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Design and Automation of Product Testing Procedures

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The purpose of this bachelor's thesis was to develop automated tester for train electronics engineering company EKE-Electronics Ltd. Their hardware research and development section is in process of upgrading preliminary product testing methods. Automated testing setup for power supply units is the first step towards another level of product testing and the developed methods may be implemented later for other automated measurements.

Research on standards and product specifications was carried out to identify electrical conditions and to define important measurable parameters for analyzing product compliance with requirements. With the gained knowledge, current measurement equipment capabilities were studied and the need for extra hardware was identified. Interface connecting measurement devices to the device under testing along with standardized connectivity was developed. C and Labview code were written for hardware control and carrying out measurements in automated manner.

As a result, most of the concepts developed during the project were proven with testing carried out with prototype interface and software. However, some software was not written within the time frame reserved for the study, as during the research phase of the project, it became apparent that significant hardware design and additional software written for it was required. Regardless of this, power supply units can now be subjected under defined electrical conditions, data can be gathered with conducting automated measurements leaving data analyzing for further development work. Also, casing and printed circuit board should be designed and produced for the prototype interface hardware.

Keywords	Automation, testing, train, electronics

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Tämän insinöörityön tarkoituksena oli kehittää automatisoitu testauslaitteisto juna elektroniikkaa suunnittelevalle EKE-Elektroniikalle. Yhtiön tuotekehityksen osaston tavoite on nostaa tuotteiden esitestaus seuraavalle tasolle. Heidän tuotevalikoiman virtalähteiden testauksen automatisointi on ensiaskel kohti tätä tavoitetta ja kehitettyjä metodeja voidaan hyödyntää myöhemmin muihin automatisoituihin mittauksiin.

Projektissa tutkittiin alan standardeja sekä tuotteiden vaatimusten määritelmiä laitteiden sähköisten ympäristöjen ja olosuhteiden tunnistamiseksi ja merkittävien mitattavien parametrien määrittelemiseksi laitteen toiminnan analysointia varten. Saavutetun tiedon avulla käytössä olevien mittalaitteiden soveltuvuutta testeriä varten sekä lisälaitteiden tarvetta arvioitiin. Mittauslaitteiston sekä mitattavan laitteen yhdistävä liitäntälaitteisto kehitettiin sekä C että Labview koodia kirjoitettiin laitteiston ohjaamiseen sekä mittausten automatisoituun suorittamiseen.

Tuloksena suurin osa projektin aikana kehitetyistä konsepteista todistettiin toimiviksi prototyyppi liitäntälaitteiston ja ohjelmiston avulla suoritetuilla mittauksilla. Kuitenkaan kaikkea ohjelmistoa ei ehditty kehittää projektiin varatun ajan raameissa, koska aiheeseen perehtyessä tunnistettiin lisälaitteiston sekä sitä ohjaavan ohjelmiston suunnittelun merkittävä tarve. Siitä huolimatta, tuloksena virtalähteet voidaan nyt altistaa määritellyille sähköisille olosuhteille sekä dataa kyetään keräämään automatisoiduilla mittauksilla, jättäen tiedon analysoinnin lisä kehitystyölle. Myös prototyyppi liitäntälaitteiston kotelointi sekä piirilevyn suunnittelu vaativat lisää kehitystä.

Avainsanat	Automatisointi, testaus, juna, elektroniikka

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List of Abbreviations

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List of Abbreviations

PSU	Power Supply Unit.
EU	the European Union
EMC	Electromagnetic Compatibility
µs	Microsecond
ms	Millisecond
DUT	Device Under Test
DMM	Digital Multimeter
PE	Protective Earth
DAQ	Data Acquisition
MOSFET	Metal-oxide-semiconductor Field-effect Transistor
ADC	Analog to Digital Converter
DO	Digital Out
GPIO	General Purpose Input Output
RTOS	Real-time Operating System
VI	Virtual Instrument
PCB	Printed Circuit Board

1 Introduction

Since developing their first generation of electronic products to be used in trains some three decades ago, EKE-Electronics Ltd. has grown their range of products to form comprehensive solutions for train automation, diagnostics, communication and system integration, with their products installed in over 30 countries. As all products are guaranteed with 30 years support, due to changes in availability of components used in their designs and requirements in standards that the products must comply with, revisions of older products are inevitable. An increasing number in new products and revisions of older designs demand more from internal quality management.

As a step to ensure quality and efficiency with each change implemented, the company's research and development section have a plan to take testing of the products to another level. Much of the current product testing inhouse is manual work on demand. By automating many of the tests that verify compliance with product requirements as well as with railway industry standards, quality with every implemented change can be ensured. With consistently produced detailed test reports the hardware team management expects improvements with traceability and prediction of rising issues, for example in type testing for compliance with standards.

As first phase of the project and as determined scope of this study, automated testing methods are developed for power supply units. Tested parameters for these types of products are largely straightforward to define and measure. Also, PSUs used in EKE systems are developed by sub-contractors and are in most need of verification testing. Test system should be expandable to cover all products and all parameters viable for automated testing, should the PSU testing prove to be successful.

As a base for testing system, a collection of programmable measurement devices and software to control them shall be used. This configuration file-controlled test sequence measurement system is used by company's sub-contractor in product development and testing. Challenge is to recognize and define parameters to be tested and modify the system to measure selected parameters of PSU products, while acknowledging future expansion plans to include other products.

2 Theoretical Background

2.1 Need for Automated Testing

Being ISO9001 certified company and bound to follow a quality management system with visible and auditable process as defined in the standard [1,34], EKE-Electronics is committed to quality management defined in ISO/TS 22163, which is rail application of ISO 9001 standard. Part of change management defined in the standard, is to document and verify all changes to their products to avoid adverse effects [2,31]. To test product changes thoroughly, regression testing of all parameters and functionality could be required to indeed verify, whether changes have a negative impact on product features and characteristics unrelated to the issue that called for the change originally. As repeating mundane measurements manually after every implemented change, results could be prone to human errors. Shortcuts with seemingly irrelevant testing parameters and documentation may occur.

By automating product testing, consistency in accuracy and level of detail in results and documentation could be achieved. Compliance with product requirements could be verified after every implemented change with minimal man hours spent for testing. Result would be automatically generated detailed report, that itself would be valid document for company to retain and to provide for customer when required. By identifying issues that create problems with type testing inhouse beforehand, extra project time and money costs are reduced.

2.2 Railway Specific Requirements for Electronics

In practice, electronics on board rolling stock must comply with requirements defined in EN 50155 [1] standard. By doing so, compliance with EU directives is also established. By requiring this from their sub-contractors, train manufacturers may install electronics onboard with more confidence. This standard describes electrical and environmental conditions occurring in trains and contains requirements for design, documentation and testing of equipment used in them. Type testing for compliance with the standard is commonly done by accredited third party, that tests the complete system delivered to the customer and produces a complete report. Some customers may accept tests done by the company that provides the equipment, but accredited independent third party performing the tests increase credibility of the results and are valid internationally. Mandatory tests for train electronics are [1,56]:

- Power supply test
- Insulation test
- Low temperature start-up test
- Dry heat and cyclic damp heat test
- EMC test
- Vibration and shock test

Tests like shock and vibration, are outside of the scope of this project. Most of EMC testing is done in facilities designed to carry out the measurements as specified in standards. Preliminary EMC tests plausible to carry out in EKE's facilities, may best be kept as separate procedure completely, since special measurement setup may be required. That is, effects of EMC interference on measurement devices used in the automated test, may require extensive evaluation. Measurement environment must be sufficiently compliant with standards for minimizing variables, while weather chamber will not comply with those requirements for EMC testing.

For some tests, chamber to control temperature will be essential as train electronics must work over broad range of temperatures. Different operating temperature classes are assigned in EN 50155 as listed in table 1 [1,22], depending where device in question is installed onboard the train.

Table 1. Operating temperature classes defined in EN 50155.

CLASS	**EQUIPMENT OPERATING TEMPERATURE RANGE (°C)**
OT1	-25 to +55
OT2	-40 to +55
OT3	-25 to +70
OT4	-40 to +70
OT5	-25 to +85
OT6	-40 to +85

If not specified, default requirement category OT3 should be applied. OT1 and OT2 are for passenger and driver compartments, while OT3 and OT4 are used for technical cabinets. Dry heat and cyclic damp heat tests simulate rapid temperature variations and occurring sweating as a result, that could happen when a train enters tunnels.

The purpose of insulation test is to verify adequate galvanic insulation of all equipotential areas against earth potential and other equipotential areas [1,67]. In practice, insulation between power supply unit’s input and output, input against protective earth and output against protective earth should be measured. Insulation is measured before and after voltage withstand test, where earlier described areas are exposed to high voltages for specified time. While these tests are plausible to include to the automated measurement, they are best left as a separate procedure at this stage. High voltages used in the test require controlled environment for safety and the test system under development is planned to be more portable and flexible by nature.

Train not only is challenging environment regarding temperatures, EMC, shocks and vibration, but also voltage source fluctuations and interruptions. Power may come from vehicle batteries with varying voltages depending on whether they are being charged, the overhead main line or for example the combustion engine powered generators. Supply change-over may occur and create power interruptions. Electronics operating in these conditions must handle the resulting voltage fluctuations and ripple factors.

In EKE systems, dedicated power supply modules will act as a buffer between these challenging parameters and the more sophisticated electronics, providing steady voltages for the rest of the modules. Product requirements consider factors presented briefly in this chapter, when product is designed with additional set of parameters.

2.3 PSU Specific Requirements

The main reason why power supplies are the first to be upgraded with testing procedures at EKE-Electronics, is increased requirements in the new revision of standard EN 50155. Many of the PSU designs date back to time when they had to comply with the requirements of the old standards. More strictly specified type tests in the updated document may cause unexpected results, hence increased preliminary testing inhouse is required.

Automated tests shall be designed according to the latest standard revision from 2017 [1] and most recent, currently in production, PSU design's requirements specification [3].

At quick glance, power supply unit appears as a simple device. Power goes in and power comes out in controlled manner. However, EKE series power modules have some more sophisticated functionality embedded in them. PSU must recognize out of specifications situations developing at input, providing signaling and enough hold on time to the rest of the system to prepare for shutdown. Also, startup inrush currents must be controlled with certain limits within specified time windows. It must be able to output enough power with enough efficiency over broad range of temperatures and input voltages, while maintaining output parameters within specified limits. To identify the parameters that need to be measured, product requirements specifications should be examined along with railway standards referenced in them.

2.3.1 PSU Environmental Requirements

Based on EN 50155, EKE-Electronics have set environmental requirements listed here in table 2 for PSU module mounted inside EKE equipment. These definitions are common for all PSU versions.

Table 2. PSU environmental requirements as defined in PSV requirements specification [3,4].

Parameter	Test condition
Operating temperature	-40 to +70 °C
Cooling test	2h at -40 °C, power off
Dry heat test	6h at +70 °C, 10 min at +85 °C, power on
Damp heat test	+55/+25 °C, 2 cycles, 2x24h

In table 2, operating temperature parameter defines that PSU must maintain normal operation with all defined parameters over stated temperature range. Considering automated measurement, all parameters identified in following chapters should be measurable in different temperatures. Therefore, option for setting up the measurement in weather chamber should be included.

Cooling test refers to low temperature start-up test defined in the standard and reprinted here in figure 1. Equipment should stabilize in low temperature minimum two hours and perform flawlessly both in low temperature and after recovery. This test can be easily integrated into the testing sequence when performing low temperature measurements.

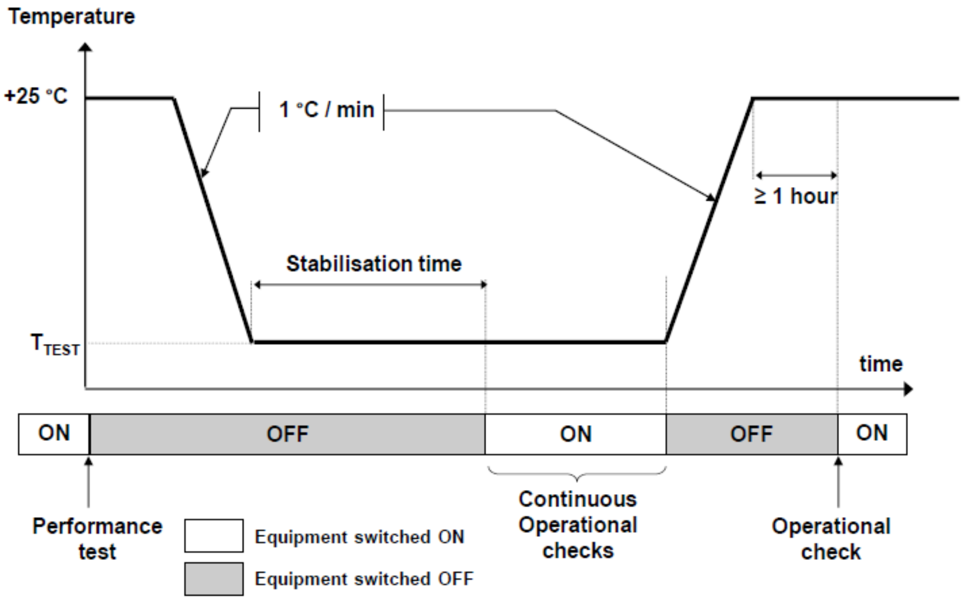


Figure 1. Low temperature start-up test [1,61].

Insulation tests are commonly performed along with damp heat test, when equipment is exposed to significant moisture. Hence, excluding this 48-hour long test from this project is justified. In dry heat test, equipment must perform normally in elevated temperature for an extended period after stabilization time, peaking shortly in maximum temperature as figure 2 reprinted from EN 50155 describes. Including this test optionally for measurement sequence should be sensible.

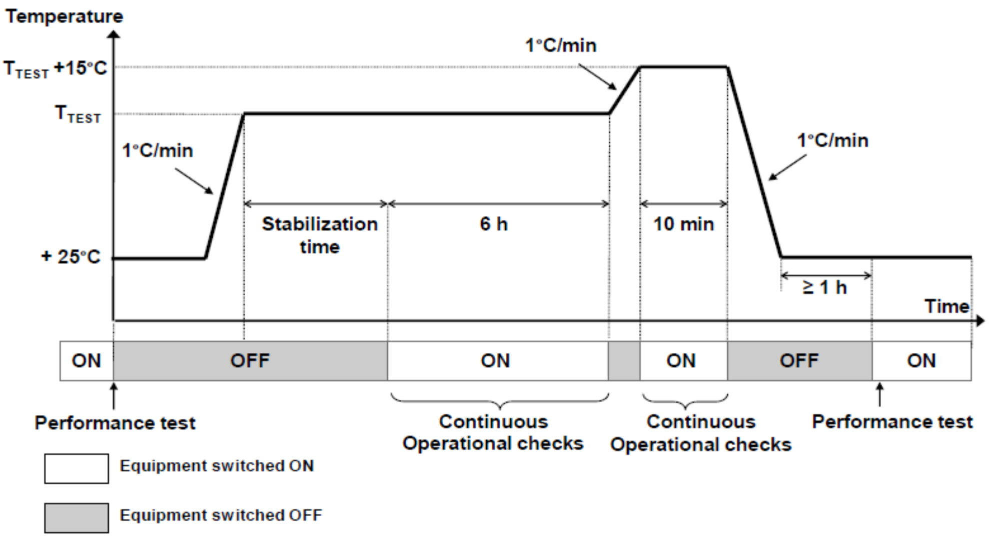


Figure 2. Dry heat thermal test – Cycle B [1,63].

2.3.2 PSU Input Parameters

According to the standard [1,24], set of nominal voltages (Un) between 24 V to 110 V are specified for train battery powered systems along with recommended values. Some EKE power supply units are designed for certain voltages only, but latest models work with a range of nominal voltages. Obviously to successfully test complete range of products, the test system must be able to generate these voltages with additional range for fluctuation and interrupt tests. Most stringent values are defined as [1,24]

$$0{,}7 * Un, and\ 1{,}25 * Un \tag{1}$$

resulting in minimum continuous voltage of 16.8 V and maximum continuous voltage of 137.5 V. However, in product requirements [3,13] maximum continuous voltage was increased to 130% resulting 143 V. It is also defined [1,26] that voltage fluctuations with

$$0{,}6 * Un\ and\ 1{,}4 * Un \tag{2}$$

shall be tolerated for 0.1 seconds with performance criterion A. That is, no deviation of function shall occur during and after the test [1,20]. EKE specified voltage fluctuation duration tolerance to one second in the requirements specification [3,13]. This requirement is more severe than supply variations described in the standard [1,57-58] and is the dominant definition for tester specification. Resulting range is between 14.4 V and 154 V. It should also be noted, that rise and fall times for these fluctuations are defined as reprinted here in figure 3. Rise and fall times are the same for temporary supply dips.

Pulling down the voltage at PSU terminals may require significant current sinking capabilities from the test setup, as power supplies may hold significant charge within filtering capacitors. It is common knowledge that

$$Q = CV, \tag{3}$$

meaning maximum charge will be achieved with a maximum voltage with a given capacitance value. Maximum peak fluctuation voltage of 154 V must return to nominal 110 V within 10 ms time as presented in figure 3.

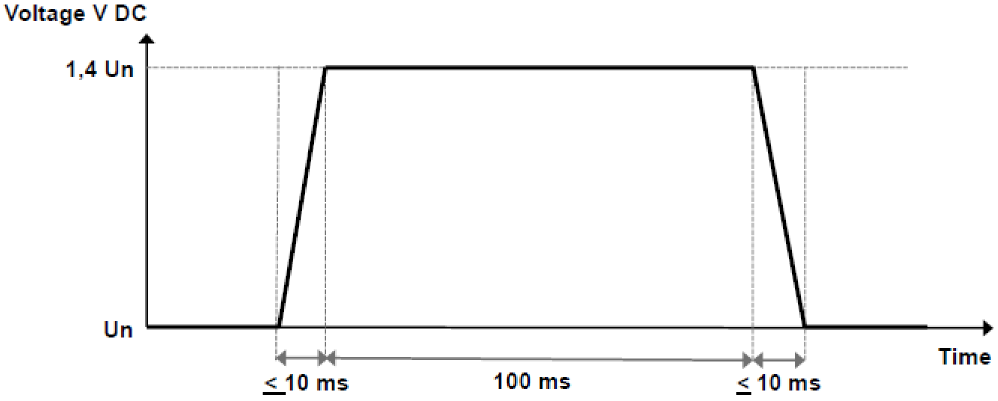


Figure 3. Temporary supply overvoltage [1,57].

Then summary of requirements for test setup voltage generation is:

- 14.4 V to 154 V range.
- minimum of 4.4 V / 1ms rate of change under PSU loading.

Interruption of voltage supply is defined [1,58-59] to present short low impedance condition to the load, short circuiting the PSU terminals. Result is a rapid drop of supply voltage to 0 V, possibly generating peak reverse current from the PSU. Rise and fall times are defined as reprinted here in figure 4. Currently, all EKE PSUs are specified for 10 ms interruption [4; 3, 14], class S2 [1, 59].

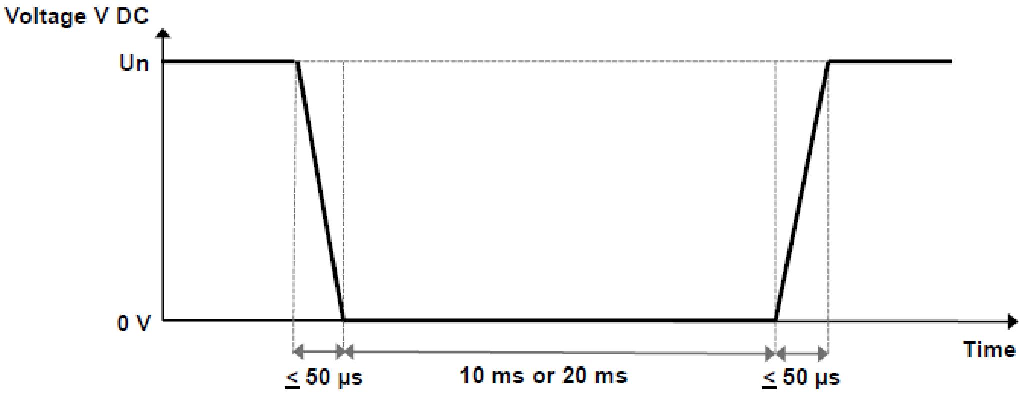


Figure 4. Interruption of supply voltage [1, 59].

Class C2 supply change-over describes [1,59] supply interruption like the one presented in figure 4, but with high impedance condition presented for the load with extended 30 ms duration. Class C1 is identical to supply dip described earlier and is already covered in this chapter. To summarize, test setup shall be able to both disconnect power source from the load, as well as short circuit load input terminals with enough current sinking ability to reach defined 50 µs rise and fall times. Duration of interruption should be adjustable with enough precision to vary between 10 and 30 ms pulses.

DC ripple voltages present in train systems as described in the standard, are allowed maximum ripple factor of 5% [1,27]. Frequencies tolerated are for supplier to define. In requirements specifications documents input ripple frequencies are specified for below 1 kHz for all PSU versions. Test system shall be able to superimpose small AC voltage on DC supply voltage and measure output parameters to verify normal operation. DC ripple factor is defined as:

$$DC\ Ripple\ Factor\ (\%) = \frac{Umax - Umin}{2Un} * 100 \tag{4}$$

In addition to requirements that are based on EN 50155 standard, set of parameters defined in PSU specification requirements [3] shall also be measured and verified:

- Withstands reverse voltage up to 130% of Un.
- Startup voltage threshold.
- Shutdown voltage threshold.
- Shutdown hysteresis voltage.
- Inrush current.
- Maximum input current.
- Input current when below shutdown voltage.

As specified and reprinted here in figure 5, first 10 µs have no limit for inrush current, but following 10 ms should be limited to a value depending on model and further 90 ms to specified maximum input current. 48-110 V model inrush peak may reach 11 A, while 24-36 V model should be limited to 22 A inrush current [3,12].

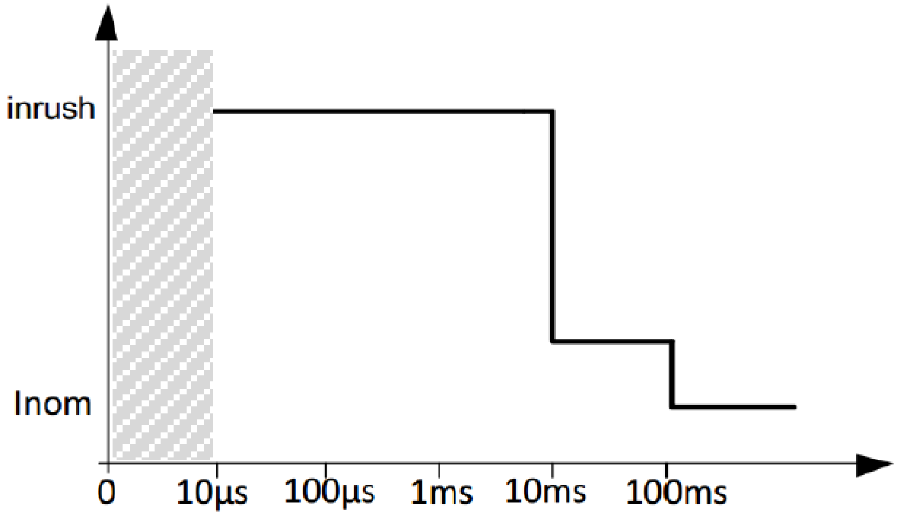


Figure 5. Inrush current limiting waveform [3,14].

As most powerful currently in production EKE series PSU can deliver 80 W minimum output with 80% efficiency [4; 3,10], power requirements for tester supply are not hard to approximate:

$$Pout = 0.8 * Pin \Rightarrow \; Pin = \frac{Pout}{0.8} = \frac{80W}{0.8} = 100W. \tag{5}$$

However, for test setup not to become a limiting factor, peak input current during inrush events and peak minimum voltage fluctuations require high current output from the tester PSU. PSR3031A has the highest continuous input current of 7.5 A and inrush current of 22 A specified. Combined with 154 V output range, test setup power supply capabilities may have to be significantly higher than the device under test.

2.3.3 PSU Output Parameters

Electronics in EKE systems are powered with different DC voltages, regulated and output by the PSU. These values are expected [3,15] to remain under defined limits, under all load and temperature conditions. Shall output voltages reach high limits, PSU should shut down until input power is switched off and back on. Similarly, output currents are defined for minimum and maximum load along with current limiting and short circuit thresholds. Output regulation must respond to specified load transients within defined time window, returning output to nominal range. Regarding output regulation, test system shall measure over operating temperature range:

- Output voltages.
- Output currents.
- Output load transient response.
- Output ripple voltages.
- Output power and efficiency.

Output voltages are 5 V and 12 V for all current EKE series power supplies, apart from PSR series that only output 5 V [13,18]. Specified maximum output currents are 13 A and 1.25 A respectively for the 80 W design [3,15]. As next generation power supplies under development are specified for 100 W continuous output [4], the load required for the test setup should be able to dissipate power well over that.

In requirements specification, load transient response is defined so that output voltage should return to specified limits within 1 ms after load change of ±80%. Output ripple is defined below 20 MHz frequencies with a limit of 50 mV peak to peak. Both parameters are identically defined for both 5 V and 12 V outputs [3,15].

In addition, EKE power supplies have a requirement to signal the rest of the system of input side power loss. ACFAIL signal shall activate after input voltage is below shutdown threshold for specified time, signaling system to prepare for shutdown. SYSRESET will set system in reset state when safe operation is not possible, that is startup and shutdown transitions. Both signals have parameters to be verified:

- Maximum leakage current. (100 µA)
- Current sinking capability for low state voltage. (48 mA, <0,6 V)

In event of power loss, PSU shall provide power under full load for required time for the rest of the system. ACFAIL and SYSRESET signals and output voltages timing are specified [3,17-18] and reprinted here in figures 6, 7 and 8.

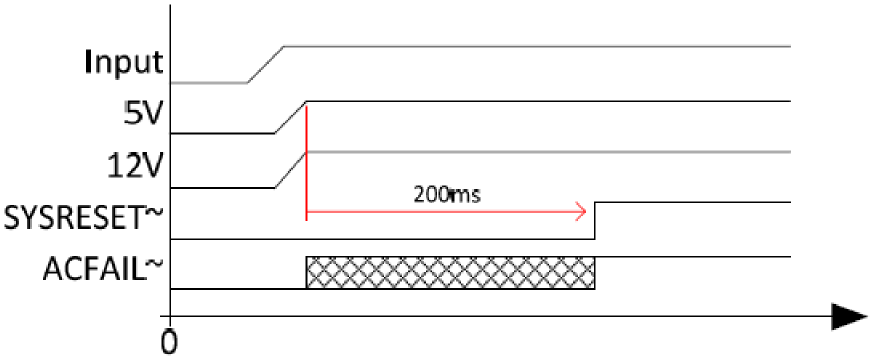


Figure 6. Startup timing [3,17].

PSU shall keep the system in reset state until 5 V is within specified limits and 200 ms time has passed, as presented in figure 6. Once activated, SYSRESET must remain active for specified time.

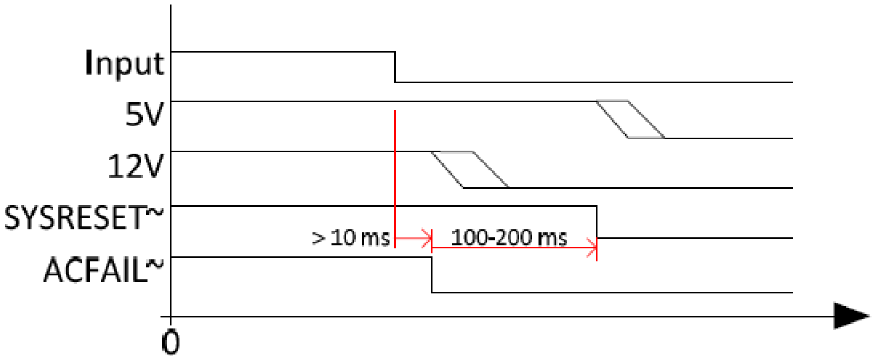


Figure 7. Shutdown timing [3,17].

Power loss at input side activates ACFAIL signal after 10 ms as shown in figure 7. Power is supplied for 5 V power rail for minimum of 100 ms until reset signal is activated or power is out. However, short interruptions should not cause deviation from normal operation as illustrated in figure 8.

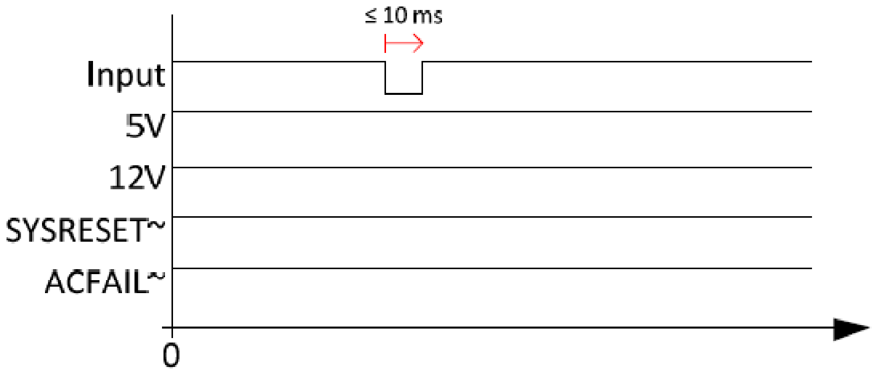


Figure 8. Short interrupt timing [3,17].

3 Testing Environment

3.1 Starting Setup Overview

As a baseline for automated test system, setup created by EKE-Electronics sub-contractor was used. During major development project this setup, based on programmable measurement devices and configurable software controlling them, was used to automate some of the preliminary testing. Following completion of the project, the setup as presented in tester documentation and reprinted in figure 9, is being used as a starting point for further developing and configuring automated testing procedures for EKE's processes and products.

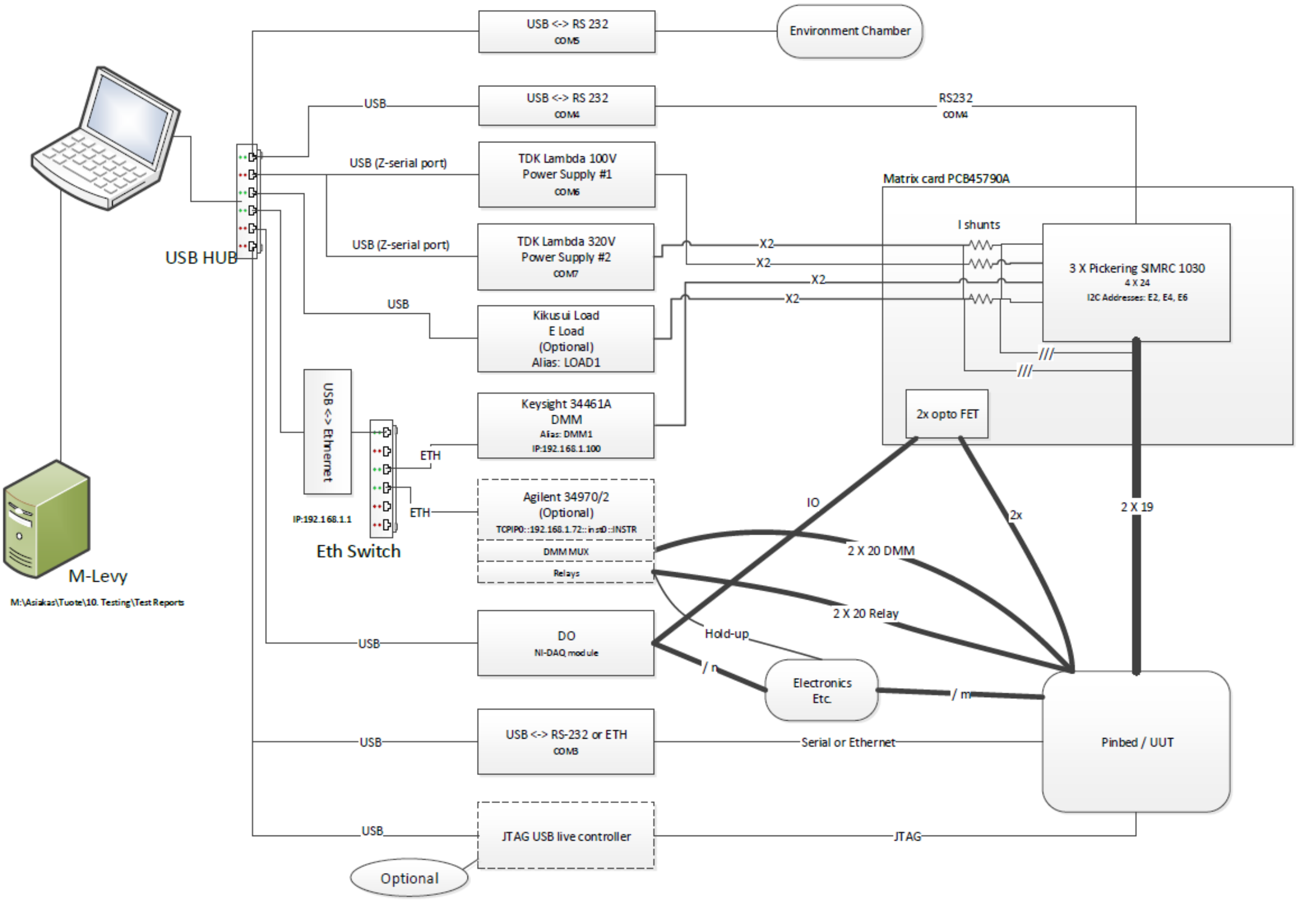


Figure 9. Overview of automated testing setup baseline [9,6].

Software developed for the test system is based on National Instruments Teststand, Labview and some additional code written with python. It is designed to be very generic, widely configurable test sequence. Since hardware interface and measured parameters are identical for all PSUs, test sequence is closer to a production tester by nature. It may be justified to rewrite test sequence program and configuration with specific software for PSU testing, while utilizing some of the lower level drivers developed already.

The signal switching matrix board developed for the test setup is based on Pickering SIMRC cards, that have 100 V and 1 A input limits specified. While these are adequate numbers for most measurements needed for other products, for power supply measurements they are not, as voltages and currents associated with PSUs are in many cases above these limits. While the digital multimeter (DMM) normally routed with the switching matrix could be utilized, this may be unnecessary as HP 34970 with 34901A module extensions will provide DMM function and signal routing withstanding voltages up to 300 V [8,21]. Using one data acquisition device to route test points to generator sensing inputs and to perform DMM measurements at rapid pace, simplifies and reduces number of devices and amount of code to control them. However, current limit of 1 A renders also this device unsuitable for creating tester input or output switching matrix. 34907A module provides digital outputs to control relays and FETs for switching circuitry. Analog outputs of the module could be used to analog program electronic loads or other voltage referenced circuits.

As discovered in chapter 2.3.2, tester power supply is required to output minimum 10 A of continuous current. Both TDK bench power supplies (Z+ 100-2 and Z+ 320-2) provided with the test setup are limited to 2 A output [5,16; 6,24]. Therefore, HP 6030A will be used as the main unit as it is programmable and able to deliver maximum 17 A of current, 200 V and over kW of power [7,17].

Remotely programmable TEMI880 controller-based weather chamber will be used over serial communication port. Both programmable PSU and the weather chamber are missing working Labview drivers and they must be developed using visa drivers.

3.2 DUT Input Side Test Setup

3.2.1 Voltage Fluctuations

Examining power supply specifications reveal [5,16; 6,24; 7,17], that none of the units have programming time response rapid enough for voltage changes to meet the 10 ms rise and fall times determined in chapter 2.3.2. Instead of searching for specialized equipment, extra circuitry shall be developed for tester output to control voltages presented for the device under test (DUT).

Switching between two preset potentials by two power supplies, as presented in figure 10, the time it takes for a voltage supply to reprogram will be eliminated and rise / fall times become a question of regulation capabilities of load changes. Hence, TDK Lambda units are required still for fluctuation test, when switching between potential levels. Depending on current sinking capabilities of the power supplies, extra voltage regulating parallel load may have to be developed to discharge DUT to reach required fall times. Performance of the setup shall be determined with testing.

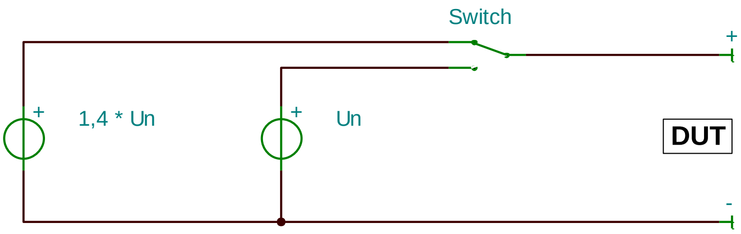


Figure 10. Voltage fluctuations circuit

3.2.2 Supply Interruption and Change-Over

For supply interruption and change-over tests, one series and one parallel switch are required for tester output to present both open and short circuit condition for DUT as shown in figure 11. Switch one will disconnect supply from input terminal of DUT and switch two will short circuit terminals to discharge DUT.

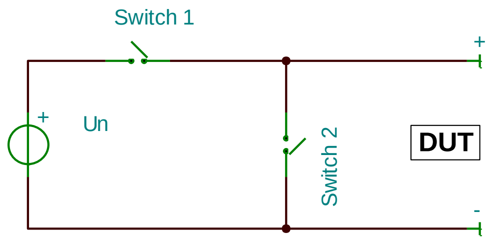


Figure 11. Supply interruption and change-over circuit

To complete tester output circuitry to include reverse polarity withstand test capability, double switch as presented in figure 12, shall be included.

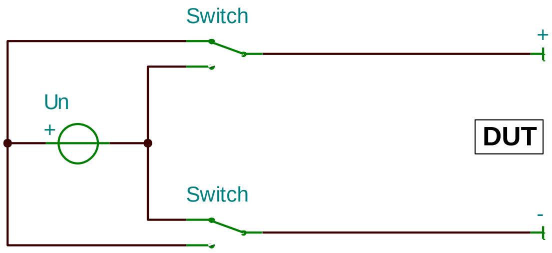


Figure 12. Reverse polarity circuit

To combine all functionality into one circuit design, tester output switches and measurement points are summed into the figure 13. Vsense+ and Vsense- represent voltage test points that shall be routed with relay-controlled signal paths to sensing input of the power supplies, to compensate for the voltage losses presented by the switching circuit.

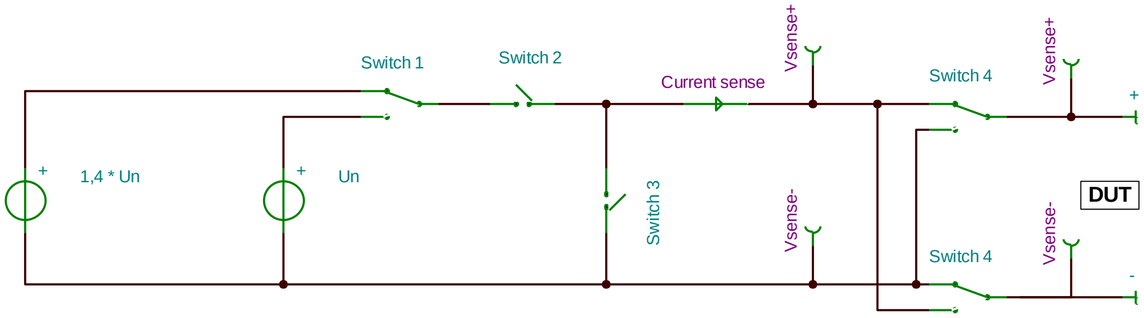


Figure 13. Tester power supply circuit

3.2.3 Ripple Voltages and Inrush Currents

To expose DUT for input ripple voltages discussed in chapter 2.3.2, switching circuit shown in figure 13 could be utilized to perform rapid switching between two power supplies. This method would require fast switching logic, while HP 34907A digital outputs may be written only 95 times per second [8,25]. Also, again current sourcing/sinking capabilities of the ripple voltage generating system may become a limiting factor, depending on the amount of input capacitance of the DUT and the frequency of the ripple voltages, as will be shown next. It is common knowledge that current is defined as

$$I = \frac{Q}{t}\,, \tag{6}$$

more specifically one ampere is one coulomb per second. It represents a rate that charge is flowing. Total charge then can be calculated integrating function of current over specified time.

$$Q = \int_0^t I(t)\,dt + q(0) \tag{7}$$

$$Q = CV \tag{8}$$

$$CV = \int_0^t I(t)\,dt + q(0) \tag{9}$$

Combining definition of charge and function of capacitor charge / voltage relationship, we arrive at function representing current flowing through capacitor that is the filter capacitor of the device under test.

$$C\frac{dV}{dt} = I(t),\ where\ V = Un + 0.05 * Un * \sin(\omega t) \tag{10}$$

Rate of change of voltage is the derivative of the sum of nominal DC voltage and a function of ripple voltage imposed at the input terminal of DUT.

$$C * 0.05 * Un * \omega * \cos(\omega t) = I(t),\ where\ \omega = 2 * \pi * f \tag{11}$$

It has already been established here that the higher the amount of capacitance and the higher the frequency, the higher the amount of current will be flowing. Using ripple frequency of 1 kHz along with 110 V nominal voltage limits as specified earlier and assuming 1 mF of input capacitance, function of current can be plotted with the resulting function as drawn in figure 14.

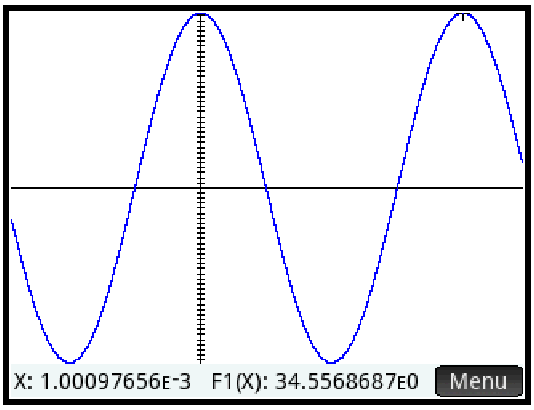


Figure 14. Function of ripple current.

Results show that peak ripple currents approach 35 A, which is more than the test setup power supplies can provide. To avoid tester power supply output capacitance contributing to ripple currents, special circuitry is required to isolate it from DUT inputs. Inductance from isolation inductor combined with class B amplifier and a function generator, as demonstrated in figure 15, could be a solution. Since input capacitance of power supply units to be measured are unknown, performance of the setup shall be tested with full range of products to determine if specified ripple voltages can be forced upon input voltages.

Measuring both input and output ripple voltages along with input inrush currents, require high sampling speed from measurement device. Oscilloscope programmable by Labview, with either magnetic field current probe or differential probe measuring voltage drop over small shunt resistor, appears as an obvious first choice. Also, output load transient response requires high speed sampling that oscilloscope can provide along with waveform pictures. As discovered in figure 5, occurring events at microsecond level are of interest here. Should the smallest period for signal function of interest be a microsecond, practically any modern oscilloscope will have the required bandwidth and sample rate.

$$f = \frac{1}{T},\ T = 10^{-6}s\ \Rightarrow\ \frac{1}{10^{-6}s} = \frac{10^{6}}{s} = 1MHz \qquad (12)$$

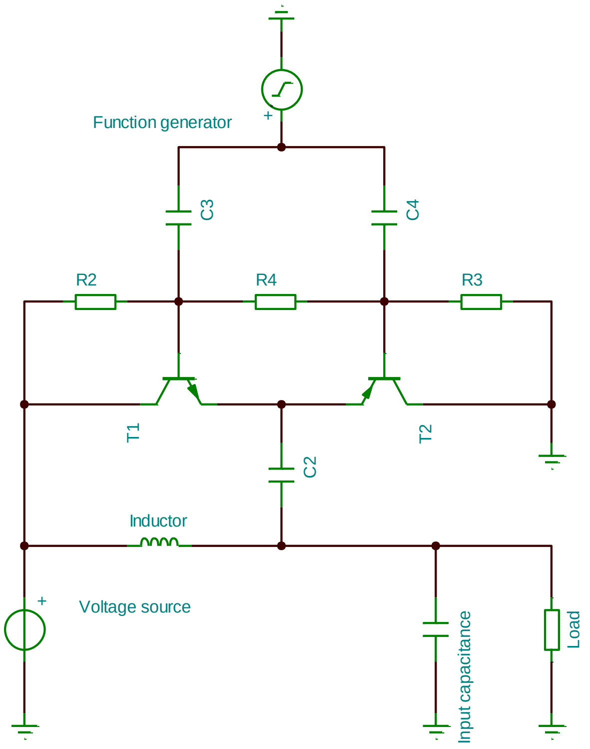


Figure 15. Ripple voltage generator circuit

3.3 DUT Output Side Test Setup

On the output side of the PSU under test, remotely programmable electronic load capable of handling the currents and power output by the DUT, is required. In EKE systems, 5 V supply is the main power source and requires a load capable of handling currents above 13 A. HP 6060B being available and suitable with 300 W power and 60 A current capabilities, will be used as the main load for the power supply under test. When stressing the power supply with maximum load, for 12 V line simple power resistor rated for >1.25 A and >15 W, may be enough.

To test SYSRESET and ACFAIL signal parameters and functionality, source of 2.4 V – 6 V capable of delivering 48 mA * 2 is required as shown in figure 16. Leakage current, low state sink current and signal functionality can be derived by connecting DMM to measure voltage drop over the current limiting resistor.

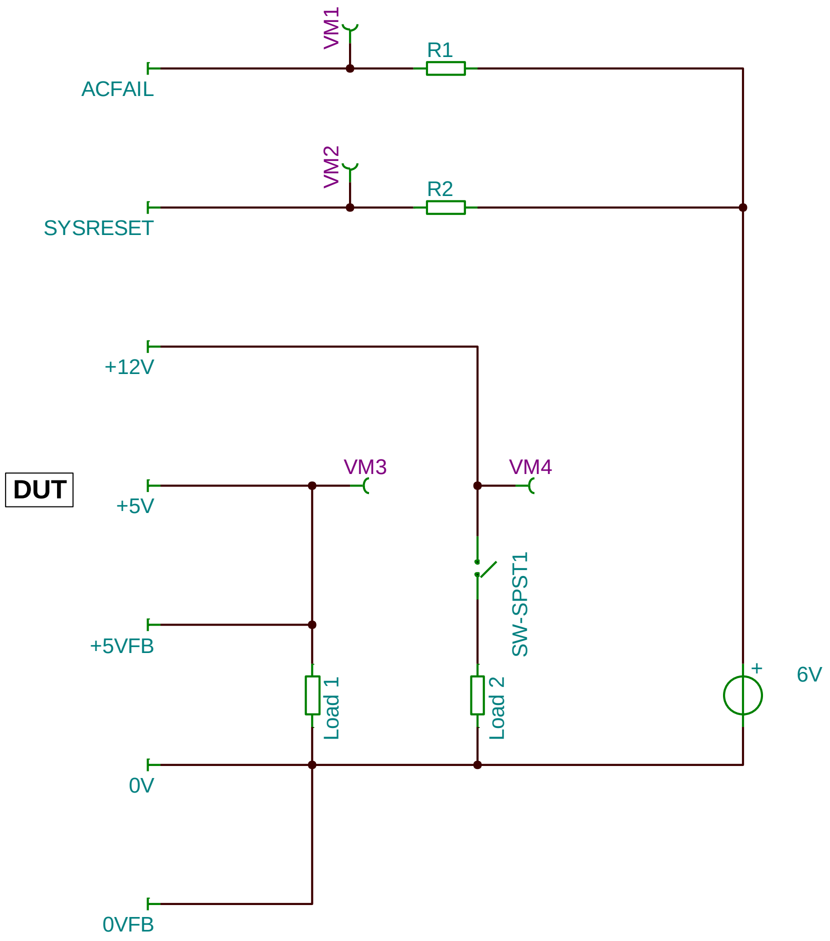


Figure 16. DUT output side tester circuit

VM pins drawn in figure 16 represent voltage measurement points, that will be measured using HP data acquisition unit or oscilloscope. Either differential probe or two standard probes are required to carry out measurements with oscilloscope, since current return line is isolated from protective earth PE. As with standard probes measurements are performed against PE, two probes should be used to measure 0 V and V+ potentials in relation to PE to derive difference between them. With unknown circuit, forcing 0 V signal return to PE by connecting probe earth to it, could produce unwanted results.

To summarize then, equipment required for automated power supply measurement system that exists in the current test setup are:

- TDK Lambda Z+ power supplies
- HP 34970 data acquisition unit with 901A and 907A extension modules
- TEMI880 controlled weather chamber
- USB hub
- USB to ethernet adapter

Additional equipment used to complete test setup:

- HP 6030A power supply
- Tektronix MDO4104C oscilloscope
- HP 6060B programmable electronic load
- Relays and electrically controlled switches for switching circuitry
- Power resistor

Additional equipment possibly needed:

- Ripple voltage amplifier and function generator
- Voltage referenced current sinking circuit for voltage fluctuations setup

4 Automating Testing Procedures for Power Supply Unit

4.1 Testing System Modifications and Hardware Setup

4.1.1 Test Setup Interface and Connectors

As established in the last chapter, some special switching circuitry along with multiple measurement devices are required to fully automate PSU testing sequence. However, the devices needed for the project will not be devoted for forever serving only PSU testing. Considering plans to expand test setup to cover other products as well, it is important to determine how to standardize the test setup configuration. Connecting the measurement devices and setting up the test sequence should be easy enough to avoid hazardous improper configurations. Interface must be developed to connect the test equipment and the device under test, along with some preliminary standardization of cable signal routing. Device with connectors for required equipment and switching circuitry embedded, will form the interface together with specialized software.

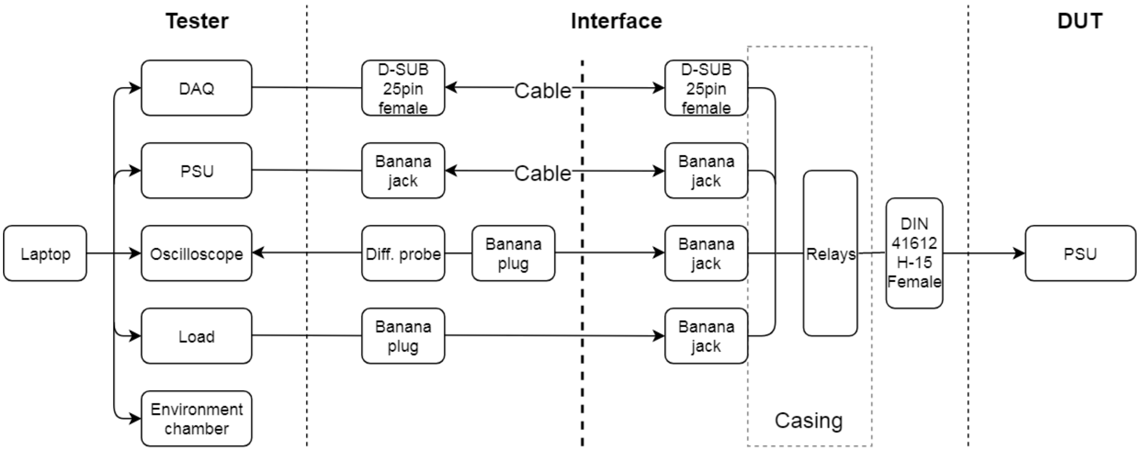


Figure 17. PSU test setup interfacing overview

Overview of the system is presented in figure 17, where interface connecting the portable tester setup and the PSU to be tested is described. Standard EKE systems rack will be used without backplane installed, exposing PSU connector for DIN41612 type H-15 terminated cable connecting the PSU to the interface. This way PSU module will be securely installed into environment chamber without exposing the interface to extreme conditions. The PSU connector and pinout configuration reprinted here in figure 18 and table 3, are the same for all EKE power supplies except for the next generation products [4]. Making interface connector cable detachable also from interface end, adapter cable may be built for the future PSU products. However, this feature will be left for future revisions of the interface. For the prototype developed in this project, cable will be hard-wired.

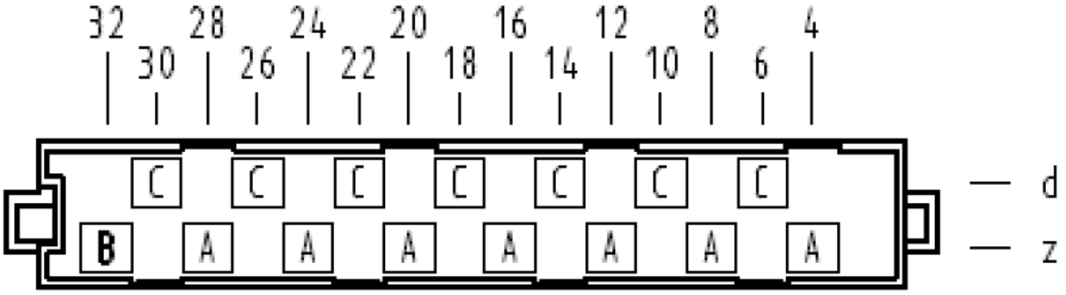


Figure 18. PSU connector pinout [3,10].

Table 3. Pinout table of PSU connector [3,10].

Pin number	Signal	Description
z4	+5VFB (sense)	+5V output feedback signal
d6	0VFB (sense)	Output return feedback signal
z8	+5V	+5V output
d10	0V	Output return
z12	+5V	+5V output
d14	0V	Output return
z16	SYSRESET~	System reset, active low
d18	Not connected	No internal connection
z20	+12V	+12V output
d22	0V	Output return
z24	ACFAIL~	Supply input failure, active low
d26	Not connected	No internal connection
z28	+VIN	Supply input, positive
d30	0VIN	Supply input return
z32	PE	Protective earth

Added resistance by the power cables should be taken into an account, as currents are relatively high and power dissipation becomes a significant loss. Let us assume cable length of 2 meters from the interface to the DUT, made of wires with 0.5mm^2 cross-sectional surface area made of aluminum. Resistance for the cable is calculated by dividing the product of cable material electrical resistance and cable length with the cross-sectional surface area [17,82].

$$R = \frac{\rho l}{A} \tag{13}$$

Electrical resistance for aluminum being $2.655 * 10^{-8}\Omega m$ [17,86], resulting cable resistance is 0.106Ω. As data gathered in appendix 1 shows, 5 V output wire may have to carry 16 A of current with PSR units. Applying Ohm’s law, voltage drop of 1.7 V and 27 W power dissipation over the length of the wire can be expected. If not compensated, royal measurement errors will be introduced. By increasing wire size to 0.75mm^2 and changing material to copper ($\rho = 1.678 * 10^{-8}\Omega m$), resistance reduces to 0.045Ω and dissipation to 11 W. Increasing number of conductors to increase total cross-sectional surface area will further assist with reducing losses.

Another compensation method is to wire tester power supply sensing wires to input terminals of the DUT. Voltage drop over input wires will be compensated, providing correct voltage for the tested PSU. DUT output voltages should be measured from the same test point as the feedback signal provided for it. Regulating output current with the electronic load and measuring output voltages at the output terminal of the DUT with high impedance input DMM, correct output power may be calculated.

Power equipment and differential probe are connected using banana connectors. Signal routing with DAQ for DMM and oscilloscope measurements will be arranged using D-SUB 25-pin 2-row connectors and twisted pair flat cables, as also used with the matrix signal routing board. Signals carried over flat cable will be arranged with DAQ multiplexer channel high and low wire forming a twisted pair. For digital out transmission, each bit should be paired with current return path as well. Standard interfacing pinout should be arranged for DAQ modules for ease of use with between testing setups. As the connector consists of 13 and 12-pin rows, first 13 numbers shall be assigned for the 13-pin row and following 12 pins are assigned with numbers 14 to 25. Adjacent cables forming a twisted pair in the flat cable, when installed to the connector, use overlapping pins from each row. Then pinout will be arranged as presented in table 4.

Table 4. DAQ interface pinout

Pin number	34901A con. 1	34901A con. 2	34907A con. 1 (port 1)	34907A con. 2 (port 2)
1, 14	Ch. 1	Ch. 11	Bit 0	Bit 0
2, 15	Ch. 2	Ch. 12	Bit 1	Bit 1
3, 16	Ch. 3	Ch. 13	Bit 2	Bit 2
4, 17	Ch. 4	Ch. 14	Bit 3	Bit 3
5, 18	Ch. 5	Ch. 15	Bit 4	Bit 4
6, 19	Ch. 6	Ch. 16	Bit 5	Bit 5
7, 20	Ch. 7	Ch. 17	Bit 6	Bit 6
8, 21	Ch. 8	Ch. 18	Bit 7	Bit 7
9, 22	Ch. 9	Ch. 19	Ch. 4 DAC	Totalize in
10, 23	Ch. 10	Ch. 20	Ch. 5 DAC	Totalize gate
11, 24	Common, source	Common, sense	-	-
12, 25	Ch. 21 (Current)	Ch. 22 (Current)	-	-

As drawn and summarized in interface circuit schematic in appendix 2, multiplexer channels one to six will be wired to route measurement points to the DAQ unit's internal DMM. Oscilloscope differential probe leads will be connected to the common channel, allowing both DMM and oscilloscope measurements at any given time of selected measurement point. Digital out bits zero to seven will be used to control MOSFETs and to command microprocessor controlling input relays.

4.1.2 Interface Circuit Design

Circuit designed for tester interface is presented in appendix 2, listing also major dissipation sources and signal routing. In this chapter, more detailed description of design decisions is presented. The circuit itself became more complicated than initially expected with addition of a microcontroller to handle time critical execution of the test sequence on hardware level. Timing in real time with Labview in windows environment turned out to be too slow in preliminary testing. DUT power feeding circuit is presented in figure 19.

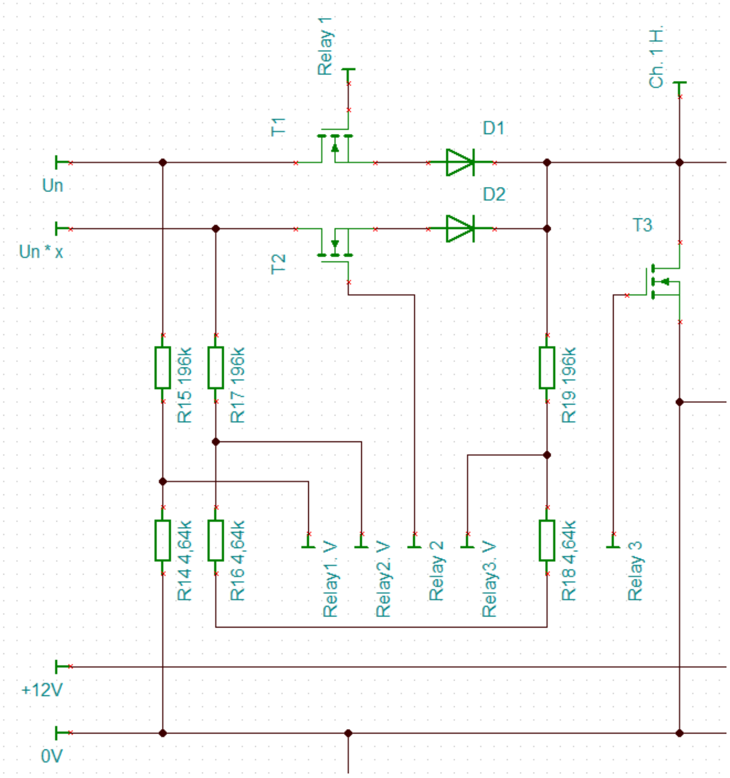
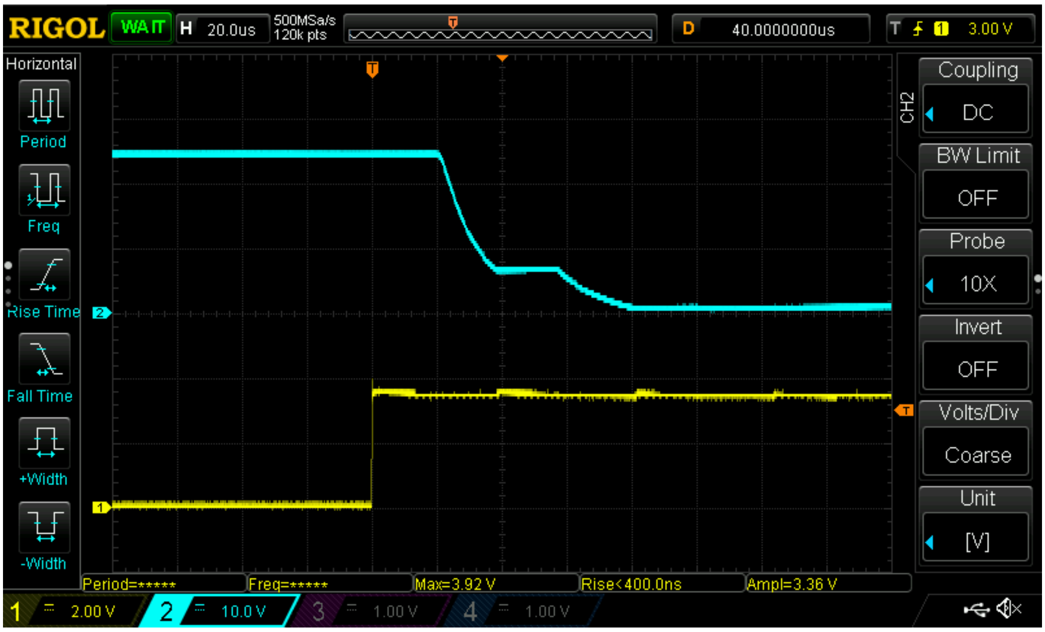


Figure 19. Interface power switching circuit

Interface itself requires a power supply of 12 V for digital communication, MOSFET and relay switching. Lower voltages would narrow selection of relays with the DC power handling capabilities required, to a few available in stock. For the same power, lower voltage means higher current and therefore higher power dissipation over resistive elements.

$$P = UI = RI^2 \tag{14}$$

MOSFETs T1, T2 and T3 are Crydom D2D12 solid state relays specified for 200 V and 12 A continuous current [16,1]. Personal previous experience with these devices have shown them to be very convenient for this task. They may be operated with logic level drive voltage producing very clean and consistent relay switching. Optical isolation of drive circuit from the switched circuit enables the device to be used in series with high voltage circuit, without a need for high driving voltage. Compromise is the relatively slow switching speed compared to normal MOSFET. In figure 20 delay can be observed between drive voltage (channel one) and main bus to be pulled to zero potential (channel two), when using the relay as parallel switch.

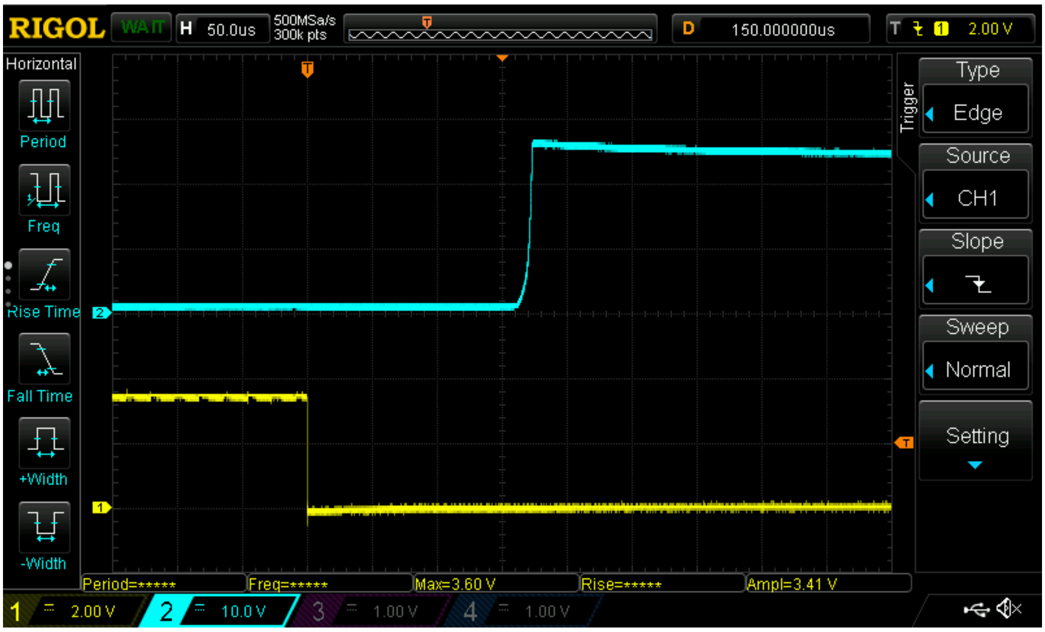


H 20.0us
500MSa/s
120k pts
D 40.0000000us
T 1 3.00 V
Coupling DC
BW Limit OFF
Probe 10X
Invert OFF
Volts/Div Coarse
Unit [V]
Period=*****
Freq=*****
Max=3.92 V
Rise<400.0ns
Ampl=3.36 V
1 2.00 V
2 10.0 V
3 1.00 V
4 1.00 V

Figure 20. Crydom D4D12 turn on delay with 24 V and 56Ω load resistor.

It seems as if the device turns on in two stages, as short plateau observed in voltage falling edge is about the same duration as the initial delay from trigger signal before voltage starts to drop. As the initial delay can be compensated with accurate timing and does not count for the fall time specified in the standard, voltage reaches near zero level in approximately 60 µs. Time it takes for D4D12 to turn off as driving voltage is removed, is significantly longer with approximately 160 µs delay, as observed with another measurement presented in figure 21. However, rise time for the bus voltage is very short and the initial delay may be compensated with designing timing.

Both turn on and turn off delays were very consistent when measured and are therefore highly predictable and can be considered when programming the microcontroller timing. Relays T1, T2 and T3 triggering circuits are connected to microcontroller pins D8, D9 and D10 respectfully.



Type Edge
Source CH1
Slope
Sweep Normal
Period=*****
Freq=*****
Max=3.60 V
Rise=*****
Ampl=3.41 V

Figure 21. Crydom D4D12 turn off delay with 24 V and 56Ω load resistor.

Diodes D1 and D2 are required to prevent current flowing in the wrong direction during voltage fluctuations, as D2D12 have reverse diode in parallel with the output stage [16,2]. Important parameters here are DC blocking voltage and continuous forward current limits. Low reverse leakage current is beneficial but not crucial for PSU leakage current measurements, as diode leakage can be measured and compensated.

Resistors R14 – R19 form voltage divider for ADC input of the microcontroller. Future development of the tester hardware will include bus voltage rate of change monitoring for more precise relay switching. Attenuation is rated for 154 V maximum input voltage established in chapter 2.3.2 equation 2 and maximum microcontroller ADC input voltage of 3.6 V [15,109]. Resistor value tolerance is not important, as an absolute value is not of an interest here. For example,

$$\frac{R14}{R14+R15} * Un = \frac{4k64}{4k64+196k} * 154\,V = 3.56\,V. \tag{15}$$

Using Ohm’s law, current through the resistors is 768 μA and applying equation 14 will result of a 115 mW dissipation over resistor R15.

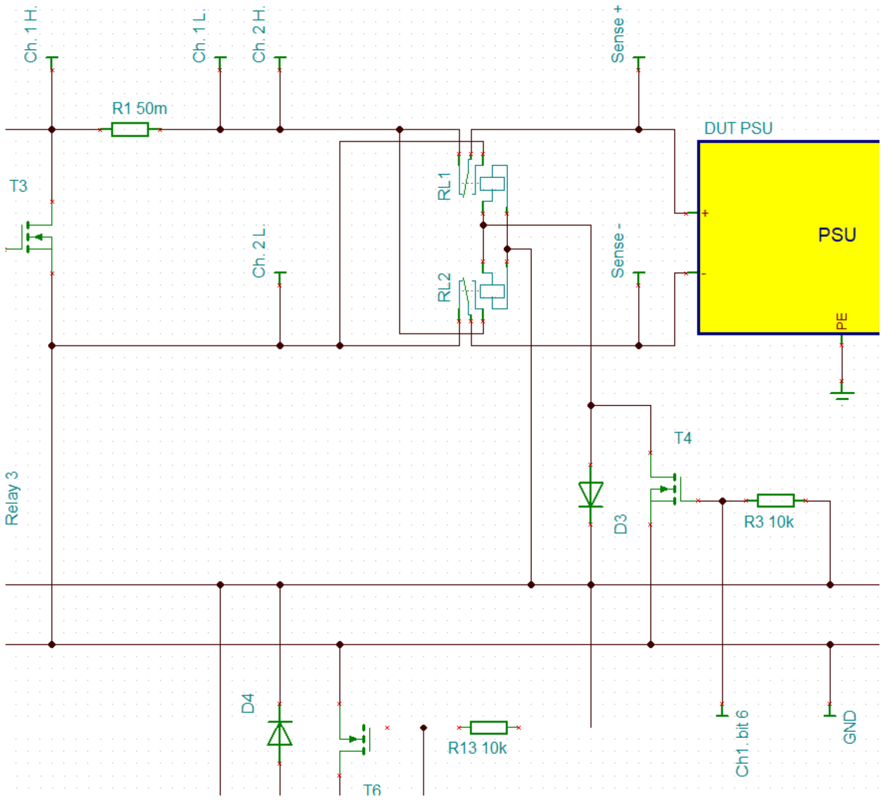


Figure 22. Reverse polarity switching circuit

In figure 22 circuit for inrush current and reverse polarity input voltage measurement is drawn. Current shunt resistor R1 of 50 mΩ is rated low resistance for low voltage drop and power dissipation. High inrush currents expected will produce measurable voltage high enough that should stand out of noise floor without extra filtering. For continuous input current of 7.5 A, estimated figure using equation 14 will be 2.8 W. Therefore, when choosing the shunt resistor, rated continuous power dissipation of 5 W was selected.

RL 1 and RL 2 are the same KUEP series relay, with contact arrangement of 2 form C non-latching type. Driving coil then will switch two contactors from one circuit position to another, connecting DUT input terminals to opposite polarity configuration when driven. Contactors are rated for 10 A maximum current depending on the voltage and 170 VDC [18,1]. Drive coil is specified to take 150 mA of current when driven with 12 V maximum operating voltage. Power dissipation with 80Ω coil resistance is 1.8 W and the relay is controlled by MOSFET T4, which in turn is controlled with DAQ DO channel 1 bit 6 by pulling drive voltage of 12 V down over resistor R3. Diode D3 is added to protect from overvoltage occurring when switching inductive load off.

Sense+ and sense- are the tester power supply sensing connections, compensating the voltage drops occurring over the switching circuit. As reverse polarity conditions are presented to these measurement points, signal routing relay is included in the circuit for reversing also sensing polarity for the power supplies, as is drawn in figure 23.

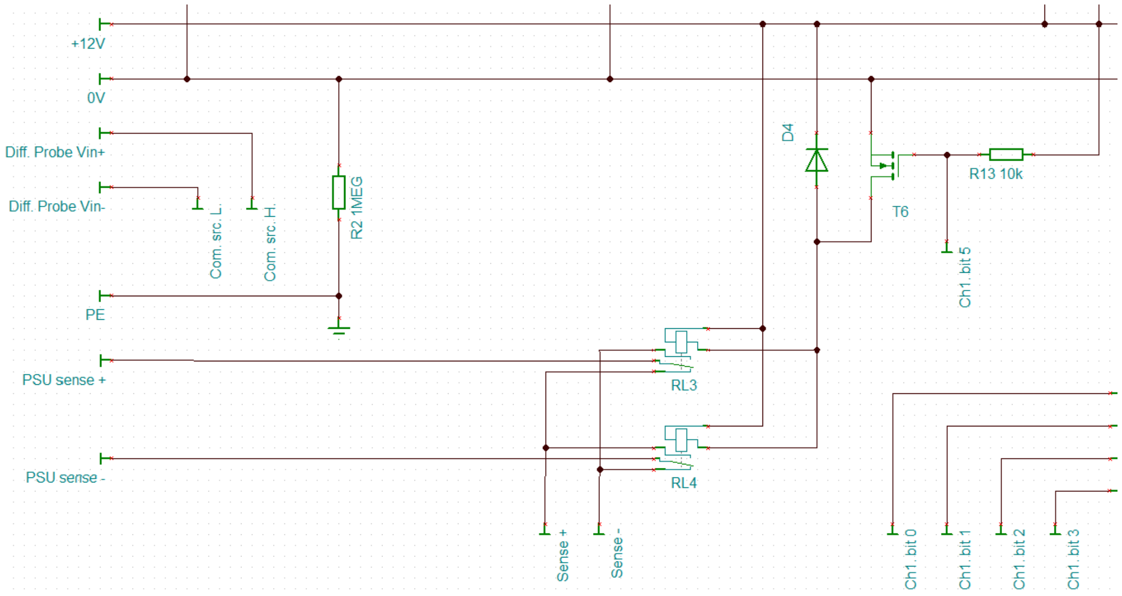


Figure 23. Sensing polarity switching circuit

Again RL 3 and RL 4 are the same relay with 2 form C non-latching contact arrangement. Here current ratings are not important, only high voltage switching capability is important and 12 V drive coil voltage rating. Drive coil is switched on with MOSFET T6 that is controlled with DAQ DO channel 1 bit 5 by pulling 12 V voltage down over resistor R13. Diode D4 is added to prevent overvoltage condition from occurring when switching inductive load off. Resistor R2 is clamping 0 V bus to protective earth to prevent circuit zero-volt level floating far from earth potential.

Previous experience with Nucleo-64 development boards led to decision to produce the time critical timing of the input switching relays with slave device microcontroller. Connection map for STM32F4 processor is presented in figure 24. Four GPIO ports D2, D4, D5 and D7 are connected to DAQ DIO bits for communication with the master device (Teststand software). Channel 1 bit 0 is the enable bit, initiating program execution, while bits one to three are program selection bits. Outputs D8, D9 and D10 control the input switching relays T1, T2 and T3. Port D12 outputs triggering signal for external devices like oscilloscope, timing the capture of waveforms to critical events of the running program. Pins tolerant of 5 V were chosen. ADC converter inputs A3, A4 and A5 monitor tester interface input voltages. Here the idea is to provide information for the microcontroller of the different voltages presented for voltage fluctuation test and the actual input voltage condition. By monitoring the rate of change of the voltage, relay T3 may be operated to sink current when attempting to drop voltage.

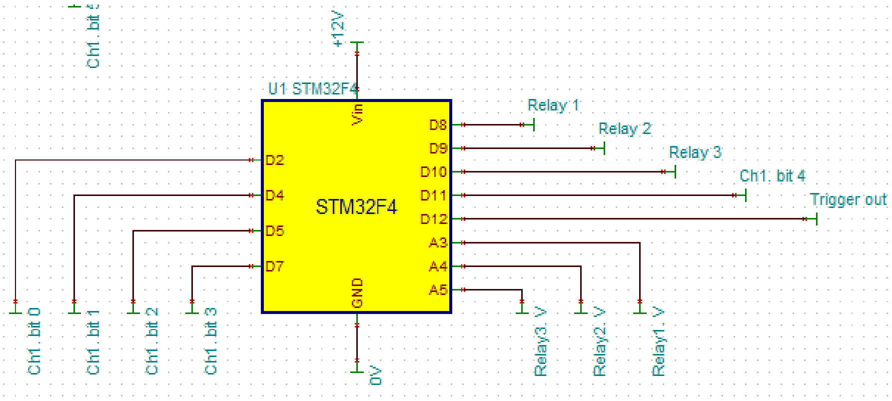


Figure 24. Microcontroller STM32F4 connections

Finally output of the PSU under test will be handled by circuitry presented in figure 25. +5 V outputs are connected straight to electronic load inputs with voltage measurement points routed to DAQ DMM. Clamping resistors R5, R11 and R12 will keep the output from floating far from earth potential and discharging any remaining charge in DUT output capacitors. 12 V output may be loaded with power resistor R4 controlled by MOSFET T5 or with external load by bypassing the loading circuit with banana connector.

Recalling parameters defined for ACFAIL and SYSRESET in chapter 2.3.3, 6 V potential is presented for these inputs with voltage divider resistor setup similarly derived as in equation 15. Resistance figures are derived from 48 mA current sinking requirements. Should the DUT pull the voltage down over resistors R6 and R8, 12 V voltage drop should occur with 48 mA currents flowing through these resistors. With Ohm’s law, resistance of 250Ω is calculated as the value for resistors R6 to R9. Then power dissipation using equation 14 results 576 mW for R6 and R8 and the resistors should be rated for preferably 1 W of dissipation. R7 and R9 are subjected to smaller 144 mW dissipation figures.

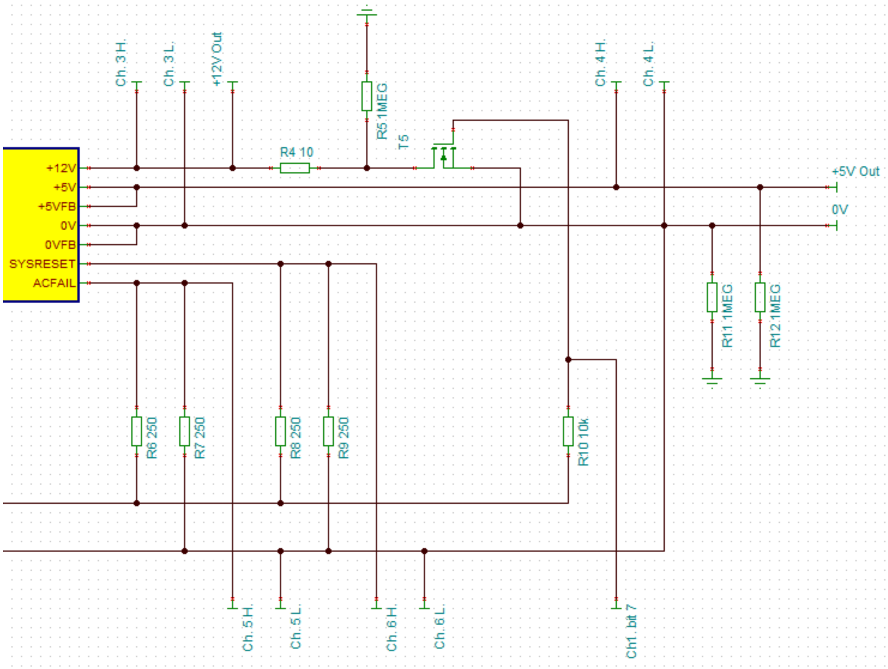


Figure 25. DUT output measurement circuit

Prototype of the tester interface was built using prototyping boards with no ready connections but plated through holes, by creating connections with wires and manual soldering work. Diodes D1 and D2 were provided with heat sink and high current routes were provided with thick copper wires. Picture of the prototype interface with DUT in the interface rack is presented in figure 26.

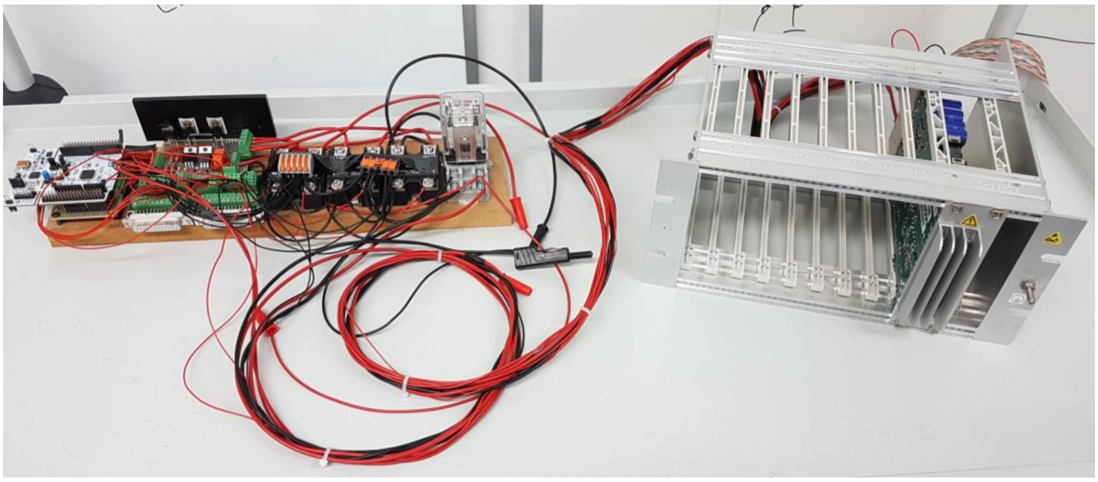


Figure 26. Prototype of the tester interface.

4.2 Testing System Software Modification

4.2.1 Microcontroller Programming

The STM32F4 microcontroller was programmed with C-language using MBED online compiler environment, using simple RTOS template as a starting point. Reason for creating operating system like program for the device is versatility and plans for expanding its functionality beyond simple logic switch. Functionality like remotely programming the device through serial interface for specialized purposes and implementing ADC thread performing measurements and providing continuous stream of data for other threads to take advantage of. For improved readability and expandability, the code was divided into several source and header files. Some debugging information is printed over serial link to terminal. Future plans for serial terminal functionality are to implement shell commands to customize program execution parameters.

After initialization, program establishes main thread, program execution thread and thread that monitors state of communication with the master device, running in parallel, communicating through global structure. Communication is initiated by master by enabling bit 0. When enable bit state change is detected, slave device reads bits one to three and writes program selection and execution commands for execution thread. Programs are listed in table 5.

Table 5. Microcontroller program selection

Bit 1	Bit 2	Bit 3	Program
0	0	0	Default program, all relays open
1	0	0	Relay 1 closed, relays 2 and 3 open
0	1	0	Relay 2 closed, relays 1 and 3 open
1	1	0	Relay 3 closed, relays 1 and 2 open
0	0	1	Inrush current test, relay 1
1	0	1	Voltage fluctuation test, relay 1 to relay 2, 100ms
0	1	1	Supply interruption test, PSU 1 to 0V, low impedance, 10ms
1	1	1	Supply change-over, PSU 1 disconnect, 30ms

Execution code is written to compensate for relay turn on and turn off delays and writing triggering signal output on notable events. Inrush current program will open relays one and two, then closing relay three to discharge DUT input capacitors. It will then open relay three and initiate the measurement with relay one. Relay will then remain closed after sequence is completed. Last three programs will close relay one and open relays two and three to establish initial conditions as seen in listing 1. After sequence is completed, relay one will remain closed.

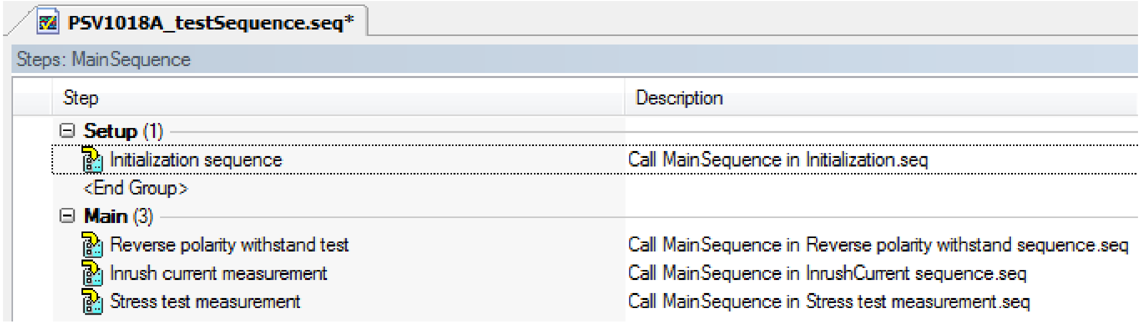
```
                case 7:                     //Low impedance interrupt 10ms
                    relayTwo = 0;
                    relayThree = 0;
                    relayOne = 1;           //Setup initial conditions
                    wait(0.5);              //Wait for DUT to stabilize
                    relayOne = 0;
                    wait(0.0001);           //Wait for relay 1 to turn off
                    relayThree = 1;
                    wait(0.00002);          //Wait for relay 3 to turn on
                    triggerOutput = 1;      //Trigger signal for external de-
vices
                    wait(0.0099);           //Wait 10ms - relay turn off time
+ 50us fall time
                    relayThree = 0;
                    wait(0.00013);          //Wait for relay three to turn off
                    relayOne = 1;
                    triggerOutput = 0;
                    program.completed = true;
                    break;
```

Listing 1. Example of microcontroller program execution code.

Once executed, thread handling the execution will flag the program completed. Microcontroller will then signal the master device with bit 4 to confirm task completed. Master device will then acknowledge by inactivating the enable bit, allowing slave device to start listen for another program call again.

4.2.2 Teststand and Labview Programming

Master device code designed to form the prototype for software architecture, is implemented using Teststand 2017 and Labview 2017 programs. It is at current state tailored for one specific PSU model using specific measurement devices. However, it is still exploring the functionality and the concepts of the planned multilayer structure. Currently, there are three layers to the software controlling the test setup. Highest level layer with the main sequence presented in figure 27 gives an overview of the progression and calls mainly other sequence files. With further development, another layer above the test sequence shall be implemented. User interface for configuring the main test sequence for selected tests, PSU model and measurement equipment.



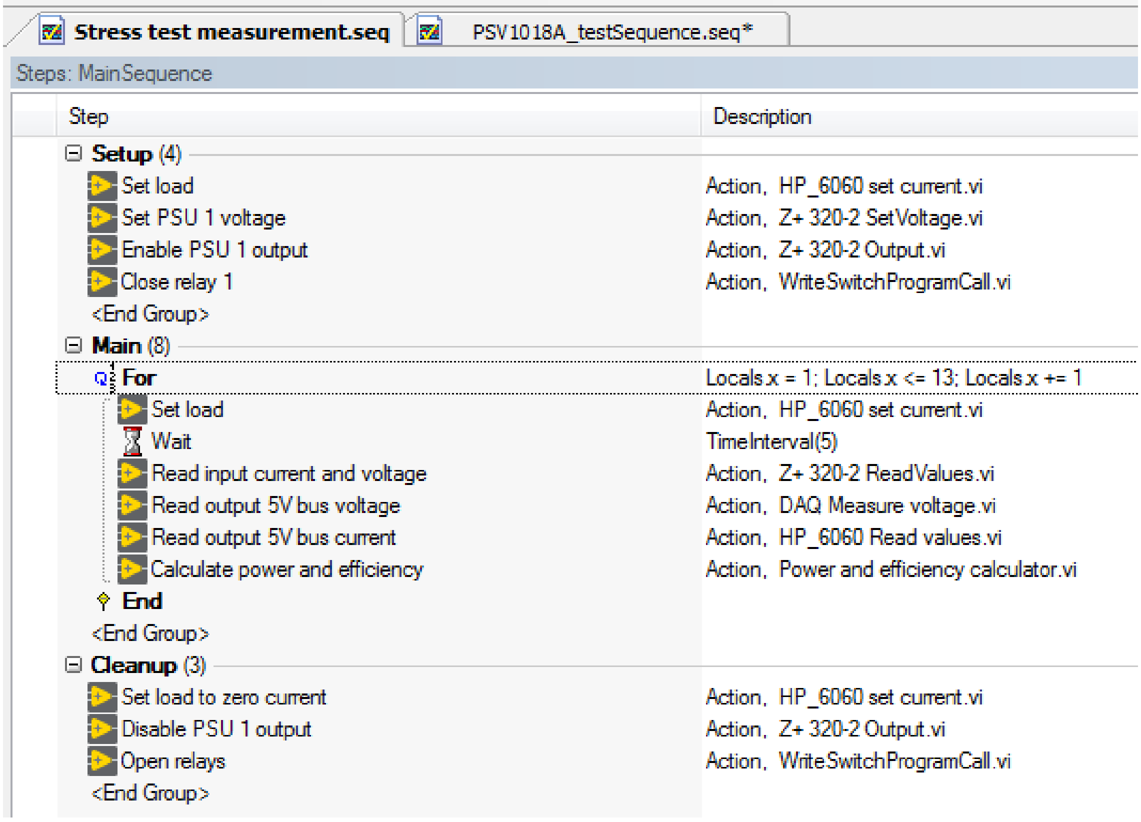
PSV1018A_testSequence.seq*

Steps: MainSequence

Step	Description
Setup (1)	
Initialization sequence	Call MainSequence in Initialization.seq
<End Group>	
Main (3)	
Reverse polarity withstand test	Call MainSequence in Reverse polarity withstand sequence.seq
Inrush current measurement	Call MainSequence in InrushCurrent sequence.seq
Stress test measurement	Call MainSequence in Stress test measurement.seq

Figure 27. Main sequence Teststand file.

The setup step of the main sequence calls initialization sub-sequence, which consists of action steps calling VIs that initialize measurement equipment to default state for the testing. Main step of the main sequence then calls sub-sequences that form the individual tests designed to test certain or several parameters of the DUT. One of the test sub-sequences is shown in the figure 28, where DUT input and output currents and voltages are measured, when subjected under heavy load.



Stress test measurement.seq

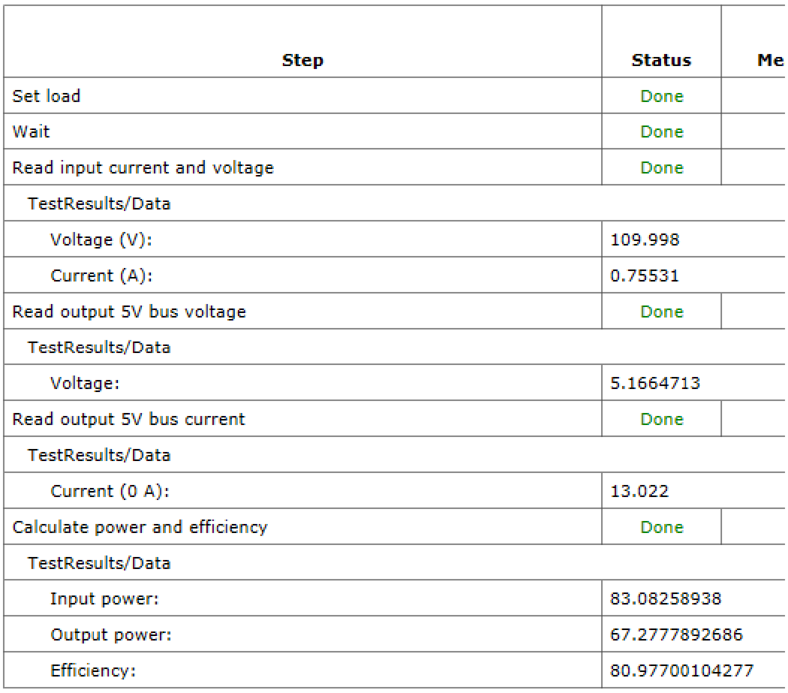
PSV1018A_testSequence.seq*

Steps: MainSequence

Step	Description
Setup (4)	
Set load	Action, HP_6060 set current.vi
Set PSU 1 voltage	Action, Z+ 320-2 SetVoltage.vi
Enable PSU 1 output	Action, Z+ 320-2 Output.vi
Close relay 1	Action, WriteSwitchProgramCall.vi
<End Group>	
Main (8)	
For	Locals.x = 1; Locals.x <= 13; Locals.x += 1
Set load	Action, HP_6060 set current.vi
Wait	TimeInterval(5)
Read input current and voltage	Action, Z+ 320-2 ReadValues.vi
Read output 5V bus voltage	Action, DAQ Measure voltage.vi
Read output 5V bus current	Action, HP_6060 Read values.vi
Calculate power and efficiency	Action, Power and efficiency calculator.vi
End	
<End Group>	
Cleanup (3)	
Set load to zero current	Action, HP_6060 set current.vi
Disable PSU 1 output	Action, Z+ 320-2 Output.vi
Open relays	Action, WriteSwitchProgramCall.vi
<End Group>	

Figure 28. Stress test sub-sequence file.

Each test sub-sequence includes setup and cleanup steps where equipment settings required for the measurement are set and later cleaned up. For the main step, array variables are declared for storing measurement data for each current step initiated by the for loop. The loop creates load conditions from 1 A to 13 A for the 5 V output bus. Each loop step, measurements are executed, and power and efficiency are calculated by calling VI designed for the task. Values are flagged to be logged and test report generated by Teststand will include the results as can be seen in figure 29. As values are stored to arrays, data may be with further code development sent to be written to a file and graphs may be drawn. Perhaps by using VI calling Excel functions writing data and graphs to an Excel sheet.



Step	Status	Me
Set load	Done	
Wait	Done	
Read input current and voltage	Done	
TestResults/Data		
Voltage (V):	109.998	
Current (A):	0.75531	
Read output 5V bus voltage	Done	
TestResults/Data		
Voltage:	5.1664713	
Read output 5V bus current	Done	
TestResults/Data		
Current (0 A):	13.022	
Calculate power and efficiency	Done	
TestResults/Data		
Input power:	83.08258938	
Output power:	67.2777892686	
Efficiency:	80.97700104277	

Figure 29. Automatically generated test report.

Lowest layer is the Labview VIs responsible for commanding the measurement equipment and performing data operations. In figure 30, code is presented of WriteSwitchProgramCall.vi used in the stress test sequence to operate the switching relays. At current state, resource and communication settings are hardcoded using constants and these will be replaced with input data from sequence configuration files.

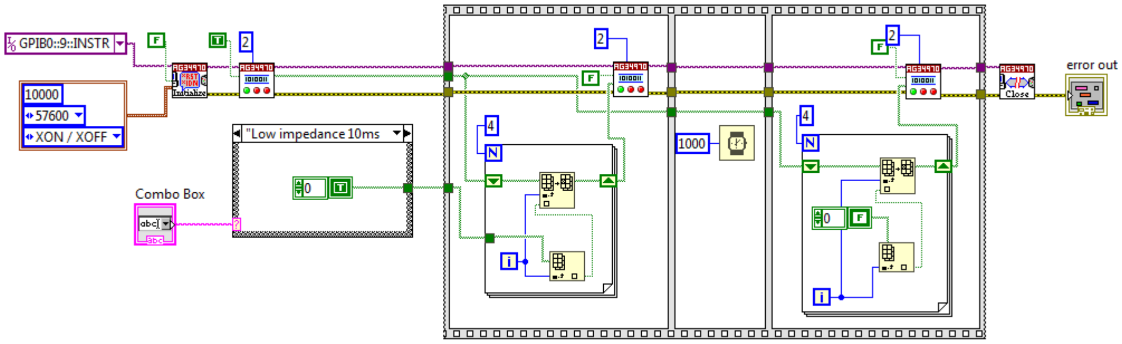


Figure 30. Labview VI file handling the low-level communication with the slave microcontroller.

Recalling the slave microcontroller communication protocol from chapter 4.2.1, Boolean arrays of data should be written to DAQ digital outputs. First, state of the digital out port is read and then bits related to microcontroller communication (bits 0 to 3) are replaced with new data and written to output. Program specific bits are developed from case structure, that is called by string commands written in sequence file VI calls.

In this project, VIs are written to do rather specific tasks for reusability in creating test sequences. For example, oscilloscope time base or channel configuration have separate files. DAQ switching operation and microcontroller communication have VIs of their own. Designing test sequence then is becoming increasingly faster as VI required for the step can be reused from earlier developed sequence steps. Continuing to develop the prototype software will show how dispersed or integrated should the functionality be for the best usability for expanding automated testing software beyond specific PSU testing.

5 Results and Discussion

While assembling the interface, no major problems were experienced, and the device performed near perfectly during the first test. Apart from few microcontroller pins wired incorrectly due to pin text misalignment, causing triggering signal not to trigger oscilloscope. Assessing with measurements, the performance of the technical solutions used in the interface are showing better than expected results. In figure 31 is presented the 10 ms supply interruption defined in chapter 2.3.2, measured with oscilloscope triggered by the microcontroller signaling. Channel one is the trigger signal and channel two is the main supply bus for DUT.

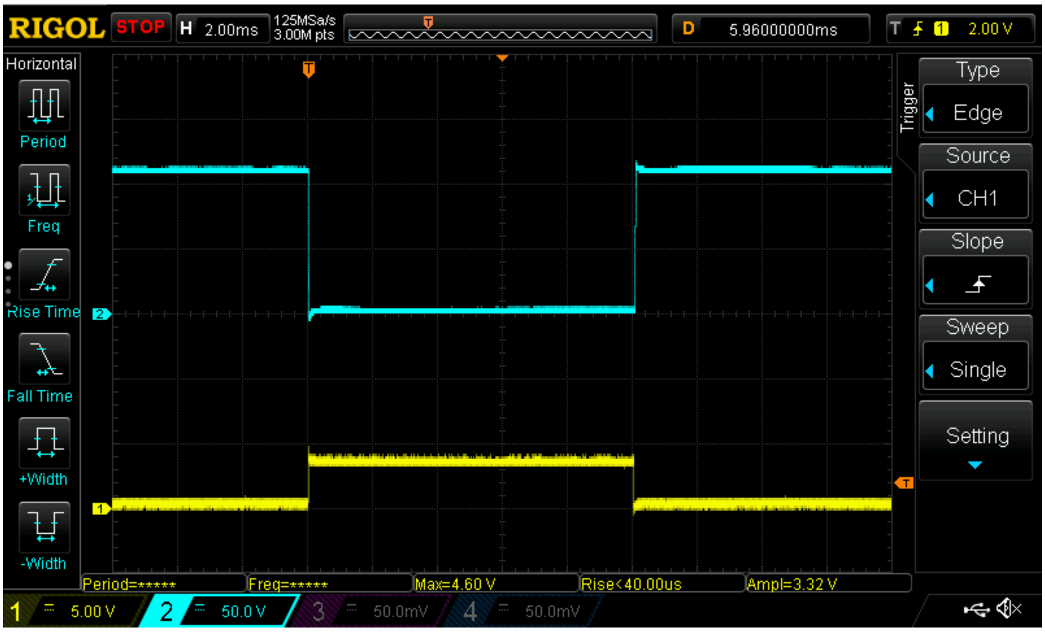
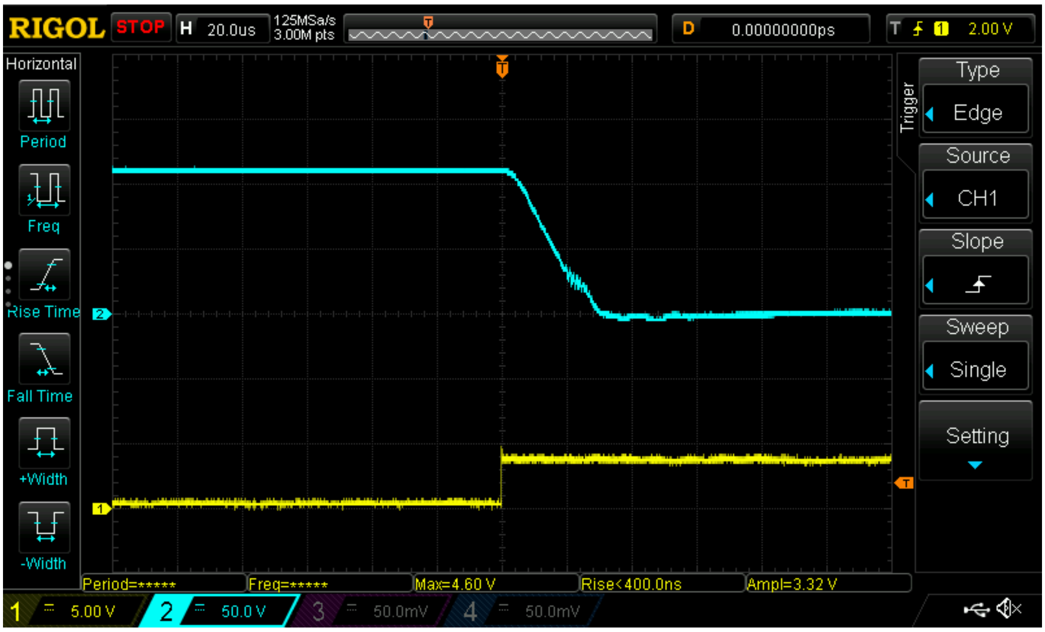


Figure 31. DUT input subjected to 10 ms supply interruption with interface switching circuit.

Duration of the break is exactly 10 ms and the dip itself is very clean without any ripple from bouncing contactors, as expected. When examining the edges in the µs scale as shown in figure 32, fall time of approximately 30µs is achieved which is well below 50µs specified in the standard EN 50155. This is better than expected performance considering preliminary component testing with similar D4D12 as discovered in chapter 4.1.2. Reason could be found in model differences or testing setup difference. D2D12 being lower voltage rated component could be in general faster or this sample might have performance favorable for the test, compared to the one used in preliminary testing.



H 20.0us 125MSa/s 3.00M pts

D 0.00000000ps

T 2.00 V

Type Edge

Source CH1

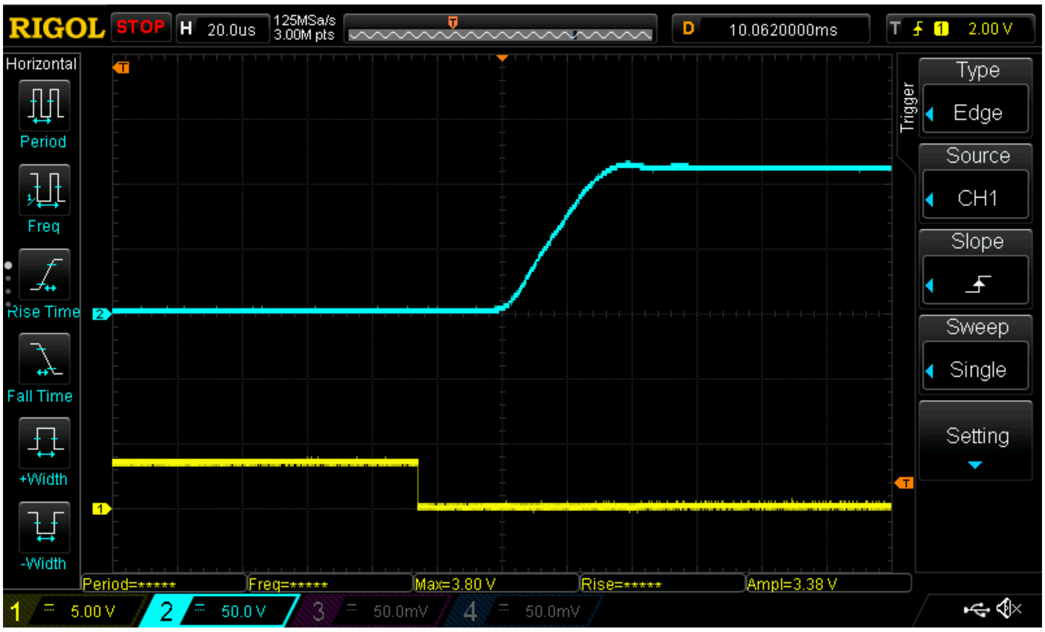
Sweep Single

Period=***** Freq=***** Max=4.60 V Rise<400.0ns Ampl=3.32 V

1 5.00 V 2 50.0 V 3 50.0mV 4 50.0mV

Figure 32. Supply interruption test voltage fall time of 30 µs was measured.

At 20 µs some ripple may be observed. This could be similar plateau developing as was seen in preliminary testing. Higher amount of charge to be conducted could lead to development of extra delay.



H 20.0us 125MSa/s 3.00M pts

D 10.0620000ms

T 2.00 V

Type Edge

Source CH1

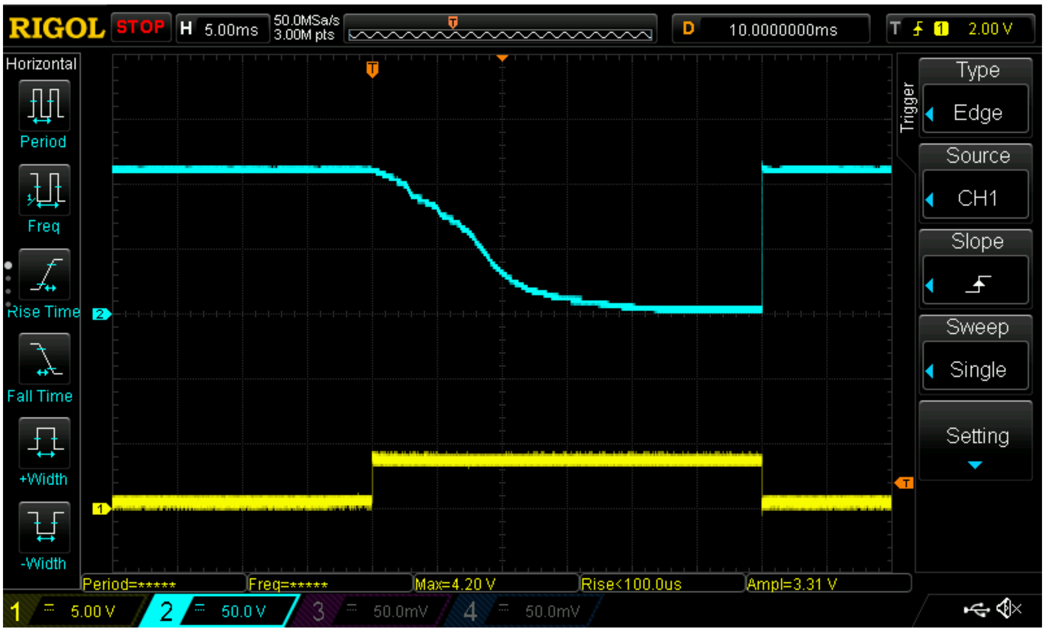
Sweep Single

Period=***** Freq=***** Max=3.80 V Rise=***** Ampl=3.38 V

1 5.00 V 2 50.0 V 3 50.0mV 4 50.0mV

Figure 33. Supply interruption test voltage rise time of 40 µs was measured.

As shown in figure 33, at the end of the voltage dip, rise time of 40µs was measured, again within the specified limits. Here three relay switching arrangement assists developing quick rise time figures. Since tester PSU output is first turned off with relay before discharging DUT input into zero potential, PSU providing the supply voltage is not in limiting mode and have full output capacitor charge to quickly bring the supply voltage up. Similar interruption but with high impedance condition is shown in figure 34. This test discovered in chapter 2.3.2 subjects the PSU under supply change-over conditions. Here relay is opened but the remaining charge is not forced to zero potential. Here it can be observed how DUT continues to consume current until voltage reach zero level. Flawless performance from the interface circuit.



H 5.00ms
50.0MSa/s
3.00M pts
D 10.0000000ms
T 1 2.00 V
Type: Edge
Source: CH1
Slope: rising
Sweep: Single
Period=*****
Freq=*****
Max=4.20 V
Rise<100.0us
Ampl=3.31 V
1 5.00 V
2 50.0 V
3 50.0mV
4 50.0mV

Figure 34. Supply change-over disconnection of 30 ms measured at DUT input.

Voltage fluctuations also discovered in chapter 2.3.2 were also tested and the result for voltage dip is presented in figure 35. Length of the dip is 100 ms plus the rise and fall times defined in the standard. Again, performance is within the specified limits. This is also better than expected performance, considering no active current sinking besides DUT itself, is implemented yet. Identical performance was achieved with fluctuation from nominal to 140% of nominal voltage test. During the power supply tests, DUT was subjected under no load. Should the load be heavy, input side rise times may suffer. That could be compensated with more powerful tester PSU.

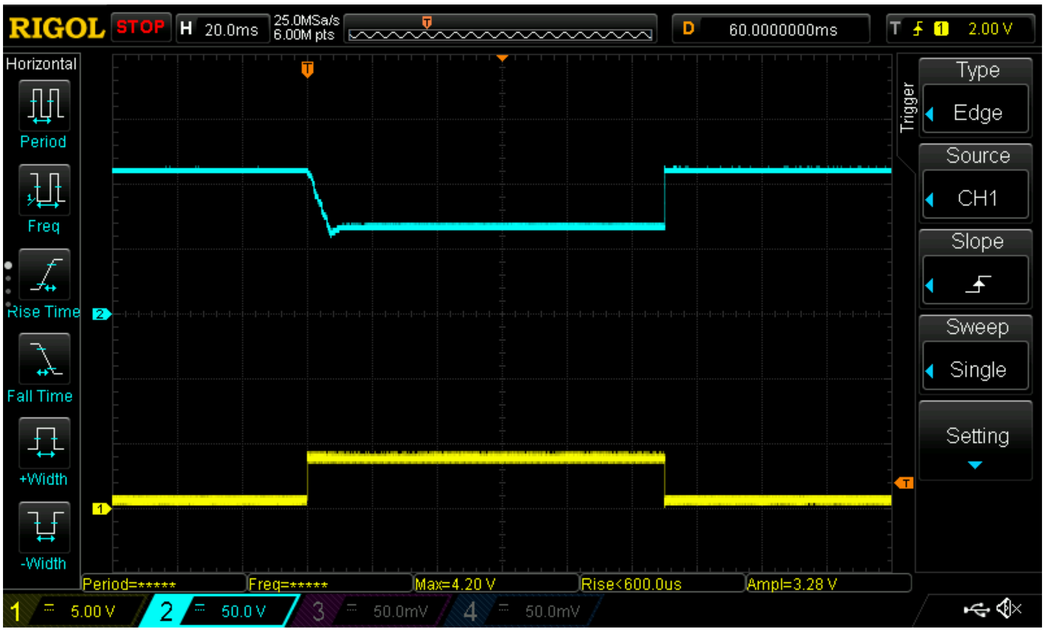


Figure 35. Voltage fluctuation test from nominal to 60% of the nominal voltage.

At current software development state, no pass/fail decision logic has yet been implemented, only recording of currents and voltages data. VI responsible for analyzing the DUT output parameters should be developed. For example, should the ACFAIL or SYSRESET signals drop below active threshold or 5 V bus deviate from specified limits during the power supply tests, by analyzing the recorded data pass/fail conditions could be formed. Also, VIs developed for controlling the oscilloscope for inrush current measurements, could be used to utilize oscilloscope to trigger on events signaled by switching microcontroller, capturing output waveform of interest.

For inrush current measurement shown in figure 36, oscilloscope was configured to trigger on signal output (channel 2) by the switching microcontroller. Differential probe then was connected to DAQ common channel as planned and test point was routed for the oscilloscope probes (channel 1). For compare, magnetic field current probe was attached to the main circuit power wire (channel 3). Here it became obvious what was established in chapter 3.1, that Lambda power supply used for the prototype testing here indeed became the limiting factor. Current limiting circuit actively working to keep the current to 2 A produces rather ripple filled waveform. Drivers for using the more powerful HP PSU will be developed and further study on this test should be conducted.

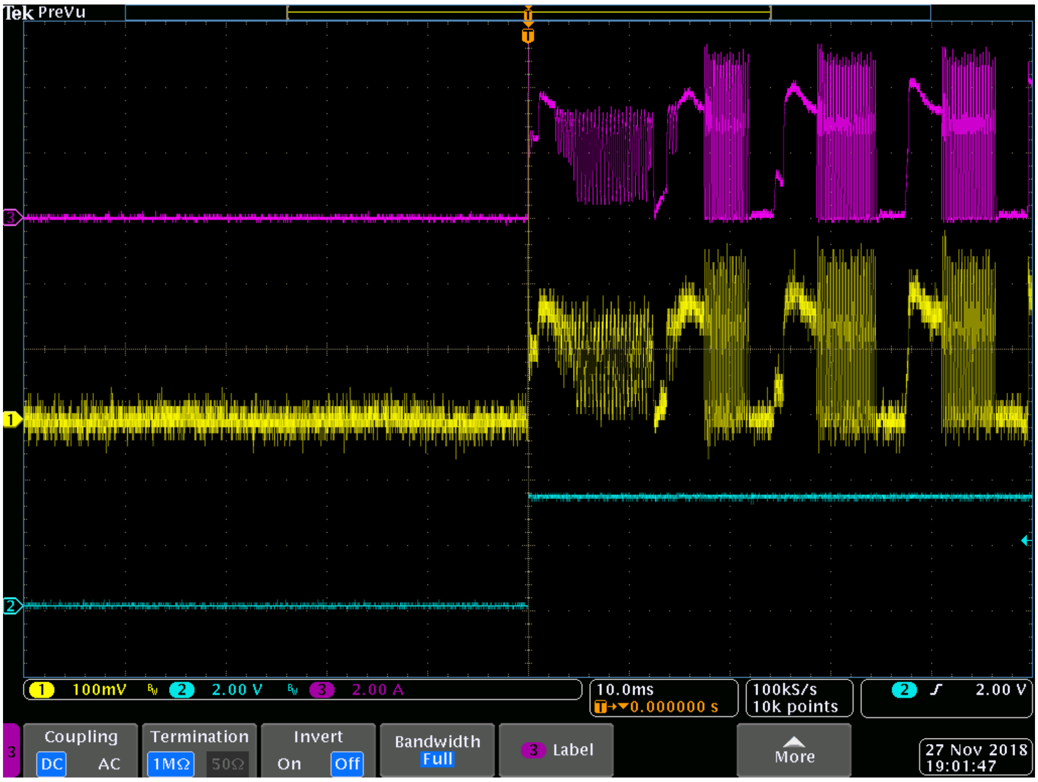


Figure 36. Captured waveforms for inrush current measurement.

Here a source of inaccuracy could be the offset presented by the differential probe used. Here the assumption was made for testing purposes that offset would be the same always and it was corrected with software initializing the oscilloscope. Further study in the probe offset drift over time should be done or evaluate more suitable differential probe for the task. Regardless, functionality of oscilloscope probing with the DAQ signal routing combined with microcontroller timing is proven here.

As the conditions can be generated and the resulting data measured, analyzing the data appears straightforward. That however could not be implemented within the time reserved for this thesis as well as environment chamber and HP 6030 PSU drivers are yet to be developed. Also, one design flaw was discovered with the microcontroller communication protocol. DAQ DIO ports could not configure individual bits for input and output mode. And when configured input, the slave device then should pull the bus voltage down for active bit. This however did not prevent the prototype from successfully working with a small software workaround and the need for microcontroller respond bit could be re-evaluated.

6 Conclusion

To automate product testing, research was conducted where standards and product requirement specifications were studied. Parameters that were required to be measured, were defined for verifying product operational capabilities and compliance with requirements. When measurable parameters were identified, data on different PSU models were gathered and compared to define range and limits for the parameters. With this knowledge, research was conducted to evaluate available measurement equipment capabilities and the required additional hardware and software.

It was discovered that the first step integrating the test equipment for automated PSU testing was to developed hardware interface connecting the test equipment and the PSU to be tested. An adapter, that allowed DUT to be subjected under specialized conditions. More time than initially expected was spent on developing hardware for the tester system, as added requirements became obvious when research on measurable parameters was conducted. Design, assembly and testing of the interface became a significant task and portion of the development project. Significant amount of C and Labview code were developed to control interface circuitry and measurement equipment to conduct automated testing sequences.

Designed interface was a success and performed together with measurement equipment sufficiently to subject the tested power supply unit under electrical conditions defined during research, while enabling the data gathering from test points of interest with either multimeter or oscilloscope probing in automated manner. Prototype software framework was developed that enabled verification of the project test concepts. However, not all the required software was developed within the time reserved for the thesis and development of the test setup will continue.

As further improvements, layout should be designed, and PCB produced along with proper casing for the interface. Software shall have another configuration layer and new VIs for additional measurement equipment. Data analyzing for DUT functionality verification shall be developed further along with improved data logging functionality. Ripple input currents may be possible to produce with current microcontroller driven switching circuit and software upgrade for the microcontroller should be written to study the theory.

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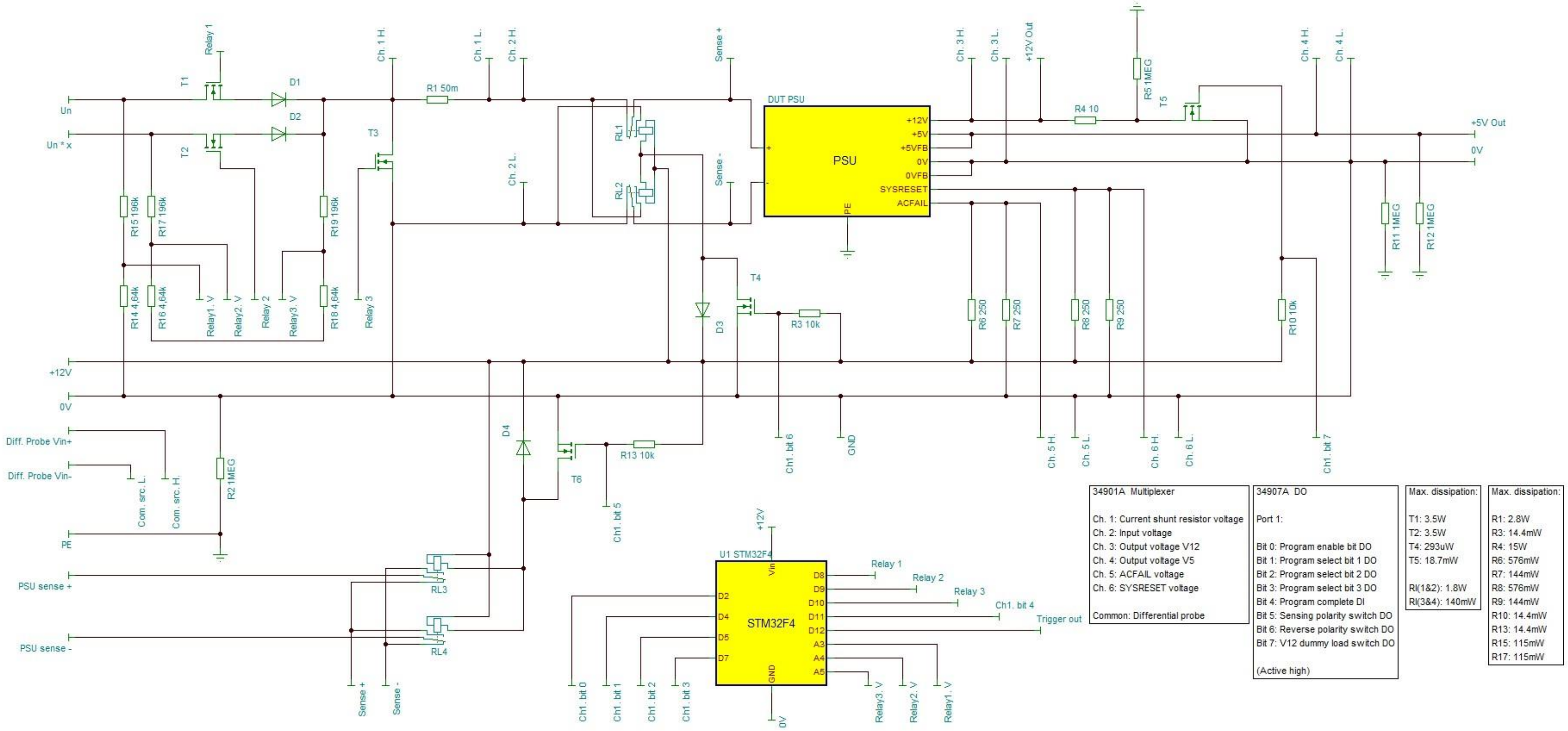
Appendix 1: PSU Electrical Specifications Comparison

Parameter	**PSV1513A**	**PSV1018A**	**PSV1133B**	**PSV3033A**	**PSV3034A**	**PSR3031A**	**PSR3032A**
Input voltage nominal range	72V	110V	24V	24V, 36V	48V, 110V	¨24V, 36V	48V, 110V
Startup voltage range	48.5V, 50.4V	74V, 77V	14V, 16.8V	14.8V, 16.8V	31.2V, 33.6V	14.8V, 16.8V	31.7V, 33.6V
Shutdown voltage range	39V, 42V	61V, 64V	11V, 13.5V	12.3V, 14.3V	26.8V, 28.7V	12.3V, 14.3V	26.8V, 28.7V
Inrush current 0.01-10ms	< 10A	< 10A	< 10A	22A	11A	22A	11A
Maximum input current	-	2A	5A	7.25A	3A	7.5A	3.6A
5V output voltage range	5.00V, 5.25V	5.00V, 5.25V	5.00V, 5.25V	5.05V, 5.25V	5.05V, 5.25V	5.05V, 5.25V	5.05V, 5.25V
5V output current range	0.5A, 13A	0.5A, 13A	0.5A, 8.5A	0.1A, 13A	0.1A, 13A	0.1A, 16A	0.1A, 16A
12V output voltage range	11.80V, 12.60V	11.80V, 12.60V	11.80V, 12.60V	11.8V, 12.6V	11.8V, 12.6V	-	-
12V output current range	0A, 1.25A	0A, 1.25A	0A, 1.25A	0A, 1.25A	0A, 1.25A	-	-
Minimum output power	80W	80W	60W	80W	80W	80W	80W
Efficiency	> 80%	> 80%	> 74%	≥ 80%	≥ 80%	≥ 80%	≥ 80%
5V grace supply	100ms	100ms	80ms	100ms	100ms	-	-

Data gathered from product requirement specifications and technical manuals [3; 10; 11; 12; 13; 14]

Appendix 2: Test Setup Interface Schematic



34901A Multiplexer

Ch. 1: Current shunt resistor voltage
Ch. 2: Input voltage
Ch. 3: Output voltage V12
Ch. 4: Output voltage V5
Ch. 5: ACFAIL voltage
Ch. 6: SYSRESET voltage

Common: Differential probe

34907A DO

Port 1:

Bit 0: Program enable bit DO
Bit 1: Program select bit 1 DO
Bit 2: Program select bit 2 DO
Bit 3: Program select bit 3 DO
Bit 4: Program complete DI
Bit 5: Sensing polarity switch DO
Bit 6: Reverse polarity switch DO
Bit 7: V12 dummy load switch DO

(Active high)

Max. dissipation:

T1: 3.5W
T2: 3.5W
T4: 293uW
T5: 18.7mW

Rl(1&2): 1.8W
Rl(3&4): 140mW

Max. dissipation:

R1: 2.8W
R3: 14.4mW
R4: 15W
R6: 576mW
R7: 144mW
R8: 576mW
R9: 144mW
R10: 14.4mW
R13: 14.4mW
R15: 115mW
R17: 115mW