test-tip style based on PCB receptacle option [23].

Part of the test probe “assembly” is also a probe receptacle which is either pressed or soldered into a carrier board. It’s two main purposes are to provide electrical connectivity from the test probe to the rest of the circuit and to be a shell for enabling easy replacements by interference fit between test probe and probe receptacle.

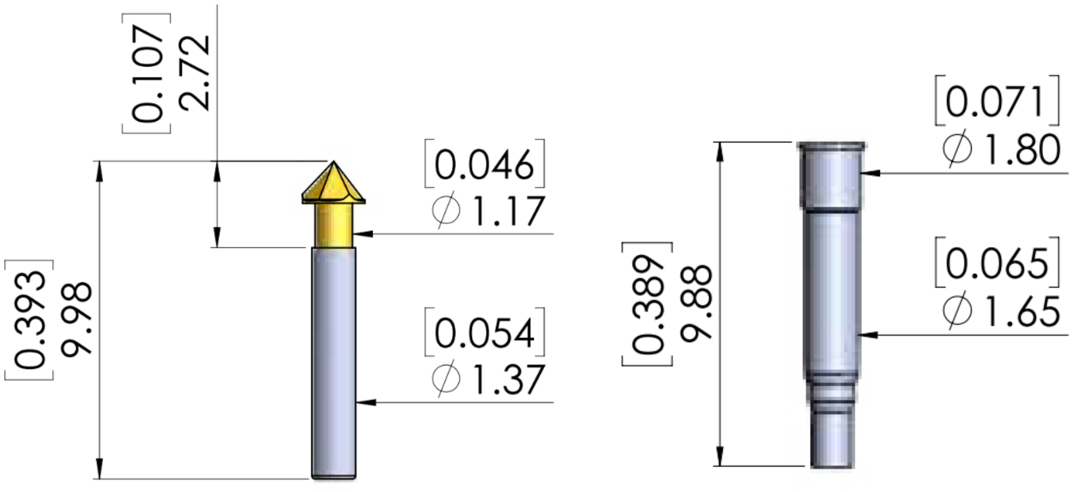

Figure 13. Equip-test test probe set, BP1000-EM (left), RCP065U (right) [24].

Choosing test probes will be a compromise between available products from such manufacturers and specifications of a test device. These requirements can involve electrical (contact resistance, maximum current), mechanical (size, tip type, plating) and operational parameters (specified lifetime, ease of replacement). A general rule applies here, that bigger is better, meaning more reliability from a mechanical viewpoint.

A single complete set of test probe and receptacle was selected to fit mostly all use cases while maintaining universality for both the simple voltage regulator module, the controller board test device and any further future developments.

- BP1000 EM03 M – test probe tip
- RCP065U CR03 – test probe receptacle

The first letters (a) of the part number shows the probe series. BP stands for battery probes which have a high current rating (<5A), enabling use for both signal and power transmission. Designator (b) shows the probe plating which is usually hard gold for least contact resistance and durability of contact surface. Tip style (c) is chosen to be a three-vertex cone as it should be the first stable option for contacting with through hole pads. Plunger material (d) is standard BeCu for good electrical properties. Tip diameter code (e) determines the dimension to be 1.57 mm which is suitable for medium pitch probe arrays. Spring force (f) shows how much pressure needs to be exerted on the probe to push it down, this also means same force is applied to the PCB contact as to when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction (Newton 3rd law). ‘M’ in this case notes 1.25N spring force at working stroke distance (2/3 of total distance travelled).

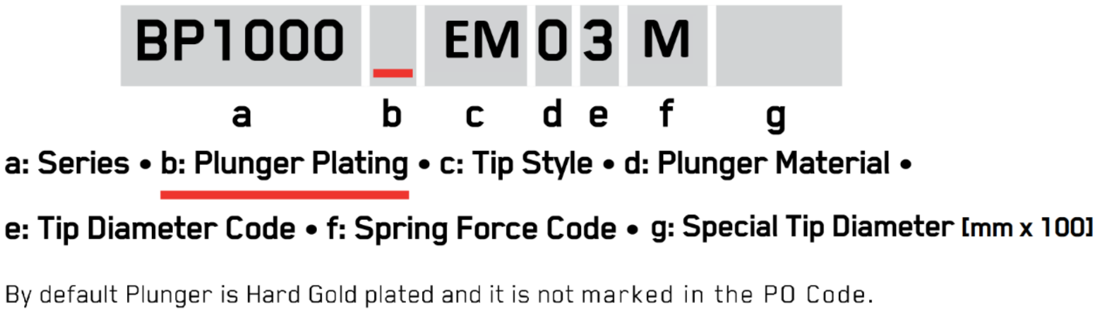

Figure 14. Test probe product code selection.

4.2.5 Mechanical test fixture

These are mechanical devices with the purpose to hold, position and achieve good electrical connectivity to DUT. Most common ones for PCB’s are sandwich-type, where the board is placed between two sides that keep it tightly aligned and apply even pressure to all test contacts. This kind of a fixture also ensures that no movement of DUT happens during test sequence to avoid any false negative results, possible manufacturing delays and retesting.

These specially built holders have protruding contacts to mate with the PCB’s testpoints (electrically unisolated contacts on the board itself). Testpoints and respective contacts’ total count does not add more time complexity *O(k)* during test cycle as would manually (dis)connecting measurement cables and probes.

For this test device a commercial solution like the Equiptest HPS-12 seen in Figure 15 was considered, but as this controller is part of a new product line meant to replace an older, phased out product series it was deemed appropriate to rather update an existing similar type mechanical fixture.

Figure 15. Equip-Test HPS-12 hand press fixture kit [11].

As this will be done by the industrial design section of the team and does not give any more insight into testing technicalities (electronics and conceptual) it will not be further discussed.

4.2.6 Main system controller

The test device's system controller's (or master device) purpose is to execute the test cycle according to planned test algorithm and to interface with other equipment. It's choice is both simple and complex, as many standard solutions are available, but each of those might have features or shortcomings that are crucial in either some test stage or have impact on the development of the system as a whole regarding available resources.

The main system controller will be a Windows based PC as it can provide higher number of universal features and is easily replaceable with a similar generic type. Another pro aspect for this choice is previous experience with developing test systems on similar platforms inside the company and having competence to achieve software related targets with less time and resource spent. Other variants were also assessed based on their suitability for this test device, numerical evaluation criteria will remain the same as in Table 7.

Table 10. Main controller choice criteria.

Criteria	**Raspberry Pi**	**Windows based PC**	**Fully custom design**
Hardware interfacing	2	3	3
Development cost	2	3	1
Price	2	1	1
WiFi	3	3	3
Screen	2	3	3
Ecosystem support	2	3	1
Physical size	2	1	3
SUM:	15	**17**	15

Smaller, simpler and less capable system controllers (Arduino, M5stack) have been left out of this table of comparison as it was clear these could not fulfil some of the minimal required specifications and were therefore excluded.

The test controller PC will have connections for all auxiliary devices that are part of the system by USB, which is the most reasonable option as it is widely used, available for connection on many devices and equipment manufacturers have invested in value added services to aid usability. See Appendix 3 [12]-[15] for the test fixture system component hierarchy view.

4.2.7 Data acquisition

A device for data acquisition is needed to measure numerical and quantifiable values from the DUT to then allow a one-to-one comparison by the main system controller. A multimeter would be a reasonable choice for this task as it has several electrical measurement types available (voltage, current, resistance etc).

Picotest M3500 was chosen as the main data acquisition device as its precision for measurements (6½ digits) is more than satisfactory for this kind of a DUT's measurements, due to most of the voltages are either logic levels, standard logic bus voltages or by design no more than two decimal places and one of its main arguments was its 20-channel input multiplexer plug-in card to make system integration simpler. There is no rational reason to discuss exact measurement uncertainties of this multimeter as the voltages intended to be measured are in the standard precision class of ±1%. The precision can be this “low” by design because all critical calibration of the DUT is done digitally through software methods.

Table 11. Picotest M3500 specifications.

Criteria	**Requirement**	**Picotest M3500**
Input voltage	voltage from 0V to ~24V	1000V DC, 750V AC
Number of inputs	Up to 20	20 with M3500-opt09 expander card
Remote data interface	USB connection for communications	Yes, USB
Data and control	Scripting/programming/system commands available for setting inputs and reading data	USB TMC/SCPI-1993 Agilent 34401A compatible command set
Overall data acquisition precision	4½ digits resolution is adequate for test statistics	6½ digits

Its pricepoint is also somewhat lower than similar and equivalent devices available on the market. For example Agilent 34401A could be ranked in the same functionality class category as the Picotest 3500A.

4.2.8 PSU

The other main component of every test system is a power supply, and for this specific test device following specifications needed to be fulfilled.

Manson PSU was chosen for its availability, price, previous experience by colleagues and its technical suitability based on experience (being robust).

Requirements for the PSU are similar to use cases found in a professional environment, these technical details are described in the following table and then compared against the chosen PSU’s specifications.

Manson HCS-3402 USB specification gives the following information about the power supply described in Table 12.

Table 12. Manson PSU specifications [10].

Criteria	**Requirement**	**Manson PSU**
Output Voltage range	voltage from 10V to 24V	1-32VDC
Output Current range	current up to 10A	0-20A
Voltage Setting Resolution	voltage set resolution 0.5V	100mV
Current Set Resolution	current resolution 50mA or equivalent	100mA
Constant Current mode	Limit current to safe value	Yes
Remote programming	USB connection for communications	Yes, USB
Data and control	Scripting/programming/system commands available for setting values and reading data	Manson Standard scripting language
Protections	overload (current) protection	Overload, Short Circuit by Constant Current, Output Tracking Over Voltage, Over Temperature

4.2.9 Testprobe interposer PCB

An interposer PCB was designed to fit a generic type test fixture to this specific controller board and to provide an easy to access and universal pinout connector for test signals. It includes one-to-one matched testpoint locations and mounting holes for the main board. In addition, two cut-outs have been added to the sub-PCB to accommodate the TH power connector and bottom side mounted voltage regulators. Testprobes are mounted to this interposer board to provide electrical connectivity when a DUT is placed and pressed against it [9].

The DUT is mounted onto the interposer board with guide posts in place through the mounting holes to guarantee as parallel placement path as possible when inserting it into the test fixture. It will either have an end position directly on the testpins fully pressed down or there will be a slightly smaller than the main board shaped cut-out intermediary holder for exact positioning. This is dependent on the exact force distribution of the board, but exact fit won’t be guaranteed by design, so an edge-based insertion depth limiter is a more likely version.

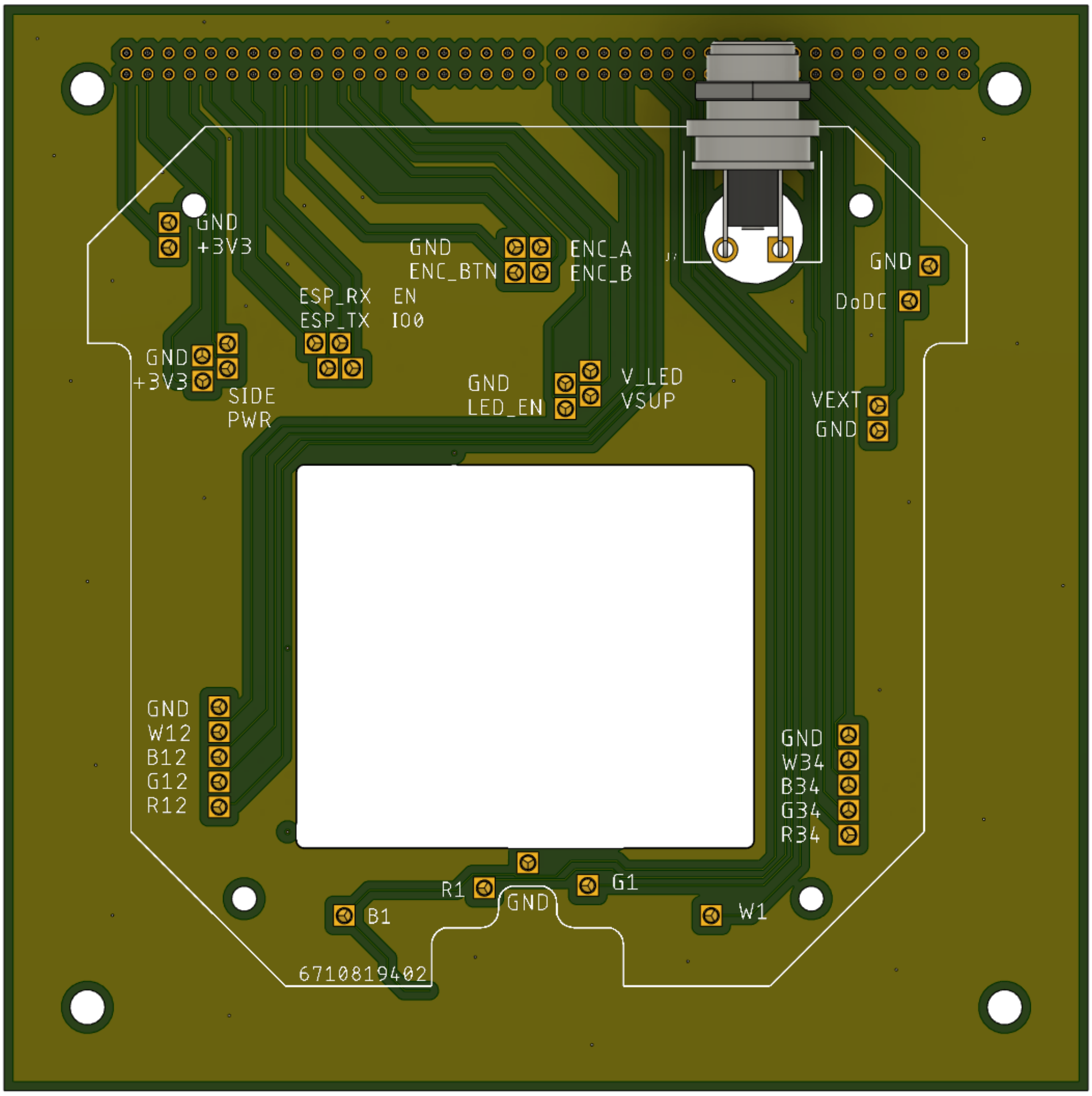

Figure 16. Interposer PCB for test device, top view.

Mechanical fixture is in development by another team member so this will only be described on a conceptual level.

A total number of 37 testprobes locations are mainly guided by function-driven design (PCB design), their distribution on the board is done as evenly as possible for structural integrity and to prevent any bow or twist of the PCB by evenly distributing the force applied. A suggested maximum allowable bow and twist for fabricated PCB’s is 0.7% by IPC-A-600 for boards with SMD components and this should not be exceeded even by flexing of the board during the test and resulting plastic deformation. Though a simulation was not done in stress analysis CAD software to estimate the deflection in the fixture. Design for testing (DFT) methodology enables to reduce both product testing times and test fixture development times.

There are also two banks of four pullup resistors not visible on the top side (mounted on the bottom to avoid placement issues) for shunt switch pullups to ease the testing of LED switching measurements. There is no reasonable argument to have these switchable in-circuit, so they are always connected.

If the regulators will be load-tested then it is possible to have a fan blowing onto them to avoid overheating during the test procedure as they are designed to be mounted to a heatsink in the final product assembly.

4.2.10 Test procedure

The testing procedure is described in the following table as an algorithmic guide. Steps are described by their purpose (target or working condition), expected output (result) and procedure notes (what should be done by the system controller and/or other equipment).

Table 13. Controller PCBA test procedure.

Step#	DUT test target	Procedure notes	Expected output
1.	No DUT	Reset system state, PSU off, waiting for input	-
2.	Controller PCB inserted into test fixture	Secure the DUT, attach power supply cable and LED output cables, close lid	-
3.	Serial number identification	Use a barcode scanner to read the unique label	Text form code: DS0xxxx00xxxxxx
4.	Input voltage 5V from main power input	Test system PSU parameters: 5V, 0.2A Shorts test	Check PSU feedback: 5V, 0A
5.	Input voltage 16.5V	Input hysteresis test, Test system PSU parameters: 16.5V, 0.2A	Check PSU feedback: 16.5V, 0A
6.	Input voltage 17.5V	Input hysteresis test, 17.5V, 0.2A Add stabilization time of 1-2s for current limited startup condition	Check PSU feedback: 17.5V, 0<I<0.2A
7.	Input voltage nominal 19V	Input hysteresis test, 19V, 1A	Check PSU feedback: 17.5V, 0<I<0.2A

8.	Test main +3.3V, 5V, 12V	No change	Measured +-1%
9.	4-pin serial data interface programming	Flash test program using Espressif module ESP-PROG	Flash successful conformation
10.	Serial commands through programming interface	Test IO, from table X “IO”	Check if IO is toggled
11.	LED voltage test	Enable voltage regulators (EN = ‘1’)	measure pairs #3-6, 7-10, compare table X
12.	Enable high current tests	PSU 19V, 3A	-
13.	Enable red ch. 50% power	Test program red channel PWM = 50%, 1s	Both red channel voltages remain +-1%
14.	Enable red ch. 50% power	Test program green channel PWM = 50%, 1s	Both red channel voltages remain +-1%
15.	Enable green ch. 50% power	Test program blue channel PWM = 50%, 1s	Both red channel voltages remain +-1%
16.	Enable red ch. 50% power	Test program blue channel PWM = 50%, 1s	Both red channel voltages remain +-1%
17.	Enable full current tests	PSU 19V, 8A	-
18.	All LED channels on	RGBW PWM = 100%	No PSU overload I<8A
19.	Short burn-in test	10-15s all on, then all off (PWM 100% ->0%) Measurement before switch-off	RGBW voltages remain +-1%
20.	Final firmware load	Flash firmware using Espressif module ESP-PROG	Flash successful conformation
21.	Save test results	Upload all gathered data to database, indicate visually PASS/FAIL	database entry successful
22.	End of test	Remove DUT	-

The test procedure should have reasonable delays between different steps and measurements or if a parameter is changed then feedback should test the changed condition before continuing (if such possibility is technically available).

Power is first applied with a small current limit to test if the DUT is mostly working or if there are any major shorts or wrong (higher) voltages that can cause an abnormal current and possibly extend the damage of the fault further. If there are no initial problems with the controller board, then full system current can be enabled from the power supply by digital control and functional testing can begin.

Input voltage hysteresis test checks if the DUT's input protection functionality triggers on the correct voltage level to avoid switching the controller ON at an inappropriate input voltage. As the designed input voltage is 19V, the switchover points are designed to be 16.5V OFF, 17.5 ON. A hysteresis is here required, otherwise the controller would continuously trigger above and under the set switch point due battery load impedance, electrical noise, PSU cable loss etc.

After testing for absolute shorts it's time to test for absolute open circuits i.e. if anything works. This can be done through programming/flashing the main SoM which, when successful, indicates that voltages are normal, processor is working and that connectors have good electrical connections.

Finally the power sections of the DUT are tested that provide the main functionality of the product. This means enabling the LED voltage regulator modules, measuring their output voltages and comparing if those are in range. Then the same test is repeated with loaded outputs to assure stability of the high current circuits.

Testing software implementation of the controller board and for the overall system controller (PC) will not be discussed as it is out of scope for this thesis. Though the testing procedure algorithm developed above will be the source document for such further work.

4.2.11 Test logging

Testing a device should result in a final “PASS/FAIL”, while this information is sufficient for the operator to choose between two shelves to put the tested product into. Though it is reasonable to have detailed test logs (or raw data of those) for both statistics about the test in general and immediate data about a specific DUT for its production lifecycle logging. The latter having its first use after failing for example a functional test and being sent to troubleshooting. If no test log for a non-functional device is available, then it’s a waste of time and resource to start manually redoing what an automatic test has done before [8]. A good test log should have at least three main components:

- test log header – which includes time, data, test station information, serial number of the DUT, test software version and any other parameters deemed necessary;
- information about the (sub)test being executed - name, purpose of test, reference number to documentation etc;
- numerically measured results - expected result (or range for continuous values), measured result, is result acceptable or not (colour coded for ease of reading).

Additional useful test log formatting guidelines would be using tables for numerical values or tab-aligned text if simpler text formats are used. If a paper copy of the test log is determined to be necessary (or a single page summary of it), its width (and height) should be formatted according to ISO paper sizes.

4.2.12 Additions next iterations

The next version(s) of the testing fixture can be divided into two categories, the first one requiring changes on the controller board and the second one not.

The first way of iterating a new version needs cooperation from the controller board designer to implement necessary layout techniques for additional testing functionality. These can be new signal testpoints added or providing some LED outputs as edge connectors for more rigid access.

The second way of iterating a new version means only changing the test fixture to achieve more test coverage and functionality. These can be additional access to through hole connectors which are currently untested or high current testprobes to supply power to the PCB directly without the power plug. The last one being useful for rejects’ repair as the main power connector has to be removed before an oven reflow (for component removal and replacement) cycle.

The only other important external connectors for the controller board are those that connect it with the LED board through four 1mm pitch flat-flex cables (FFC). The dimming of LEDs is implemented by high frequency PWM modulation, meaning high current pulses with short rise and fall times. This inherently causes electromagnetic interference, but can be contained to an acceptable level when the positive/negative pair is routed as short as possible and as close to each other to reduce loop inductance. Another issue with non-designed paths is its capacitive compensation which is taken into account for operating conditions (cable length etc.). More inductance on those high speed lines can increase over- and undershoot pulses which in the worst case can damage switching transistors. Therefore it is not reasonable to route these out through testpins giving them a longer path and introducing unknowns into the system. In addition when the cables are plugged in to the corresponding sockets, this step would verify the quality of the contacts as well. It is still under question if there will be:

a) a universal set of cables is used for the tester which are replaced after recommended time of mating cycles;

b) each LED board has their own set which is used during the testing as well;

c) A special variant of cables will be used that are either with a stronger backing material for less flexing and therefore more rigid for the operator to handle, a purpose designed thin PCB with a better (longer lasting) surface finish or a industry special connector-inserts that are designed exactly for this special application.

Another aspect of this problem is power delivery network (PDN) resonances under certain conditions. Though these are unlikely, but hard to determine analytically and without special simulation software [5].

Having longer routed out cables would introduce a constant error to any measurements (current through finite resistance), which might have some affect to the system, but could be subtracted out to achieve the “in system” result as this error would be constant across all measurements.

4.3 Testing the test devices

As the testing devices are a combination of other complicated electronic devices the question of calibration arises. Both of the test devices cannot be calibrated as single units because they don’t have a quantifiable “PASS/FAIL” criterion themselves such as SI base or base derived units i.e. voltage, current, resistance etc.

Only the data acquisition part can be compared to a reference such as a multimeter which is calibrated as a standalone unit and any deviation after that comes from the signal passing through the test device itself and therefore degrading the measurement system’s coherence [3].

Calibration (for measurement equipment) is mandatory if the measured value has impact on the product’s quality, but not strictly required if the result is used for reference only, though precision and repeatability is highly desired for trustworthy test result.

5 Summary

The target of this thesis was to design and conceptually describe two test devices: one for a simple voltage regulator module and the second one for a controller PCBA for a LED based lighting system.

The first test device was needed to test voltage regulator modules of unknown quality and origin as part of incoming test. A simple test controller was developed to give the module necessary input stimulus and check whether correct output conditions were achieved by different loading conditions. A small size-factor ESP32 based IoT product was chosen to be the controller of the test device and adjust both module’s input voltages from a USB-C power supply, switch the enable signal and load (through relay) for the output. The voltage regulator modules could be tested quickly with a cycle time of about 10s.

The other test device designed was needed to do a functional test on a controller PCBA to check its proper function in a similar application to the end assembly. For this the target was to firstly test if the DUT is safe to power up with full power (check input protection). After that basic voltage checks are made, the main SoM is programmed to enable IO testing through measuring if toggling “LOW/HIGH” is possible. Then the LED outputs can be tested with full power for full loop case. Finally all test and measurement data is to be written to a database with the device’s serial number and and other requisite information. An interposer PCB was designed to enable easier access to the DUT with test probes and to interface with rest of the test equipment necessary for fully automatic testing procedure.

Both designed devices should be easy and straightforward to assemble and use for production testing as they are designed to be made from (rhetorical) relatively common components.

This thesis gave an insight to electronics testing and how choices were made for test methods and test equipment based on the task specified to reach a given target.

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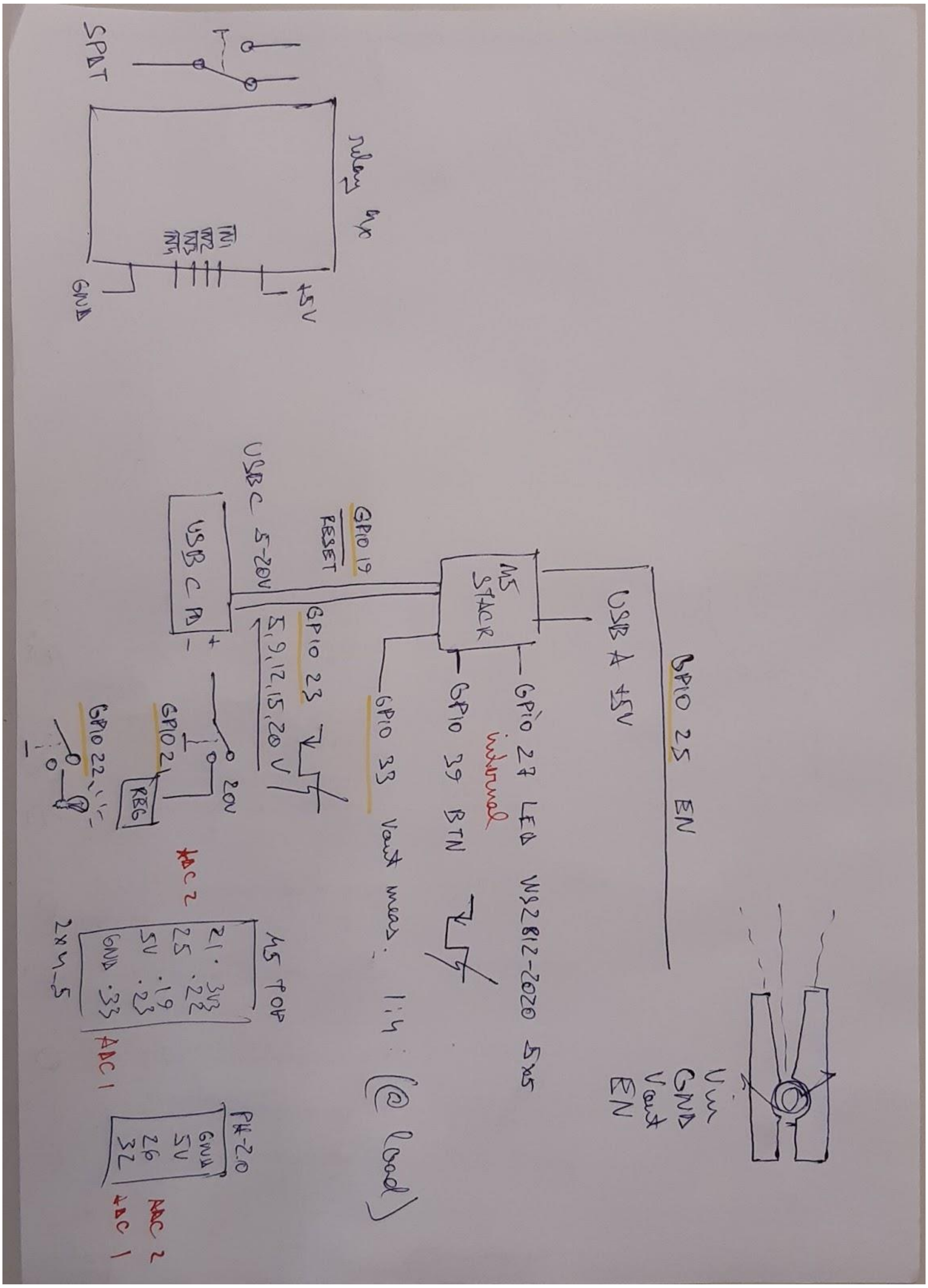
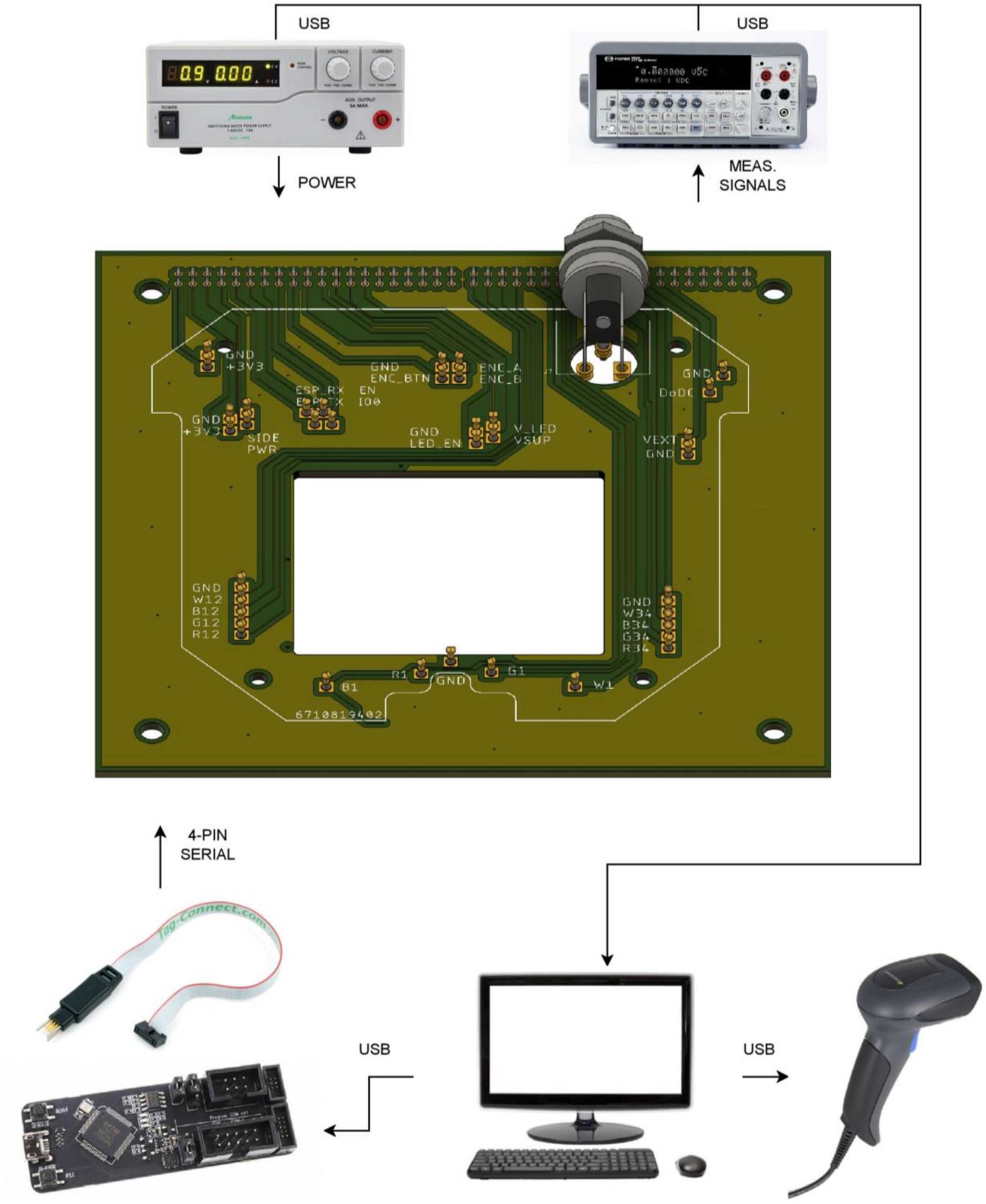
Appendix 2 – Original design drawing for voltage regulator module test device



First and initial drawing, design details differ from final version.

Appendix 3 – Controller PCBA test fixture system view



Test fixture interposer PCB shown under a 45deg isometric view for 3D, other system components shown by their connectivity hierarchy.