AKADEMIA GÓRNICZO-HUTNICZA IM. STANISŁAWA STASZICA W KRAKOWIE
FACULTY OF COMPUTER SCIENCE, TELECOMMUNICATION AND ELECTRONICS
DEPARTMENT OF ELECTRONICS

Engineering thesis

Components test and validation for new design of the radiation tolerant electronic cards driving the LHC accelerators' beam screen heaters

Author: *Kajetan Kalafarski*
Degree programme: *Electronics and Telecommunication*
Supervisor: *Jarosław Bułat PhD*

Kraków, 2014

Oświadczam, świadomy(-a) odpowiedzialności karnej za poświadczenie nieprawdy, że niniejszą pracę dyplomową wykonałem(-am) osobiście i samodzielnie i nie korzystałem(-am) ze źródeł innych niż wymienione w pracy.

Contents

Introduction

CERN - The European Organization for Nuclear Research (abbreviation from French: Conseil Européen pour la Recherche Nucléaire) is an international scientific research center with the biggest accelerator in the word - the LHC. The Large Hadrons Collider was built in a LEP (Large Electron–Positron Collider) circular tunnel, with a circumference of 27 kilometers, at a depth ranging from 50 meters to 175 meters underground located at the French-Swiss . The "heart" of LHC is a duet of two parallel pipes with a special punched screen – beam screen and ultrahigh vacuum inside. A beam screen is a perforated co-axial liner, which function is cleaning beam pipes by trapping gas molecules created by the synchrotron radiation. The beam screens are equipped with temperature sensors and heating elements. The heaters purpose is to raise temperature up to 90 K and the result of this operation is to release of gas molecules trapped on the beam screen. There are two independent 100 Ω resistive elements with heating power of up to 200 W and limited to 25 W during LHC operation. The sensors are thermocouple types J which purpose is to protect heaters from overheating. Under LHC magnets there are place cryogenic instrumentation crates with different cards:

– power card is source of very stable power supply of 9 V, 30 V and 60 V,
– communication cards are used to collect data and control sensors and card via WordFIP protocol (bus linking sensors, actuators and PLCs in industrial system),
– conditioning cards,
– Electrical Heater (EH) card's purpose is to deliver 0-60 VDC or 230 V PWM (Pulse Width Modulation) to resistive load and provide measurement of VDC, IDC and thermocouple protection.

The beam screen heater card was redesigned due to consolidated of LHC beams screen heaters [2]. The main features which will be present inside EH card are: additional heater protection mechanism- manual restart on either power-up or interlock, independent supply, additional fuses for PCB protection. The new card will be compatible with LHC background radiation which means instrumentation should be operational under at least 100 Gy [3]. The purpose of this document is to present the test and verification of components regarding cryogenics instrumentation in the LHC accelerator. The description of the methods of testing of subsequent components will be provided. At the end of document the portable tool design and built for checking the correct electrical wiring of the beam screen heater will be presented. The main objective of this work is to test components for new design of electronic card driving LHC beam screen heaters. All components must have well defined parameters which include: electrical, thermal and radiation tolerance. Their behaviour in circuits in which they will work must be known. Performance under different loads should be good and do not exceed design assumptions. What is more, new cards should be tested and installed in the LHC before the end of LS1 (Long Shutdown 1 – time to modernize the infrastructure of LHC).

1. Components test and verification

In the first section of chapter one, tests of Power card prototype are presented. The main fields of testing this card are thermal characteristics and power efficiency. Both were test for different load configurations, starting from 9 V / 1 A, ending on 230 / 11.5 A. The results of this test should fit the requirements for card in cryogenics instrumentation crate. The durability of relays inside card will be tested and they are supposed to work after one thousand operations (switching off and on) for high load.

The three next sections of the first chapter deal with testing components for a new Electrical Heater (EH) card. The first component that was tested was the toroidal transformer of the 70022K series. It is the voltage source for the components of the card and for this reason needs to be tested in the matter of giving a stable power supply. To perform testing, a special testing environment was prepared. It consists of a dedicated circuit for load simulation of EH card. During tests, the relation between capacitors use in circuit and output voltage was investigated. Another part of testing was dedicated to measurements transformer temperature and components, as well as temperature of high power version of used transformer. The next tested component was the VB 0,35/2/24 transformer. It is related with AC input voltage measurement and so-called ZeroCross function which will be described latter. This component was tested to find out the best configuration of resistances (output voltage) and capacitances (ZeroCross synchronization) inside circuit according to design specification. The following results should by obtained for ZeroCross function for the following settings: pulse should have amplitude of 4.3 V and width of 230 us for 230 V AC. It should start at the moment of AC input signal crosses zero by. Those parameters must be precisely known for correct configuration of the FPGA located in EH card. Another parameter which will be tested in VB 0,35/2/24 transformers is output voltage of circuit use to measure the AC input voltage. The output of this circuit should be exactly 0.875 V for both channels. If transformer and cards pass all of the above mentioned tests it will be tested with higher (400 V) power supply. The third section of chapter one refers to the testing of the OPA 541 AM amplifiers. More precisely it is not parameters verification but checking the correctness of the OPA 541 AM operation. This component will be recovered from old and damaged cards. The aim of the test is to check all of them and select those that will work correctly. The results of this test are unpredictable because no one know how this components will behave. The assumptions is to find as many as possible working amplifiers because of its price. It will be reused in new cards.

The five and also last section of chapter one is dedicated to radiation tolerance test of components for new EH card. Tests will be performed outside CERN, in the Paul Scherrer Institute. The goal is to test the following components: 10 MHz crystal oscillators, diodes, low leak capacitors, amplifiers (OPA541AM, OPA627) and transistors. The components will be marked as radiation tolerant and can be used in radiation areas if they survive (without parameter changing) radiation doses of at least 1000 Gy[5]. Such a radiation is an expected dose for 10 years of LHC operation. All components will be placed on three PCB and each should be irradiated by dose of a 1000 Gy. OPA 541 Am and diodes probably work perfectly after radiation, the behaviour of transistor, OPA 627 and oscillator will probably change. The two types of low leak capacitors are taken into consideration and test should show the differences between them. Significant changes in the behavior of components will lead to the necessity of changing the entire design of heater new card or part of it.

1.1. Power card

Goal and summary of test results

The goal of the performed tests in this chapter was to investigate thermal characteristics, power efficiency and durability of relays of Power Card EDA-02542-V2. Thermal properties of components and card are important for two reasons. First, card is located in the grid without active cooling (heat sink only). Therefore, it cannot overheat environment, because that could damage all the cards in the crate. The second reason is the heating of the tracks on the card. This can lead to damage of solder and components that are not a source of heat. Temperature measurements were performed at different loads configuration using a thermal imaging camera. Expected results are temperature characteristics of components and the card in the form of graphs. Power efficiency was tested for statistical purposes and verification the power efficiency of the card. It will be done by measuring input and output power. If the card were badly designed in terms of energy consumption, this test would reveal this. In this test, measurements of temperatures of several configurations will be used. Testing will be done by disconnecting some components of the card responsible for generating different voltages. Relays[1] were tested due to the issue of choosing one of the two models. Another reason is to check hard durability and the damage threshold. They are not frequently used, so the test should contain approximately 1000-2000 cycles to see if they will have to be replaced during operation. For all above mentioned tests, the following outcomes were expected.

Introduction to Power Card

Power Card EDA-02542-V2 consisting of two identical channels (top and bottom). It is designed to provide 8-9 V, 48 V, 64 V and 230 V power supply at full load. One of inputs are signals to disable whole channel or only the 230 V output. The card is powered from standard power grid (230 V) and is protected with a 16 A fuse. Tabel 1.1 shows labels and values of voltages produce by card. In figure 1.1 the image of the card and the layout are presented.

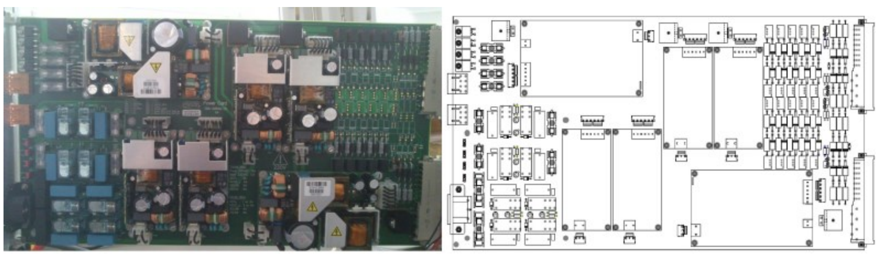


Figure 1.1: Image and layout of power card

[1]EN 50205 safety relays, detailed description in section: Durability of relays

Table 1.1: Designation of voltages produced by card and its values

Voltage label	Voltage value	Current value
VCC0 1a	8 V	3 A
VCC0 1b	8 V	3 A
VCC 1a-5a	8 V	1 A
VCC 1b-5b	8 V	1 A
VCC 48a	48 V	3.5 A
VCC 48b	48 V	3.5 A
VCC 64a-1/64a-2	64 V	3.5 A
VCC 64b-1/64b-2	64 V	3.5 A
220 VAC L/N top	230 V	11.5 A
220 VAC L/N bottom	230 V	11.5 A

Thermal characteristic

The card was tested in laboratory with ambient temperature of about 35 ℃. Transformers in power supply reached temperature of 110 ℃ and DC/DC regulators 87 ℃. There was not observed any damage or degradation.

Power efficiency of card

According to measurements for 64 V, the card works with an efficiency >90%. For full load the efficiency after DC/DC regulators is 74% and after diode 72%. V1 and V2 on figure 1.2 shows measurements points (after DC/DC, after diode).

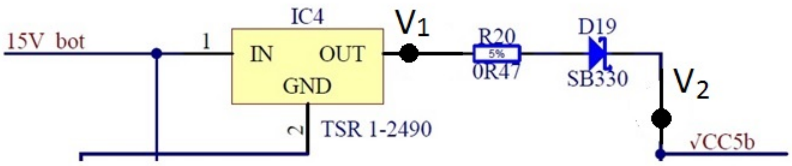


Figure 1.2: Power card schematic, measurements points for power efficiency test

V1 denotes the point called “after DC/DC”. As follows V2 denotes the point called “after diode”. In these points voltage was measured in order to take into account the voltage drop on the diode. The purpose of the diode is to reduce voltage to 8-9 V and balance whenever another diode is put in parallel. If there is need, the diode and resistor can be short.

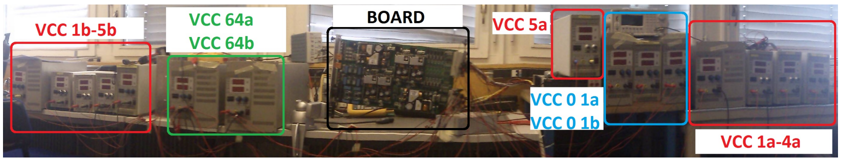
Durability of relays

The durability of the relays was tested during two ten minute cycles for each relay. During test it works with a frequency of 2 Hz. This results in almost 2400 operations per relay.

Temperature measurement and power consumption test configuration

Figure 1.3 presents an overview of the measurement station setup. In the center board on holder is presented. Labels for voltages are labeled according to table 1.1.

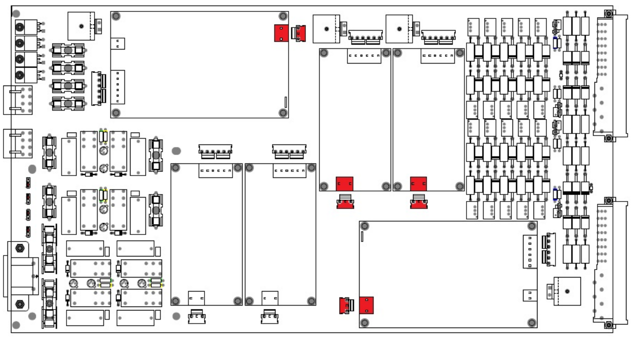
Figure 1.3: General setting of measurements station



Temperature measurement test configuration.

Configuration T1: Temperature of elements with 8-9 V regulators connected, without load. Figure 1.4 marks disconnected circuit which generates 48 V and 64 V.

Figure 1.4: Power card, red mark connector which is disconnected for this test



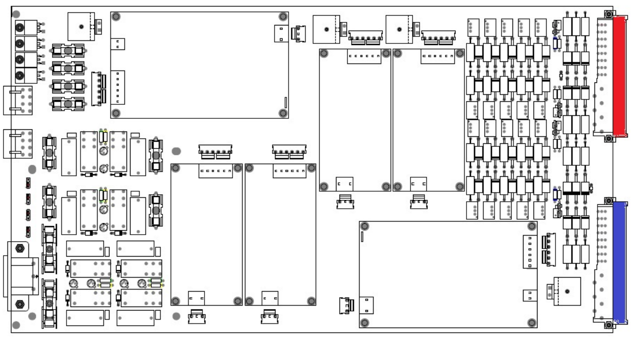
Following configurations are use for temperature measurement.
Configuration T2: Top channel: 1 A load on each of five 9 V outputs, 3.5 A load on 64 V output and 11.5 A load on 230 V output. Bottom channel: 1 A load on each of five 9 V outputs and 3.5 A load on 64 V output.

Configuration T3: Top channel: 1 A load on each of five 9 V outputs and 3.5 A load on 64 V output. Bottom channel: 1 A load on each of five 9 V outputs, 3.5 A load on 64 V output and 11.5 A load on 230 V output.

Configuration T4: Top channel: 1 A load on each of five 9 V outputs, 3.5 A load on 64 V output and 6.9 A load on 230 V output. Bottom channel: 1 A load on each of five 9 V outputs, 3.5 A load on 64 V output and 6.9 A load on 230 V output.

Configurations T2 and T3 have different places of connecting 230 V which is shown in figure 1.5. Configuration T4 uses both, top and bottom pins and equal division of 230 V load.

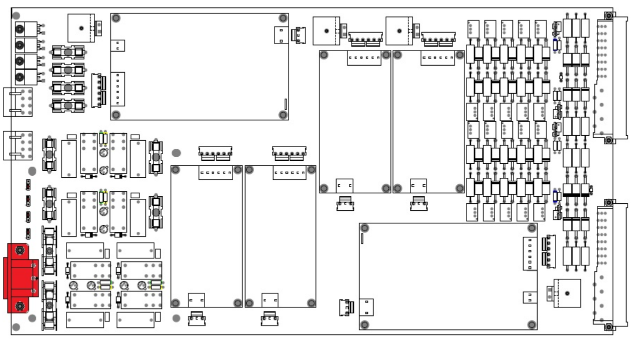
Figure 1.5: Schematic of power card, top channel is marked in red, bottom channel is marked in blue



Power efficiency test configuration

Configuration PE1: Power consumption without any load, measurement points are marked as a red color in figure 1.6.

Figure 1.6: Power card, red mark 230 V AC connector

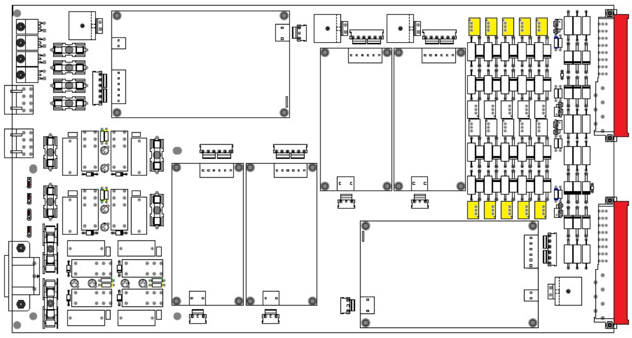


Configuration PE2: Power efficiency of board with load on 64 V output.
Configuration PE3: Power efficiency “after diode” (V2 on figure 1.2 of board with load on five 9 V and one 64 V outputs for both channels.
Configuration PE4: Power efficiency “after DC/DC” of board with load on five 9 V and one 64 V outputs for both channels.

Figure 1.6 presents configuration PE1, measurement of input power in idle state. Figure 1.7 presents configuration PE3, measurement of power after diode was done at the back of board and is marked in yellow. Placed of measurement of power after DC/DC is marked in red.

Figure 1.7 presents configuration PE3, power measurement after diode was done at the back of board (marked in yellow). Points of measurement of power after DC/DC are marked in red.

Figure 1.7: "After diode" vs. "after DC/DC" power measurement



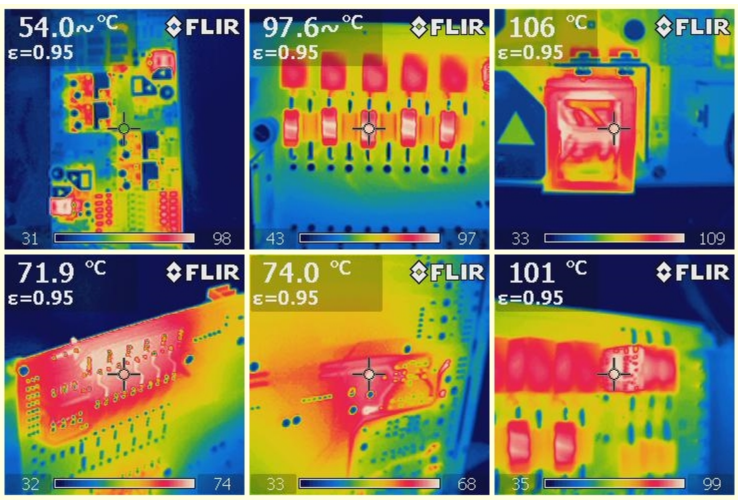
Thermal analysis using thermal imaging camera

This section shows components with the highest temperature. Infrared Images (IR) were recorded for all configuration assigned for this test (Temperature measurement test configuration). The test was performed at the ambient temperature of 30 ℃ and the elements were warmed up until the temperature reach a stable point. All measurements related to thermal characterization of the power card are presented in table 2.5 in Appendix A.

In figures description first, the name of the measured element is given. Then the label of voltage from table 1.1 which it relates to. Temperatures for configuration T2 are presented in figure 1.8.

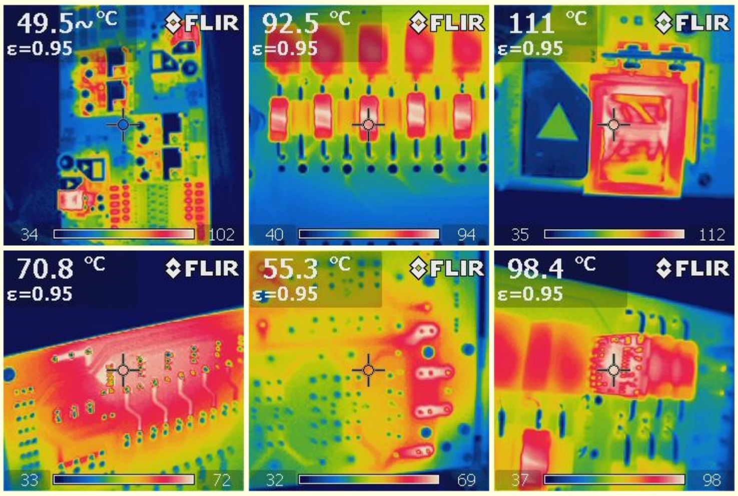
Temperatures for configuration T2 are presented in figure 1.8.

Figure 1.8: Figures are described starting from the left upper corner (a b c) then from left lower corner (e f g); a) Entire board, b) resistor - VCC 3a, c) transformer – VCC 48,a d) back side of integrated circuit - VCC0 1a, e) back side of relays, f) integrated circuit – VCC0 1a



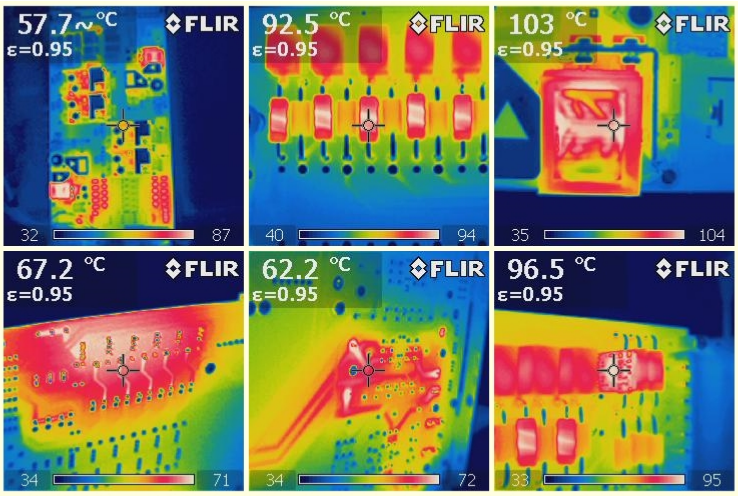
Temperatures for configuration T3 are presented in figure 1.9.

Figure 1.9: a) Entire board, b) resistor - VCC 3a, c) transformer – VCC 48,a d) back side of integrated circuit - VCC0 1a, e) back side of relays, f) integrated circuit – VCC0 1a



Temperatures for configuration T4 are presented in figure 1.10.

Figure 1.10: a) Entire board, b) resistor - VCC 3a, c) transformer – VCC 48,a d) back side of integrated circuit - VCC0 1a, e) back side of relays, f) integrated circuit – VCC0 1a



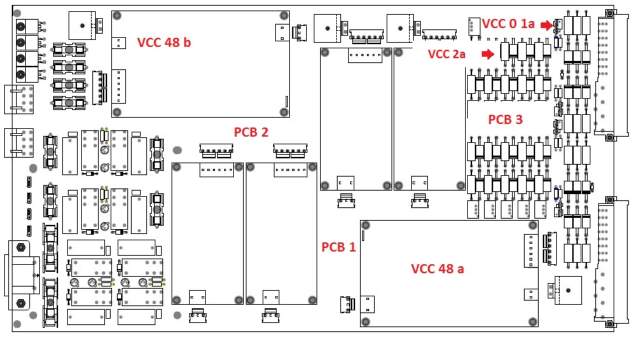
Hottest points

Table 1.2 shows the temperature of elements that reach above 90 ºC and temperature of board in particular places. This values are important for the arrangement of CI crates inside LHC tunnel. All elements presented in table 1.2 are marked in figure 1.11. There are some cells with "no data" inside. This was caused by inaccurately taking pictures from which reading particular values was impossible. It has been noticed after test that could not be repeated.

Table 1.2: Temperature at different points and loads configuration

Measurement points	Configuration T2	Configuration T3	Configuration T4
VCC 0 1a	101 ºC	95.5 ºC	98.4 ºC
VCC 0 1b	90.1 ºC	94 ºC	92.9 ºC
VCC 2a	97.6 ºC	90.7 ºC	No data
VCC 48a	106 ºC	103 ºC	111 ºC
VCC 48b	101 ºC	No data	98.2 ºC
PCB-1	47.6 ºC	51.6 ºC	49.4 ºC
PCB-2	56 ºC	50.8 ºC	52.8 ºC
PCB-3	60.2 ºC	58 ºC	59.1 ºC

Figure 1.11: Power Card with marked point of temperature measurement



Efficiency of Power Card

Table 1.3 presents measurements of input and output power and calculation of power efficiency according to formula below:

$$efficiency = \frac{output\ power}{input\ power} * 100\%$$

Table 1.3: Power efficiency for different configuration

Load configuration	AC RMS input power [W]	DC output power [W]	Efficiency [%]
No load	49.05	0.00	**0.00**
On 64 V output	468.43	430.28	**91.86**
On 8-9 V and 64 V outputs. Measured “After DC/DC”	771.46	569.96	**73.88**
On 8-9 V and 64 V outputs. Measured “After diode”	771.46	557.13	**72.22**

Durability of relays

Safety relays are components of power cards. Depending on the configuration they are responsible for cutting of top channel, bottom channel and 230 V load. In order to control those relays the signal 5 V DC was used. During test, first the relays control signal were connected to the power supply and set to 5 V DC. To input and output 230 V AC supply and 230 V load were connected. At the beginning, the signal was switched manually but it was too slow to check the real performance. The next step of testing was replacing the signal source to pulse generator. The signal was 5 V like before and had a switching frequency of 2 Hz. This part lasted two cycles, 10 minutes each. It results in 2400 on-off cycles per relay. Figure 1.12 shows measurement station for this test.

Figure 1.12: Pulse generator and spectrometer for observation reset signal changes

Instrumentation.

In order to perform all tests described in this section, measurement devices from table 1.4 were use.

Table 1.4: Instrumentation use for tests

model	purpose	company
DC -load SL - family	Load	ET System Electronic GmbH
TG5011 - Pulse Generator	Pulse generator for relay	AIM & TTI
190-204 - 4CH 200MHz ScopoMeter	Observation of pulse generator	FLUKE
75 III - Digital Multimeter	Current/Voltage measurements	FLUKE
345 - PQ Clamp Meter	Current measurement	FLUKE
i50 - Thermal Imaging Camera	Temperature measurement	FLIR
RRS80R - Potentiometer	Load	Oh mite
HD 9214 - Digital Thermometer	Ambient temperature measurement	Delta OH M
TCP312 AC/DC Current Probe	Current measurement	Tektronix
TCPA300 Current Probe Amplifier	Current measurement	Tektronix

1.2. Verification of toroidal transformers 70022K and 70032K series

Goal and summary of test results

For circuit in which this transformers will be used, important parameters is output ripple. This phenomenon is caused by the Graetz bridge in unregulated power supply. Various capacitance (blue in figure 1.13) values were tested against output ripple. In terms of voltage and temperature characteristics the following configurations where tested:

- no load,
- load channel separately,
- full load for both channel.

Capacitance.

Electrolytic capacitor of 470 μF and 220 μF were used for output ripple adjustment. Capacitor of 470 μF in parallel with 220 μF gives smaller ripple than 220 μF for full loaded transformer, 1320 mV and 3360 mV respectively. In case of low load, output ripple were measured at the level of: 286 mV and 536 mV respectively. According to those results, capacitors in configuration: 220 μF parallel to 470 μF were chosen for final design.

Voltage characteristic and current flow

Output voltage for 2.5 VA transformer varies from 11 V to 14 V. In case of 3.5 VA transformer voltage varies from 12.4 V to 14.6 V. These results are within the limits of manufacturing tolerance and fit prediction. Current flowing through Zener diode depends on load but do not exceed 200 mA for 2.5 VA transformer and 290 mA for 3.5 VA transformer.

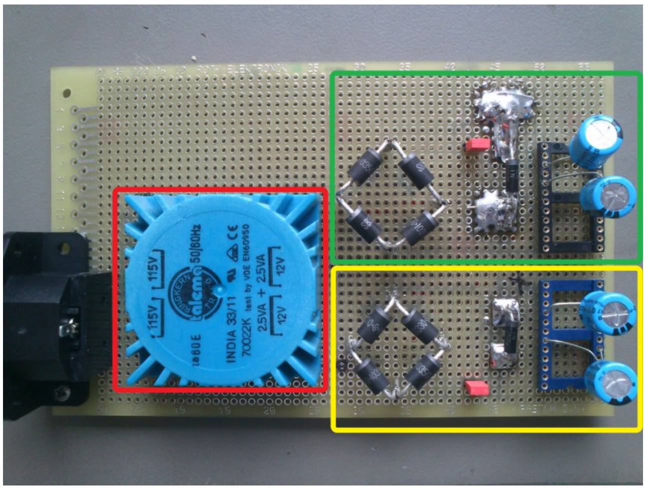
Temperature characteristic

EH were not designed for external cooling. That is why, system and components must have know temperature characteristic to avoid burning crate. Transformers and Zener diodes were tested in laboratory with ambient temperature about 30 ºC. Both 2.5 VA and 3.5 VA transformers reach 60 ºC which is exact to assuming in datasheet Δt = 29 ºC.
Zener diodes reached temperatures of 100 ºC in circuit with first transformers and >150 ºC in circuit with the second one. The precise temperature in second case cannot be measured because it exceeds the range of the camera which is 150 ºC.

Introduction to Toroidal transformers 70022K and 70032K series

The test circuit was prepared to verify electrical and thermal properties for the following toroidal transformers: 70022K and 70032K, manufactured by TALEM. Both have 230 V AC input and 2 x 12 V output windings, first have 2.5 VA output power per channel second 3.5 VA. Transformer 70032K is physically larger because of higher output power. PCB was designed manually, based on the part of the EH card schematic present in Appendix B. In the circuit, instead of SMD Schottky rectifiers, diodes rectifiers were used for the Graetz bridge. In addition, a jumper was placed between bridge and Zener diode (see small red jumper in figure 1.14). It allows to disconnect one channel or measure current in this channel. It can be done by plugging mulimeter in place of the jumper in order to simulate heat sink of real card, some solder was added to anode and cathode of Zener diode (see figure 1.13).

Figure 1.13: Test PCB, transformer with input (2x115V) on left and outputs on right (2x12V) was mark in red, green box cover top (1st) channel, yellow marks bottom (2nd) channel



Points of measurements, results and graphs

Since only one board had been used for measure two transformers, they were replaced as it was necessary. Output voltage, both DC and ripple values were measured between anode and cathode of Zener diode. Current was measured on jumper. All measurement points are presented in figure 1.14. Important elements were covered by colour rectangle and described below:

– blue rectangles- diode bridge,

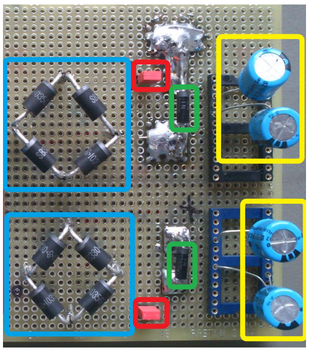
– red rectangles- switch,

– green rectangles -13 V Zener diode,

– yellow - parallel connection of 470 μF and 220 μF capacitors.

Around connectors of Zener diode, solder heat sink are placed. For top channel, solder heat sink have a bigger surface. This difference was intentional, and was part of testing.

Figure 1.14: Detailed image of test board, description below



Results for 2.5 VA transformer

Figures 1.15 and 1.16 present output voltage and output ripple respectively. Top and bottom channels are quite symmetrical similar, that is why only top channel characteristics are presented.

Figure 1.15: Output voltage for 2.5 VA transformer

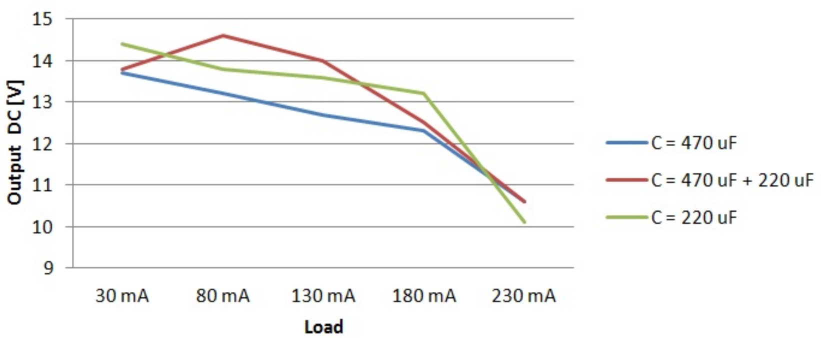
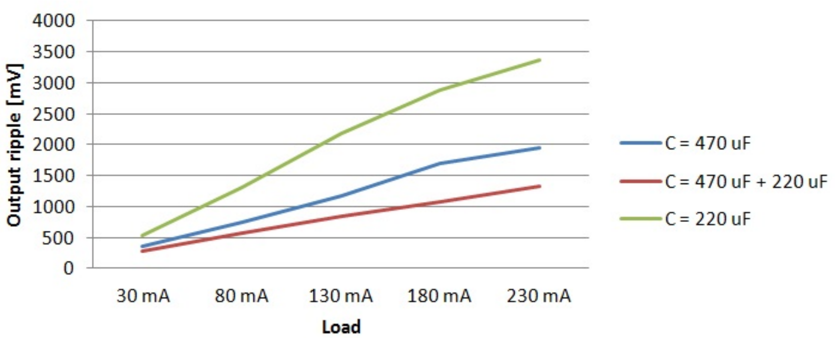


Figure 1.16: Output ripple for 2.5 VA transformer



Results for 3.5 VA transformer

Figures 1.17 - 1.18 presents characteristic of output voltage, output ripple, total current and temperature of elements based on load.

Figure 1.17: Output voltage and ripple for 3.5 VA transformer

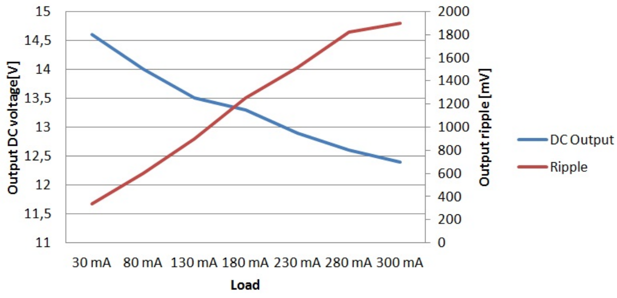


Figure 1.18: Temperature of elements for 3.5 VA transformer

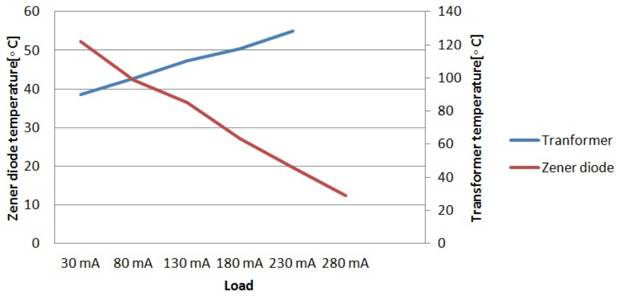
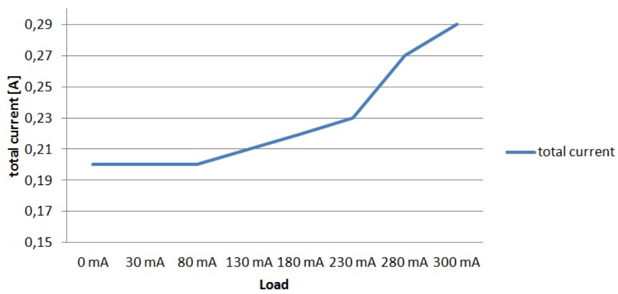


Figure 1.19: Total current for 3.5 VA transformer



1.3. Verification of transformer VB 0,35/2/24

Goal and summary of test results

Below one can find specific goals which were investigated during this test:

– Investigate output voltage for variable input and output resistance of circuit with tested transformer.

– Measure output voltage with constant resistances of circuit with tested transformer but with different transformers (8 different units of the same type).

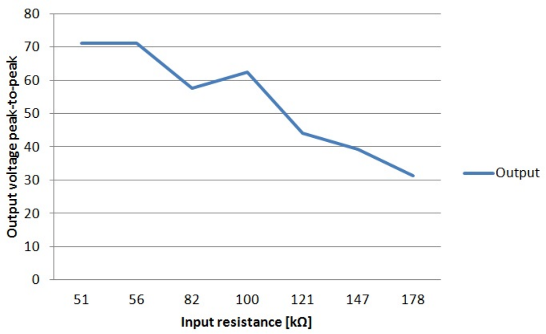
– Concern parameters of zero cross: pulses width, amplitude and accuracy.

– Verification of the possibility to work transformers with 400 V AC input. Supply changes are considered due to new design assumption.

Relation between input resistance and output voltage

There were used input resistors parallel to transformer with 7 resistances varied from 51 kΩ to 178 kΩ. Resistor is green marked in figure 1.21. For these resistances, output voltage values varies from 71 V to 31 V. The relation between resistance and output voltages is presented in figure reffigR.

Figure 1.20: Output voltage for VB 0,35/2/24 transformer



Relation between output resistance and output voltage

There were test three combinations of resistor voltage divider R1/R2 which is presented in figure 1.21 (red frame). In theory, this divider multiply signal by 0.039 (2/51 ratio) and its output should be as close to 0.875 V as possible. This result was obtained for R1 = 2 kΩ and R2 = 51 kΩ. Output voltage was 0.822 V compared to theoretical value: 0.875 V.

Output voltage of different copies of the transistor (8 pieces)

The output voltage of 8 different copies of transformer were measured using single test board. Input voltage changes from 20 V to 230 V by means of 6 steps. For 230 V supply, output voltage of circuit changes no more than +/1% from average value. The maximum observed variation of output voltage from average value were observe for 145 V and it was equal to -5.5%.

ZeroCross pulse and accuracy

Pulse was generated when input signal cross zero (see figure 1.24). Pulse amplitude reach 4 V (theoretically should by 4.3 V because of 4.3 V Zener diode at the output) and width of 230 us, which is exactly the expected value. Capacitors C1 of 42 μF and 47 μF makes good synchronization of input AC voltage and cross zero signal. There was also requirement to testing +/- 20% production margins for capacitors. This test reveal that 47 μF is better.

400 V supply test

Testing 400 V supply reveal differences between VAC_MEAS for top and bottom channel of card . Differences was observed with respect to number of outputs used and is presented in figure 1.21 b). Transformer with only one circuit connected (bottom channel of AC measurement) gives 1296 mV output voltage which is about 16% higher comparing to transformer with two circuit connected (top channel of AC measurement and ZeroCross). To makes this difference smaller, resistor R=17.35 kΩ were used instead of not connected output. This modification makes difference smaller by 50%.

Introduction to VB 0,35/2/24 transformer

The test board was prepare to verify electrical properties of VB 0,35/2/24 transformer manufactured by BLOCK. It has 230 VAC input and 2 x 24 V output windings. Output windings have could be loaded by 0.175 VA per channel. There are use for AC voltage measurement (VAC_MEAS signal) and so-called zero cross[2] detection which will be described later. In one card there were use two such as transformers, one for VAC_MEAS of card top channel and zero cross detection, second for VAC_MEAS of card bottom channel.Transformer VB 0,35/2/24 schematics for VAC_MEAS and zero cross is presented in figure 1.21 a).

Zero cross detection can be considered as a type of phase detection. Circuit detects moments when a supply signal crosses the 0 V level. Whenever signal cross 0 V there is generated voltage pulse with width from 230 us to 800 us. It depends on supply. For 50 V AC and 230 V AC, pulses should last 800 and 230 us respectively. Figure1.22 show signals for zero cross detection for 230 V with pulse width of 250 us.

[2]ZeroCross is a specific implementation of the zero cross function. Therefore, it will be written in the form ZeroCross while the zero cross signal refers to the actual intersection of the axis of 0V (http://en.wikipedia.org/wiki/File:Zero_crossing.svg).

Figure 1.21: Circuits schematic with transformer VB 0,35/2/24for: a) zero cross and AC voltage measurement b) output connections for first and second transformer

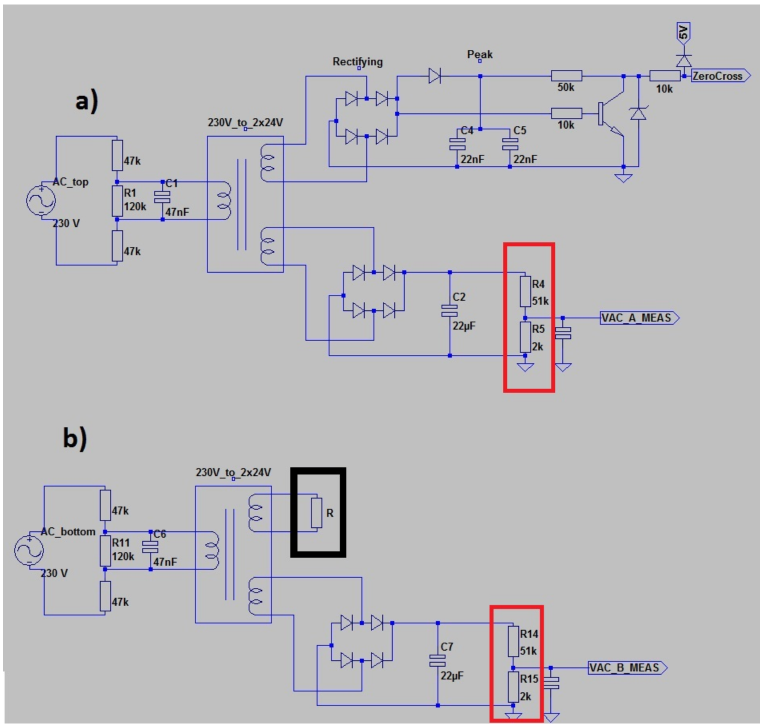
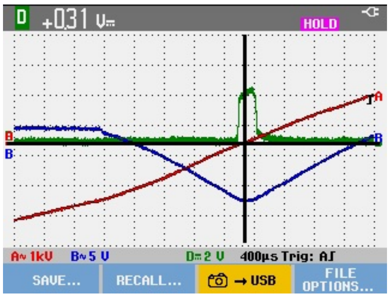


Figure 1.22: Signals for zero cross detection, green signal mark zero cross detection pulse



Output voltage measurements

The difference between output voltage of different copies of the transistor (8 different pieces)

Table with results of this test is extensive. Therefore is placed in the Appendix C. The following table includes only the average values of outputs and maximum deviation (in percent) from them for each measurement point.

Figure 1.23: VB 0,35/2/24 test circuits schematic, jumpers mark in blue were use for changing top and bottom channel and or vice versa

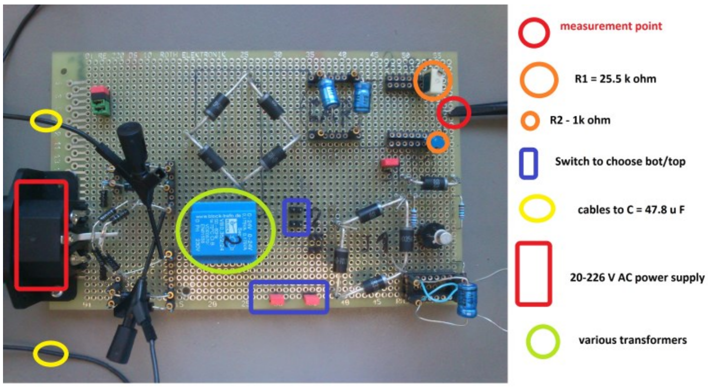


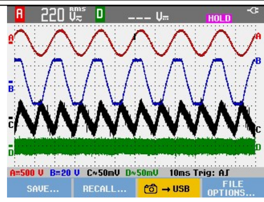
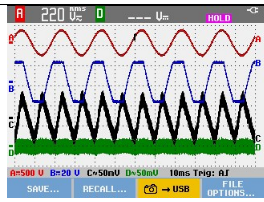
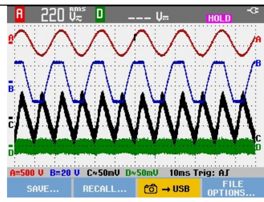
Table 1.5: Transformer VB 0,35/2/24, differences between output of variuos pieces

Input	top channel output average value	top channel deviation in output voltage from average value	bottom channel output average value	bottom channel deviation in output voltage from average value
[V]	[V]	[%]	[V]	[%]
226	905	-0,99	915,5	-0,82
185	748,5	-1,67	757	-1,19
145	586,25	-1,07	590,75	-5,54
105	419,5	-1,79	427,5	-1,75
65	257,88	-3,05	262	3,82
20	77	-3,9	77,5	-4,52

Output voltage (for relay/bottom part) changes due to different output resistances

There were tested 3 different combination of output resistors. The ratio should by 2/51 (0.039) and its output should be as close to 0.875 V as possible. This result were obtain for R1 = 2 kΩ and R2 = 51 kΩ. Output voltage was 0.822 V compared to theoretical value: 0.875 V. Results of all measurements are presented in table 1.6. Measurement point was the same like in previous test (V AC signal measurement). To measure and observe results the Fluke ScopoMeter and Fluke Digital Multimeter were use. Description of colors use in figures are as follow: **power supply**, **signal after transformer**, **signal after bridge**, **output signal**.

Table 1.6: Transformer VB 0,35/2/24, different voltage devider configuration (see figure 1.21)

ratio R1/R2	R1	R2	Voltage supply	Voltage after r transforme	Voltage after bridge	Output voltage	Figure
	[Ω]	[kΩ]	[V]	[V]	[mV]	[V]	[image from ScopoMeter]
0,039	1996	51,14	226	44	80	0,822	
0,0398	1000	25,13	226	39,2	118	0,749	
0,04	500,9	12,51	226	33,6	162	0,637	

Dependence of ZeroCross and zero cross position from transformer input capacitor

Different positions of ZeroCross and zero cross are presented in figure 1.25. Zero crossing point depends on capacitance placed parallel to transformers input (C1 in figure 1.21). There were check 2 different value of this capacitor. Result are present in table 1.7 Additionally, there were requirement to check +/- 20% of base values of capacitance, because of the manufacture margin for capacitors that were taken into consideration.

Figure 1.24: Time interval between ZeroCross (middle of green pulse) and zero cross point (black line)

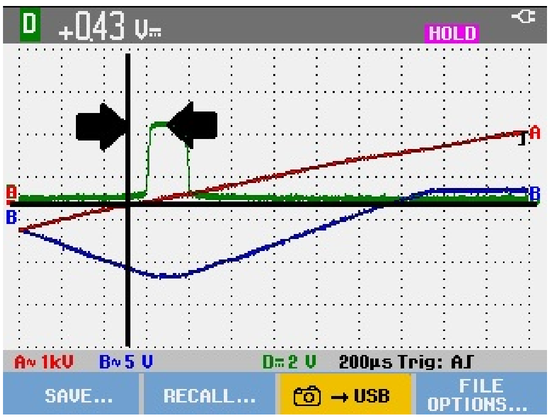


Table 1.7: Results of testing accuracy of the ZeroCross function due to the capacity value and its margin. In brackets are presented multiplier of capacity, which is equal to margins

Capacitance parallel to input resistor	Time interval between ZeroCross and zero cross point
uF	us
(0.8 x 33) = 24.3	-352
(1 x 33) = 33.4	-192
(0.8 x 47) = 37.6	-160
(1.2 x 33) = 42.26	0
(1 x 47) = 47	0
(1.2 x 47) = 56.4	112

ZeroCross pulse amplitude and width

During this test, parameters of ZeroCross function such as pulse amplitude and width were check. Both of this parameters are important for proper operation of other components of card. Table 1.8 show brief results of this test. Pulses were observe on Fluke ScopoMeter and tested in two configurations: with 1x 22 μF capacitor and with 2x 22 μF capacitor.

Table 1.8: ZeroCross pulse amplitude and width with respect to different number of capacitors

Input AC V	2x 22μF pulse amplitude	2x 22μF pulse width	1x 22μF pulse amplitude	1x 22μF pulse width
	[V]	[us]	[V]	[us]
50	3,22	690	3,24	678
95	3,76	430	3,64	421
140	3,86	326	3,86	327
185	3,98	269	3,98	267
230	4,04	235	4,06	232

Configuration of resistance and outputs for 400 VAC input

Following test were performed in a few configurations. First for configuration presented in figure 1.21 a). In this case to top output of transformer zero cross circuit is connected. To bottom output of transformer, top channel of VAC_MEAS (AC voltage measurement). After measurements, test were repeated but in different configuration. Top output of transformer was left free and to bottom was connected VAC_MEAS for card bottom channel. During the test it turned out that the difference between the channels of the AC voltage measurement is not acceptable. For 230 V input, top channel AC output was 1099 mV, bottom output was 1286 mV. Therefore, there was need to perform test of additional resistance connected to left unconnected output of transformer, in order to align signals VAC_A_MEAS and VAC_B_MEAS (V AC measurement for top and bottom channels of card). Results of this test are presented in table 1.9.

Table 1.9: Output of transformers with different occupancy of channels

Input of transformer	Output of transformer with two circuit connected	Output of transformer with one circuit connected	Output of transformer with R=17.35 kΩ instead of one circuit
[V]	[mV]	[mV]	[mV]
48	136	161	139
100	279	338	292
150	423	516	446
206	585	714	619
256	729	887	772
298	852	1034	903
352	1004	1196	1065
398	1099	1286	1182

1.4. Verification of operational amplifier OPA 541 AM

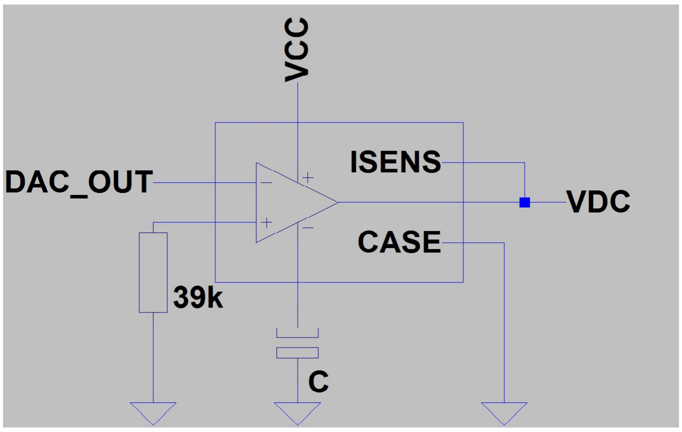
Goal and summary of test results

Main goal of testing and verification OPA 541 AM was divide into two part. In first part the main idea was to test amplifiers recovered from card which were damaged. It was destroyed or had badly mounted connectors. Second goal, was to test device in terms of radiation tolerance. Despite it was done by manufacturer, it have to be repeated for safety reasons. This test will be present in section 1.5. Results of first test were very satisfied. Among tested 278 amplifiers, 263 (95%) were fully functional.

Introduction to OPA 541 AM

OPA 541 AM from TEXAS INSTRUMENT is high power monolithic operation amplifier with power supply +- 40 V and TO-3 package. The TO-3 industry package isolate circuit and allows to mount amplifier directly to heat sink. OPA 541 AM were use in previous design of heater cards which working before LS1 (Long Shutdown 1). After testing it will be use in new one. In one heater card, there are place two amplifiers. They are sources of voltage use for heating. Configuration of circuit (figure 1.25) assumes amplifiers gain at level 8.33 and output voltage 70.8 V. Test circuit in which OPA 541 AM were tested was different that this from heater card in order to check parameters of amplifier.

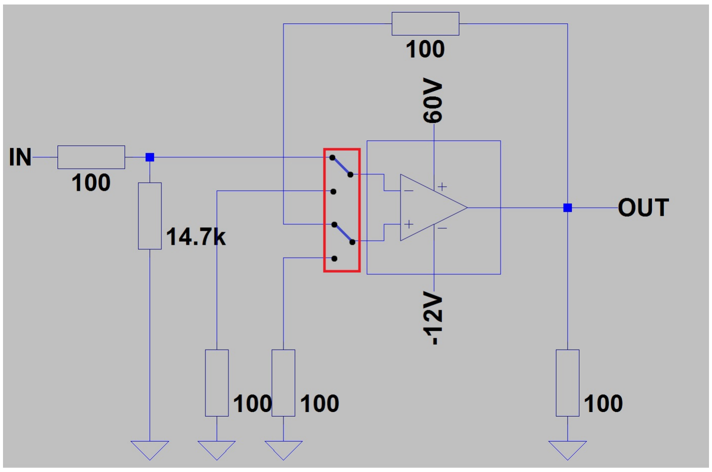
Figure 1.25: Part of the heater card schematic containing the OPA 541 AM.



Schematic and measurements

Test station consist of two power supplies for OPA 541 AM, signal generator for input signal simulation, two multimeters, sourcemeter and ScopoMeter for amplifier output observation. All those elements were connected to PCB via standard cables with banana connectors. Two board was equipped with TO-3 adapter which allow to connect OPA 541 without soldering it. Schematic of this circuit is presented in figure 1.27.

Figure 1.26: Circuit for testing OPA 541 AM



OPA 541 AM were tested at four different field:

– current consumption,

– current leak,
  Current was measure via supply line using two independent multimeters, offset by ScopoMeter with scale of 100 mV connected to output. Those test were basic but at this point most of damaged amplifiers were found.

– offset at output,
  Investigating range of operational .It was done by finding input voltage for which, output sine-wave changed shape. Input sine-wave with changing amplitude were generate by signal generator. Values start from 0 V and at most cases reach 5.8 V – 6.2 V peak-to-peak.

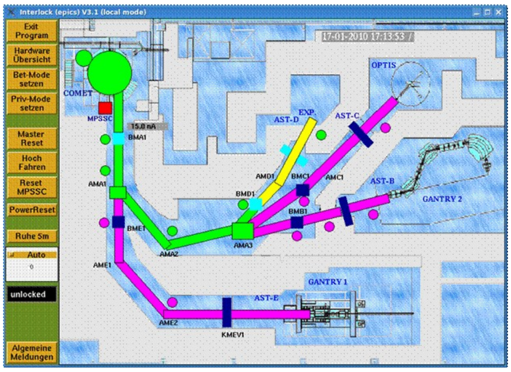
– output collapse.
  During all previous test switches presented in figure 1.27 keep their position. In fourth test were change to connect both inputs of OPA 541 AM to banana connectors. Current leak test need special configuration and special instrumentation. For this test first supplies were switched off then position of both switches were changed. Next, to "+" input was connected KEITHLEY sourcemeter set on +/- 7 V and 2 mA. The "-" input was connected to the ground and supplies were switched on. After measuring current leak for "+" input the whole procedure was repeated for "-" input.

1.5. Radiation tolerant electronic test in Paul Scherrer Institute

Introduction to proton irradiation test in Paul Scherrer Institute

The new heater card requires components never used before in LHC radiation areas. Currently used components have confirmed radiation tolerance. It was done in CERN Neutrinos to Gran Sasso (CNGS) experiment and CERN radiation facility. Some test were performed outside CERN in Proton Irradiation Facility (PIF). This facility is placed in Paul Scherrer Institute (PSI) near Zurich and presented in figure 1.27[3]. The facility was built under the contract of European Space Agency (ESA) and PSI for testing spacecraft components. Laboratory can be use by external users like CERN scientists and was choose for testing components for heater card to confirm their theoretical resistance to radiation. There was also need to check the components like OPA 541 AM, which radiation tolerance were confirmed but production line change and test need to be repeated. The tests in PIF lasted from 20/07/13 to 22/07/13, with total irradiation time more than 25 hours for three PCB with components, and were carried out by Kajetan Kalafarski and Nikolaos Trikoupis.

Figure 1.27: Overview of COMET outputs, PIF experiment chamber is located at the end of yellow tunnel.



Radiation test use proton beam from COMET accelerator. The entire study was preceded by a preparation of measuring equipment and test schemes in the laboratory of Cryolab & Instrumentation section of CERN.

Cryolab & Instrumentation section of CERN

One of crucial part of radiation tolerance test in PIF took place in the laboratory of Cryolab & Instrumentation section of CERN. Starting from preparation of the measuring instrumentation and checking of triaxial, coaxial and 112 wire cables ending on preparation of the boards (control and experiment). List of all electronic devices used in this test is presented in table 1.10.

Power supplies were set to 15.5 V, 5.3 V, 3 V, 0.7 V depending on diode voltage. Oscillator 10 MHz were powered by 5 V. Transistors VCC and base voltages were equal to 2 V. Transistor OPA 627 has

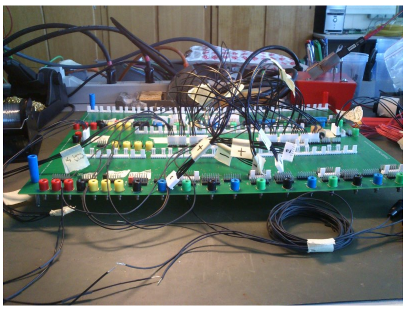
[3] `http://pif.web.psi.ch/pif_files/image012.gif`

Table 1.10: Instrumentation use for radiation tolerance in PIF

model	purpose	company
DC - load SL family	Power supply (OPA 541 & 627, diode, transistors)	ET System Electronic GmbH
TG5011 - Pulse Generator	Input signal (OPA 541& 627, diode, transistors)	AIM & TTI
TCPA300 Current Probe Amplifier	Current Measurement (Transistor VCC current)	Tektronix
TCP312 AC/DC Current Probe	Current Measurement (Transistor VCC current)	Tektronix
190-204 - 4CH ScopoMeter	Oscillators output measurements, OPA 627 measurements	Fluke
197A Microvolt	Voltage measurement - diode, current measurement - T1 Base I	Keithley
2400 SourceMete	Oscillators supply, I leak measurements, OPA 627 +/- 12 V supply	Keithley
34401 A Multimeter	Transistor Current Measurement	Hawlet-Packard
DPO 4054 Digital Phosphor Oscilloscope	Output Measurement (OPA 627, transistor)	Tektronix

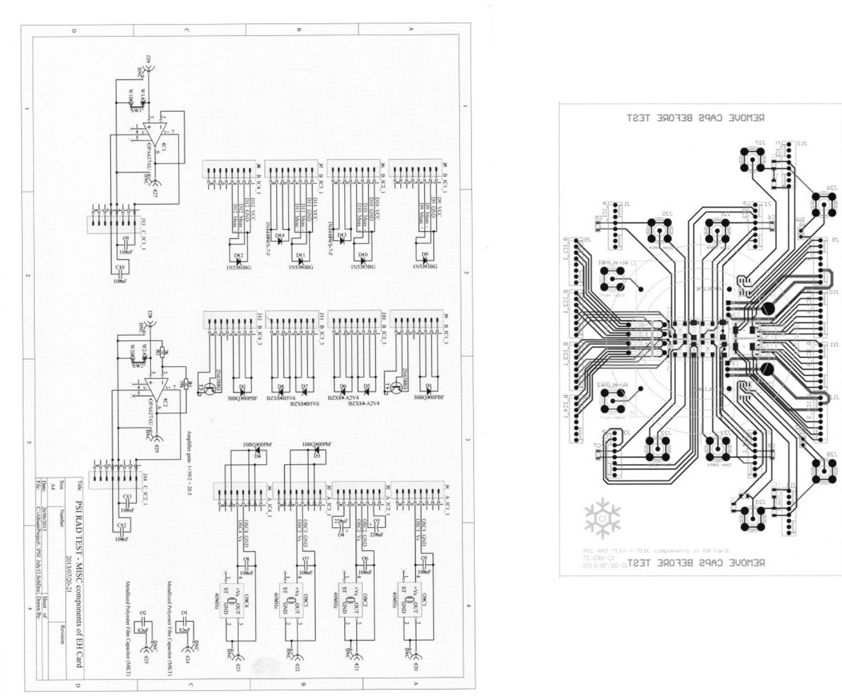
supply of +/- 12 V. There were also pre-defined inputs for OPA 541 AM and transistor. Sine waves of amplitudes 2.6 V and 9 V for were used for OPA 541 AM. For transistor square wave of amplitude 5 V and duty of 20 % was applied. After preparing power supplies and input signal generators the control board was prepared. Control board is show in figure 1.28 and it collect signals from experiment board and carry via two 112 wire cables. It allows to connect experiment board via standard banana to all instrumentation. Board was designed for previous radiation tolerance test, that is why, some changes like shorting track or changes the labels was done. Opposite to control board the experiment board was designed and prepared for this test by project engineer. Schematic of both boards are presented in figure 12.

Figure 1.28: Control board use to connect cables from experimental chamber to instrumentation in control room



Important point of preparation was laboratory tests. During test parameters of cables connecting board in experiment area to PIF control room were measured. The cable parameters have to be known precisely to minimize the impact on the measurement results. For 30 meters triaxial cables which were use for low current leakage measurement, impedance, reactance, capacitance and resistance were precisely measured. Four best cables were selected as a primary, others are marked as a backup. The parameters of 30 m coaxial cables which carry signals for OPAs and from oscillators were test too and eight with best parameters were choose to be primary. Other were marked as a backup cable. Two 50 meter cables with 112 shielded wire each were test for conduction.

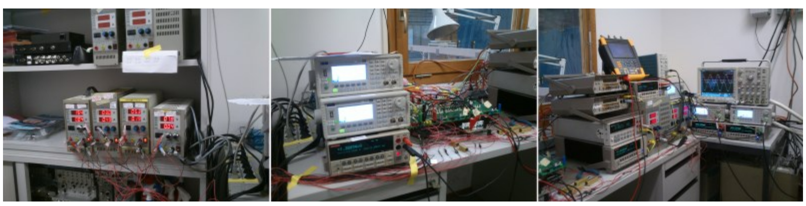
Figure 1.29: Control board schematic (left), experiment board schematic (right)



Proton Irradiation Facility (PIF)

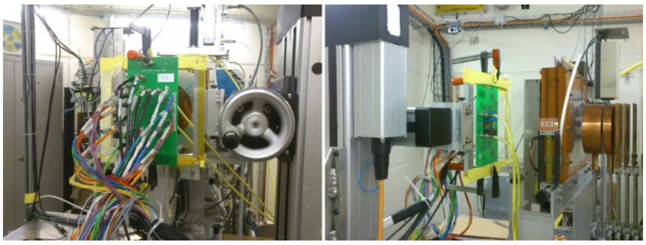
Equipment were placed in control room and connected to control board. Cables were unreel and connected to control board and experiment board in experiment chamber. Figure 1.30 show equipment during test.

Figure 1.30: Intrumentation in PIF control room



The next point of preparations was putting tested board with components in experiment chamber and connect to it all cables which is presented in figure 1.31.

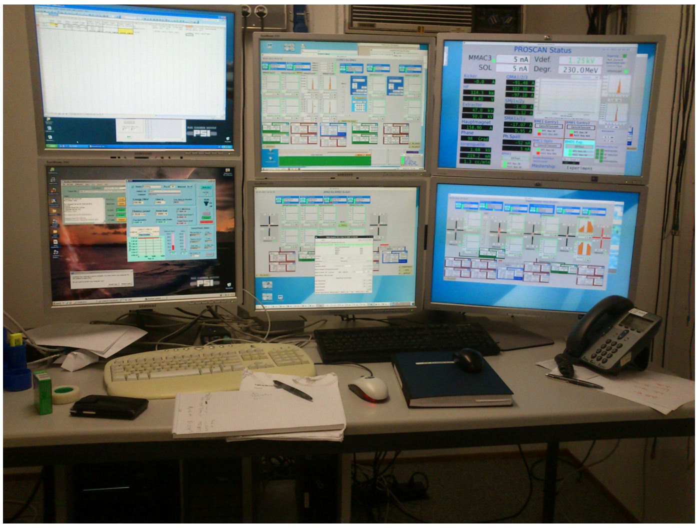
Figure 1.31: Board with tested components inside PIF experiment chamber



Procedure and measurements

After distribution of measurement equipments and placing connected board in the experiment chamber the parameters of the beam in PIF control room have been set. Setting the beam was conducted by PSI employee who held duty on the machine during this experiment. Setting parameters such as positioning and focusing the beam of protons were use special computer station and its presented in figure 1.32.

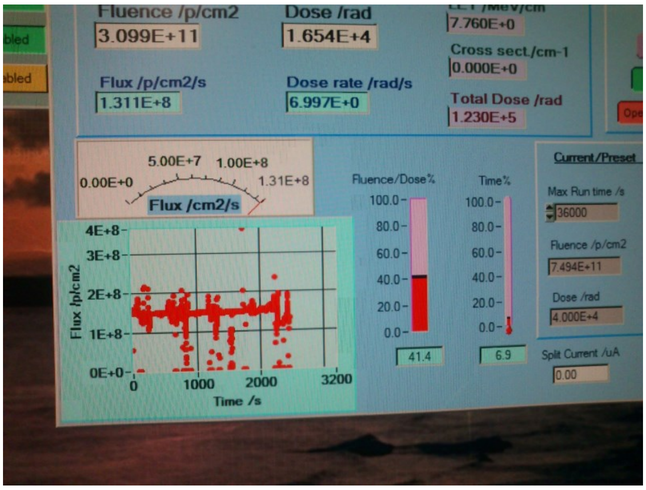
Figure 1.32: PIF control station. Screen in bottom, left corner show the current status of beam



Setting beam take less than half hour and then main experiment starts. First tray failed because of beam instability. It was probably caused by requested beam characteristic. After re-setting it some of problems was resolved but some don't. It was probably caused due to inaccurate configuration of the accelerator and beam line from it to experiment chamber. It is possibly caused by previous group, which testing other electronic for CERN, and uses the beam with different characteristics. Every disruption of power and flux of beam, shown in figure 1.33, ended up with damping the beam. This the main reason of quite high difference between irradiation time.

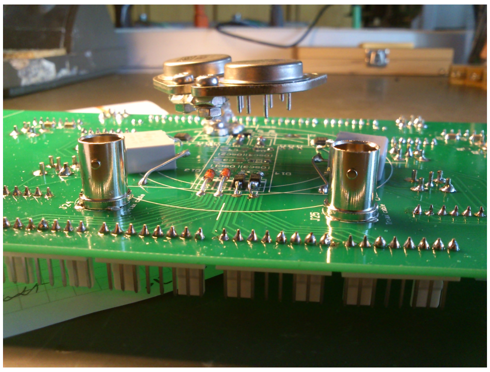
Radiation tolerance investigation of heater card components was divide in three parts, each dedicated to one board. First two has the same components: two types of capacitors, diodes, OPA 627 and transistor.

Figure 1.33: Unstable proton flux from COMET



Last board was modified due to requirement of testing OPA 541 AM and because project engineer decide to change one of capacitor to other - smaller. Gained place was use to mount OPA 541 AM above board surface, which is present in figure 1.34.

Figure 1.34: OPA 541 AM mounted on experiment board



Testing of single board was divide into five stages. First consists of connecting cable to board and mounting it on holder in experiment chamber. Next was pre-testing each connection and components. After confirmation from PIF control room, beam was turned on and board starts to irradiate. During this process which least from 5 to 10.5 hours parameters of each components were measure, details of time and doses are present below:

- PCB 1 – 1094 Gy – 10.5 hour,
- PCB 2 – 1004 Gy – 9.5 hour,
- PCB 3 – 919 Gy – 5 hour.

PCB 1 and PCB 2 components were measured in seven checkpoints: before radiation, at 200 Gy, 400Gy, 700Gy (PCB-1 932 Gy, due to instability of beam), 1000 Gy and after test. Boards were also test after rest time which were equal eight hours for PCB 1 and three hours for PCB 2. Large dose of radiation cause inability to change plate and forced downtime between irradiations. PCB 3 received smallest radiation dose but the numbers of measurements step was thirteen plus test before radiation and 10 hours after. As a consequence test for OPA 541 AM have much better resolution especially in manner of current consumption (9 steps).

Goal and summary of test results

The following components were tested: 10 MHz crystal oscillators, diodes, low leak capacitors, amplifiers (OPA541AM, OPA627) and transistor. Components comes from new heater card. There were placed for test on three PCBs, called experiment boards. Brief results of all test are presented below.

10 MHz crystal oscillators

There were tested 8 pieces 10MHz oscillators. During first irradiation, after 356 Gy, one of oscillators double its frequencies and after 623 Gy stop working at all. Seven remaining work without changes.

Diodes

There were tested four types of diodes (15.5 V, 5.3 V, 3 V, 0.7 V) for stability of forward and reverse voltages. During and after radiation test, non of diodes changes its parameters. All components works perfectly.

Low leak capacitors

There were tested two types of capacitors. During radiation occur small (1%) changes in capacitance. However, current leaks have changed as much as 400%. This changes disqualified one of two capacitors which additionally was the expensive one.

OPA 541 AM

Amplifiers current consumption decrease from 34.9 mA to 24.17 mA (786 Gy) and after 10 hours without radiation slightly increase to 24.73 mA. Current leak increases from 0.001 uA to 0.43 uA (900 Gy) and decrease to 0.03 uA (after reach 920 Gy irradiation). No reason was fond for such a behavior but the values stay within tolerance.

OPA 627

This amplifier behave more stable than previous one. Current for +/- 12 V supply were the only one parameter that change noticeably. It changes from 6.85 mA to 6.77 mA (1004 Gy) for “+” input and from 6.8 mA to 6.73 mA for (1004 Gy) “-“ input.

Transistor

Emitter current decrease from 235 mA to 191 mA (1094 Gy). After 10 hours without irradiation, emitter current increase back to 235 mA. Base current increase from 0.08 mA to 0.35 mA (1094 Gy). In contrast to the previous parameter it don’t return back to initial value after some time.

2. Design and fabrication of field tool for checking the correct electrical wiring of the beam screen heater

In the second chapter the design and fabrication of field tool for checking the correct electrical wiring of the beam screen heater is presented. Device should by portable and as simple as possible to provide easy installation verification. It should works like a simple EH card simulator with capability of showing heater cartridges temperature change. Another function should by powering the heater cartridges inside LHC magnets. Design and fabrication process should be preceded by measuring time and power required to increase the temperature of heater by 10 ° C. Assuming a weight "to warm" of 0.5 kg and knowing approximate heat capacity there where calculate energy, which was equal to 250 J[1]. This mean multiplication of heating time and power should by 250 J.

2.1. Design and configuration

To avoid issues such as the delivery power to disconnected heaters or inversely connected sensor (heated show temperature drop) there was need to check connection to heaters and sensors. Wiring of both will be checked in machine part (interconnection) and in crate part, according to document. "Beam Screen Heater Commissioning"[4]: *"The main goal of this document is [. . .] design a portable tool for checking the correct electrical wiring of the beam screen heater, in particular it is important to check that no inversion exist in the protection J-type thermocouple wires"*. Test device works like a simple, two channel simulator of electrical heater card. Each channel has independent input, output and controlling. Beam screen thermocouple type-J sensors outputs are treated as an input for device. Sensor produce 0.5 mV for each 10C temperature change which is presented on display. The output of device is an electrical circuits of the following parameters: ≈45 V AC and ≈0.4 A, per each of two channels. It simulates 20 W of heating power of card. Output is controlled by relays built inside signal transmitters in device. Special push buttons are use to controlling power delivered from device to beam screen heaters. First step of designing portable tool was determining power supply and heating duration. From theoretical calculation, time needed to change temperature of heater cartridge by 10C using 20 W of power was 12.5 s. Solutions with less power and longer duration were considering but after testing in CI laboratory this idea was rejected because. of significantly longer waiting time for 0.5 mV changes of thermocouple

[1] J = W x s

output (see figure 2.1). To measure this value, signal amplifier were used and oscilloscope for observing voltage changes. For heating, 0-50 V supply were used It was connected to model of heater cartridge and is presented in figure 2.2.

Figure 2.1: Thermocouple output P = 20 W, ΔU = 0.5 mV, Δt = 90 s

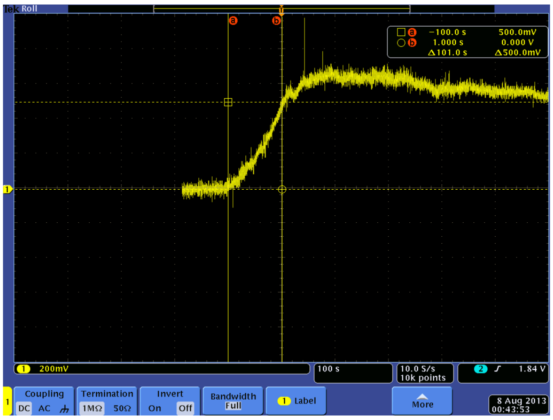
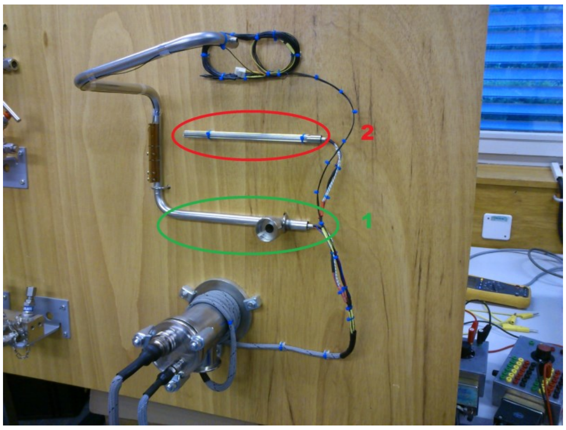


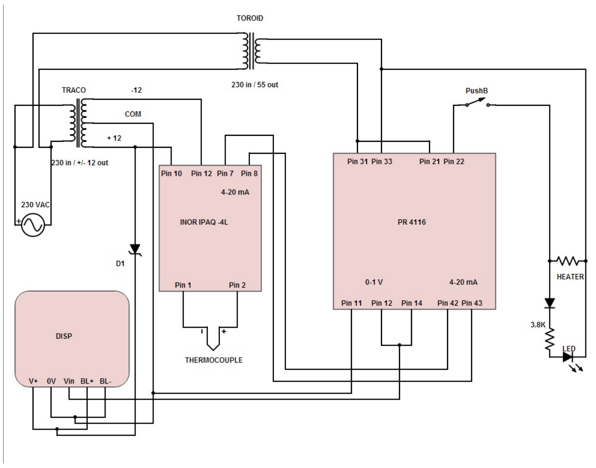
Figure 2.2: Model of heater cartridges, heater and thermocouple sensor inside metal radiator (top) and beam screen cooling line (bottom)



Second step was choosing appropriate transmitters to change milivolts signals from sensors to 0-1 V signal for display. After a few trials and tests a serial connection, of PR-4116 and INOR-IPAQ-4L was selected. IPAQ-4L is simple transmitter which collect signal from thermocouple sensors and translate it to output current signal transmitted to PR-4116. To change the screen indicator properly, input range for IPAQ-4L was set to -0.5 mV - 2 mV with 0.005 mV sensor error. This range was than translated to standard for measurement 4 mA - 20 mA current output which after PR-4116 was translate to 0-5 V output. This setting of inputs and outputs of signal conditioners allow to omission certain restrictions on the equipment and allow for dynamic display of temperature changes in +/- 10C range. Additional function of PR-4116 was use of built-in relays, program to automatic cut-off power when temperature goes beyond selected range. Part of wiring and configurations was tested by trial and errors and the final version of connections for one channel is presented in figure 2.3. Full configurations are placed in

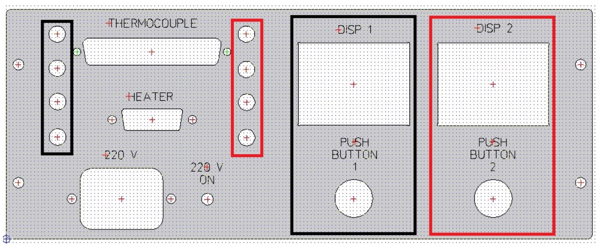
Appendix D. Channels are symmetrical and common for them are voltage supplies. Transformer with +/-12 V output is use for powering INOR transmitter and display. Transformer with 55 V output is use for heating purpose and supply of PR-4116.

Figure 2.3: One channel of portable tool



Portable tool should have box-shape and following features: 230 V AC supply, sub-D 36 and small banana inputs, 5-pin connector and banana outputs, displays showing change and direction of temperature changes. Double input and output were needed to work in interconnections (banana connector) and the cryogenics instrumentation crate (sub-D 36 and 5-pin connectors). An additional advantage of such a solution is ability to check the current status of input and output using multimeter (see figure 2.9) connected to unused connectors. Based on these requirements and connection configuration front panel of device has been designed, presented in figure 2.4. Ready and working device will be presented in next section.

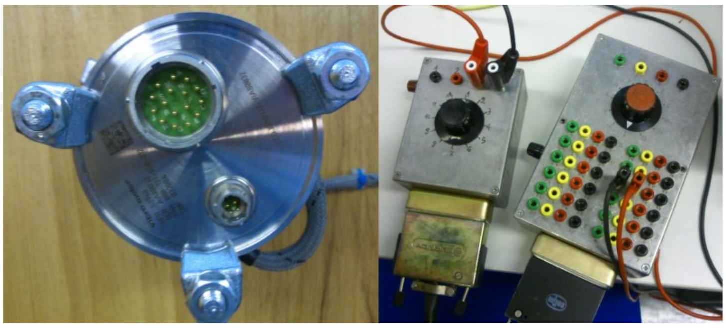
Figure 2.4: Front panel of portable tool. Color mark first (black) and second (red) channel of device



2.2. Field test inside LHC tunnel and it results

First the formal procedure of using device will be presented, next the images from first and successful operation of device. Device must by stable placed, it could be placed in interconnection or crate. For use in interconnections, special adapter for connecting bananas is need. Interconnections connectors and adapter are presented in figure 2.5.

Figure 2.5: Heater (4-pin) and thermocouple (16-pin) connector from machine (left) heater (4-pin) and thermocouple adapters (right)



Next, heater have be connected to device, thermocouple and 230 V AC supply. It is important to connect sensor before switching on power. After this actions operator should wait about minute to stabilize displays indictors in vertical position, then proceed to heating. To transfer power to heater cartridges push button must by pushed and stay in that position. LED diode inside button or above indicate power transfer to heater cartridge. Heating should took no more than 45 second till observing movement on display. Proper connection of heater and thermocouple sensor should give change of indicator in about 20-45 seconds, depending on the ambient temperature. Possible errors which can be present during testing heater and thermocouple and solutions are enumerated below:

- 230 V LED shining but device no react, displays are black – try to connect again / change supply line, possible damage inside box,
- display is full of blinking lines – thermocouple not connected or value out of range,
- no reaction on display after pushing buttons, buttons LED shining – check connection of thermocouple,
- no reaction on display after pushing buttons, buttons LED not shining – check connection of heater,
- indicator line move left and then diode confirming heating stop shining – thermocouple is invert (relays cut off power).

Figure2.6 and 2.7 show tool before connecting to crate and after successful test.

Figure 3.8 show two possible errors: left channel – reverse connection of thermocouple, right channel– not connected thermocouple.

Figure 2.6: Preparation of workplace, in left corner CI crate

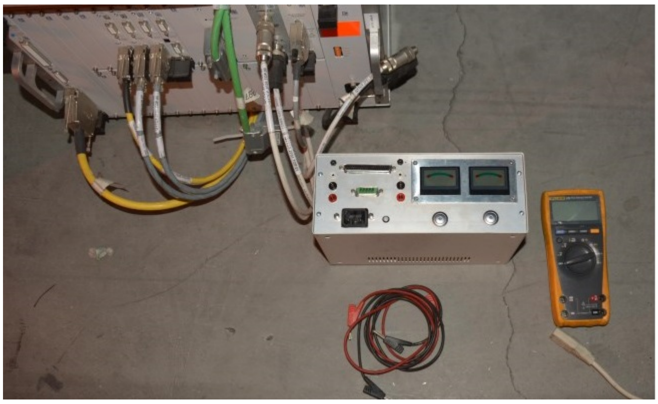


Figure 2.7: Result of good working both heater and thermocouple, test on crate side

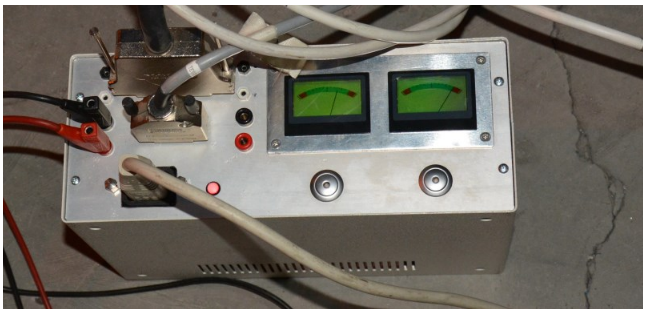


Figure 2.8: Test on machine side, on right side adapter connected to LHC magnet

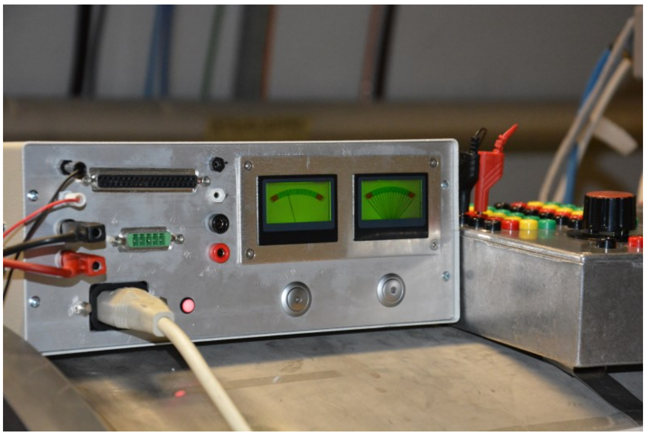
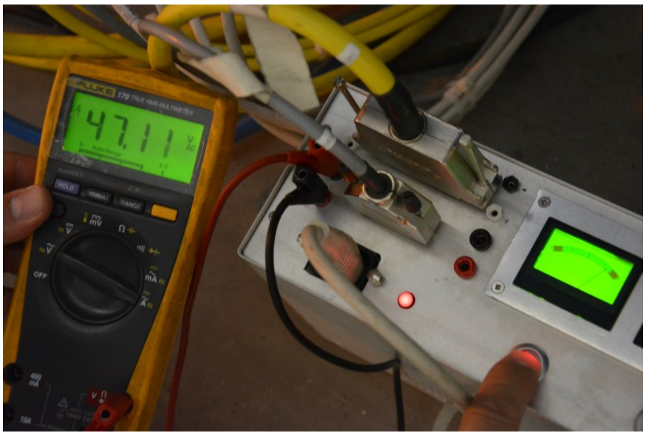


Figure 2.9: Measurement of output voltage of device connected to crate. In bottom right corner shining button can be seen



Conclusion

Main goal of this document was descriptions of tests of components for a new project of beam screen heater card. Parameters that have been tested can be divided into electrical, thermal and radiation. An additional objective was to examine power card, which is one of card cooperating with the heater card in cryogenics instrumentation crate. In case of card there were examined thermal characteristic, power efficiency and durability of built-in relays.

Power card had good thermal characteristic and power efficiency. Card temperature does not exceed 110 ℃ and the power efficiency was 72%. All these parameters were agree with the design assumptions and project is already at the stage of production.

The first components test concern the toroidal transformers 70022K. Component works flawlessly and its temperature agree precisely with the data from its datasheet. In the circuit which will it work to reduce the ripple were use combination of capacitor 220uF + 470uF. Additionally was also test more powerful version that also work without problems and is fully compatible with the circuit in which transformer 700022K works.

The second test of components concerns the transformer VB 0,35/2/24. In the circuit in which it worked were matched resistance values to set the output voltage to value from design assumptions. It was also chosen value of capacitance to make the best setting of zero cross point.

The next tested component was OPA 541 AM. The main goal was to verify tolerance to radiation after change of the manufacturer. An additional task was to verify the operation of amplifiers recovered from damaged cards and verification if they can be used in new beam screen heater card. Results of first test were positive with the exception of changes in current consumption (from 34.9 mA to 24.17 mA). It change during irradiation but after idle return to initial parameters. Reason of this behavior were not found but change the parameter was small and not excluding this component from use. Verification of recovered amplifiers ended with positively evaluating performance of 95% of the tested components.

The last test were performed to verify the radiation tolerance of components for a new heater card. During the tests the following components were examined: mentioned before amplifier, amplifier OPA 627, several types of diodes, low leakage capacitor and 10MHz oscillators. In the case of the amplifier 627 and the diode there were not observed any significant changes in the parameters. In the case of transistor emitter current decrease during irradiation and after 10h idle returned to the initial state, as in the case of OPA 541 the reasons for such behavior is unknown. There were tested eight oscillators and only one of them stopped working (after a dose of 623 Gy) in remaining seven no changes were observed. In the case of low leakage capacitors the current leak change significantly. This exclude one type of capacitor from use in heater card. The entire test radiation ended successfully and allow to verify components for a new beam screen heater card.

Additional task was to design and fabricate device for checking the correctness of electrical wiring of the beam screen heater. The portable tool were built and tested in the LHC accelerator tunnel. Testing device was successful and now will be used to verify the connection throughout tunnel. Positive verification of components to by radiation tolerance allows to use them in other projects in which radiation can occur like new card or accelerators. The test tool will be used to check about 400 connectivity, and then after modification can be used for any other purpose.

Bibliography

[1] Jacquemod, A. Poncet, B. Skoczen, J.Ph. Tock. *THE INTERCONNECTIONS OF THE LHC CRYO-MAGNETS*. CERN, Geneva.

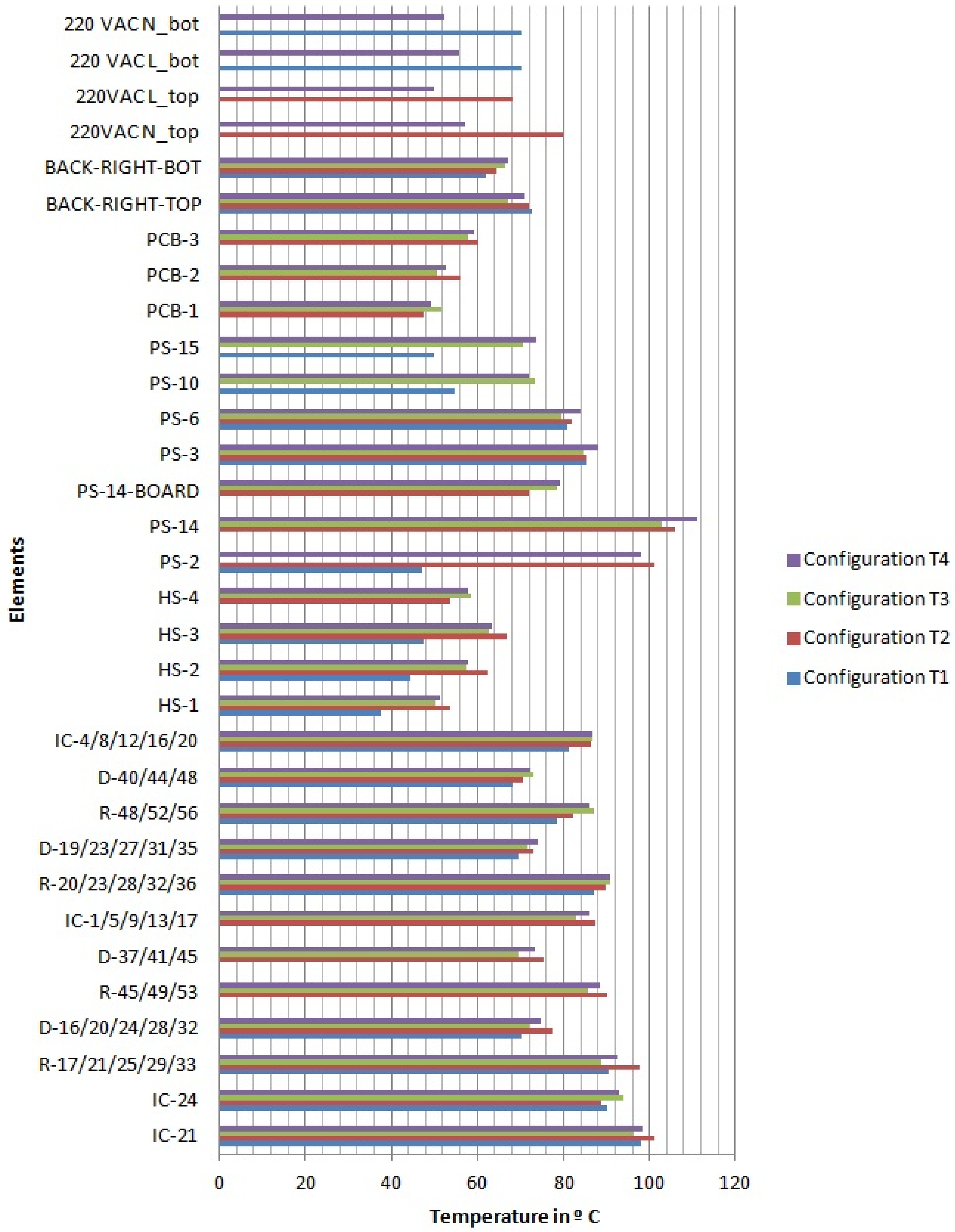
[2] *LHC Beam Screen Heaters: System overview, consolidation needs and project Planning*. Wydawnictwo Ariel, Krakow, 1992.

[3] K. Wittenburg, DESY, Hamburg, Germany, R. Schmidt,T. Spickermann *RADIATION DOSE FOR EQUIPMENT IN THE LHC ARCS*. CERN, Geneva, Harvard University, Cambridge

[4] *http://cds.cern.ch/[...]. https://edms.cern.ch/[...].* CERN, Geneva,

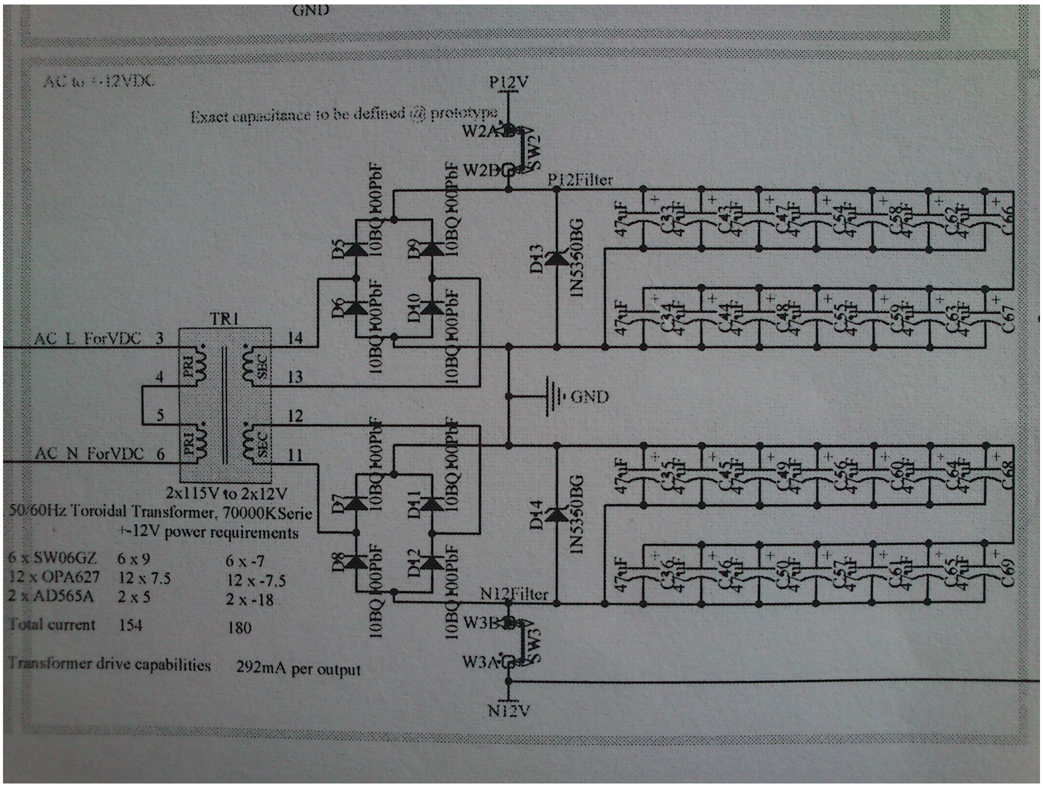
Appendix A

Figure 10: Temperature of different component of power card with different configuration of load. Name of components are taken from schematic[6]



Appendix B

Figure 11: Schematic of circuit in which transformer 70022K series are use



Appendix C

Measurement of different pieces of Vb 0,35/2/24 transformers

Table 1: Top channel of transformer

number of transformer	1	2	3	4	5	6	7	8
Input V	DC output	DC output	DC output	DC output	DC output	DC output	DC output	DC output
[V]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]
226	912	912	900	904	908	908	896	900
185	756	752	736	752	752	756	740	744
145	588	584	584	592	588	588	580	586
105	424	420	416	420	416	424	412	424
65	260	250	256	256	260	264	259	258
20	74	76	78	78	76	76	78	80

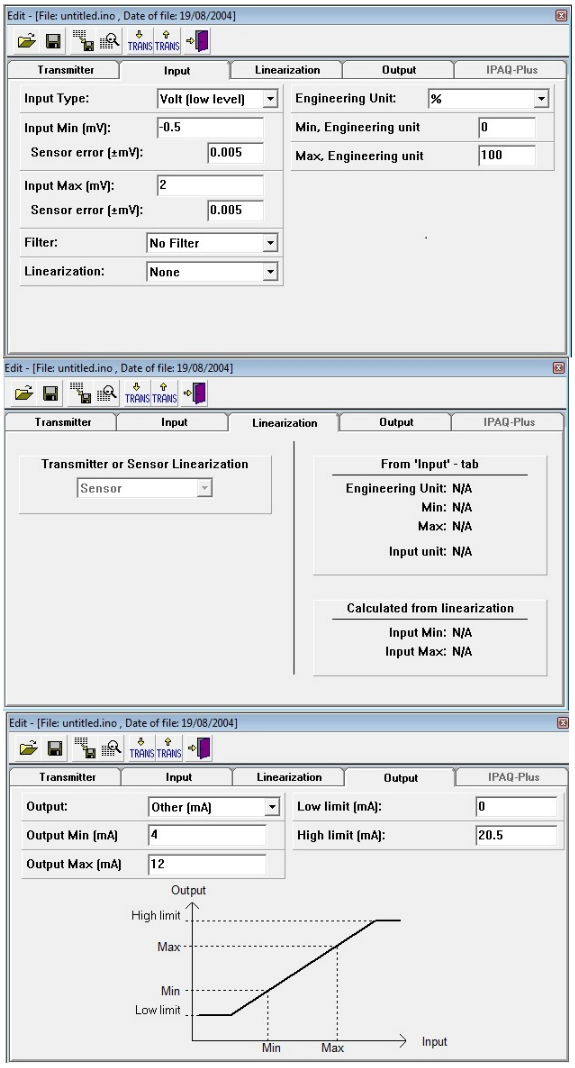
Table 2: Bottom channel of transformer

number of transformer	1	2	3	4	5	6	7	8
Input V	DC output	DC output	DC output	DC output	DC output	DC output	DC output	DC output
[V]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]	[mV]
226	920	920	908	920	916	920	912	908
185	752	760	748	764	760	764	752	756
145	592	596	558	596	596	600	596	592
105	420	424	428	432	432	432	424	428
65	258	264	260	260	262	272	260	260
20	74	78	78	78	78	80	76	78

Appendix D

Signal conditioners configuration for portable tool

Figure 12: INOR configuration, screen from programmer



PR-4116 was configure via special front panel. Below are present only those options which were change during configuration.

IN.TYPE: CURR	**I.RANGE**: 4-20	**%(unit)**: mA
DEC.P: 11.11	**R1.FUNC**: WIND	**R1.CONT**: C.I.W (close in window)
SETP.LO: 15	**SETP.HI**: 85	**ANA.OUT**: VOLT
O.RANGE: 0-5		