TALLINNA TEHNIKAÜLIKOOL
INSENERITEADUSKOND
Elektroenergeetika ja mehhatroonika instituut

TESTRAKISE DISAIN JA ARENDUS RELEE- JA JUHTTRÜKKPLAADILE

DESIGN AND DEVELOPMENT OF IN-CIRCUIT AND FUNCTIONAL TEST FIXTURE FOR RELAY AND CONTROL BOARD

MAGISTRITÖÖ

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LÕPUTÖÖ LÜHIKOKKUVÕTE

Autor: Ingmar Seidelberg	*Lõputöö liik:* Magistritöö
Töö pealkiri: Testrakise disain ja arendus relee- ja juhttrükkplaadile.	
Kuupäev: 24.05.2019	58 *lk*
Ülikool: Tallinna Tehnikaülikool *Teaduskond:* Inseneriteaduskond *Instituut:* Elektroenergeetika ja mehhatroonika instituut	
Töö juhendaja(d): M.Sc. Mahdiyyeh Najafzadeh; Ph.D. Indrek Roasto	
Sisu kirjeldus: Lõputöö on 58 lehel, sisaldab 6 tabelit ja 24 illustratsiooni Lõputöö eesmärk on funktsionaalse ja komponendi testrakise disainimine ja arendus I2C relee- ja juhttrükkplaadile, et automatiseerida ja kiirendada testimise protsessi, samal ajal saavutades võimalikult suur testi katvus. Lõputöö ülesande ja selle lahenduse eripära seisneb terviklikus eraldiseisvas testsüsteemis kus erinevalt tavapärasest viisist on samaaegselt lahendatud funktsionaal- ja komponenditest. Lisaks toimub samaaegselt mikrokontrolleri programmeerimine. Testrakis, tester ja liides peavad olema seadistatud vastavalt trükkplaadi eripärale ja suutelised testima trükkplaadi kõiki katsele määratud komponentide väärtusi, programmeerima juhttrükkplaadil olevat mikrokontrollerit ja kontrollima funktsionaalsust ehk signaali olemasolu juht- ja releetrükkplaadi vahel. Lisaks on antud projektis tähtsal kohal disainida rakis mida on operaatoril ohutu kasutada. Testrakis peab olema täpne ja kvaliteetne, et minimialiseerida võimalus ebakorrektseteks mõõtetulemusteks. Projekti disainimisel ja koostamisel on arvestatud kõikide antud valdkonnas kehtivate normide ja ohutusnõuetega. Seletuskirjas on esitatud põhilised rakise tootmiseks vajalikud komponendid ja andmed. Töös on kasutatud üldlevinud projekteerimistarkvara „DipTrace“, „AutoCAD“ kui ka spesiifiliselt testimise valdkonnas kasutatavat tarkvara „VayoPro Test Expert“. Lõputöös on analüüsitud testi kiiruse ja testi katvuse tulemusi võrdluses hetkel kasutuses olevate süsteemidega. Lisaks on antud hinnang uudsele rakise ehitusele ja mis tingimustel antud süsteemi kasutada saab. Projekti maksumus on ca. 1500 €.	
Märksõnad: Trükkplaadi test, testrakis, funktsionaaltest, komponenditest, mikrokontrolleri programmerimine	

ABSTRACT

Author: Ingmar Seidelberg

Type of the work: Master Thesis

Title: Design and Development of In- Circuit Test and Functional Test Fixture for Relay and Control board

Date: 24.05.2015

58 *pages*

University: Tallinn University of Technology

School: School of Engineering

Department: Department of Electrical Power Engineering and Mechatronics

Supervisor(s) of the thesis: M.Sc. Mahdiyyeh Najafzadeh; Ph.D. Indrek Roasto

Abstract:

Final paper is written on 58 pages, contains 6 tables, 24 figures

The aim of the thesis is to design and develop ICT and FCT test fixture for I2C relay and control board, in order to automate and speed up the testing process, while obtaining high test coverage.

The significance of the final paper lies in the comprehensive stand- alone test system where Functional Test, In- Circuit Test and In- System Programming is implemented into one fixture. The fixture and tester have to communicate through several interface modules in order to test all the required components according to PCBA design. Compared to more traditional way of testing where all test methods are tested separately, the system developed during this project is capable of programming the microcontroller using the same fixture that is performing ICT and FCT. Functionality between PCBAs is checked using In- System programmed IC. Functionality test assures the signal between control and relay board and determines whether relays will function according to the program. Additionally it is important that the designed and constructed fixture is easy and safe to use for the operator. To minimize false measurements the fixture has to be accurate and durable. All the norms and safety standards have been fulfilled during the project's design and construction period. The main component list and data is given in order to successfully construct the test fixture. General design software programs like „DipTrace“ and „AutoCAD“ were used to complete the project and also test specific software „VayoPro Test Expert“ was used to determine test point coordinates. The result of test speed, test coverage and overall design advantages is analysed. The cost of the project would be ca. 1500 €.

Keywords: PCBA test, test fixture , functional test, in- circuit test, programming microcontroller

THESIS TASK

Thesis title: **Design and Development of In- Circuit Test and Functional Test Fixture for Relay and Control board**
Student: **Ingmar Seidelberg, 190592AAAM**
Programme: **Energy Conversion and Control Systems**
Type of the work: **Master Thesis**
Supervisor of the thesis: **M.Sc. Mahdiyyeh Najafzadeh**
Validity period of the thesis task:
Submission deadline of the thesis: **24.05.2019**

____________________ ____________________ ____________________

Student (signature) Supervisor (signature) Head of programme (signature)

1. Reasons for choosing the topic

Testing is one of the most time consuming and costly phases within electronic manufacturing process. In order to guarantee the quality of end product all devices need to pass several tests. The topic would be important for all electronic manufacturers as it would show the possibilities and advantages of combining several test methods.

2. Thesis objective

The aim of this thesis is to find possibilities to improve and automate PCBA testing for small and mid-sized manufacturers.

3. List of sub-questions:

- How to decrease testing time within electronic industry?
- How to reduce the cost of testing within electronic industry?
- How to keep high test coverage while reducing testing time and cost?
- What are the possibilities to maximize the flexibility of testing process within electronic industry?
- Is one test method enough to guarantee the quality of PCBA?

4. Basic data:

The project was made in collaboration with Equip- Test Kft. Data and initial documents were received from the company. References from past projects were used to analyse the outcome and advantages of this project.

5. Research methods

Prototype version is designed and built in order to analyse and achieve results. Test measurements, observations and references from the past projects will be used to analyse whether the project was a success. Excel, CAD, VayoPro Test Expert , TRI, DipTrace and DrillC software programs are used to analyse the data.

6. Graphical material

Graphic content is included in the main body and appendices.

The list of most important graphs would be:

- Test Coordinates of Control/ Relay board
- Program for connecting Relays
- PCBA Layout/ Schematic for Control/ Relay board
- PCBA Schematic of Guarding
- ICT Test Coverage
- User interface for TRI tester

7. Thesis structure

- LÕPUTÖÖ LÜHIKOKKUVÕTE
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- 1.2 Control and Relay Board
- 1.3 Software used to design Test fixture
- 1.4 Design of mechanical test fixture parts
- 1.5 Interface

8. References

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9. Thesis consultants

Peter Gyebnar- Equip- Test Kft

Josias Lopes- Equip- Test Kft

10. Work stages and schedule

- Collecting basic data (01.02.2019)
- Designing fixture (01.03.2019)
- Writing first part of the thesis- the design (08.03.2019)
- Manufacturing hardware (30.03.2019)
- Writing second part of the thesis-hardware (05.04.209)
- Assembly and wiring (07.04.2019)
- Software and debugging (25.04.2019)

- Putting together different sections and comparing with theoretical books and articles (10.05.2019)
- Completing the final version of the work (23.05.2019)

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FOREWORD

The thesis project was chosen and developed together with Hungarian company Equip- Test Kft in order to improve the testing possibilities within electronic field. During the project, several departments were involved in order to finalize the full working system. That includes design department, mechanical department, electrical department, assembly department and quality department.

In addition to Equip- Test Kft team, I would like to thank tutors Mahdiyyeh Najafzadeh and PhD Indrek Roasto who guided and helped me during the project process.

LIST OF ABBREVIATIONS AND TERMS

AOI	Automated optical inspection
AXI	Automated X-ray inspection
BOM	Bill of materials
CKT	Circuit
CLK	Clock line used in I2C bus
DPPM	Defect Parts Per Million
DUT	Device under test
EOL	End of Line Test
EOL	End of Line test
FCT	Functional Test
HC	High Current
I2C	The Inter-integrated Circuit Protocol
IC	Integrated circuit
ICT	In- Circuit Test
IoT	Internet of Things
Mil	Equal to one thousandth of an inch (0.001 inch)
PCBA	Assembled Printed Circuit Board
PN	Part number
RF	Radio Frequency
SDA	Data line used in I2C bus
THT	Through-hole technology
TP	Test point
UART	Universal asynchronous receiver-transmitter
UUT	Unit under test
VCC	Voltage source
Xtal	Crystal oscillator

INTRODUCTION

In modern world where electronic devices play even greater part in our everyday lives, the importance of device reliability is greater than ever. Digitalization is visible in every field and while the complexity of electronic design is increasing, the size of the PCBA and electronic devices in most cases is decreasing. Compact PCBA design with higher component numbers, multiple layers and functionalities increase the risk of making mistakes during manufacturing cycle. Taking future IoT, 5G and Industry 4.0 technologies into account then the volume of manufacturing electronic components will continue to rise rapidly. To satisfy the demand of growing electronic sector, every aspect of production needs to be as efficient as possible.

The PCBA production consists of following phases [1]:

Step 1: Solder Paste Stencilling
Step 2: Pick and Place
Step 3: Reflow Soldering
Step 4: Inspection and Quality Control
Step 5: Through-Hole Component Insertion
Step 6: Final Inspection and Functional Test

One of the most important phases in PCBA production would be the last 6th step. Final inspection, Functional and In- Circuit test would give the final feedback regarding PCBA quality before sending a ready product out to the client. Compared to other steps it is also most difficult part to fully automate. In some cases it is not easy or even impossible to access test points or connectors due to the miniature size, component location or other electrical/ mechanical obstacles. The need to design individual test system specifically for every project is also the reason why testing is one of the most time consuming and expensive parts of the PCBA production.

Failure to pass Open/ Short test is the main reason why PCBAs fail during production (Table 1), meaning that there would be no connection between components or there would be unwanted connection.

Table 1. The comparision of PCBA Defects and the statistical frequency [2]

DEFECT	RATE	TYPE	SOLDER RELATED
Open	25%	Structural	Yes
Insufficient	18%	Structural	Yes
Short	13%	Structural	Yes
Missing electrical component	12%	Structural	No
Misaligned	8%	Structural	Yes
Defective electrical component	8%	Electrical	No
Wrong component	5%	Electrical	No
Excess solder	3%	Structural	Yes
Missing non-electrical component	2%	Structural	Yes
Wrong orientation	2%	Structural	No
Defective non- electrical component	2%	Structural	No

In order to assure the reliability of the device, several tests need to be carried out. In addition to final inspection and ICT/ FCT test, continuous tests are made throughout the production cycle to localize and detect the potential defects as early as possible.

The quality of PCBA test is stated by overall test coverage. The correct calculation of test coverage could be difficult to determine due to several tests being carried out simultaneously and independently [3]. Even within ICT, Device and Connection Coverage are calculated separated. Test coverage of the designed test system will be calculated in this thesis and the results will be analysed to determine whether the value would be high enough.

This paper studies different testing methods of PCBAs. The aim of the project is to find a solution to increase the testing speed while decreasing the cost and keeping required testing standards and coverage.

The major test methods are following:

• ICT- In circuit test
• FCT- Functional test
• Flying probe tester

• EOL- End of Line Test
• Dual Stage ICT/ FCT- Functional and In- Circuit both implemented into one fixture
• Visual Inspection
• AOI- Automatic optical inspection
• AXI- Automatic X- ray inspection

Depending on the production volumes and product complexity, the combination of test methods are used to reach the desired test coverage. The PCBA test coverage requirement differs according to field and location where PCBA is used.

In case of high mix low volume production, it is critical that the testing re-configuration period would be as flexible and fast as possible. Whereas high volume, low mix production line would benefit using less flexible In- Line system, where no test operator presence is required as all the processes are automated. In that case the DUT testing period would be significantly lower than in manual off- line systems. In addition there is also a possibility to use vacuum and pneumatically operated test systems. Another option for high flexibility and low volume operations is the use of Flying probe tester.

The core of this study is to design and build manually operated off- line test fixture to perform In-Circuit Test, Functional test and also perform In-System programming. Typically ICT and FCT tests are done separately which is simple solution but time consuming. In my work I propose a new approach where both of these steps are done simultaneously. Additionally IC programming is done during same step. Combining 3 separate steps under one fixture and controlling it with TRI Tiny tester could reduce testing time up to 2 times.

PCBAs are sometimes tested to the extent where the question arises weather they are over tested [5]. In this thesis I will examine if it would be sufficient to only use one type of test method and what risks could under testing have .

During the design and development phase several hardware and software programs are examined. In this master project the whole test system is designed, built, programmed and debugged.

1. DESIGN AND DEVELOPMENT OF TEST SYSTEM

The aim of this project is to develop a stand-alone off-line manual fixture capable of covering Functional Test, In- Circuit Test and IC programming. The reason for implementing all of the parts into one system is to save time and money that is critical for the manufacturer. We will determine whether executing both ICT and FCT test method is necessary and what could be the risk of having only one type of testing method being carried out.

Developed Test System contains the following parts:

- FIXTURE- Mechanical bed of nails fixture for placing and testing PCBA.
- INTERFACE- Interface between fixture and tester
- TEST SYSTEM - TRI Tiny tester and test program

Developed system would provide compact solution with high coverage for testing PCBAs. The compact solution is achieved by implementing ICT and FCT testing into one fixture. Compared to the standard way of executing every test separately, the combined test system would reduce testing time, manufacturing time and also manufacturing cost. In addition to FCT and ICT testing, additional feature of flashing IC function is added to maximize the capability of the tester. Implemented Algocraft In- System could program the IC in any desired way.

Stand- alone manual test system with two nests for Relay and Control Board would measure the value of every testable component on the board and determine if the measured value would be within limits. Having two different PCBAs that under normal circumstances need to communicate with each other, we will implement FCT test to determine whether the signals are passing and if the commands would be performed according to the program.

The first step of the project would be to select the optimal fixture type, which would depend on the size and complexity of PCBA. Before manufacturing and modifying any components, there should be clear test description. “VayoPro Test Expert” and “DrillC” software programs are used to determine the exact number and coordinates of test points. Component manufacturing is done according to the design. After manufacturing initial fixture components, we need to modify the parts according to the specific project that is mainily done by CNC machines. In this project two separate PCBs need to be tested. For that reason there would be need for drilling receptacle holes for two nests. The next step would be placing receptacles and test probes. After initial assembly the wiring from receptacles to interface block would be done according to the wiring list. Final construction step would be the quality inspection of the whole fixture.

Programing part of the test system is done using TRI Tiny programming software. Both ICT and FCT test programs are programmed using the same user interface. Algocraft's In- System programmer is programmed using WriteNow! Software.

The last step would be to connect the whole system by using interface modules and debug for any manufacturing or programming mistakes. All these steps would assure the required quality outcome.

1.1 Test methods used in the project

ICT and FCT are two main test methods used in this project. Both test methods complement each other, meaning that while ICT excels at detecting the presence and values of all components, it does not detect the shortcomings and failures of the overall board design. The functionality of the board is assured by the FCT test.

1.1.1 In- Circuit Test

In- Circuit test will measure the values and functions of analogue and digital components. In our project following components are tested with ICT test:

- Capacitor (C)
- Diode (D)
- Relay (K)
- Connector (J)
- Resistor (R)
- Switch (S)
- Integrated Circuit (U)
- Connector (X)
- Crystal Resonator (Y)
- Relay (K)
- Transistors (Q)

Full list of tested components and given values can be found in Appendix 8 and Appendix 9.

ICT can detect:

- Solder shorts
- Missing components
- Wrong components
- Open connections
- Short connections

1.1.2 Functional Test

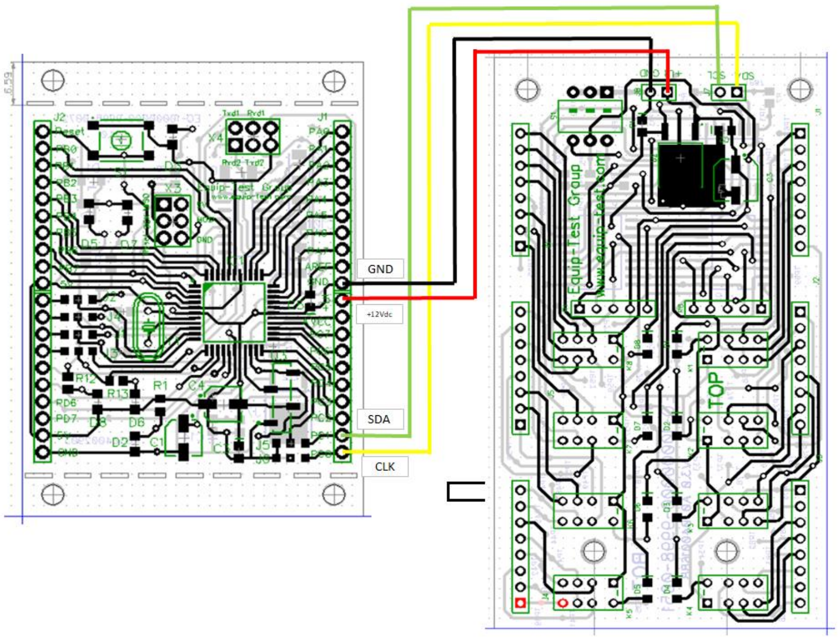

Figure 1.1 Wiring between control board and relay board

Designed functional test is using open port communication to send signals to relays through control card. Firstly the command is generated by the program and sent to the control board (Figure 1.1). After receiving the command, control board would re- send the signal to the relay board and flash memory, Xtal CKT, I2C lines are tested. We can conclude that once the controller accepts the command from the serial port then Flash memory, Xtal and UART would have no failures. Once the relay card has received the command from the control board, it should close the specific relay that was commanded by the program and turn on the LED on relay card. The step for closing the Relays is shown in the program (Figure 1.2). If the relays open/close and LEDs do turn on/ off according to the program, then we can conclude that that there would be no failures with LEDs nor relays and that the I2C lines are connected and signal is passing correctly.

```
CONST
        DEBUG='NO';
        PORTNUMBER=11;          //SET COM PORT 11 FOR RELAY CARD
        BAUDRATE=19200;         //SET COMMUNICATION SPEED BPS
        DATA_LENGTH=8;          //SET DATA LENGTH
        STOP_BITS=1;            //SET STOP_BITS

        COMMAND_QUANTITY=8;     //SET number of commands to be sent from control board to relay card

VAR                                                     // Declare variables
        I,COM_STATUS:INTEGER;
        COM_MESSAGE:CHAR[100];
        COMMAND:CHAR[10][10];
        I_STRING:CHAR[20];

SUBROUTINE COM_ERROR();         // Subroutine for COM port access error
{
        FLAGTESTFAIL();
        COMSTA(STATUS=COM_STATUS,MESSAGE=COM_MESSAGE);
        WRITELN('COM ',PORTNUMBER,' ERROR: ',COM_MESSAGE);
        CLOSECOM(PORT=PORTNUMBER);
};

MAIN
        COMMAND[1]='cr11';      //On RelayCard_1 Relay_nr1
        COMMAND[2]='cr12';      //On RelayCard_1 Relay_nr2
        COMMAND[3]='cr13';      //On RelayCard_1 Relay_nr3
        COMMAND[4]='cr14';      //On RelayCard_1 Relay_nr4
        COMMAND[5]='cr15';      //On RelayCard_1 Relay_nr5
        COMMAND[6]='cr16';      //On RelayCard_1 Relay_nr6
        COMMAND[7]='cr17';      //On RelayCard_1 Relay_nr7
        COMMAND[8]='cr18';      //On RelayCard_1 Relay_nr8
        COM_STATUS=OPENCOM(PORT=PORTNUMBER,BAUD=BAUDRATE,NDATA=DATA_LENGTH,NSTOP=STOP_BITS);
        SETCOM(PORT=PORTNUMBER,TIMEOUT=0.5);
        IF COM_STATUS<0 THEN COM_ERROR();

        FOR I=1 TO COMMAND_QUANTITY DO
        {
                COMMAND[I][STRLEN(COMMAND[I])+1]=0h0D;  //Loop on constant I

                IF DEBUG='YES' THEN WRITELN('Command for sending to relay card: ',COMMAND[I]);
                COM_STATUS=COMWRT(PORT=PORTNUMBER,DATA=COMMAND[I],NWRITE=STRLEN(COMMAND[I]));
                IF COM_STATUS<0 THEN COM_ERROR;
                MDLY (50); //Small delay between commands
        };

        CLOSECOM(PORT=PORTNUMBER); //Close COM port
```

Figure 1.2 Functional program to connect relays on

1.1.3 In- System Programmer

In System Programming (ISP) is a process where programming or flashing of IC is done after IC has already been mounted on the PCB. The possibility to program ready circuits gives an advantage of flexibility to add updates or rewrite the programs.

In this project programmable Atmel microcontroller was programmed to customize control board to fulfil required operations on a relay board.

Algocraft WN-PRG08A model was used. With WN-PRG08A model 8 ICs can be programmed simultaneously. [4]The ability to program several ICs in parallel is significantly decreasing overall testing time.

WriteNow! Software User interface is used to write the program for IC.

Listing some of the IC's that can be programmed with Algocraft's programmer would be Adesto, Atmel, Cypress, Giga Device, Infineon, Microchip, Micron, Nordic Semiconductor, NXP (Freescale), Renesa [4]. In our project Atmel microcontroller was programmed and the whole program can be seen in Appendix 3 and Appendix 4.

1.2 Control and Relay Board

The last step of the manufacturing needs to be taken into consideration already in the very first steps. During the designing phase of the PCB, the designer has to think about the testing capabilities of that PCBA. Otherwise there would be high probability that some of the component/ nodes on test board cannot be accessed by test probes. Inability to test some of the components would result in lower test coverage and lower quality assurance.

In this project a fixture was developed for 2 PCBAs and the PCBAs were designed in a way that all test points are on one side. In this case it would be bottom side. There reason for preferring the one sided test, is mainly the cost and time consumption to produce the fixture.

The designed Relay Board together with Control Board is universal and can be used in several applications. One example would be switching multiple VCC lines on a panelised UUT.

1.2.1 Control Board

Control card receives commands from PCs serial port and it will re-send the signal to the relay board through I2C lines. The main part of the control board would be microcontroller TME ATMEGA1284P-AU Mikrokontroller AVR Flash. The microcontroller together with all other components can be found from the Control Board's BOM list (Table 1.1).TME ATMEGA's microcontroller is programmed by Algocraft and in total 8 relay cards can be controlled by one control card. The control board is universal, meaning that depending on program generated by the Algocraft, it could have numerous applications. The layout of Control Board can be found from Appendix 6.

Table 1.1 The BOM list of Control Board

Item number	Article	Quantity	
1	Equip Univerzális Vezérlő V3.0 ATMEGA1284 Nyáklap	1	pcs
2	Lomex 820125 SMD Kondenzátor Kerámia 100nF 50V 10%	5	pcs
4	TME ATMEGA1284P-AU Mikrokontroller AVR Flash	1	pcs
5	Lomex 890784 MAX232ID Soros Illesztő SO-16	1	pcs
6	On Semiconductor MC7805BDTG Feszültség Stabilizátor 5V 1A	1	pcs
7	Lomex 400073 Kvarc 20pF HC49/S 16Mhz	1	pcs
8	Lomex 820095 SMD Kondenzátor Kerámia 22pF 50V 5%	2	pcs
10	Lomex 811099 SMD Ellenállás Standard 10kOhm 0,125W 5%	1	pcs
11	Diotec Semiconductor SL1M Dióda Egyenirányító 1A 1000V	2	pcs
12	Samwha RC1V107M6L07KVR Kondenzátor Elektrolit 100uF 35V 20% SMD	1	pcs
13	Samwha SC1E476M6L005VR Kondenzátor Elektrolit 47uF 25V 20% SMD	1	db
14	Lomex 950276 SMD LED Zöld 40mcd	2	pcs
15	Lomex 950147 SMD LED Sárga 8mcd	3	pcs
16	Lomex 950168 SMD LED Piros 100mcd	1	pcs
17	Omron B3FS-1010 Mikrokapcsoló 6x6mm	1	pcs
18	lomex 430896 apa tápcsatlakozó 3 pólusú 2,54mm	1	pcs
19	Lomex 430837 Tüskesor 40Pol 12/3 Tördelhető 2,54mm	1	pcs
20	TÖRÖLT!!! 2x32 tűsor 2,54 tördelhető	1	pcs
21	TÖRÖLT!!! Lomex 920113 SMD Kondenzátor Tantál 10uF 16V 10%, helyette A0601001521	4	pcs
22	Adam Tech PH1-40-UA-SMT-A SMT Tüskesor 1x40 2,54 mm Függőleges Apa	1	pcs
23	Lomex 811186 SMD Ellenállás Standard 300Ohm 0,125W 5%	1	pcs
24	Lomex 811002 SMD Ellenállás Standard 0Ohm 0,125W Rövidzár	6	pcs
25	YAGEO RC0805JR-07680RL SMD Ellenállás 680ohm 5% 0805	5	Pcs

1.2.2 Relay board

Received signals from Control Board will switch the relays into on or off state depending on the specific command. Each relay card contains 8 relays and these relays could be controlled individually. The relays (K1, K2, K3, K4,K5, K6, K7, K8) together with other components can be seen on TOP Layout in DipTrace software (Figure 1.3). The BOM list of Relay board can be found from Appendix 7.

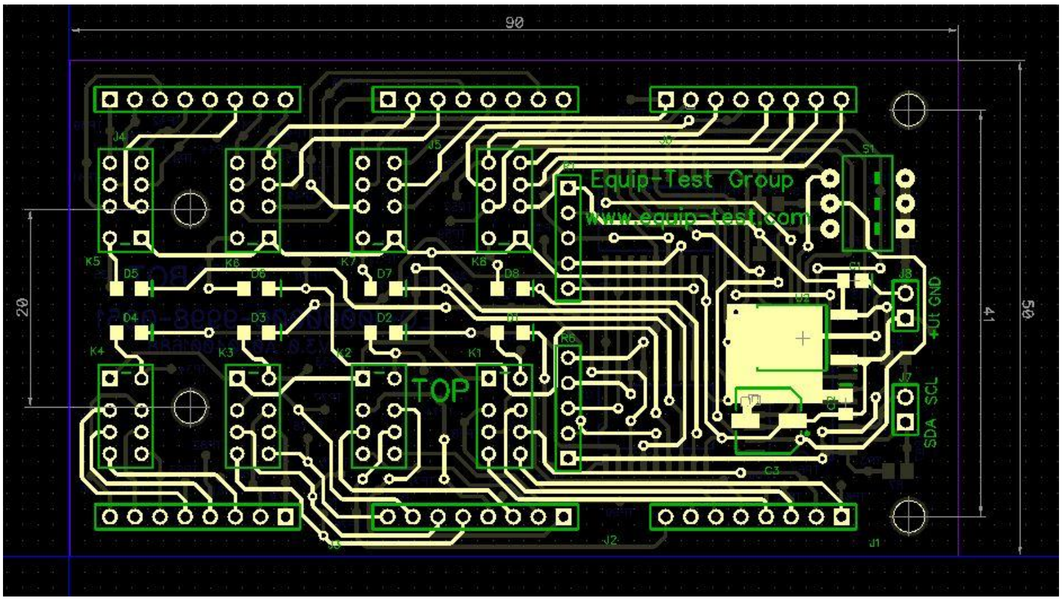

Figure 1.3 TOP Layout of Relay Board

1.3 Software used to design Test fixture

To find the best mechanical and electrical parameters for test fixture, several software programs were used before manufacturing.

1.3.1 VayoPro Test Expert

Having all the necessary PCBA schematics, layouts and/or Gerber files, we can import necessary data into test specific software VAYO Test Expert. Following the steps on the flowchart (Figure 1.4), the system will generate the test point coordinates. Most optimal test point location and availability will be calculated.

The main steps when using VayoPro Test Expert:

The first step would be inserting initial data and generate TP list. Having all the coordinates and correct file formats to further analyse the data, the next step would be importing BOM list. Value and type of components is determined and set. During Net parameter step power or ground is determined and set. After choosing the correct test probes we can do some minor changes before the project would be completed.

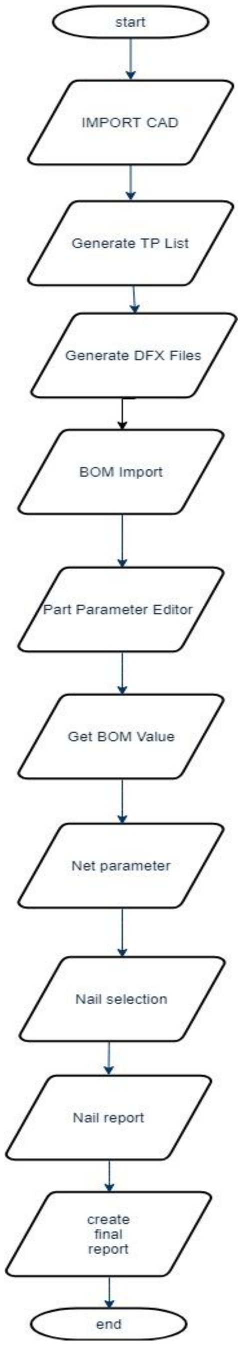

Figure 1.4 Generating test point coordinates with Vayo Test Expert

1.3.2 Test Points

A test point also called PCB node is a location within electronic circuit that is used to connect test probes and receive test signals. Modern miniature surface-mount electronic circuits contain a large number of tinned solder pads which can be test points. The size of a test point is usually between 0,7-1,0 mm [6].

Test point location and drilling coordinates are calculated and designed automatically by Test software program VayoPro Test Expert. Test point map (Figure 1.5) will be generated using the values of coordinates. Full list of coordinates can be found from Appendix 1 and Appendix 2. The preferred test points are usually as close to 100mil as possible. 100mil is the most optimal size and thus also most economically reasonable.

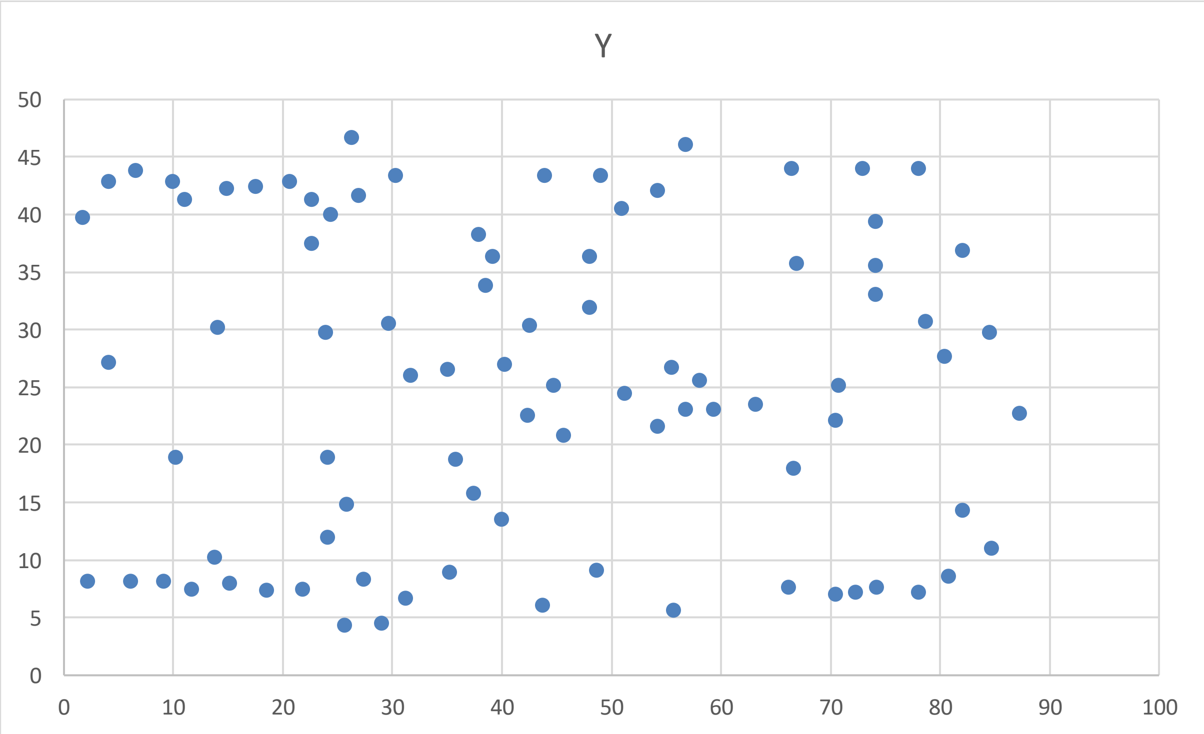

Figure 1.5 Relay Board test point map from cordinates generated by VayoPro Test Expert

Test points can be:

- Test pad- Preferable minimum diameter: 0,70mm
- Via
- Component leg- Preferable minimum diameter: 0,64mm
- Connector/ component

In order to prevent short circuit between probes, a minimum distance between probes is required. The minimum distance is calculated using the distance between the centres of two mounting holes and considering the geometry of the test probe. In case the plunger tip diameter is greater than the diameter of the mounting hole then the diameter of plunger tip is used for calculations. If not, then the diameter of the hole is considered.

The most common distance between test points as mentioned previously is: 100mil = 2,54mm

Other common distances between test points are:

- 40 mil
- 50 mil
- 75 mil
- 100 mil
- 160 mil
- 260 mil

In this project there are total of 267 test points. Relay card has 144 test points and the Control card has 123 test points. Out of total 267 tests probes, 261 test probes are 100mil and the remaining 6 are 75mil. It can be seen on DrillC graph (Figure 1.6) where green circles indicate the critical distance between test points. In order to avoid potential short circuit, smaller 75mil diameter receptacles are used. 100mil receptacles are used for blue circles.

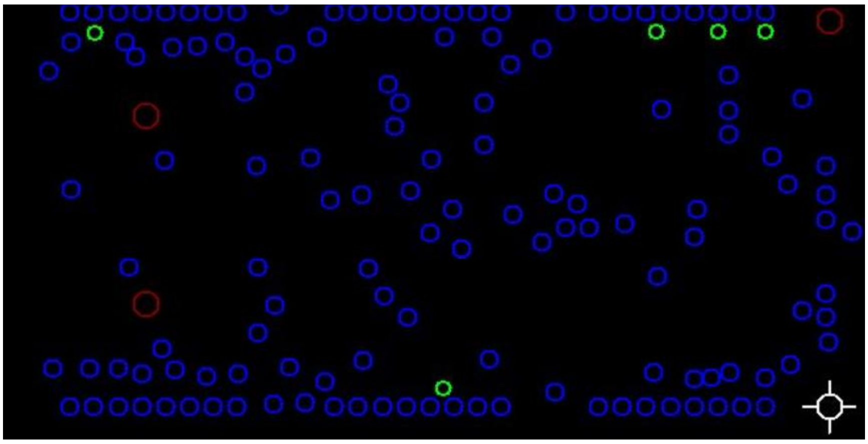

Figure 1.6 Test points for Relay board

Organic Solderability Preservative is widely used as a protective layer for copper parts since lead cannot be used in soldering materials. Test points are covered with OSP during storage to protect copper from oxidation. During the soldering process OSP is dissolved by flux and temperature. In case the temperature is not optimized then OSP could crystallize and form a hard non-conductive surface. That could result in having difficulties to establish a good contact with test probes.

1.3.3 Test Coverage

During ICT test we can calculate the test coverage to have approximate indication of testing quality. The aim is to test all of the components/ nodes on PCBA. Due to several limitations not all values can be measured. For example capacitor under 100pF cannot be tested due to hardware limitations. On the other hand only ICT test coverage does not give the accurate test coverage for the whole system.

During ICT test 21 components on Control board were not tested (Table 1.2). There was no access to 6 components and 15 components did not require testing. That means out of 45 components, 24 were tested. Full list with values for Control board can be found in Appendix 8.

Table 1.2 ICT Tested Control board

Total Components	45
Missing Components	0
No Access	6
Not Tested	15
Tested Components	24

$$Device\ Coverage = \frac{Number\ of\ devices\ tested}{Total\ numbe\ of\ devices}$$

$$Device\ Coverage = \frac{45-(15+6)}{45} = 53{,}3\%$$

$$Shorts\ Coverage = \frac{Number\ of accessible\ nodes}{Total\ number\ of\ nodes}$$

During ICT test 8 components on Control board were not tested (Table 1.3). That means out of 37 components 24 were tested. Full list with values for Relay board can be found in Appendix 9.

Table 1.3 ICT tested Relay board

Total Components	37
Missing Components	0
No Access	0
Not Tested	8
Tested Components	29

$$Device\ Coverage = \frac{37-(8+0)}{37} = 78{,}4\%$$

The following conclusions could be made: Control Board had lower device coverage than Relay board. Having coverage of 53,3 % (Table 1.2) and 78,4 % (Table 1.3) respectively. These values are high enough, taking the complexity of PCBA design into account. Test coverage does not mean that there are no mistakes in PCBA design.

1.4 Design of mechanical test fixture parts

First the fixture size and type is chosen taking the PCB size(s) into account. Another important factor to consider is the number of test points. For this project HPS- 25 fixture model was chosen as the fixture should fit two nests for relay and control board. As the force generated by the number of test probes did not exceed the fixtures 300N limit nor is the combined size of the PCBS greater than the maximum usable area of the test fixture. The HPS series is meant for applications up to 300N [6]. After the fixture choice, the calculation of project timing is made. Project department provides the drawing of the fixture and the production steps will start with manufacturing the fixture components.

Available machines:

- CNC Machines
- Manual milling machines – for precision milling on the parts
- Turning machines –For round shaped parts
- LENZ machine – Used for drilling flat plates

HPS- 25 fixture (Figure 1.7) will consist of base kit and exchangeable kit. The advantage of having an exchangeable kit is to have higher flexibility when it comes to testing different UUTs. In that way the same base kit can be used to test several PCB designs and only the change of exchangeable kit would be required. Measurements of HPS-25 can be found from Appendix 5.

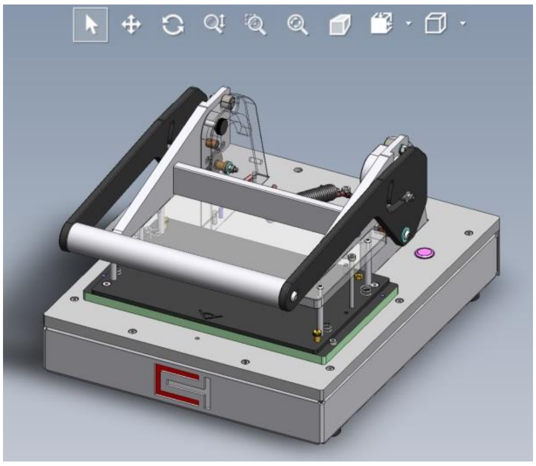

Figure 1.7 Full HPS-25 fixture designed in AutoCad.

1.4.1 Driving Unit

Driving unit (Figure 1.8) is part of the base kit and it is absolutely crucial that there would be no undesired movement in any direction. The hitting accuracy of test points would determine the quality of connection and thus the quality of measurement value. It is also important that the pressure would be exactly parallel towards UUT.

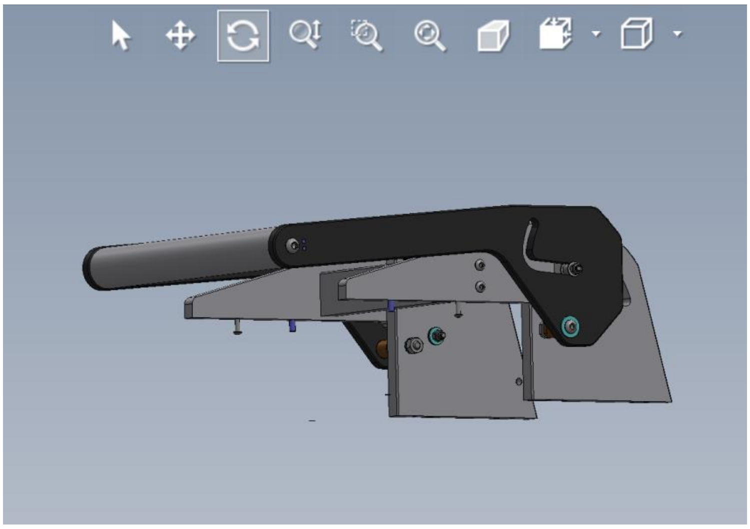

Figure 1.8 Driving Unit of the fixture

1.4.2 Top, middle and probe plate

The exchangeable kit consists of Top Plate, Middle Plate and Probe Plate that can be seen on Figure 1.9. The material of each plate should be strong enough to assure that there would be no bending and no stress on UUT. Otherwise it could damage the PCBA or give incorrect test measurments.

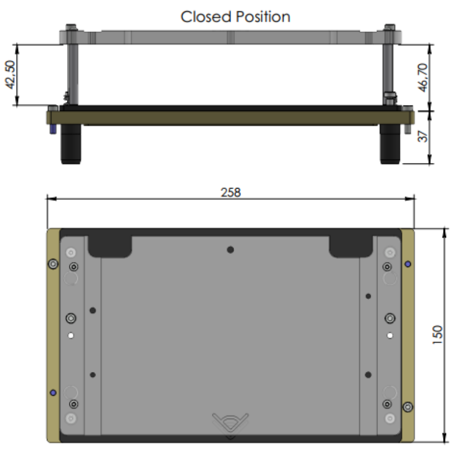

Figure 1.9 Exchangable kit (top, middle and probe plate)

Top plate is used for pushing the UUT down in order to establish a connection between test points and test probes. For that reason push fingers are placed to locations where there would be no components and would not disturb test measurement. Push finger are added to balance the UUT during testing, so that the bending and stress would be minimal. Otherwise there would be high risk for damaging the PCBA and end up with incorrect test result. In case the PCB is more complex and needs to be tested from both sides (TOP/ BOTTOM) then the test probes would be placed on top plate so that the test points could be accessed from top as well as bottom.

Middle plate would be for placing the UUT during the test and it would nova together with probe plate. It is important to highlight that the material is full ESD thus it is safe to operate and has no unwanted charge to manipulate the test result.

Probe plate is used to place the receptacles. Depending on the material of the probe plate the sizes of the drilled holes vary. If the material of the probe plate is harder (FR 4), bigger holes need to be drilled.

The usable area (Figure 1.10) of the fixture determines the maximum size of the tested UUT. Tested PCBA dimension cannot be greater than the usable area. In this project two PCBAs are tested and the combined size is less than the usable area, allowing us to test both PCBAs at the same time.

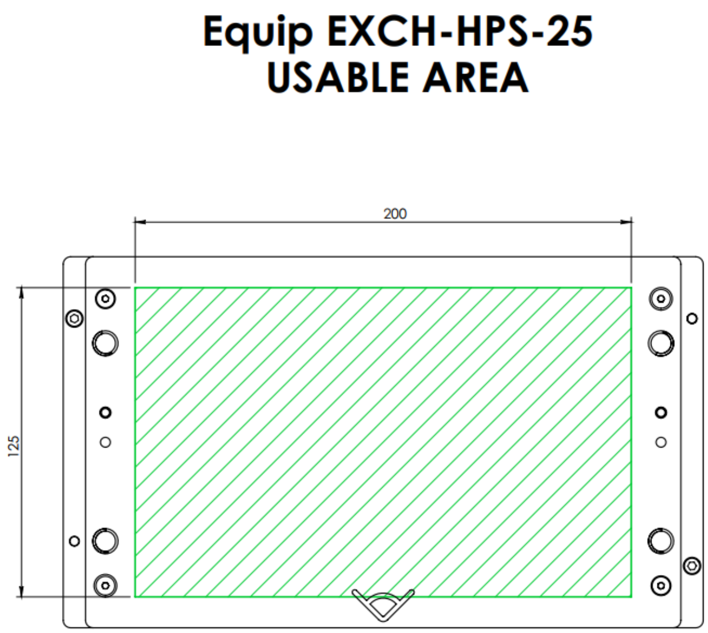

Figure 1.10 The usable area of HPS- 25

1.4.3 Test Probe and receptacles

Test probes are directly in connection with UUT and for that reason it is crucial that the test probes are selected correctly in order not to damage the PCBA. Additionally the quality of test probes is vital to assure the received signal is correct.

Test probes consist of:

- Barrel
- Spring
- Plunger

The part of the probe that connects to test point is called the tip of the test probe. Test probes can vary depending on application. Some examples would be RF, HC, pneumatic, etc. Additionally test probes can differ in dimension, material, shape (sharp, flat, crown, etc.) and spring force. Test probes have mechanical and electrical life time that is given:

Theoretical Mechanical life time:

- 1 million strokes for 100 mil Test probes
- 100 000 strokes for 75mil Test probes
- 100 000 strokes for 50 Mil Test probes
- < 10 000 for smaller than 50 Mil Test probes

Factors influencing electrical life time

- Temperature
- Contamination
- Current Intensity
- Design or manufacturing mistakes
- Loading force (side)

The life time of test probe in normal production circumstances is still significantly lower than theoretical due to combination of electrical and mechanical factors mentioned above.

In this project 3 type of test probes were used:

- ST1000 LA 53 M
- ST1000 CG 53 M
- ST750 LA 53 M

The first letters of code determine the probe family. ST would stand for standard ICT test probe. The number would determine the diameter of the probe. In this case 1000 would be equal to 100mil (Figure 1.11). 750 would be equal to 75mil. Number 53 would determine the plunger material and tip diameter. The last letter of the code (M) determines the spring force to be 2N.

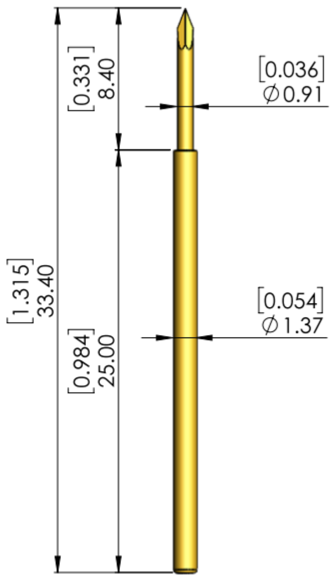

Figure 1.11 Test probe ST1000 LA 53 M [6]

The sharp LA tip is ideal to connect Test points. The properties are given in a table (Figure 1.12) and two possibilities with different tip diameter can be chosen from. In this project sharp tip style with diameter 0,91mm was chosen.

 ⊕	LA	5	3	0.91	0.036
		5	5	1.30	0.051

Figure 1.12 Tip Style LA (Sharp) [6]

All ICT testing is done using Test points, while functional testing is also using THS components. Most of the components values are measured from nodes via TPs but on side of both PCBAs we have THT components which are connected directly using test probes with CG tip style (Figure 1.13). The reason for using a tip style with bigger diameter is that when THT component is inserted then there are bigger holes for the component legs resulting in bigger soldering tolerance compared to TP. The CG tip has 1,3mm tip diameter compared to sharp LA. Covering bigger area means that the connection between THT component leg and the test probe is more secure. In addition test area might be angled and test probe could have a miss hit if sharp tip style would be used.

	CG	0	5	1.30	0.051
		0	6	1.50	0.059
		0	8	2.00	0.079
		0	8 /SP229/*	2.29	0.090
		0	● 9	2.50	0.098
			● 10	3.00	0.118

Figure 1.13 Tip Style CG (Crown) [6]

Receptacles are used to forward the signals received from test probes to tester. In this case two types of receptacles were used for different test probe dimensions. Both types are using wire wrap mechanism to connect wires. (Figure 1.14)

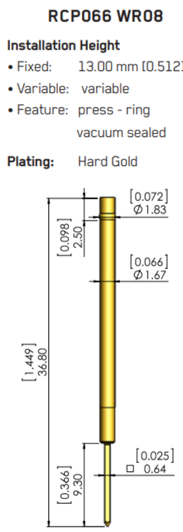

Figure 1.14 Receptacle for 100mil Test probe [6]

The reason for using receptacles:

- Easier to replace a Test probes
- No need of re-wiring when test probes are replaced
- Help to balance-out assembly hole drilling tolerances
- Ensures vacuum within the vacuum chamber
- Available with different wire contact types

1.5 Interface

TRI Tiny has several Interface options depending on the measurements and applications. In this project the following Interfaces were used (Figure 1.15)

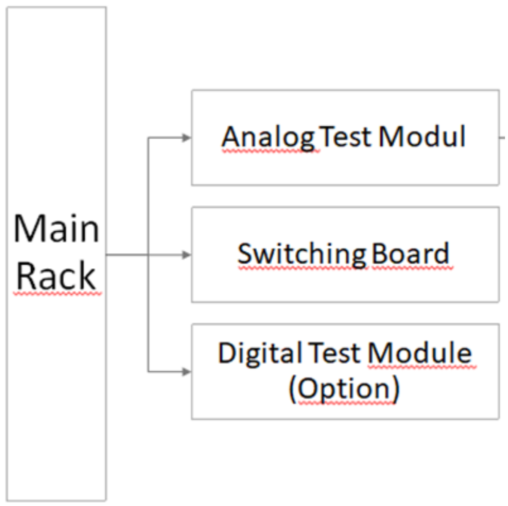

Figure 1.15 TRI tester interface cards

In this project three cards have been used.

- ATM card is used for making measurements.
- SWB card is used for multiplexing
- eDTM card is used for power output.

The whole list of interfaces used in the system can be found from Table 1.4.

Table 1.4 Interfaces used in test system

Location	Description	Qty	Functions	Connector	Qty	Code
TRI S2 Tiny	ANALOG SWITCH BOARD (SWB)	2	Provide channel for analog testing of board under test	Harting 64 Pin	4	NA
	eDTM Board	1	Provides two fixed power outputs Provides four programmable power outputs Provides 16 DIO channels	Harting 34 Pin Harting 64 Pin	1 1	NA

			Provides 16 Relay channels			
Fixture	Rear Panel	1	Receive connections	124718 Connector DSUB 9 Pole Male with Long Wrap Legs	1	EE3315
				10 pol male flat cable connector with wire wrap pins	1	EE1810
				SEK 18 Male Standard Connector 64Pol	1	EE1274

1.6 Test fixture assembly and wiring

1.6.1 DrillC

DrillC software was used to calculate and determine the required receptacles and their dimensions. The initial data in the form of coordinates were received from the VayoPro Test Expert. Visual representation of the receptacles and its locations is generated (Figure 1.16). DrillC software is also used during wiring process as it links the correct interface pins to the corresponding receptacle.

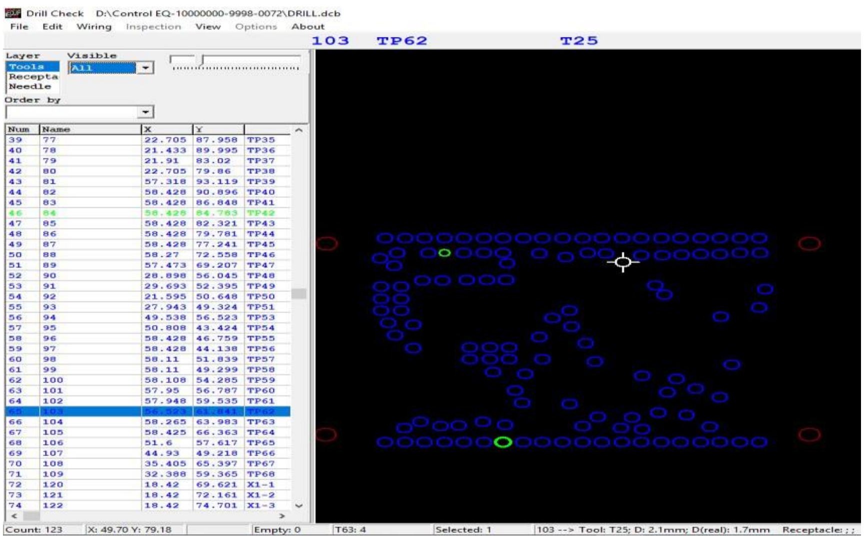

Figure 1.16 DrillC User interface for wiring

1.6.2 Wiring

There are mainly 3 ways to wire receptacles:

- Wrap wire
- Soldering
- Crimping

In this project the wrapping method was used. That is mainly the case if not high current signals are needed. The reasons for preferring wire wrap over soldering are related to time consumption and price. Wire wrap method is faster and less costly.

Wrapping is the process during which the wire is wrapped to a wrap terminal of an applicable receptacle. It can be done manually or using wrap wire gun.

AWG30 wires were used during this project. AWG is a unit system based on inch, where every AWG size is a fraction of an inch. Because of the inverse ratio AWG26 has a higher cross sectional area than AWG30. In order to get a firm and reliable grip, the wire cannot be elastic. The object, which in our case is the receptacle terminal, has to have at least two edges.

1.7 TRI Tiny Tester

TRI Tiny tester is used to control the whole system. It the ideal choice for compact and complete system as it can test ICT, FCT and has other optional test features depending on the project requirements.

TRI Tiny capabilities:

- Open/Short, R/L/C, Transistors and FETs Test
- 6-wire Milliohm Measurement
- Clamping Diode and TestJet Test
- Voltage/Current Measurement
- Frequency Measurement up to 200MHz
- TTL Digital Test
- LED Hue, Luminance, Saturation Test

- 60V High Voltage for LED Test

1.8 Cost of the project

The cost of the production can be divided into:

- Design cost
- Component cost
- Tester cost
- Software cost
- Production cost

Table 4. The cost of mechanical fixture

Item	Article	Qty (pcs)	Price (EUR)	Total (EUR)
Fixture Kit	HPS-25	1	800	800
Exchangeable kit	EXCH- HPS-25	1	300	300
100mil Test Probe	ST1000	267	1	267
100mil Receptacle	RCP066	267	0,6	160
70mi Test probe	ST750	7	1	7
70mil Receptacle	RCP052	7	0,6	4,2

The total cost of the fixture would be ca. 1500EUR (Table 4).

Calculated price includes only the material cost of the fixture. Design, programming, wiring, assembling and debugging cost were not taken into account.

2. DEBUGGING, TEST RESULTS AND FUTURE DEVELOPMENT

Debugging is the procedure where the failures of the test system itself is detected and eliminated. Debugging will determine whether wiring and assembly is done correctly. In addition it will detect any flaws there might be regarding test probe signals. In addition to hardware related testing, software is also tested during this step. All the component values are set and the program is tested under normal circumstances. Having a golden sample of PCBA, we know that the entire list of component values should be within limits and that the board should pass the test. In case the Golden Sample does not pass the test, then it is clear that there are mistakes within test system itself. For that reason debugging is done to determine whether incorrect measurements are caused by program, hardware or the circuit design where not all measurements can be done directly.

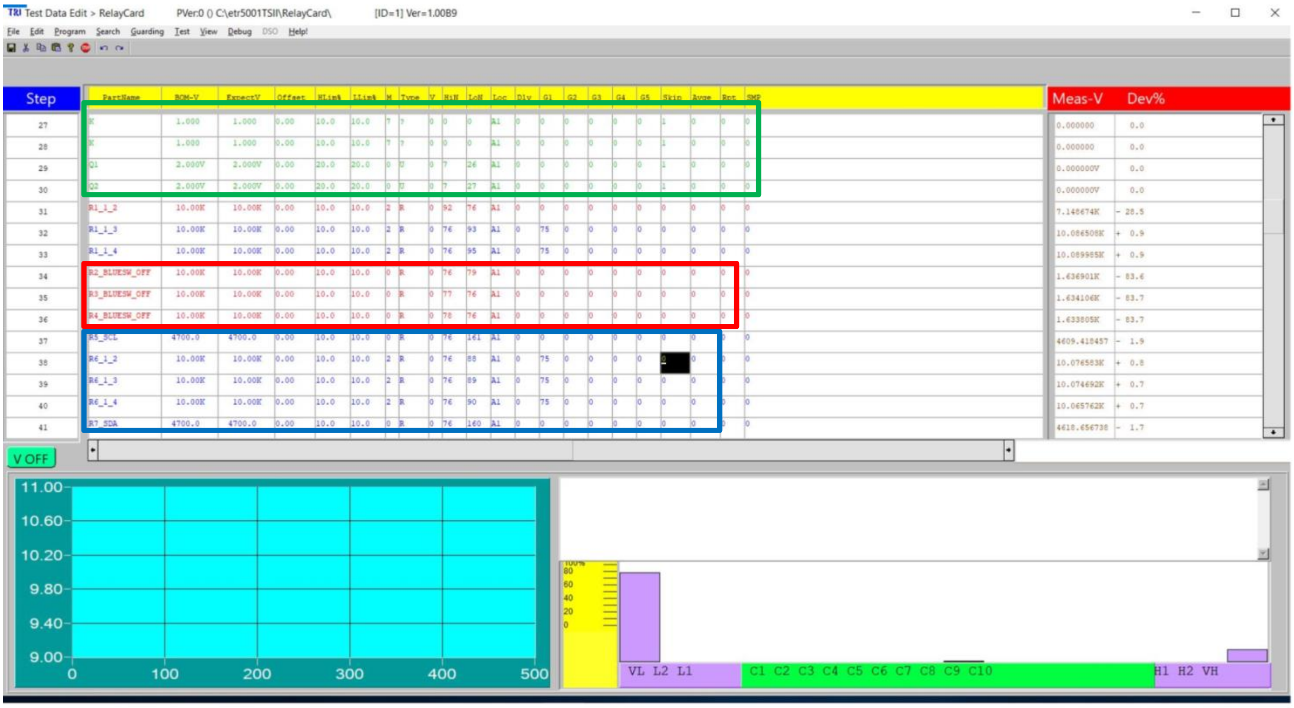

Figure 2.1 TRI User Interface for ICT Test

User interface (Figure 2.1) shows the debugging mode of TRI Tester user interface. Under yellow main box all the components on PCBA are listedand together with set parameters. The green color means that the part can not be tetsed. Blue color menas that the measured value is correct and red value means that the measured value is incorrrect. Measured value can be seen on the right hand side where the value and deviation both are indicated. It is possible to test every component separately and the whole PCBA together. In that way it is possible to set the parameters to desired value.

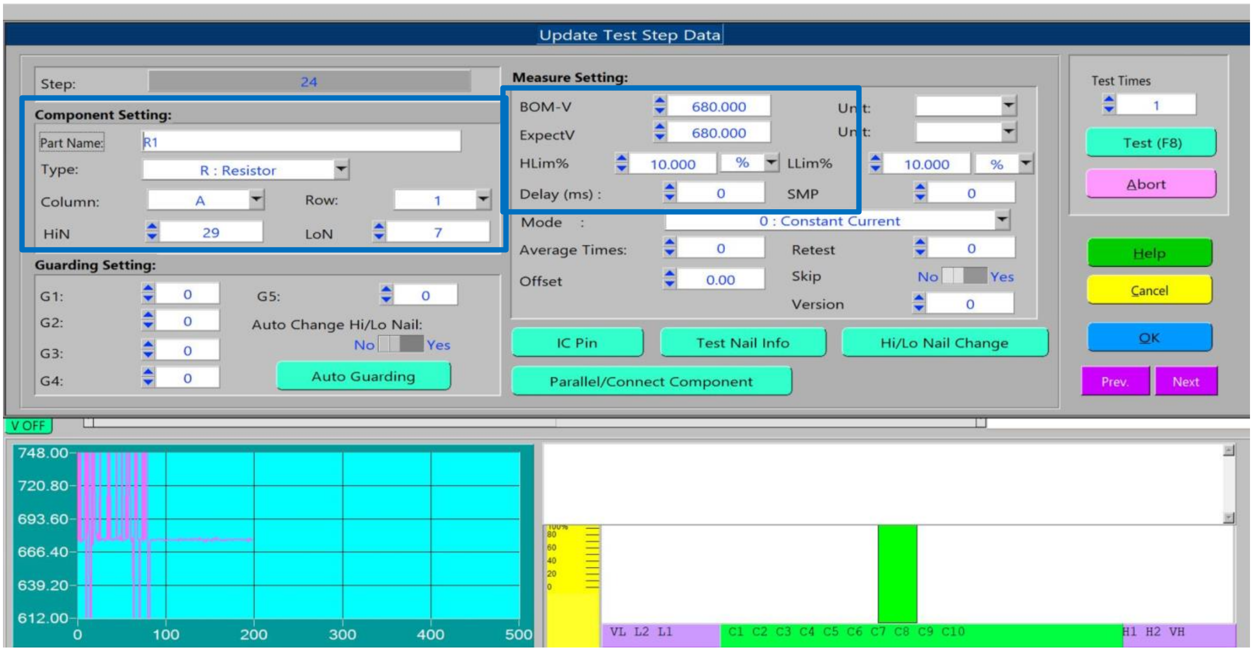

Figure 2.2 TRI Component parameter settings

To change the set parameters, every component is addressed individually. In component setting table the following parameters are set: part name, type of the component and test point location HiN/ LoN. HiN and LoN are test points. The measuremnet is made between High Node and Low Node. (Figure 2.2)

In Measure Settings column the value of component is set according to the BOM list. In most cases the expected value is the same as BOM value. HLim and LLim are the allowed tolerances. (Figure 2.2)

The graph shows the measurement value more in detail, where the peak values can be seen.

The guarding is used in case the circuit is designed in a way that direct measurments would not be correct due to the circuit design. Depending on the location of the nodes, there might be a need for additional measurement point. The reason for incorect direct measurement is the result of parallel pathways, meaning that another component is connected within the same node and is affecting the measurement. The ammeter would not measure the value only through the correct component because current from the parallel path also gets to the ammeter. In order to elimiminate the faiult, additional test point is applied. That procedure is called called guarding. Basically the difference between guarding and non- guarding measurement is the same as the difference between 2- wire measurement vs 3- wire measurement. The value can be calculated by Ohm's law. In some cases several guards need to be applied, but it would be still called 3- wire measurement. As there are also losses in wires, test probes, relays, etc. then additional sense wires might be used to get more accurate measurmeent result . [7]

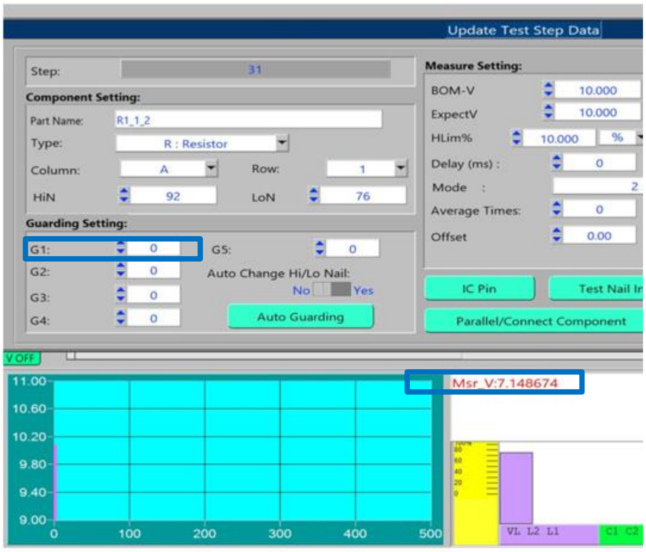

Figure 2.3 Measuring the value of R1_1_2 without guard

It can be seen that the resistor R1_1_2 has an expected value 10,0 Ohms, but the measured value is 7,1 Ohms (Figure 2.3). That is more than allowed 10% deviation. If measured separately, the value is correct thus the reason has to be that there is another component within the node that is affecting the measurement. In order to receive a correct measurement, guarding had to be applied.

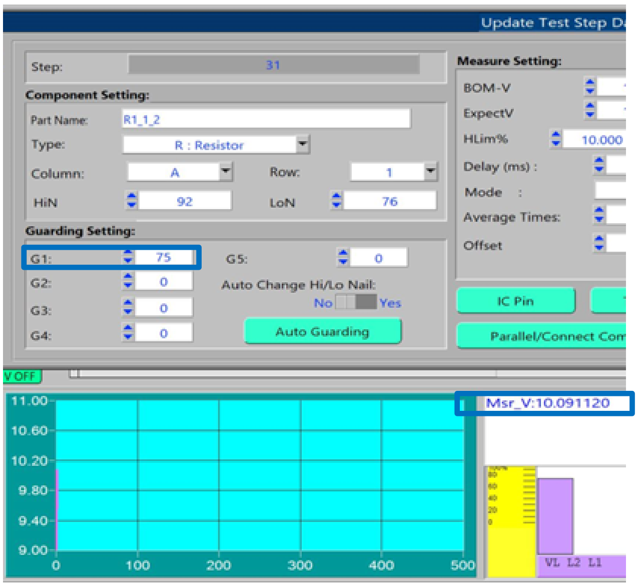

Figure 2.4 Measuring the value of R1_1_2 with guard

The use of guarding can be seen in our project where R1_1_2 is now getting a different value reading after 3- wire measurement was applied by adding guard G1 (Figure 2.4). If only 2- wire measurement was done using HiN 92 LoN 76 the measured value was 7,1 Ohms. After adding guard G1 75, the measured value changed to 10 Ohms. According to the BOM list, the value is supposed to be 10 Ohms thus it can be concluded that the guarding will give correct results.

The location needing guarding can be seen in a schematic (Figure 2.5). The resistor R1 will be affected by Q1 and Q2. Due to Darlington pair there will be disturbances and for that reason if we do not add the third test probe (ground) as a guard, we would receive incorrect values as seen above.

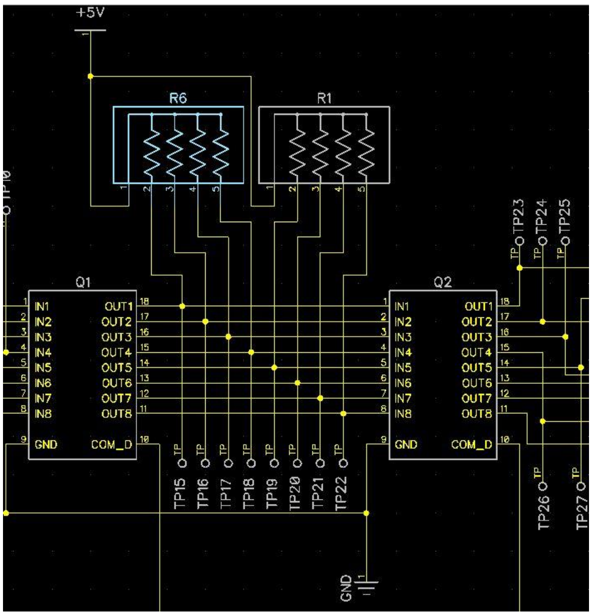

Figure 2.5 Schematic of the section needing guarding

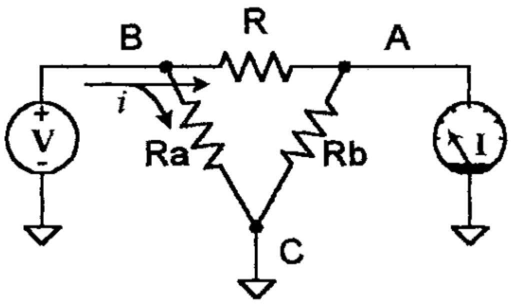

Figure 2.6 Example of guarding [7]

On Figure 2.6 it can be seen that in case of two wire (point A and B) measurment is used to measure the value of R , the value would be incorrect as it would also take Ra and Rb into conisderation. For that reason guarding (point C) is added. Part C is grounded and thus we would receive a correct R value. [7]

2.1 Test Results

After debugging and having set all the parameters according to the golden sample the fixture was put in test. The aim was to increase the testing speed by combining ICT and FCT test in one complete system. The complete system consists of only one fixture and is controlled by one TRI Tiny tester. Traditional way of testing is to have a different test system for every test method. With designed compact test system there is no need to test the same PCBA over several fixtures. Not only does it save time but also the overall cost would decrease significantly as there would be no need to manufacture multiple test fixtures or use several testers. In this project all tests were completed using one user interface. TRI Tiny is capable of testing ICT and also FCT to some extent. Additionally In- System programming was implemented. Combining all three phases in one complete system has significantly increased the testing speed.

Newly manufactured PCBAs were provided by external manufacturer. In total 5 PCBA samples were tested which according to the PCBA manufacturer were supposed to be exactly the same as golden sample.

Table 2.1 Testing results

Issue Date:	15th May 2019
Production Quantity of PCBs	5 pcs
Defect Quantity	5 pcs
DPPM	100 %

Every sample of relay card that was received by external supplier failed at Functional test as seen from the table (Table 2.1). The problem was that test program was supposed to send the signal to relays separately so that every relay would close one by one. But when testing new received PCBAs then after sending command (cr11) to close first relay nr.1, the result was that all 8 relays closed simultaneously. When testing the Golden sample, then after sending command (cr11) to close relay nr.1, only relay nr. 1 was closed. After thorough examination it was detected that the problem relies on PCBA and the mistake was tracked back to transistors. Golden sample was using TBD62084AFWG transistor which is a 8 channel sink type DMOS transistor array, whereas the received samples used ULN2804LW 8 channel sink type CMOS transistor array and can't be used in this application.

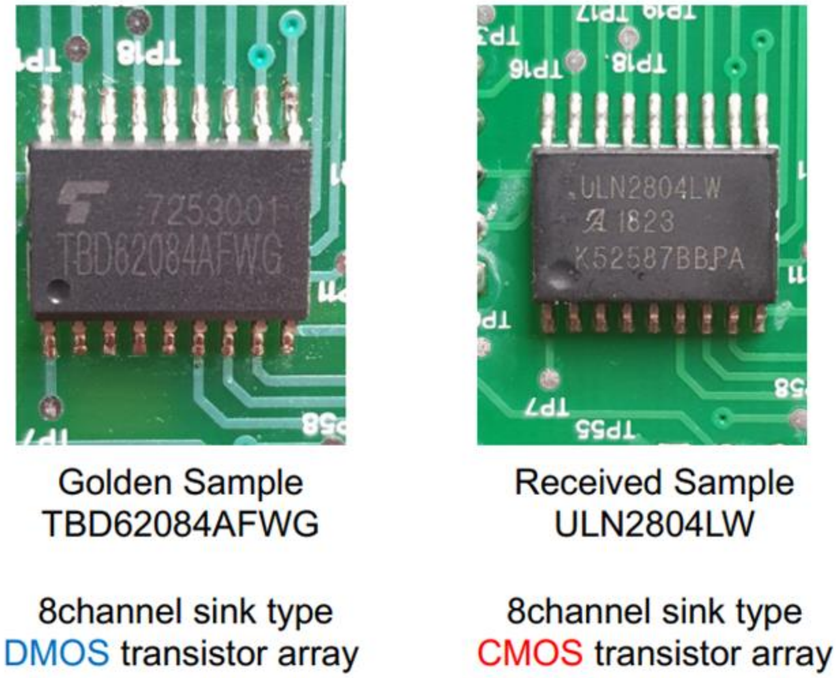

Figure 2.7Transistors differences between Golden Sample and Received sample

It can be clearly seeen that transistors on a figure (Figure 2.7) do not match. ULN2804LW passed the ICT test but failed at FCT test. The reason was that wrong transistors were placed. It can be seen that the Golden sample used TBD62084AFWG while the tested PCBA consisted of ULN2804LW. As the outcome of the using CMOS transistor array was incorrect then we can conlude tha this type of component is not suitable for this circuit. After replacing the CMOS transistor array with DMOS transisitor array, there were no faults in the system.

It clearly shows that whilethe PCBA passed the ICT test and showed that all the components vaues were correct then it could not detect if the component PN number was incorect. ICT detected that there were no open or shorts or other component deftects but AOI or functional test is needed to determine if the correct PN is mounted on the PCBA.That is clearly a sign that it is not sufficient to just use one type of test method.

I have also included a final user interface window (Figure 2.8) that of fully debugged system. In this view the operator in normal testing condition within mass production can see whether the UUT passed or failed and shows the overall reason (open, short or component fail). In case more specific analyzation is need then the board will be tested separately in diagnostic mode.

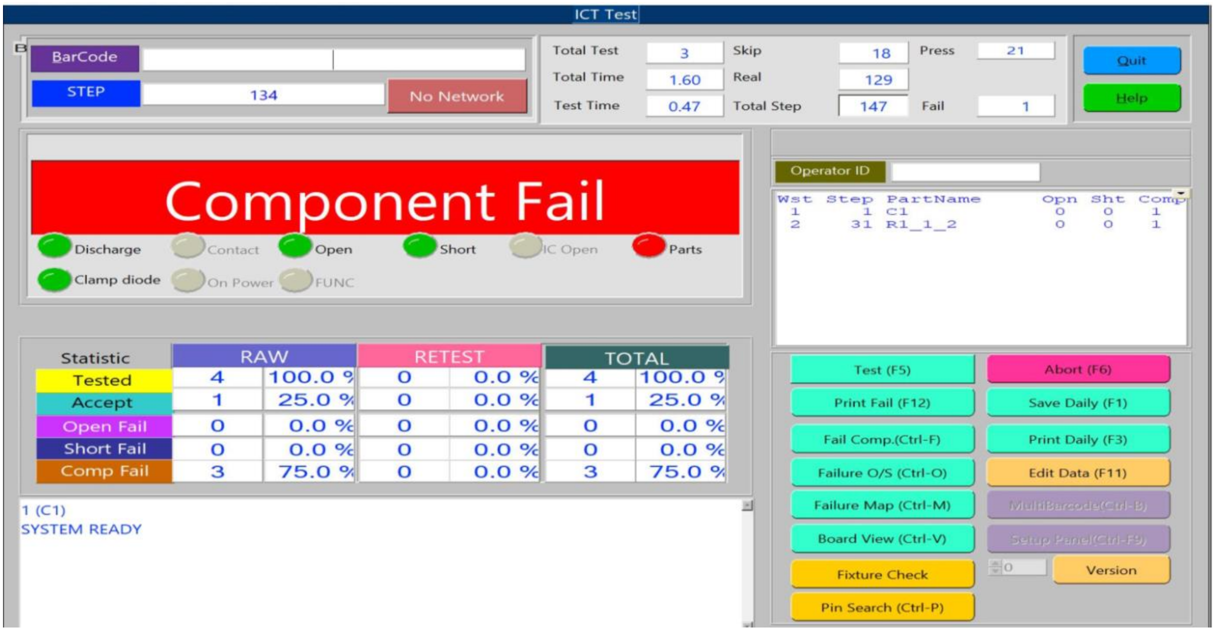

Figure 2.8 Mass production FAIL view.

2.2 Future project development

It would be possible to implement extra devices and methods to further improve developed fixture. The development path can be divided into two areas where test coverage can be increased and secondly test operation speed and safety can be improved.

Currently TRI Tiny does not support flash memory reading or frequency measurement. For that reason for example Xtal frequency and flash memory is not tested in this project.

In order to increase the test coverage the following steps could be made:

- Implement Boundary-Scan to test ICs
- Implement frequency meter

In order to increase the operation speed and safety, more sensors and counters would be needed. Some suggestions to further automate the process or secure the operator would be:

- Failure printer
- Datamatrix printer
- Barcode scanner
- Cover closed sensor

- UUT test sensor

The PCBAs used in this project were not that complex and the volumes are not high enough to implement more advanced features. The most optimal fixture was designed taking the exact project requirements into account.

In near future robotic arms will replace operators and totally new test system should be designed, where specific co- robot/ cobot requirements need to be considered while building test fixture.

3. CONCLUSION

Electronic devices have a huge impact in our everyday lives and taking future IoT technology and Industry 4.0 innovation into consideration, then it is inevitable that the trend of electronic manufacturing and automation is continuing to grow. Due to the development of electronic manufacturing and even higher manufacturing volumes, it is vital to find new advanced possibilities to raise the production efficiency. Testing is one of the most costly and time consuming parts within PCBA manufacturing process and is one of the areas where improvements could be made.

Current thesis concentrates on design and development of a PCBA test fixture that would decrease testing time of the UUT and would be also more affordable than traditional way of testing.

Faster testing times and overall fixture productions savings were accomplished by designing a test fixture that is capable of testing components and functionality together within one test system. Without the need to transport PCBs between several test fixtures, the time saved would be close to double. Additionally there would be no need to produce more than one fixture and the fixture can be operated by only one operator. Considering the savings from the hardware side and adding the savings from reduced workforce requirement, the overall savings could be several times depending on the complexity of fixture. 100% test coverage is not possible in reality. Even if all the devices will be tested, there will be still room for errors. In addition not everything can be automated and for that reason testing should be taken into consideration already in the design phase of PCBA. The project fulfilled the requirement that test coverage was not less than the system with separate test fixtures.

Developed fixture is meant for electronic manufacturers whose production volumes are low to medium. High volume needs fully automated In- Line system where every process is automated. Fully automated systems on the other hand are not flexible.

The project consists of several mechanical and electrical devices that need to fit and communicate in order to guarantee the desired end result. Using high quality and durable materials result in longer life cycle which will decrease the overall cost of testing even more.

Test results clearly show that ICT test separately does not guarantee the quality of produced PCBA. For that reason a compact test solution that can perform both ICT and FCT is advised. In- System programmer was implemented into the fixture to add even more flexibility to the system.

In future, improvements could be made by integrating additional meters and sensors to existing test system. Improvements would result in higher test coverage. The test period per UUT would decrease even further. In addition, the system would be also easier and safer to operate.

In conclusion the project fulfilled all the expectations as it decreased the testing time of UUT while keeping the test coverage at the same level. While the testing speed per UUT was increased, the overall fixture manufacturing cost was decreased. Full compact system was easy and safe to operate and it detected all the required faults during ICT and FCT test. For all these reasons the project can be considered a success. Implementation of several test methods within one fixture is advised in projects where PCBA design allows multiple tests to be carried out simultaneously. Based on this project, the advantages are clearly visible.

4. KOKKUVÕTE

Tänapäeval on elektroonilistel seadmetel järjest suurem osa meie igapävasest elust ja arvestades IoT tehnoologia ja Industry 4.0 arengut, siis elektroonikaseadmete tootmise ja automatiseermise trend on lähiajal hüppeliselt tõusmas. Elektroonikatööstuste kiire arengu ja suurenevate tootmismahtude juures tekib vajadus leida võimalusi kuidas tootmisprotsessi efektiivsust tõsta, et rahuldada üha suurenevat nõudlust. Elektroonikatööstuse üks kulukamaid osasid on seadmete testimine. Seda nii majanduslikust kui ka ajalisest vaatenurgast.

Käesolev töö keskendub uudsema testlahenduse leidmisele, et vähendada trükkplaatide testimiesele kuluvat aega. Antud projekti raames disainiti ja koostati terviklik trükkplaadi testseade mis lisaks trükkplaadi testperioodi olulisele vähendamisele oli ka majanduslikult soodsam.

Eesmärk saavutati kombineerides erinevad testmeetodid ühtseks terviklikuks testsüsteemiks kus testimine toimub üheagselt kasutades ühte testrakist ja ühte testrit. Antud lahendus osutus väga edukaks kuna puudus vajadus erinevate testide vahel trükkplaate ühest rakisest teise transportida. Võimalusega kus ühes rakises sooritati komponendi- ja funktsionaaltest vähendas testimisele kuluvat aega kuni 2 korda. Lisaks puudub vajadus koostada mitut testrakist ehk tootmiselt säästetav kulu vastavalt testrakise keerukusastmele võib küündida mitmekordseks. Arvestades,et üks süsteem vajab opereerimiseks vaid ühte testseadme operaatorit suureneb majanduslik kasu veelgi. Antud projekt täitis nõude, et testi katvus ehk protsentarv komponentidest mida testitakse, ei tohi olla väiksem kui süsteemil kus sooritatakse funktsionaal- ja komponenditest eraldi.

Lõputöö raames arendatud testrakis on mõeldud väikse ja keskmise tootmisvõimekusega elektroonikatootmisettevõtetele. Suuremate tootmismahtude juures ja keerukamate trükkplaatide puhul ei ole antud lahendus sobiv.

Lisaks komponendi- ja funktsionaaltestile programmeeritakse samaaegselt trükkplaadil olev mikrokonroller, mis lisab oluliselt testsüsteemi võimekust ja paindlikust. Projekti testtulemused tõestavad selgelt, et ühest testmeetodist ei piisa, et tagada toodetud trükkplaadi kvaliteet.

Kuna kogu süsteem koosneb suurest hulgast komponentidest siis lõppresultaat sõltub kõikide mehaaniliste ja elektrooniliste seadmete sobivusest. Antud lõputöös on välja toodud kõik tähtsamad detailid, et antud projekti edukalt sooritada.

Tulevikku silmas pidades on võimalik antud süsteemi täiendada erinevate andurite ja test meetodidega, mis konkreetses projektis jäi lisamata. Seega on võimalusi saavutada veel kõrgemaid testi katvusi kui ka vähendada testile kuluvat aega veelgi. Lisaks testi katvuse ja kiiruse tõstmisele toob andurite ja mehhanismide integreerimine kaasa automatiseerimise taseme kus operaatoril on kergem ja ohutum töötada.

Kokkuvõtteks võib öelda, et antud lõputöö raames disainitud ja koostatud rakis täitis püstitatud eesmärke vähendada trükkplaadi testimisele kuluvat aega olukorras kus testi katvuse protsent ei muutunud. Võrreldes testsüsteemidega kus testimine toimub erinevates rakistes, on kombineeritud testrakise koostamise ja opereerimise hind kordades soodsam. Lisaks on operaatoril kompaktset süsteemi ohutum ja kergem käsitleda. Testimise käigus tuvastas süsteem kõik komponendi ja funktsionaaltestiga seotud vead. Põhinedes eelnevalt väljatoodud põhjustele on trükkplaadi testimiseks soovitatav kasutada kompakset kombineeritud täislahendust olukorras kus trükkplaadi disain ja tootmise eripära seda lubavad. Projekti tulemused toovad kombineeritud süsteemi eelised selgelt esile.

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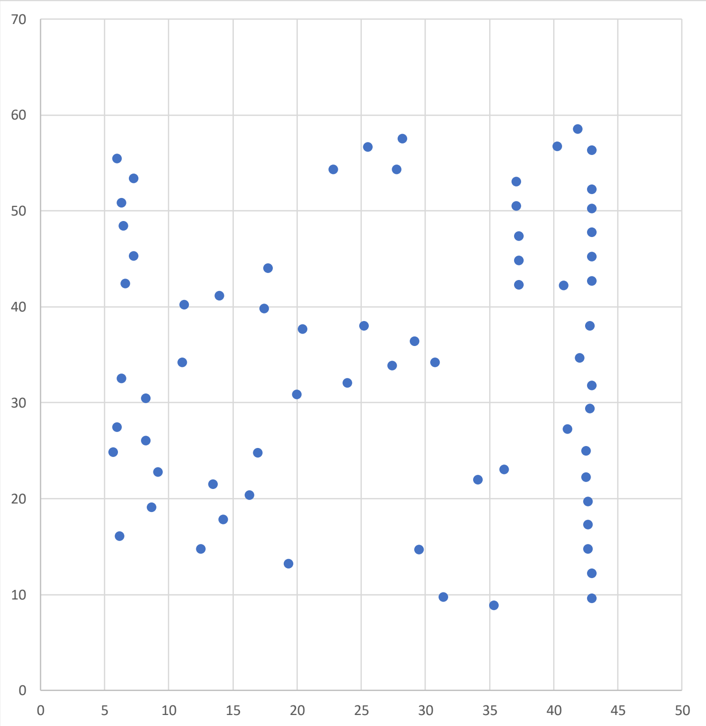
APPENDICES

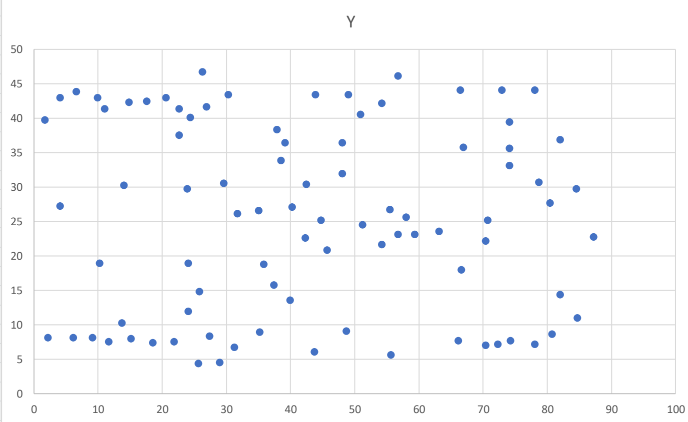
Appendix 1 Test Coordinates of Control board

Test point	X	Y
TP1	27.784167	54.2982
TP2	40.326733	56.6797
TP3	31.4358	9.684767
TP4	28.257767	57.4575
TP5	25.561433	56.600467
TP6	37.310167	42.231933
TP7	6.6682	42.3907
TP8	37.1514	53.028067
TP9	37.1514	50.4878
TP10	37.310167	47.312467
TP11	37.310167	44.7722
TP12	40.803033	42.1527
TP13	27.466633	33.8173
TP14	30.800733	34.134833
TP15	29.213067	36.357567
TP16	8.255	25.985
TP17	23.971167	32.042567
TP18	6.0325	27.413767
TP19	11.111067	34.118867
TP20	6.3511	32.466
TP21	9.208467	22.703633
TP22	5.7156	24.7676
TP23	8.2563	30.402033
TP24	11.272433	40.167967
TP25	16.352967	20.322133
TP26	13.971467	41.120567
TP27	8.701633	19.033133
TP28	20.4809	37.6277
TP29	19.369533	13.177633
TP30	17.778767	43.9505
TP31	17.464	39.771
TP32	22.8624	54.2982
TP33	25.241767	37.9295
TP34	6.347767	50.7895
TP35	7.303267	53.3456
TP36	6.030767	55.3815
TP37	6.506833	48.407867
TP38	7.303267	45.2485
TP39	41.9144	58.505667
TP40	43.025767	56.282933
TP41	43.025767	52.234233
TP42	43.025767	50.170267
TP43	43.025767	47.709533
TP44	43.025767	45.169267
TP45	43.025767	42.629
TP46	42.867	37.945233
TP47	42.070567	34.595167
TP48	13.495167	21.4335
TP49	14.289	17.781867
TP50	6.1919	16.035433
TP51	12.539967	14.712333
TP53	34.134833	21.9098
TP54	35.4054	8.810567
TP55	43.025667	12.145467
TP56	43.025767	9.526
TP57	42.708133	17.226
TP58	42.708133	14.685733
TP59	42.705633	19.6711
TP60	42.546867	22.174367
TP61	42.545	24.923733
TP62	41.120567	27.228633
TP63	42.862	29.369
TP64	43.021	31.75
TP65	36.1962	23.0052
TP66	29.5275	14.605
TP67	20.001767	30.7845
TP68	16.985767	24.7515



Appendix 2 Test Coordinates of Relay Board

TP	X	Y
TP1	87.321667	22.703633
TP2	84.622633	29.689367
TP3	80.812233	8.5734
TP4	74.144033	39.374133
TP5	74.144033	35.563733
TP6	74.144033	33.023467
TP7	54.2982	42.073167
TP8	70.809933	25.085133
TP9	66.682	17.940633
TP10	70.4924	22.068567
TP11	66.999533	35.7225
TP12	82.082367	36.833867
TP13	80.4947	27.6254
TP14	78.748267	30.641967
TP15	54.2982	21.592267
TP16	55.568333	26.6728
TP17	56.838467	23.021167
TP18	58.1086	25.561433
TP19	59.378733	23.021167
TP20	48.1063	36.357567
TP21	48.1063	31.9121
TP22	63.189133	23.497467
TP23	48.741367	9.0497
TP24	42.3907	22.544867
TP25	31.753333	26.037733
TP26	35.087433	26.514033
TP27	44.7722	25.085133
TP28	23.974	29.689
TP29	40.326733	26.990333
TP30	51.281633	24.450067
TP31	45.7248	20.798433
TP32	35.881267	18.734467
TP33	24.132533	18.893233
TP34	10.319833	18.893233
TP35	4.127933	27.1491
TP36	14.130233	30.165667
TP37	29.689367	30.4832
TP38	42.549467	30.324433
TP39	4.127933	42.867
TP40	6.6682	43.8196
TP41	1.746433	39.691667
TP42	10.0023	42.867
TP43	11.113667	41.279333
TP44	14.924067	42.231933
TP45	17.6231	42.3907
TP46	20.639667	42.867
TP47	26.990333	41.596867
TP48	22.703633	41.279333
TP49	22.703633	37.468933
TP50	26.355267	46.6774
TP51	30.324433	43.3433
TP52	43.978367	43.3433
TP53	24.450067	40.0092
TP54	49.0589	43.3433
TP55	56.838467	46.042333
TP56	37.945233	38.262767
TP57	39.215367	36.357567
TP58	66.523233	43.978367
TP59	38.5803	33.8173
TP60	73.032667	43.978367
TP61	50.9641	40.4855
TP62	78.1132	43.978367
TP63	78.1132	7.1445
TP64	74.3028	7.6208
TP65	72.3976	7.1445
TP66	70.4924	6.985733
TP67	66.2057	7.6208
TP68	40.0092	13.495167
TP69	55.7271	5.556833
TP70	29.0543	4.445467
TP71	31.277033	6.6682
TP72	35.2462	8.890933
TP73	43.8196	6.033133
TP74	37.468933	15.7179
TP75	25.7202	4.2867
TP76	27.466633	8.255867
TP77	25.878967	14.7653
TP78	24.132533	11.9075
TP79	21.9098	7.462033
TP80	18.5757	7.303267
TP81	15.2416	7.938333
TP82	13.8127	10.161067
TP83	11.748733	7.462033
TP84	9.208467	8.0971
TP85	6.1919	8.0971
TP86	2.222733	8.0971
TP87	84.781	10.955
TP88	82.082367	14.289



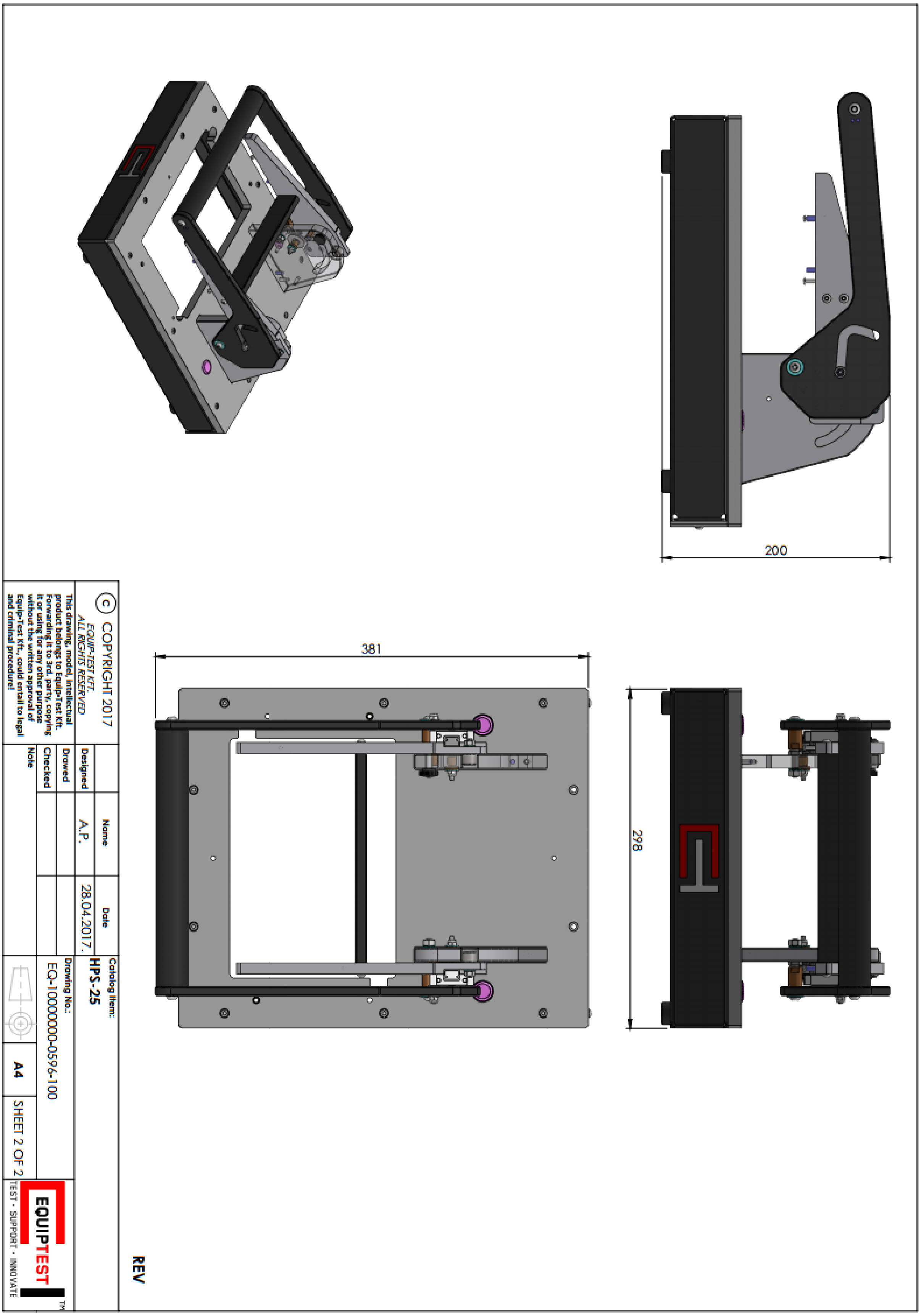
Appendix 3 Program for connecting Relays

```
CONST
	DEBUG='NO';
	PORTNUMBER=11;			//SET COM PORT 11 FOR RELAY CARD
	BAUDRATE=19200;			//SET COMMUNICATION SPEED BPS
	DATA_LENGTH=8;			//SET DATA LENGTH
	STOP_BITS=1;		//SET STOP_BITS

	COMMAND_QUANTITY=8;//SET number of commands to be sent from control board to relay card

VAR								// Declare variables
	I,COM_STATUS:INTEGER;
	COM_MESSAGE:CHAR[100];
	COMMAND:CHAR[10][10];
	I_STRING:CHAR[20];

SUBROUTINE COM_ERROR();			// Subroutine for COM port access error
{
	FLAGTESTFAIL();
	COMSTA(STATUS=COM_STATUS,MESSAGE=COM_MESSAGE);
	WRITELN('COM ',PORTNUMBER,' ERROR: ',COM_MESSAGE);
	CLOSECOM(PORT=PORTNUMBER);
};

MAIN
	COMMAND[1]='cr11';	//On RelayCard_1 Relay_nr1
	COMMAND[2]='cr12';	//On RelayCard_1 Relay_nr2
	COMMAND[3]='cr13';	//On RelayCard_1 Relay_nr3
	COMMAND[4]='cr14';	//On RelayCard_1 Relay_nr4
	COMMAND[5]='cr15';	//On RelayCard_1 Relay_nr5
	COMMAND[6]='cr16';	//On RelayCard_1 Relay_nr6
	COMMAND[7]='cr17';	//On RelayCard_1 Relay_nr7
	COMMAND[8]='cr18';	//On RelayCard_1 Relay_nr8
	COM_STATUS=OPENCOM(PORT=PORTNUMBER,BAUD=BAUDRATE,NDATA=DATA_LENGTH,NSTOP=ST
OP_BITS);
	SETCOM(PORT=PORTNUMBER,TIMEOUT=0.5);
	IF COM_STATUS<0 THEN COM_ERROR();

	FOR I=1 TO COMMAND_QUANTITY DO
	{
		COMMAND[I][STRLEN(COMMAND[I])+1]=0h0D;		//Loop on constant I

		IF DEBUG='YES' THEN WRITELN('Command for sending to relay card: ',COMMAND[I]);

	COM_STATUS=COMWRT(PORT=PORTNUMBER,DATA=COMMAND[I],NWRITE=STRLEN(COMMAND[I]));
	//To write selected command in the selected COM port
		IF COM_STATUS<0 THEN COM_ERROR;
		MDLY (50);
									};

	CLOSECOM(PORT=PORTNUMBER);
								//Close COM port
END
```

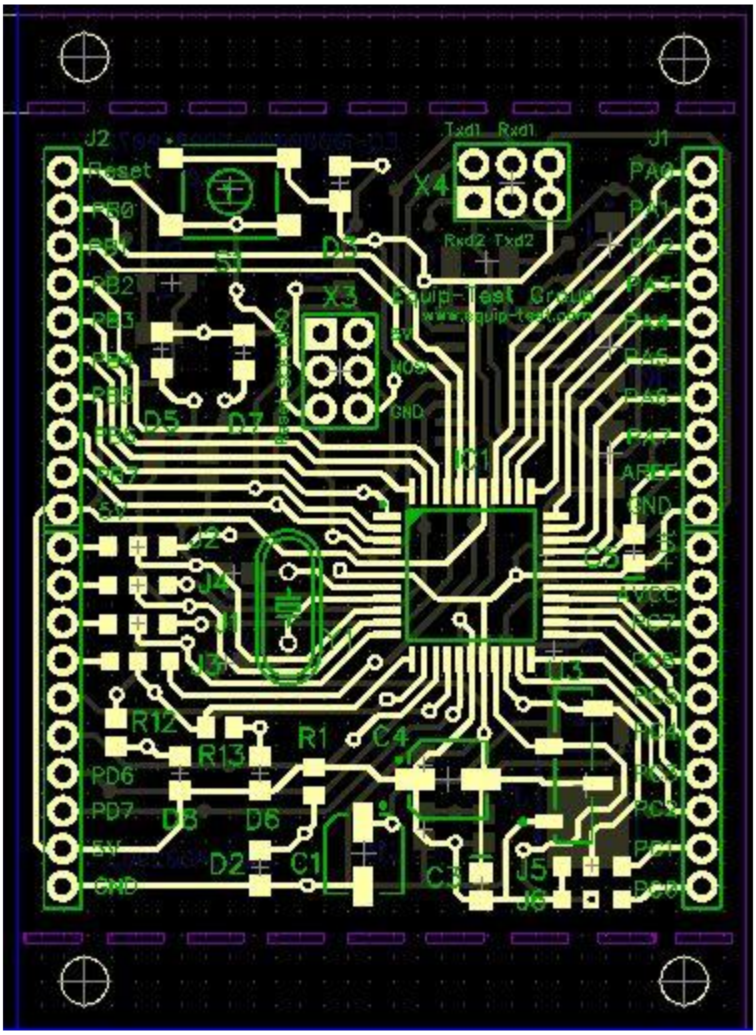
Appendix 4 Program for disconnecting Relays

```
CONST
        DEBUG='NO';
        PORTNUMBER=11;                  //COM PORT 4 FOR RELAY CARD
        BAUDRATE=19200;                 //COMMUNICATION SPEED BPS
        DATA_LENGTH=8;
        STOP_BITS=1;

        COMMAND_QUANTITY=8;

VAR
        I,COM_STATUS:INTEGER;
        COM_MESSAGE:CHAR[100];
        COMMAND:CHAR[10][10];
        I_STRING:CHAR[20];

SUBROUTINE COM_ERROR();
{
        FLAGTESTFAIL();
        COMSTA(STATUS=COM_STATUS,MESSAGE=COM_MESSAGE);
        WRITELN('COM ',PORTNUMBER,' ERROR: ',COM_MESSAGE);
        CLOSECOM(PORT=PORTNUMBER);
};

MAIN
        COMMAND[1]='dr11';      //Off RelayCard_1 Relay_nr1
        COMMAND[2]='dr12';      //Off RelayCard_1 Relay_nr2
        COMMAND[3]='dr13';      //Off RelayCard_1 Relay_nr3
        COMMAND[4]='dr14';      //Off RelayCard_1 Relay_nr4
        COMMAND[5]='dr15';      //Off RelayCard_1 Relay_nr5
        COMMAND[6]='dr16';      //Off RelayCard_1 Relay_nr6
        COMMAND[7]='dr17';      //Off RelayCard_1 Relay_nr7
        COMMAND[8]='dr18';      //Off RelayCard_1 Relay_nr8
        COM_STATUS=OPENCOM(PORT=PORTNUMBER,BAUD=BAUDRATE,NDATA=DATA_LENGTH,NSTOP=ST
OP_BITS);
        SETCOM(PORT=PORTNUMBER,TIMEOUT=0.5);
        IF COM_STATUS<0 THEN COM_ERROR();

        FOR I=1 TO COMMAND_QUANTITY DO
        {
                COMMAND[I][STRLEN(COMMAND[I])+1]=0h0D;

                IF DEBUG='YES' THEN WRITELN('Command for sending to relay card: ',COMMAND[I]);

        COM_STATUS=COMWRT(PORT=PORTNUMBER,DATA=COMMAND[I],NWRITE=STRLEN(COMMAND[I]));
                IF COM_STATUS<0 THEN COM_ERROR;
                MDLY (50);
        };
        CLOSECOM(PORT=PORTNUMBER);
        END.
```

Appendix 5 HPS- 25 Fixture drawings



Appendix 6 PCBA Layout of Control board



Appendix 7 BOM list for Relay board

Item number	Article title	Qunatity	
1	Equip I2C Relékártya 90x50mm 8db DPDT Relé 12V EQ-10000000-9998-0051	1	pcs
2	Lomex 950276 SMD LED Zöld 40mcd	8	pcs
3	On Semiconductor MC7805BDTG Feszültség Stabilizátor 5V 1A	1	pcs
4	Samwha RC1V107M6L07KVR Kondenzátor Elektrolit 100uF 35V 20% SMD	1	pcs
5	Lomex 820125 SMD Kondenzátor Kerámia 100nF 50V 10%	2	pcs
6	Toshiba TBD62084AFWG 8 Csatornás DMOS Tranzisztor Tömb 500mA 50V	2	pcs
7	TME NXP PCF8574AT.112 Interface I/O Bővítő I2C SO16-W	1	pcs
8	TME DS-03 Kapcsoló ON/OFF Szekciók Száma:3	1	pcs
9	TME 4605X-101-103LF Ellenállás Létra 10kOhm Ellenállás Száma:4	2	pcs
10	Lomex 811095 SMD Ellenállás Standard 4,7kOhm 0,125W 5%	2	pcs
11	lomex 430900 apa tápcsatlakozó 8 pólusú 2,54mm	6	pcs
12	Lomex 430837 Tüskesor 40Pol 12/3 Tördelhető 2,54mm	1	pcs
13	lomex 430911 anya tápcsatlakozó 8 pólusú 2,54mm	6	pcs
14	Lomex 430917 Tápcsatlakozó Anya Crimpelhető 2,54mm	50	pcs
25	TE Connectivity IM06NS Relé 250VAC 12VDC 140mW 2A	8	pcs
30	Lomex 811099 SMD Ellenállás Standard 10kOhm 0,125W 5%	3	pcs
35	lomex 430895 apa tápcsatlakozó 2 pólusú 2,54mm	2	pcs
40	lomex 430906 anya tápcsatlakozó 2 pólusú 2,54mm	2	pcs

CRD	Value	TESTED?	Comment
C1//C13	100uF	YES	
C3//C4	100nF	YES	
C5	100nF	YES	
C6	22pF	NO	NO PROBE
C7	22pF	NO	NO PROBE
C8	100nF	YES	
C9	10uF	YES	
C10	10uF	YES	
C11	10uF	YES	
C12	10uF	YES	
C14	100nF	YES	
D1	0.7V	YES	
D2	2v	YES	
D3	2v	YES	
D4	2v	YES	
D5	2v	YES	
D6	2v	NO	NO PROBE
D7	2v	YES	
D8	2V	NO	NO PROBE
IC1	0.7V	YES	
J1		NO	
J2		NO	
J3		NO	
J4		NO	
J5		NO	
J6		NO	
J7	0 0HM	YES	
R1	680 OHM	YES	
R2	10K OHM	YES	
R3	300 OHM	YES	
R11	680 OHM	YES	
R12		NO	NO PROBE
R13		NO	NO PROBE
R14	680 OHM	YES	
S1		NO	
U1	0.7V	YES	
U2	0.7V	YES	
X1		NO	
X2		NO	
X3		NO	
X4		NO	
X5		NO	
X6		NO	
X7		NO	
Y1		NO	

Appendix 9 ICT Test Coverage for Relay Board

CRD	Value	TESTED?	Comment
C1	100nF	YES	
C2//C3	100nF	YES	
D1	2V	YES	
D2	2V	YES	
D3	2V	YES	
D4	2V	YES	
D5	2V	YES	
D6	2V	YES	
D7	2V	YES	
D8	2V	YES	
K1	1000 0HM	YES	
K2	1000 0HM	YES	
K3	1000 0HM	YES	
K4	1000 0HM	YES	
K5	1000 0HM	YES	
K6	1000 0HM	YES	
K7	1000 0HM	YES	
K8	1000 0HM	YES	
R1	10K 0HM	YES	
R2	10K 0HM	YES	
R3	10K 0HM	YES	
R4	10K 0HM	YES	
R5	4K7 0HM	YES	
R6	10K 0HM	YES	
R7	4K7 0HM	YES	
S1	0	NO	
U1	0.7V	YES	
U2	0.7V	YES	
Q1	0.7V	YES	
Q2	0.7V	YES	
J1		NO	
J2		NO	
J3		NO	
J4		NO	
J5		NO	
J6		NO	
J7		NO	